



National Aeronautics and
Space Administration

MSFC-HDBK-3575
BASELINE

EFFECTIVE DATE: September 16, 2009

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

MULTIPROGRAM/PROJECT COMMON-USE DOCUMENT

Outgassing Rate Measurements for the Screening of Nonmetallic Materials

DRAFT NO. 1

Approved for Public Release; Distribution Unlimited

CHECK THE MASTER LIST—
VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

Multiprogram/Project Common-Use Document		
EM50		
Title: Outgassing Rate Measurements for the Screening of Nonmetallic Materials	Document No.: MSFC-HDBK-3575	Revision: Baseline
	Effective Date: September 16, 2009	Page 2 of 22 Pages

DOCUMENT HISTORY LOG

Status (Baseline/ Revision/ Canceled)	Document Revision	Effective Date	Description
Baseline		09/16/09	

CHECK THE MASTER LIST
VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

Multiprogram/Project Common-Use Document		
EM50		
Title: Outgassing Rate Measurements for the Screening of Nonmetallic Materials	Document No.: MSFC-HDBK- 3575	Revision: Baseline
	Effective Date: September 16, 2009	Page 3 of 22 Pages

FOREWORD

This handbook is published by the National Aeronautics and Space Administration (NASA) to describe a processes and methodology by which the rate of outgassing of nonmetallic materials can be measured.

CHECK THE MASTER LIST
VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

Multiprogram/Project Common-Use Document		
EM50		
Title: Outgassing Rate Measurements for the Screening of Nonmetallic Materials	Document No.: MSFC-HDBK-3575	Revision: Baseline
	Effective Date: September 16, 2009	Page 4 of 22 Pages

TABLE OF CONTENTS

<u>SECTION</u>	<u>PAGE</u>
DOCUMENT HISTORY LOG	2
FOREWORD	3
1. SCOPE	6
1.1 Purpose	6
1.2 Applicability	6
.....	
2. APPLICABLE DOCUMENTS	8
2.1 General	8
2.2 Government Documents.....	8
2.3 Non-Government Documents.....	8
3. MEASUREMENT METHODOLOGY	8
3.1 <u>The Outgassing Measurement</u>	8
3.1.1 Measurement Limit	8
3.1.2 The Temperature of the Source or Emitting Surface	8
3.1.3 Vacuum Chamber Pressure	8
3.1.4 Mean Free Path	8
3.1.5 The Temperature of the Deposition Surface	9
3.1.6 Quartz Crystal Microbalance	10
3.1.7 Cryogenic Shroud	10
3.1.8 The Disposition Process.....	11
3.2 Analysis	11
3.2.1 Conversion of Frequency to Mass	11
3.2.2 View Factor.....	12
3.2.3 Sample Surface Area	12
3.2.4 Source Term.....	12
3.2.5 Configurational Analysis	13
3.2.7 Determining ASTM E-595 %TML and %CVCM from Deposition Rate Measurements	13
3.3 Operations	13
3.3.1 Chamber Background Measurement	13
3.3.2 Order of Measurements	14
3.3.3 Measurement Duration	14
3.3.4 Deposition Surface Regeneration	14
3.3.5 Thickness of a Material Deposited on Contamination Sensitive Surfaces.....	14
3.3.6 Material Acceptance Criteria.....	15

CHECK THE MASTER LIST
VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

Multiprogram/Project Common-Use Document		
EM50		
Title: Outgassing Rate Measurements for the Screening of Nonmetallic Materials	Document No.: MSFC-HDBK-3575	Revision: Baseline
	Effective Date: September 16, 2009	Page 5 of 22 Pages

TABLE OF CONTENTS (Continued)

<u>SECTION</u>	<u>PAGE</u>
3.3.7 Identification of Candidate Samples	16
3.3.8 Materials with High Outgassing Rates.....	16
3.3.9 Documentation	17
4. GUIDANCE	17
4.1 Reference Documents	17
4.2 Key Word Listing	17
4.3 Definitions	17
Appendix A. Acronyms and Definitions.....	19
Appendix B. Calculation of the Dwell Time of Contaminants on Surfaces	20
Appendix C. Calculation of the Clausing Factor for an Orifice or Short Tube	21

List of Figures

<u>Figure</u>	<u>Page</u>
1 Measurement Process	7

Multiprogram/Project Common-Use Document		
EM50		
Title: Outgassing Rate Measurements for the Screening of Nonmetallic Materials	Document No.: MSFC-HDBK-3575	Revision: Baseline
	Effective Date: September 16, 2009	Page 6 of 22 Pages

1. SCOPE

1.1 Purpose. The purpose of this handbook is to present a methodology for the systematic screening of nonmetallic materials with a line of sight to an optical surface, thermal control surface, or other contamination sensitive surfaces in a vacuum environment. The outgassing measurements made using the methods described here will support configurational analysis of the release of molecular contamination from the surface of a material and facilitate the prediction of the deposition of condensable materials on one or more adjacent surfaces.

