MINUTES OF MEETING

FIRST/Planck Project

SPIRE-ESA-MOM-000575

date	30 October 2000	reference	SCI-PT/08287	page	1/2
meeting date	27 October 2000	meeting place	ESTEC		
chairman					
participants	P. Oliver, J. Guyt, M. von Hoegen, M. Anderegg – ESTEC, A. Heurtel – IAS, J. Charra – IAS, A. Dragoni – Laben, H.-M. Jacobs – SRON-	copy			

subject **FIRST/Planck Contamination Working Group Meeting # 2**

description	action	due date
1. Control plan presentation		
- HFI – See annex 1		
- HFI to clarify the discrepancy between the requirement at 1200 (page 9) and the objective at 5000 (page 14)	1	24 Nov.
- For the PDR a budget will be issued		
2. Typical material outgassing curves – See annex 2		
3. Presentation of particulate contamination requirements		
4. LFI – See annex 3		
5. LFI to provide type of ecosorb used	2	6 Nov.
6. SPIRE – See annex 4		
7. HFI – A model for particulate contamination exists but only for spherical metallic particule. This is being upgraded.		
For molecular contamination, 1μm ice has been used. Results: ~1% loss with two layers on a window. In reflexion it yields ~0,01% loss. – See annex 5		
Next meeting will be on 24 November 2000 at 09:00		
SPIRE to explain the level of contamination they can tolerate and the last paragraph before conclusion of document dated 26/09/00 provided for this WG meeting.	3	24 Nov.
All instruments to refine their particulate contamination	4	24 Nov.

description	action	due date
requirement.		
Presentation of molecular contamination sensitivity (due date changed from 29 to 24 Nov.)	5	24 Nov.
All to provide a list of organic material with their expected mass for focal plane units	6	24 Nov.
ESTEC to provide evaluation data of alternative cleaning processes due to updating processes as a result of Freon use interdiction.	7	24 Nov.

Annex 1

PLANCK HFI

HFI Cleanliness

(Cleanliness Control Plan Presentation)

Contamination Working Group

27 October, 2000

HFI Scientific Objectives

- Measurement of the diffuse sky radiation concentrated by a telescope, on the Focal Plan Unit (FPU) through feedhorns, spectral filters and solid state bolometers.
- Production of 2 maps over most of the sky for 15 months.

↳ 6 bands central frequencies are optimized:

- For CMB anisotropy variations 100-357 GHz
- For detection of galactic clusters 143-217-357 GHz
- For galactic dust emission 545-857 GHz

Wavelength : 0.3 - 3 mm

Cleanliness tasks

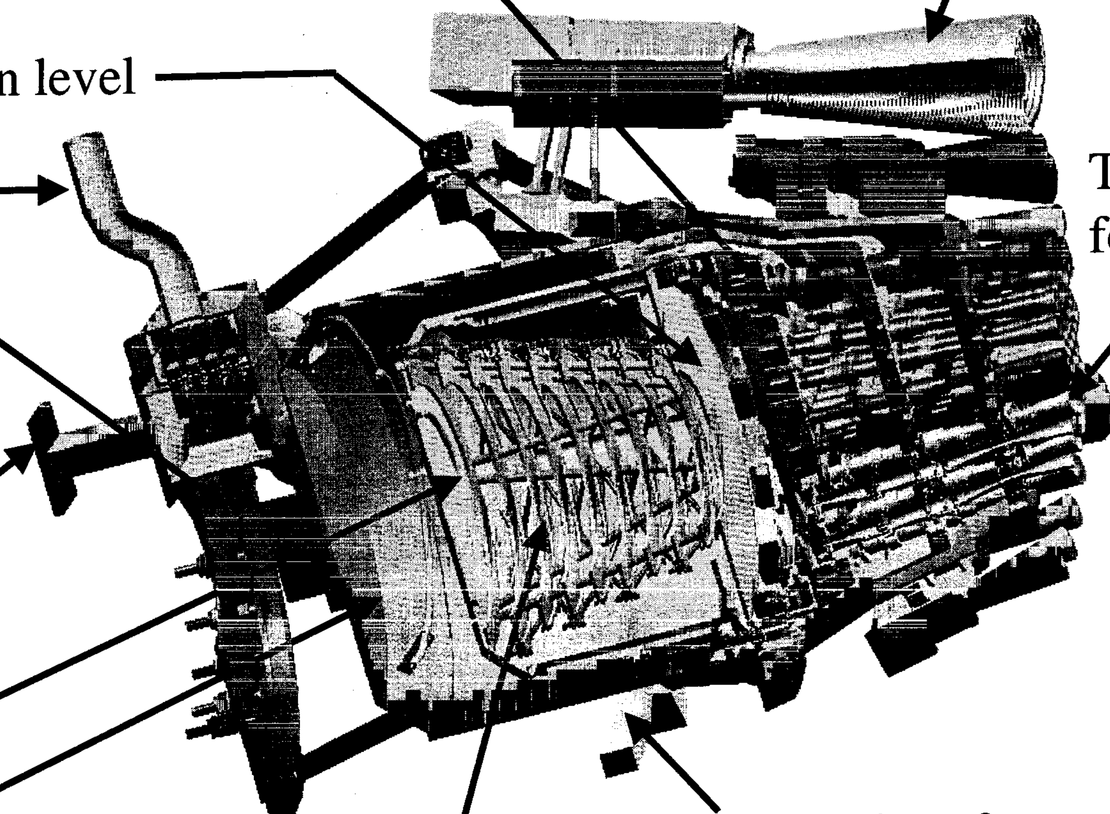
1- Cold stages in FPU from 0.1 to 4K,

2- Interfaces with LFI at 20K,

3- Whole instrument with interfaces with SVM, PPLM at RT.

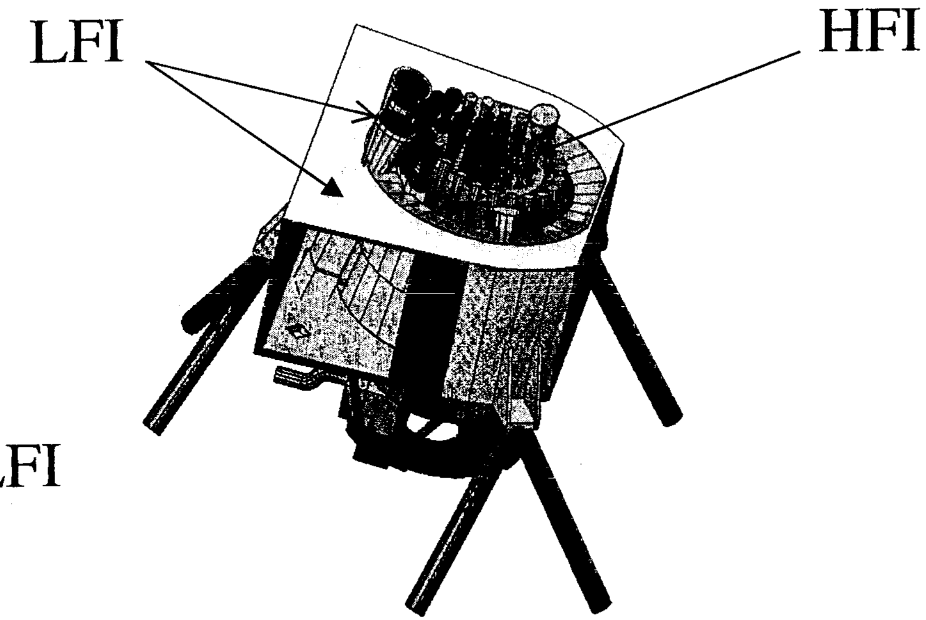
HFI Cleanliness

1- Cryostat details (FPU): *"Russian doll"*



Layout: JJ Fourmond IAS

2- Cryostat interfaces with LFI



Before integration with LFI

↳ Cleaning of:

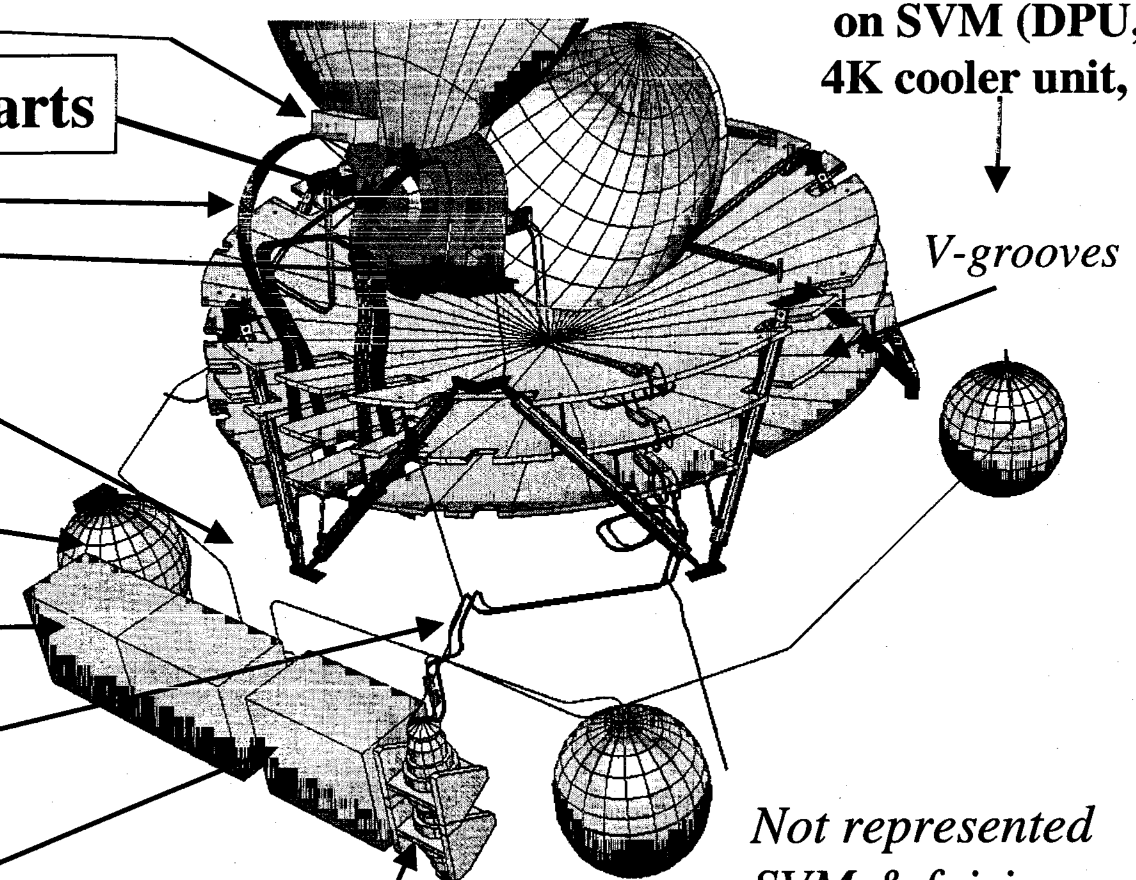
- connectors,
- coolers cold tips and pipes,
- harnesses.

HFI cleanliness budget will be coordinated with LFI budget

Alcatel view

HFI Cleanliness

3-Planck: HFI items



Legend: bold in charge

ALCATEL design

HFI Cleanliness

- ESA requirements PT-RQ-04410 for Planck

"At delivery to ESA:

1- Particulate contamination:

Less than 300 ppm inside the cold instrument

Less than than 100 ppm on the outside of these units

2- Molecular contamination:

Less than $2x10^{-7}$ g/cm^2 "

- IAS proposition:

Budget established in function of real needs for HFI (or other items) and appropriated with budget of other instruments:

↳ ESA requirements look too severe

HFI cleanliness requirements Specification (1)

1 - The driver for HFI particulate cleanliness is the scattering by dust, that induces straylight.
Parts that are relevant are the telescope mirrors and the horns. Parts internal to the FPU are also, in a lesser amount, sensitive to dust.

2 - The driver for molecular contamination is the transmission of the telescope and horns. Internally to the FPU, the bolometers are also sensitive to any kind of molecular contamination.

HFI Cleanliness

HFI cleanliness requirements Specification (2)

1 - Particulate contamination on optical parts:

- Telescope: less than 1200 ppm (TBC)
This requirement comes from the studies of P.d.M. (Meeting of Sept. 13, 2000), that shows that scattering by dust is the main source of straylight at high frequency. Ideally, lower scattering levels should be wished. Compromises may be necessary.

- 4K Horns: less than 1200 ppm (TBC)
For the same reasons

- Parts internal to HFI-FPU (filters,): less than 1200ppm

HFI cleanliness requirements Specification (3)

2- Molecular contamination on optical parts:

- Telescope: Less than $3x10^{-6}$ g/cm^2 (TBC)
This makes a layer of $0.03\mu m$ of contaminant, i.e. 10^{-4} wavelength. There is no absorbing material known to be an effective absorber in the sub millimeter domain at this thickness. Numbers still to be given.

