

NASA/CR—2007–214961



Space Environmental Effects Knowledgebase

B.E. Wood

Bob Wood Aerospace Consulting Services, Inc., Tullahoma, Tennessee

Prepared for Marshall Space Flight Center
under Grant NRA8-31
and sponsored by the
Materials and Processes Laboratory
managed at the Marshall Space Flight Center

June 2007

The NASA STI Program...in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Report Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- **TECHNICAL PUBLICATION.** Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- **TECHNICAL MEMORANDUM.** Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- **CONTRACTOR REPORT.** Scientific and technical findings by NASA-sponsored contractors and grantees.

- **CONFERENCE PUBLICATION.** Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.
- **SPECIAL PUBLICATION.** Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.
- **TECHNICAL TRANSLATION.** English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include creating custom thesauri, building customized databases, and organizing and publishing research results.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at <<http://www.sti.nasa.gov>>
- E-mail your question via the Internet to <help@sti.nasa.gov>
- Fax your question to the NASA STI Help Desk at 301-621-0134
- Phone the NASA STI Help Desk at 301-621-0390
- Write to:
NASA STI Help Desk
NASA Center for AeroSpace Information
7115 Standard Drive
Hanover, MD 21076-1320

NASA/CR—2007–214961



Space Environmental Effects Knowledgebase

B.E. Wood

Bob Wood Aerospace Consulting Services, Inc., Tullahoma, Tennessee

Prepared for Marshall Space Flight Center
under Grant NRA8-31
and sponsored by the
Materials and Processes Laboratory
managed at the Marshall Space Flight Center

National Aeronautics and
Space Administration

Marshall Space Flight Center • MSFC, Alabama 35812

June 2007

Available from:

NASA Center for AeroSpace Information
7115 Standard Drive
Hanover, MD 21076-1320
301-621-0390

This report is also available in electronic form at
<<https://www2.sti.nasa.gov>>

TABLE OF CONTENTS

I. Introduction	1
II. Structure of the Satellite Contamination and Materials Outgassing Knowledgebase	3
A) Material Outgassing Data	3
B) Round-Robin Material Outgassing Tests	5
C) Flight QCM Data	6
D) MSX Satellite Program	7
E) Optical Properties of Contaminant Films at Cryogenic Temperatures	9
III. To obtain your copy of the Space Environment Effects Knowledgebase	12
IV. Summary	13
V. Acknowledgements	15
References	16
Appendix 1	29
Appendix 2. Refractive and Absorptive Indices listing for thin solid films condensed from gases and material outgassing products	36
Appendix 3. Software Usage Agreement Application for gaining access to NASA Space Environment Effects Knowledgebase	39

LIST OF FIGURES

1.	Typical ASTM E-1559 Test Apparatus	20
2.	Typical Mounting bracket for the 4 QCMs used in the E1559 Test Method	21
3.	Typical deposition curves for a material tested using the ASTM E-1559 Test Standard Procedure	22
4.	Typical Thermo gravimetric procedure test results	23
5.	Comparison of deposition data taken during Round-Robin series of tests for Butyl Orings	24
6.	Comparison of deposition data taken during Round-Robin series of tests for Polyethylene beads	25
7.	Comparison of thermo gravimetric data taken during Round-Robin series of tests for Butyl Orings	25
8.	Comparison of thermo gravimetric data taken during Round-Robin series of tests for Polyethylene beads	26
9.	Calculated values (using CALCRT) for reflectance and transmittance for film thicknesses formed from condensed outgassing products from Polyclad on a germanium window for a wavenumber of 2000 cm ⁻¹ (wavelength = 5 microns)	26
10.	Calculated values (using CALCRT) for reflectance and transmittance for film thicknesses formed from condensed outgassing products from Uralane on a germanium window for a wavenumber of 3000 cm ⁻¹ (wavelength = 3.33 microns)	27
11.	Calculated values (using CALCRT) for reflectance and transmittance for a one micron thick film formed from condensed outgassing products from ChemglazeA276 on a germanium window as a function of wavenumber	28

LIST OF TABLES

1.	Summary of the facility and QCM operational characteristics	18
2.	Tabulated results of the Round-Robin series of E1559 outgassing tests for Butyl O-rings and Polyethylene beads.	19

I. Introduction

This report describes the results of an NRA funded program entitled “Space Environmental Effects Knowledgebase” that received funding through a NASA NRA (NRA8-31) and was monitored by personnel in the NASA Space Environmental Effects (SEE) Program. The NASA Project number was 02029.

The Satellite Contamination and Materials Outgassing Knowledgebase (SCMOK) was created as a part of the earlier NRA8-20 (Ref. 1). One of the previous tasks was to accumulate data from facilities using QCMs to measure the outgassing data for satellite materials. A special emphasis was placed on datasets taken using the ASTM E-1559 satellite materials outgassing standard. A user friendly database platform compatible with SEE requirements was established to input the data into separate, linked databases, and this Knowledgebase was then turned over to the NASA/SEE Program office. This Knowledgebase also included data and references in which space flight data using QCMs were available.

NRA8-31 provided an opportunity to essentially double the amount of E1559 information included in the Knowledgebase. Large NASA programs such as the International Space Station (ISS), James Webb Space Telescope (JWST), and Living With a Star (LWS) utilize newly developed materials. These materials outgassing datasets for the newer materials from various facilities should be especially beneficial to these programs. The main objective of this current program was to increase the number of material outgassing datasets from 250 up to ~ 500. As a part of this effort, a round-robin series of materials outgassing measurements program was executed that allowed comparison of the results for the same materials tested in 10 different test facilities.

Other program tasks included obtaining datasets or information packages for 1) optical effects of contaminants on optical surfaces, thermal radiators, and sensor systems and 2) space environmental effects on surfaces and materials. These tasks included the collection of contamination optical property data and related space environmental effects data and incorporating these data into the already existing NASA/SEE Knowledgebase. Previously, the emphasis was on the collection of only QCM related data but as a part of this program, the Knowledgebase was expanded to include the contamination and optical effects data. The Knowledgebase was modified to include data from these two additional topics. In many mission areas contamination of sensors and optics is a continuing concern. The E1559, optical effects, space environmental effects, and flight QCM data will undoubtedly be beneficial to those programs through the availability of materials outgassing data and the contaminant optical and space environmental effects information. More than 150 requests for access to this Knowledgebase have already been processed through the NASA/SEE Program office.

Initially, the SCMOK could be accessed online by obtaining the appropriate login name and password from the NASA/SEE program office. Due to several problems associated with hackers, NASA decided to protect the SCMOK by restricting access to only those in need of this information. This wasn't the preferred course of action but it did provide access to those who needed it with considerably

more control and at the same time eliminated the hacker problems. This new method of access to the Knowledgebase provided the user with a CD containing all of the information previously accessible online. The new method also required that the user have access to the Internet Information Service (IIS) which meant that the user's computer operating system had to be either Windows 98, Windows 2000, or Windows XP Professional. Based on the original sets of data, the CD system was satisfactory but as more data was added, the CD was no longer capable of storing all the necessary data. A DVD is now available to users that contains all of the added data accumulated throughout this current program.

II. Structure of the Satellite Contamination and Materials Outgassing Knowledgebase

- A) Material Outgassing Data
- B) Round-Robin Material Outgassing Results
- C) Flight QCM Data
- D) Midcourse Space Experiment (MSX) Spacecraft
- E) Optical Properties of Contaminant Films at Cryogenic Temperatures
- F) Space Environmental Effects

A) Material Outgassing Data

The ASTM-1559 Standard test method was first established in 1993 as an improved version of the ASTM E595 Standard for measurement of material outgassing. The older E595 method was originally designed as a screening technique to determine the suitability of materials for space flight. The total mass loss (TML) of the materials was determined by weighing the material samples beforehand, heating them to 125C for 24 hours under vacuum, and reweighing them after removal from the vacuum chamber. The loss in mass was divided by the original mass to get the percentage TML. However, this standard has been used far beyond its original intent to provide information related to the screening of materials for use in space. In order to provide a method for the characterization of materials outgassing kinetics, E1559 was established. It has now been adopted in many programs for screening materials that are to be used in space applications. The outgassing raw data are converted to TML and collected volatile condensable material (CVCVM) levels.

Test Method E1559 uses a method that allows the total mass loss to be determined through the use of 3 to 4 quartz crystal microbalances cooled to various temperatures. Figure 1 shows a typical experimental arrangement used in making the outgassing measurements. Two methods (A and B) may be used for determining the outgassing kinetics. In method A, specific QCM and specimen temperatures as well as geometry of the source/receiver are required, whereas in method B, there is considerable flexibility in the temperatures that can be used and even in the test geometry. Test Method A requires that three of the QCMs be maintained at 90, 160, and 298K. One other QCM operating at a different temperature can be used, but is not required. Although an effusion cell temperature of 125C typically is used for Method A, other temperatures can be used in Method B that may be more closely related to the actual operational material temperatures. One version of the QCM mounting fixture used for E1559 testing is shown in Figure. 2.

The test chamber is evacuated to a vacuum level on the order of 10^{-8} torr before QCM cooling is commenced. The QCMs are maintained at approximately 300K until the chamber liner and baffles have reached temperatures of less than approximately 75K. At this point the heaters to the QCMs are commanded to set point temperatures varying from 77K for the coldest to as high as 298K for the warmest. The QCMs are thermally shielded from each other to allow the temperatures to be independently controlled. Once these temperatures have become constant, outgassing data can be collected. The sample material, on the order of 10 to 20 grams, is placed inside the effusion cell and mounted in the interlock chamber. After the interlock chamber has been evacuated to a level of approximately 10^{-7}

torr, the interlock valve is opened and the effusion cell moved to the location where the orifice is 150 mm from each of the QCM sensing crystals. Once this location has been established, the effusion cell temperature controller is set to the desired temperature – usually 75 to 125°C, and the QCM frequencies recorded as a function of time. The time required for completion of an outgassing test varies depending on the needs of the user. In many instances outgassing times of up to 6 days are used in order to determine the long-term outgassing rates. Typical deposition curves for a material tested using the E-1559 standard procedure is shown in Figure 3.

After the condensed mass of the outgassing products has reached a plateau, the effusion cell is withdrawn from the chamber and back into the interlock chamber. At this point the QCM temperatures are commanded to a much warmer temperature, usually 125°C, to boil off the condensed contaminants. A warmup rate of 1°C/min is suggested in E1559. Using this thermogravimetric procedure allows one to collect valuable information as to the various species condensed as well as the deposition and evaporation temperatures of each specie (See Figure 4).

Upon completion of the testing, the material test sample is removed from the effusion cell and weighed. The value obtained is compared to the value prior to the start of the outgassing measurements. The total mass loss is determined from these data and then compared with that obtained from the calculated values determined using the QCM deposition data.

During NASA NRA8-31 approximately 275 additional datasets have been added to the SCMOK during this program. The following have provided these data:

- 1) NASA Goddard -- Molekit Chambers (George Meadows and Randy Hedgeland)
- 2) NASA Goddard – Molidep Chamber (Alex Montoya and John Scialdone)
- 3) Lockheed Space and Missiles Chambers (Stainless Steel and Bell Jar) (Eric Lay and Norbert Ching)
- 4) OSI – Chambers A and B (Jeff Garrett and Doug McCroskey)
- 5) Agilent – (Vijaya Raghavan and Mark Sullivan)
- 6) AEDC – 20K Facility (Bill Bertrand)
- 7) Marshall Space Flight Center (Keith Albyn)

A listing of all material outgassing datasets obtained during this program is given in Appendix 1. A typical dataset contains the following:

- A) An Excel file (.xls) containing all of the available data collected during the test. This includes the data for all of the QCMs that were available. Multiple plots are also included. Since these are relatively large files, they are downloaded as zipped files.
- B) An Excel file (.csv) which contains only the Time, Temperature, and QCM Frequency for each of the QCMs. No plots are included. This file is mainly used for the Java online plotting routine.
- C) A pdf file that describes the materials and test conditions

- D) Usually 1-4 gif files (images) are included that are figures of the frequency vs time deposition data or the thermogravimetric analysis (TGA) warmup data. This provides a quick overview of the results without having to download the larger files.

B) Round-Robin Material Outgassing Tests

One of the suggestions made by previous users of the SCMOK was to provide a comparison of data taken at different facilities by performing a round-robin series of tests. The objective of a round robin series of tests was to quantify the variations observed within each facility and between facilities. A round-robin series of testing was completed during 2004 in which ASTM E1559 type measurements were in ten different measurement facilities that included OSI (2), NASA/GSFC (3), Lockheed/Martin (2), AEDC, Agilent and NASA/MSFC. Measurements were made on two materials that were chosen based on several factors. It was desirable to provide samples to the test facilities that were already prepared so there wouldn't be any differences in the sample preparations. The samples were also chosen to have outgassing properties that would allow condensation of all species on each of the QCMs that were maintained at 80, 160, 220, and 298K. A summary of the facility and QCM operational characteristics are provided in Table 1.

