Hardware Outgassing Certification

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Overview

- Theory
- Instrumentation
- Requirements
- Configuration
- Data
- Error Analysis

Theory

- Description
- Criteria
- Sequence
- Physics

Purpose and Scope

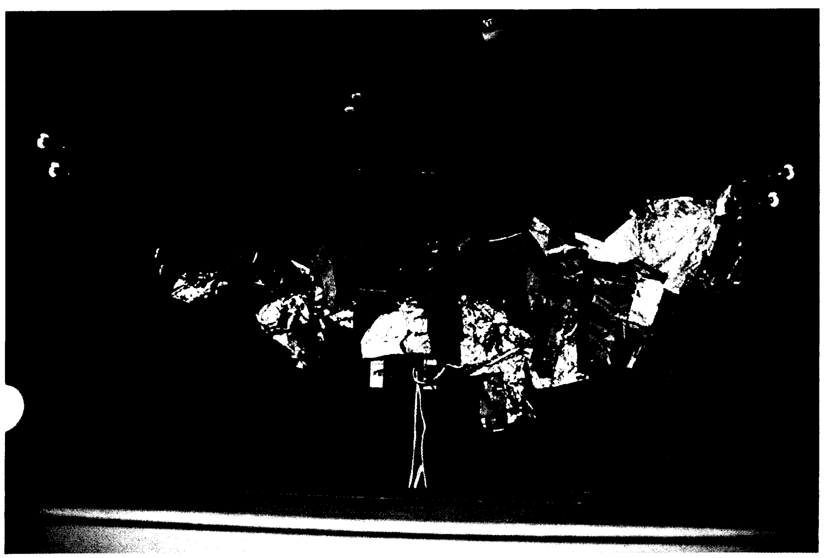
- Purpose
  - To reduce contamination levels such that the effects are acceptable
- Contaminant types removed
  - Surface molecular
  - Bulk molecular
- Scope
  - Raw material, component, or system level
  - Temperature limits generally become stricter as integration proceeds
  - The sum of the parts equals the whole

Baking out every part before integration could eliminate system level bakeouts – except for extra sources like torque striping on bolts that are added during assembly!

Criteria Types

- Time/Temperature
- Coarse Bakeout
- Certification Conditions

- Applies to raw materials, components, or parts that have a history of monitored bakeouts and show good uniformity
- Specify the item temperature and the duration
- Outgassing rate data may or may not be collected but is not part of the certification
- Cost and schedule can be predicted



Criteria Types

- Time/Temperature
- Coarse Bakeout
- Certification Conditions

- Quickly reduce the bulk contaminant reservoir
- Highest permissible temperature
- Specify either a rate (using temperature scaling to convert from the requirement at a representative temperature) or a change in rate
- Change in rate (delta-delta) is often used because it indicates when the point of diminishing returns is being reached
- Little data analysis required

Time	Freq	Delta	Delta Delta	Shroud	Hardware
1:00	2787			30.1	46.2
2:00	2904	117		30.0	46.2
3:00	3010	106	-11	30.1	46.5
4:00	3108	98	-8	30.0	46.4
5:00	3200	92	-6	30.2	46.3
6:00	3220	20	-72	30.0	35.1
7:00	3225	5	-15	30.1	30.4

Criteria Types

- Time/Temperature
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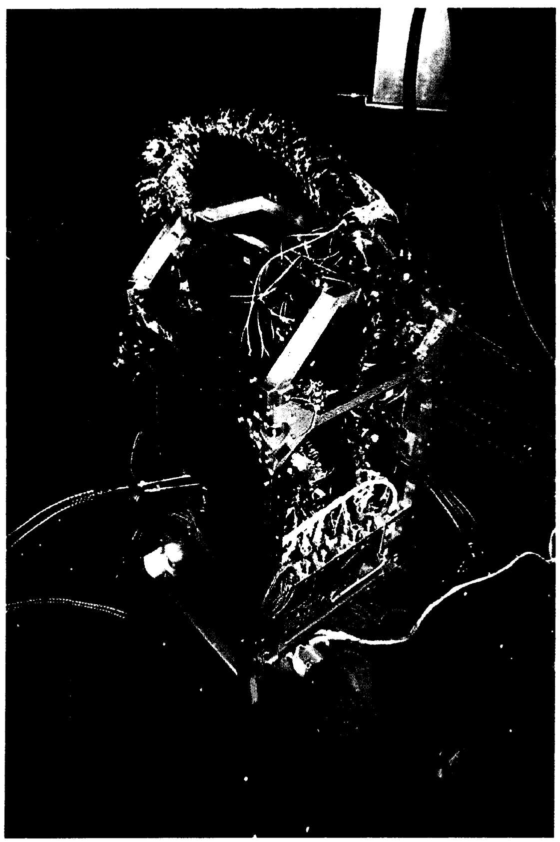
- Certification Conditions



- Sample and collection temperatures should be representative of on-orbit conditions
- Rule of thumb
  - Hardware 10 degrees above maximum prediction
  - Collection 10 degrees below sensitive surface minimum prediction
- Outgassing requirement is converted to collection rate requirement based on chamber configuration
- Best characterization of hardware

Typical Sequence

Days to Months

- Definition of test setup
  - Test plan
  - Measurement devices
    - Placement
    - Data rates
  - Enclosure vent definition
  - Heater temperature ranges and limits
  - Other equipment

Days

- Surface cleaning
  - Fixtures and GSE
    - Match cleanliness level of test article
  - Visual inspection and fallout plates
    - May be required depending on length of setup time (exposure to ambient)

Preparation	Chamber Cert	Hardware Bake	Hardware Cert	Data Analysis

Typical Sequence

Days to Weeks

- QCM criteria
  - As low as possible
  - As stable as possible
  - Below a fraction of the hardware criteria
- Species present
- Temperature
  - As high as possible for bakeout purposes
  - Match hardware criteria for background measurement purposes

Preparation	Chamber Cert	Hardware Bake	Hardware Cert	Data Analysis

Typical Sequence

Days to Weeks

- Establish vacuum
- Set hardware temperature
  - Highest permissible temperature
- Set collection temperature
  - Interested in condensable species
  - Representative temperature of sensitive surfaces
- Record data
  - Sample frequency and format
- Terminate bakeout phase
  - Diminishing returns
  - Schedule
  - Already meeting certification criteria

Preparation	Chamber Cert	Hardware Bake	Hardware Cert	Data Analysis

Typical Sequence

Days

- Set hardware temperature
  - Representative of on-orbit temperature
- Record data
- Terminate certification phase
  - Return to bakeout conditions if criteria was not met
  - Collect cold finger data if certification criteria was met

Preparation	Chamber Cert	Hardware Bake	Hardware Cert	Data Analysis

Typical Sequence

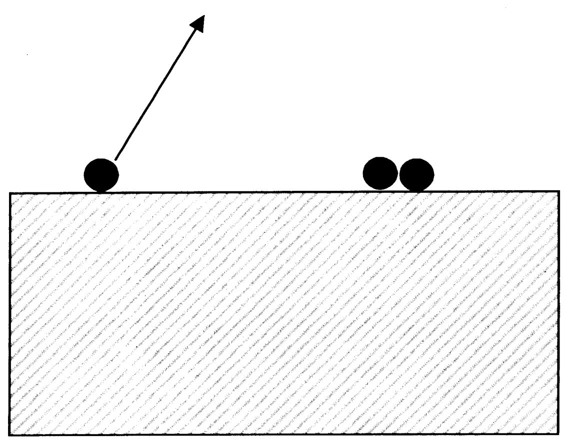
Days to Weeks

- Process data
  - Note artifacts
  - Curve fit
- Calculate hardware outgassing
  - Subtract background
  - Convert to desired units
- Compute error estimation
- Write report

Preparation	Chamber Cert	Hardware Bake	Hardware Cert	Data Analysis

Physical Process

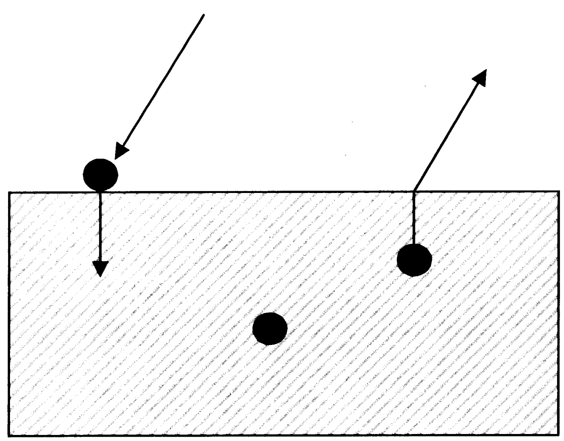
- Surface Desorption
- Bulk Outgassing
- Rate Equations



- Cleanroom Non-volatile Residue
  - Molecules are bound to the surface by Van Der Waals forces
  - Thermal energy can overcome the bonding and release the molecule
  - Small quantity
  - Quickly depleted
- Examples
  - Water
  - Mold release compounds
  - Fingerprints

Bakeout Theory

- Surface Desorption
- Bulk Outgassing
- Rate Equations



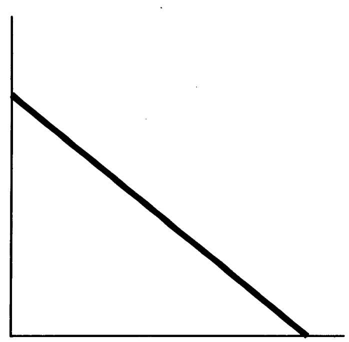
- Chemicals present in organic materials
  - As molecules at the surface desorb, they are replaced by molecules diffusing out from the interior
  - Diffusion coefficient is temperature dependent
- Molecules can diffuse back into the bulk
  - After leaving the surface, they may return by diffusion in the air
  - Negligible effect below 10^{-3} torr – reason for vacuum bakeouts
  - If diffusion rate through air is high enough, "offgassing" can occur without a vacuum environment
- Examples
  - Un-reacted catalyst in a bead of epoxy
  - Fire retardant added to wire insulation

Bakeout Theory

- Surface Desorption
- Bulk Outgassing
- Rate Equations

$$\frac{dm}{dt} = -k$$

$$m = -kt$$



- 0th order evaporation or sublimation
  - evaporation rate is independent of how much is present
- 1st order desorption
  - rate is proportional to the mass present
  - exponential decay in mass remaining
  - tau is the time constant
  - Ea is activation energy and tau_0 is the fundamental vibration frequency of the molecules
  - rate = -A/tau e^-t/tau
- Diffusion limited bakeout
  - dc/dt = -Ddc/dx; Fick's law
  - solution is a function of t^0.5; power law
  - rate = At^-b