1.2 Applicability. This handbook is applicable to the test methodology used to evaluate the outgassing of nonmetallic materials used adjacent to contamination sensitive surfaces. This methodology is based on the American Society for Testing and Materials (ASTM), Standard Test Method for Contamination Outgassing Characteristics of Spacecraft Materials, Method E-1559, and describes methodology by which the outgassing source terms (rates) for nonmetallic materials should be measured. This measurement differs from the measurement described in the ASTM Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment (Method E-595) which is a less complex outgassing measurement; possibly an alternative to the E-1559 measurement. The outgassing rate data obtained from the E-1559 measurement will support configurational analysis of the emittance and deposition of contaminants while the data obtained from the E-595 measurement will not. (See Figure 1.)

1.3 The selection of either measurement is a Program/Project decision and should take into account both the duration that a contamination-sensitive surface will be exposed to the outgassing material and the amount of volatile condensable materials (Vim's) that can be deposited on a contamination-sensitive surface before the performance of the surface is degraded and/or no longer functional. In addition to deciding which measurement is the correct measurement to meet Program/Project needs, the Program/Project should identify a person or office to act as the Technical Authority. The Technical Authority will be charged with defining the criteria for the outgassing rate measurement as guidance to the technical community supporting the Program/Project.

Multiprogram/Project Common-Use Document		
EM50		
Title: Outgassing Rate Measurements for the Screening of Nonmetallic Materials	Document No.: MSFC-HDBK-3575	Revision: Baseline
	Effective Date: September 16, 2009	Page 7 of 22 Pages

Measurement Process - Outgassing

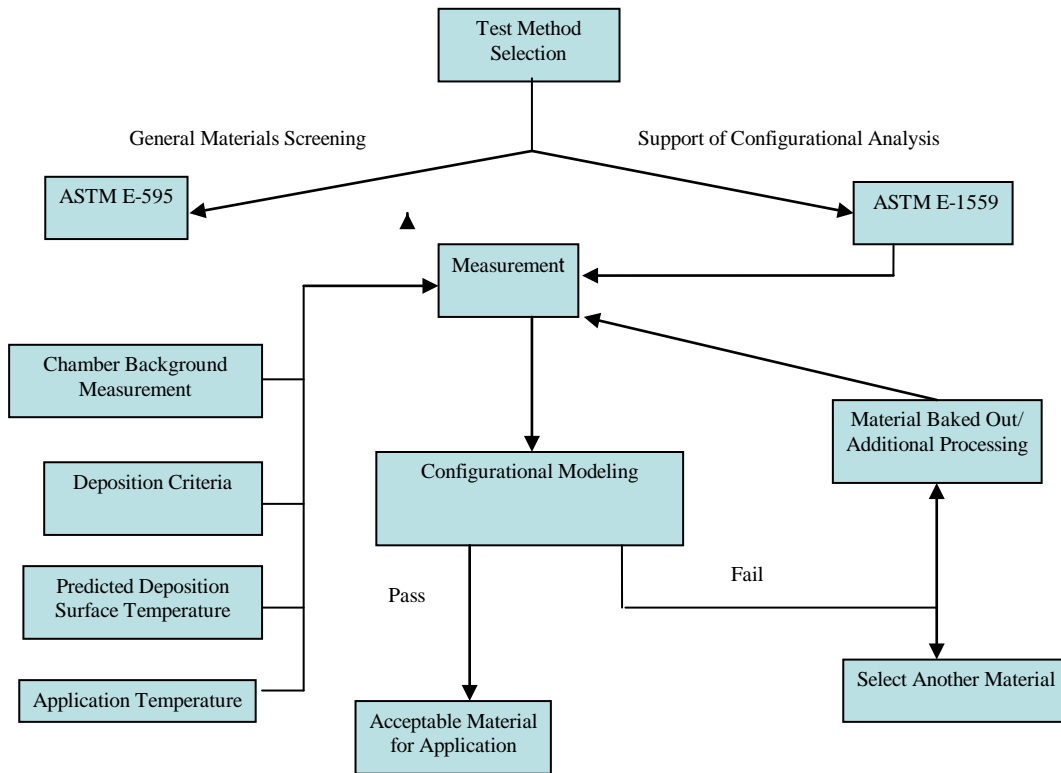


Figure 1. Measurement Process

1.4 This handbook may be cited in contract, Program/Project, and other Agency documents as a technical reference for guidance. Except where noted as mandatory, individual provisions of this reference may be tailored (i.e., modified or deleted) by contract or Program/Project direction to meet specific Program/Project needs and constraints. Tailoring shall be formally documented and approved as part of Program/Project Materials and Processes oversight.