The test samples provided for the ASTM E 1559 Round-Robin test consisted of two materials – polyethylene beads and Parker Butyl B612-70 O-rings. The raw materials were obtained from Jeff Garrett at OSI in Palo Alto, CA. Jeff is a member of the ASTM E 21.05 committee that oversees the ASTM E 1559 standard test method. Vials containing the samples were distributed to the participating facilities and contained ~ 1 gram of polyethylene beads and ~ 2 grams of butyl O-rings. Each vial contained enough material for one test. Extra vials were provided just in case some malfunction should occur during the test and a restart required. The participants contributed their time and facilities to make this Round-Robin effort possible. This test series helped to quantify E1559 measurements accuracy and any systematic variations between facilities

Material outgassing tests were performed per the ASTM E 1559 test method with QCM temperatures at <90 K, 160 K, 220 K, and 298 K. Both samples were tested at an effusion cell temperature of 125°C and the duration of each test was 72 hours. Test data including the QCM frequencies and temperatures, as well as the reduced data (Total Mass Loss, Volatile Condensable Material, etc.) were submitted as Excel data files. Test information such as sample mass, sample dimensions, QCM type and sensitivity, apparatus view factors, and any exceptions to the ASTM method were also included. Similarly, the thermogravimetric test (TGA) data were included as a separate Excel Work Sheet within the Excel file.

Description of the Round-Robin Samples

Parker Butyl B612-70 O-Rings

Parker Size – 2-203

ID = 0.296 inches, W = 0.139 inches

Nominal size = 5/16" x 1/8"

Surface Area per O-Ring = 3.85 cm²

High Density Polyethylene Beads

Lot #19

CAS # 25213-02-9

CAT # 041

ID = 0.125"

Length = 0.155"

Figure 5 shows a comparison of the deposition data taken during the Round-Robin series of testing for the Butyl O-rings. The QCM temperature for all of these curves was ~ 90K so this data serves as the Total Mass Loss (TML) data. The total change in frequency (Delta Frequency) for 7 of the 9 facilities over the 72 hour outgassing time was between 14,000 and 16,000 Hz depending on the facility. The two curves that overlay at the top of the graph were from the NASA/GSFC Molekit facilities that used a non-standard effusion cell aperture which allowed more outgassed material to be collected by the QCMs. However, the TML and CVCM values determined in the Molekit facilities were in good agreement with the values determined from the other facilities, see Table 2.

Similarly, Figure 6 shows a comparison of the deposition data taken during the Round-Robin E1559 tests for Polyethylene beads. Seven of the 9 facilities had a delta frequency varying between about 1700-1900 Hz with the GSFC data being considerably higher for the reason explained earlier.

The facilities that used the ASTM E1559 method for calculating TML were AEDC, Agilent, Lockheed, and OSI. The CVCM values for MSFC were calculated using this method. As can be seen from comparison of the data in Table 2, there is good agreement of the outgassing results for all of the facilities for both TML and CVCM values.

At the conclusion of each outgassing test, the coldest QCM was warmed up to 400K using an internal QCM heater. The TGA curves for the Butyl O-rings and Polyethylene beads are shown in Figures 7 and 8, respectively. The different species condensed from the Butyl O-rings in Fig. 7 can be seen by the different inflections in the curves as the temperature is increased.

C) Flight QCM Data

QCMs have been flown on many spacecraft for the purpose of measuring the contamination levels at various locations on or about the spacecraft or to measure atomic oxygen levels. The objective of this effort was to locate those flight experiments that had QCMs on board and to make available the data collected during those flights. In some instances processed or raw QCM data have been included whereas in other instances only papers or reports describing the results were available. The data have been subdivided into Shuttle and Satellite subsets. The NASA shuttle program has had several missions on which quartz crystal microbalances (QCMs) were flown. NASA shuttle flights containing QCM experiments have been researched to provide summaries of the data that were collected as part of each mission in which QCM data was available. The QCMs were used for either monitoring contamination deposition or the measurement of environmental effects - such as atomic oxygen. In the early days of the shuttle, the Induced Environment Contamination Monitor (IECM) was developed by NASA and flown on flights STS 2,3,4, and 9, with QCMs being part of the instrument package. Another monitoring package, the Contamination Monitoring Package (CMP) was a smaller version and was flown on flights

STS 3,8, and 11. An Environment Monitoring Package (EMP) containing QCMs for measuring atomic oxygen was flown on STS-46 as part of EOIM 3. A Contamination Environment Package (CEP) was flown on STS-82 for measuring contamination in the vicinity of the Hubble Telescope during the second servicing mission.

The satellite QCM datasets are for missions that required much longer times in space than for the typical NASA shuttle experiments. Typically, exposure times for these missions were measured in months or years. Included in this section are results from the Russian Mir Space Station and eventually the International Space Station.

D) MSX Satellite Program

The Midcourse Space Experiment (MSX) satellite was launched into a 903 Km, 99.4-deg orbit from Vandenberg Air Force Base on April 24, 1996. This section provides tabulated quartz crystal microbalance (QCM) data that were accumulated over the first 20 mission months in space. Technical summaries, reports and papers are available for all of the contamination measuring onboard instruments. The QCM data collection was stopped on August 25, 2004 after more than 8 years of operation in space. MSX is the only known space flight experiment that has provided continuous contamination monitoring for this extended length of time.

The MSX satellite program was funded by the Ballistic Missile Defense Organization (BMDO). The MSX satellite was part of a demonstration/validation program which had both defense and civilian applications. With telescopes and imagers operating in the wavelength range from the UV through the infrared spectrum, data from the spacecraft were used in the identification and tracking of ballistic missiles during midcourse flight. Data were also collected for test targets and space background phenomena. The MSX program provided an opportunity to monitor in-flight contamination and to investigate the composition and dynamics of the Earth's atmosphere. The UV-Visible data were collected by a suite of four imagers and five spectrographic imagers (UVISI) which were operating in wavelength segments from 110 – 900 nm. Visible and near IR data were collected by the Space-Based Visible (SBV) sensor system which was comprised of a CCD camera operating in the 400 – 1000 nm wavelength range. Both UVISI and SBV sensor systems operated over the –20C to +30C temperature range.

The other major sensor system was the Spatial Infrared Imaging Telescope (SPIRIT 3). It was a cryogenic telescope that was cooled from an onboard dewar of solid hydrogen with component temperatures ranging from 8.5K up to 65K depending on their location and spacecraft orientation. A gold coated sun shield was placed near the entrance of SPIRIT 3 to protect against unwanted solar radiation getting into the telescope. It should be noted that all of the science instruments were located on the +X face of the spacecraft with the electronics placed near the –X face at the other end of the spacecraft. This was designed to minimize contaminants outgassing from warm electronic boxes and condensing on science instrument surfaces. A contamination control plan was followed throughout the mission to minimize contamination levels on orbit. Based on results from all of the contamination instruments, this goal was achieved.

The MSX organization was comprised of 8 scientific/technical teams for the functional areas of 1) Early Midcourse Targets 2) Late Midcourse Targets 3) Space Surveillance 4) Earthlimb Backgrounds 5) Shortwave Terrestrial Backgrounds 6) Celestial Backgrounds 7) Data Certification and Technology Transfer and 8) Contamination. Each of these principal investigator teams was responsible for designing experiments, providing necessary flight instrumentation, and performing analysis of the ground calibration and flight data.

The Contamination Experiment was comprised of using a suite of instruments for monitoring various aspects of contamination around and within the spacecraft. These instruments included a total pressure sensor (TPS), neutral and ion mass spectrometers, krypton and xenon flashlamps for measuring water molecular density and particulates, respectively, 4 temperature controlled qcms (TQCMs) and one cryogenic QCM (CQCM). that was located inside the SPIRIT 3 cryogenic telescope. With these instruments it was possible to characterize the time varying health of the spacecraft throughout its mission.

The 5 QCMs on board the satellite have provided on-orbit data that have been invaluable in characterizing contamination levels around the spacecraft and inside the SPIRIT 3 cryogenic telescope. The CQCM was located internal to the SPIRIT 3 cryogenic telescope, was mounted adjacent to the primary mirror, and provided contamination accretion measurements during the 10 month lifetime of SPIRIT 3. Real-time monitoring of contaminant mass deposition on the primary mirror was provided by this CQCM which was cooled to the same temperature as the mirror -- ~20K. Thermogravimetric analyses (TGAs) on the CQCM provided insight into the amount and species of contaminants condensed on the SPIRIT 3 primary mirror during various spacecraft activities.

The 4 temperature controlled QCMs (TQCMs) were mounted on external surfaces of the spacecraft for monitoring contaminant deposition. The TQCMs operated at ~ -50C and were positioned strategically to monitor the silicone and organic contaminant flux arriving at specific locations.

The data downlinked for the contamination related experiments was of two types. Two tape recorders were used to record data for individual experiments and about 10 minutes of real time data was downlinked each orbit from the spacecraft to the receiving station at the Johns Hopkins University / Applied Physics Laboratory (JHU/APL). The MSX spacecraft makes one revolution about the earth in about 102 minutes. Therefore, the real-time data were downlinked approximately 15 times per day. The tape recorder data were also downlinked during the passes over JHU/APL.

MSX stayed in its parked mode orientation for most of the time. In this mode, the -Y face of MSX was facing towards the sun for maximum power generation by the solar panels. The +Z face was into ram and the -X face was always facing earth. The +X direction was always perpendicular to the sun vector and looking out and away from earth to minimize thermal loading on the Spirit 3 telescope. Generally, the spacecraft remained in the parked mode prior to spacecraft maneuvers for dedicated experiments that required other orientations. Upon completion of the data collection event, the spacecraft was returned to the parked mode.

A paper describing the 8+ years of QCM data was presented at the 43rd AIAA Aerospace Sciences Meeting, AIAA paper No. 2005-0067. A summary of the complete QCM data time histories

of the contaminant thickness deposition for each of the QCMs is available in Ref. 2 . Approximately 90 papers describing results of the MSX program are included in pdf format in the Knowledgebase and can be accessed through two different searchable methods.

E) Optical Properties of Contaminant Films at Cryogenic Temperatures

In this section, optical properties (refractive and absorptive indices) are provided for contaminant films condensed at cryogenic temperatures between 20K and 77K. Designers of telescopes that require cryogenic optics and sensors are especially concerned with the condensation of contaminants that can alter the reflective or transmissive characteristics of a sensor system. Most of these telescopes operate in the infrared region – therefore, all of the indices presented here are for the wavenumber range from about 3700 – 700 (wavelength range from about 2.7 μm to 14 μm). The contaminant films investigated fall into 3 categories:

- 1) Films formed from pure gases such as CO_2 , H_2O , NH_3 , CO and others
- 2) Films formed from outgassing products from spacecraft materials such as composites, paints, films, or silicones
- 3) Films formed from bipropellant gases and plume exhaust products – such as hydrazine, nitrogen tetroxide, monomethyl hydrazine

These optical properties were determined from laboratory measurements made at the Arnold Engineering Development Center (AEDC) at the Arnold Air Force Base in Tennessee by Dr. Jeffrey A. Roux and Bobby E. Wood. These properties have been used to support space-based optical systems such as cryogenic telescopes for both defense and civilian efforts.

The refractive and absorptive indices (n 's and k 's) were determined by condensing the films on a cryogenically cooled germanium window, and measuring the transmittances of the window plus films (See References 3-10). This was done for films varying in thickness from about 0.12 μm up to a maximum of about 5 microns. For each material, transmittance measurements were made for 10 – 25 film thicknesses depending on the experimental conditions caused by the unique behavior of each material. An infrared interferometer-spectrometer was used in determining the transmittance values. All of the transmittance spectra for each material were combined with a program called TRNLIN (developed by Dr. J.A. Roux) that used a non-linear least-squares curve fit to determine the refractive and absorptive indices. The non-linear option was required due to the optical interference exhibited by the thin films. In some special cases, a Subtractive Kramers-Kronig technique was used to determine refractive indices.

The equations used and details involved in determining these n and k properties can be found in References 6-9.

To realize the maximum utility of the data (n 's and k 's) generated from the experimental and analytical studies, it was necessary to develop another computer program. A model was developed that allows one to calculate the effects of these contaminant films on other optical surfaces. This program

(CALCRT) was developed by Dr. Kent Palmer of Westminster College in Fulton, Missouri (while under contract to the Arnold Air Force Base) to allow such calculations. The acronym CALCRT stands for the **CALC**ulation of **R**eflectance and **T**ransmittance. The reflectance and transmittance of an optical element can be calculated as a function of wavelength, incidence angle, contaminant film thickness, and substrate. The user must supply the substrate optical constants and thickness, the contaminant optical constants and thicknesses, and the radiation beam incidence angle. The executable DOS version of this model (CALCRT.exe) can be downloaded to your pc. Instructions to help run this program are included in the files that can be downloaded. Some results of the use of CALCRT are presented in References 11 and 12.