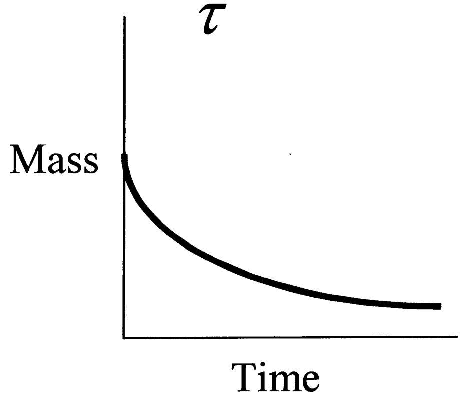
Bakeout Theory

- Surface Desorption
- Bulk Outgassing
- Rate Equations

$$\frac{dm}{dt} = -km$$

$$m = Ae^{-kt}$$

$$k = \frac{1}{\tau}; \quad \tau = \tau_0 e^{E_a/RT}$$



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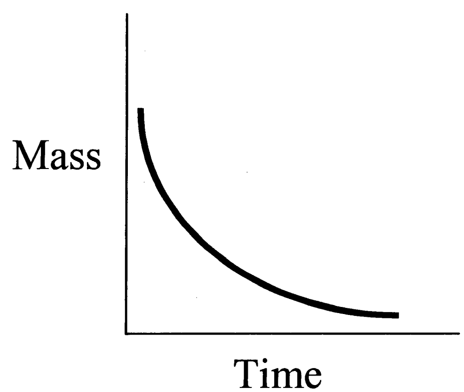
Bakeout Theory

- Surface Desorption
- Bulk Outgassing
- Rate Equations

$$\frac{\partial m}{dt} = -D\frac{\partial m}{dx}$$

$$\frac{dm}{dt} \approx At^{-b}$$



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  - rate is proportional to the mass present
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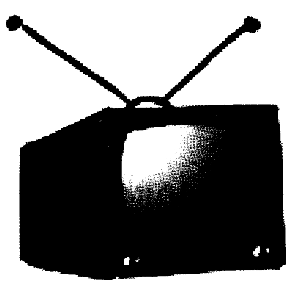
  - tau is the time constant
  - Ea is activation energy and tau_0 is the fundamental vibration frequency of the molecules
- Diffusion limited bakeout
  - dc/dt = -Ddc/dx; Fick's law
  - Numerical solution required
  - Short term rate follows a power law
  - Long term rate follows an exponential

Instrumentation

• QCM	Outgassing rate
• Coldfinger	Condensable species
• RGA	Volatile species
• Thermal	Temperature

Quartz Crystal Microbalance

- Theory
- Response
- Stability
- Types
- Field of View

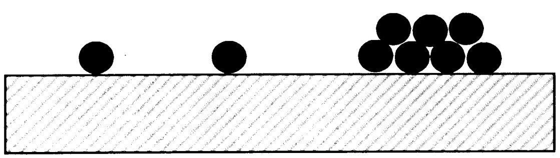


- Oscillating quartz crystal
  - Frequency inversely proportional to mass
  - Frequency varies with temperature
  - Range is MHz
- Two crystals of nearly equal frequency are used
  - One is exposed, the other is the reference
  - Beat frequency of the crystals is KHz
  - Because the reference crystal has nearly the same temperature, the effect of temperature changes is reduced

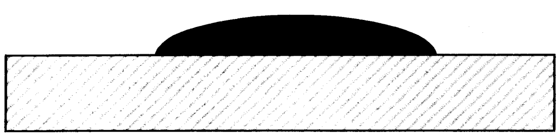
Quartz Crystal Microbalance

- Ability of the deposit to vibrate affects the maximum measurable limit
  - Hard or ice-like films form below the freezing point of the condensing molecules
  - Liquid droplets form above the freezing point
- Dynamic range
  - Hard films: hundreds of kHz
  - Liquid films: tens of kHz

Hard Film

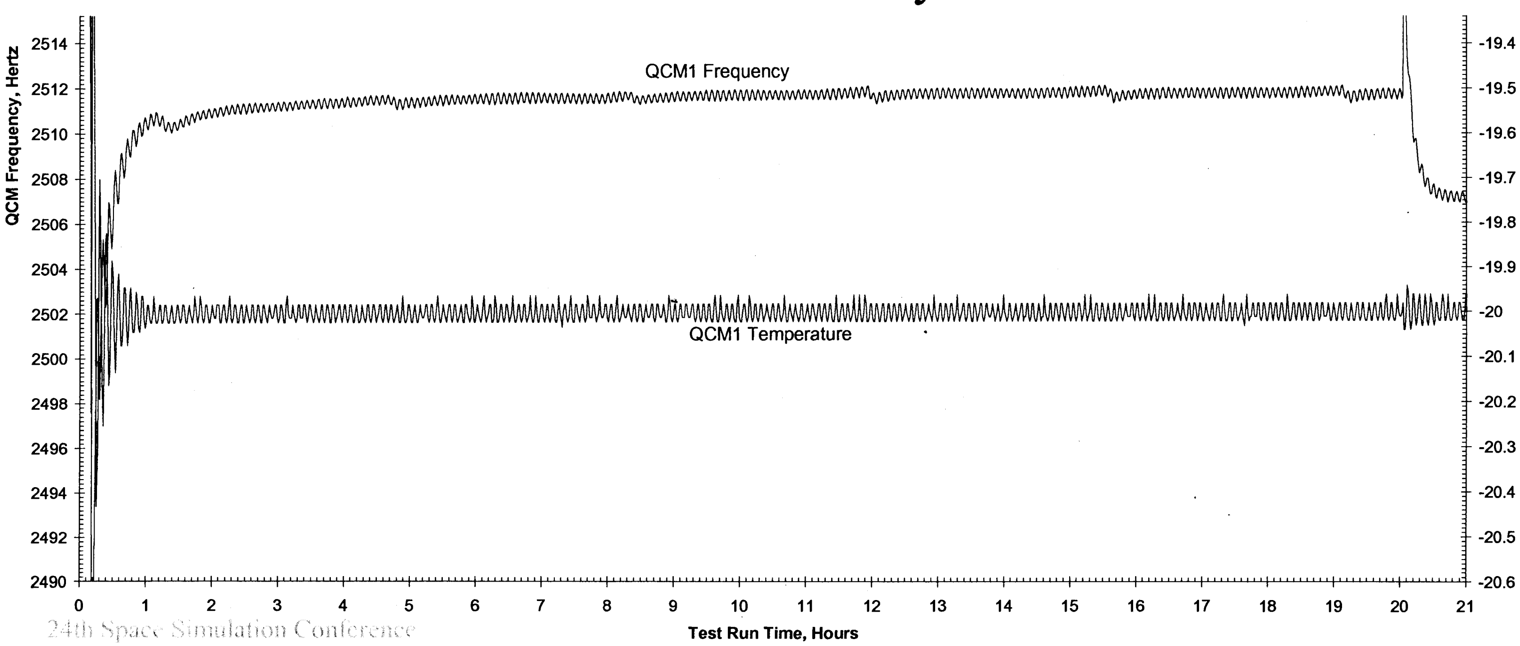


Liquid Film



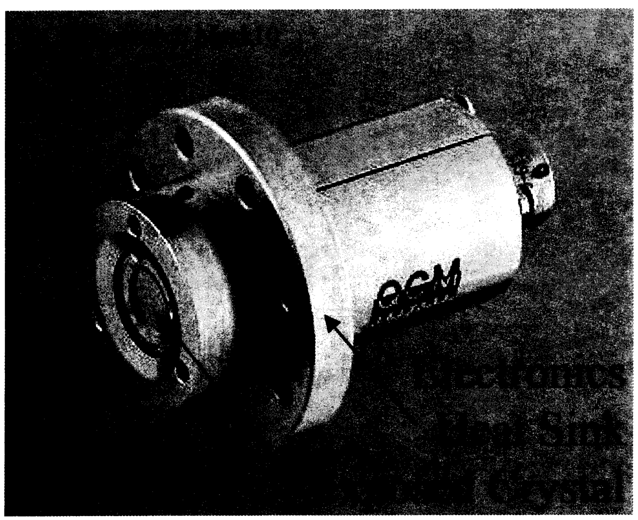
Quartz Crystal Microbalance

- Aging may cause drift in QCM output
  - Stress relief in resonators, electrodes, etc
  - Oscillator circuit aging
  - Quartz outgassing or absorption of gasses such as helium
  - Diffusion effects
  - Radiation effects on quartz
- Yearly rate of 5-51 Hz drift for 15 MHz



Quartz Crystal Microbalance

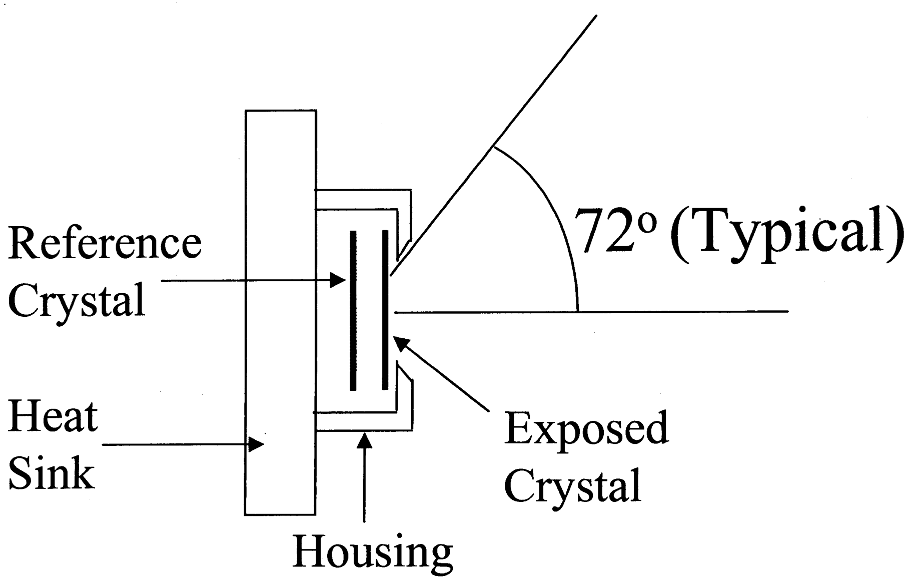
- Theory
- Response
- Stability
- Types
- Field of View



- Thermoelectric use a peltier device to control crystal temperature
- Cryogenic use a cold heat sink and a heater for control
- Available with different base frequencies (higher frequency is more sensitive) and different exposed crystal areas
  - Faraday and QCM Research are the brands used at GSFC
- Surface Acoustic Wave (SAW) uses a transverse instead of perpendicular vibration
  - Sensitivity 50 times higher

Quartz Crystal Microbalance

- Housing design determines FOV
  - Varies by manufacturer and model
  - Must be accounted for in modeling transport of molecules to the QCM
- Conversion factor from Hz to g/cm^2 is provided by manufacturer



