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MSFC TECHNICAL STANDARD

THERMAL VACUUM BAKEOUT SPECIFICATION FOR CONTAMINATION SENSITIVE HARDWARE

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DOCUMENT HISTORY LOG

Status (Baseline/ Revision/ Canceled)	Document Revision	Effective Date	Description
Baseline	Baseline	11/1986	Initial baseline.
Revision	A	07/29/2007	Document Rewrite.
Revision	B	01/10/2020	Update for change in OPRD, acceptable clean room films. Add flexibility in choosing wavelengths.

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APPENDIX

1. PURPOSE

The purpose of this specification is to present in detail the test requirement and procedures necessary for the thermal vacuum bakeout of “contamination sensitive hardware”. These requirements and procedures as defined within this specification provide the methodology to achieve an acceptable level of molecular outgassing from components, subsystems, and totally assembled systems; and the verification that these levels have been achieved. This document generally follows the ASTM E2900 method for thermal vacuum bakeout, method C, with optical witness sample(s) in lieu of or in addition to nonvolatile residue (NVR) witness plates.

1.1 Scope

This specification applies to all discrete components, subsystems, and totally assembled systems which together comprise either “contamination sensitive hardware” or hardware that has been determined to be a potential contamination source for the “contamination sensitive hardware”. Of particular critically are those discrete components or subsystems which have either a direct line of sight to, or are located in the same enclosure as the “contamination sensitive element”. Included is all ground support equipment (GSE) to which the flight hardware is exposed during ground operations, where the environmental conditions during this exposure could cause the GSE to outgas molecular contaminants. An example of such GSE is hardware used inside vacuum chambers during thermal vacuum testing.

1.2 Applicability

This document applies the following: all mandatory actions (i.e., requirements) are denoted by statements containing the term “shall.” The following terms also apply: “may” or “can” denote discretionary privilege or permission, “should” denotes a good practice and is recommended, but not required; “will” denotes expected outcome, and “are/is” denotes descriptive material.This specification is applicable to any space flight mission where molecular contamination could jeopardize mission success. This includes instruments and telescopes, particularly those in the X-ray, extreme ultraviolet (EUV), vacuum ultraviolet (VUV), near ultraviolet (NUV), and visible wavelengths, and flight hardware in line-of-sight to these instruments and telescopes.

2. APPLICABLE DOCUMENTS

2.1 Government Documents

EM40-OWI-094	Operation of Vacuum Ultraviolet Reflectometer

2.2 Non-Government Documents

ASTM E595	Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment
ASTM E1559	Standard Test Method for Contamination Outgassing Characteristics of Spacecraft Materials
ASTM E2900	Standard Practice for Spacecraft Hardware Thermal Vacuum Bake
ISO 14644-1	Cleanrooms and Associated Controlled Environments, Classification of Air Cleanliness
ISO 14644-2	Cleanrooms and Associated Controlled Environments, Cleanliness Levels

3. APPLICATION

4. EXCEPTIONS

This specification does not take into consideration the operational parameters of the electrical or mechanical performance of the component or subsystem in a thermal/vacuum environment.

5. BAKEOUT PROCEDURE

Thermal vacuum bakeout of contamination sensitive hardware is a process to reduce to an acceptable level the outgassing rates of flight equipment associated with instrumentation that is sensitive to molecular contamination and the verification that this level has been achieved.

Successful bakeout is dependant upon all materials meeting the criteria in ASTM-E595 for Total Mass Loss (TML) and Collected Volatile Condensable Materials (CVCM) and the optical witness sample (OWS) acceptance criteria as defined in Paragraph 5.1.6.6 of this document**.** An alternative option is meeting criteria for TML, CVCM and OWS acceptance established by the Program for which the materials are being processed. International Space Station payloads may be required to test all materials per ASTM E1559 to define the outgassing rate over time, to be used for contamination modeling.

Some materials may require pre-conditioning prior to the bakeout. This conditioning may consist of an ambient cure of a few hours or a high temperature vacuum cure of several days, in either case these materials must be conditioned before the thermal vacuum bakeout certification process described in this document is performed. Failure to perform this conditioning can and has resulted in extensive schedule and cost impacts.