Examples of contaminant effects calculated using CALCRT are shown in Figs. 9-11. Figure 9 shows the reflectance/transmittance values for contaminant films condensed on a germanium window. The condensate was deposited at 77K and was composed of the outgassing products from Polyclad. The data are for a wavenumber of 2000 cm^{-1} or 5.0 microns wavelength. Figure 10 shows similar data taken at 3000 cm^{-1} or 3.33 microns wavelength for outgassing products from Uralane. Figure 11 shows the reflectance/transmittance of 77K germanium with a 1 micron thick contaminant film deposited from the outgassing products of Chemglaze A276 paint. These types of calculated spectra can be accomplished using the CALCRT program and refractive/absorptive indices for any of the contaminants listed in Appendix 2.

Space Environmental Effects

To survive in the space environment one has to contend with ultra-violet radiation, atomic oxygen, materials outgassing, plumes, protons, electrons, plasmas, spacecraft charging, micrometeorites, space debris, vacuum, and the cold black 4K background. There is considerable information regarding the effects of the space environment on surfaces, instruments, and spacecraft. This includes both space flight data and ground simulation data. In this section, many of the previously written papers/reports describing these effects have been included in a single database. The database includes extensive data for the LDEF program (all of the information available from all three post retrieval conferences) and from other programs such as MIR, POSA, MSX, and others. Including the approximately 100 papers previously available, there are now approximately 300 papers/reports that can be accessed through the Knowledgebase. The papers/reports are now available in PDF format and can be accessed using Acrobat (preferably 6.0 or 7.0). The Acrobat 7.0 Reader is now available and can be downloaded free of charge from the following website: <http://www.adobe.com/products/acrobat/readstep2.html>.

Two different search routines are provided in the Knowledgebase. One uses the Global Search routine that has been used previously with the MSX papers/reports and the other is the 'Search SEE Paper' using the Acrobat 6.0 search index.

Some of the more notable recently added reports to the Knowledgebase and now in pdf form include:

- LDEF -- 69Months in space Part 1
- LDEF -- 69Months in space Part 2
- LDEF -- 69Months in space Part 3
- LDEF -- Second Post Retrieval Part 1

LDEF – Second Post Retrieval Part 2
LDEF – Second Post Retrieval Part 3
LDEF – Second Post Retrieval Part 4
LDEF – Third Post Retrieval Part 1
LDEF – Third Post Retrieval Part 2
LDEF – Third Post Retrieval Part 3
LDEF Materials Results for Spacecraft Applications
Space Environmental Effects on Spacecraft -- LEO Materials 1
Space Environmental Effects on Spacecraft -- LEO Materials 2
Proceedings of the USAF/NASA International Spacecraft Contamination Conference
Second Workshop on Spacecraft Glow
Atomic Oxygen Effects Measurements for STS-8 41-G Vol 1
Atomic Oxygen Effects Measurements for STS-8 41-G Vol 2
Atomic Oxygen Effects Measurements for STS-8 41-G Vol 3

This collection of contamination and space environmental effects papers makes this an ideal starting point for anyone needing to review past

III. To obtain your copy of the Space Environment Effects Knowledgebase

In order to meet export control and maintain the integrity of the NASA models, the SEE Program has agreed to review the provided information and perform the necessary paperwork. All models are executable only and the source code can only be obtained by contacting the **SEE Program Office**.

Before access is granted, you must send to NASA the following TWO forms:

1. **[SEE Product Access Form](#)** (submit thru online)
2. **Software Usage Agreement (SUA) Form/s** (link below) - hardcopy of the form must be completed, signed, and FAX to Sopo Yung at 256-544-8807
3. Link to SUA: http://see.msfc.nasa.gov/ModelDB/outgassing_sra.htm

IV. Summary

The main four objectives for this program were the following:

- (1) Expand and improve the existing Satellite Contamination and Materials Outgassing and Effects Knowledgebase. Include available material outgassing data for newer materials would increase the knowledgebase from ~250 to ~500 materials.”
- (2) Develop an electronic knowledgebase that addresses the issue of space environmental effects on surfaces and spacecraft. This was to include effects of absorption and reflectance due to contaminants on surfaces in the presence of AO, UV, radiation, etc.
- (3) Develop a spectral library of the optical properties of contaminant films on optical and thermal control surfaces. This would include characteristics, absorption, and emission for typical contaminants that might be encountered in space.
- (4) Establish a round-robin test program for material outgassing test facilities that use the ASTM E1559 Materials Outgassing Test Method. This would provide a measure of the confidence one could assume by testing at any of the laboratories at which these types of measurements are made.

All four of these objectives were met. Currently the materials outgassing section of the Knowledgebase contains ~ 575 datasets for materials tested using the E1559 standard plus another 100 or so that used a modified version by the European Space Agency. Material outgassing data were obtained from 10 different facilities using during this program.

The refractive and absorptive indices for thin films of gases condensed at 20-77K are presented in tabular form. This includes data for 50 sources such as pure gases (e.g. water, CO₂, NH₃ and others), mixtures of these, gases from rocket engine plumes, and satellite material outgassing products. These data are available through the Knowledgebase along with a thin film software program (CALCRT) for calculating the effects of these films on an optical surface reflectance or transmittance.

Electronic or PDF files for approximately 200 additional papers/reports relating to space environmental effects was added to the Knowledgebase. This included many papers concerning LDEF, POSA, MIR, MSX, and other satellite programs. This should provide an opportunity for one to review much of the work accomplished in the past at a single location.

One of the shortcomings of the earlier version of the knowledgebase reported by previous users was that comparison of material outgassing data obtained between various E1559 measurement facilities was extremely difficult. To remedy this problem a round-robin series of testing was established which included E1559 type measurements being made by measurement facilities at OSI, NASA/GSFC, Lockheed/Martin, NASA/MSFC, Agilent, and AEDC. This round-robin series consisted of testing the

outgassing from two materials (Butyl O-rings and Polyethylene Beads) at 125C for 72 hours. All of the test data were provided to BWACS, Inc. where the data were processed, analyzed, and summarized and will be reported at an upcoming technical conference. The results currently exist in the Knowledgebase.

Plans were to include some of the results of the MISSE and GENESIS programs in the Space Environment Effects portion of the Knowledgebase. However, MISSE has not yet been returned from the ISS and the GENESIS results were not available at the time of this contract end.

Large NASA programs such as the International Space Station (ISS), James Webb Space Telescope (JWST), and Living With a Star (LWS) can utilize the data for the newly developed materials. Since the data included in each of these databases will be beneficial to Spacecraft Systems, Instrument Systems, and Communication Systems, this effort is an example of a crosscutting technology with applications to the Space and Planetary, Development of Space, Earth Science, and Commercial Remote Sensing NASA Customer Mission areas. In each of these mission areas contamination of sensors and optics is a continuing concern. Although not specifically aimed at the Living with a Star Program (LWS), the E1559, Flight QCM, and Space Environment Effects data will undoubtedly be beneficial to that program also through the availability of materials outgassing and contaminant optical and space environmental effects information.

V. Acknowledgements:

The author would like to acknowledge the following:

- A) Jody Minor, Billy Kauffman and Robby Newton of the NASA/SEE Program Office, Sopo Yung of Morgan Research, and Gayle Brown of USRA for their support in carrying out this program.
- B) USRA students Nicholas Segraves, Kyle Brickhouse, and Jason Baxley for helping with the inputting of the data into the Knowledgebase.
- C) Tom Carson of the New Economy Institute (NEI) in Chattanooga, TN and NEI employees who assisted the author in converting many of the documents relating to space environmental effects on spacecraft into pdf files. Those participating included: Tom Carson and Lyn Price – NEI staff, Angela Milton, Robert Smith, Katie Lane, Heather Rogers – NEI Interns, John Carson – Contract Scanner, and Chris Carson -- Boy Scout Volunteer for Merit Badge Project.
- D) Jeff Garrett of OSI, George Meadows of Swales at NASA/GSFC, Eric Lay and Norbert Ching of Lockheed Space and Missiles Company, Vijaya Raghavan and Mark Sullivan of Agilent, Alex Montoya and John Scialdone of NASA, Bill Bertrand of ATA at USAF/AEDC, and Keith Albyn at NASA Marshall for providing material outgassing data.
- E) Dr. B. David Green of Physical Sciences Incorporated for support and assistance in executing the goals of the project.

References:

- 1) Green, B.D., "Satellite Contamination and Materials Outgassing Knowledgebase – An Interactive Database Reference", NASA/CR –2001—210909, March 2001.
- 2) Wood, B.E., Bertrand, W.T., O. M. Uy, J. C. Lesho, R. P. Cain, D. F. Hall, B. D. Green, G. E. Galica, M. T. Boies, and J. S. Dyer, "Review of Midcourse Space Experiment (MSX) Satellite QCM Contamination Results after Eight Years in Space", Paper No. AIAA 2005-0067, presented at the 43 Aerospace Sciences Meeting, Reno, NV, January 10-13, 2005.
- 3) Roux, J.A. and Wood, B.E., "Infrared Optical Properties of Solid Monomethyl Hydrazine, N2O4, and N2H4 at Cryogenic Temperatures", Journal of the Optical Society of America, Vol. 73, No.9, September, 1983, pp. 1181-1188, also AEDC-TR-83-59, April, 1984 (AD# A144731).
- 4) Palmer, K.F., Roux, J.A., and Wood, B.E., "Infrared Optical Properties of Solid Mixtures of Molecular Species at 20K", Progress in Astronautics and Aeronautics: Spacecraft Contamination - Sources and Prevention, Ed. J.A. Roux and T.D. Mccay, Vol.91, 1984, pp. 162-179 (also AIAA paper number 83-1452).
- 5) Wood, B.E., and Roux, J.A., "Infrared Optical Properties of Thin H2O, NH3, and CO2 Cryofilms", J. Opt. Soc. Am., Vol. 72, No. 6, June, 1982, pp. 720-728.
- 6) Roux, J.A., Wood, B.E., Alt, R.E., Frazine, D.F., Smith, A.M., and Scott, H.E., "Optical Properties of Bipropellant Exhaust Constituents Condensed at 77K", Journal of Spacecraft and Rockets, Vol.16, Number 6, Nov.-Dec. 1979, pp.373-381 (also AIAA paper number 79-0096r).
- 7) Roux, J.A., Wood, B.E. and Smith, A.M., "Infrared Optical Properties of Bipropellant Cryocontaminants", AEDC-TR-79-50, August, 1979 (AD# A073186).
- 8) Palmer, K.F., Wood, B.E., and Roux, J.A., "Infrared Optical Properties of Solid Mixtures of Molecular Species at 20K", AEDC-TR-80-30, January, 1981, (AD# A094214).
- 9) Roux, J.A., Wood, B.E., and Smith, A.M., "IR Optical Properties of Thin H2O, NH3, and CO2 Cryofilms", AEDC-TR-79-57 (AD-A074913), September, 1979.
- 10) Roux, J.A., Wood, B.E., Smith, A.M., and Plyler R.R., "Infrared Optical Properties of Thin CO, NO, CH₄, HCl, N₂O, O₂, N₂, Ar, and Air Cryofilms", AEDC-TR-79-81, August, 1980 (AD# A088269).
- 11) Bertrand, W.T. and Wood, B.E., "Effects of Spacecraft Materials Outgassing Products on Cryogenic Surfaces", AEDC-TR-92-18, March 1993 (AD# A262671).

- 12) Bertrand, W.T., B.E. Wood, and Palmer, K.F., "Effects of Cryogenic Contaminants on Optical Surfaces - CALCRT Thin Film Reflectance / Transmittance Model", SPIE International Symposium, San Diego, CA, Optical System Contamination: Effects, Measurements, and Control IV, Volume 2261, 1994, pp.135-142.

Table 1: Summary of the facility and QCM operational characteristics

Facility	298K	220K	160K	80K	20K	80K	QCM Sensitivity	QCM Crystal	QCM Vendor
	QCM	QCM	QCM	QCM	QCM	QCM TGA	$\times 10^{-9} \text{ g/cm}^2 \cdot \text{Hz}$	Frequency	
AEDC	yes	No	Yes	Yes	Yes	Yes	1.96	15 MHz	QCM Research
Agilent	No	No	Yes	Yes	No	Yes	4.42	10 MHz	QCM Research
GSFC Molekit #1	Yes	Yes	Yes	Yes	No	Yes	4.42	10 MHz	QCM Research
GSFC Molekit #2	yes	Yes	Yes	Yes	No	Yes	4.42	10 MHz	QCM Research
GSFC Molidep	yes	No	No	No	No	No			Cahn Microbalance
Lockheed Belljar	yes	Yes	Yes	Yes	No	Yes	4.42	10 MHz	QCM Research
Lockheed SS	yes	Yes	Yes	Yes	No	Yes	4.42	10 MHz	QCM Research
MSFC	yes	Yes	Yes	No	No	No	1.73	15 MHz	Faraday Laboratories
OSI #1	yes	Yes	Yes	Yes	No	Yes	4.42	10 MHz	QCM Research
OSI #2	yes	Yes	Yes	Yes	No	Yes	4.42	10 MHz	QCM Research

Table 2. Tabulated results of the Round-Robin series of E1559 outgassing tests for Butyl O-rings and Polyethylene beads.