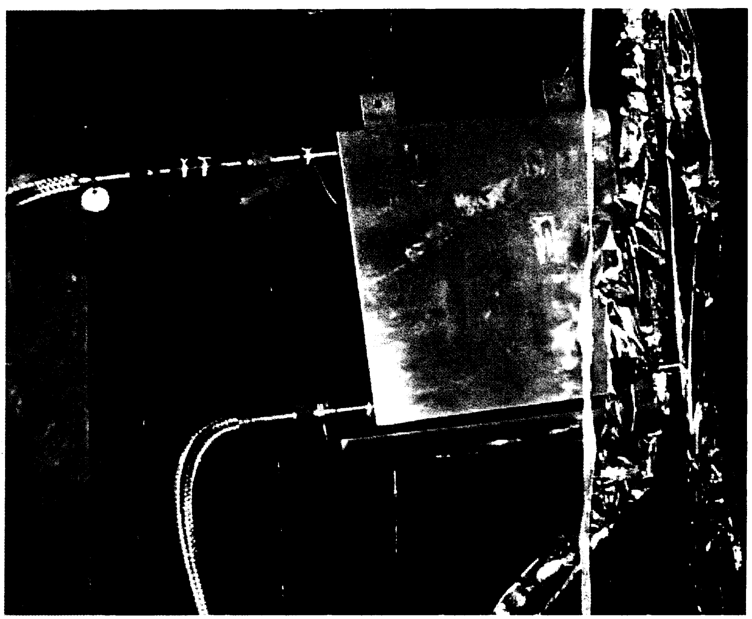
Species Collection

- Coldfinger
- Scavenger Plate

- Used to collect everything that condenses above liquid nitrogen temperature for quantity and species analysis
- Aluminum or Stainless Steel
- Cooled by liquid nitrogen
  - 8 hours at the end of a test
  - Representative of future outgassed species
  - Shortening the coldfinger duration reduces the quantity of contaminants collected – may be an issue when identifying trace species
- Allowed to warm up after the chamber has been backfilled to 600 Torr of nitrogen (traps less volatile species on the cold finger)

Species Collection

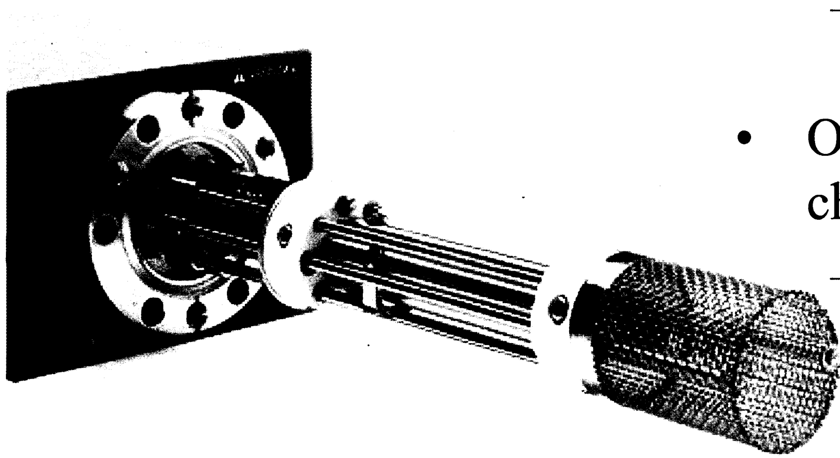
- Coldfinger
- Scavenger Plate



- Larger version of coldfinger
- Cooled during entire test
  - Used to reduce molecular flux to pumps and QCM
  - Can be rinse sampled but will include species that are depleted by the end of the test
- Typically has a "drip tray"

Residual Gas Analzyer

- Measures pressure of non-condensable species
- Only operates below 10^{-4} torr
- Data must be interpreted similarly to FTIR
  - Ionizes and breaks molecules into fragments
  - Collects the ions with an electric field
  - Measures the current to determine quantity of molecules at different masses
- Often mounted to the side of the vacuum chamber
  - True pressure may be higher than indicated due to obstructed view of chamber



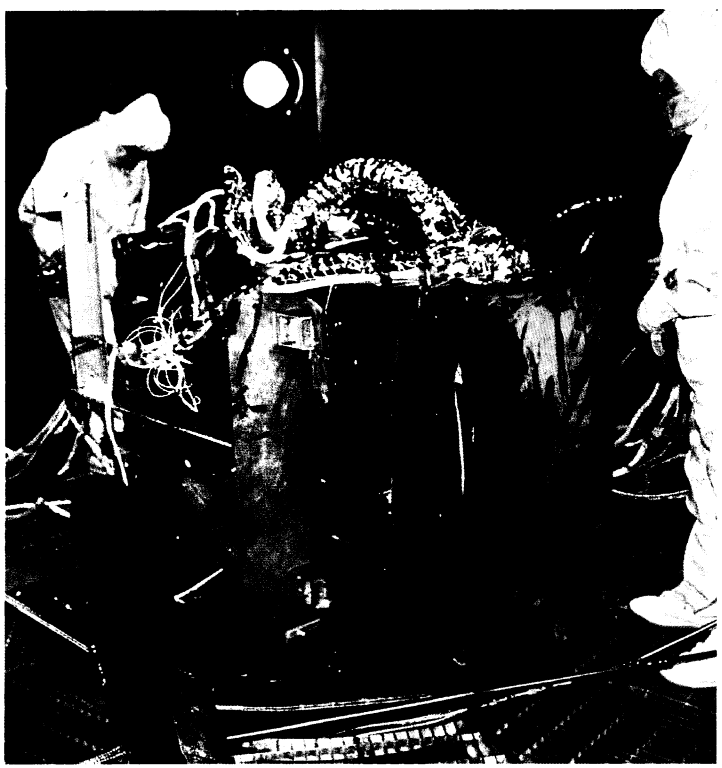
Thermal Instrumentation

- Chamber Shroud
- Heater Plates
- Miscellaneous

- Cylindrical metal insert in the chamber
- Typically plumbed with LN2 lines for cooling
- May also have heaters installed
- May be painted or black anodized for high emissivity
- The chamber wall is not temperature controlled
  - Stays near room temperature
  - May heat up during shroud driven bakeouts

Thermal Instrumentation

- Chamber Shroud
- Heater Plates
- Miscellaneous

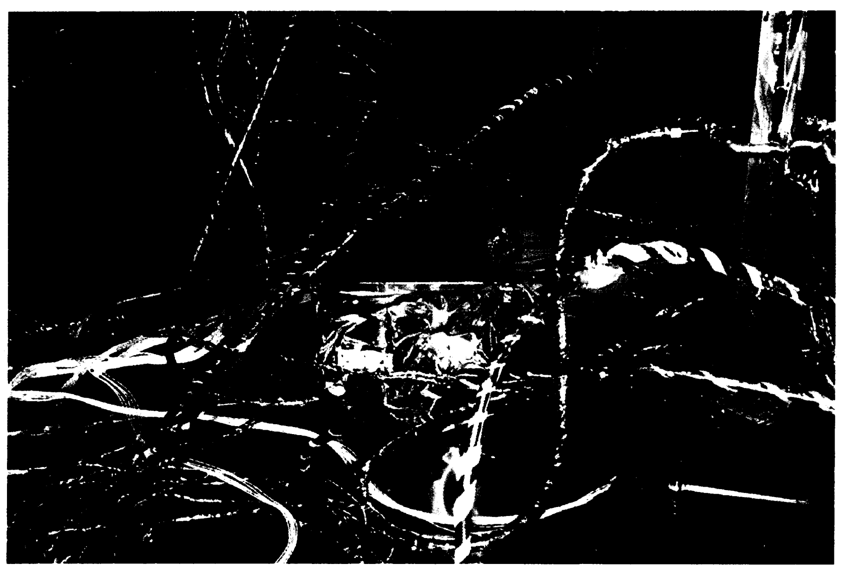


- Usually assembled into unique configurations for each test
  - May form an enclosure closed out with MLI
  - Chamber configuration affects the view of the QCM
- May heat and cool
  - Kapton heaters on aluminum
  - Plumbed plates that can have heated or cooled gas, liquid nitrogen, or liquid helium pumped through

Thermal Instrumentation

- Chamber Shroud
- Heater Plates
- Miscellaneous

- Thermocouples
  - Required to monitor the temperature of the hardware
  - Difficult to keep free from particle contamination
- LN2 lines
  - May need to be baked out if they are new

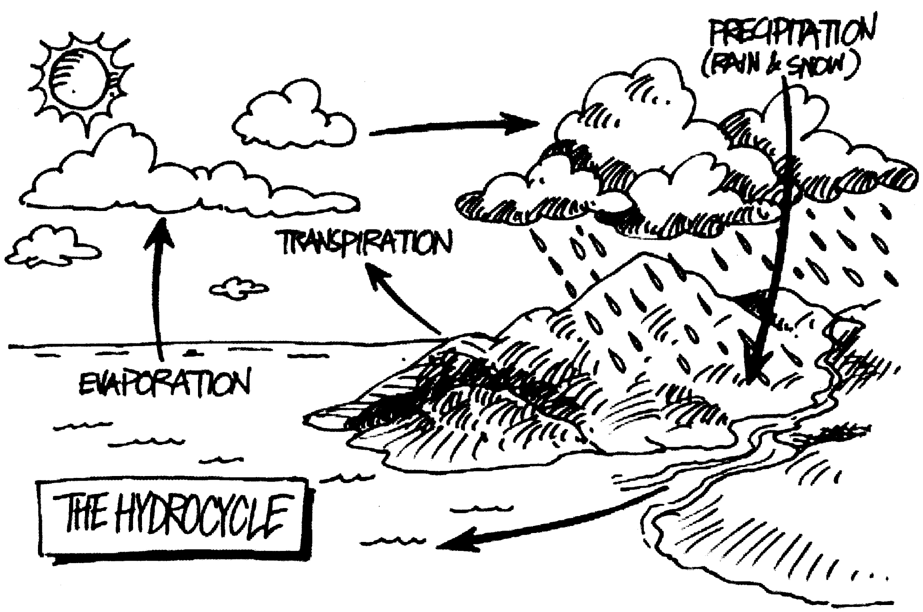


Does any of this contribute to the chamber background?

Requirements

- Definition
- Hardware Outgassing
- Background Outgassing
- Chamber Environment

- The QCM measures deposition rate at a particular location in the chamber
  - Chamber modeling is used to determine the deposition rate that results from the desired outgassing rate
  - Specify hardware and QCM temperatures
  - Specify QCM location and orientation



Just as measuring rainfall in Annapolis does not tell you the how much water evaporated from the ocean, QCM deposition alone does not tell us the outgassing rate of hardware.