Multiprogram/Project Common-Use Document		
EM50		
Title: Outgassing Rate Measurements for the Screening of Nonmetallic Materials	Document No.: MSFC-HDBK-3575	Revision: Baseline
	Effective Date: September 16, 2009	Page 8 of 22 Pages

2. APPLICABLE DOCUMENTS

2.1 General. The documents listed in this section contain information that supplements the measurement methodology presented in this handbook. The latest issuances of cited documents should be used unless otherwise approved by the assigned Technical Authority.

2.2 Government Documents.

None

2.3 Non-Government Documents.

ASTM Standard Test Method for Total Mass Loss and Collected Volatile
Method E-595 Condensable Materials from Outgassing in a Vacuum Environment

ASTM Standard Test Method for Contamination Outgassing
Method E-1559 Characteristics of Spacecraft Materials

3. MEASUREMENT METHODOLOGY

The outgassing process is simply the emittance or sublimation of molecular species from a surface, in a vacuum environment, and the subsequent condensation of some portion of the emitted species on a second surface. The outgassing measurement provides a method to quantify the transfer of material between the surfaces.

3.1 The Outgassing Measurement. The purpose of this measurement is to determine an outgassing source term for nonmetallic materials, a potential source of condensable molecular contaminants, which could condense (deposit) on contamination-sensitive surfaces. The measurement should be made under controlled laboratory conditions in order to provide quality data on which Program/Project material selection decisions can be based.

3.1.1 Measurement Limit. The deposition of molecular contaminants, at deposition rates approaching 5×10^{-15} grams/cm²-s, can be easily be measured using a quartz crystal microbalance. However, the measurement parameters must be tightly controlled for the measurement to be accurate and for the measured outgassing rates to be useful as input for computer simulations (configurational modeling) of the deposition process. The maximum deposition rate typically falls between 10^{-7} grams/cm²-s and 10^{-9} grams/cm²-s, varying with the quartz crystal microbalance being used for the measurement and its mass capacity.

CHECK THE MASTER LIST
VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

Multiprogram/Project Common-Use Document		
EM50		
Title: Outgassing Rate Measurements for the Screening of Nonmetallic Materials	Document No.: MSFC-HDBK-3575	Revision: Baseline
	Effective Date: September 16, 2009	Page 9 of 22 Pages

3.1.2 The Temperature of the Source or Emitting Surface. The source temperature is typically one of the measurement parameters stipulated by the Technical Authority requesting the outgassing measurement. The temperature of material that is the source of the emitted material, one or more molecular species, controls the rate at which the material is emitted. As the temperature of the material is increased the rate at which volatile materials, present in the core of the material, diffuse to the surface/vacuum interface of the material where those molecular species can be emitted into the surrounding environment.

3.1.2.1 The source temperature is typically defined by the Technical Authority in one of two ways. Either the Technical Authority:

- a. Establishes a defined temperature for the screening of all nonmetallic materials by a Program/Project (simply the source or sample temperature would be fixed for all materials/measurements).

Or

- b. Implements the practice of matching the source temperature to the application temperature at which the material (source) will be used.

3.1.2.2 A single, defined source temperature simplifies measurement control parameters but runs the risk of making a measurement unrelated to the use/application temperature for the material being tested. Tailoring the source temperature will require an understanding of the use/application temperature, possibly requiring a thermal analysis of the material with its environment, incurring additional Program/Project cost. However, tailoring the measurement will avoid testing the material at a temperature that is much hotter/colder than the application temperature resulting in a rate measurement that is significantly higher/lower than would have been measured had the application temperature been used for the measurement. The resulting error in any predictions based on a measurement, made at a significantly hotter/colder source temperature, could be large and result in the cost of testing additional materials or the use of a high outgassing material and degradation of a contamination sensitive surface.

3.1.3 Vacuum Chamber Pressure The rate of sublimation of material from the surface of the source material is, in addition to the temperature of the material, dependant on the vapor pressure above the surface/environment interface. The lower the surrounding vapor pressure the less energy is required for a molecule to diffuse away from the surface of the material into the surrounding environment.