Butyl O-Rings

	TML(80K), %	VCM - 160K	VCM - 220K	VCM - 298K	
AEDC-Bertrand	1.48	0.78	--	0.0144	
Agilent - Raghavan	1.4946	0.7915			
GSFC - Meadows	1.6451*	0.942	0.73	0.015	4-Aug-24
GSFC - Meadows	1.661*	0.88	0.675	0.0151	4-Jul-02
GSFC - Montoya	1.382				
Lockheed – SS -Lay	1.3	0.7	0.54	0.018	
Lockheed – BJ - Lay	1.36	0.7	0.54	0.012	
MSFC-Albyn	2*	0.551	0.509	0.026	
OSI #1 - Garrett	1.3812	0.72	0.58	0.0137	
OSI #2 - Garrett	1.403	0.721	0.567	0.0118	

* Measured by weighing before and after outgassing

** Used Cahn

Microbalance

Polyethylene Beads

	TML(80K), %	VCM - 160K	VCM - 220K	VCM - 298K	
AEDC-Bertrand	0.348	0.322		0.0751	
Agilent - Raghavan	0.3542	0.3516			
GSFC - Meadows	0.3844*	0.374	0.342	0.106	26-Jun
GSFC - Meadows	0.378*	0.373	0.339	0.105	9-Aug
GSFC - Meadows	0.3841*	0.38	0.348	0.107	16-Aug
GSFC - Montoya	0.6**				
Lockheed - Lay - SS	0.31	0.311	0.293	0.08	
Lockheed - Lay - BJ	0.32	0.307	0.282	0.064	
MSFC - Albyn	0.56*	0.295	0.232	0.061	
OSI #1 - Garrett	0.3148	0.3036	0.2889	0.0725	
OSI #2 - Garrett	0.313	0.3083	0.2896	0.0631	

* Measured by weighing before and after outgassing

** Used Cahn

Microbalance

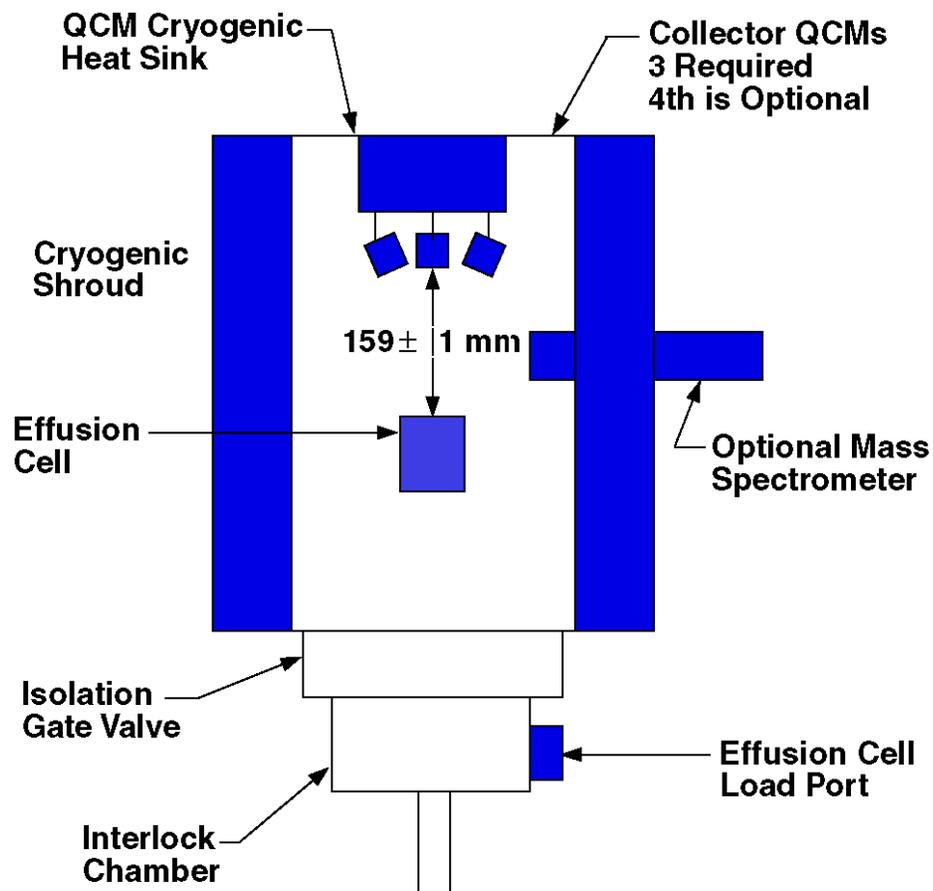


Fig. 1 Typical ASTM E-1559 Test Apparatus

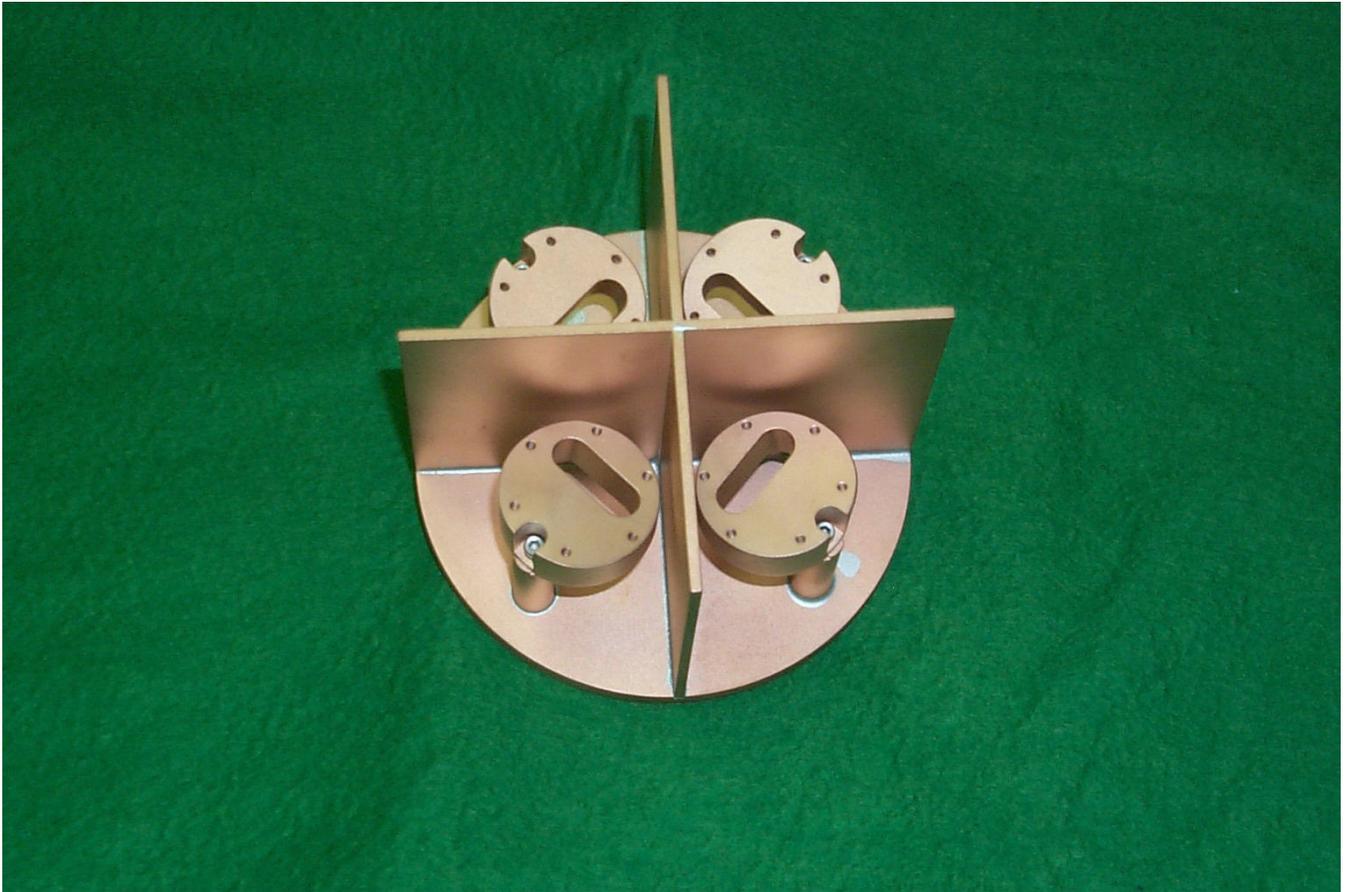


Fig. 2 Typical Mounting bracket for the 4 QCMs used in the E1559 Test Method

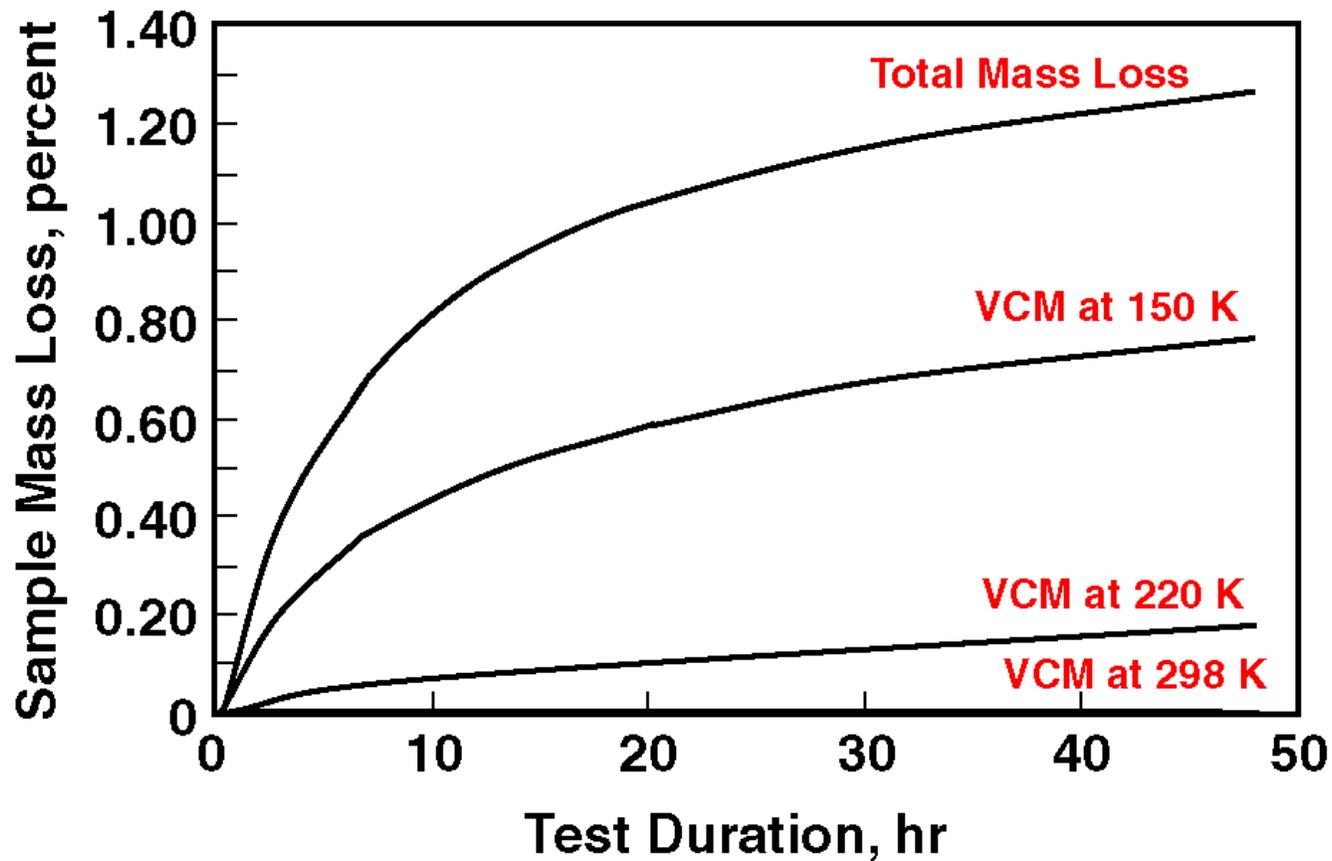


Fig 3 Typical deposition curves for a material tested using the ASTM E-1559 Test Standard Procedure.