Outgassing and Deposition

- Definition
- Hardware Outgassing
- Background Outgassing
- Chamber Environment

- Outgassing rate (OGR) in g/cm²/s to Deposition Rate (DPR) in g/cm²/s
  - A is area in cm²
  - VF is viewfactor
  - Subscript HW for hardware

$$\frac{OGR_{HW} \cdot A_{HW} \cdot VF_{HW->QCM}}{A_{QCM}} = DPR_{QCM}$$

- Deposition rate (g/cm²/s) to Delta (Hz/hr)
  - CF is conversion factor from QCM manufacturer (g/cm²/Hz)

$$DPR_{QCM} \div CF \cdot (3600 \frac{s}{hr}) = Delta$$

Derivation

- Outgassing requirement
  - Derived from the project performance specifications
  - Contaminant effects are used to deduce accretion limits
  - Molecular transport modeling of the spacecraft provides outgassing rate limits that result in acceptable accretions on sensitive surfaces
- Bakeout requirement (deposition on QCM)
  - Outgassing requirement
  - Chamber configuration
  - Transport modeling of the chamber provides the correspondence between outgassing and deposition

Background Levels

- Definition
- Hardware Outgassing
- Background Outgassing
- Chamber Environment

If the background is high, it is likely to decrease over the course of the hardware test, making data interpretation difficult.

- Chamber history
  - Presence of undesirable species (eg, silicones)
  - High background outgassing rates
- Acceptable background rate
  - Rule of thumb (non-critical): half the hardware requirement
  - Rule of thumb (critical): 1/10th the hardware requirement
  - High backgrounds also mean that the coldfinger results are less representative of the hardware being tested
- Pre-test chamber bakeouts are used to reduce the background

Theory
Instrumentation
Requirements
Configuration
Data
Error Analysis

- Definition
- Hardware Outgassing
- Background Outgassing
- Chamber Environment

Surface Requirements

- Usually not a controlled clean environment
  - Some chambers are located in clean tents
  - Some have filtered air flow inside
- Air quality and surface requirements of the hardware should be in the test plan
  - Small items
    - Easy to reclean the outside
    - Minimize the exposure time with bagging
    - No special requirements
  - Large items
    - Usually require a clean tent because of the time involved in chamber configuration
    - Class 100,000 with VCHS surfaces typical
- Backfill rates
  - Control particle redistribution by low flow rate

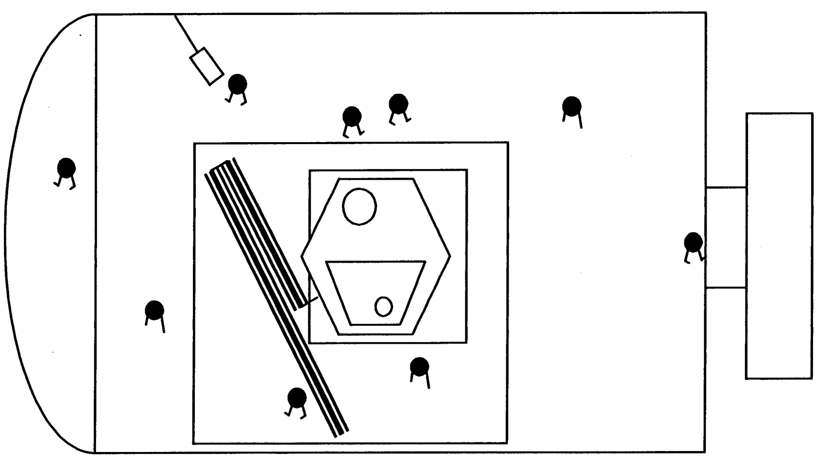
Configuration

- Molecular Transport
- Chamber Characterization
- Viewfactors

- Chamber configuration determines the relationship between sample outgassing and QCM readings
- Multiple QCMs may be required

Molecular Transport

- Random Walk
- Implications
- Radiation Viewfactors
- Molecular Viewfactors



- At low pressures, most collisions are with chamber or hardware surfaces, not other molecules
- Molecules do not bounce like balls; they stick to the surface momentarily and then re-emit in a random direction
- Molecules move randomly until they condense on a cold surface
- They do not know where the QCM and pump are located (cold surfaces act like fly paper, not like magnets)

Theory
Instrumentation
Requirements
Configuration
Data
Error Analysis

Molecular Transport
Chamber Characterization
Viewfactors

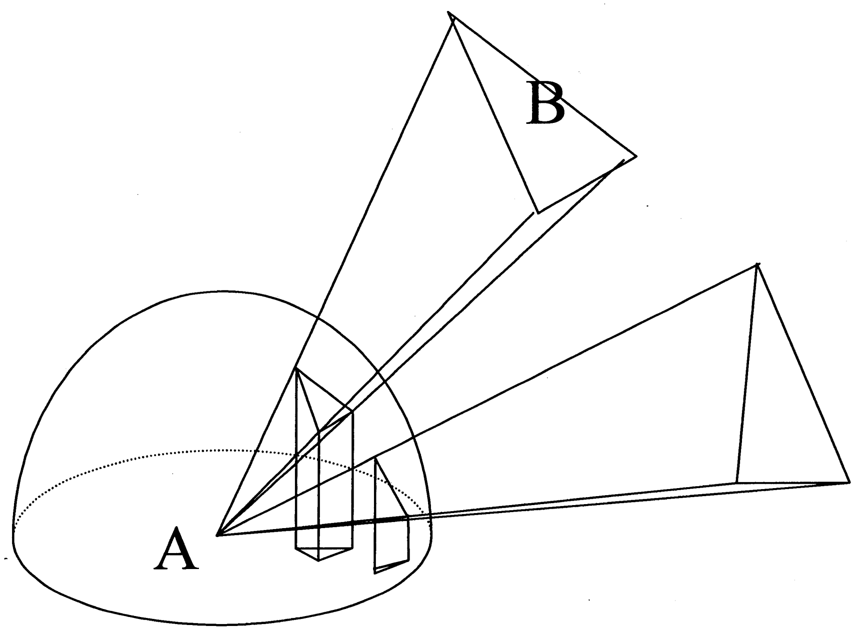
Molecular Transport

- Random Walk
- Implications
- Radiation Viewfactors
- Molecular Viewfactors

- If the chamber walls are colder than the QCM crystal, condensable molecules must have a line of sight to the QCM to be detected
- If the chamber walls are warm and the direct view from the hardware to the pump is obstructed, a uniform contaminant pressure may be assumed

Viewfactor Definition

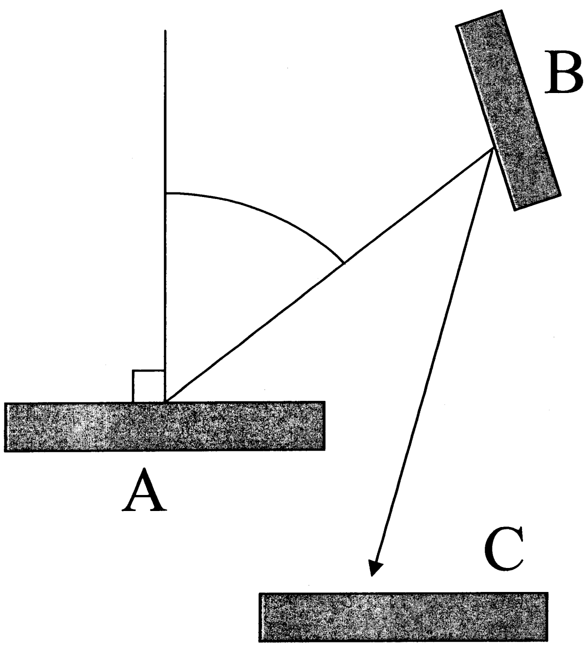
- Random Walk
- Implications
- Radiation Viewfactors
- Molecular Viewfactors



- Viewfactor from surface A to surface B
  - Strictly speaking, this is a radiation term and only line of sight transport is considered
  - Project surface B onto a hemisphere centered on (infinitesimally small) surface A
  - The fraction of the hemisphere's area covered by B is the viewfactor (A->B)
  - Except for very simple cases, viewfactors must be found by numerical methods
  - The sum of all viewfactors from a surface adds to 1

Viewfactor Definition

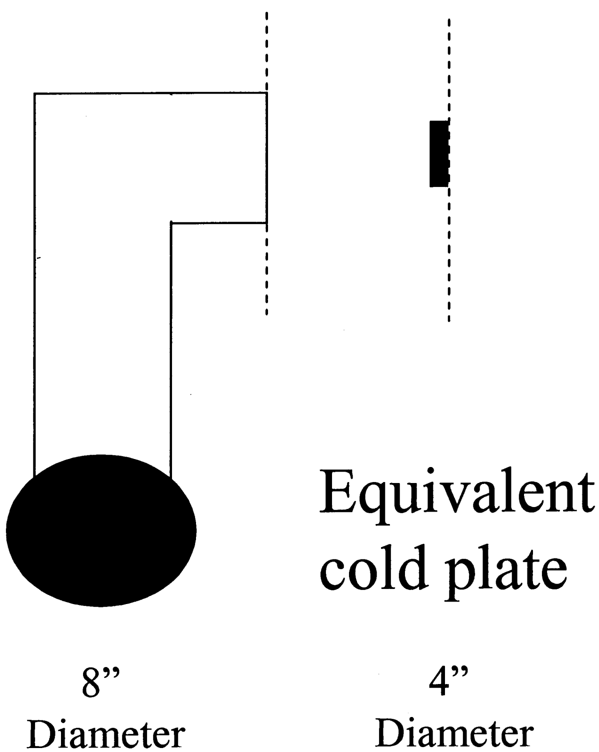
- Random Walk
- Implications
- Radiation Viewfactors
- Molecular Viewfactors



- For molecular transport, we allow multiple bounces
  - The viewfactor from A->B must now include paths other than line of sight
  - Molecules that do not stop on a surface do not contribute to the viewfactor to that surface
  - The sum of all viewfactors is still 1

Effective Pump Area

- The vacuum pump is located at the end of a tube, so does not have 100% efficiency
  - Molecules entering the tube can bounce back out
- The pump effective area is the area of a cold plate that would remove molecules at the same rate as the pump
  - Even for simple cases, the chamber pump efficiency must be known
  - The efficiency may be calculated by modeling the pump and chamber, or by running a characterization test



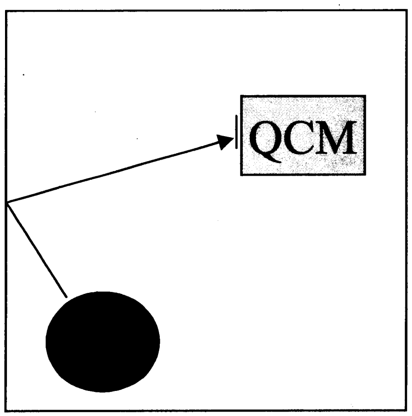
Viewfactors

- Complex test configurations
  - Multiple hardware elements in view of QCM
  - Non-isothermal environment
  - Numerical analysis is required
- Ideal chamber configurations
  - Viewfactor to the QCM is nearly independent of hardware geometry
- Simple test configurations
  - Isothermal environment
  - Single hardware element
  - Viewfactor may be found statistically

Geometry Independent

- Ideal "Hot Wall"
- Ideal "Cold Wall"

- The chamber is sealed
- Only the QCM crystal is cold enough to condense the outgassed species
- The hardware and chamber are the same temperature

