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THERMAL VACUUM BAKEOUT SPECIFICATION FOR CONTAMINATION SENSITIVE HARDWARE

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DOCUMENT HISTORY LOG

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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.

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.

2. APPLICABLE DOCUMENTS

ASTM-E595	Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment
ISO 14644-1	Cleanrooms and Associated Controlled Environments, Classification of Air Cleanliness
ISO 14644-2	Cleanrooms and Associated Controlled Environments, Cleanliness Levels

3. APPLICATION

This specification is applicable to Space Transportation System Missions, Space Station missions, or any other space flight mission where molecular contamination could jeopardize mission success.

4. EXCEPTIONS

This specification provides no information regarding 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 OWS acceptance criteria as defined in Paragraph 5.1.6.6**.** An alternative option is meeting criteria for TML, CVCM and OWS acceptance established by the Program for which the materials are being processed.

Successful bakeout requires that the hardware/material meet the CVCM and OWS acceptance requirements and 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 preformed. 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 ($<1 \times 10^{-5}$ 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 connective 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

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 all GSE required for hardware bakeout. This includes such equipment as heating lamps, instrumentation, and cabling.

5.1.3 INSTRUMENTATION

Include measurements and recording of chamber pressure, temperatures (hardware, TQCM, OWS), and TQCM frequency output. During atmospheric operations include measurements of humidity, particulate fallout, air particulate levels and the total hydrocarbon levels.

5.1.3.1 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 1.56×10^{-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 must 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 include particulate fallout plates and nonvolatile residue (NVR) plates, utilized to measure the magnitude of both particulate fallout and NVR.

5.1.3.3 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 must be defined to accurately represent the critical contamination element or component. OWS chosen must 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 1.0 inch in diameter and 0.125 inch 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 ENVIRONMENTAL REQUIREMENTS

5.1.4.1 AMBIENT OPERATIONS

Maintain 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.

Maintain a temperature of 22 degrees Celsius (+/- 2.7 degrees Celsius), and a Relative Humidity of 45 +/-5%. 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.

5.1.4.2 VACUUM OPERATIONS

Maintain a pressure of less than 1×10^{-5} Torr during certification testing.

5.1.5 TEMPERATURE REQUIREMENTS

5.1.5.1 TQCM TEMPERATURE

Maintain the TQCM at a temperature of 10 degrees C (18 degree Fahrenheit (F)) 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 (50 degree F).

5.1.5.2 OWS TEMPERATURE

During the bakeout operation phase, maintain the OWS at a temperature at least 10 C (18 degree F) 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, lower and maintain the OWS temperature to 10 degrees C (18 degrees F) below minimum on-orbit temperature of the "critical contamination sensitive element".

5.1.5.3 GSE TEMPERATURE

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

5.1.6 ACCEPTANCE PROCUDURE AND CRITERIA

5.1.6.1 TQCM OPERATION FOR BAKEOUT PHASE

Monitor and record the TQCM frequency 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 must 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 OPERTAION FOR BAKEOUT PHASE

Maintain the OWS at a temperature of 10 degrees C (18 degree F) above any other surface in the vacuum chamber.

5.1.6.3 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 can then be lowered to the value defined in Paragraph 5.1.5.2 for the vacuum system certification phase.

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 is to 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 will be required to bring it back into specification.

Control sequence of chamber cryowall warm up to prevents 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 must be installed and secured. Then the samples can be removed and stored in sealed protective transportation containers or bags and delivered to the appropriate analysis laboratory.

5.1.6.6 OWS ACCEPTANCE CRITERIA

OWS test specimens are to 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 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 121.6 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.

5.1.6.7 CALCULATION OF THE CHANGE IN OWS REFLECTANCE

Calculate the percent change in reflectance for the wavelength of 121.6nm, using the following formula.

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

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.
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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 TIME PERIOD

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 will nullify certification.

5.2.2 HARDWARE SELECTED FOR BAKEOUT

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 (18 degrees F) 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 either Capran 980 ® (Allied Chemical, very clean Nylon 6 material) or 3M2100 ® (3m Corp., clean layered material consisting of polyethylene/polyester/nickel). The 3M2100 provides electrostatic protection, but must be used with the polyethylene side outside. In addition, the conductive bag (3M2100) must be grounded to the hardware, and earth ground when possible. A potential problem when using 3M2100 is that this material is flammable and all potential ignition sources must be controlled.

Other bagging materials can be utilized, but must be tested to determine their compatibility with contamination sensitive element. In addition any bagging material chosen must 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 require in the summary report include OWS data, TQCM data, vacuum system pressure history during bakeout/certification, and temperature data for hardware, TQCM's and OWS's. Any anomalous observations will also be included in the report.

7. ACRYONYMS

ASTM	American Society for Testing and Materials
C	Celsius
cm^2	Square centimeter
CVCM	Collected Volatile Condensable Materials
F	Fahrenheit
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