

Contamination Control

Materials and Processes Division

Materials Physics and Chemistry Section

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Presentation Outline

- **Why Contamination Control?**
- **Contamination Types**
- **Contamination Requirements**
- **Interactions**
- **Contamination Control Process**
- **Materials Selection**
- **Effects of Contamination**
- **Case Studies**

Why Contamination Control?

Contamination has caused a large number of problems with satellites including:

- Degradation of satellite power
- Degradation of thermal control surfaces
- Electro-static discharge effects
- Degradation of optical systems
- Noise in electrical contacts
- Failure of precision mechanisms

Hence we must understand what the contaminants are, how much contamination we have and how the contamination will effect the functioning of the satellite or satellite subsystem

Furthermore, once a satellite is launched it is usually impossible to repair in orbit.

Contamination Sources

Definition:

“Any unwanted molecular or particulate matter on, or in a material, component, or Environment, that can lead to a degradation in the functional performance of the material or component or environment”



**People/Clothing/
Materials**



Machining



Thrusters/Pyro-valves/Wire cutters

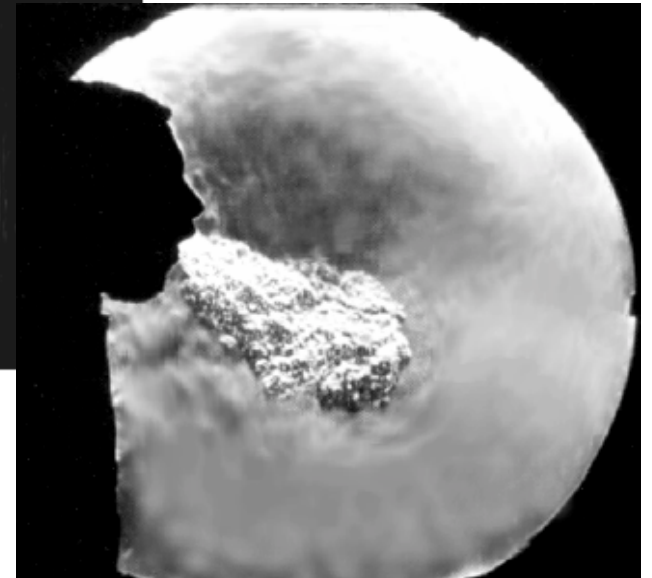


Working Activities/Soldering



Vacuum Testing

Human Contamination



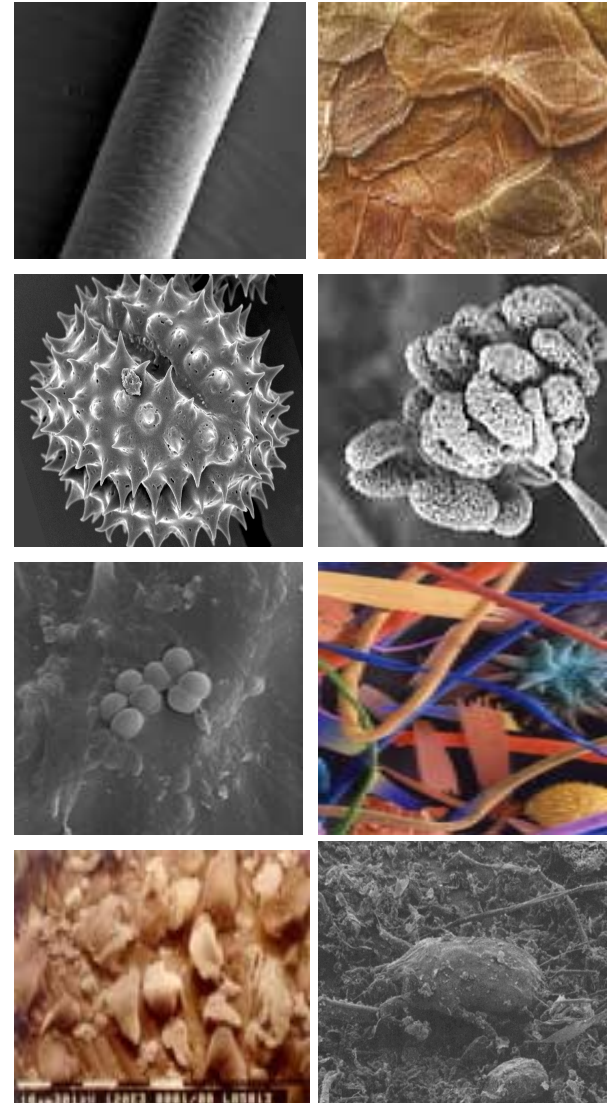
Common Particulate Contaminants

Contaminant Type	Size (μm)
Human hair	70-100
Human skin flakes	0.4-10
Pollen	5-100
Mold	2-20
Smoke	0.01-1
House dust	0.05-100
Bacteria	0.25-10

Sizes of a number of common cleanroom contaminants

Activity	Rate ($>0.3\mu\text{m}/\text{min}$)
Motionless/Sitting/Standing	100,000
Head/Arm/Neck/Leg motion	500,000
All above with foot motion	1,000,000
Standing to Sitting Position	2,500,000
Walking (2 mph)	5,000,000
Walking (3.5 mph)	7,500,000
Walking (5 mph)	10,000,000

Particle generation rates for a number of human activities



Contamination Requirements - Particulate

Airborne Particulate

*FED-STD-209 “Airborne Particulate Cleanliness Classes in Cleanrooms and Clean Zones”

ISO-14644-1 “Cleanrooms and associated controlled Environments”

ECSS-Q-70-01A “Cleanliness and Contamination Control”