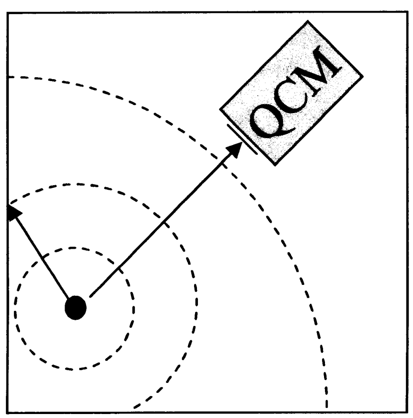


$$VF_{HW->QCM} = 1$$

Configuration

- Ideal "Hot Wall"
- Ideal "Cold Wall"

- The hardware is a point source
- All surfaces condense the outgassed species
- Molecules outgas as expanding sphere
- QCM crystal plane is tangent to the sphere

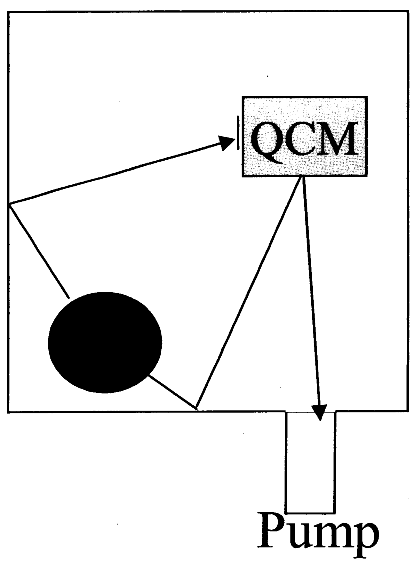


$$VF_{HW->QCM} = \frac{A_{QCM}}{4\pi \cdot d^2_{HW->QCM}}$$

Simple Configurations

- Hot Wall
  - Chamber Characterization
- Cold Wall
- Vented Cavity

- Chamber and hardware are isothermal
- Cold surfaces and pump effective area are small (or baffled)
  - When molecules are well mixed (many bounces) before reaching a cold surface, the ratio of areas gives the statistical viewfactor



$$VF_{HW->QCM} = \frac{A_{QCM}}{A_{QCM} + A_{Pump} + A_{Other}}$$

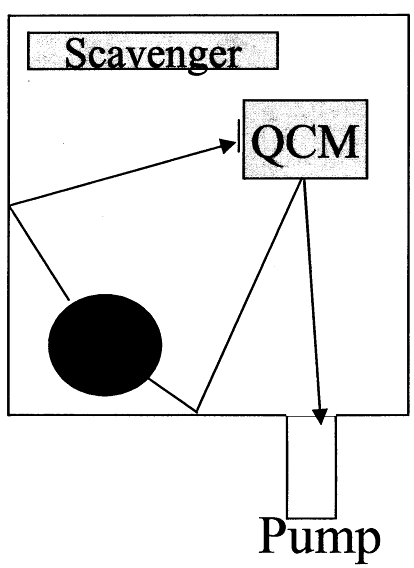
Effective Pump Area

- Hot Wall
  - Chamber Characterization
- Cold Wall
- Vented Cavity

$$VF_{HW->QCM} = \frac{A_{QCM}}{A_{QCM} + A_{Pump} + A_{Other}}$$

$$\frac{OGR_{HW} \cdot A_{HW} \cdot VF_{HW->QCM}}{A_{QCM}} = DPR_{QCM}$$

- Solve for unknowns: $OGR_{chamber}$, A_{pump}
  - Two equations required
    - Achieve a stable QCM reading
    - Then activate the cold finger or scavenger plate
- Pump effective area is a function of the ratio of before and after rates

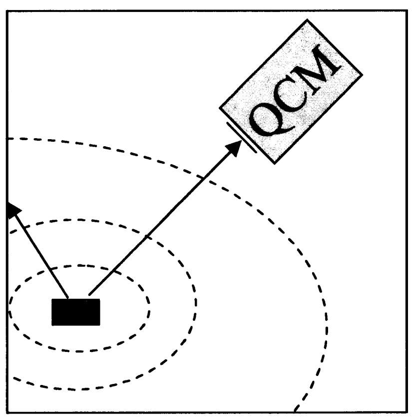


$$\frac{Rate_{NoScavenger}}{Rate_{WithScavenger}} = \frac{A_{QCM} + A_{Pump} + A_{Scavenger}}{A_{QCM} + A_{Pump}}$$

$$A_{Pump} \approx \frac{A_{Scavenger}}{Ratio - 1}$$

Simple Configurations

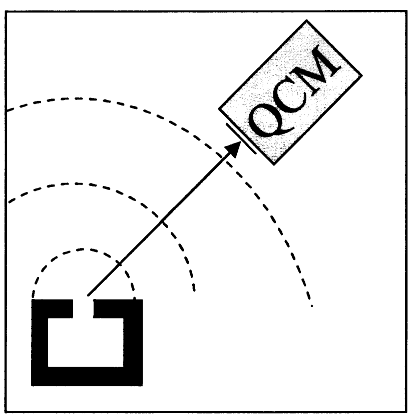
- Hot Wall
  - Chamber characterization
- Cold Wall
- Cold Wall, Vented Cavity



- Chamber wall is colder than the QCM
- The hardware item is relatively uniform
  - No vents, lubricated mechanisms, etc
- Item is either small (size < distance to QCM) or has a simple shape
  - Small items can use the ideal formula
  - Radiation viewfactor formulas have been tabulated for simple shapes (plate to plate, cylinder to plate, etc)

Simple Configurations

- Hot Wall
  - Chamber characterization
- Cold Wall
- Cold Wall, Vented Cavity



- Chamber wall is colder than the QCM
- Primary outgassing source is inside a cavity with one vent
- The QCM faces the vent
- Vent is small enough to treat as a point source
  - Diameter << distance to QCM
- Assume molecules exiting the vent are uniformly distributed over a hemisphere
  - Not the end of a tube

$$VF_{HW->QCM} = \frac{A_{QCM}}{2\pi \cdot d^2_{HW->QCM}}$$

Test Boxes

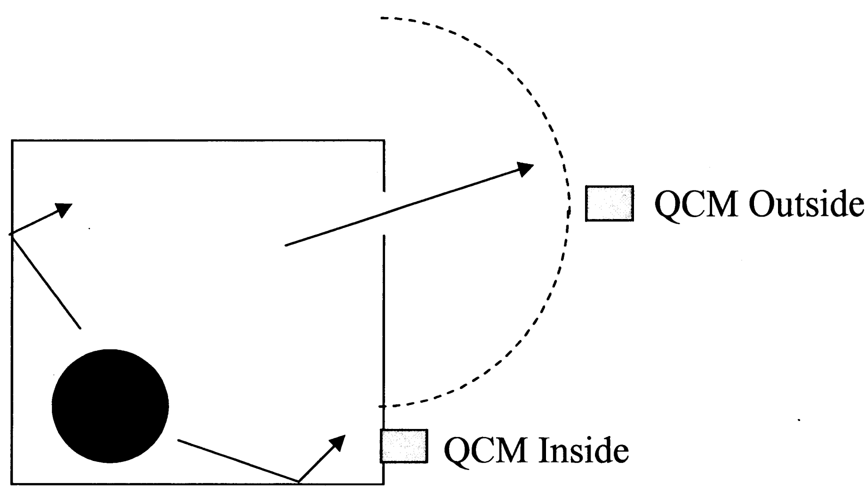
- Description
- Test Box w/ Cold Wall
- Test Box w/ Hot Wall

- We may create a near ideal situation by using an enclosure around the hardware
- Test box may be much cleaner than the chamber
- Specify that a test box is required in the test plan
  - Test phases may incorporate changing the vent area
  - Test box may have a coldfinger installed inside

Test Boxes

- Description
- Test Box w/ Cold Wall
- Test Box w/ Hot Wall

- QCM inside the box
  - Hot Wall equation applies
  - Use the box vent area as the chamber pump area
- QCM outside the box
  - Vented Cavity equation applies

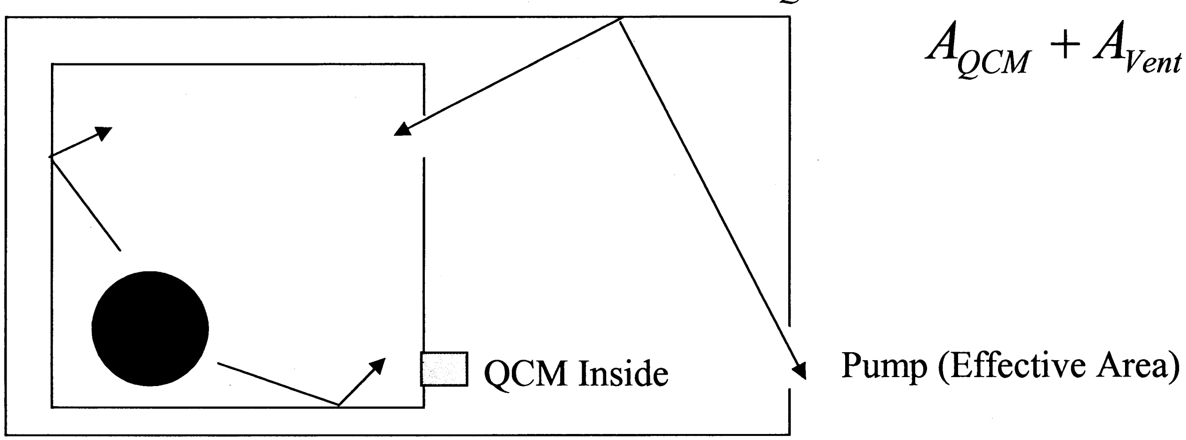


Test Boxes

- Description
- Test Box w/ Cold Wall
- Test Box w/ Hot Wall

- QCM must be inside the box
  - Adjustment of Hot Wall equation
- Random walk causes some molecules to re-enter the box
  - The portion re-entering is A_vent/(A_pump+A_vent)
  - This fraction is used to reduce the effective area of the vent

$$VF_{HW->QCM} = \frac{A_{QCM}}{A_{QCM} + A_{Vent} \cdot \left[1 - A_{Vent} / (A_{Vent} + A_{Pump})\right]}$$



Viewfactor Summary

- Hot Wall $$VF_{HW->QCM} = \frac{A_{QCM}}{A_{QCM} + A_{Pump} + A_{Other}}$$
- Ideal Cold Wall $$VF_{HW->QCM} = \frac{A_{QCM}}{4\pi \cdot d^2_{HW->QCM}}$$
- Vented Cavity $$VF_{HW->QCM} = \frac{A_{QCM}}{2\pi \cdot d^2_{HW->QCM}}$$
- Test Box, Hot Wall $$VF_{HW->QCM} = \frac{A_{QCM}}{A_{QCM} + A_{Vent} \cdot \left[1 - {A_{Vent}}\Big/{(A_{Vent} + A_{Pump})}\right]}$$

$$\frac{OGR_{HW} \cdot A_{HW} \cdot VF_{HW->QCM}}{A_{QCM}} = DPR_{QCM}$$

Data

- Interpreting the QCM data can be tricky
  - Often we see patterns that don't make sense at first
  - Sometimes the data acquisition process is at fault, sometimes there is a physical explanation
- Plotting the data in Excel and curve fitting is always a good idea
  - Closer samples (2 minutes vs hourly) help diagnose problems
  - Overlay temperature data for the shroud, hardware, and QCM