The bakeout procedure consists of heating the flight hardware in a clean, certified vacuum system (<1 x 10^{-5} Torr pressure) at the highest temperature permitted without endangering the hardware but at least 10 degree Celsius (C) above its in-flight operating extreme, assuming this temperature does not exceed the maximum exposure temperature. During this bakeout the outgassing level is monitored using a temperature controlled quartz crystal microbalance (TQCM) and a temperature controlled optical witness sample (OWS). The TQCM and the OWS are held at a minimum of 10 degrees C below the on-orbit temperature of the contamination sensitive element (such as an optical mirror, lens, detector, solar cell, or thermal control surface).

Hardware certification for passing the bakeout is based on both TQCM and OWS data. Certification is divided into two separate but connected procedures. First, the deposition rate on the TQCM during the bakeout must eventually be less than 1-Hz/Hour, average over 36-hours. Secondly, after this low rate is reached the OWS mirror is exposed by lowering its temperature to the value for certification and held at this temperature for 24-hours while being directly exposed to the hardware. Final certification depends upon the optical properties analysis of the exposed OWS meeting the limit criteria defined for the project.

5.1 Vacuum Chamber Certification

The procedure for certification of the vacuum chamber is described below and generally follows ASTM E2900.

5.1.1 Time Period

Conduct chamber certification immediately prior to hardware bakeout. Any other use or operation of the system after certification and prior to hardware bakeout will nullify certification.

5.1.2 Support Hardware

Included in chamber certification is all GSE required for hardware bakeout. This includes such equipment as heating lamps, instrumentation, and cabling.

5.1.3 Instrumentation

Test records shall include chamber pressure, temperatures (hardware, TQCM, OWS), and TQCM frequency output data. During atmospheric operations humidity, particulate fallout, air particulate levels and the total hydrocarbon levels measurements shall be recorded.

5.1.3.1 Temperature Controlled Quartz Crystal Microbalance (TQCM)

The TQCM's recommended are temperature controlled quartz crystal microbalances, which sense mass deposition with a change in resonance frequency from a matched set of quartz crystals (cut for minimum temperature change at 0 degrees C, AT cut). The minimum sensitivity level required is 1.56 x 10^{-9} grams/cm ^{2} – Hz). In order to achieve this sensitivity level and long term stability, thermally matched 15-MHz crystal sets are utilized. Precision temperature control is achieved using a Peltier (thermoelectric) cooler and monitoring thermister built into the sensor head for active temperature control. In addition the whole sensor head shall be mounted on a temperature controlled heat sink. This combination provides for both the required sensitivity and long term stability for mass deposition rate measurements.

5.1.3.2 Witness Sample/Plate

Passive witness samples may include particulate fallout plates per ASTM F24 or program specification and nonvolatile residue (NVR) plates, utilized to measure the magnitude of both particulate fallout and NVR.

5.1.3.3 Optical Witness Sample (OWS) Contamination Witness Sample

In general the OWS is a test specimen representing the contamination sensitive elements that are critical to the performance of the flight instrument. It is this representative element or witness sample that ultimately is utilized to certify the hardware undergoing thermal bakeout. This OWS shall be defined to accurately represent the critical contamination element or component. OWS chosen shall not contribute to any measurable degree to the contamination level.
For the Hubble Space Telescope project, the OWS selected represented the surface of the primary and secondary mirrors. The OWS was a first surface mirror consisting of a substrate of fused silica polished to at least a 0.1 wave at 546.1 nm. Mirror dimensions were 2.54 cm in diameter and 0.318 cm in thickness. The fused silica substrate was coated with aluminum and a protective overcoat of magnesium fluoride (MgF_2) such to optimize the reflectance at 121.6 nm. Reflectance was required to be at least 78% at 121.6 nm, and at least 80% at 250.0 nm. In general the actual OWS size and configuration of the OWS must be compatible with the actual instrument to be utilized for the reflectance measurements.

5.1.4 <u>Environmental Requirements</u>

5.1.4.1 Ambient Operations

A clean 10,000 clean environment or less per ISO-14644-2 and a total hydrocarbon level of less than 15-ppm per ISO-14644-1 shall be maintained.