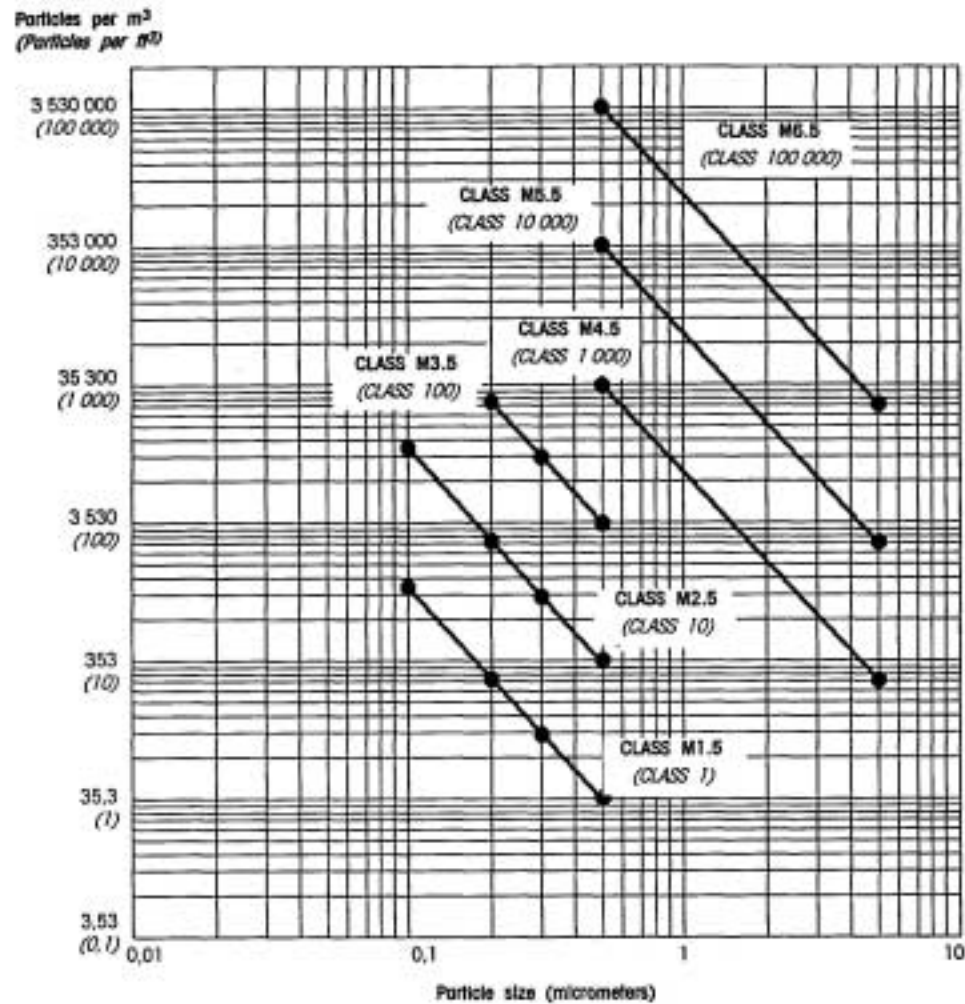
Surface Particulate

MIL-STD-1246C “Product Cleanliness levels and Contamination Control Programme”

ECSS-Q-70-01A “Cleanliness and Contamination Control”

*Note: now superceded

FED-STD-209E



FED-STD-209E

**Table F-1: Airborne particulate cleanliness classes
(taken from FED-STD-209E)**

Class Name		Class Limits									
		0,1 μm		0,2 μm		0,3 μm		0,5 μm		5 μm	
		Volume Units		Volume Units		Volume Units		Volume Units		Volume Units	
Metric Class	Old Class	m^3	ft^3	m^3	ft^3	m^3	ft^3	m^3	ft^3	m^3	ft^3
M1		350	9,91	75,7	2,14	30,9	0,875	10	0,283	-	-
M1,5	1	1 240	35	265	7,5	106	3	35,3	1	-	-
M2		3 500	99,10	757	21,4	309	8,75	100	2,83	-	-
M2,5	10	12 400	350	2 650	75	1 060	30	353	10	-	-
M3		35 000	991	7 570	214	3 090	87,5	1 000	28,3	-	-
M3,5	100	-	-	26 500	750	10 600	300	3 530	100	-	-
M4		-	-	75 700	2 140	30 900	875	10 000	283	-	-
M4,5	1 000	-	-	-	-	-	-	35 300	1 000	247	7
M5		-	-	-	-	-	-	100 000	2 830	618	17,5
M5,5	10 000	-	-	-	-	-	-	353 000	10 000	2 470	70
M6		-	-	-	-	-	-	1 000 000	28 300	6 180	175
M6,5	100 000	-	-	-	-	-	-	3 530 000	100 000	24 700	700
M7		-	-	-	-	-	-	10 000 000	283 000	61 800	1 750

ISO 14644 1

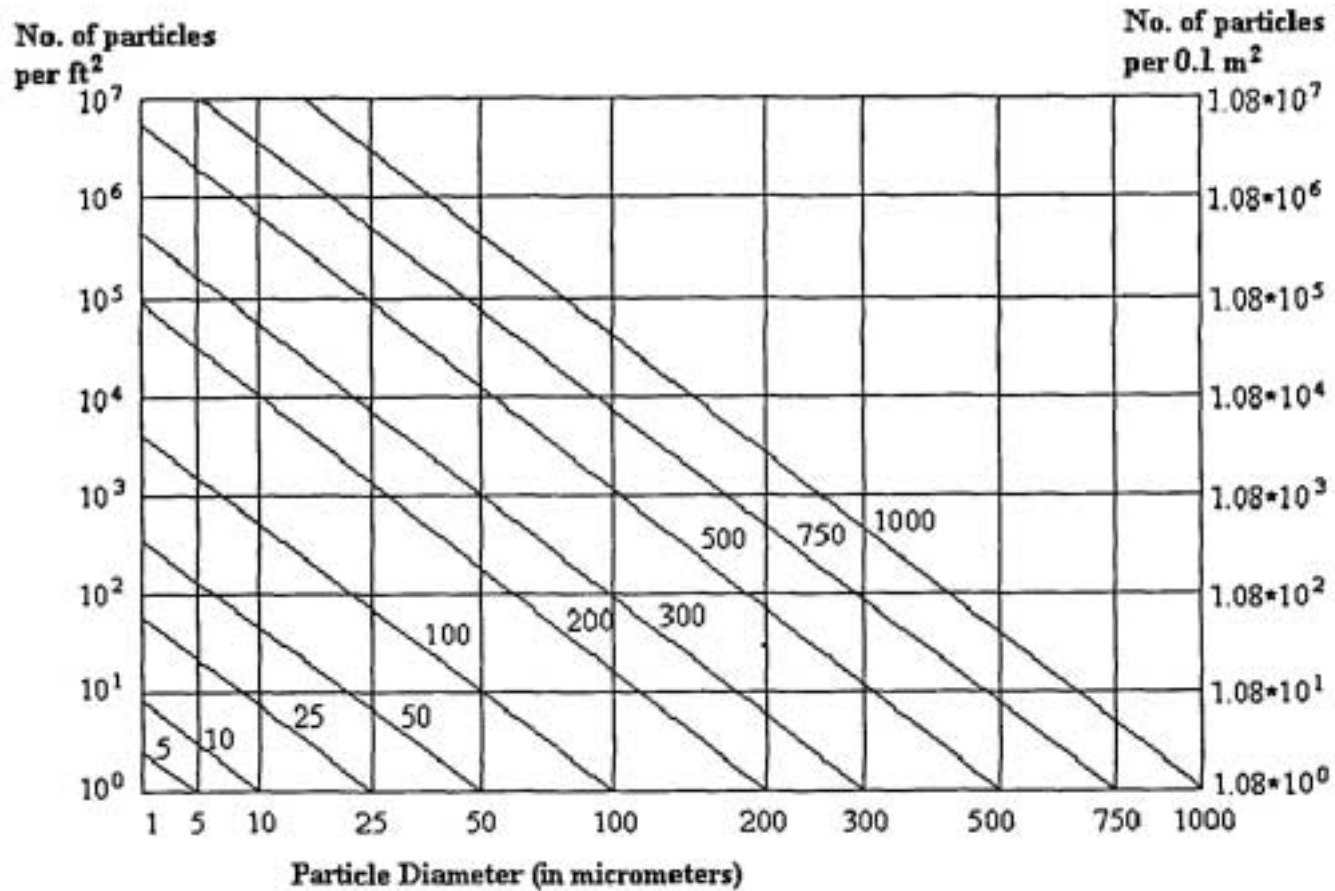
Table 1 — Selected airborne particulate cleanliness classes for cleanrooms and clean zones