Data

- Hourly Data
- Averaging

Time	Freq	Delta	Delta Delta	Shroud	Hardware
1:00	2787			30.1	46.2
2:00	2904	117		30.0	46.2
3:00	3010	106	-11	30.1	46.5
4:00	3108	98	-8	30.0	46.4
5:00	3200	92	-6	30.2	46.3
6:00	3220	20	-72	30.0	35.1
7:00	3225	5	-15	30.1	30.4

- Reported as
  - Frequency in Hz
  - Delta in Hz/hr
  - Delta Delta in Hz/hr/hr
  - Temperature in Celsius
- The rate (Delta) and derivative (Delta Delta) are backwards difference
  - Delta Delta depends on 3 hours of data
  - Make sure the temperatures are the same at each time step involved
    - Hardware
    - QCM
    - Coldfinger
    - Scavenger plate

Data

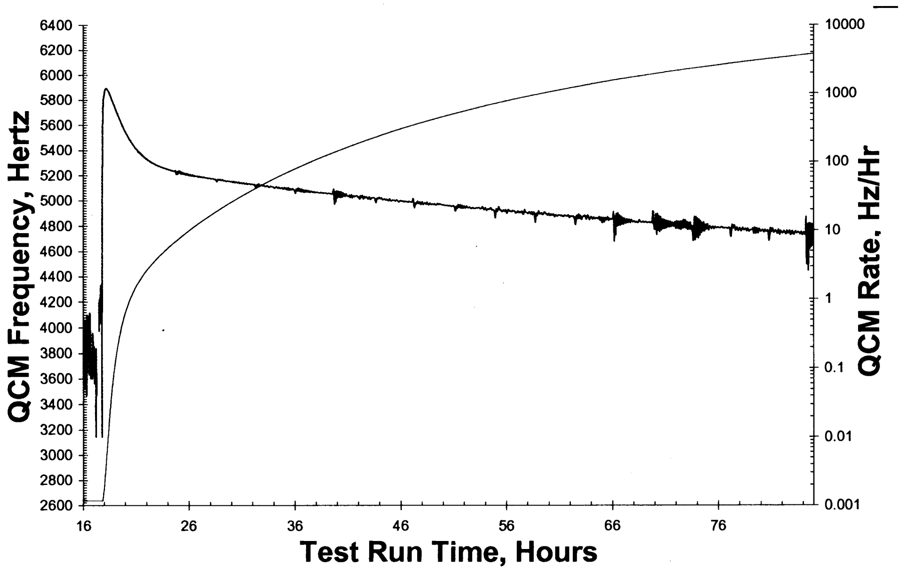
- Hourly Data
- Averaging

Spurious data points may appear because of temperature effects. Looking at higher resolution data helps to eliminate these points.

- Averaging removes random noise
  - Temperature fluctuations
  - Electrical noise
- How long depends on purpose
  - Certification
    - 8 hour average
    - Delta
  - Point of diminishing returns
    - 5 hour average
    - Delta Delta
    - Delta Delta as percent of Delta
  - Readings near limit of detection
    - Collect until total frequency change of 10 Hz

Data

- Nominal
- Problems



- In some cases, simply meeting a pre-determined QCM rate is sufficient to declare success
- If the background is non-negligible, or the rate is changing significantly, analysis of the data may be required
  - Enough background data must be collected to make statistically valid predictions
  - Curve fit the rate (Delta) vs. test hour
    - Exponential
    - Power Law

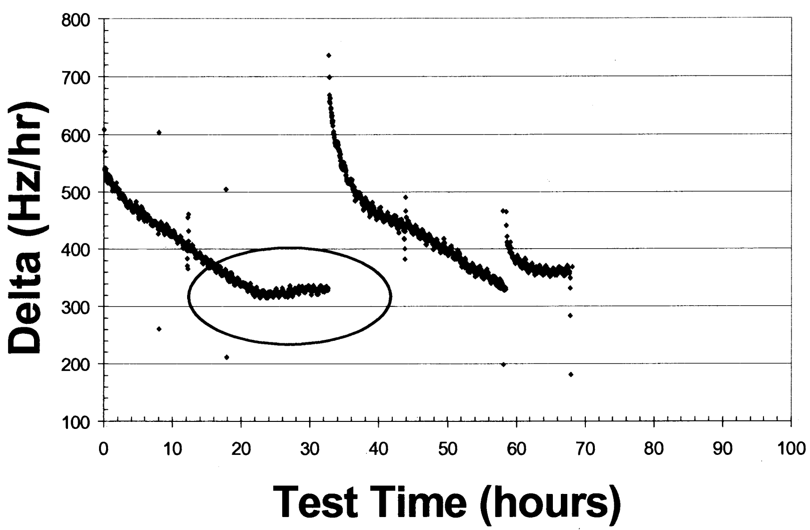
Data

- The QCM data includes artifacts
  - Jumps due to crystal stress relaxation
  - Frequency change due to thermal inputs
  - Data collection errors (repeated numbers, clipping of large values)
  - Failure to bake off the QCM
    - Between hardware temperature changes (which can change the species being outgassed)
    - When saturation occurs (15000-30000 Hz)
- QCM failure
  - Sometimes the crystal or controller fails and stops giving accurate frequency output
- Clues that data is bad
  - Sudden changes in QCM frequency
  - Behavior that can not be explained by the physics of outgassing
  - Repeated (flat line) values

Crystal Saturation

- Nominal
- Problems
  - Examples

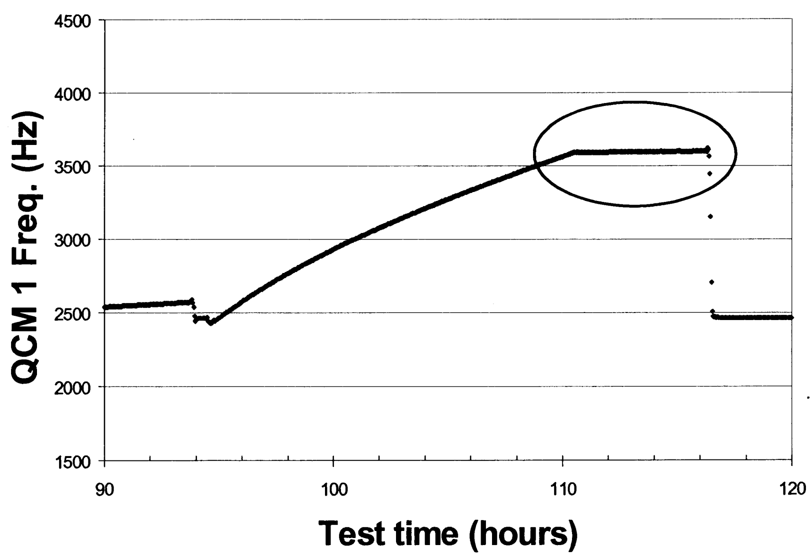
- QCM rate should decrease over time
  - Non-physical behavior was observed
  - Baking off the QCM corrected the behavior



Crystal Failure

- Nominal
- Problems
  - Examples

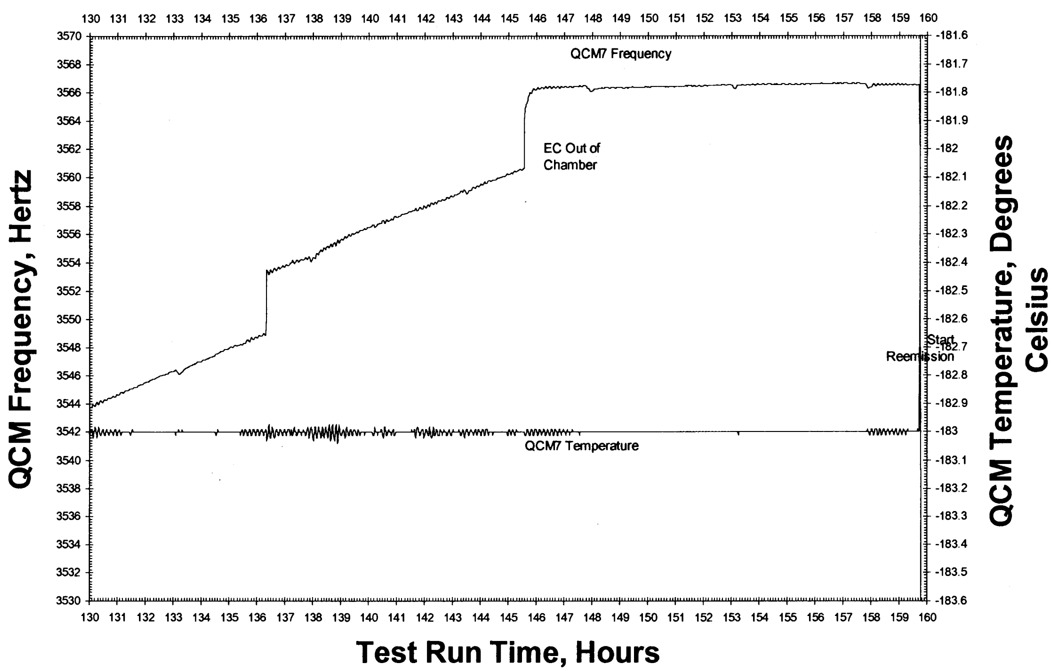
- Frequency should increase over time
  - Data showed identical values
  - After baking off the frequency did not increase
  - The QCM was replaced



Crystal Shift

- Nominal
- Problems
  - Examples

- Frequency should not jump instantaneously
  - Jump in frequency occurred over a single two minute data interval
  - Rate before and after jump was consistent



Generate Requirements

- Hot Wall Requirements
- Plot of QCM Rates
- Synchronizing Rates
- Analyzing the Data
- The Wrong Way

- Actual test of hardware
- Spreadsheet used with hot wall formula to derive QCM requirement
  - 1.56e-9 g/cm^2/hr outgassing
  - 3.6 hz/hr deposition

					uncertainty
A	Flight outgassing area total	21434	cm2		10%
B	Required surface rate	1.56E-09	g/cm2/hr		
C	Total Outgassing (A*B)	3.34E-05	g/hr		10%
D	25% margin (C*0.25)	2.34E-06	g/hr		
E	Requirement (C-D)	3.11E-05	g/hr		10%
F	Chamber Effective Pump Area	4440	cm2	With out scavenger plate	25%
G	QCM Crystal Area	1.27	cm2	QCM Research 15 MHz	5%
H	QCM "viewfactor" (G/(F+G))	0.000285			30%
I	Impingement on QCM (E*H)	8.87E-09	g/hr		40%
J	Deposition on QCM (I/G)	7.00E-09	g/cm2/hr		45%
K	QCM conversion factor	1.96E-09	g/cm2/hz	QCM Research 15 MHz	
L	QCM Requirement (J/K)	**3.6**	hz/hr		45%