Temperature of 22 degrees Celsius (+/- 2.7 degrees Celsius), and a Relative Humidity of 45 +/- 5% shall be maintained. These are typical values for temperature and humidity; actual requirements may be different for specific payloads. Note: low humidity (<30%) can pose hazards to electronic equipment. Electronic equipment sensitive to electrostatic discharge shall be handled in accordance with MSFC-RQMT-2918.

5.1.4.2 Vacuum Operations

Pressure of less than 1 x 10^{-5} Torr shall be maintained during certification testing.

5.1.5 Temperature Requirements

5.1.5.1 Temperature Controlled Quartz Crystal Microbalance (TQCM) Temperature

The TQCM shall be maintained at a temperature of 10 degrees C below the minimum on-orbit temperature of the "critical contamination sensitive element", during vacuum system bakeout and certification operations. For the Hubble Space Telescope project this temperature was 10 degree C .

5.1.5.2 Optical Witness Sample (OWS) Temperature

During the bakeout operation phase, the OWS shall be maintained at a temperature at least 10 C higher than any other surface in the chamber until the TQCM frequency rate of 1-Hz/hour is achieved, averaged over 36-hours.

During the vacuum system certification phase to be initiated only after the TQCM rate is less than 1-Hz/hour, the OWS temperature shall be lowered and maintained to 10 degrees C below minimum on-orbit temperature of the "critical contamination sensitive element".

5.1.5.3 Ground Support Equipment (GSE) Temperature

Maintain all surfaces at least 10 degrees C higher than during the Flight Hardware bakeout and certification runs.

5.1.6 Acceptance Procedure and Criteria

5.1.6.1 Temperature Controlled Quartz Crystal Microbalance (TQCM) Operation for Bakeout Phase

The TQCM frequency shall be monitored and recorded during vacuum system bakeout.

Bakeout criteria requires that when the rate of increase of the TQCM frequency data level out at a rate1-Hz/hour or less, that the rate shall be maintained (on the average) for a period of 36-hours.

After this deposition criteria has been satisfied as measured by the TQCM; the "OWS Operation for Certification Phase", Paragraph 5.1.6.3, can be initiated.

5.1.6.2 OWS Operation for Bakeout Phase

The OWS shall be maintained at a temperature of 10 degrees C above any other surface in the vacuum chamber.

5.1.6.3 Optical Witness Sample (OWS) Operation for Certification Phase

After the TQCM deposition rate of 1-Hz/hour or less, averaged over a 36-hour period, has been achieved, the OWS temperature shall then be lowered to the value defined in Paragraph 5.1.5.2 for the vacuum system certification phase.

The test operator shall maintain the OWS temperature including all other system parameters constant for a minimum period of 24-hours. Special note, if the hardware temperature will be close to the on-orbit operating temperature, then the exposure period for the OWS is to be increased to 36-hours.

5.1.6.4 Test Termination

After the certification phase is completed, initiate the repressurization of the vacuum chamber using clean purge gas, while maintaining the environmental control criteria requirement levels, such as Class 10,000 particulate level and less than 15-ppm hydrocarbon.

Repressurization shall be controlled at a sufficiently low rate as to preclude chamber particulates from being transported onto the surface or into the interior of the contamination sensitive hardware. If the particulate level on the surface of the hardware exceeds its cleanliness specification from the repressurization, then a surface cleaning shall be required to bring it back into specification.

The sequence of chamber cryowall warm up shall be controlled to prevent transfer of contaminants from cryowalls to the witness plates and other GSE.

5.1.6.5 Witness Sample Removal and Analysis

After repressurization is completed and the chamber environment is at ambient, the Witness Samples can be removed.

Sample covers shall be installed and secured. Then the samples shall be removed and stored in sealed protective transportation containers or bags and delivered to the appropriate analysis laboratory.