3.1.4 Mean Free Path. If the environment that a molecule is emitted into is a vacuum, the less likely it is for the molecule to collide with another molecule, altering its direction of travel. In an environment where viscous flow is the dominant feature, the mean free path of the molecule will

Multiprogram/Project Common-Use Document		
EM50		
Title: Outgassing Rate Measurements for the Screening of Nonmetallic Materials	Document No.: MSFC-HDBK-3575	Revision: Baseline
	Effective Date: September 16, 2009	Page 10 of 22 Pages

be relatively short and the straight line migration of molecules between two surface very difficult. In a true vacuum environment ($< 5 \times 10^{-5}$ torr) where molecular flow predominates, the molecular mean free path will be reasonably long and the straight line travel of molecules between surfaces will be the dominate form of mass transfer. Often this straight line path between surfaces is called the “line of sight”.

3.1.5 The Temperature of the Deposition Surface. The surface on which the emitted, molecular species condenses is often identified as the receiver or deposition surface. For the deposition surface to be an effective collector, the temperature of the surface must be colder than the emitting surface. The greater the difference in temperature between the emitting surface and the deposition surface, the more effective the deposition process becomes at condensing the array of molecular species released by the source material.

3.1.5.1 Typically the temperature of this surface is stipulated by the Technical Authority as:

- a. A defined deposition surface temperature for the screening of all nonmetallic materials by a Program/Project (the deposition (receiver) surface temperature would be fixed for all measurements).

Or

- b. The Technical Authority adopts the practice of matching the deposition (receiver) surface temperature to the temperature of the actual surface on which material is predicted to deposit.

3.1.5.2 The use of a fixed deposition surface temperature can simplify a series of measurements but can also lead to the elimination or acceptance of a material that is unsuited to the application for which it will be used. A deposition surface that is warmer than the contamination sensitive surface of a specific application can result in an artificially low but seemly acceptable deposition rate being measured. A deposition surface that is significantly colder than the contamination sensitive surface of a specific application can result in an artificially high and unacceptable deposition rate being measured.

3.1.5.3 However, a degree of conservatism is often introduced into outgassing measurements by making the measurement at a slightly colder temperature than the temperature of the contamination sensitive surface addressed by the measurement. Typically the deposition surface is held ten degrees Celsius (10 C) colder than the predicted application temperature of the contamination sensitive surface with the concurrence of the Technical Authority, adding some conservatism to the measurement.

Multiprogram/Project Common-Use Document		
EM50		
Title: Outgassing Rate Measurements for the Screening of Nonmetallic Materials	Document No.: MSFC-HDBK-3575	Revision: Baseline
	Effective Date: September 16, 2009	Page 11 of 22 Pages

3.1.6 Quartz Crystal Microbalance. Quartz Crystal Microbalances are commonly used to measure the rate of deposition of molecular species on a surface. The usual process is that the deposition rate for a specific material is measured and then mathematically modified to calculate a source term or outgassing rate for the material. The source term, representative of the materials outgassing rate, can be used as input for computer programs that predict the rate of deposition of the emitted or outgassed material on another surface.

3.1.6.1 Quartz crystal microbalances typically fall into two major categories and three subcategories. Quartz crystal microbalances have either a single quartz crystal or a matched pair of quartz crystals, forming a clear distinction between the two major classes of quartz crystal microbalances. This document will only address the quartz crystal microbalances that have a matched pair of quartz crystals. One of the crystals serves as a reference oscillator while the deposition of volatile condensable materials (VCM's) occurs on the surface of the other quartz crystal. This "class" of microbalances can be further subdivided into:

- a. Quartz Crystal Microbalances (QCM's): These microbalances do not have an active mechanism to control the temperature of the deposition surface. Heating and cooling of the microbalance is typically done by controlling the temperature of the structure on which the QCM is mounted. These are the simplest of the quartz crystal microbalances that have a matched pair of crystals.
- b. Temperature-controlled Quartz Crystal Microbalances (TQCM's): The temperature of the quartz crystals in these balances is actively controlled. Both cooling and heating of the crystals is controlled, often by building a Peltier device, a solid state heater/cooler, into the balance.
- c. Cryogenic Quartz Crystal Microbalances (CQCM's): These microbalances can actively heat the crystal pair but rely on passive cooling to control the temperature of the deposition surface. Cryogenic deposition surface temperatures are passively achieved by mounting this microbalance on a cryogen, typically liquid nitrogen, and cooled surface.

3.1.6.2 Throughout the remainder of this document, the abbreviation QCM will be used as a generic label for all three types of quartz crystal microbalances.