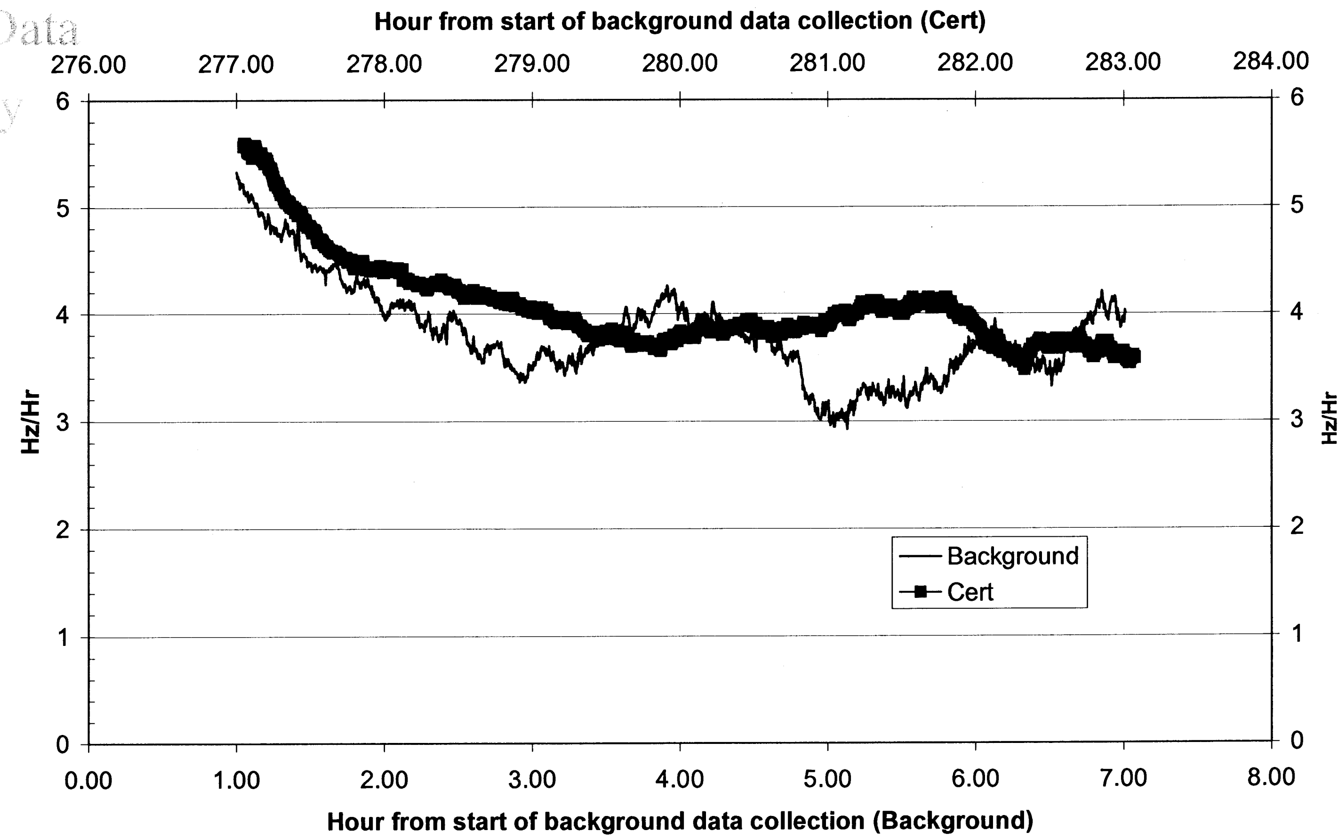
Theory
Instrumentation
Requirements
Configuration
Data
Error Analysis

Data Format
Analysis
Example

Collect Data

- Hot Wall Requirements
- Plot of QCM Rates
- Synchronizing Rates
- Analyzing the Data
- The Wrong Way

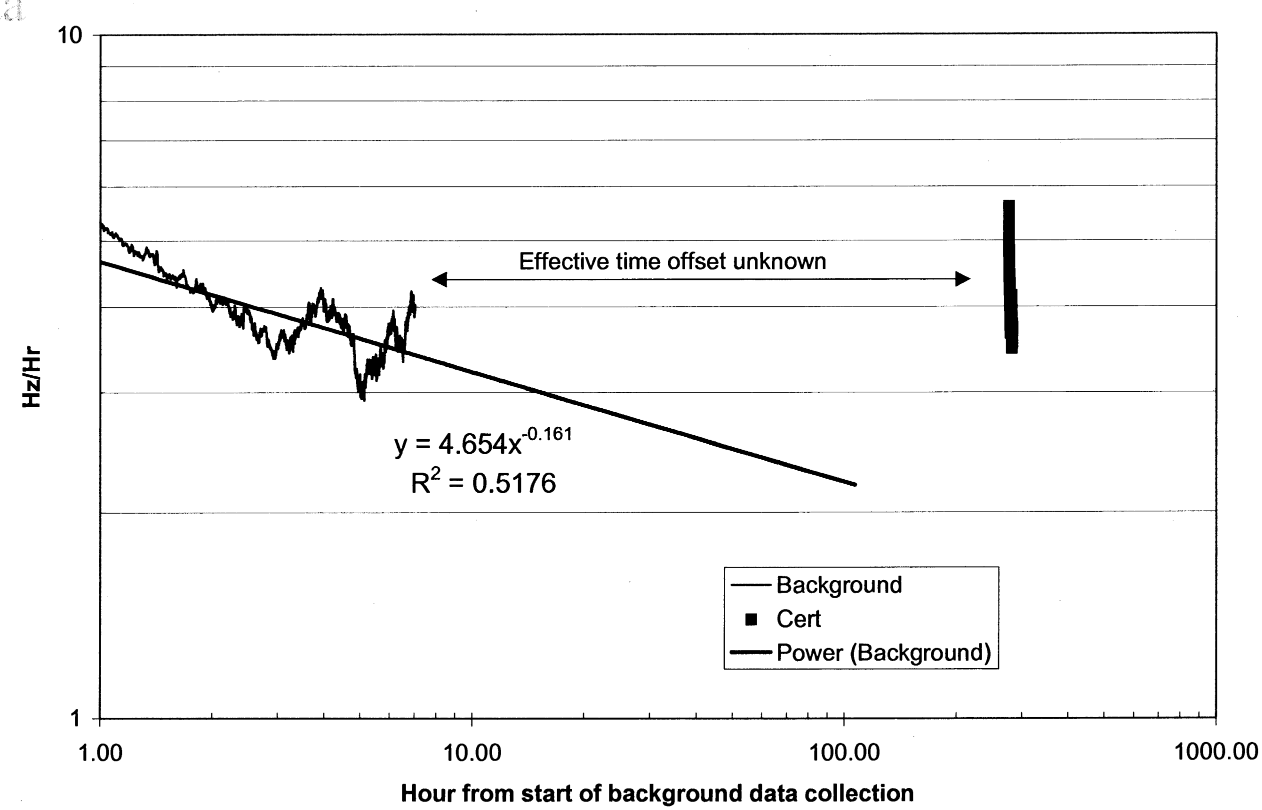
- Data aligned to superimpose time under vacuum for background and certification



Plot Data

- Hot Wall Requirements
- Plot of QCM Rates
- Synchronizing Rates
- Analyzing the Data
- The Wrong Way

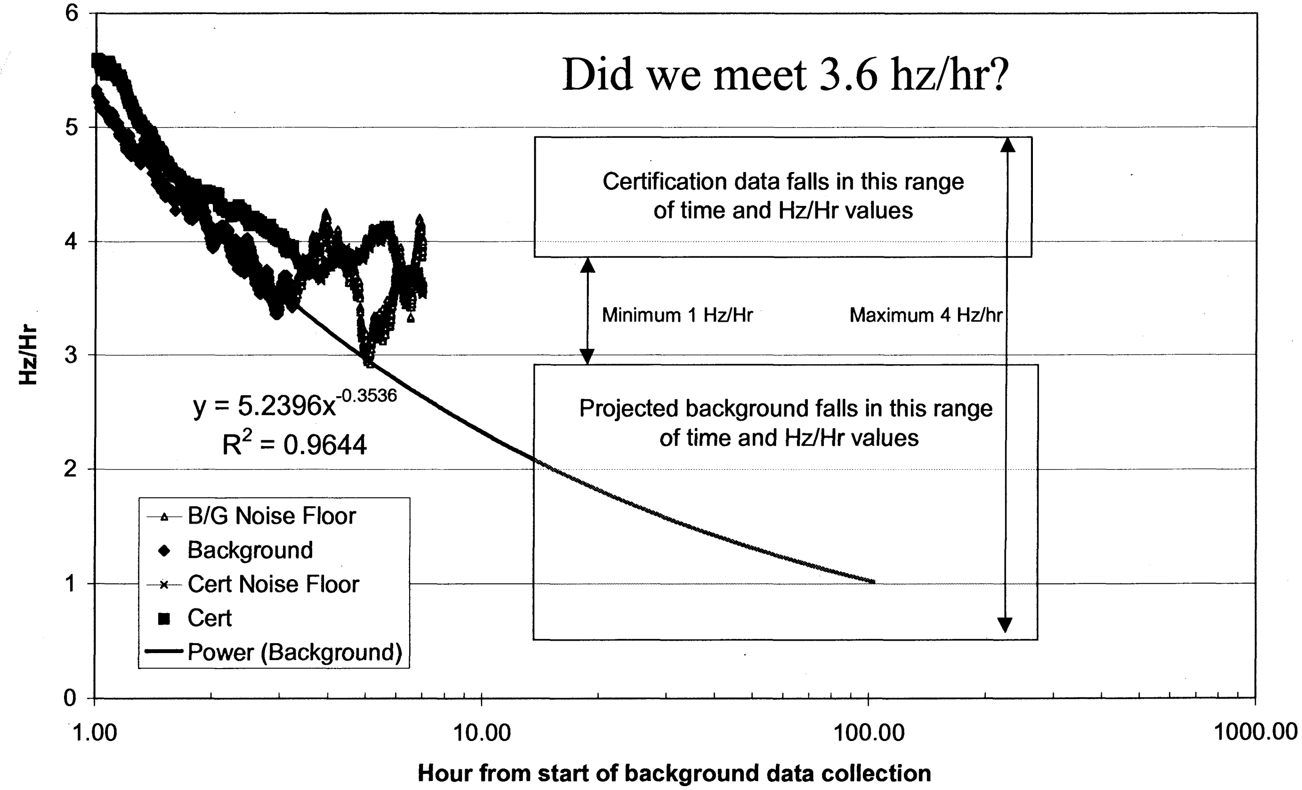
- Data aligned to show time under vacuum for chamber
- Chamber background outgassing was accelerated by bakeout