ISO classification number (N)	Maximum concentration limits (particles/m ³ of air) for particles equal to and larger than the considered sizes shown below (concentration limits are calculated in accordance with equation (1) in 3.2)					
	0,1 μm	0,2 μm	0,3 μm	0,5 μm	1 μm	5 μm
ISO Class 1	10	2				
ISO Class 2	100	24	10	4		
ISO Class 3	1 000	237	102	35	8	
ISO Class 4	10 000	2 370	1 020	352	83	
ISO Class 5	100 000	23 700	10 200	3 520	832	29
ISO Class 6	1 000 000	237 000	102 000	35 200	8 320	293
ISO Class 7				352 000	83 200	2 930
ISO Class 8				3 520 000	832 000	29 300
ISO Class 9				35 200 000	8 320 000	293 000

NOTE Uncertainties related to the measurement process require that concentration data with no more than three significant figures be used in determining the classification level

ISO-14644	FED-STD-209	FED-STD-209 Metric
5	Class 100	M3.5
7	Class 10,000	M5.5
8	Class 100,000	M6.5

MIL-STD 1246C



PFO Monitoring



For spacecraft the airborne particulate Contamination is not as important as the particle Fallout contamination

Table F-2: Correlation airborne and PFO for normal clean-rooms

Metric class	PFO (ppm/24 hours)
3,5	1,5
4,5	12
5,5	60
6,5	275

$$\text{PFO} = 0,069 \cdot 10^{(0,72M - 1,08)}$$

where M is the metric numerical class (e.g. 3,5)

or:

$$\text{PFO} = 0,069 \cdot N_c^{0,72}$$

where N_c is the old numerical classification (e.g. 100 or 100 000)

Tape-Lift Testing

Tape lift method as performed at ESTEC:

- Define area which needs to be checked
- Take Polyethylene transparent tape from 3M Scotch 480
- Stick it on a surface of at least 5 x 5 cm
- Take with tweezers the 0.45 micron filter paper with grid
- Apply the filter paper against the just released tape
- Cut excessive tape away
- Count particles by Microscope in different size ranges

See ASTM-E1216-87



Contamination Requirements - Molecular

Organic Contamination

ECSS-Q-70-01A “Cleanliness and Contamination Control”

PSS-01-705 “The detection of organic contamination of surfaces by infrared spectroscopy”

For one week continuous exposure in a cleanroom: $<2.0 \times 10^{-7} \text{gcm}^{-2}$

Exposure in vacuum chamber after blank test of 24hrs: $<1.0 \times 10^{-7} \text{gcm}^{-2}$

Outgassing Requirements

ECSS-Q-70-02 “Thermal vacuum outgassing test for the screening of space materials”

Surface Contamination

MIL-STD-1246C “Product Cleanliness levels and Contamination Control Programme”

Level A/100 till F , which is $0.01 \text{mg}/0.1 \text{m}^2$ up to $25 \text{mg}/0.1 \text{m}^2$

Surface Cleanliness Requirements - Organics

- PSS-01-705 (ECSS-Q-70-05) “The detection of organic contamination of surfaces by infrared spectroscopy”
 - Identification due to specific absorption of the molecule due to vibrations and rotations of atoms
 - Quantification by Lambert/Beers Law relation

$$\text{Abs.} = E * b * C$$

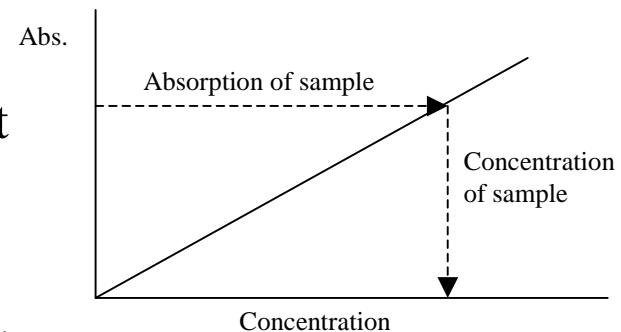
E = Molar Absorption Coefficient

b = Pathlength

C = Concentration

- Calibration curves for four standards

- Paraffin, Di-octylPhthalate ester, Methylsilicone and MethylPhenylsilicone



MIL-STD 1246C

TABLE II. Non-volatile residue cleanliness levels

Level	Limit, NVR mg/0.1m ² * 1/ (or ug/cm ²)	Limit, NVR mg/liter
A/100	0.01	0.1
A/50	0.02	0.2
A/20	0.05	0.5
A/10	0.1	1.0
A/5	0.2	2.0
A/2	0.5	5.0
A	1.0	10.0
B	2.0	20.0
C	3.0	30.0
D	4.0	40.0
E	5.0	50.0
F	7.0	70.0
G	10.0	100.0
H	15.0	150.0
J	25.0	250.0

1/ Limits on non-volatile residue (NVR), mg) for surface, liquid, or gas to meet the level of cleanliness.

* One square foot = 0.0929 m².