5.1.6.6 Optical Witness Sample (OWS) Acceptance Criteria

OWS test specimens shall be analyzed to determine if the Project defined contamination degradation limits were exceeded. As an example of acceptance criteria; the Hubble Space Telescope project utilized the following criteria. Optical Witness Samples are measured per EM40-OWI-094 to determine the magnitude of the change in reflectance over the wavelength

range from 121.6 nm to 200.0 nm. The acceptance criterion is for no more than a 3% decrease in reflectance at specific wavelengths, either the critical wavelength for the sensitive hardware or 121.6 nm, 140 nm, 160 nm, 180 nm, and 200 nm in terms of a percent change of the original reflectance of the OWS at this wavelength. An increase in the reflectance of the OWS will result in the rejection of the reflectance measurement data, requiring the test to be repeated with a clean OWS.
An OWS with visible contaminant deposition, i.e. a fogged mirror, is not required to be measured but should be photographed as documentation of the failure.

5.1.6.7 Calculation of the Change in Optical Witness Sample (OWS) Reflectance

Calculate the percent change in reflectance for each wavelength, using the following formula.

$$\Delta R\ \% = (([(R_{co}/R_{cf})\ R_{tf}\ ]\text{– } R_{to})/R_{to})\ \ x\ 100$$

R_{co} = Pre-test reflectance of control OWS

R_{cf} = Post-test reflectance of control OWS

R_{to} = Pre-test reflectance of test OWS

R_{tf} = Post-test reflectance of test OWS

In the calculation, the post exposure OWS measurement is normalized to the control reflectance measurements. Then the percent change in reflectance is calculated using the normalized, post exposure change in reflectance and the pre-exposure reflectance measurement.

For the initial or baseline reflectance to be a valid measurement, the measurement shall be made on the clean OWS prior to the hardware test and deposition of any material on the OWS.

5.2 Hardware Bakeout and Certification

5.2.1 <u>Time Period</u>

Conduct contamination sensitive hardware bakeout and certification immediately after vacuum system bakeout and certification (Paragraph 5.1). Any other use or operation of the system after the vacuum system certification and prior to hardware bakeout shall nullify certification.

5.2.2 <u>Hardware Selected for Bakeout</u>

Include in the contamination sensitive hardware bakeout and certification all components, subsystems, assembled systems, and GSE having the potential for transfer of molecular contamination, by the process of outgassing, to the contamination sensitive element of the flight hardware. This includes such equipment as electrical cables, “black boxes”, orbital replacement units, space support equipment, science instruments, and contamination protective enclosures for orbital replacement units.

5.2.3 Hardware Temperature

Temperature of contamination sensitive hardware defined for bakeout shall be the highest value permitted without endangering the hardware, but at least 10 degrees C above the maximum orbital operating temperature.

5.3 Post Test Hardware Handling

Following bakeout, the hardware shall be protected from surface recontamination resulting from subsequent handling and environments to which it will be exposed.

In general this protection is to be provided by bagging the contamination sensitive hardware immediately after ambient conditions have been re-established and witness plates removed.

Bagging material recommended when optical type hardware is involved is Capran 980 ® or other clear, heat-stabilized Nylon 6, such as NBF-980, or Dunshield for ESD-sensitive materials.

Other bagging materials can be utilized, but shall be tested to determine their compatibility with contamination sensitive element. In addition any bagging material chosen shall meet stringent material usage requirements for various facilities in which operations or storage are planned.

6. DATA REPORTING

A summary report describing results of contamination sensitive hardware bakeout shall be prepared and included in the hardware "Data Package" along with a copy submitted to the appropriate Project Office for review. Data required in the summary report includes OWS data, TQCM data, vacuum system pressure history during bakeout/certification, and temperature data for hardware, TQCM's and OWS's. Any anomalous observations shall also be included in the report.

APPENDIX A. ACRONYMS

ASTM	American Society for Testing and Materials
C	Celsius
cm^2	Square centimeter
CVCM	Collected Volatile Condensable Materials
GSE	Ground Support Equipment
Hz	Hertz
MgF_2	magnesium fluoride (chemical formula for)
MHz	Mega Hertz
nm	Nanometer
NVR	Nonvolatile Residue
OWS	Optical Witness Sample
ppm	parts per million
TML	Total Mass Loss
TQCM	Temperature Controlled Quartz Crystal Microbalance