Data

- Hot Wall Requirements
- Plot of QCM Rates
- Synchronizing Rates
- Analyzing the Data
- The Wrong Way

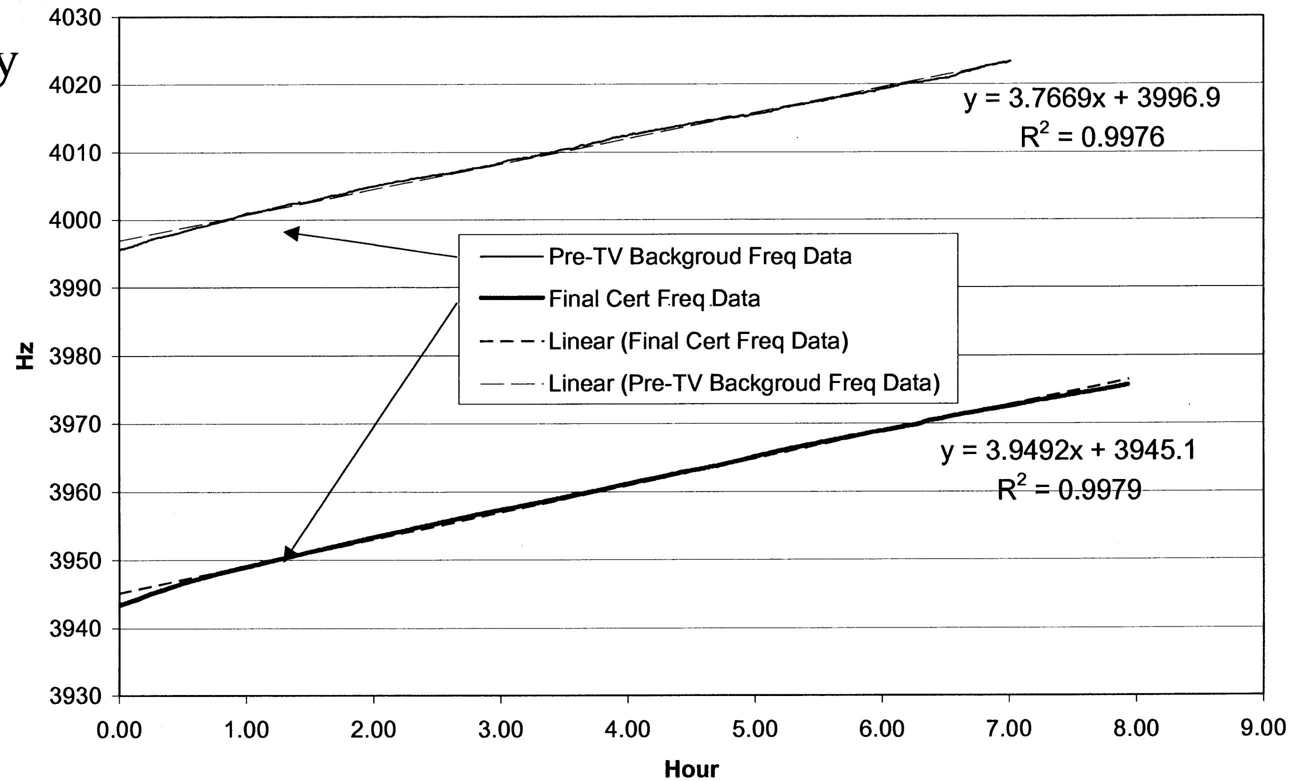
- Observation of sinusoidal behavior provides noise floor
- Exponential decay for surface outgassing of chamber extrapolated to certification time



Data

- Hot Wall Requirements
- Plot of QCM Rates
- Synchronizing Rates
- Analyzing the Data
- The Wrong Way

- Non-contamination engineer's approach
  - Curve fit frequency with straight line
  - Compare the slopes directly
- 3.9 - 3.7 = 0.2 hz/hr … Easily met criteria!



Error Analysis

- Error analysis is the mathematical study of how random errors in the value of variables (measurements) affects the answer given by a formula
- Good reference text
  - "An introduction to error analysis", Taylor, J.

Error Analysis

- Why Use Error Analysis
- How To Perform
- Example Spreadsheet
- Plot With Error Bounds

- In the case where the results are well within specification, it may not be necessary
- Where the results of the test are close to the requirement, it is useful to know if the error in the reported outgassing rate is sufficient to cause failure to certify
- Extrapolation over long periods of time increases the effect of small errors
  - Important for chamber backgrounds because the limited source may be rapidly depleted
  - Very important when extrapolating a decaying rate measured over days to on-orbit time scales of years

Error Analysis

- Why Use Error Analysis
- How To Perform
- Example Spreadsheet
- Plot With Error Bounds

$$A = \frac{\sum X^2 \sum Y - \sum X \sum XY}{N\sum X^2 - \left(\sum X\right)^2}$$

$$B = \frac{N\sum XY - \sum X \sum Y}{N\sum X^2 - \left(\sum X\right)^2}$$

- The representative outgassing equation and viewfactor equation (if used) must be analyzed first to determine the error equations
  - Convert to linear form (Y = AX + B) by working in logarithms
  - y=(a)x^b
  - log(y) = log(a)+(b)log(x)
  - Y: log(y), X: log(x)
  - A: b, B: log(a)
- A spreadsheet of the data can be constructed using the derived error equations
  - Least squares solution uses Excel functions SUM, SUMSQ and SUMPRODUCT
- The error bounds can be plotted over the data

$$\sigma_Y = \sqrt{\frac{1}{N-2}\sum_{i=1}^{N}\left(Y_i - A - Bx_i\right)^2}$$

$$\sigma_A = \sigma_Y \sqrt{\frac{\sum x^2}{N\sum X^2 - \left(\sum X\right)^2}}$$

$$\sigma_B = \sigma_Y \sqrt{\frac{N}{N\sum X^2 - \left(\sum X\right)^2}}$$

Error Analysis

- Why Use Error Analysis
- How To Perform
- **Example Spreadsheet**
- Plot With Error Bounds

- Data taken early in the test
  - Stronger response vs time for power law
  - Lower uncertainty
- Data taken later
  - As asymptote is approached
  - More uncertainty for same data gathering length

OGR = A * t^(-b)
(time in hours by convention)

	measured or calculated value	sigma (errc	units	sigma/value
A	10.42866	0.51608	g/s	4.9%
-b	-0.133188	0.02512		19%
QCM Temp	233.15	0	K	0%
Src Temp	371.946	0.153867	K	0%
future time	20	1	hr	5%
future rate	6.997573	0.63197	g/s	9% ←

OGR = A * t^(-b)
(time in hours by convention)

	measured or calculated value	sigma (errc	units	sigma/value
A	10.60813	1.506953	g/s	14.2%
-b	-0.138984	0.055756		40%
QCM Temp	233.15	0	K	0%
Src Temp	371.9471	0.152869	K	0%
future time	20	1	hr	5%
future rate	6.995461	1.534665	g/s	22%

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Error Analysis

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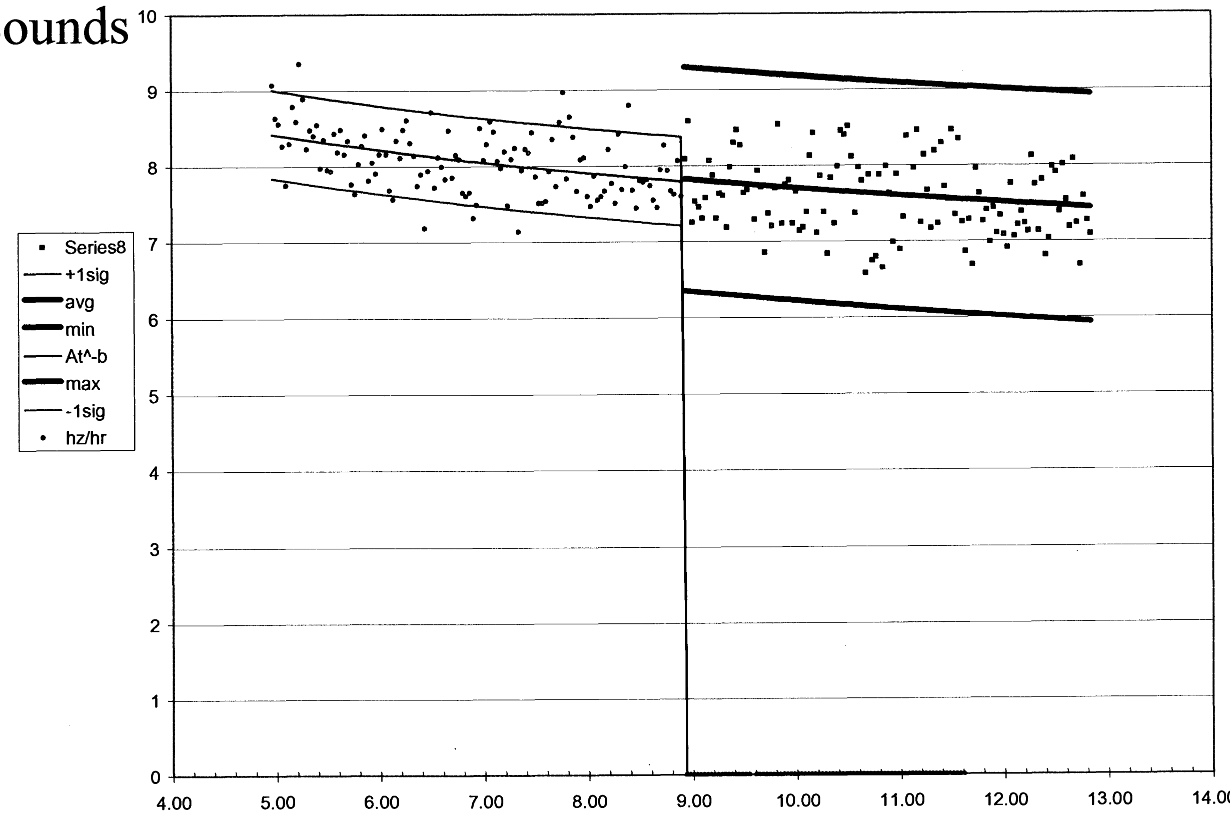
Error Analysis

- Why Use Error Analysis
- How To Perform
- Example Spreadsheet
- Plot With Error Bounds

- Note that the fit equation came out the same, but the error bounds differ depending on when the data was collected



Summary

- Chamber configuration determines the relationship between hardware outgassing and the QCM reading
- Except in simple, clear cut cases, QCM data should be carefully analyzed before presenting the interpretation to the project
- Error analysis may be required in some cases