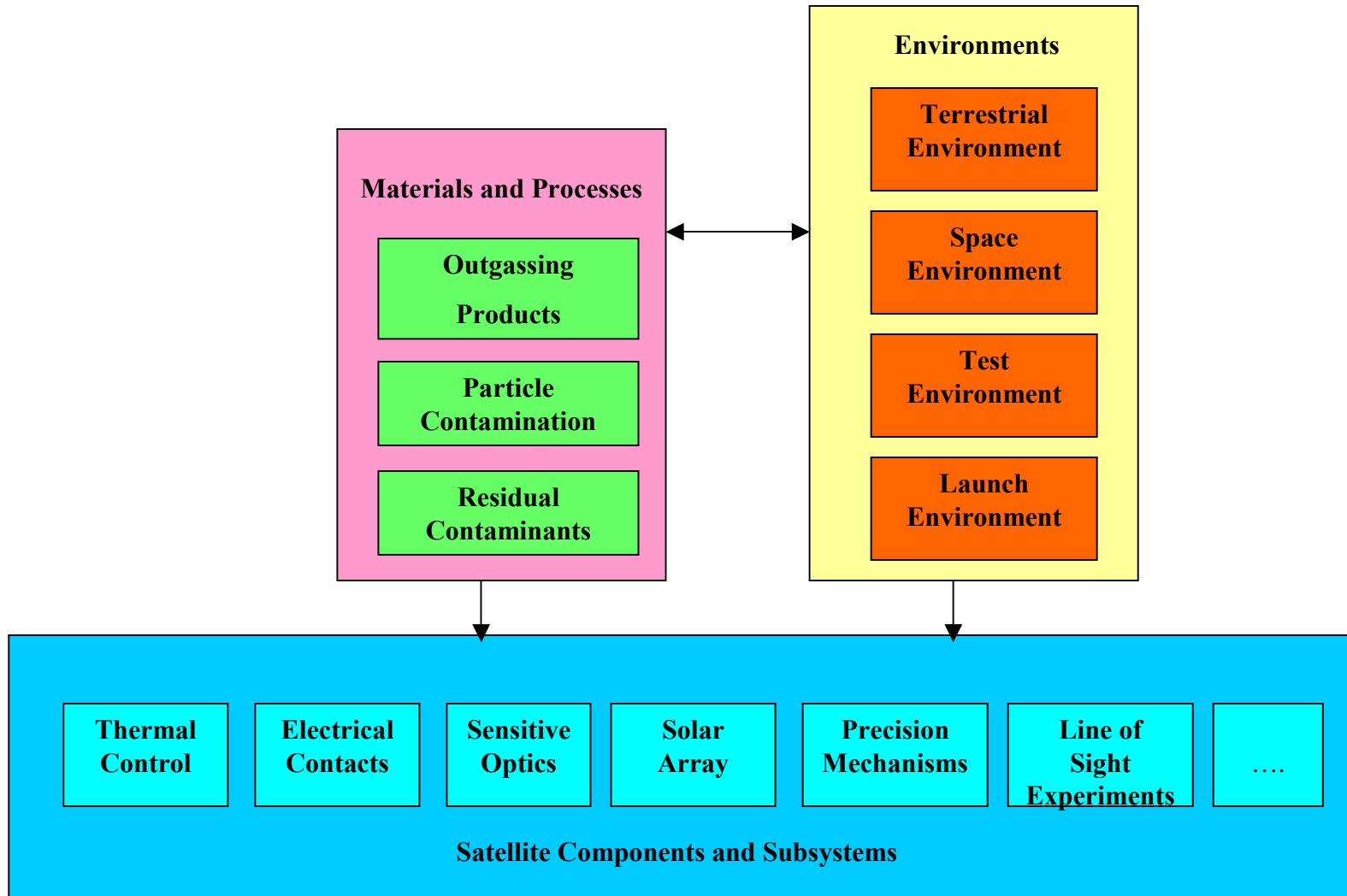
Contamination Monitoring – Use of Witness Samples

Witness samples are often the only practical method of quantifying contamination as they avoid contact (and hence additional risk) with the actual components and are, in this sense non-destructive

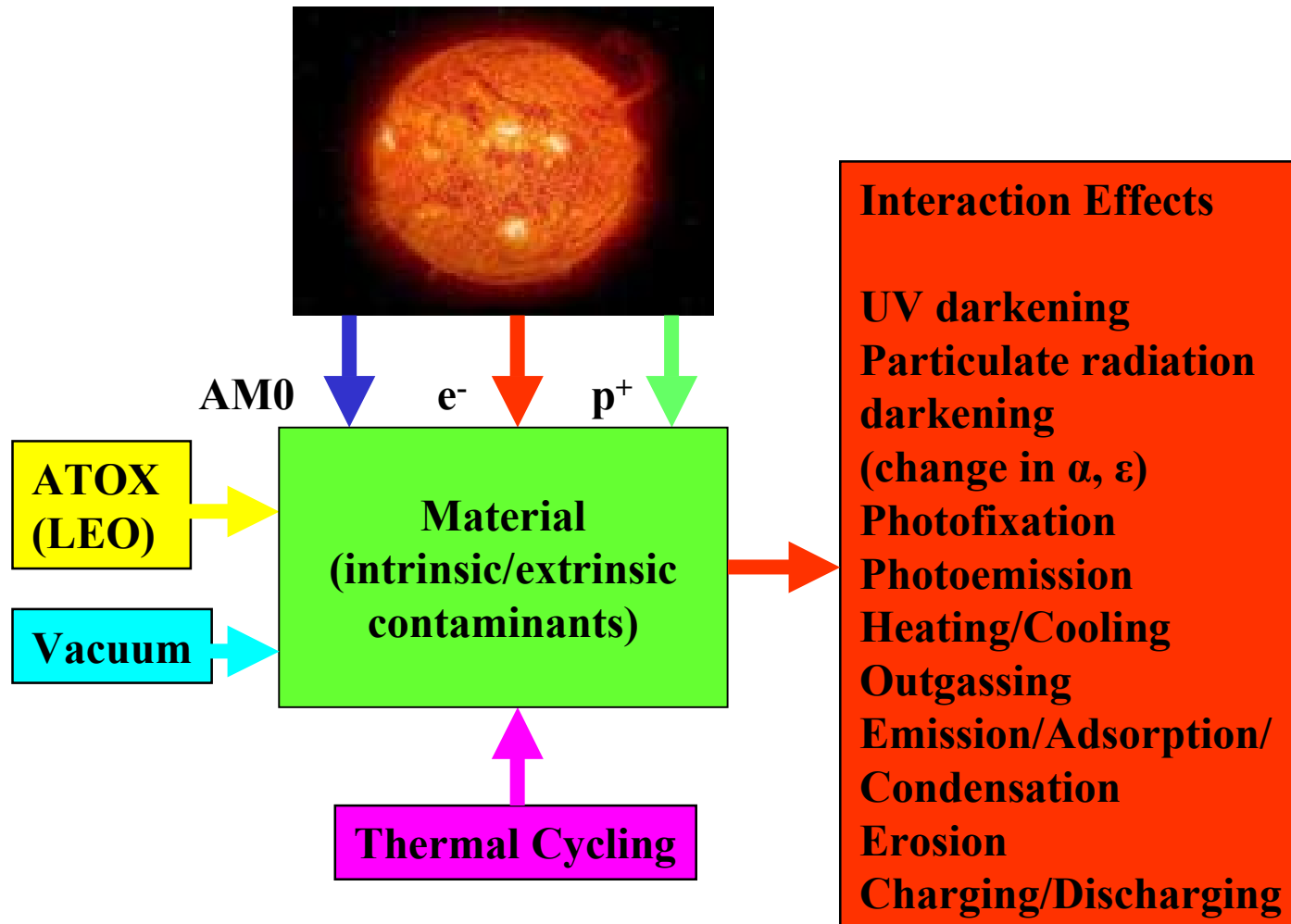
However, if witness sampling is to be used then the following must be considered:

- The witness must be representative of the component it is monitoring
(i.e. exposed in the same environment, same view factor to contamination sources, same orientation, representative material etc.)
- Enough witness samples should be used to make the monitoring statistically valid and to isolate localised events

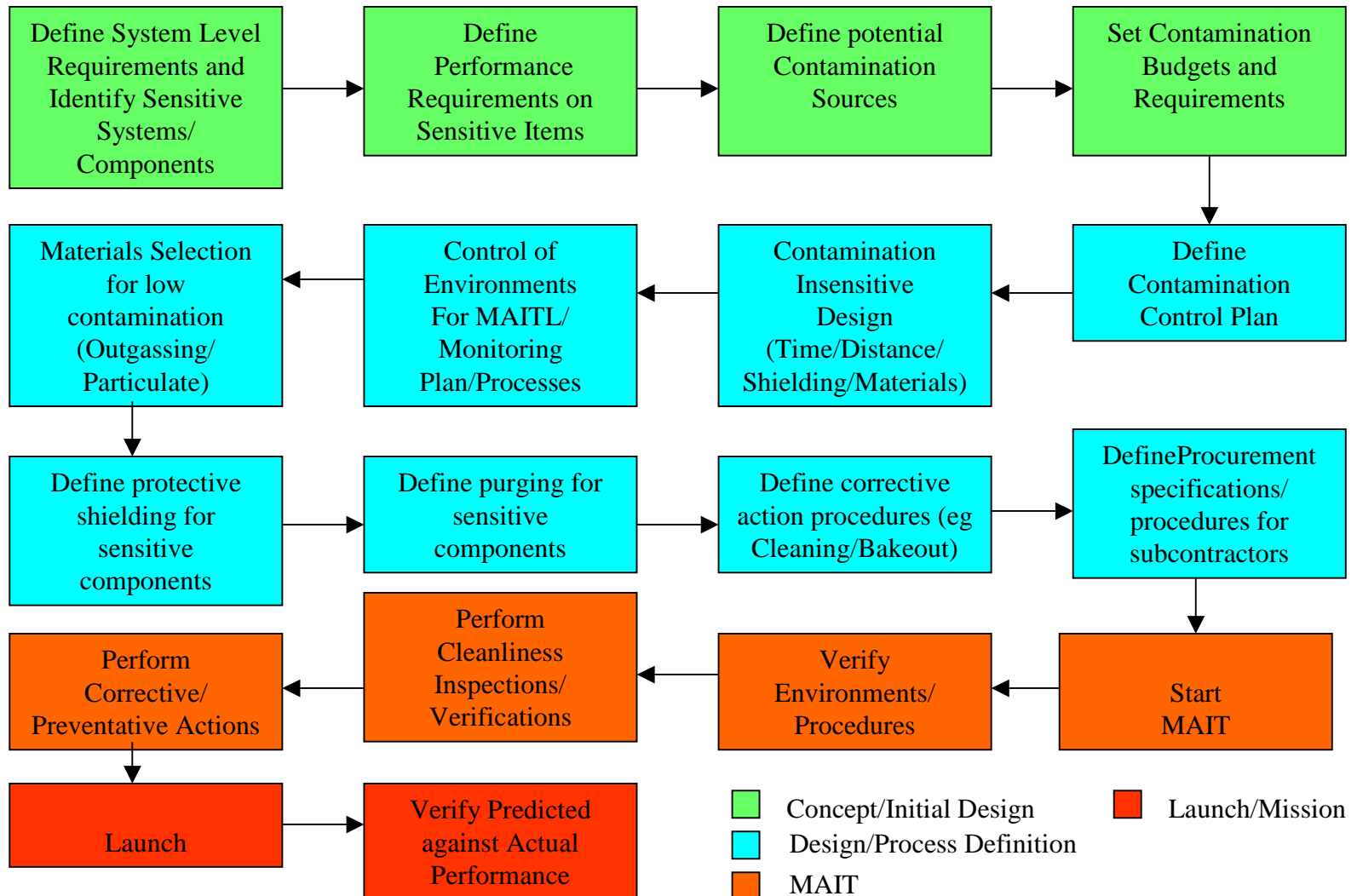
Interactions



Interactions with Space Environment