3.1.7 Cryogenic Shroud. The vacuum chamber should be equipped with a shroud that is cooled by a cryogenic material such as liquid nitrogen. The shroud serves as a cryogenic getter that captures condensable materials emitted by the components of the vacuum system which would artificially increase a measured deposition rate. The shroud should be at least 10-degrees Celsius, or more, colder than the coldest deposition surface temperature for which a deposition measurement is reported in order to produce high-quality deposition measurements. Cold fingers used to collect samples of the condensable molecular species for chemical analysis should not be

Multiprogram/Project Common-Use Document		
EM50		
Title: Outgassing Rate Measurements for the Screening of Nonmetallic Materials	Document No.: MSFC-HDBK-3575	Revision: Baseline
	Effective Date: September 16, 2009	Page 12 of 22 Pages

substituted for a cryogenic shroud because of the limited surface area of these devices. A large cryogenic surface is more effective at reducing the chamber, background deposition rate than a smaller cryogenic surface.

3.1.8 The Deposition Process. A surface at absolute zero (0 degrees Kelvin) should in theory condense all molecular species, and those species should remain on the surface as long as the temperature does not increase. The instruments that are commonly used in the laboratory to measure deposition rates operate at much warmer temperatures, and not all materials coming in contact with the deposition surface stick to that surface. Some materials deposit on a surface and are then re-emitted from the surface at a later time. It is convenient to think of the deposition process as a balance between material being deposited (flux on) on the deposition surface and material being re-emitted (flux off) from the deposition surface.

$$\text{Measured Deposition Rate} = \text{Flux On} - \text{Flux Off}$$

3.1.8.1 This is especially true of complex materials such as elastomers that may contain plasticizers and other materials in addition to the parent material. The species emitted from complex materials will have different concentrations and deposition rates depending on the temperature of the source and the temperature of the deposition surface. Over time, the concentration of one or more materials in the parent material may be depleted, reducing the overall source term for the material which will be observed as a decrease in the measured deposition rate.

3.1.8.2 In many real world applications, a direct line of sight exists between the source of the outgassing and the contamination sensitive surface. However, the “reflection” of contaminants off one or more intermediate surfaces cannot always be ignored. Typically, the emitted molecule temporally deposits on the intermediate surface which is warm enough to re-emit (Appendix B) the molecule along a new line of sight path much like light is redirected by reflecting off a surface. Each reflection typically reduces the rate of deposition, as measured on the surface the molecules ultimately condense on, when compared to a direct line of sight transfer of material.

3.2 Analysis.

3.2.1 Conversion of Frequency to Mass. The output of contemporary QCM's is a change in a quantity called the beat frequency (dHz/time). The beat frequency is the change in the oscillation of the “sampling” crystal, the deposition surface, as referenced to the oscillation of the reference crystal. Typically the QCM vendor supplies a conversion factor or “sensitivity” for each QCM. The sensitivity is expressed in units of grams/Hz-cm² and is simply multiplied by the change in the beat frequency to obtain the rate of deposition on the “sampling” crystal.

Multiprogram/Project Common-Use Document		
EM50		
Title: Outgassing Rate Measurements for the Screening of Nonmetallic Materials	Document No.: MSFC-HDBK-3575	Revision: Baseline
	Effective Date: September 16, 2009	Page 13 of 22 Pages

$$(\text{dHz/second}) \times (\text{grams/Hz-cm}^2) = \text{grams/cm}^2\text{-s}$$

This mass is not the outgassing rate or source term for the material sample but only the rate of deposition on the QCM “sampling” crystal or deposition surface. A second calculation involving three additional factors, the Chamber background deposition rate, the View Factor and the Sample Surface Area must be made to obtain the source term or outgassing rate of the material.

3.2.2 View Factor. The view factor, a geometric relation between the outgassing source and the deposition surface, should be taken into account in mathematically converting the measured deposition rate to a source term. For measurements in which the sample is heated in an effusion cell, the view factor calculation presented in the ASTM Method E-1559 should be used.

3.2.2.1 If the sample is not contained in an effusion cell, then a different view factor calculation will be required which is not addressed in the ASTM E-1559 Methodology. The calculation for the view factor for this situation can be found in several references¹. The major difference in the two calculations is that there is no provision made for the flow of outgassing species through an orifice, the Clausing factor (K), for materials not contained in an effusion cell or similar enclosure (Appendix C).

3.2.3 Sample Surface Area. The area of the sample is used in the ASTM methodology to calculate a source term or outgassing rate for the material. Ideally, the ratio between the view factor and the sample surface area should be close to 1.0 (+/- 0.5). Larger or smaller view-factor-to-surface-area ratios should be avoided to lessen the effect of the view factor to sample area ratio on the calculated source term.

