Thermal Vacuum Bakeout Procedures

for the

Solar X-Ray and EUV Sensor (XRS/EUV), the Energetic Particle Sensor (EPS), and the High Energy Proton and Alpha Detector (HEPAD) for GOES NO/PQ

prepared for

Hughes Space and Communications Company
1700 E. Imperial Highway
El Segundo, CA 90245

by

Panametrics, Inc.
221 Crescent Street
Waltham, MA 02454-3497

Signed and Dated/by:

Product Assurance ______________________________
Frank Fantasia Date

Configuration Control ______________________________
Gil Andrade Date

Program Engineer ______________________________
Jeffrey E. Belue Date

Program Physicist ______________________________
Frederick A. Hanser Date

Program Manager ______________________________
Paul R. Morel Date

RELEASE AND REVISION RECORD

REV	AUTHORITY	DESCRIPTION	RELEASE	
			DATE	APPROVED
-	M.Gummin	Initial release	4/14/2000	
A	A. Harris	In response to HSCs comments	7/17/2000	

Table of Contents

Reference Documents

ASTM E595	Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment
ASTM E1559	Test Method for Contamination Outgassing Characteristics of Spacecraft Materials
MIL-STD-1246	Military Standard Product Cleanliness Levels and Contamination Control Program
SN-C-0005	Contamination Control Requirements for the Space Shuttle Program
GOESN-RTP-190	Thermal Vacuum Bakeout Procedures for the Solar X-Ray and EUV Sensor (XRS/EUV), the Energetic Particle Sensor (EPS), and the High Energy Proton and Alpha Detector (HEPAD) for GOES NO/PQ
GOESN-RTP-197	Handling, Storage, Packaging, and Transportation Procedures for the XRS/EUV
GOESN-RTP-198	Handling, Storage, Packaging, and Transportation Procedures for the EPS/HEPAD
GOESN-ENG-005	Controlled Area Practices Guide
GOESN-ENG-001	Contamination Control Plan

1.0 Introduction and Scope

This document establishes the vacuum bakeout procedures for components of the GOES XRS/EUV and EPS/HEPAD in the Panametrics Thermal Vacuum and Thermal Bakeout Chambers.

Thermal-vacuum bakeouts help to reduce the outgassing rates of organic materials by accelerating the molecular outgassing within a controlled vacuum environment. A typical thermal-vacuum bakeout consists of exposing materials, subassemblies, and higher-level assemblies to thermal vacuum conditions until the molecular outgassing rate has stabilized at a low level. Elevating the temperatures to the highest allowable limit accelerates the outgassing process, and can result in time and cost savings over low temperature bakes. Also, baking out components at the lowest possible assembly level often results in lower cost and risk because higher temperatures can be used, and the smaller bakeout chamber can be used. Using these methods, a thermal vacuum bakeout program has been developed for the GOES instruments to assure that they are not degraded by self contamination.

NASA-qualified parts normally meet the minimum vacuum stability requirements of 1.0% TML and 0.1% CVCM. There are some parts, however, which only meet these requirements after pre-conditioning (such as air-bake or vacuum bakeout). Special care must be taken to verify that all parts and materials have been preconditioned in the same manner as those that have passed the outgassing tests. In certain cases, materials that do *not* meet NASA outgassing requirements must be used. If such cases arise, individual plans will be developed to qualify those materials, which will include high-temperature bakeout and controlled outgassing rate tests (ASTM E595 or E1559) to justify their use.

The following procedures are highly modified versions of a roughly drafted ASTM procedure, which has been modified to be specific to the needs and requirements for Panametrics, specifically for the XRS/EUV and EPS/HEPAD on GOES NO/PQ.

2.0 Thermal Vacuum Chamber -Setup and Certification

Thermal vacuum bakeouts of GOES flight hardware will be performed in both the small and large thermal vacuum chambers. All thermal vacuum operations will be performed in such a manner as to preclude the possibility of contaminating or otherwise damaging the item(s) under test. All instrument level bakeouts shall be performed per the following procedures, except for special preconditioning or certification as mentioned in Section 1.0, for which individual procedures will be written. To prevent contamination of the instruments post delivery, the Panametrics CCE or representative must also approve all satellite-level thermal-vacuum tests.

The configuration of the chamber and all GSE should be noted for all tests, including detailed measurements of the location of each item. Time, pressure, temperature, and TQCM frequency data shall be recorded at regular intervals.