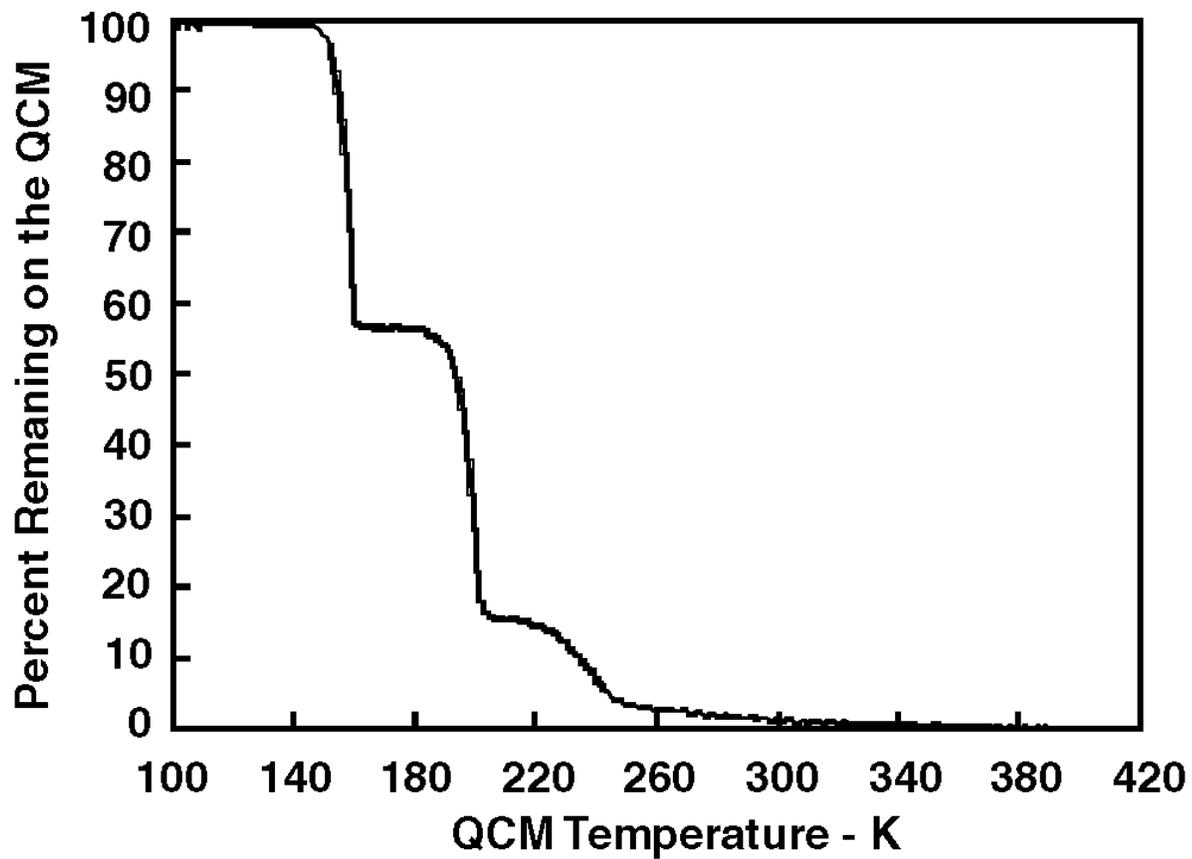


Fig. 4 Typical Thermo gravimetric procedure test results

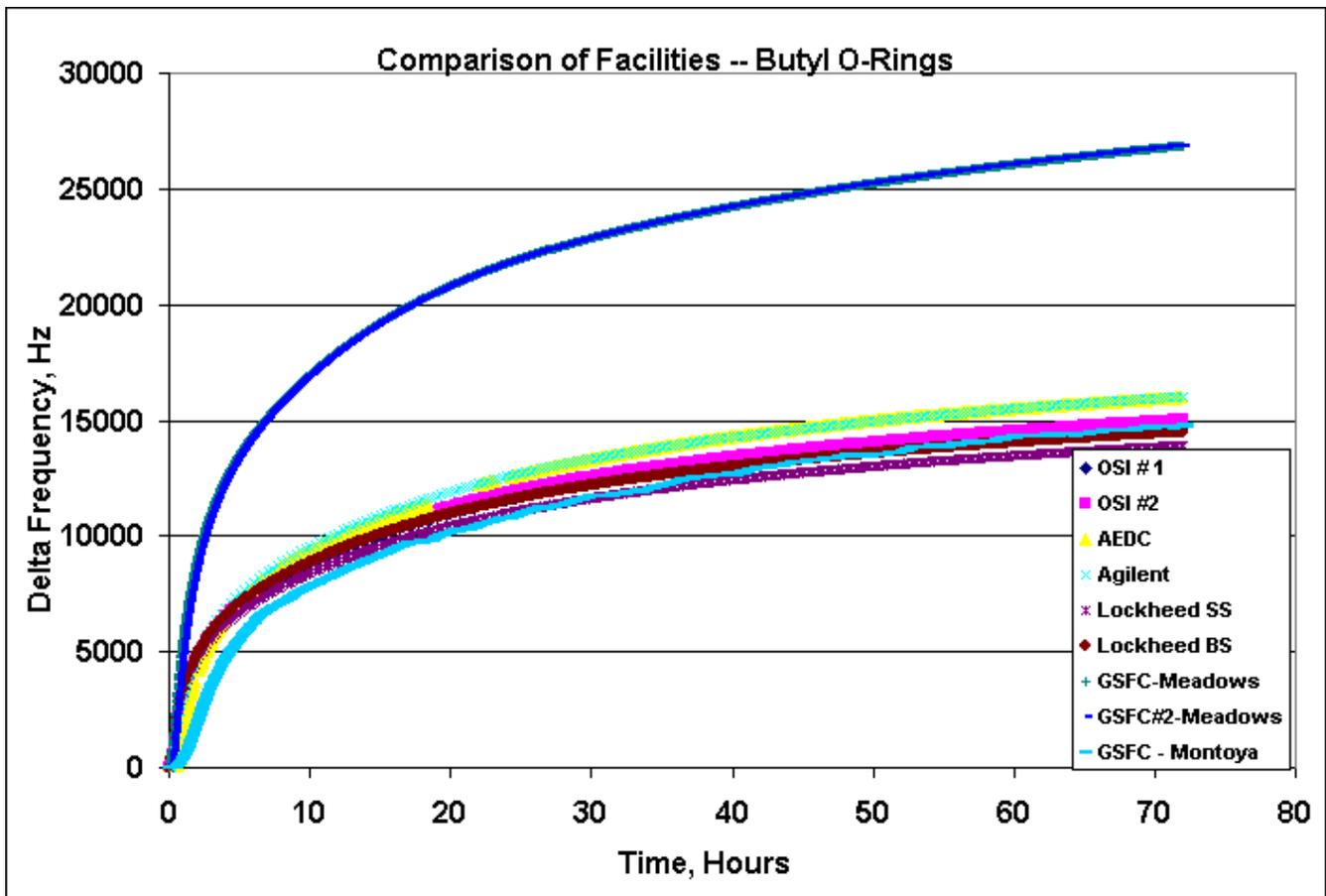


Fig. 5 Comparison of deposition data taken during Round-Robin series of tests for Butyl Orings.

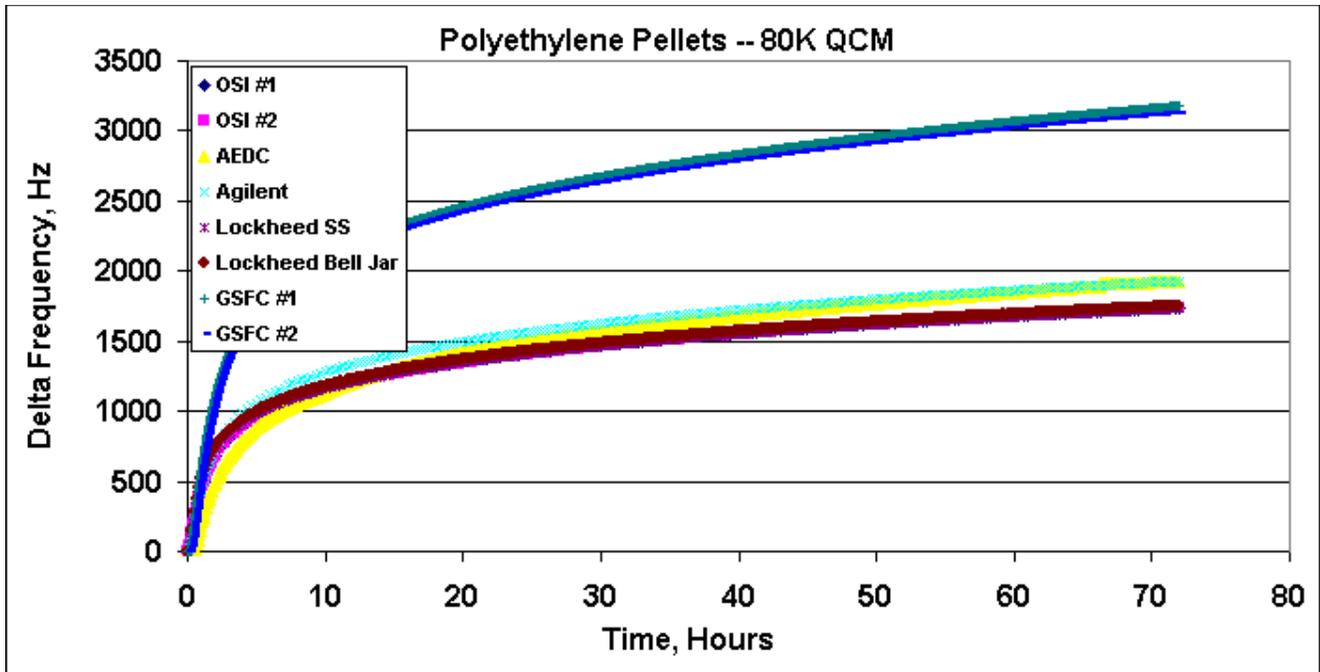


Fig. 6 Comparison of deposition data taken during Round-Robin series of tests for Polyethylene beads.

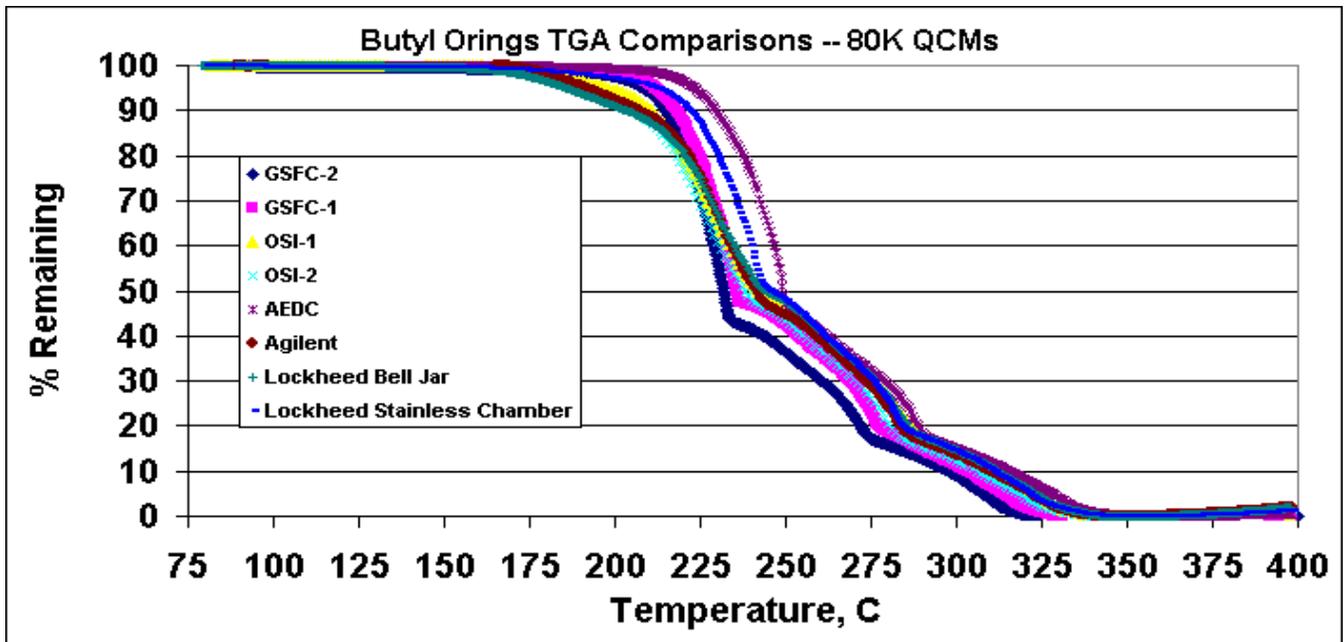


Fig. 7 Comparison of thermo gravimetric data taken during Round-Robin series of tests for Butyl Orings.

