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THERMAL VACUUM BAKEOUT SPECIFICATION

FOR

CONTAMINATION SENSITIVE HARDWARE

Prepared by:
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George C. Marshall Space Flight Center

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Thermal Vacuum Bakeout Specification for Contamination Sensitive Hardware

1. PURPOSE

The purpose of this specification is to present in detail the test requirements 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.

2. SCOPE

This specification applies to all discrete components, subsystems, and totally assembled systems which togather comprise either "contamination sensitive hardware" or hardware that has been determined to be a potential contamination source for the "contamination sensitive hardware". Of particular criticality 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.

3. APPLICATION

This specification is applicable to Space Transporation System missions, Space Station missions, or anyother 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 dependent upon all materials meeting the VCM criteria in JSC-SP-R-0022A or equivalent, and that the fabricated parts have been cleaned to remove surface contaminants such as cutting oils, and that the cleanliness level is maintained during assembly and testing. Normally the required cleanliness level can only be maintained if final assembly is performed in a controlled clean environment with procedures to minimize induced contaminants.

Successful bakeout not only requires that the hardware material meet the VCM requirements but that the material be conditioned as decribed in the VCM data base as necessary to pass the VCM test requirements. This conditioning may only consist of an ambient air cure of a few hours or a high temperature vacuum cure of several days, in either case the material used for fabrication 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 (<10-6 Torr pressure) at the highest temperature permitted without endangering the hardware but at least 10 deg. C above its inflight operating extreme. During this bakeout the outgasing level is monitored using a TQCM(temperature controlled quartz crystal microbalance) and a temperature controlled CWS (contamination witness sample). The TQCM and CWS are held at a minimum of 10 deg. C below the on-orbit minimum temperature of the contamination sensitive element (such as optical mirror, lense, detector, solar cell, or thermal control surface).

Hardware certification for passing the bakeout is based on both the TQCM and CWS data. Certification is divided into two separate but consecutive procedures. First, the deposition rate on the TQCM during bakeout must eventually be less than 1 Hz/Hr (corresponding to a sensitivity of 1.56 x 10-9 gm/sq. cm-hr) averaged over 36 hours. Secondly, after this low rate is reached the CWS mirror is exposed or temperature lowered 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 CWS meeting the limit criteria defined for the project.

5.1 VACUUM SYSTEM CERTIFICATION

5.1.1 TIME PERIOD

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

5.1.2 SUPPORT HARDWARE

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

5.1.3 INSTRUMENTATION

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

5.1.3.1 TQCM

The TQCMs 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 Ø deg.C, AT cut). The minimum sensitivity level required is 1.56 nano gm/sq cm 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 senser 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 monitoring.

5.1.3.2 Witness Samples/Plates

Passive witness samples include particulate fallout plates and non-volatile residue (NVR) plates, utilized to measure the magnitude of both of particulate fallout and NVR.

5.1.3.3 CWS CONTAMINATION WITNESS SAMPLE

In general the CWS 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 vacuum bakeout. This CWS must be defined to accurately repersent the critical contamination element or component. CWS chosen must not contribute to any measureable degree to the contamination level.

For the Hubble Space Telescope project the CWS (designated OWS for optical witness sample) 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 lease a Ø.1 wave at 546.1 nm. Mirror dimensions were one inch in diameter and 1/8 inch in thickness. The fused silica substrate was coated with aluminum and a protective overcoat of MgF_2 such as to optimize the reflectance at 121.6 nm. Reflectance was required to be be at lease 78% at 121.6 nm, and at lease 84% at 25Ø.Ø nm. In general the actual CWS size and configuration of the CWS must be compatable with the analysis instrumentation to be utilized.

5.1.4 ENVIRONMENTAL REQUIREMENTS

5.1.4.1 AMBIENT OPERATIONS

Maintain a Class 1Ø,ØØØ clean environment or less per FED-STD-2Ø9B and a total hydrocarbon level of less than 15 ppm.

Maintain a temperature of 7Ø$\pm$2Ø deg. F, and a humidity of Ø to 3Ø% RH. These are typical values for temperature and humidity, actual requirements may be different for specific payloads.

5.1.4.2 VACUUM OPERATIONS

Maintain a pressure of <5 micro Torr during certification testing.

5.1.5 TEMPERATURE REQUIREMENTS

5.1.5.1 TQCM TEMPERATURE

Maintain TQCM at a temperature of 1Ø centigrade degrees (18

F deg.) below minimum the 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 deg.C (50 deg.F).

5.1.5.2 CWS TEMPERATURE

During the bakeout operation phase maintain the CWS at a temperaure at least 10 centigrade degrees(18 F deg.) higher than any other surface in chamber until the TQCM rate of 1Hz/Hr is achieved averaged over 36 hours.

During the vacuum system certification phase, to be initiated only after the TQCM rate is ≤ 1Hz/Hr; lower and maintain the CWS temperature to 10 centigrade degrees (18 F deg.) below minimum on-orbit temperature of the critical contamination sensitive element.