2.1 Chamber and GSE Certification

A vacuum chamber must be cleaned and certified prior to performing a thermal vacuum bakeout on flight hardware or GSE. This certification does not need to be performed prior to each and every bakeout. Chamber bakeout logbooks shall be kept for each of the chambers to help maintain visibility into prior bakeout items, and the test director must determine whether the chamber and associated GSE had been left in a suitably clean condition. The level of cleanliness will be based upon the materials and TQCM frequencies during the previous bake. The chamber must be cleaned and certified following 'dirty' bakeouts (typically those with large amounts of polymeric material). Since the EPS/HEPAD does not have the same cleanliness requirements as the XRS/EUV, chamber bakeout and certification must be performed if XRS/EUV hardware is to follow EPS/HEPAD hardware bakeouts. Bakeout chamber scheduling should take account of this requirement. Observe the following procedure for chamber bakeout and certification:

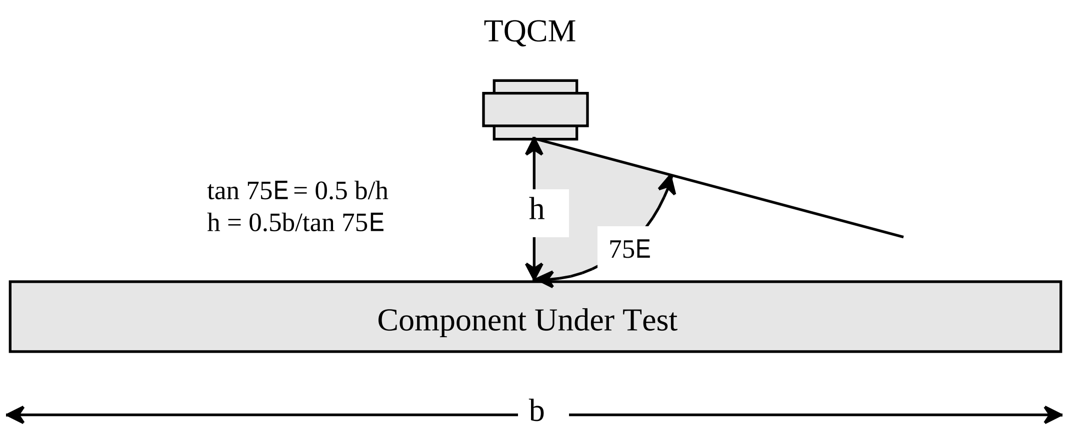
1.) Observe standard cleanroom operating procedures (see Controlled Area Practices Guide), which includes donning smocks, bonnets, face masks, and Nitrilite® gloves.
2.) Configure the vacuum chamber in the manner it will be configured for hardware bakeout. This implies that all GSE used for the bakeout is in place, including the TQCM. Place the TQCM according to 'TQCM Setup' below.
3.) Clean the interior of the vacuum chamber and all GSE (including TQCM) to SN-C-0005 VCHS (see the Controlled Area Practices Guide for definitions) by wiping with cleanroom wipers and Isopropyl Alcohol. If the chamber is excessively dirty (contaminated with oils or hard-to-remove residues), use the Simple Green procedure for precision cleaning as stated in the CCP. Visually inspect chamber with white and ultraviolet light illumination for complete removal of adhesive residues, grease, oil, particles, metal shavings or other foreign materials. Areas not adequately cleaned shall be re-cleaned.
4.) Close the vacuum chamber door and evacuate chamber to 5.0E-05 Torr or better vacuum. Maintain TQCM at 25˚C during evacuation.
5.) Once the desired vacuum level is reached, fill cold plate (if used) with LN_2.
6.) Raise the temperature of the base plate and shroud to 70˚C ± 2˚C$^{(*)}$ for the large chamber, or 100˚C ± 2˚C$^{(*)}$ for the small chamber.
7.) Begin logging the time, temperatures, and TQCM readings hourly, or on changes.
8.) Increase temperature of TQCM to 80˚C for cleaning, and maintain this temperature until TQCM frequency becomes stable (typically ≤2-3 hours). This may be done in parallel with Step 6.). This step may be omitted if the initial frequency readings of the TQCM at 25˚C are stable and below 2000 Hz (for a 15MHz crystal).
9.) Decrease temperature of the TQCM to -20˚C.
10.) Following a change in set-point temperature for a TQCM, a “settling” period of at least 2 hours is required before valid measurements can be taken.
11.) Maintain this condition until a background certification rate of less than 300 Hz/hr $^{(**)}$ is reached on the TQCM. It is expected that this condition should be met within 48 hours of temperature stabilization. If not, note TQCM readings and contact the CCE. If at any time the Δ-Δ $^{(***)}$ is below 15 Hz/hr/hr, the chamber bakeout can be stopped.
12.) Initiate return to ambient by returning the TQCM to 25˚C and slowly backfilling the chamber with clean dry GN_2, until a pressure of 400 Torr is reached.
13.) Warm cold plates or cold shrouds (if filled with LN_2) to ambient and continue to vent chamber to ambient pressure.
14.) The chamber is certified, and is ready for Thermal Vacuum Bakeouts.