Contamination Control Process



Materials Selection Criteria

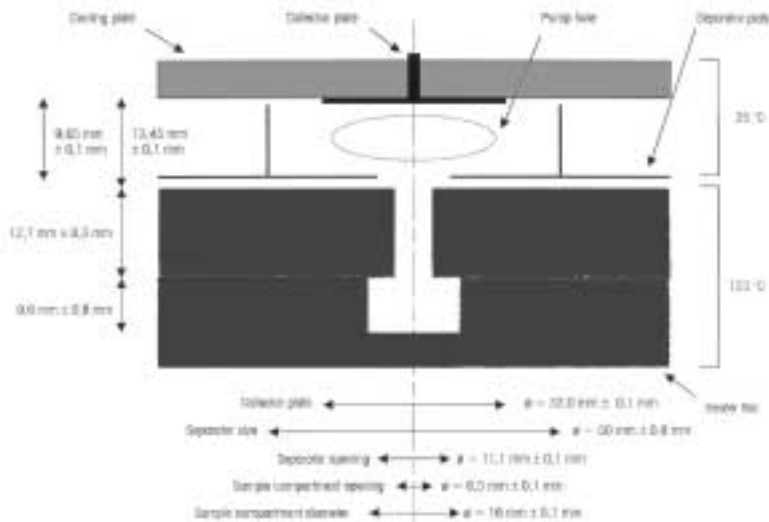
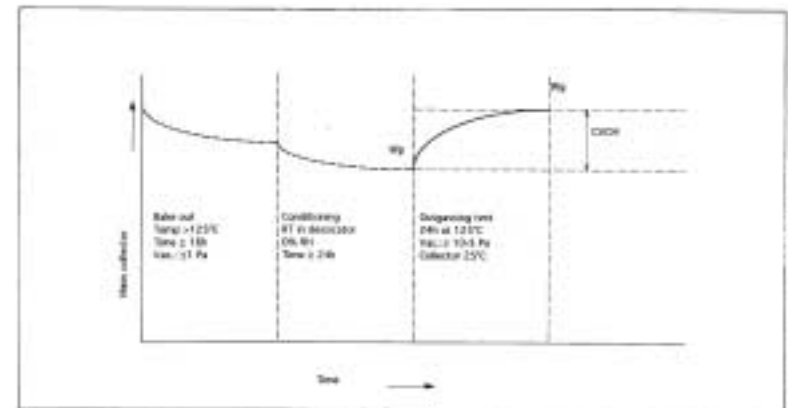
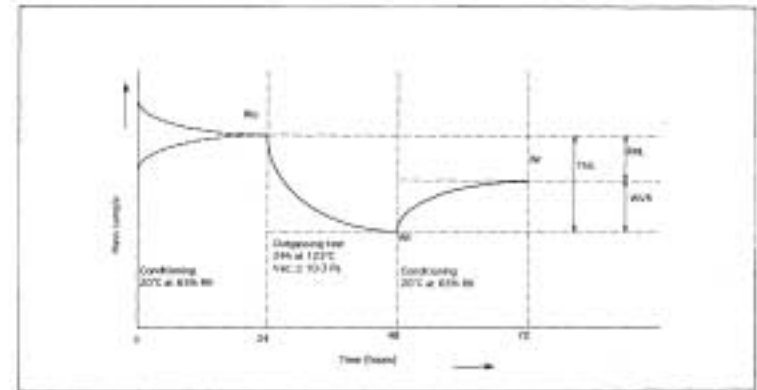
Materials selection is critical for contamination control

For outgassing characteristics the **Micro-VCM test** is used as general control

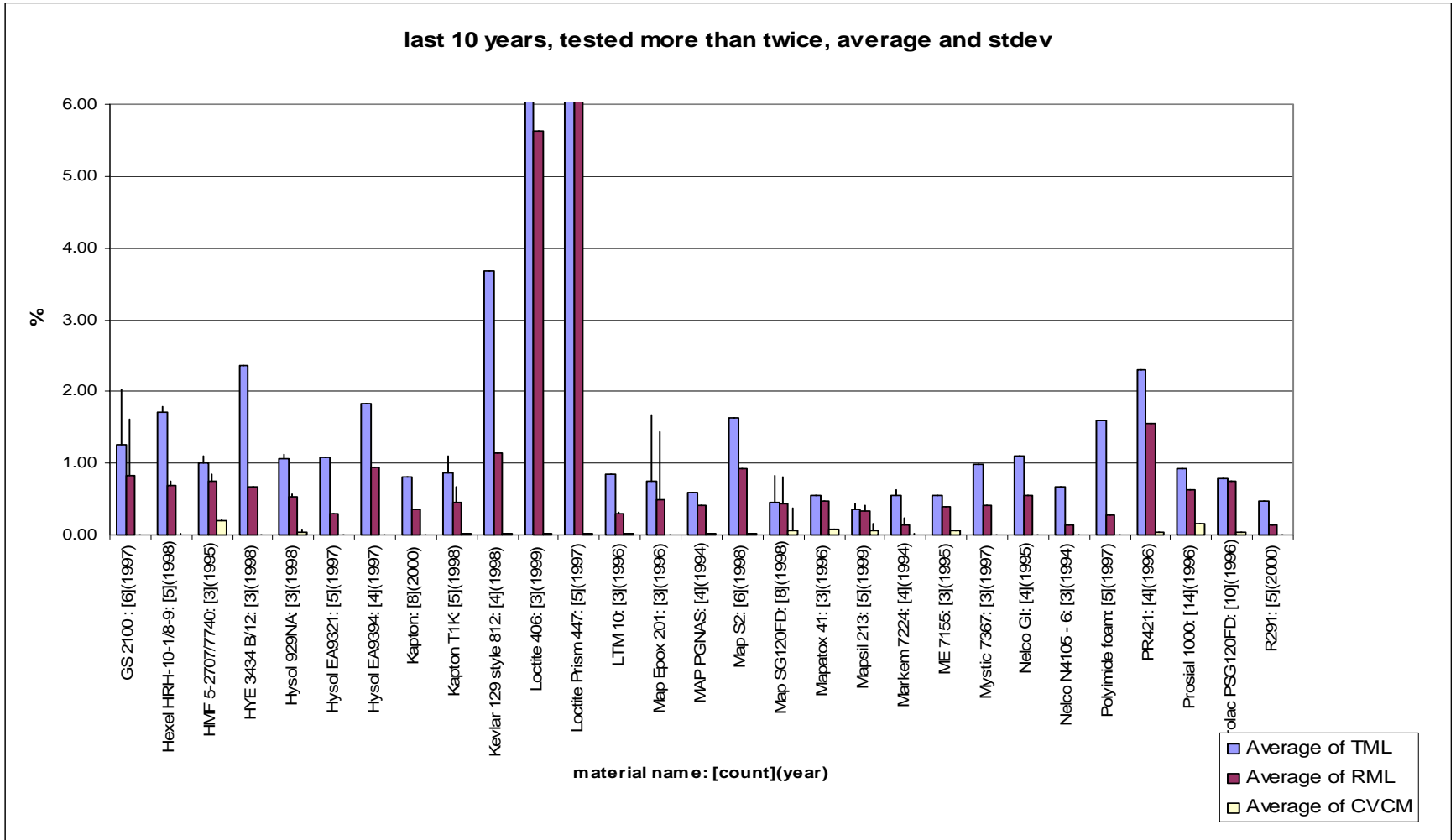
General Guidelines: TML < 1.0% CVCM < 0.1%