- 4K Horns: Less than $3x10^{-6}$ g/cm^2 (TBC)
For the same reasons

- Parts internal to HFI-FPU (filters,): Less than $3x10^{-6}$ g/cm^2 (TBC)

HFI Cleanliness

Budget determination: Concerns and responses

1-Molecular and particulate deposition onto spiderweb bolometers and into contacts:

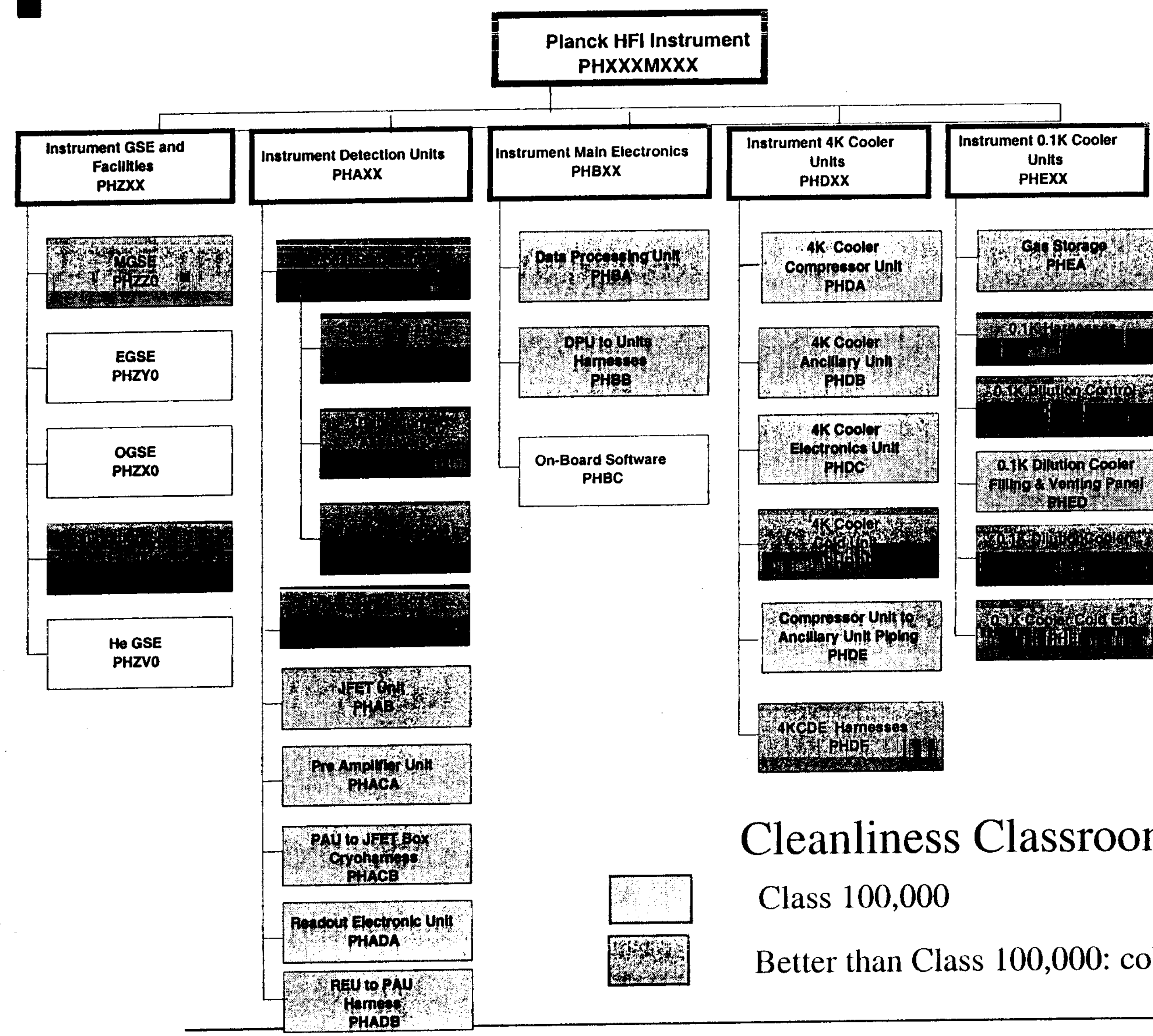
The *Russian doll* FPU architecture constitutes a succession of protecting screens against molecular contamination: each element is a trap preventing *condensate produces* from arriving up to bolometers.

- Bolometers are protected by filters into the 4K box,
- Bolometers are bound to exterior only by a porous dust proof plug for pressure equilibrium,
- No direct visibility between bolometers and exterior feedhorns.

2- Adoption of an assembly sequence preserving the cleanliness of the interior of cryostat (during AIT/AIV and integration).

HFI Cleanliness

HFI Particulate Cleanliness Needs :1st approach



Cleanliness Classroom

Class 100,000

Better than Class 100,000: cold units and harnesses

PLANCK HFI

HFI Cleanliness

HFI Particulate Cleanliness Needs : possible approach based on by assembly processes (1/2)

HFI operations	Operation	Institute	Cleanliness Class (FED-STD-209)	Contamination rate (per day)	Duration in days	Instrument proposed budget OF in ppm
Bolometers	- Fabrication	Caltech	100 (TBC)	1.5	TBD	TBD
	- Mounting		100 (TBC)	1.5	TBD	Id
	- Crystal gluing	JPL	1000 (TBC)	12	TBD	Id
	- Test		1000 (TBC)	12	TBD	Id
	- Packaging to delivery to QMW		1000 (TBC)	12	TBD	Id
Feedhorns assembly	- Assembly with feedhorns on 4K plate	QMW	1000 (TBC)	12	TBD	Id
	- Tests		1000 (TBC)	12	TBD	Id
	- Setting of protective cover		1000 (TBC)	12	TBD	Id
Assembly into FPU	- Cleanliness procedure before assembly	IAS	1000 (TBC)	12	TBD	TBD
	- 4K box dustproof		1000 (TBC)	12	TBD	Id
Partial budget for cryostat assembly	- **Interior of bolometer**					**better than 1200 ppm**
	- **FPU (4K box)**					**better than 3000 ppm**

Relative humidity 40-50% in cleanrooms and for storage.

HFI Cleanliness

HFI Particulate Cleanliness Needs : 2^{nd} approach based on by assembly processes (2/2)

HFI operations	Operation	Institute	Cleanliness Class (FED-STD-209)	Contamination rate (per day)	Duration in days	Instrument proposed budget OF in ppm
FPU calibration in IAS (without 4K and 20K)	- Separating cable bake-out at 80°C - Protecting cover	IAS	<10,000	60	TBD	TBD
Integration with LFI	- Integration - Global protecting cover	TBD	<10,000 (TBC)	60	TBD	TBD
Delivery to ESA	- Cleaning - Delivery	TBD	<10,000 (TBC)	60	TBD	TBD
Total HFI at delivery to ESA	**All mechanical surfaces**	**<1200 ppm**				

Opening of covers only at ESA . Optical tests made with alignment references on covers (TBC)

Objective: < 5000 ppm at launch

Particle Cleanliness strategy

1- Design of HFI:

- Cleaning processes evaluation for reservoirs, tubes, pre-operational feeding on ground (purges) etc..
- Materials chosen generating no particles.

2- Mirrors and baffles cleanable:

3- AIT/AIV:

- Cognizant staff,
- Use of cover for tests and storage in Class 10,000,
- Continuous monitoring of cleanliness on witness samples.

4-Delivery to ESA:

- Cleaning before delivery,
- Visual inspection,
- Packaging according to ESA-PSS-01-202,
- Delivery of validated cleaning procedure.

5- Documentation: List of records.

Particulate Telescope Budget: Proposition (1/2)

1- Remark:

Cleaning of telescope is not in charge of IAS.

2- Proposed budget : (Revisited Alcatel data)

Step/environment	Contamination rate (ppm/day)	Duration days	Obscuration Factor (ppm)
Equipment of telescope after cleaning			500
Dust coming from protective area			400
Integration with LFI/HFI (Class 10,000)	60	5	300
Total at delivery to ESA			1200

Then : tests at ESA, launch preparation for a total budget of 5000ppm

Molecular contamination strategy

1- Design:

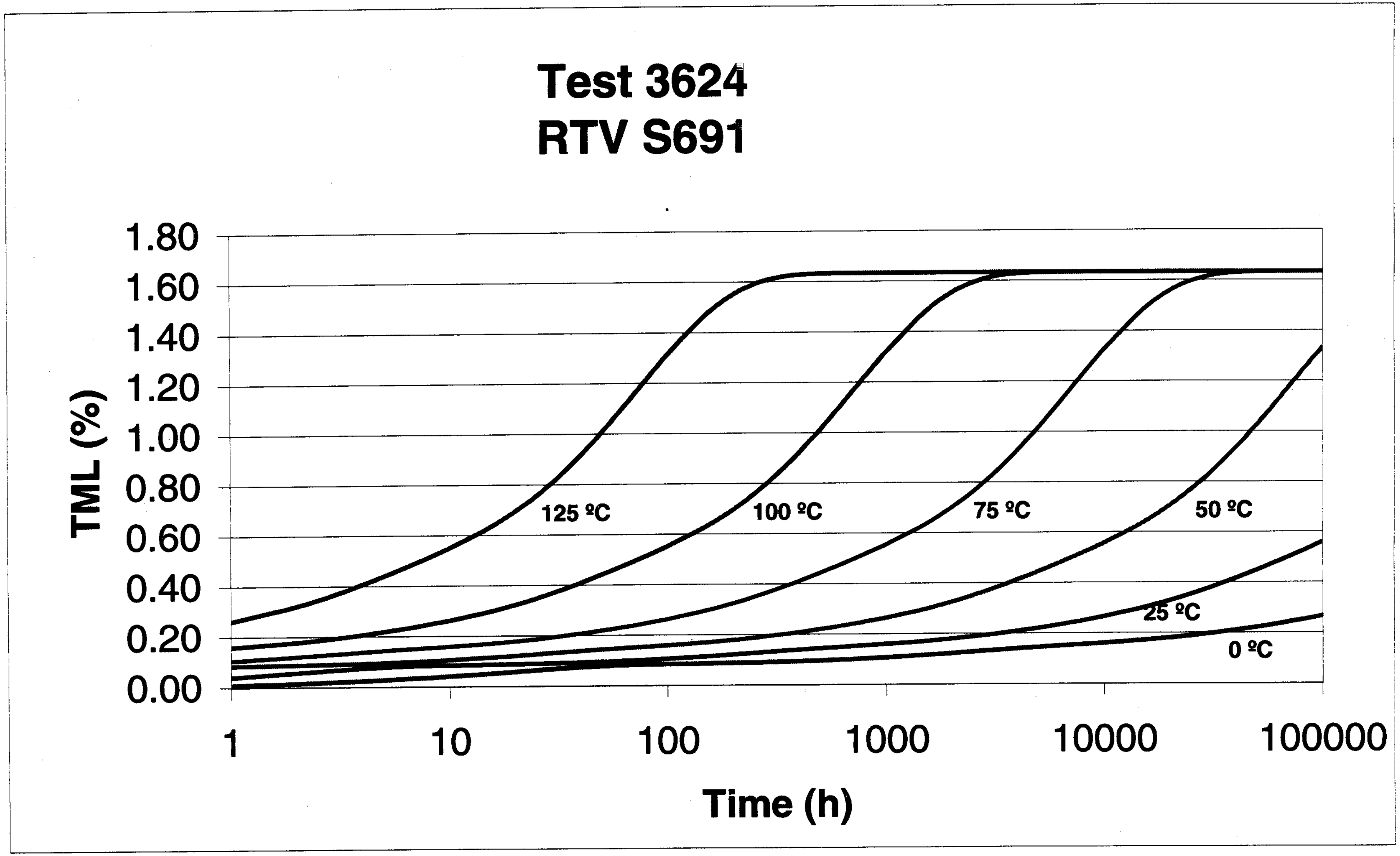
- Material selection :TML < or = 1 (ESA PSS-01-722)
  and CVCM < or = 0.1,
- Use of materials with very low out-gassing rate,
- Contaminants specified as well as possible:
  - condensable contaminants,
  - vapors gas and liquids,
- Cleaning process evaluation.

2- AIT/AIV:

- Systematic bake out at 80°C (including bolometers filters),
- Cognizant staff,
- Class 10,000,
- Facility monitoring - IR (ESA PSS-01-705),
- Permanent flushing and venting (TBC).