15.) The chamber must be cleaned and certified following bakeouts that may be suspected of contaminating the chamber walls. Typically, 'dirty' bakes are those which involve bakeouts of large quantities of polymeric material.

(*) 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. The unit control thermocouple must be mounted in such a manner as to represent the average unit temperature. For small parts, unit control thermocouples are not required, and stabilization of the shroud or baseplate will suffice. This rate can be extrapolated over a 20-minute sample time. For example, stabilization has been achieved if two temperature measurements taken 20 minutes apart are within 1˚C of each other.
(**) This is the GSFC certification requirement for thermal vacuum chambers.
(***) If 'Δ' is the outgassing rate in Hz/hr (averaged over 20-minute intervals), then 'Δ-Δ' is the change in the outgassing rate in Hz/hr/hr.

2.2 TQCM Setup and Use

The placement of the TQCM has a significant effect on the measured outgassing rates. If the TQCM views hot chamber surfaces capable of re-emitting contamination, such as it would in a hot box, the readings will be artificially high. If it views a cold shroud, the readings will be too low. The outgassing rate must be monitored by the TQCM positioned such that its field of view is completely filled by the non-outgassing support equipment and/or the item undergoing the bakeout. Since the TQCM has a 150˚ field-of-view, this means placing the TQCM within inches of the hardware as shown below.



If the TQCM cannot be placed appropriately, which may be the case due to support equipment or thermal requirements, the rate must be adjusted by solid-angle modeling. For this reason, it is important to document the exact location of the TQCM or take photographs of the test set-up. If several components or parts are baked-out at once, multiple TQCMs may be used to get an accurate representation of the outgassing rates. For assembled electronics boxes, the TQCM(s) should be placed as close to the box vent as possible, or near a connector if there is no vent.

Calculations herein are based upon the use of a QCM Research 15 Mhz crystal, with an assumed sensitivity of 1.965E-09 $g \cdot cm^{-2} \cdot Hz^{-1}$.

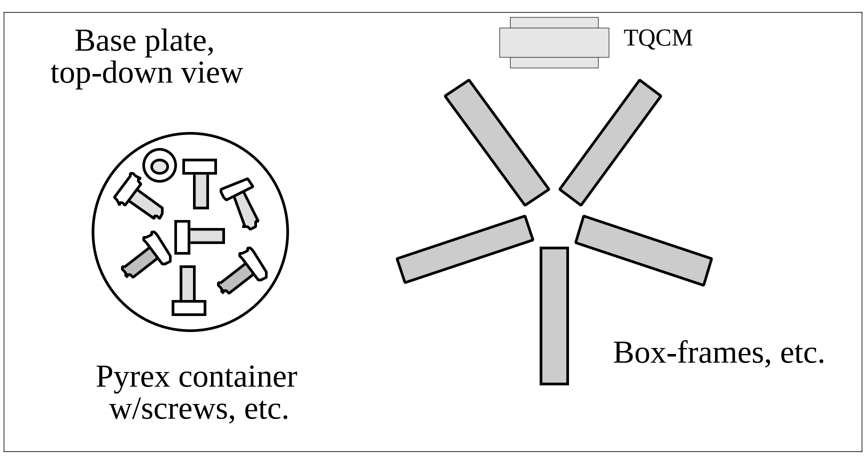
The TQCM must be thermally connected to a heat sink that can be maintained at 25˚C, enabling the TQCM to operate through its full temperature range. If the TQCM is used for extended periods, it may be necessary to cool the heat sink mounting bracket (with fluid or gas) to keep it from rising above 25˚C. (See TQCM manual for details).