For sensitive components: TML < 0.1%

CVCM < 0.01%



Micro-VCM Test



VBQC Test

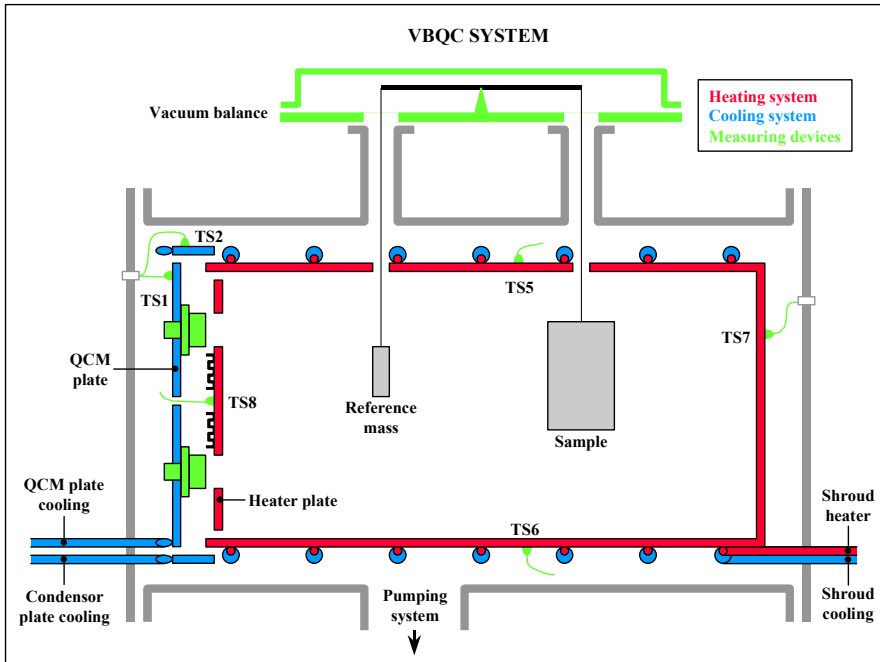
One of the main problems with outgassing is the long term evolution. This is the purpose of the VBQC test which uses the Arrhenius principle for diffusion limited mechanisms

- Results taken out of the Mathematical treatment consist of Acceleration factor, Activation energy, Residence time - Temperature dependency.
- Long term predictions with VBQC data is used within the temperature range of test.
- The TML or CVCM data are fitted period by period with a sum of 6 exponential equations.

$$W = \sum_{i=1}^6 W_{0,i} \times \left(1 - e^{-t/\tau_{0,i}} \right)$$

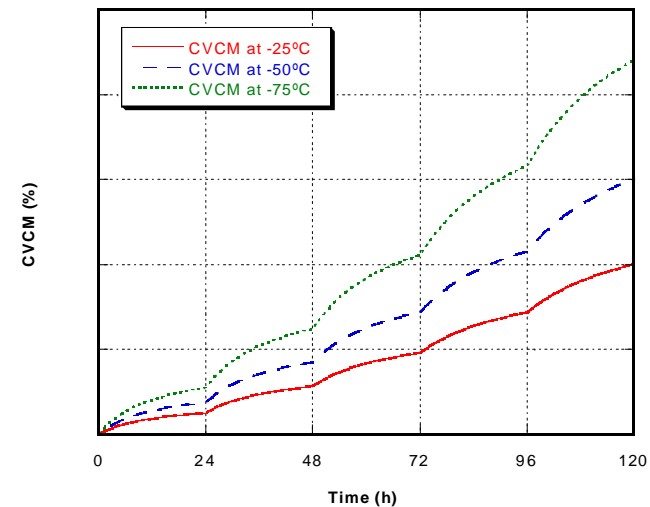
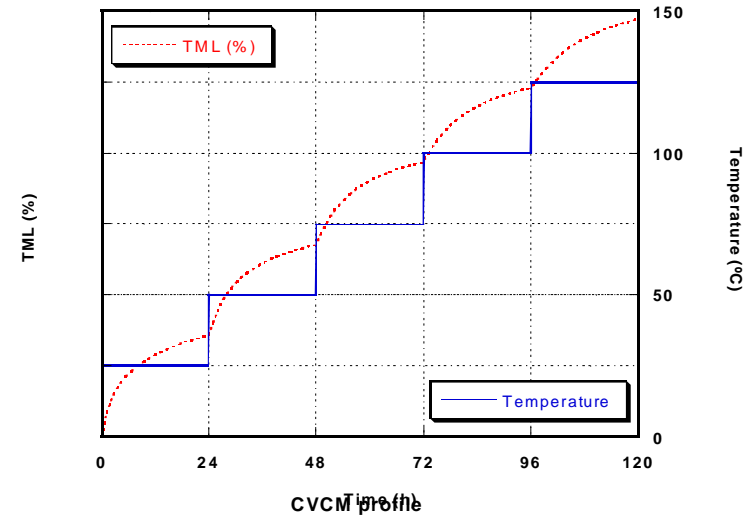
With $W_{0,i}$ the variables, affected with the time constant $\tau_{0,i}$, which are 50, 20, 5, 1, 0.5 and 0.1 hour.

VBQC Test



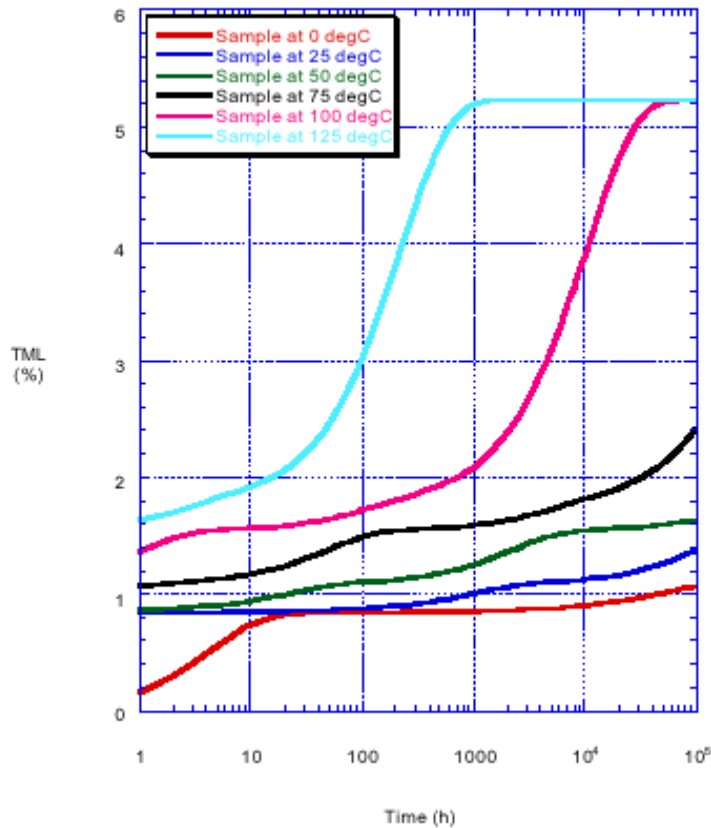
Acceleration factors are calculated from the Rate of change of mass and the end of T_i and The beginning of T_j for $T_j > T_i$