3.2.4 Source Term. The outgassing rate or source term for a material is calculated using the measured deposition rate, the chamber background measurement, the view factor and the surface area of the sample.

Source Term (grams/cm²-s) =

(measured deposition rate (grams/cm²-s) – chamber background deposition rate

(grams/cm²-s)) x (view factor (cm²)/sample surface area (cm²))

Multiprogram/Project Common-Use Document		
EM50		
Title: Outgassing Rate Measurements for the Screening of Nonmetallic Materials	Document No.: MSFC-HDBK-3575	Revision: Baseline
	Effective Date: September 16, 2009	Page 14 of 22 Pages

3.2.5 Configurational Analysis. Configurational modeling, typically called “computer modeling” predicts the transfer of condensable contaminants from a source to a second condensing surface. The measured source term for a material is the input for the mathematical model which predicts the amount of material condensing on the receiving or condensing surface. Typically a cosine distribution of the emitted species is captured in the view factor which describes the geometric relation between the two surfaces and most models assume a line of sight path between those surfaces.

3.2.6 Compliance with the acceptable deposition rate can be demonstrated by configurational analysis (computer modeling) of the relation of the material, the outgassing source, to the contamination-sensitive surface. The analysis is based on the measured source term for the material, the “real world” geometric relationship between the outgassing source and the contamination sensitive surface, and the temperature of the contamination sensitive surface.

3.2.7 Determining ASTM E-595, %TML and %CVCM from Deposition Rate Measurements. The criteria of 1.0 percent Total Mass Loss (TML) and 0.1 percent Collectible Volatile Condensable Material (CVCM) have historically been used to determine if a material has acceptable outgassing properties when the measurement was made using the ASTM E-595 methodology. However, measuring the rate of deposition, ASTM E-1559 methodology, does not directly provide the quantity (mass) needed to calculate CVCM as a percentage of the original sample weight. The amount of CVCM can be calculated by integration of the source term over the duration of the deposition rate measurement. The usefulness of a CVCM obtained by integration is that a direct comparison of the amount of material deposited can be made to CVCM data previously measured using the ASTM 595 methodology.

3.1.7.1 The mass of the sample, before and after the outgassing measurement, is used to directly calculate the Total Mass Loss (TML) for the material and follows same process for both the ASTM E 595 and the ASTM E 1559 methodology.

3.3 Operation.

3.3.1 Chamber Background Measurement. The chamber background is a term that describes the deposition of condensable materials emitted by the components of the vacuum system in which the outgassing measurement is made. Since these materials can co-deposit with the condensable materials emitted by the sample material the chamber background deposition rate (grams/cm²-s) can introduce an error into the measurement. Chamber background deposition levels that are a decade, or more, less than the Program/Project defined acceptable deposition rate are satisfactory for the measurement and allow materials with outgassing rates less than the established specified maximum deposition rate to be identified. The measurement of the chamber background should

CHECK THE MASTER LIST
VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

Multiprogram/Project Common-Use Document		
EM50		
Title: Outgassing Rate Measurements for the Screening of Nonmetallic Materials	Document No.: MSFC-HDBK-3575	Revision: Baseline
	Effective Date: September 16, 2009	Page 15 of 22 Pages

be made with all the hardware to be used for the actual outgassing measurement, except the sample, in the chamber and in the configuration to be used during the deposition measurement. The chamber background measurement shall be made at the temperatures that the actual outgassing measurement will be made, including the cryogenic surfaces (Section 3.1.7). At a minimum the deposition rate measured in this configuration should be no greater than one third of the acceptable VCM deposition level established by the Technical Authority for material outgassing.

3.3.2 Order of Measurements. The chamber background should be measured before the outgassing rate for the sample is measured. Screening a material prior to making a background measurement can contaminate the chamber, resulting in an error in the background measurement and an artificially low source term being calculated for the sample.

3.3.3 Measurement Duration. The duration for the measurement should take into account the functional life of the hardware. Typically the outgassing rate for a material is greatest during the initial 24 to 72 hours of heating in a vacuum environment and then the outgassing rate slowly drops off over the following 24 to 48 hours. The asymptotical decay in the source term after 72 hours is typically less dramatic; and for hardware with a long operational “lifetime”, the data collected after 72 hours can better describe the long-term outgassing process.