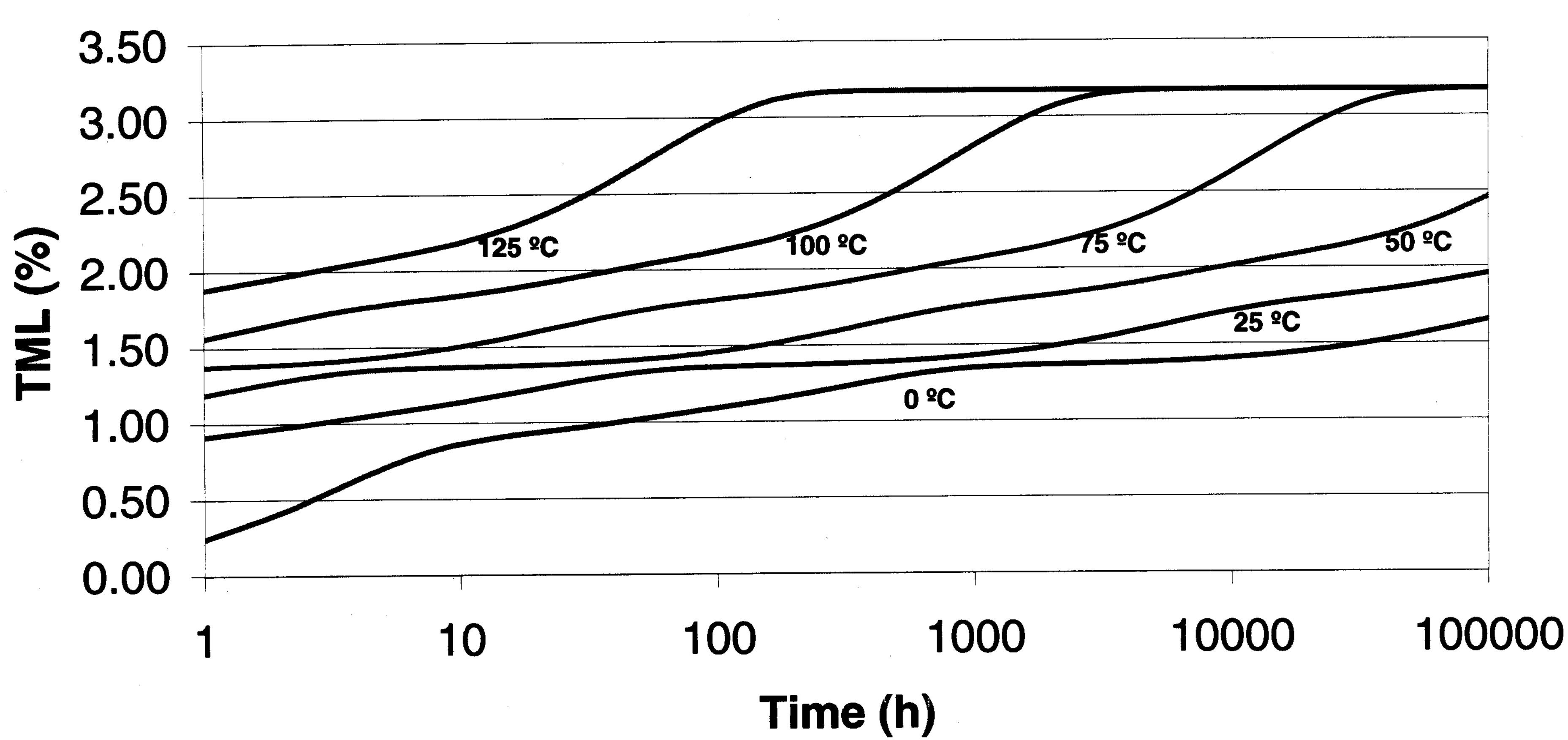
3- Delivery conditions and documentation:

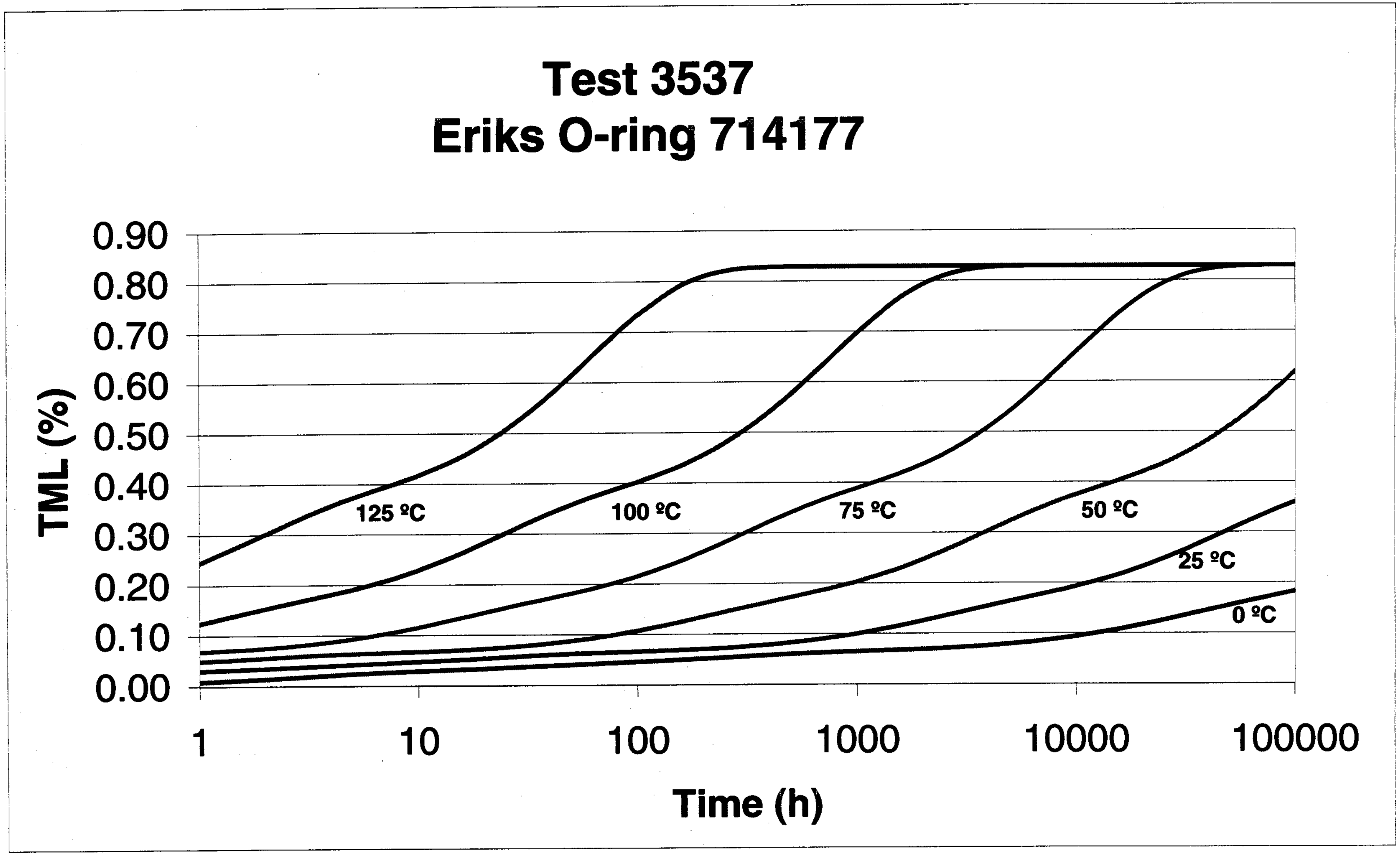
See particular contamination.

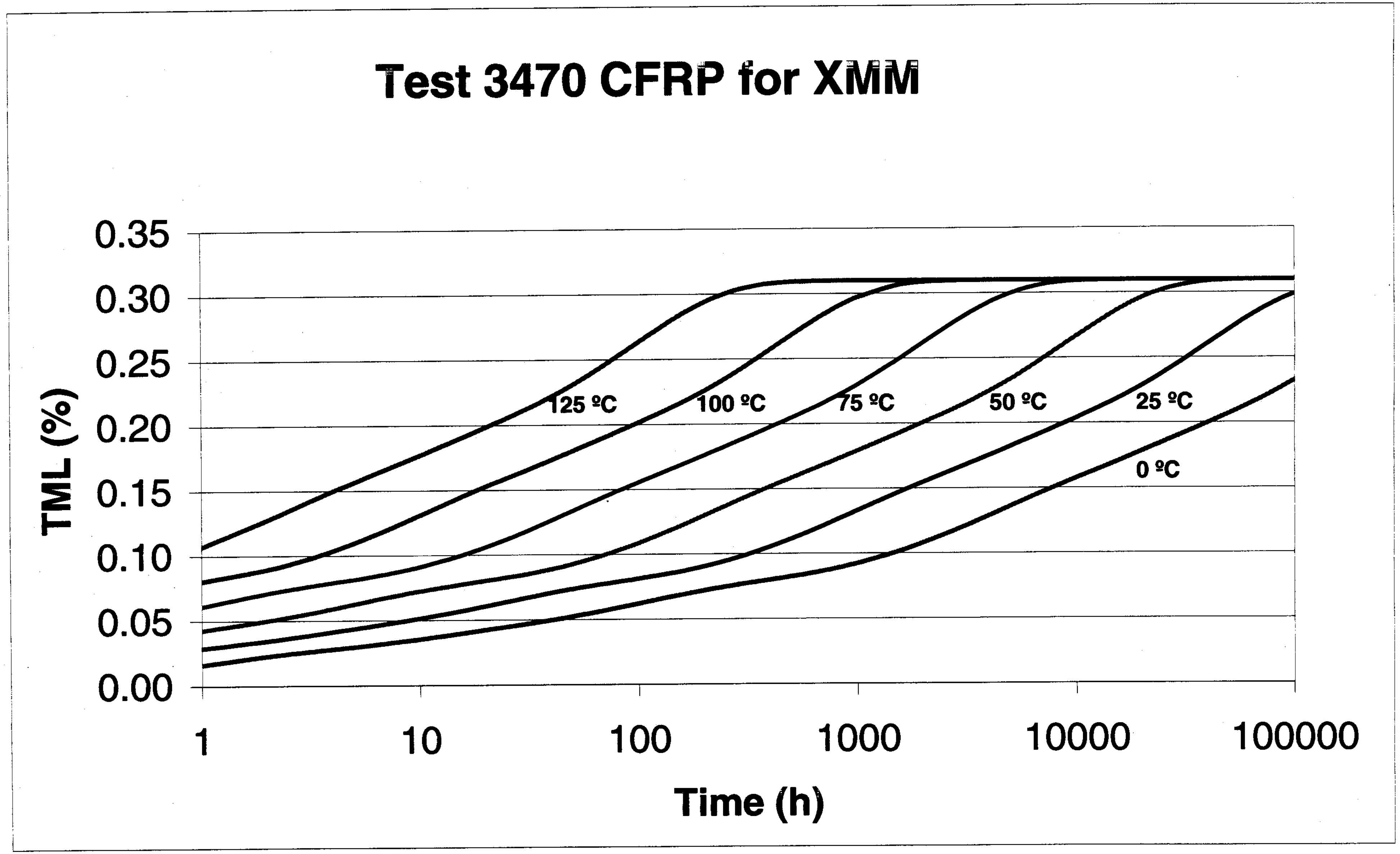


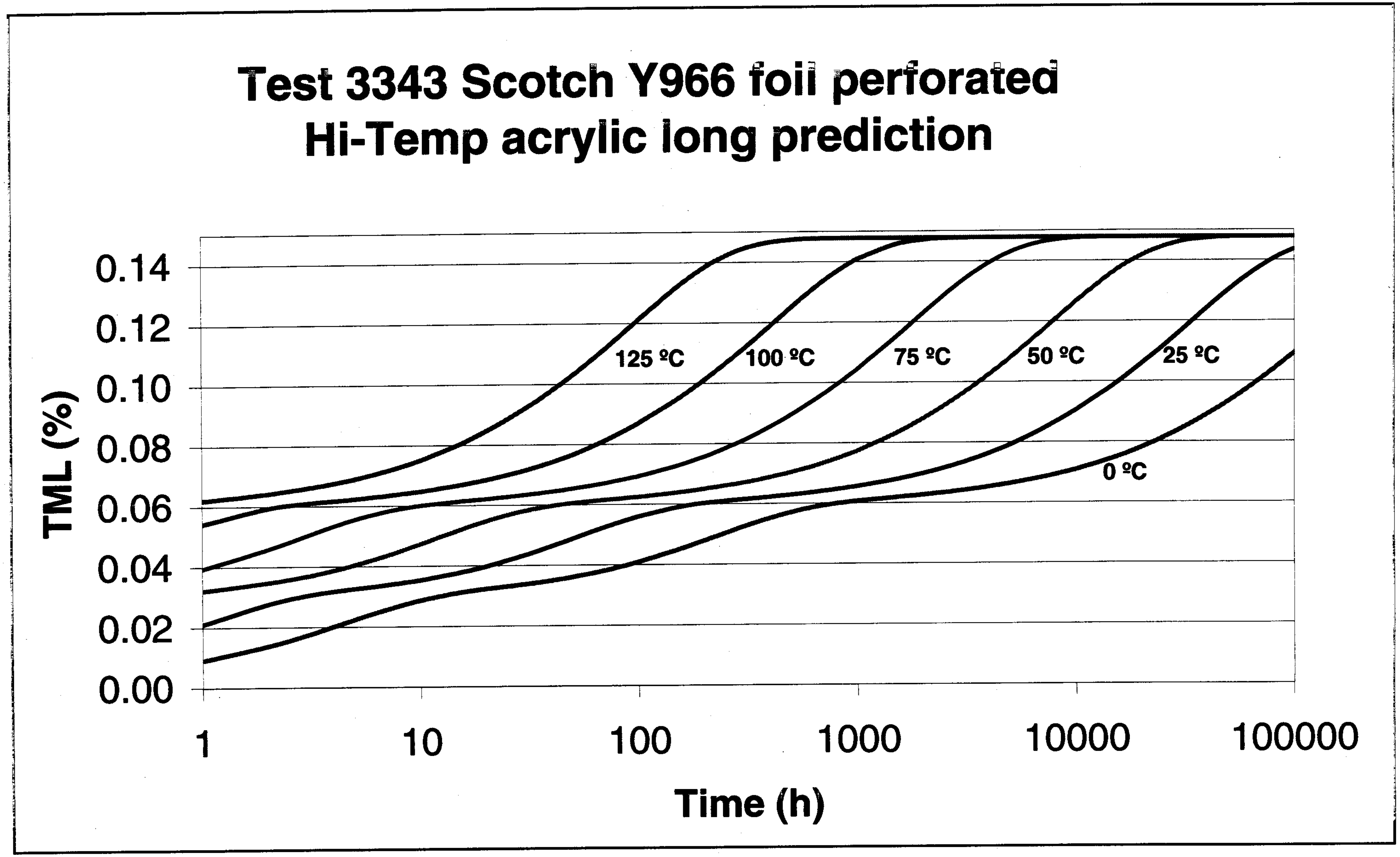
Test 3624
RTV S691
TML (%)
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
125 ºC
100 ºC
75 ºC
50 ºC
25 ºC
0 ºC
1
10
100
1000
10000
100000
Time (h)