Whenever the TQCM rate exceeds 10,000 Hz, the crystal needs to be heated while at high vacuum to drive contaminants from the crystal (see Certification Step 8.) above). This can be done either during the chamber certification, or as a separate activity. Observe the manufacturer requirements for maximum temperature difference between the TQCM Crystal and TQCM heat-sink (typically 60°C) during this activity and all TQCM operation.

A Residual Gas Analyzer (RGA) may also be installed into the vacuum chamber for chemical identification of outgassing species. Operation of the RGA will not affect the bakeout in any way, and analysis can be done at any time during the bakeout. Note – the RGA must not be turned on at pressures $>1 \times 10^{-4}$ torr, which may occur during initial bakeout.

2.3 Bakeout Support Equipment

The object of vacuum bakeout is to remove contaminants that outgas from an instrument, by pumping them away or collecting them on a cold plate for removal. It is important, therefore, to provide good vent paths from the object(s) being baked. This requires the use of vacuum stable GSE to hold or support the hardware in a manner that enables removal of the molecular outgassing products. Articles should always be well spaced, and have large view-angles to the chamber walls. An example is illustrated below.



3.0 Thermal Vacuum Bakeout

Following certification of the chamber, flight hardware bakeouts can be performed. The following procedure should be used for all flight hardware. The variables in the procedure are 1) the bakeout temperature and 2) the bakeout time, which will be supplied by the Project Scientist prior to bakeout, and will be denoted in the Assembly Instructions or Route Sheets. Use of the TQCM is not necessary for small items or subassemblies. If a TQCM is not used, a 'time @ temperature' bakeout is performed. Avoid baking dissimilar components if possible. For example, perform one bakeout on fasteners, another on covers, frames and chromate conversion treated aluminum, then another on cable ties and tools. This helps prevent cross contamination, and allows the highest bakeout temperatures. The maximum temperature of an assembly is governed by the lowest temperature requirement within the assembly. For instance, a complete sensor subassembly can be baked only at the maximum sensor temperature. Hardware must have been precision cleaned prior to bakeout. See Contamination Control Plan or Assembly Instructions for cleaning procedures.

3.1 Flight Hardware Bakeout Procedure

1.) Don appropriate cleanroom attire including gloves.
2.) Clean LN2 cold-plates (if used) with IPA dampened cleanroom wipers.
3.) Load precision-cleaned hardware into chamber. Document the configuration of bakeout chamber, noting positions of GSE, H/W, and TQCM prior to start.
4.) Close chamber door and evacuate to 5.0E-05 Torr or better vacuum. Maintain TQCM (if used) at ambient temperature.
5.) Once desired vacuum level is reached, fill cold plate (if used) with LN_2.
6.) Increase chamber (shroud and baseplate) temperature to indicated "Bakeout Temperature". Turn on TQCM (if used). If TQCM frequency exceeds 10,000 Hz at any time during the bakeout, increase TQCM temperature to 80˚C until the frequency becomes stable (typically ≤2-3 hours).
7.) Decrease the temperature of the TQCM (if used) to -20˚C.
8.) Following a change in set-point temperature for a TQCM, a "settling" period of at least 2 hours is required before valid measurements cam be taken.
9.) Once temperature stabilization has occurred [*], begin hourly logging of time, pressure, temperature, and TQCM frequency (~16 hour unattended gaps are permissible, but the TQCM should generally be turned off if left unattended for more than 24 hours). Maintain this condition for no less than the indicated "Bakeout Time" [#]. During the final 6 hours of the bakeout, verify that the chamber pressure is below 3.0E-06 Torr and that the pressure has stabilized within a pressure tolerance of ±0.1 of a decade.
10.) If hardware certification is required, lower the chamber temperature to the maximum on-orbit operating temperature of the hardware under test. Temperature changes should not exceed ~1°C/minute for flight electronics. Raise the TQCM temperature to -10˚C. Maintain this condition until Outgassing Rate Stabilization of ≤5% has been demonstrated for 8 hours [##]. Repeat bakeout procedure if rate has not stabilized. These requirements are given for the XRS/EUV, as taken from the CCP.
11.) Initiate return to ambient by returning the TQCM (if used) to ambient temperature and slowly backfilling the chamber with clean dry GN_2, until a pressure of 400 Torr is reached.
12.) Warm LN_2 cold-plates (if used) to ambient temperature.
13.) Continue to vent chamber to ambient pressure.
14.) Open the chamber door and remove hardware when GN_2 has reached a safe level.