3.3.4 Deposition Surface Regeneration. The typical beat frequency observed for a clean QCM crystal pair will fall between 500-Hz and 2000-Hz. Condensation of material on the QCM crystal will cause a linear increase in the beat frequency until the deposition of material on the crystal begins to degrade the measurement being made. The capacity of each QCM is typically provided by the vendor, a maximum frequency value or microbalance loading, as a guideline for the user. The deposition surface can be “re-generated” by raising the temperature of the crystal pair, thermally reversing the deposition process. Some hystereses maybe observed at the end of the crystal cleaning process as a slight increase in the baseline frequency.

Note: Not all QCM’s measure the deposition process as an increase in the beat frequency. Some QCM’s measure the increase in deposited material as a decrease in the measured beat frequency. Either approach to the deposition measurement process is acceptable as long as the frequency change observed is consistent with the proper functioning of the QCM.

3.3.5 Thickness of a Material Deposited on Contamination Sensitive Surfaces. Using performance-based criteria, such as a change in the optical absorbance of a surface, the impact of material deposited on a contamination-sensitive surface can be rigorously assessed for a specific application. A Program/Project should define the allowable amount of deposition on a contamination-sensitive surface, such as a thermal control surface, to ensure mission success by guiding the selection of materials with low outgassing properties.

CHECK THE MASTER LIST
VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

Multiprogram/Project Common-Use Document		
EM50		
Title: Outgassing Rate Measurements for the Screening of Nonmetallic Materials	Document No.: MSFC-HDBK-3575	Revision: Baseline
	Effective Date: September 16, 2009	Page 16 of 22 Pages

3.3.5.1 The allowable amount of deposition can be stated as a deposited mass (grams/centimeter squared) or a thickness (angstroms) either of which can be calculated from deposition rate measurements. Conversion of a deposited mass to a thickness requires that the density of the material(s) be known. Often the density of the deposited material(s) is not known and a default value needs to be defined by the Program/Project as the density to be used for the conversion of a deposited mass to a thickness.

3.3.6 Material Acceptance Criteria. The criteria for the acceptance of a material for use in a vacuum environment that has the potential to deposit contamination on a contamination-sensitive surface should be defined and documented by the Program/Project. The criteria should be based on the performance requirements of the hardware and will be defined as the allowable amount of material that can be deposited on the hardware without loss of functionality of the hardware. The definition should include the surface temperature of the deposition surface and the sample temperature to be used for the measurement (Section 3).

3.3.7 Identification of Candidate Samples. A list of all nonmetallic materials used in an application that are exposed to a vacuum environment should be compiled to identify the materials that are potential sources of VCMs. The outgassing source terms for these materials can then be obtained from either outgassing rate measurements or in some cases databases of applicable outgassing rate data.

3.3.8 Materials with High Outgassing Rates. In most instances, The outgassing source term for many materials will not demonstrate compliance of the material with the pre-established criteria for material acceptability. The source term is typically larger than the allowable rate of deposition on the contamination sensitive surface. Materials that fail to meet the established requirements for outgassing (surface deposition rate) may be used if the deposition rate of the material can, by vacuum baking or another process, be brought into compliance with the established requirements. Vacuum baking is the process of heating the material in a vacuum oven for a period to drive off the volatile molecular species by depleting the concentration of those species in the parent material.

3.3.8.1 Compliance with the acceptable deposition rate can be demonstrated by measuring the post, vacuum bake out, deposition rate for the material. Often the vacuum bake-out process is developed by vacuum baking a small, representative sample of the material and then measuring the deposition rate for this processed material. Once a successful combination of bake-out duration and temperature has been established using this small sample a larger amount of the material, sufficient for the application, is processed using the same processing parameters. A post vacuum bake-out deposition measurement is often made on a small quantity of material taken from the bulk material to verify the successfully processing of the material.

Multiprogram/Project Common-Use Document		
EM50		
Title: Outgassing Rate Measurements for the Screening of Nonmetallic Materials	Document No.: MSFC-HDBK-3575	Revision: Baseline
	Effective Date: September 16, 2009	Page 17 of 22 Pages

3.3.9 Documentation. A record of each material screened should be created to document the outgassing rate determined by the measurement process. The record should include the vendor's name, the vendor's nomenclature and part number for the material, any special processing of the material, and the measurement parameters. The source of samples not received directly from the vendor supplying that material shall be identified in the documentation.