Test 3558
Black Paint MAP S2 + Phosmap 11

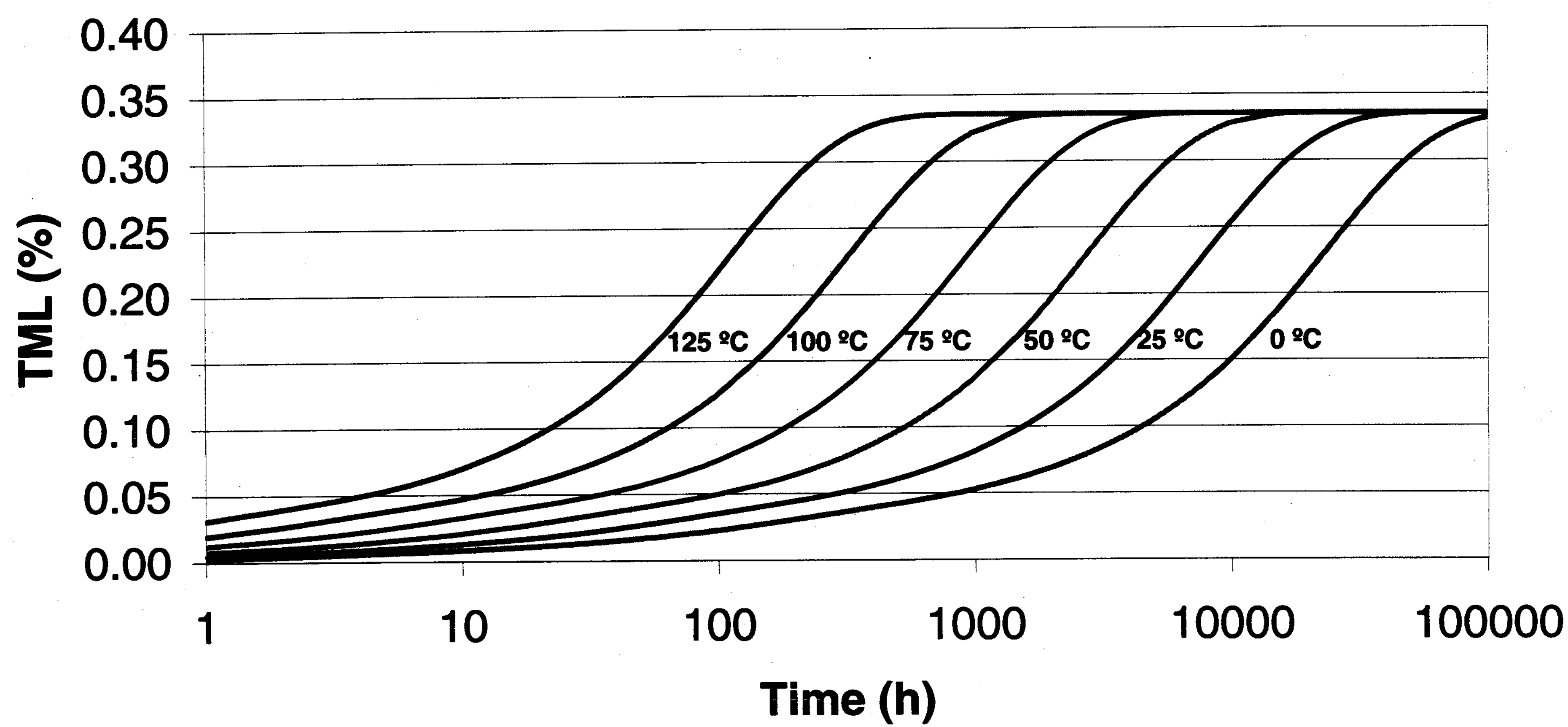


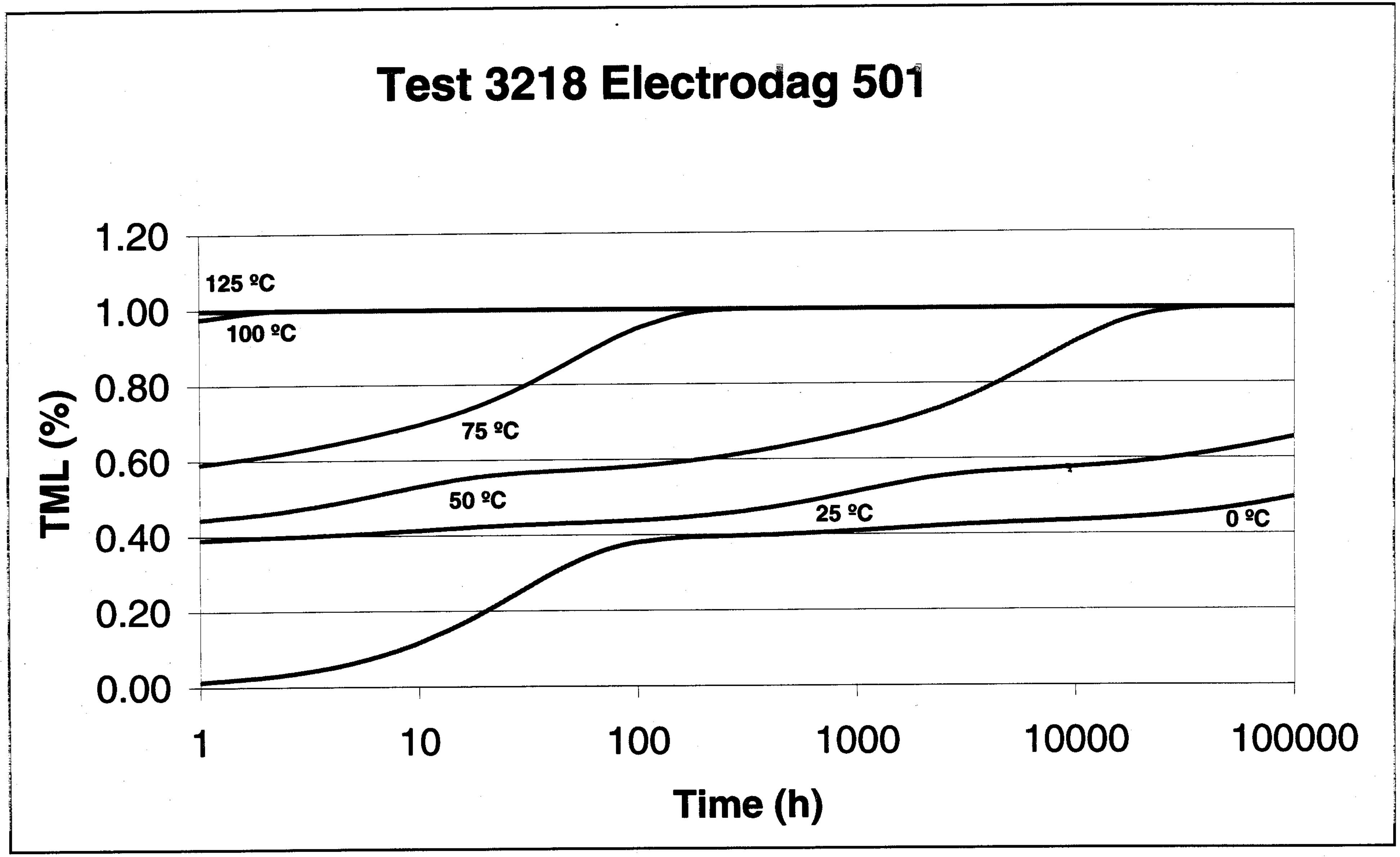

Test 3537
Eriks O-ring 714177
TML (%)
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
125 ºC
100 ºC
75 ºC
50 ºC
25 ºC
0 ºC
1
10
100
1000
10000
100000
Time (h)

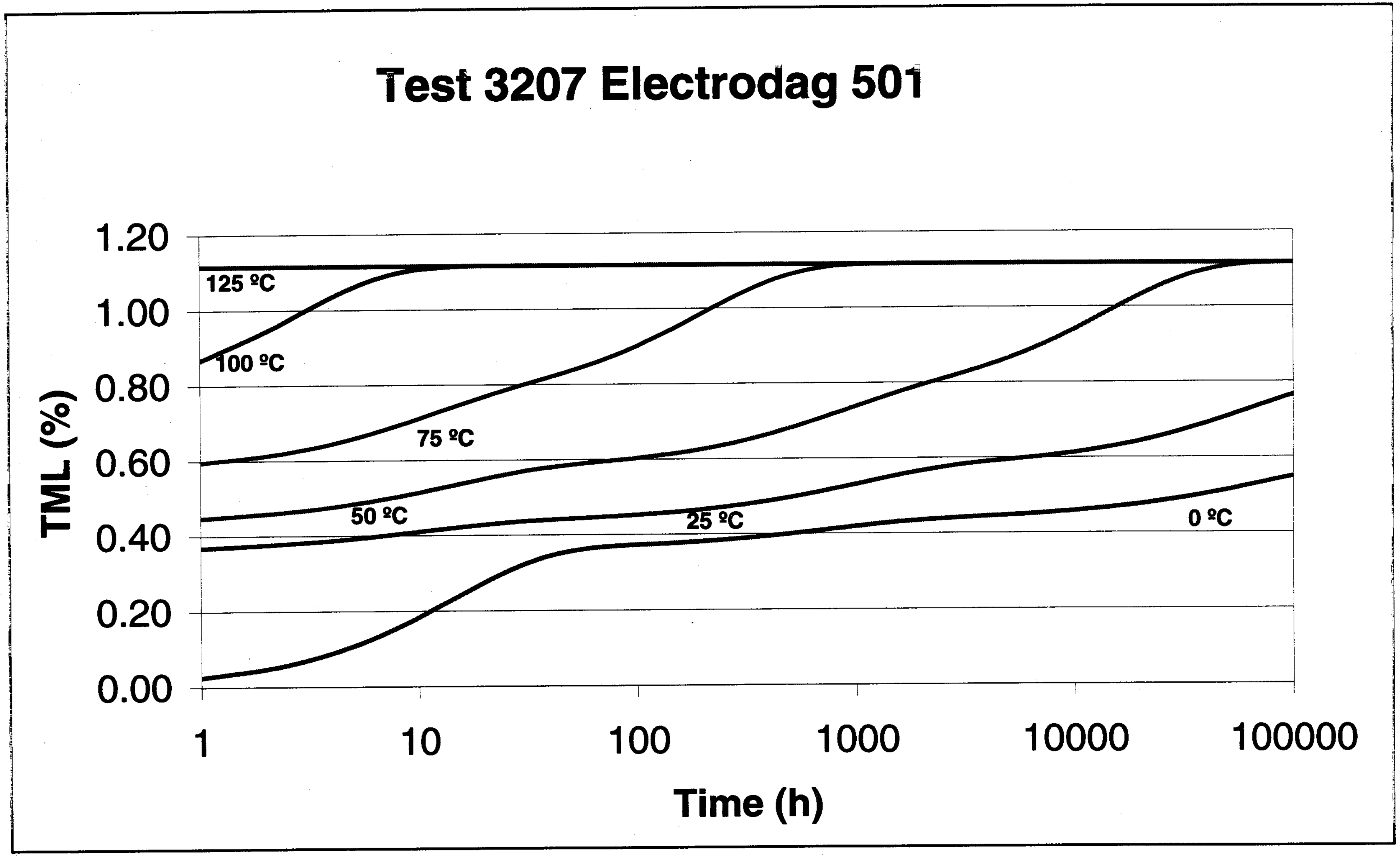

Test 3470 CFRP for XMM
TML (%)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
125 ºC
100 ºC
75 ºC
50 ºC
25 ºC
0 ºC
1
10
100
1000
10000
100000
Time (h)