15.) Solvent wipe the LN2 cold plate (if used), with IPA and non-particulating wipes when chamber is opened.

16.) Following bakeout, items must be stored in a manner that does not compromise their cleanliness. Package and store items in cleanroom according to packaging and storing sections of GOESN-RTP-197 and GOESN-RTP-198, until required for assembly. This typically requires packaging items in clean ESD-safe zip-lock bags, or in precision-cleaned tote-boxes.

(*)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. The unit control thermocouple must be mounted in such a manner as to represent the average unit temperature. For small parts, unit control thermocouples are not required, and stabilization of the shroud or baseplate will suffice. This rate can be extrapolated over a 20-minute sample time. For example, stabilization has been achieved if two temperature measurements taken 20 minutes apart are within 1˚C of each other.

(#) Sudden increases of TQCM rate should be noted on data sheets.

(##) Outgassing Rate Stabilization, expressed in Hz/hr/hr, indicates that there is little to be gained by continuing the current test. It only indicates that a) the hardware is clean, or b) it needs to be further baked. The actual outgassing rate is important, in that the goal is ~50 Hz/hr for the complete XRS/EUV instrument. There is no corresponding goal for the EPS/HEPAD, but certification outgassing rates in excess of 300 Hz/hr must be brought to the attention of the CCE. TQCM readings should be averaged over 20-minutes. The outgassing rate, Δ (Hz/hr) should be taken from 3, 20-minute readings.

3.2 Special Bakeout Cases and Circumstances

3.2.1 -Stabilization of Silicone and Other Polymeric Compounds

Though strongly discouraged for use in the XRS/EUV instruments, silicones must sometimes be used in small quantities (and may be used in the EPS/HEPAD). When silicone use is necessary, the amount of material used must be minimized, and the outgassing rate will be stabilized by vacuum bakeout. Special procedures will be written for each of the 'special case' bakeouts. As an example, to stabilize the vacuum outgassing of silicone items, the items will be baked at 125° C for 7 days in air, then vacuum baked for not less than 48 hours at 110° C at a pressure of 5.0E-5 Torr or better.

To stabilize other items such as Nylon screws and bushings, Kalrezä O-rings, and Tefzelä cable ties, special procedures will be written. The items will be baked at 125˚C for 48 hours in air, then vacuum baked for not less than 24 hours at 110˚C at a pressure of 5.0E-5 Torr or better. Similar bakeouts should be done for tools and supplies used in the assembly of flight hardware.

Representative ASTM-E595 testing will be done following such bakeouts to verify that the outgassing requirements have been met with the bakeout.

3.2.2 -Conversion Coated Aluminum

Chromate conversion coated aluminum (alodyned or iridited) components shall not be baked higher than 60˚C due to possible changes in the physical properties of the coating (may start flaking).

4.0 List of Acronyms

CCE	Contamination Control Engineer
CCP	Contamination Control Plan
CVCM	Collected Volatile Condensable Material
Mhz	Megahertz
RGA	Residual Gas Analyzer
TML	Total Mass Loss
TQCM	Thermoelectric Quartz Crystal Microbalance
UV	Ultraviolet
VC	Visibly Clean
VCHS	Visibly Clean Highly Sensitive
VCHS+UV	Visibly Clean Highly Sensitive plus Ultraviolet Light

5.0 Appendix A, Temperature Conversions

To convert degrees Centigrade to degrees Fahrenheit, multiply by 1.8 and add 32 as shown:

$$^{\circ}C \times 1.8 + 32 = {}^{\circ}F$$

Or use the lookup table below.