4. GUIDANCE

4.1 Reference Documents.

1. Tribble, A. C.; The Space Environment, Implications for Spacecraft Design, Princeton University Press; Princeton, New Jersey, 1995
2. Afeedy, H.Y.; Liebman, J.F.; Stein, S.E.; Neutral Thermo chemical Data. In NIST Chemistry WebBook, NIST Standard Reference Database Number 69; Mallard, W.G. Linstrom, P.J., Eds.; National Institute of Standards and Technology: Gaithersburg, MD, Nov 1998; <http://webbook.nist.gov>
3. Dushman, S.; Scientific Foundations of Vacuum Technique, Lafferty, J. M., Ed., John Wiley & Sons, Inc. New York, 1965

4.2 Key Word Listing.

None.

4.3 Definitions.

Collected Volatile Condensable Material (CVCM): The quantity of outgassed matter from a sample that condenses on a collector, maintained at a constant temperature, during the duration of the measurement. The CVCM is usually stated as a percentage of the original sample weight

Configuration Analysis: The prediction of the amount of condensable material deposited on a surface based on a measured outgassing rate and the geometric relationship between the source of the condensable material and the surface it is depositing on. Typically this analysis involves computer modeling techniques.

Multiprogram/Project Common-Use Document		
EM50		
Title: Outgassing Rate Measurements for the Screening of Nonmetallic Materials	Document No.: MSFC-HDBK-3575	Revision: Baseline
	Effective Date: September 16, 2009	Page 18 of 22 Pages

Deposition Rate: The rate at which material accumulates or deposits on a surface. This quantity is generally stated as grams/centimeter squared-second ($\text{g}/\text{cm}^2\text{-s}$).

Effusion Cell: The sample is placed in a container which provides uniform heating of the entire sample, regardless of the sample geometry. The molecular species emitted by the sample leave the effusion cell through an orifice in the wall of the cell. Another common name for an effusion cell is a “Knudsen cell.”

Program: The project that is responsible for the hardware, spacecraft, or subsystem and is typically the authority which sets the criteria by which materials are selected or approved.

Sample: The material being screened by the outgassing measurement.

Source Term: The rate at which volatile condensable materials (VCM's) are released from the surface of the sample. The deposition rate is the rate at which material is deposited on the detector, usually a quartz crystal microbalance, which is typically less than the source term.

Total Mass Loss: The total amount of material lost from a sample during the outgassing measurement.

Volatile Condensable Materials: Molecular species emitted from a material that condense on a surface. Normally the condensing surface is colder than the emitting surface.

Multiprogram/Project Common-Use Document		
EM50		
Title: Outgassing Rate Measurements for the Screening of Nonmetallic Materials	Document No.: MSFC-HDBK- 3575	Revision: Baseline
	Effective Date: September 16, 2009	Page 19 of 22 Pages

APPENDIX A

Acronyms and Definitions

ASTM	American Society for Testing and Materials
CQCM	Cryogenic Quartz Crystal Microbalance
CVCM	Condensable Volatile Condensable Materials
QCM	Quartz Crystal Microbalance
TML	Total Mass Loss
TQCM	Temperature Controlled Quartz Crystal Microbalance
VCM	Volatile Condensable Materials

CHECK THE MASTER LIST
VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

Multiprogram/Project Common-Use Document		
EM50		
Title: Outgassing Rate Measurements for the Screening of Nonmetallic Materials	Document No.: MSFC-HDBK-3575	Revision: Baseline
	Effective Date: September 16, 2009	Page 20 of 22 Pages

APPENDIX B

Calculation of the Dwell Time of Contaminants on Surfaces

Surface dwell time τ (in seconds) for a contaminant can be calculated if the vibration frequency of the species, the activation energy of the species, and the temperature of the surface are known.

$$\tau = \tau_0 \exp(E_a/RT)$$

Where τ_0 = the vibration frequency (vibrations/second)

E_a = activation energy (cal/mole)

R = gas constant (1.9872 cal/K/mole)

T = surface temperature (degrees Kelvin)

The activation energy and characteristic vibration frequency of a molecule (atom) for a species can be obtained from literature references, chemical handbooks and databases² or measurements made in the laboratory.

Multiprogram/Project Common-Use Document		
EM50		
Title: Outgassing Rate Measurements for the Screening of Nonmetallic Materials	Document No.: MSFC-HDBK-3575	Revision: Baseline
	Effective Date: September 16, 2009	Page 21 of 22 Pages

APPENDIX C

Calculation of the Clausing Factor for an Orifice or Short Tube

The Clausing factor (K) is a unit-less number that describes the conductance of material through short tubes or the orifice of an effusion cell. This factor was developed by Clausing and a good description of the factor and the theoretical background for the calculation can be found in Dushman³.

$$K = 1 / [1 + (3/8)(L/A)]$$

Where L = orifice length

A = orifice radius