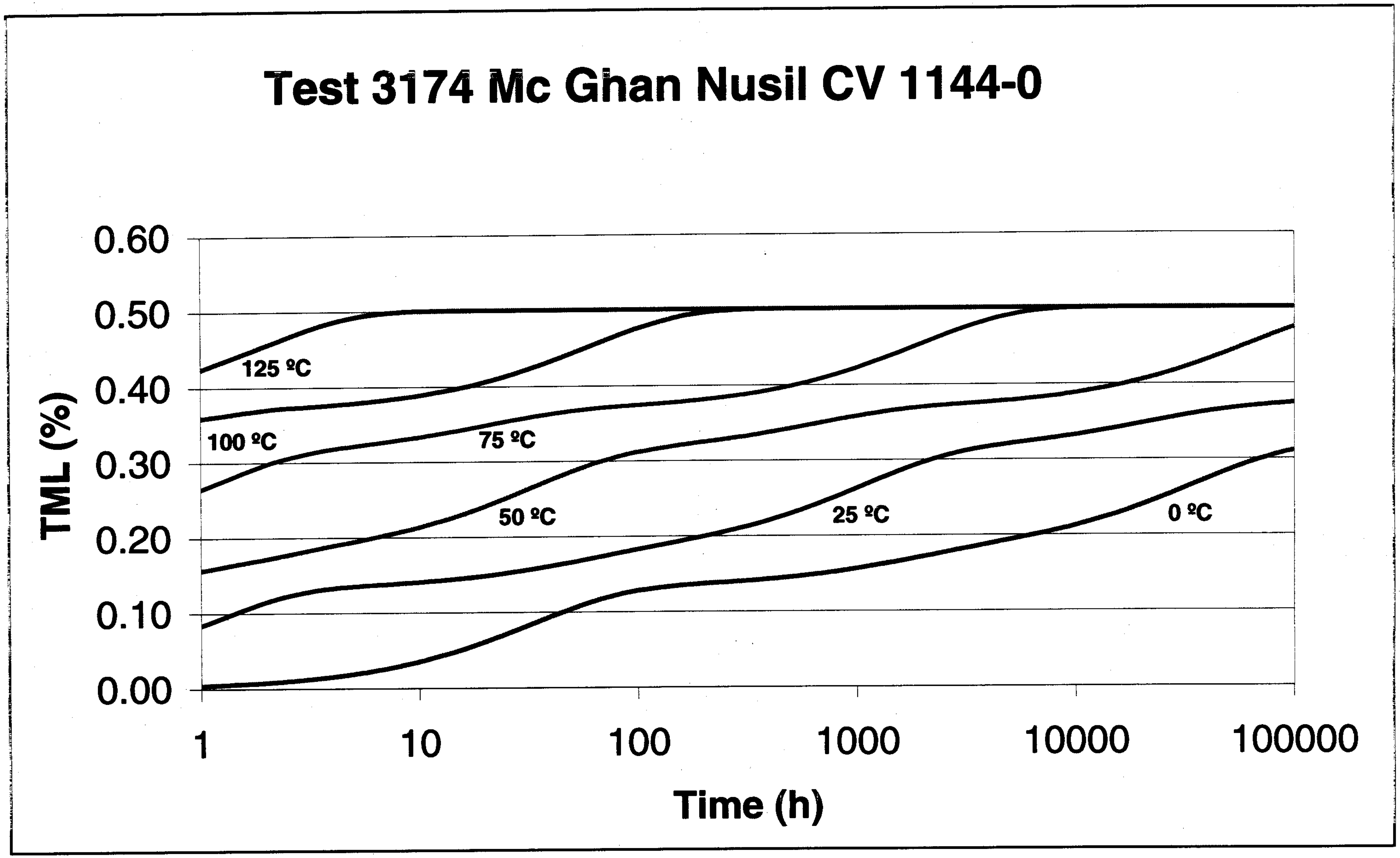

Test 3343 Scotch Y966 foil perforated
Hi-Temp acrylic long prediction
TML (%)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
125 ºC
100 ºC
75 ºC
50 ºC
25 ºC
0 ºC
1
10
100
1000
10000
100000
Time (h)

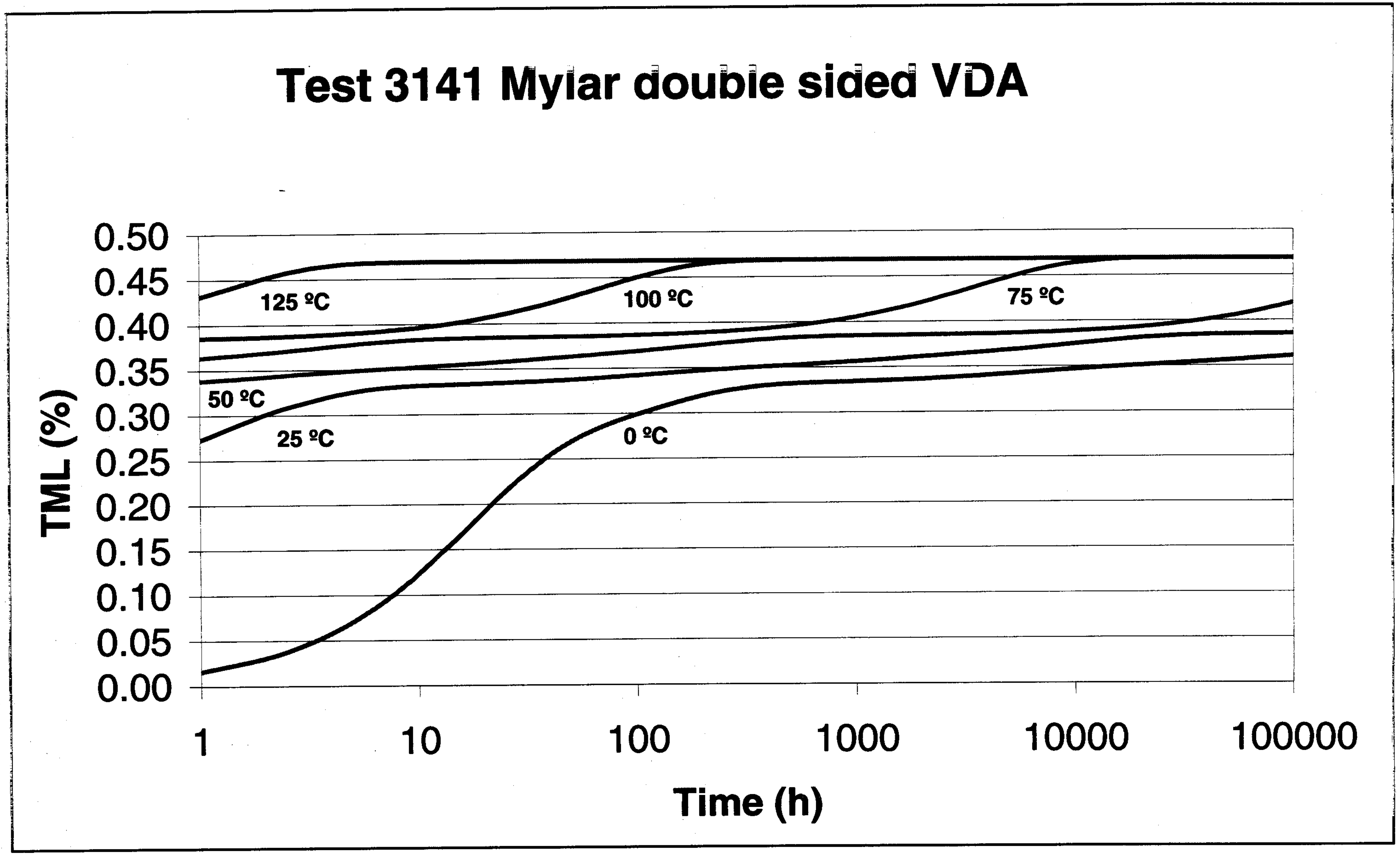
Test 3277 OSR Panel using RTV566

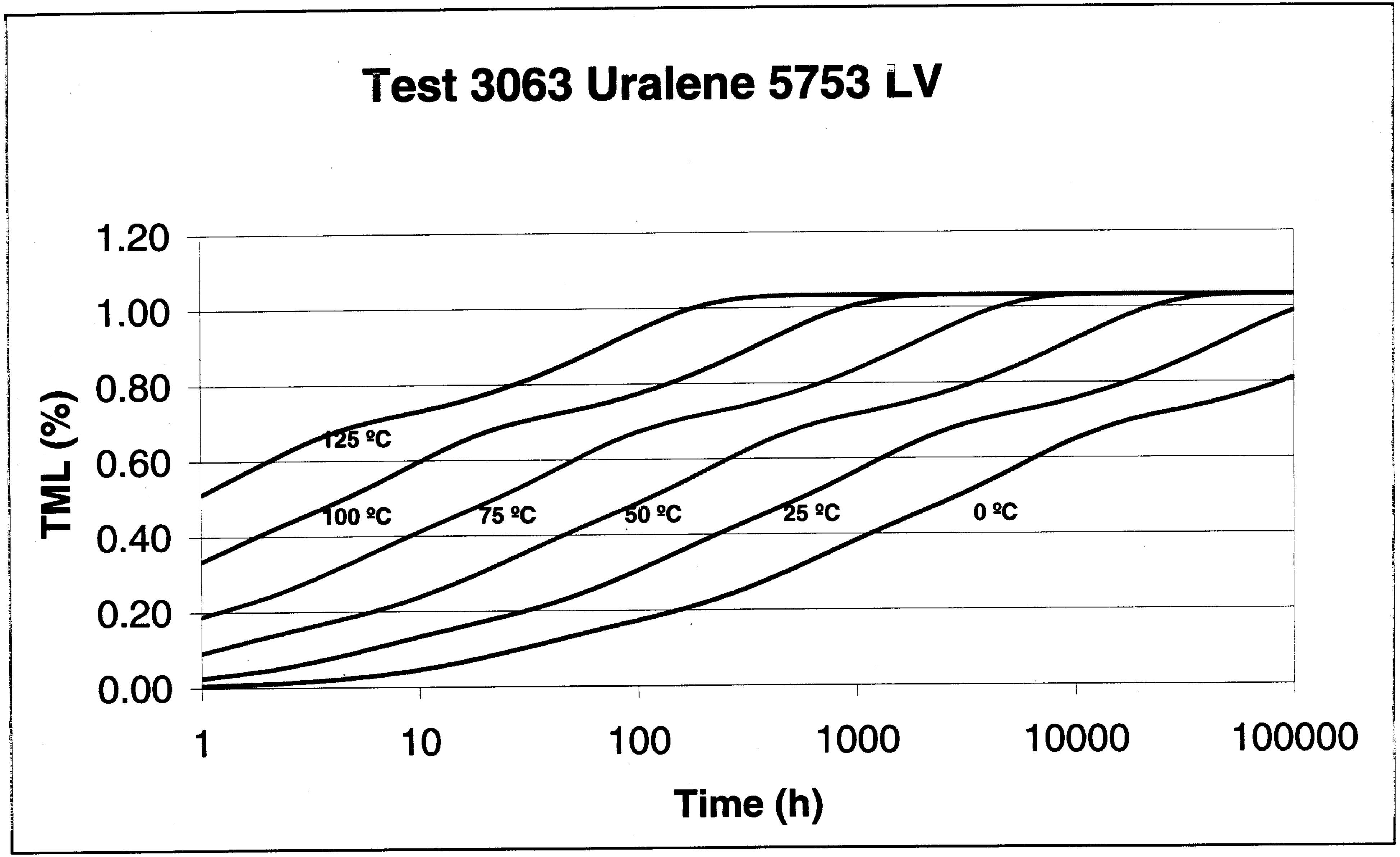



Test 3218 Electrodag 501
TML (%)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
125 ºC
100 ºC
75 ºC
50 ºC
25 ºC
0 ºC
1
10
100
1000
10000
100000
Time (h)


Test 3207 Electrodag 501
TML (%)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
125 ºC
100 ºC
75 ºC
50 ºC
25 ºC
0 ºC
1
10
100
1000
10000
100000
Time (h)


Test 3174 Mc Ghan Nusil CV 1144-0
TML (%)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
125 ºC
100 ºC
75 ºC
50 ºC
25 ºC
0 ºC
1
10
100
1000
10000
100000
Time (h)


Test 3141 Mylar double sided VDA
TML (%)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
125 ºC
100 ºC
75 ºC
50 ºC
25 ºC
0 ºC
1
10
100
1000
10000
100000
Time (h)


Test 3063 Uralene 5753 LV
TML (%)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
125 ºC
100 ºC
75 ºC
50 ºC
25 ºC
0 ºC
1
10
100
1000
10000
100000
Time (h)

Annex 3

FIRST / Planck, 2nd Contamination Working Group

27/10/2000 - ESTEC - Noordwijk (NL)

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Topics

- Planck LFI Equipments
- Main integrations
- Cleanliness policy
- LFI Particulate Contamination Requirements

Planck LFI Equipments

- Cryo items:
  - Feed Horns (FHs), Ortho-Module Transducers (OMTs), Waveguides (WGs)
  - 4 K Loads
  - Front End Modules (FEMs)
  - Mainframe structure (MS)
- Items at 300 K:
  - Back End Structures (BEMs)
  - Data Acquisition Electronics (DAE)
  - Radiometer Electronics Box Assembly (REBA)
  - Sorption Cooler Subsystem (SCS, apart the Cold End placed in the Focal Plane)

Main integrations

- 1st step
  - FHs + OMTs
- 2nd step
  - WGs + FEMs + BEMS = RCA
- 3rd step
  - DAE + BEMs = Back End Unit (BEU)
- 4th step
  - MS + FEMs = Front End Unit (FEU)

Main integrations (cont.)

- 5th step
  - BEU + FEU = Radiometer Array Assembly (RAA)
- 6th step
  - RAA + REBA
- 7th step
  - (RAA + REBA) + SCC =
    Low Frequency Instruments (LFI)

The cleanliness policy

- The following activities shall be implemented in order to reduce the particulate contamination for each level of integration:
  - use of materials with reduced particle generation as much as possible
  - monitoring of the cleaning level
  - use of appropriate and validate cleaning procedures for each integration level
  - use of dedicated protection cover (caps for FHs)
  - remove protection cover at latest moment

LFI Particulate Contamination Requirements

- The present status does not permit to finalize the particulate contamination requirements.
- It is worthwhile pointed out that:
  - There are no sensitive items in the LFI with respect to the particulate contamination (The InP LNA detectors shall not be packaged and shall be passivated).