5.1.5.3 GSE TEMPERATURES

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

5.1.6 ACCEPTANCE PROCEDURE and CRITERIA

5.1.6.1 TQCM OPERATION for BAKEOUT PHASE

Monitor and record TQCM frequency during the vacuum system bakeout.

Bakeout criteria requires that when the rate of increase of the TQCM frequency data levels out at a value of ≤1Hz/Hr, that this rate (or less) must be maintained (on the average) for a period of 36 hours. This rate value corresponds to the required sensitivity of ≤1.56 nano gm/sq. cm*hr).

After this outgasing rate criteria has been satisfied as measured by the TQCM; the "CWS Operation for Certification Phase" section 5.1.6.3 run can be initated.

5.1.6.2 CWS OPERATION for BAKEOUT PHASE

Maintain the CWS at a temperature of 10 centigrade degrees (18 deg. F) above anyother surface in the vacuum chamber.

5.1.6.3 CWS OPERATION for CERTIFICATION PHASE

After the TQCM deposition rate of $\leq$ 1 Hz/Hr averaged over a 36 hour period has been achieved, the CWS temperature can then be lowered to the value defined in section 5.1.5.2 for the vacuum system certification phase.

Maintain the CWS 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 CWS is to be increased to 36 hours.

5.1.6.4 TEST TERMINATION

After the certification phase is completed, initiate repress using clean purge gas, while maintaining the environmental control criteria requirement levels, such as Class 10,000 particulate level and <15 ppm total hydrocarbon.

Repress rate 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 repress operation, then a surface cleaning will be required to bring it back into specification.

Control sequence of chamber cryowall warmup to prevent transfer of contaminants from cryowalls to witness plates and other GSE.

5.1.6.5 WITNESS SAMPLE REMOVAL and ANALYSIS

After repress is complete and the chamber environment is at ambient the Witness samples can be removed.

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

5.1.6.6 CWS ACCEPTANCE CRITERIA

CWS test specimens are to be analysed 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. CWS (OWS mirrors) contamination 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 criteria is for no more than a 3% loss in reflectance at 121.6 nm; in terms of a percent change of the original reflectance of the OWS at this wavelength.

Other witness plates are to be analysed according to d procedures for NVR and particulate fallout. Data from these other witness plates alongwith all other recorded data must be consistant in confirming that the hardware meets outgasing requirements.

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". Any other use or operation of system after vacuum system certification and prior to hardware bakeout can nullify certification.

5.2.2 HARDWARE SELECTED FOR BAKEOUT

Include in the contamination sensitive hardware bakeout and certification all discrete components, subsystems, assembled systems, and GSE having potential for transfer of molecular contamination from outgasing to the contamination sensitive elements 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 unit.

5.2.3 INSTRUMENTATION:

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

5.2.3.1 TQCM

The TQCMs 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 deg.C, AT cut). The minimum sensitivity level required is 1.56 nano gm/sq cm 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 senser 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 monitoring.

5.2.3.2 Witness Samples/Plates

Passive witness samples include particulate fallout plates and non-volatile residue (NVR) plates, utilized to measure the magnitude of both of particulate fallout and NVR.

5.2.3.3 CWS CONTAMINATION WITNESS SAMPLE

In general the CWS 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 vacuum bakeout. This CWS must be defined to accurately repersent the critical contamination element or component. CWS chosen must not contribute to any measureable degree to the contamination level.

For the Hubble Space Telescope project the CWS (designated OWS for optical witness sample) 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 lease a 0.1 wave at 546.1 nm. Mirror dimensions were one inch in diameter and 1/8 inch in thickness. The fused silica substrate was coated with aluminum and a protective overcoat of magnesium flouride such as to optimize the reflectance at 121.6 nm. Reflectance was required to be be at lease 78% at 121.6 nm, and at lease 84% at 250.0 nm. In general the actual CWS size and configuration of the CWS must be compatable with the analysis instrumentation to be utilized.

5.2.4 ENVIRONMENTAL REQUIREMENTS

5.2.4.1 AMBIENT OPERATIONS

Maintain a Class 10,000 clean environment or less per FED-STD-209B and a total hydrocarbon level of less than 15 ppm.

Maintain a temperature of 70$\pm$20 deg. F, and a humidity of 0 to 30% RH. These are typical values for temperature and humidity, actual requirements may be different for specific payloads.

5.2.4.2 VACUUM OPERATIONS

Maintain a pressure of <5 micro Torr during certification testing.

5.2.5 TEMPERATURE REQUIREMENTS

5.2.5.1 TQCM

Maintain TQCM at a temperature of 10 centigrade degrees (18 F. deg.) below the minimum on-orbit temperature of the critical contamination sensitive element. For the Hubble Space Telescope project this temperature was 10 deg. C. (50 deg. F.).

5.2.5.2 CWS TEMPERATURE

Maintain CWS at a temperaure at least 10 centigrade degrees (18 deg.F) higher than any other surface in the chamber until the TQCM rate of ≤1Hz/Hr is achieved (averaged over 36 hours).