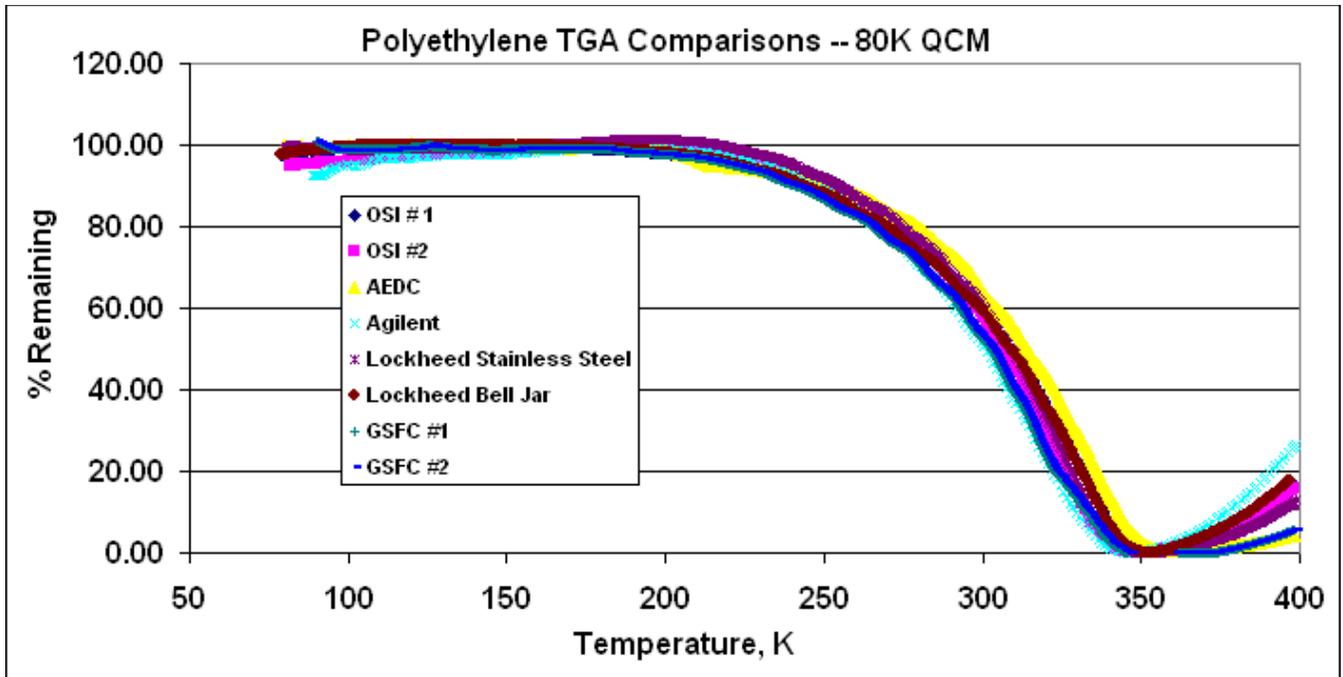


Figure 8 Comparison of thermo gravimetric data taken during Round-Robin series of tests for Polyethylene beads.

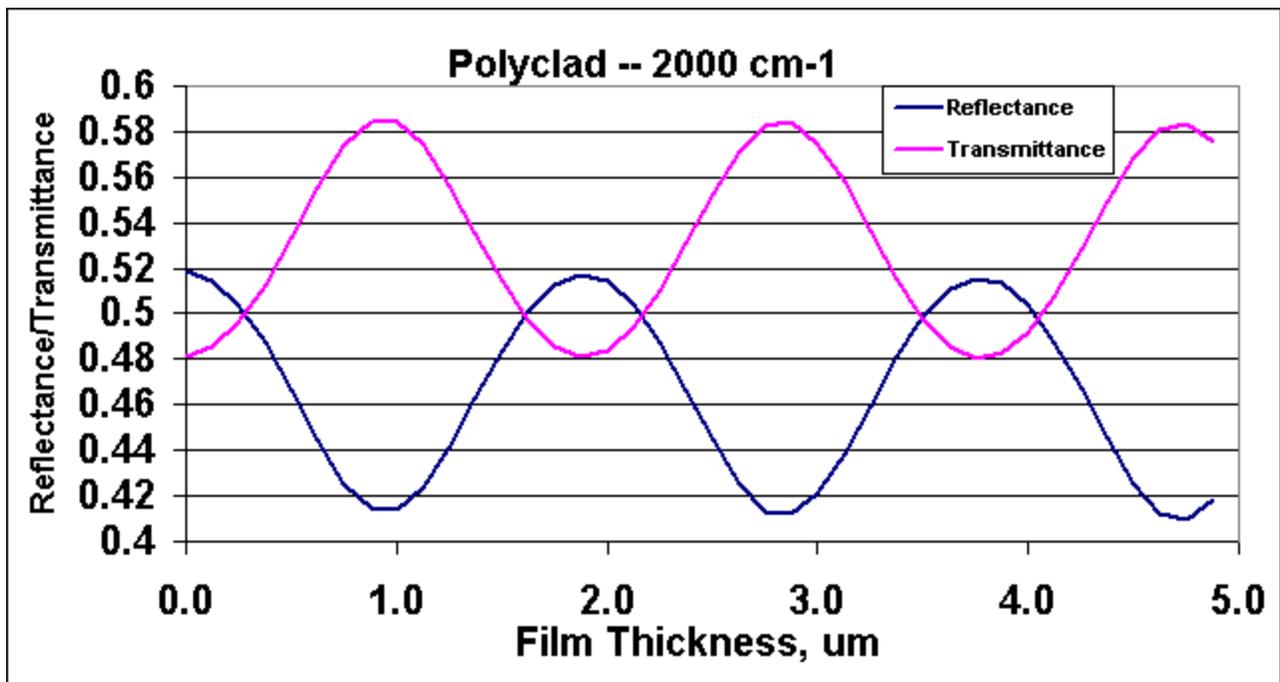


Fig. 9 Calculated values (using CALCRT) for reflectance and transmittance for film thicknesses formed from condensed outgassing products from Polyclad on a germanium window for a wavenumber of 2000 cm⁻¹ (wavelength = 5 microns).

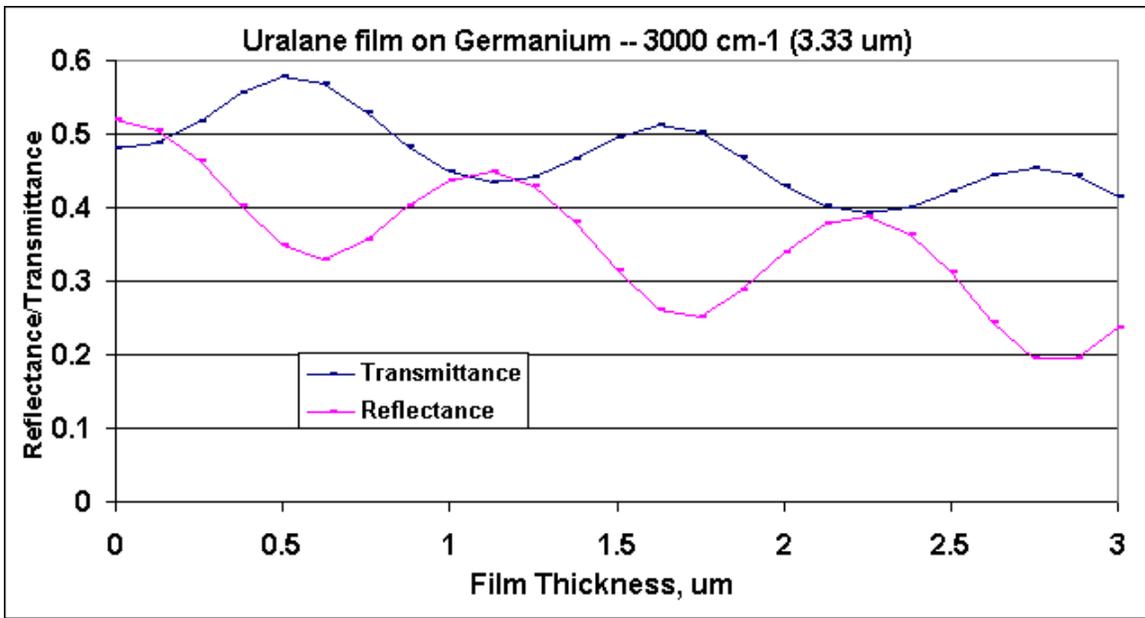


Fig. 10 Calculated values (using CALCRT) for reflectance and transmittance for film thicknesses formed from condensed outgassing products from Uralane on a germanium window for a wavenumber of 3000 cm⁻¹ (wavelength = 3.33 microns).

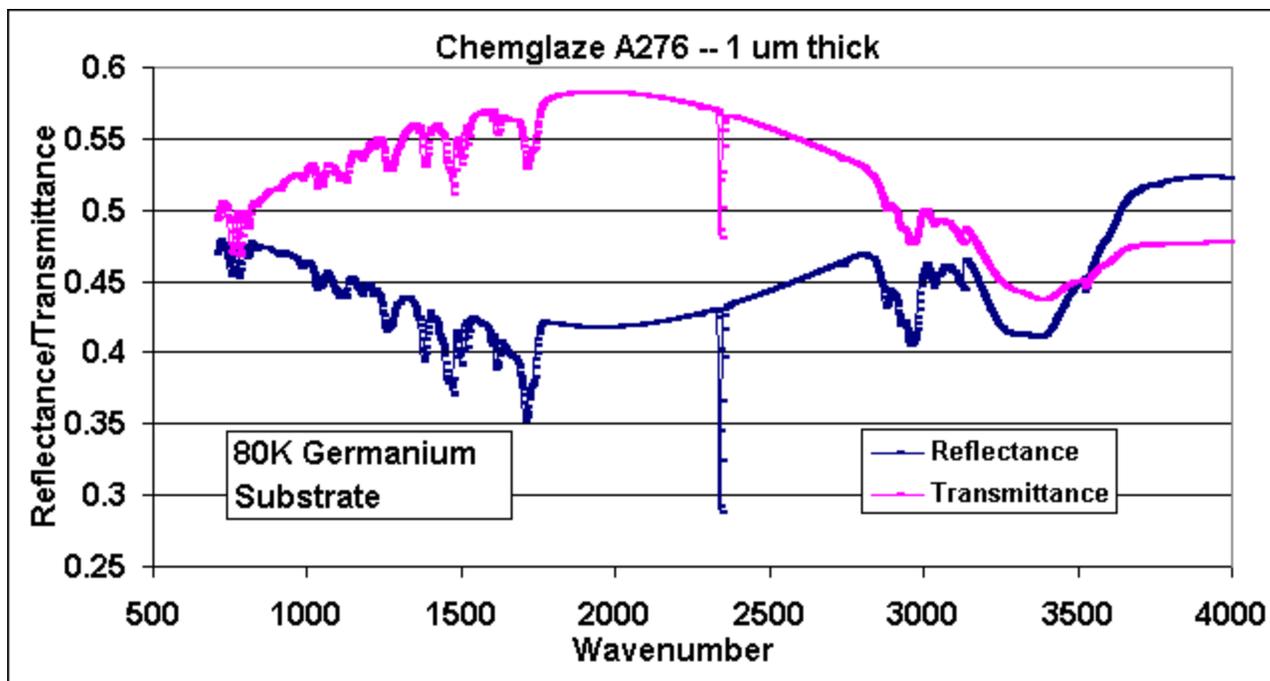


Fig. 11 Calculated values (using CALCRT) for reflectance and transmittance for a one micron thick film formed from condensed outgassing products from ChemglazeA276 on a germanium window as a function of wavenumber.

Appendix 1:

Listing of E1559 outgassing data for new materials added to the Knowledgebase during this program

Key to Facility Providers:

AGI --- Agilent

AEDC – AEDC, Arnold AFB, TN

JSC—Johnson Space Center

OSI – Outgassing Services International

GSFC- Goddard Space Flight Center – Molekit

GSFC- Molidep – Goddard Space Flight Center -- Molidep

LMSC—Lockheed Space and Missiles Company

MSFC -- Marshall Space Flight Center

<u>Material Name</u>	<u>Facility Provider</u>
3M Scotchweld	AGI
303 Stainless Steel at 30C	AGI
DC6-1104 at 343K	AGI
DC93-500 at 303K	AGI
Invar FM at 303K	AGI
Lexan 500 Injection Molded Plastic at 303K	AGI
Noryl EN 265-701 IM Plastic	AGI
Stainless Steel 416	AGI
Ultem 2400-7301 Injection Molded Plastic	AGI
Valox 420 BK 1066 Injection Molded Plastic at 303K	AGI
Varian Torr Seal at 303K	AGI
3M-361 Epoxy (85F)	JSC
3M-361 Epoxy (125F)	JSC
3M-361 Epoxy (180F)	JSC
CV 1144 Epoxy (125F)	JSC
CV 1144 Epoxy (180F)	JSC
CV 1144 Epoxy (250F)	JSC
CV 1146 Epoxy (125F)	JSC
CV 1146 Epoxy (180F)	JSC
CV 1146 Epoxy (250F)	JSC
Flown FRSI at 50C	JSC
Flown FRSI at 100C	JSC
Unflown FRSI at 50C	JSC
Unflown FRSI at 100C	JSC
Hysol Epoxy Paste at 353K	JSC
Hysol Epoxy Paste at 383K	JSC
Hysol Epoxy Paste at 423K	JSC

Kapton Tape at 383K	JSC	
Kapton Tape at 423K	JSC	
High Air Velcro – 110C		JSC
High Air Velcro – 150C		JSC
HTSCE – 50C		JSC
Kevlar Epoxy -- Alenia --398K – No Preconditioning		JSC
Kevlar Epoxy – Alenia -- 398K -- 100 Hours of preconditioning		JSC
Kevlar Epoxy – Alenia -- 398K – 200 Hours of preconditioning		JSC
Kevlar Epoxy – Alenia -- 398K – 300 Hours of preconditioning		JSC
Kevlar Epoxy –Alenia -- 428K		JSC
Kynar – 300K	JSC	
Kynar -- 325K	JSC	
Kynar -- 355K	JSC	
Nextel – Alenia -- 150C no preconditioning	JSC	
Nextel – Alenia -- 150C preconditioning	JSC	
Nomex Velcro – 80C	JSC	
Nomex Velcro – 110C	JSC	
RTV 560 – 50C	JSC	
Teflon 52C	JSC	