LFI Particulate Contamination Requirements (cont.)

- The particulate contamination does not influence the optical properties of the instrument considering the LFI wavelength range ($\approx$ 1 - 10 mm).
- The thermal properties should not be affected by the particulate contamination if the below proposed requirements shall be applied.

LFI Particulate Contamination Requirements (cont.)

- Cryo items
  - Obscuration factor inside the equipments:

    600 ppm
  - Obscuration factor outside the equipments:

    300 ppm
  - Cleanroom class identification:
    - **class 10000** (TBC) during integration and tests without protective cover
    - **class 100000** during integration and tests with dedicated protective cover

LFI Particulate Contamination Requirements (cont.)

- items at 300 K:
  - Cleaning level:
    - visually clean
  - Clean room class identification:
    - class **100000**

<u>Note</u>: if during integration cryo items shall be assembled with "300 K" equipments, the cleaning rules for cryo items shall be applied.

Annex 4

Effect of Particulate Contamination on SPIRE Mirror Performance at 200 μm.
B. Swinyard RAL
26/9/2000
Draft for discussion

Introduction
The effect of exposure of optical surfaces in a given particulate environment will depend on a number of factors. At the most basic level we need to consider two aspects:

- Fairly obviously, the number and size of particles deposited on the surface in a given time. This in turn will depend on the environment in which the optics are stored and handled – generally designated by the cleanroom "class" – and the activities that are carried out on, or in the vicinity, of the optical components.
- The optical properties of the particles deposited on the surface. The particles can, under the correct circumstances, scatter, absorb and emit radiation. All of these effects are to some degree undesirable. Analysis of the optical properties of dust is complex and generally dependent on the wavelength of interest; the size distribution of the particles and the material from which the particles are made.

Effective Obscuration by Particulate Contamination
So, we can take the analysis of the problem in two sections. First, how much dust will there be? RD1 gives a summary of a semi-empirical analysis of the subject and I quote only the results here. The rate of fall out of particles of radius >5 μm from air in a cleanroom class C is given by:

$$\dot{n} = \rho(0.00634C)^{0.773} \text{ per square foot per day} \qquad (1)$$

The parameter ρ depends on the type of clean room. For conventional cleanrooms with 15-20 air changes per hour, the value is given as 2851 (seems a very accurate value!). For laminar flow benches it may be as low as 800. For still air or a low number of air changes (say test facilities) it may be as high as 28510. In RD1 there is some discussion of correction factors for equation 1 depending on the orientation of the surface (vertical or horizontal) and the activity being carried on in the clean room. In the all the following analysis I set both of these to the worst case values of 1 – i.e. I ignore them.

We now wish to know the number of particles deposited on a surface as a function both of time and particle diameter $n(x,t)$. RD1 gives this as:

$$n(x,t) = 2\alpha(t)\frac{\log(x)}{x}N_s(x,t) \qquad (2$$

Here $\alpha(t)$ is a coefficient that describes the evolution of the surface cleanliness with time. In RD1 the following semi-empirical formula is used to describe the surface contamination evolution:

$$\alpha(t) = \frac{t+18}{\frac{5}{2}t+20} \qquad (4)$$

$N_s(x,t)$ is the total number of particles per unit area for particles >x after time t. The definition of N_s is given by the MIL-STD-1246C definition of surface cleanliness:

$$\mathrm{Log}(N_s(x,t)) = \alpha(t)[\log^2(X_c) - \log^2(x)] \qquad (5)$$

Where X_c is the surface cleanliness factor and can be taken as the maximum radius particle present in the distribution.

The *obscuration ratio* for particles with an area given by A(x) and a number distribution of n(x,t) is defined in RD1 as:

$$\Phi = \int_{x\min}^{x\max} A(x) n(x,t) dx \qquad (6)$$

If we assume that all the particles deposited are spherical in form with $A(x) = \pi x^2/4$, then the obscuration ratio is given by, combining equations 1-6 and converting to radius in microns:

$$\Phi = \frac{\pi\alpha(t)\rho(0.00634C)^{0.773}t}{2\times 9.29\times 10^{10}} \int_{x\min}^{x\max} x\log(x) 10^{\alpha(t)(\log^2(x\min)-\log^2(x))} dx \qquad (7)$$

As this function can go greater than 1 – indicating particles falling on particles – a "corrected" obscuration ratio is further defined:

$$\Phi_{corr} = \frac{\Phi}{1+\Phi} \qquad (8)$$

Optical Effects and Effective Area

The scattering, absorption and emission of particles is described by the Mie scattering theory and, although treated explicitly in RD1, is beyond the scope of the present study. For our purposes we need to estimate the loss in throughput per optical surface after some period of exposure to a given cleanroom environment. In the previous section we have shown how to estimate of the surface coverage by particles – we now need a robust estimate of the effect of those particles on the effective area of each optical surface.

We can define the effective obscuration in terms of the standard *extinction efficiency* from scattering theory, Q_{ext}, by rewriting equation 6 as:

$$\Phi = \int_{x\min}^{x\max} Q_{ext}(kx) A(x) n(x,t) dx \qquad (9)$$

and Φ_{eff} is then found using the corrected form for Φ given in equation 8. Q_{ext} is a function of the size parameter kx where $k=2\pi/\lambda$, is the wavenumber. The form of $Q_{ext}(kx)$ is highly complex and dependent on the shape and material properties of the particles. RD1 attempts to treat these explicitly because there the interest is in the details of the scattering from the Planck mirror. As we are only interested in the general loss of throughput we can take a simplified form for Q_{ext} given by

$$Q_{ext} = \frac{2(x/\lambda)^4}{1+(x/\lambda)^4} \qquad (10)$$

and shown in figure 1. This follows the general form shown in RD1 and tends to $Q_{ext}=2$ at large values of kx as expected.

Setting the wavelength to 200μm and the maximum and minimum radii to 5 and 1995μm, we can now calculate the effective obscuration versus time for different cleanroom classes. This is shown in figure 2. To convert to affective area – i.e. percentage throughput – we can use the simple form given in RD2:

$$A_{eff} = \exp(-\Phi_{eff}) \qquad (11)$$

A_{eff} is plotted as a function of time for the same cleanroom classes in figures 3a and 3b. We can see from figure 3b that this analysis indicates that the effective area of any exposed optical element will fall to 99% of the clean value after approximately 100 days for class 100; 40 days for class 1000; 16 days for class 10000 and 7 days for class 100000.

Conclusions

Although the SPIRE team's initial estimate was that the instrument can live with a reasonably large degree of particulate contamination, the analysis here shows that, in order to maintain the optical throughput per surface >99% some caution is required in their handling. The assumptions made in the analysis are pessimistic in the estimate of the amount of particles that will be deposited, but possibly optimistic in the assessment of the optical extinction properties of the particles. On this basis, and emphasising the pre-cautionary approach to be taken for flight model AIV I recommend the following procedures for the SPIRE assembly and integration:

1. Use at least class 1000 laminar flow environments wherever possible when assembling and aligning the optical system. Wherever possible class 100 laminar flow environments are preferred for bare optical elements.
2. Where this is not feasible the maximum allowed cleanroom class is 10000 and the exposure of any optical surface should be no more than one day.
3. When the instrument is stored for prolonged periods of time (>1 day) with optical elements exposed it must be in a class 100 laminar flow environment or equivalent (vacuum chamber or suitable cover)
4. Particle counters and witness mirrors must be provided in all environments where bare optics are exposed.
5. Whatever the general cleanroom class in which the instrument is held, all operations carried out on the optics or in the vicinity of the optics should be done by personnel with cleanroom standard coat; hat; shoes and gloves. Facial hair must also be covered with a mask.
6. When optical elements have been exposed to non-clean (i.e. class >1000) environments they should be inspected and, if necessary, particulate contamination removed using dry nitrogen gas to blow the contamination away in a safe direction.
7. Structure and other non-optical surfaces that have been exposed to non-clean environments must be inspected and, where necessary, cleaned before introducing optical elements into their vicinity.
8. Once the instrument is fully integrated and with a cover fitted to the optical aperture to protect the input filter, it may be exposed to relatively dirty environments without affecting the performance of the instrument. However it is not recommended that environments greater than class 10000 are used for prolonged periods of time as particulate contamination on the outside of the instrument may find its way to the inside following removal of the cover. The instrument should be inspected following prolonged (>1 day) exposure to class>1000 and, if necessary, the outside cleaned by blowing off particulate contamination using dry nitrogen.

References:

RD1 "Scattering in sub-mm range by dust on reflectors and its consequences in the caes of the Planck telescope." ESA memorandum 170500/EEA/PDM

RD2 "Practical significance of dust contamination scattering effect" ESA memorandum 270700/EEA/PDM

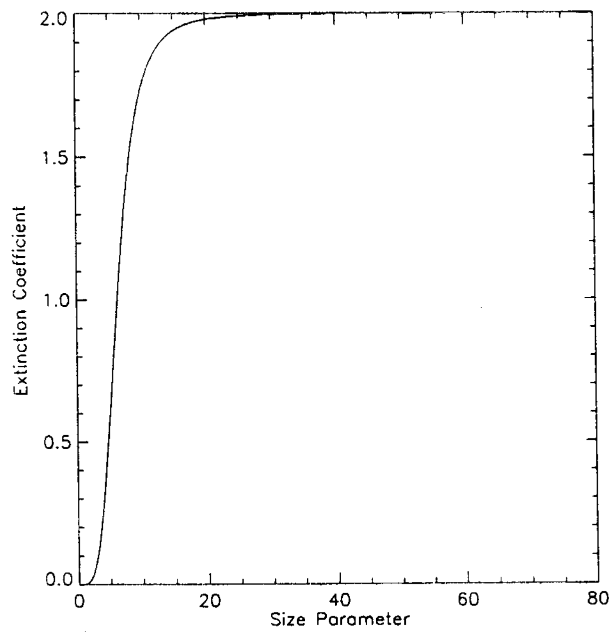


Figure 1: Extinction coefficient versus size parameter used for estimating the effect of dust on the performance of the SPIRE optical surfaces. In reality the form of the extinction coefficient may be very much more complex than shown here.

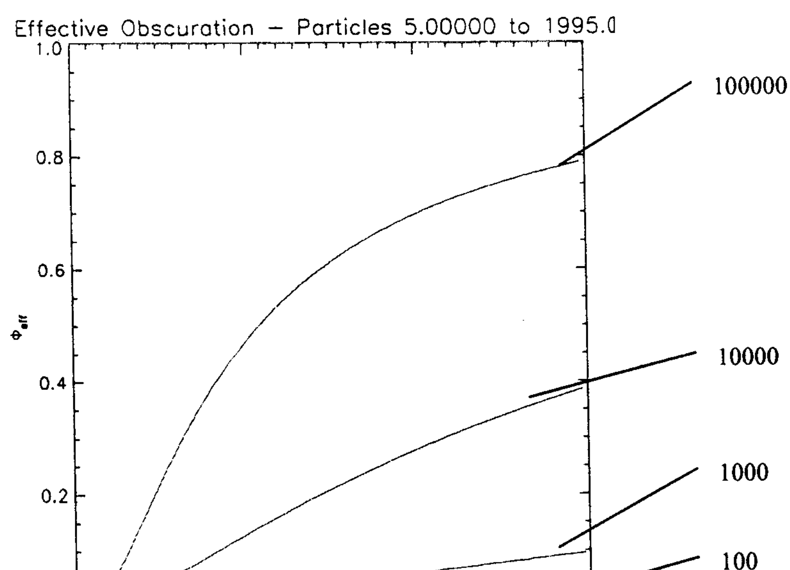


Figure 2: Effective obscuration versus time for cleanroom class 100, 1000, 10000 and 100000 for a "standard" environment and 5<x<1995 µm.

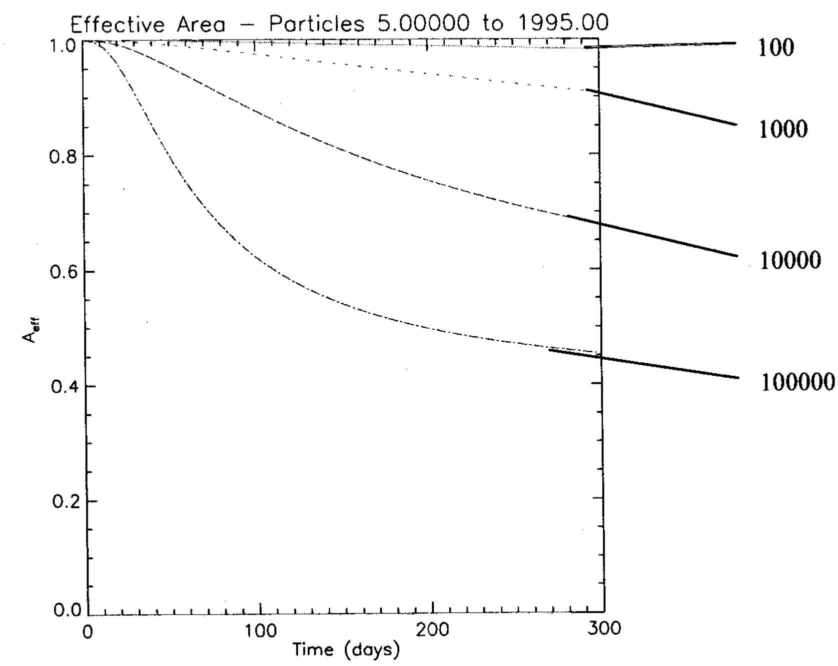


Figure 3a: Effective area versus time for cleanroom class 100, 1000, 10000 and 100000 for a "standard" environment and 5<x<1995 µm.

