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Standard Practice for Spacecraft Hardware Thermal Vacuum Bakeout[1]

This standard is issued under the fixed designation E2900; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice establishes methods for thermal vacuum bakeout of spacecraft and spacecraft components.

1.2 This practice defines the equipment, environment, and certification criteria for each type of bakeout.

1.3 The methods defined in this practice are intended to reduce component outgassing rates to levels necessary to meet mission performance requirements of the contamination sensitive hardware. Times, temperatures, and configurations contained in this document have been found to provide satisfactory results. Experienced operators may find that other, similar times, temperatures and configurations have provided satisfactory results. If deviations from these criteria are deemed appropriate, they should be detailed in the bakeout report.

1.4 This practice describes three bakeout methods: Method A, using prescribed time and pressure criteria; Method B, using prescribed QCM stabilization rate criteria; and Method C, which measures the QCM deposition rate.

1.5 Determination of the acceptable molecular outgassing, selection of the bakeout method, and determination of the specific test completion criteria are the responsibility of the user organization.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E1546 Guide for Development of Fire-Hazard-Assessment Standards
E296 Practice for Ionization Gage Application to Space Simulators
E834 Practice for Determining Vacuum Chamber Gaseous Environment Using a Cold Finger
E1234 Practice for Handling, Transporting, and Installing Nonvolatile Residue (NVR) Sample Plates Used in Environmentally Controlled Areas for Spacecraft
E1235 Test Method for Gravimetric Determination of Nonvolatile Residue (NVR) in Environmentally Controlled Areas for Spacecraft
E1549 Specification for ESD Controlled Garments Required in Cleanrooms and Controlled Environments for Spacecraft for Non-Hazardous and Hazardous Operations
E1559 Test Method for Contamination Outgassing Characteristics of Spacecraft Materials
E1560 Test Method for Gravimetric Determination of Nonvolatile Residue From Cleanroom Wipers
E1731 Test Method for Gravimetric Determination of Nonvolatile Residue from Cleanroom Gloves
E2311 Practice for QCM Measurement of Spacecraft Molecular Contamination in Space

2.2 *Other Standards:*

IEST-STD-CC1246 Product Cleanliness Levels and Contamination Control Program[3]
MIL-STD-1246 Product Cleanliness Levels and Contamination Control Program[4,5]
MIL-P-27401 Propellant Pressurizing Agent, Nitrogen[5]
ISO-14644 Cleanrooms and associated clean environments[3]
FED-STD-209 Federal Standard, Airborne Particulate Cleanliness Classes in Cleanrooms and Clean Zones[5,6]

3. Terminology

3.1 *Definitions:*

3.1.1 *ambient conditions, n*—room temperature and pressure.

3.1.2 *pre-bakeout, n*—to clean or condition, or both, a vacuum chamber prior to its use for flight hardware.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from Institute of Environmental Sciences and Technology (IEST), Arlington Place One, 2340 S. Arlington Heights Rd., Suite 100, Arlington Heights, IL 60005-4516, http://www.iest.org.

[4] MIL-STD-1246 may be used in lieu of IEST-STD-CC1246 by mutual agreement of the parties in the contract.

[5] Available from DLA Document Services, Building 4/D, 700 Robbins Ave., Philadelphia, PA 19111-5094, https://assist.daps.dla.mil/quicksearch/

[6] FED-STD-209 may be used in lieu of ISO-14644 by mutual agreement of the parties in the contract.

3.1.3 *bakeout, n*—a process by which volatile molecular contaminants are removed from a spacecraft component or article by exposing it to vacuum and elevated temperature". When the intent is to describe an action, this should be two words: to "bake out".

3.1.4 *cold finger, n*—the device that is used in collecting the sample of the residual gases in an evacuated vacuum chamber.

3.1.5 *cold plate, n*—a vacuum stable metal plate filled with liquid nitrogen used to condense the volatile molecular (or outgassing) contamination generated by the space component undergoing the bakeout.

3.1.6 *cold shroud, n*—the metal lining of the vacuum chamber (usually black painted or black anodized) used as a heating device or when filled with liquid nitrogen, used to simulate deep space.

3.1.7 *cold wall test, n*—a test configuration used to simulate deep space, requiring analytical view factors for the calculation of outgassing rates.

3.1.8 *hot wall test, n*—a test configuration, in which the hardware is isothermal with the surrounding environment. It assumes homogenous mixing for calculating outgassing rates.