During the hardware certification phase, to be run only after the TQCM rate is ≤ 1Hz/Hr; lower and maintain the CWS temperature to 10 centigrade degrees (18 F. deg.) below the minimum on-orbit temperature of the critical contamination sensitive element. For the Hubble Space Telescope project this temperature was 10 deg. C. (50 deg. F.)

5.2.5.3 HARDWARE TEMPERATURE

Temperature of the Contamination Sensitive hardware defined for bakeout shall be the highest value permitted without endangering the hardware, but at lease 10 centigrade degrees (18 F deg.) above the maximum orbital operating temperature.

5.2.6 HARDWARE ACCEPTANCE PROCEDURE and CRITERIA

5.2.6.1 TQCM OPERATION for <u>BAKEOUT</u> <u>PHASE</u>

Monitor and record TQCM frequency during the vacuum system bakeout.

Bakeout criteria requires that when the rate of increase of the TQCM frequency data levels out at a value of ≤1Hz/Hr, that this rate (or less) must be maintained (on the average) for a period of 36 hours. This value corresponds to a required sensitivity rate of ≤1.56 nano gm/sq. cm-hr).

After this criteria is satisfied for the TQCM, the "CWS Operation for Certification Phase" section 5.2.6.3 can be initated for hardware certification.

5.2.6.2 CWS OPERATION for BAKEOUT PHASE

Maintain CWS at a temperature 10 centigrade degrees (18 deg.F) above anyother surface in the vacuum chamber.

5.2.6.3 CWS OPERATION for CERTIFICATION PHASE

After the TQCM deposition rate of ≤ 1 Hz/Hr averaged over a 36 hour period has been achieved, the CWS temperature can be lowered to the value defined in section 5.2.5.2 for the hardware certification phase.

Maintain the CWS 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 CWS is to be increased to 36 hours.

5.2.6.4 TEST TERMINATION

After the certification phase is completed, initiate repress using clean purge gas, while maintaining the environmental control criteria requirement levels, such as Class 10,000 particulate and <15 ppm total hydrocarbon.

Repress rate 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.

Control sequence of chamber cryowall warmup to prevent transfer of contaminants from cryowalls to witness plates and other GSE.

5.2.6.5 WITNESS SAMPLE REMOVAL and ANALYSIS

After repress is complete and the chamber environment is at ambient the Witness samples can be removed.

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

5.2.6.6 CWS ACCEPTANCE CRITERIA

CWS test specimens are to be analysed 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. CWS (OWS mirrors) contamination 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 criteria is for no more than a 3% loss in reflectance at 121.6 nm; in terms of a percent change of the original reflectance of the OWS at this wavelength.

Other witness plates are to be analysed according to standard procedures for NVR and particulate fallout. Data from these other witness plates alongwith all other recorded data must be consistant in confirming that the hardware meets outgasing requirements.

5.2.7 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 baging 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 on the 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 compatability with the Contamination Sensitive Element. In addition any bagging material chosen must meet stringent material usage requirements for the various facilities in which operations or storage are planned.

6. DATA REPORTING

A summary report describing results of contamination sensitive hardware bakeout will be prepared and included in the hardware "Data Package" alongwith a copy submitted to the appropriate Project Office for review. Data required in the summary report includes CWS (OWS) data, TQCM data, vacuum system pressure history during bakeout/certification, and temperature data for hardware, TQCMs and CWSs. Any anomalous observations will also be included in report.

Log Book entries will reflect results of certification bakeout with Quality Control verification.

Cleanliness certification data results will also be included in summary report alongwith Quality Control verification.

APPENDIX A

HST BAKEOUT CERTIFICATION PARAMETERS

CONTAMINATION SENSITIVE ELEMENTS

Primary Mirror surface: MgF_2 over Al on "fused silica"
Secondary Mirror surface: MgF_2 over Al on "fused silica"

CONTAMINATION WITNESS SAMPLE (CWS)

First surface mirror: designated "Optical Witnes Sample (OWS)"

Specification:
- Dimensions: 1 inch diameter by 1/8 inch thick
- Surface finish: polished to 0.1 wave at 546.1 nm
- Material: substrate fused silica
- Coating: Aluminum overcoated with Magnesium Floride
- Reflectance: $\geq$78% at 121.6nm and $\geq$84% at 250.0nm

ACCEPTANCE CRITERIA

$\leq$3% change in reflectance (R) at 121.6nm
Specified in terms of a ((change in R)/R) * 100%

TEMPERATURE MINIMUM for CRITICAL CONTAMINATION SENSITIVE ELEMENT

20 Degree Centigrade (Celsius)

TQCM TEMPERATURE

10 Degree Centigrade (Celsius)
(note: parameter is 10 centigrade degrees below the 20 deg.C temp. minimum for the critical contm. sensitive element)

CWS TEMPERATURE

Hardware or Vacuum chamber bakeout: 10 C. Deg. > GSE or Hardware.

Hardware or Vacuum Chamber certification: 10 Degree Centigrade.