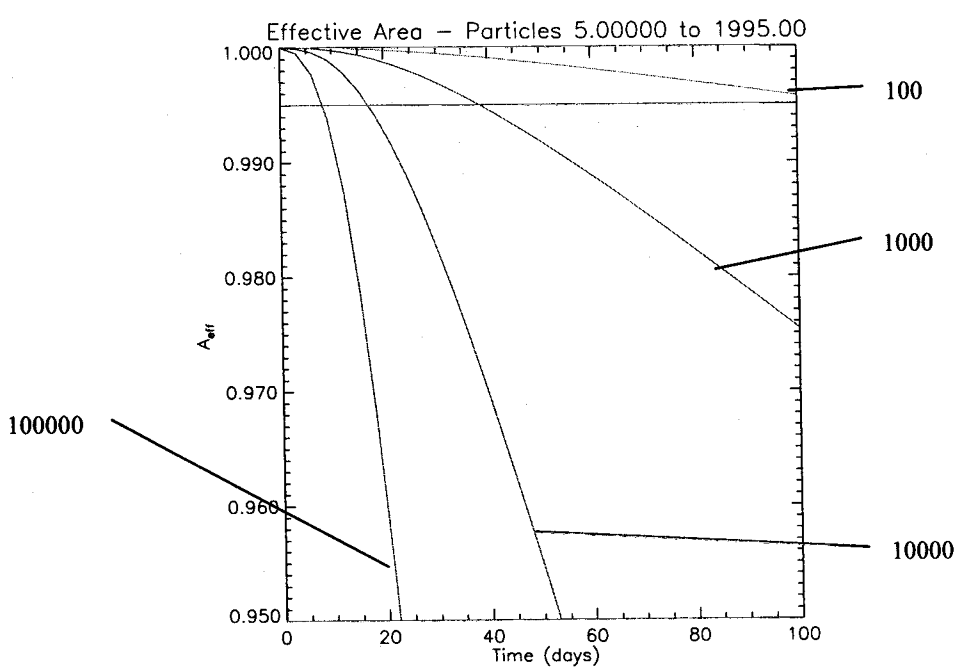


Figure 3b: As 3a with x-axis blown up.

SPIRE Contamination Risk Analysis.
B. Swinyard
27/9/2000
Draft for discussion.

Sensitive Part	Description item and risk	Performance to be maintained	Risk
Mirrors	Optical surfaces – diamond turned to r.m.s. roughness <10 nm for optical alignment purposes. Sensitive to particulate contamination >5 um	R(>200 μm) > 0.99 BDRF TBD	Contamination during instrument integration and optical alignment. Major risk is particulate. Molecular contamination during cool down if cryostat environment is not clean or sufficiently well pumped.
Bolometer Arrays	Spider web silicon nitride structures with surface mount electronics and deposited conductors Heat capacitance sensitive to particulate contamination. Sensitivity to molecular contamination unknown	Heat capacitance (Dominated by thermistor) Conductivity to sink NEP<3×10^{-17} W $Hz^{-1/2}$ (both could be affected by corrosion of conductors?)	Contamination during sub-system (array module) assembly and integration. Once fully integrated the arrays are protected by the feedhorns and detector filter.
Feedhorn optics	Open cones with very small waveguide apertures at base (~100 μm) Sensitive to particulate contamination changing characteristics. .Large particles could block waveguide. Low or negligible sensitivity to molecular contamination.	Optical efficiency >0.8 Quasi-single mode beam pattern.	Contamination during sub-assembly test and characterisation. Contamination during bolometer array assembly and integration. Once fully integrated the feedhorns are protected by the detector filter.
Optical Filters	Polymer substrates (mylar; polypropylene) with vacuum deposited metal. Particulate contamination as for other optical surfaces (TBC) Gross molecular contamination (solvents) could lead to performance degradation. Other molecular contamination as for mirrors (TBC) Filters are possible source of molecular contamination from out gassing from polymer substrates.	Depends on filter – transmission loss across band to be no more than 1% of initial value. BDTF TBD	Contamination during filter build; test and characterisation. Contamination during instrument integration. Once the instrument is integrated all filters and mirrors are protected by the filter at the instrument input. This will need protection by a removable instrument aperture cover. Filters must be pre-baked before integration to avoid risk of molecular contamination.
SMEC (FTS mirror mechanism)	Mechanical parts no or very low susceptibility. Optical encoder may be sensitive to particulate contamination (increased scattering?) or	Signal from optical encoder must be >TBD. Contrast in fringes from optical encoder >TBD	Contamination during sub-system assembly; integration and verification. All parts always exposed?

	molecular contamination. Freezing of H_2O or other molecular species on detector/grating elements much more serious as they work in 400-700 nm band. Roof top mirrors as per mirrors above.	Roof tops must have R>0.99	Contamination during instrument assembly and integration. Once the instrument is integrated the SMEC is protected by input filter. Molecular contamination during cool down if cryostat environment is not clean or sufficiently well pumped.
BSM Mechanism	Mechanical parts have no or very low susceptibility Mirror as per mirrors above	R>0.99	As for SMEC.
Calibrators	No susceptibility. Possible source of particulate or molecular contaminant.	N/A	FTS calibrator may use blackening material that has the potential to shed particles and molecular contamination. Special care must be taken with the preparation and handling of this material.
Structural Elements	No susceptibility. Possible source of particulate and molecular contamination if not cleaned and handled in correct environment.	N/A	Lots of nooks and crannies in the structural elements where particles and molecular contamination might hide. Structure will also absorb small amounts of water (aluminium) and must be pre-baked before integration.
Harnesses and connectors	No susceptibility. Possible source of particulate and molecular contamination if not cleaned and handled in correct environment.	N/A	Insulating material may crack and flake giving rise to particulate contamination. Insulating material may be source of molecular contamination – harness must be pre-baked before integration.
Black Baffles	No susceptibility. Possible source of particulate and molecular contamination (black paint)	N/A	Blackening material as for FTS calibrators.
Cooler	No susceptibility. Possible source of particulate and molecular contamination if not cleaned and handled in correct environment.	N/A	Again lots of nooks and crannies. Also polymeric materials are used in the construction of the cooler.

A calculation of the effect of water ice contamination on quasi-optical components

speed of light $c_0 := 300$

free-space impedance $Z_0 := 120 \cdot \pi$ ohms $\omega(f) := 2 \cdot \pi \cdot f$

Reference:E:\NICKS\MICROCAD\MICROCAD7.MCD

refractive index and dielectric constant of quartz $n_{quartz} := 2.1134 - i \cdot 4.2 \times 10^{-4}$ from Russel & Bell 1967, J. Opt. Soc. Am., 57, 341.

$\varepsilon_{quartz} := n_{quartz}^2$ $\varepsilon_{quartz} = 4.466 - 1.775i \times 10^{-3}$

dielectric constant of HDPE $\varepsilon_{HDPE} := 2.2$ $\varepsilon_{HDPE} = 2.2$

refractive index of ice $n_{ice} := 1.8326 - i \cdot 6.9 \cdot 10^{-2}$ (Warren 1984, *App.Optics*, **23**, 1206.)

dielectric constant water ice $\varepsilon_{ice} := n_{ice}^2$ $\varepsilon_{ice} = 3.354 - 0.253i$

dielectric constant substrate $\varepsilon_{sub} := \varepsilon_{quartz}$ $\varepsilon_{AR} := \varepsilon_{HDPE}$

properties of Gold $\varepsilon_{Au} := 1$ $\mu_{Au} := 1$ $\sigma_{Au} := \left(0.98 \cdot 10^{-6} \cdot 10^{-2}\right)^{-1}$ @80 K

thickness of substrate $t_{sub} := 6$ mm

propagation constants & wave impedances

$$\gamma_{sub}(f) := \frac{2i \cdot \pi \cdot f}{c_0} \cdot \sqrt{\varepsilon_{sub}} \qquad \eta_{sub} := Z_0 \cdot \varepsilon_{sub}^{-0.5}$$

$$\gamma_{AR}(f) := \frac{2i \cdot \pi \cdot f}{c_0} \cdot \sqrt{\varepsilon_{AR}} \qquad \eta_{AR} := Z_0 \cdot \varepsilon_{AR}^{-0.5}$$

$$\gamma_{ice}(f) := \frac{2i \cdot \pi \cdot f}{c_0} \cdot \sqrt{\varepsilon_{ice}} \qquad \eta_{ice} := Z_0 \cdot \varepsilon_{ice}^{-0.5}$$

$$\gamma_{Au}(f) := \sqrt{i \cdot \omega(f) \cdot \mu_{Au} \cdot \left(\sigma_{Au} + i \cdot \omega(f) \cdot \varepsilon_{Au}\right)}$$

$$\eta_{Au}(f) := \sqrt{\frac{i \cdot \omega(f) \cdot \mu_{Au}}{\sigma_{Au} + i \cdot \omega(f) \cdot \varepsilon_{Au}}}$$

$$\left[1 - \left(\frac{\sqrt{\varepsilon_{sub}} - 1}{\sqrt{\varepsilon_{sub}} + 1}\right)^2\right]^2 = 0.761 + 1.081i \times 10^{-4} \qquad \left[1 - \left(\frac{\varepsilon_{sub} - 1}{\varepsilon_{sub} + 1}\right)^2\right] = 0.598 + 1.507i \times 10^{-4}$$

set band 6 frequency limits $f_{band\_6L} := 1410$

$f_{band\_6H} := 1910$

Analysis of a window with matching layers

$t_{AR} := 0.03$ (band 6)

$f_{start} := 1300$ $f_{end} := 2000$ $f := f_{start}, f_{start} + 1 .. f_{end}$

$AR(f) := ABCDtr\_line(\eta_{AR}, \gamma_{AR}(f), t_{AR})$

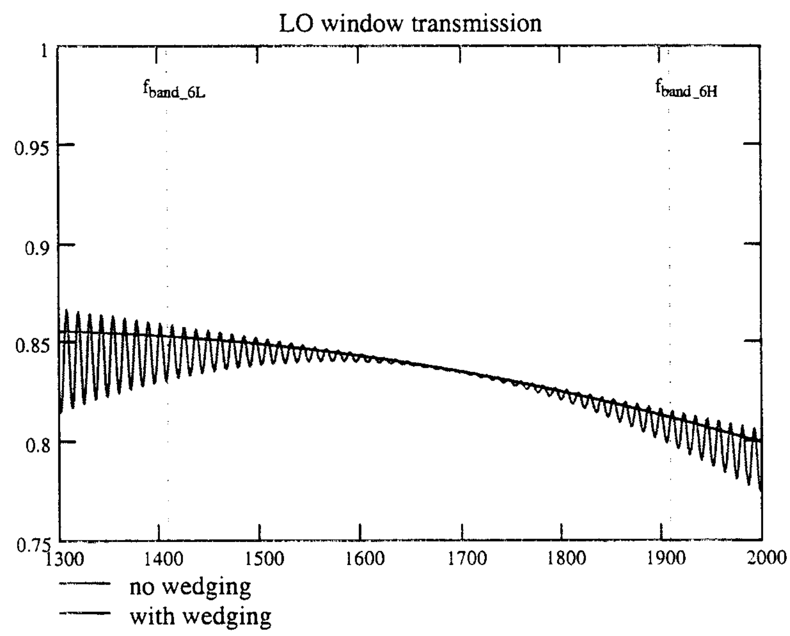
$sub(f) := ABCDtr\_line(\eta_{sub}, \gamma_{sub}(f), t_{sub} \cdot 1)$

$struct(f) := AR(f) \cdot sub(f) \cdot AR(f)$ N.B. there is no wedging of the window here!

voltage reflection coefficient $S22(f) := S_{22}(struct(f))$

voltage transmission coefficient of F-P structure $S21(f) := S_{21}(AR(f) \cdot sub(f) \cdot AR(f))$

voltage transmission coefficient of wedged structure $S21_w(f) := S_{21}(AR(f) \cdot sub(f) \cdot tfr)$



Analysis of a window with matching layers and ice contamination

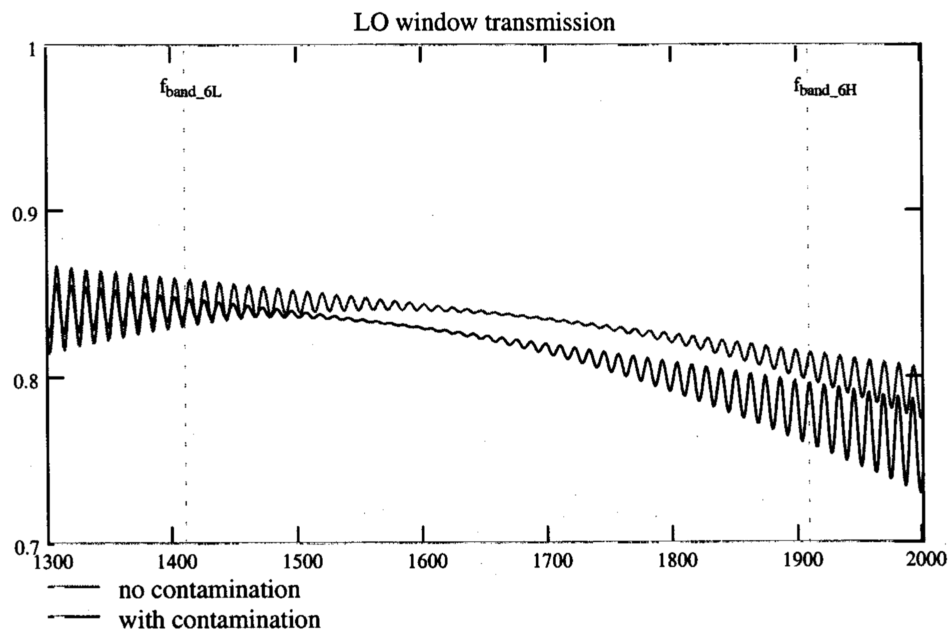
ice layer thickness $t_{ice} := 0.001$ mm

define ice layer $ice(f) := ABCDtr\_line(\eta_{ice}, \gamma_{ice}(f), t_{ice})$

define structure $struct(f) := ice(f) \cdot AR(f) \cdot sub(f) \cdot AR(f) \cdot ice(f)$ N.B. there is no wedging here!

voltage reflection coefficient with contamination $S22_c(f) := S_{22}(struct(f))$

voltage transmission coefficient with contamination $S21_c(f) := S_{21}(struct(f))$



Conclusion

The ice layer detunes the anti-reflection layer which moves the transmission peak to lower frequencies. The effect is roughly equivalent to an increase of AR layer thickness of 1.8 times the water film thickness.