Chemglas 250F Betacloth @30C	OSI	
Chemglas 250F Betacloth @75C	OSI	
Chemglas 250F Betacloth @125C	OSI	
Chemglas 500F Betacloth @30C	OSI	
Chemglas 500F Betacloth @75C	OSI	
Chemglas 500F Betacloth @125C	OSI	
CombiTherm VPC 07 @43C	OSI	
CombiTherm VPC 07 @ 68C	OSI	
CombiTherm VPC 07 @102C	OSI	
Derakane 470HT @50C	OSI	
GE RTV 142 @75C	OSI	
GE RTV 142 @90C	OSI	
GE RTV 142 @125C	OSI	
Hi-Temp Velcro HT-1773 @51.7C	OSI	
Hi-Temp Velcro HT-1773 @81.2C	OSI	
Hi-Temp Velcro HT-1773 @110C	OSI	
Kevlar 29 @ 32C	OSI	
Kevlar Epoxy Unbaked @80C	OSI	
Kevlar Epoxy Unbaked @100C	OSI	
Nextel 312 –8-95 @33C	OSI	
Nextel 312 (600C Prebake) @150C (Large sample Prebaked)		OSI
Nextel 312 (600C Prebake) @150C (No Prebake)		OSI
Nextel 312 (600C Prebake) @150C (Small sample Prebaked)		OSI
Nextel 312 (Polyethylene Coated) @43C		OSI

Nextel 312 (Polyethylene Coated) @68C	OSI
Nusil CV1-2502 Adhesive @75C	OSI
Nusil CV2-1147 Adhesive @75C	OSI
Nusil CV-2946 Adhesive @10C	OSI
Nusil CV-2946 Adhesive @25C	OSI
Nusil CV-2946 Adhesive @40C	OSI
Nusil CV-9042 Grease @ 10C	OSI
Nusil CV-9042 Grease @ 25C	OSI
Nusil CV-9042 Grease @ 40C	OSI
Polyethylene Film @30C	OSI
Polyethylene Film @43C	OSI
Polyethylene Film @68C	OSI
Raychem RT220 Shrink Tubing @25C	OSI
Raychem RT220 Shrink Tubing @70C	OSI
Russian Betacloth (Black) @100C	OSI
Russian Betacloth (Black) @150C	OSI
Russian Betacloth (White) @100C	OSI
Russian Betacloth (White) @150C	OSI
Russian TP-CO-2 Paint @25C	OSI
Russian TP-CO-2 Paint @75C	OSI
Solimide TA-301 Foam @50C	OSI
Solimide TA-301 Foam @100C	OSI
Solimide TA-301 Foam @150C	OSI
Superflex Cable @75C	OSI
Superflex Cable @100C	OSI
Superflex Cable @ 125C	OSI
Tefzel Cable Insulation 5-95 @120C	OSI
Tefzel Cables @52C	OSI
Tefzel Cables @82C	OSI
Z1 Truss Cable Clamps @27C	OSI
Z1 Truss Cable Clamps @52C	OSI
Z1 Truss Cable Clamps @82C	OSI
3M 2216 Translucent Epoxy	GSFC-Molidep
Aluminum Foil Substrate @102C	GSFC
9 Pin D Connector + Wires@80C	GSFC
Baked Urelane 5753LV@30C	GSFC
Baked Urelane 5753LV@50C	GSFC
Baked Urelane 5753LV@80C	GSFC
Aluminum Substrate @80C	GSFC
Lacquer on Aluminum @50C	GSFC
Lacquer on Aluminum @80C	GSFC
Urelane 5753LV@50C	GSFC
Urelane 5753LV@80C	GSFC
Urelane 5753LV@80C RGA	GSFC
Lacquer on Aluminum Substrate@80C	GSFC

Lacquer on Aluminum @30C	GSFC
Chemglaze Z306 + primer on Al@10C	GSFC
Chemglaze Z306 Al Substrate @10C	GSFC
Chemglaze Z306 – No primer on Al@10C	GSFC
Urelane 5753 Mix 2 @30C	GSFC
NS43C on Al Foil @80C	GSFC
Gap Pad VO (yellow) @40C	GSFC
Gap Pad VO Soft (Pink) @40C	GSFC
Gap Pad VO Soft (Pink) Air Baked @40C	GSFC
Gap Pad VO (Yellow) Air Baked @40C	GSFC
P-touch Label Tape @30C	GSFC
CdZnTe Detector @15 and 30C	GSFC
9 Pin D Connector + Wires @80C #2	GSFC
Chemglaze Z306 + Primer on Al @80C	GSFC
Chemglaze Z306 Al Foil @80C	GSFC
Oil-Contaminated Nickel Foil @25C	GSFC
Chemglaze Z306 + Primer on Al @50C	GSFC
Chemglaze Z306 + Primer on Al @30C	GSFC
Chemglaze Z306 on Al @80C	GSFC
Chemglaze Z306 on Al @50C	GSFC
RTV566 @30C	GSFC
Unbaked NSB 6982 @102C	GSFC
Al Foil @102C	GSFC
RTV566 @10C	GSFC
Urelane 5753 Mix 1 @70C	GSFC
Urelane 5753 Mix 1 @30C	GSFC
Urelane 5753 Mix 1 @30C #2	GSFC
Urelane 5753 Mix 2 @70C	GSFC
Urelane 5753 Mix 2 @30C	GSFC
Al Substrate @80C	GSFC
Aluminized Kapton @30C	GSFC
Aluminized Kapton @50C	GSFC
Aluminized Kapton @80C	GSFC
Bare Kapton @30C	GSFC
Bare Kapton @50C	GSFC
Bare Kapton @80C	GSFC
Chemglaze Z306 on Al @30C	GSFC
Lacquer on Al @80C	GSFC
Lacquer Al Substrate @80C	GSFC
Chemglaze Z306 + Primer on Al @10C	GSFC
QCM Verification with Cetyl Alcohol	GSFC
Carbon Phenolic Nozzle @300C	GSFC
RTV157 on Cloth Backing @35C	GSFC
Aptek 2706 on Al @75C	GSFC
EC2216 @80C	GSFC

Carbon Phenolic Nozzle @100C	GSFC
Carbon Phenolic Nozzle @200C	GSFC
Carbon Phenolic Nozzle @200C #2	GSFC
Lacquer on Al Foil @80C	GSFC
Lacquer on Al Foil VDA Overcoat @80C	GSFC
Al Foil Substrate VDA Lacquer @80C	GSFC
Al Substrate Lacquer Test @80C	GSFC
EC2216 @30C	GSFC
EC2216 @50C	GSFC
Exposed RTV560 @20C	GSFC
Exposed RTV560 @20C RGA	GSFC
RTV566 @30C	GSFC
VEC Sample @75C	GSFC
Black Cable Sleeve @80C	GSFC
Black Cable Sleeve @50C	GSFC
Black Cable Sleeve @30C	GSFC
Black Cable Sleeve @80C #2	GSFC
Exposed Puck Adsorber @30C	GSFC
Exposed Puck Adsorber @50C	GSFC
Exposed Puck Adsorber @80C	GSFC
Exposed Puck Adsorber @100C	GSFC
Teflon Cable @80C RGA	GSFC
Teflon Cable @80C no RGA	GSFC
9 Pin D Connector + 6 Wires @80C	GSFC
9 Pin D Connector + 6 Wires @30C	GSFC
RTV566 @80C	GSFC
Exposed Puck Adsorber @30C #2	GSFC
Exposed Puck Adsorber @50C #2	GSFC
Exposed Puck Adsorber @80C #2	GSFC
Exposed Puck Adsorber @100C #2	GSFC
Exposed Puck Adsorber @125C	GSFC
Exposed Puck Adsorber @150C	GSFC
Variable Emittance Sample (split) @25C	GSFC
Exposed RTV560 @40C	GSFC
9 Pin D Connector + 6 Wires @80C #2	GSFC
2 Conductor Teflon Cable @80C	GSFC
2 Conductor Teflon Cable @30C	GSFC
CV1142 @125C	GSFC
CV1142 @75C	GSFC
CV1142 @125C #2	GSFC
9 Pin D Connector + 2 Conductor Cable @30C	GSFC
9 Pin D Connector + 2 Conductor Cable @50C	GSFC
9 Pin D Connector + 2 Conductor Cable @80C	GSFC
Laminated Brass Washers @ 40C	GSFC
RTV 142 Epoxy @15C	GSFC

RTV 142 Epoxy @30C	GSFC
Teflon Cable @80C	GSFC
Teflon Cable @50C	GSFC
Teflon Cable @30C	GSFC
Teflon Cable @80C #2	GSFC
Teflon Cable @50C #2	GSFC
Epotek 410E @15C	GSFC
Epotek 410E @30C	GSFC
Adsorber Puck Cleaning	GSFC
Exposed RTV 560 @20C	GSFC
Exposed RTV 560 @50C	GSFC
Pennzane 2000 + Pb Napthenate @30C	GSFC
Twisted Teflon Wire @80C	GSFC
Twisted Teflon Wire @30C	GSFC
9 Pin D Connector + 6 Teflon Wires @80C	GSFC
9 Pin D Connector + 6 Teflon Wires @50C	GSFC
CV-2289@30C	GSFC
Sil-Pad @30C	GSFC
Sil-Pad @50C	GSFC
Aluminized Blanket @200 and 350C	GSFC
Polyimide Printed Board @ 0C	GSFC
Polyimide Printed Board @ 20C	GSFC
Polyimide Printed Board @ 60C	GSFC
Variable Emittance Sample @25C	GSFC
Variable Emittance Sample @50C	GSFC
Variable Emittance Sample @70C	GSFC
Shuttle Panel B KP1A276@20C	GSFC
Shuttle Panel C KP2A276@90C	GSFC
Shuttle Panel F -P1 +A276@80C	GSFC
Shuttle Panel F P1A276@20C	GSFC
Shuttle Panel G P2A276@50C	GSFC
Llualloy	MSFC
Teflon	MSFC
Epoxy coated Kevlar	MSFC
S-383 Silicone Rubber, 75C	MSFC
S-383 Preconditioned 25C	MSFC
S-383 Preconditioned 50C	MSFC
S-383 Preconditioned 75C	MSFC
Teflon TE9302 at 25C	MSFC
Teflon TE9302 at 50C	MSFC
Teflon TE9302 at 77C	MSFC
Scotch Weld 3501 at 25C	MSFC
Scotch Weld 3501 at 50C	MSFC
Scotch-Weld 3501at 75C	MSFC
MLI Preconditioned 25C	MSFC

MLI Preconditioned 50C	MSFC
MLI Preconditioned 75C	MSFC
MLI-Pre 50C Retest	MSFC
Butyl B612-70 Orings @125C-AEDC	AEDC
Butyl B612-70 Orings @125C-Agilent	AGI
Butyl B612-70 Orings @125C-GSFC Molidep	GSFC-Molidep
Butyl B612-70 Orings @125C-GSFC Molekit-1	GSFC
Butyl B612-70 Orings @125C-GSFC Molekit-2	GSFC
Butyl B612-70 Orings @125C-LMSC –1	LMSC
Butyl B612-70 Orings @125C-LMSC –2	LMSC
Butyl B612-70 Orings @125C-MSFC	MSFC
Butyl B612-70 Orings @125C-OSI –A	OSI
Butyl B612-70 Orings @125C-OSI-B	OSI
Polyethylene Beads @125C-AEDC	AEDC
Polyethylene Beads @125C-Agilent	AGI
Polyethylene Beads @125C-GSFC Molidep	GSFC-Molidep
Polyethylene Beads @125C-GSFC Molekit –1	GSFC
Polyethylene Beads @125C-GSFC Molekit –2	GSFC
Polyethylene Beads @125C-LMSC –1	LMSC
Polyethylene Beads @125C-LMSC-2	LMSC
Polyethylene Beads @125C-MSFC	MSFC
Polyethylene Beads @125C-OSI-A	OSI
Polyethylene Beads @125C-OSI-B	OSI

Appendix 2: Refractive and Absorptive Indices listing for thin solid films condensed from gases and material outgassing products