Outgassing and sample temperature profile

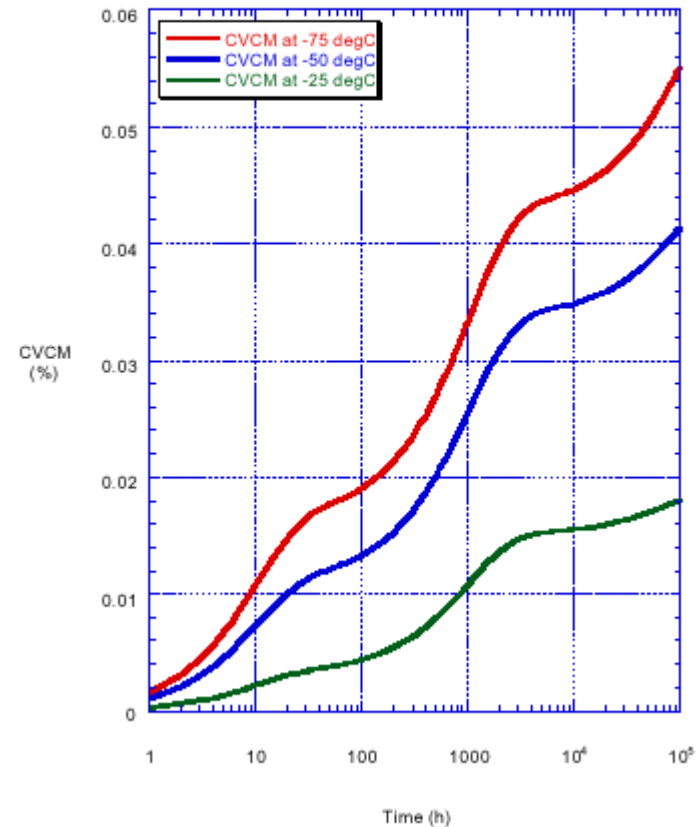


VBQC Test

Kinetic outgassing of Z306 + primer 123
VBQC 3841
LONG TERM PREDICTION TML



Kinetic outgassing of Z306 + primer 123
VBQC 3841
LONG TERM PREDICTION CVCM
Sample at +25C



Corrective Actions – Cleaning Methods

Particulate

Vacuum

Care required for exhaust, HEPA filtered for cleanrooms

Compressed gas

Redistribution can be a problem

Wiping

Care required for sensitive surfaces (scratches)

Tape removal

Residues can be a problem

CO₂

Very good for high resolution topographies

Polymer film

Can have a detrimental effect on some coatings

Molecular

Wiping

Drag wiping very affective

Dissolution

Many methods – dipping, spraying, vapour cleaning, ultrasonics

Detergent

Similar to above (often in combination)

Plasma

Good for polymers, can cause electrode material sputtering

Bakeout

High vacuum, >60C, >72hrs

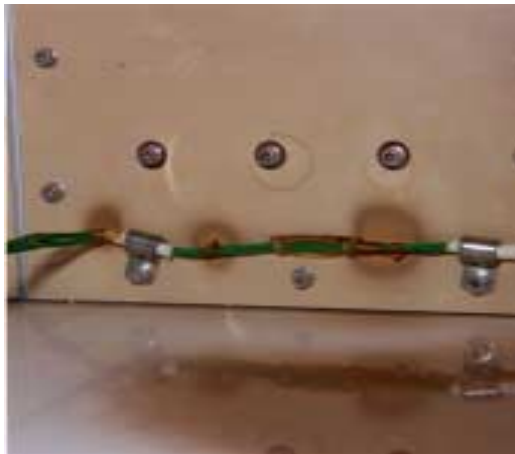
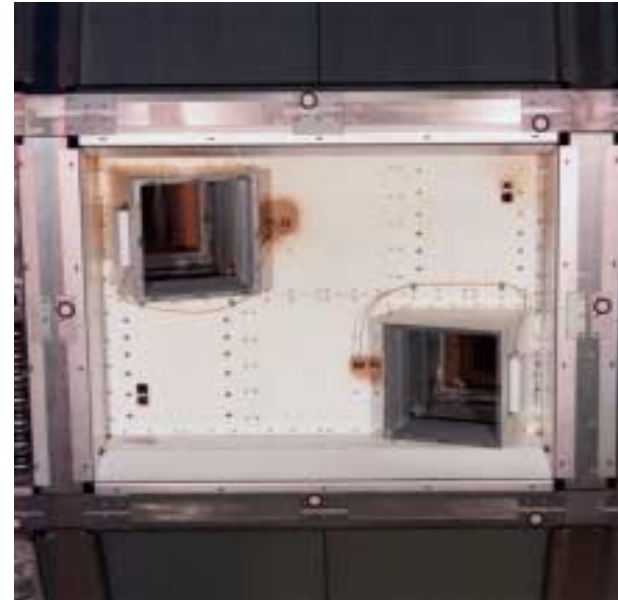
Ozone

Good for organics, slow diffusion so only for small quantities

Case Study – Long Duration Exposure Facility (LDEF)



Case Study - LDEF



Summary (1)

- **Control the environment that the hardware will reside**
- **Know what the sensitive items in the hardware are and what the level of sensitivity is**
- **Keep contamination sources away from sensitive hardware (separate “dirty” processes from clean processes)**
- **Expose sensitive hardware for the minimum possible time (if necessary use covers or purging)**
- **Monitor contamination throughout manufacturing**
- **Choose materials that will minimise contamination**

Summary (2)

- **Contamination Control is an important driver in the success of most space missions as most missions have equipment sensitive to contamination**
- **Seemingly innocuous levels of contamination can have disastrous effects due to the subsequent interaction with the space environment**
- **It is always cheaper to prevent contamination from happening than removing it later in space, this is usually impossible**
- **The best way to do this is to understand the requirements and to formulate a contamination control plan and carry it through to meet these requirements**
- **Controlling contamination at the manufacturing stage can also have the added benefit of increasing yields and so is added value and makes commercial sense**