˚C		*˚F*
-20	=	-4
0	=	32
20	=	68
60	=	140
70	=	158
80	=	176
90	=	194
100	=	212
110	=	230
125	=	248
150	=	302

6.0 Appendix B, Tear-out Vacuum Bakeout Procedure

Starting Date: ____________

Item(s) Under Test: ____

Test Conductor: ______________________________

Bakeout Time @ Temperature: ________ hours @ ________˚C

Certification Required: _Yes / No_ Certification Temperature ________ ˚C

Project Scientist Signoffs: ______________________________ Maximum Time/Temp

______________________________ Actual Time/Temp

	Procedure	Initials	Comments
1.)	Don appropriate cleanroom attire including gloves.		
2.)	Clean LN2 cold-plates (if used) with IPA dampened cleanroom wipers.		
3.)	Load precision-cleaned hardware into chamber. Document the configuration of bakeout chamber, noting positions of GSE, H/W, and TQCM prior to start.		
4.)	Close chamber door and evacuate to 5.0E-05 Torr or better vacuum. Maintain TQCM (if used) at ambient temperature.		
5.)	Once desired vacuum level is reached, fill cold plate (if used) with LN2.		
6.)	Increase chamber (shroud and baseplate) temperature to indicated "Bakeout Temperature". Turn on TQCM (if used). If TQCM frequency exceeds 10,000 Hz at any time during the bakeout, increase TQCM temperature to 80˚C until the frequency becomes stable (typically ≤2-3 hours).		
7.)	Decrease the temperature of the TQCM (if used) to -20˚C.		
8.)	Following a change in set-point temperature for a TQCM, a “settling” period of at least 2 hours is required before valid measurements cam be taken.		
9.)	Once temperature stabilization has occurred (*), begin hourly logging of time, pressure, temperature, and TQCM frequency (~16 hour unattended gaps are permissible, but the TQCM should generally be turned off if left unattended for more than 24 hours). Maintain this condition for no less than the indicated		

	Procedure	Initials	Comments
	"Bakeout Time" (#). During the final 6 hours of the bakeout, verify that the chamber pressure is below 3.0E-06 Torr and that the pressure has stabilized within a pressure tolerance of ±0.1 of a decade.		
10.)	If hardware certification is required, lower the chamber temperature to the maximum on-orbit operating temperature of the hardware under test. Temperature changes should not exceed ~1°C/minute for flight electronics. Raise the TQCM temperature to -10˚C. Maintain this condition until Outgassing Rate Stabilization of ≤5% has been demonstrated for 8 hours (##). Repeat bakeout procedure if rate has not stabilized. These requirements are given for the XRS/EUV, as taken from the CCP.		
11.)	Initiate return to ambient by returning the TQCM (if used) to ambient temperature and slowly backfilling the chamber with clean dry GN2, until a pressure of 400 Torr is reached.		
12.)	Warm LN2 cold-plates (if used) to ambient temperature.		
13.)	Continue to vent chamber to ambient pressure.		
14.)	Open the chamber door and remove hardware when GN2 has reached a safe level.		
15.)	Solvent wipe the LN2 cold plate (if used), with IPA and non-particulating wipes when chamber is opened.		
16.)	Following bakeout, items must be stored in a manner that does not compromise their cleanliness. Package and store items in cleanroom according to packaging and storing sections of GOESN-RTP-197 and GOESN-RTP-198, until required for assembly. This typically requires packaging items in clean ESD-safe zip-lock bags, or in precision-cleaned tote-boxes.		

(*)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. The unit control thermocouple must be mounted in such a manner as to represent the average unit temperature. For small parts, unit control thermocouples are not required, and stabilization of the shroud or baseplate will suffice. This rate can be extrapolated over a 20-minute sample time. For example, stabilization has been achieved if two temperature measurements taken 20 minutes apart are within 1˚C of each other.

(#) Sudden increases of TQCM rate should be noted on data sheets.

(##) Outgassing Rate Stabilization, expressed in Hz/hr/hr, indicates that there is little to be gained by continuing the current test. It only indicates that a) the hardware is clean, or b) it needs to be further baked. The actual outgassing rate is important, in that the goal is ~50 Hz/hr for the complete XRS/EUV instrument. There is no corresponding goal for the EPS/HEPAD, but certification outgassing rates in excess of 300 Hz/hr must be brought to the attention of the CCE. TQCM readings should be averaged over 20-minutes. The outgassing rate, Δ (Hz/hr) should be taken from 3, 20-minute readings.

7.0 Appendix C, Tear-out Bakeout Log

Starting Date: ____________

Item(s) Under Test: ____

Test Conductor: ______________________________

Bakeout Temperature: ______________________________

Date/Time	Chamber Pressure (torr)	TQCM Temperature (˚C)	TQCM Frequency (Hz)	ΔTime (hrs) (since previous reading)	Δ (Hz/hr) (since previous reading)