3.1.9 *outgassing, n*—the evolution of a gas from a material, usually in a vacuum.

3.1.10 *outgassing rate (g/s), n*—the net rate of mass loss from a material sample as a result of outgassing. Outgassing rate can be normalized per unit sample surface area and expressed as $g \cdot cm^{-2} \cdot s^{-1}$ or it can be normalized per unit initial sample mass and expressed as $g \cdot g^{-1} \cdot s^{-1}$.

3.1.11 *QCM deposition rate stabilization (Hz/hr/hr), n*—the acceleration of the QCM deposition rate.

3.1.12 *quartz crystal microbalance or QCM, n*—a device for measuring small quantities of mass using the properties of a quartz crystal oscillator.

3.1.13 *QCM deposition rate, n*—the QCM output (or beat) frequency change per unit time caused by the mass of a molecular species condensing on the QCM crystal. The QCM deposition rate units may be converted to $g/cm^2/s$ by multiplying by the mass loading constant (m) provided by the vendor for the crystal used (i.e., for a 10 Mhz crystal, m=4.42E-9g/cm^2Hz).

3.1.14 *QCM thermogravimetric analysis or QTGA, n*—a technique in which a QCM is heated at a constant rate to remove a collected deposit.

3.1.15 *temperature stabilization, n*—temperature stabilization has been reached when the unit temperature is within 2°C of the specified temperature and the rate of change is less than 3°C per hour as measured with the unit control thermocouple. This rate can be extrapolated over a 20 min sample time. For example, stabilization has been achieved if two temperature measurements taken 20 min apart are within 1°C of each other.

3.1.16 *total collection area, n*—the sum of the surface area in the vacuum chamber that is equal to or colder than the QCM crystal temperature.

3.1.17 *visibly clean highly sensitive, VCHS, n*—visual inspection conducted at a distance of 15–50 cm (6–18 in.) with white light of at least 1076 lumens/m^2 (100 fc) intensity. It may be accompanied by ultraviolet (UV) inspection as well.

3.2 *Acronyms:*

3.2.1 *GN2*—Gaseous Nitrogen

3.2.2 *LN2*—Liquid Nitrogen

3.2.3 *MLI*—Multi-Layer Insulation

3.2.4 *NVR*—Nonvolatile Residue

3.2.5 *RGA*—Residual Gas Analyzer

3.2.6 *QCM*—Quartz Crystal Microbalance

3.2.7 *QTGA*—QCM Thermogravimetric Analysis

3.2.8 *TQCM*—Temperature controlled Quartz Crystal Microbalance

3.2.9 *VCHS*—Visibly Clean Highly Sensitive

4. Summary of Practice

4.1 A vacuum chamber is configured in the same manner it would be configured for the hardware bakeout, except that the test article is omitted.

4.2 The empty chamber and its support equipment is cleaned and inspected to VCHS. Then, the chamber is evacuated and pre-baked at a temperature 10°C above the hardware bakeout temperature, using the same procedure used for the component hardware.

4.2.1 For Method A, the chamber is ready for installation of flight hardware after 24 h under vacuum and temperature and a visual inspection.

4.2.2 For Methods B and C, the chamber is ready when the measured QCM deposition rate, witness sample data and visual inspection results are acceptable.

4.3 The spacecraft component to be thermal vacuum baked is exposed to an elevated temperature and a vacuum of 5.0E-5 torr or less for a specified amount of time or until the desired outgassing rate is reached.

4.3.1 *Method A*—The bakeout is terminated at a specified time limit and stabilized chamber pressure.

4.3.2 *Method B*—The bakeout is terminated when the QCM deposition rate stabilizes to a specified level.

4.3.3 *Method C*—There is a bakeout phase and a certification phase. The hardware is exposed to the program specific qualification temperature (usually 10ºC above maximum predicted on-orbit operating temperatures) or the maximum tolerable temperature of the component in accordance with Method B. In the certification phase, the temperature is lowered to the predicted maximum on-orbit operating temperatures and the rate is measured. This provides realistic information that can be used to obtain outgassing rates in on-orbit conditions and also provides information about the dependency of the component outgassing rates on temperature. The bakeout is terminated when the QCM deposition rate reaches a specified level.

4.3.4 At the end of the bakeout, witness plates are removed and NVR wipe samples are taken of the cold plate.