- 1) Ammonia (NH₃) at 20K
- 2) Ammonia (NH₃) at 77K
- 3) Argon at 20K
- 4) Argon-H₂O mixture at 20K
- 5) Carbon Dioxide (CO₂) at 77K
- 6) Carbon Dioxide (CO₂) at 20K
- 7) Carbon Monoxide (CO) at 20K
- 8) Carbon Monoxide-H₂O mixture at 20K
- 9) Water (H₂O) at 20K
- 10) Water (H₂O) at 50K
- 11) Water (H₂O) at 77K
- 12) H₂O-CO₂ mixture at 77K
- 13) Hydrogen Chloride (HCL) at 20K
- 14) Methane (CH₄) at 20K
- 15) N₂-CO₂ mixture at 20K
- 16) N₂-CO mixture at 20K
- 17) N₂-CO-CO₂ mixture at 20K
- 18) N₂-H₂O mixture at 20K
- 19) N₂-NH₃ mixture at 20K
- 20) Nitrogen (N₂) at 20K
- 21) Nitric Oxide (NO) at 20K
- 22) Oxygen (O₂) at 20K
- 23) Bipropellant engine exhaust gases at 25K
- 24) Bipropellant engine exhaust gases at 75K
- 25) Hydrazine (N₂H₄) at 80K
- 26) Monomethyl hydrazine (MMH) at 20K
- 27) Monomethyl hydrazine (MMH) at 80K
- 28) Nitrogen Tetroxide (N₂O₄) at 20K
- 29) Nitrogen Tetroxide (N₂O₄) at 80K
- 30) Simulated Bipropellant engine gases at 20K
- 31) Chemglaze A276 Paint
- 32) Chemglaze Z306 Paint
- 33) Crest 74
- 34) DC6-1104
- 35) DC93-500
- 36) EP30LI Composite
- 37) J2AS4 Composite
- 38) Kapton

- 39) Lockheed-100 Paint**
- 40) Lockheed-200 Paint**
- 41) Lockheed-300 Paint**
- 42) Mylar**
- 43) NVF**
- 44) Polyclad**
- 45) RTV-560**
- 46) RTV-566**
- 47) RTV-732**
- 48) Torrseal**
- 49) Uralane 5753**
- 50) Vackote Oil**

Appendix 3 Software Usage Agreement Application for gaining access to NASA Space Environment Effects Knowledgebase

SOFTWARE USAGE AGREEMENT (SUA)

**Satellite Contamination and Materials Outgassing Knowledgebase
“...An exhaustive database reference...”**

Export Classification of CCL ECCN EAR 9D001

Please note: The signature of this SUA must be a US Citizen and may be responsible for any export control issues that may arise from this technology transfer.



[Recipient’s Name] (hereinafter RECIPIENT) has requested that the United States Government as represented by the National Aeronautics and Space Administration, Marshall Space Flight Center, located at Marshall Space Flight Center, AL 35812 (hereinafter NASA), release the following computer software:

Name: Satellite Contamination and Materials Outgassing Knowledgebase Version 2.0

Version: 2.0 NASA Case No: 32183-1 (hereinafter SOFTWARE).

The authority for NASA to release SOFTWARE is NASA Policy Directive (NPD) 2210.1.

NOW THEREFORE, in consideration of NASA releasing the SOFTWARE to RECIPIENT and granting RECIPIENT the right to use such SOFTWARE for the stated purposes, RECIPIENT agrees as follows:

1. This SOFTWARE is not in the public domain and nothing in this Agreement shall be construed as making the SOFTWARE available to the public without restriction. The SOFTWARE shall be released only to employees of RECIPIENT and shall be used for internal use only.
2. There shall be no further distribution or publication of the SOFTWARE by RECIPIENT, neither the source code, nor the executable code, nor associated run-time applications, whether standalone or embedded, to or for use by any third party without the express prior written approval of NASA.
3. Excluded from the foregoing restrictions is information that:
 - a. was published, known publicly or otherwise in the public domain prior to the effective date of this agreement;

- b. was known to RECIPIENT prior to the effective date of this agreement, provided that RECIPIENT shall have the burden of establishing such prior knowledge by competent written proof;
 - c. subsequent to the effective date of this agreement, is published by NASA, or becomes publicly known, or otherwise becomes part of the public domain through no act or omission of RECIPIENT; or
 - d. subsequent to the effective date of this agreement, is made available to RECIPIENT by a third party under no obligation of confidentiality.
4. The SOFTWARE, and/or any modified or enhanced version thereof, shall not be published by RECIPIENT, given to another entity, or in any manner offered for sale to the U.S. Government or any other entity. The SOFTWARE may be used in contracts with the U.S. Government, but no charge may be made for its use.
5. The SOFTWARE remains the property of NASA. If the SOFTWARE is modified or enhanced, NASA will be provided the complete source code of the modified or enhanced version and RECIPIENT will assign all rights to the U.S. Government.
6. NASA shall be neither liable nor responsible for any maintenance or updating of the provided SOFTWARE, nor for correction of any errors in the SOFTWARE.
7. The SOFTWARE is intended for domestic use only and shall not be made available to anyone outside of the United States. In addition, within the United States, the SOFTWARE shall not be made available to foreign persons (as defined by 22 CFR §120.16). Furthermore, the SOFTWARE shall not be provided to any person or entity listed on any “denied parties/persons” list (including the Office of Foreign Assets Control, Specially Designated Nationals and Blocked Persons; Office of Foreign Assets Control, Changes to List of Specially Designated Nationals and Blocked Persons; Office of Defense Trade Controls, List of Debarred Parties; Bureau of Export Administration, List of Denied Persons; Bureau of Export Administration, Entity List). RECIPIENT certifies that it is not a foreign person (as defined by 22 CFR §120.16) and is not listed on any of the aforementioned lists.
8. Notwithstanding any provisions contained herein, RECIPIENT is hereby put on notice that export of any goods or technical data from the United States may require some form of export license from the U.S. Government. Failure to obtain necessary export licenses may result in criminal liability of RECIPIENT under U.S. laws. NASA neither represents that a license shall not be required nor that, if required, it shall be issued. Nothing granted herein to RECIPIENT provides any such export license.
9. THE SOFTWARE IS PROVIDED “AS IS” WITHOUT ANY WARRANTY OF ANY KIND, EITHER EXPRESSED, IMPLIED, OR STATUTORY, INCLUDING, BUT NOT LIMITED TO, ANY WARRANTY THAT THE SOFTWARE WILL CONFORM TO SPECIFICATIONS, ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND FREEDOM FROM INFRINGEMENT, AND ANY WARRANTY THAT THE DOCUMENTATION WILL CONFORM TO THE SOFTWARE, OR ANY WARRANTY THAT THE SOFTWARE WILL BE ERROR FREE. IN NO EVENT SHALL NASA BE LIABLE FOR ANY DAMAGES, INCLUDING, BUT NOT LIMITED TO, DIRECT, INDIRECT, SPECIAL OR CONSEQUENTIAL DAMAGES, ARISING OUT OF, RESULTING FROM, OR IN ANY WAY CONNECTED WITH THIS SOFTWARE, WHETHER OR NOT BASED

UPON WARRANTY, CONTRACT, TORT , OR OTHERWISE, WHETHER OR NOT INJURY WAS SUSTAINED BY PERSONS OR PROPERTY OR OTHERWISE, AND WHETHER OR NOT LOSS WAS SUSTAINED FROM, OR AROSE OUT OF THE RESULTS OF, OR USE OF, THE SOFTWARE OR SERVICES PROVIDED HEREUNDER.

RECIPIENT AGREES TO WAIVE ANY AND ALL CLAIMS AGAINST THE U.S. GOVERNMENT, THE U.S. GOVERNMENT'S CONTRACTORS AND SUBCONTRACTORS, AND SHALL INDEMNIFY AND HOLD HARMLESS THE U.S. GOVERNMENT AND THE U.S. GOVERNMENT'S CONTRACTORS AND SUBCONTRACTORS FOR ANY DAMAGE THAT RECIPIENT MAY INCUR FROM RECIPIENT'S PRIOR OR FUTURE USE OF THE PROVIDED SOFTWARE, INCLUDING ANY DAMAGES FROM PRODUCTS BASED ON, OR RESULTING FROM, THE USE THEREOF.

IF FURTHER RELEASE OR DISTRIBUTION OF THIS SOFTWARE OR TECHNICAL DATA DERIVED FROM THIS SOFTWARE IS PERMITTED, RECIPIENT AGREES TO OBTAIN THIS IDENTICAL WAIVER OF CLAIMS, INDEMNIFICATION AND HOLD HARMLESS AGREEMENT WITH ANY ENTITIES THAT ARE PROVIDED WITH THE SOFTWARE OR TECHNICAL DATA DERIVED FROM USE OF THE SOFTWARE.

10. If the SOFTWARE and/or any documentation provided with the SOFTWARE includes a copyright notice, or other restrictive marking or legend, identifying it as a work of a third party, the third party software or documentation will be governed by the terms and conditions of its copyright, or other restrictive marking. NASA disclaims all warranties and liabilities regarding third party software, if present in the NASA generated SOFTWARE, and distributes it "as is."

11. This Agreement does not, in any manner, constitute an exclusive release of the SOFTWARE to RECIPIENT. NASA's distribution of the SOFTWARE to other entities is in no manner limited.

12. This Agreement does not, in any manner, constitute an endorsement by NASA of any test results, resulting designs, hardware, or other matters resulting from use of the SOFTWARE.

13. This Agreement does not, in any manner, constitute the grant of a license to RECIPIENT under any NASA copyright, patent, patent application or other intellectual property.

14. The restrictions on disclosure and distribution imposed by this Agreement shall apply to any software code developed by RECIPIENT that incorporates any portion of the SOFTWARE.

15. Any use of the SOFTWARE by RECIPIENT other than that authorized in this Agreement may result in liability of the RECIPIENT to the U.S. Government and/or other parties.

16. This Agreement shall be construed, and the legal relations between the parties hereto shall be determined, in accordance with United States federal law.

17. This Agreement constitutes the entire understanding and agreement between the parties hereto relating to release of the SOFTWARE and may not be superseded, modified or amended except by further written agreement duly executed by the parties.

18. RECIPIENT shall inform all employees of RECIPIENT given access to the SOFTWARE of the restrictions specified herein, and RECIPIENT shall require that such employees be bound by such restrictions. Furthermore, RECIPIENT represents that it has authority to bind such employees to the restrictions specified herein.

19. Either NASA or RECIPIENT may terminate this Agreement, at any time by written notice to the other thirty (30) days before the desired date of termination. Upon termination of this Agreement, RECIPIENT shall return the SOFTWARE to NASA, or if so instructed, shall certify that the SOFTWARE has been destroyed and/or deleted from the computer systems on which it resided.

20. The effective date of this Agreement shall be the date of RECIPIENT'S execution of this Agreement as set forth below. The person signing below on behalf of RECIPIENT represents that he or she is a United States citizen and has the authority to sign this Agreement on behalf of RECIPIENT.

21. Due to the unique requirement of the software release, the subject Software will be released to the under signed recipient by Bill Kauffman/ED03

Executed on Behalf of RECIPIENT by:

Caroline K. Wang
Software Release Authority

Date

Recipient Signature

Date

Recipient Name (printed)

Title

(Indicate formal title if signing as an authorized representative of a company or entity. If signing as an individual, fill in the Title line as "Individual")

Name of RECIPIENT: _____

Address: _____

____City/State/Zip: _____

Phone: _____

Fax: _____

E-mail: _____

REPORT DOCUMENTATION PAGEForm Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operation and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503

1. AGENCY USE ONLY (Leave Blank)		2. REPORT DATE June 2007	3. REPORT TYPE AND DATES COVERED Contractor Report	
4. TITLE AND SUBTITLE Space Environmental Effects Knowledgebase			5. FUNDING NUMBERS NAS8-02029N	
6. AUTHORS B.E. Wood				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Bob Wood Aerospace Consulting Services, Inc. (BWACS) 402 Lannom Circle Tullahoma, TN 37388-2464			8. PERFORMING ORGANIZATION REPORT NUMBER M-1190	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001			10. SPONSORING/MONITORING AGENCY REPORT NUMBER NASA/CR-2007-214961	
11. SUPPLEMENTARY NOTES Prepared for Technical Monitor: Dr. Dale Ferguson				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified-Unlimited Subject Category 23 Availability: NASA CASI 301-621-0390			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) This report describes the results of an NRA funded program entitled "Space Environmental Effects Knowledgebase" that received funding through a NASA NRA (NRA8-31) and was monitored by personnel in the NASA Space Environmental Effects (SEE) Program. The NASA Project number was 02029. The Satellite Contamination and Materials Outgassing Knowledgebase (SCMOK) was created as a part of the earlier NRA8-20. One of the previous tasks and part of the previously developed Knowledgebase was to accumulate data from facilities using QCMs to measure the outgassing data for satellite materials. The main object of this current program was to increase the number of material outgassing datasets from 250 up to ~500. As a part of this effort, a round-robin series of materials outgassing measurements program was also executed that allowed comparison of the results for the same materials tested in 10 different test facilities. Other programs tasks included obtaining datasets or information packages for 1) optical effects of contaminants on optical surfaces, thermal radiators, and sensor systems and 2) space environmental effects data and incorporating these data into the already existing NASA/SEE Knowledgebase.				
14. SUBJECT TERMS spacecraft materials, outgassing, QCM, quartz crystal microbalance, optical properties, refractive indices, contamination, database, satellite			15. NUMBER OF PAGES 50	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT Unlimited	

National Aeronautics and
Space Administration
IS20

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama
35812