A second effect is the increased absorption. For a 1 μm ice layer on each side of the window the extra loss is about 1.5% on top of ~16% loss in the window.

Analysis of a transmission grid (on a thin Mylar film) with ice contamination on both sides

I neglect the mylar film for this calculation, i.e. I assume a self-supporting ice film of 2 times the contamination thickness.

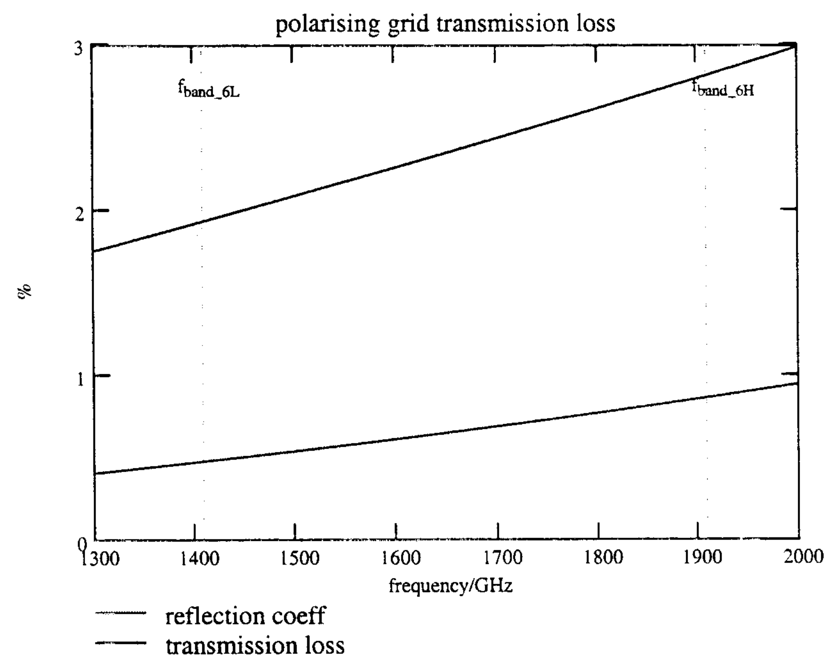
ice layer thickness $t_{ice} := 0.001$ mm

define ice layer $ice(f) := ABCDtr\_line(\eta_{ice}, \gamma_{ice}(f), t_{ice})$

define structure $struct(f) := ice(f) \cdot ice(f)$

voltage reflection coefficient with contamination $S22_c(f) := S_{22}(struct(f))$

voltage transmission coefficient with contamination $S21_c(f) := S_{21}(struct(f))$



$-\left(\left|S21_c(1700)\right|\right)^2 = 0.024$

$\left|S22_c(1700)\right|)^2 = 6.891 \times 10^{-3}$

Conclusion

For a 1 μm ice layer on each side of the film the loss is about 2.8%, around 0.5% is reflected. These reduce to 0.19% and 7×10^{-5} respectively for a 0.1 μm layer on each side.

Analysis of a mirror with ice contamination

ice layer thickness $t_{ice} := 0.001$ mm

Gold layer thickness $t_{Au} := 0.0009$ mm

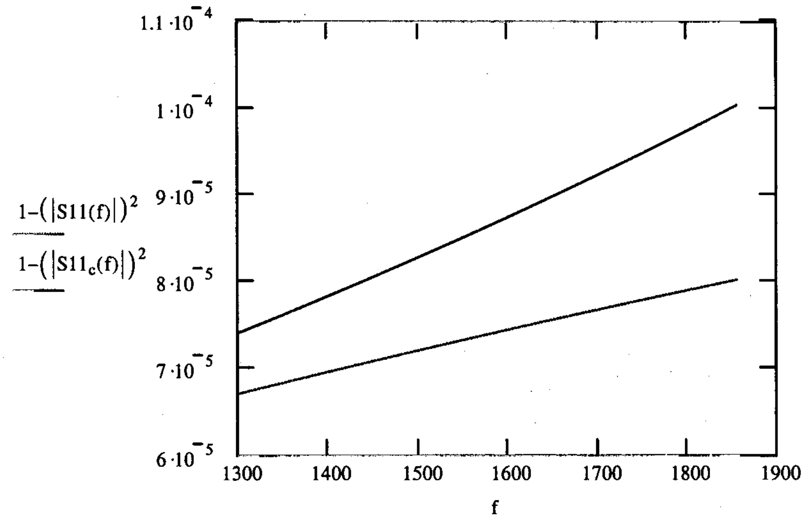
define ice layer $ice(f) := ABCDtr\_line(\eta_{ice}, \gamma_{ice}(f), t_{ice})$

define mirror $mir(f) := ABCDtr\_line(\eta_{Au}(f), \gamma_{Au}(f), t_{Au})$

define structure $struct(f) := mir(f)$ N.B. there is no wedging here!

reflection coefficient without contamination $S11(f) := S_{11}(struct(f))$ $S11(1700) = -1 + 3.838i \times 10^{-5}$

reflection coefficient with contamination $S11_c(f) := S_{11}(ice(f) \cdot struct(f))$ $S11_c(1700) = -0.997 + 0.071i$



Conclusion

For a perfect reflector, a 1μm ice layer gives an extra loss of about 0.0015% (1.5e-5) per reflection. This should be compared with a theoretical loss 0.8e-4. I.e. 1 μm of ice on the mirror gives an 19% fractional increase in the loss, which is negligable.

$$(|S11(1700)|)^2 - (|S11_c(1700)|)^2 = 1.551 \times 10^{-5}$$

$$\frac{.1572}{1.416} = 0.111$$

$$1 - (|S11(1700)|)^2 = 7.676 \times 10^{-5}$$

Analysis of a mirror with ice contamination

ice layer thickness $t_{ice} := 0.001$ mm

Gold layer thickness $t_{Au} := 0.0009$ mm

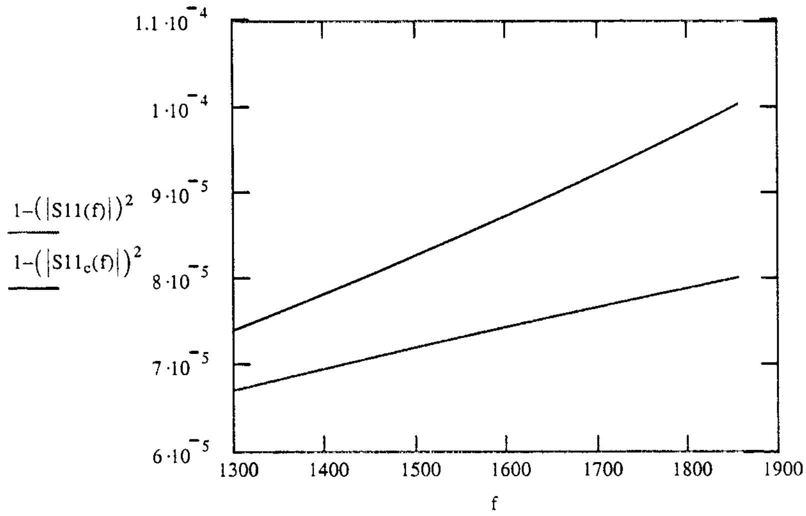
define ice layer $ice(f) := ABCDtr\_line(\eta_{ice}, \gamma_{ice}(f), t_{ice})$

define mirror $mir(f) := ABCDtr\_line(\eta_{Au}(f), \gamma_{Au}(f), t_{Au})$

define structure $struct(f) := mir(f)$ N.B. there is no wedging here!

reflection coefficient without contamination $S11(f) := S_{11}(struct(f))$ $S11(1700) = -1 + 3.838i \times 10^{-5}$

reflection coefficient with contamination $S11_c(f) := S_{11}(ice(f) \cdot struct(f))$ $S11_c(1700) = -0.997 + 0.071i$



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$$\frac{.1572}{1.416} = 0.111$$

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Annex 1

PLANCK HFI

HFI Cleanliness

(Cleanliness Control Plan Presentation)

Contamination Working Group

27 October, 2000

HFI Scientific Objectives

- Measurement of the diffuse sky radiation concentrated by a telescope, on the Focal Plan Unit (FPU) through feedhorns, spectral filters and solid state bolometers.
- Production of 2 maps over most of the sky for 15 months.

➪ 6 bands central frequencies are optimized:

- For CMB anisotropy variations 100-357 GHz
- For detection of galactic clusters 143-217-357 GHz
- For galactic dust emission 545-857 GHz

Wavelength : 0.3 - 3 mm

Cleanliness tasks

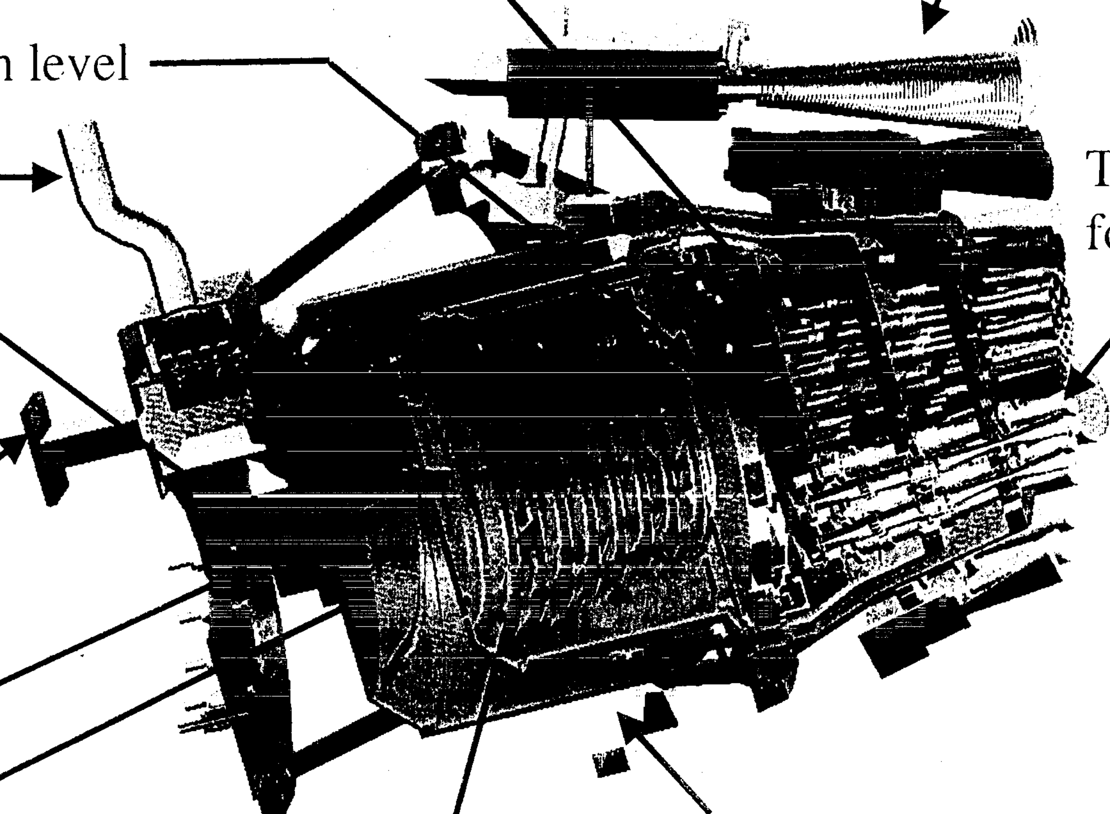
1- Cold stages in FPU from 0.1 to 4K,

2- Interfaces with LFI at 20K,

3- Whole instrument with interfaces with SVM, PPLM at RT.

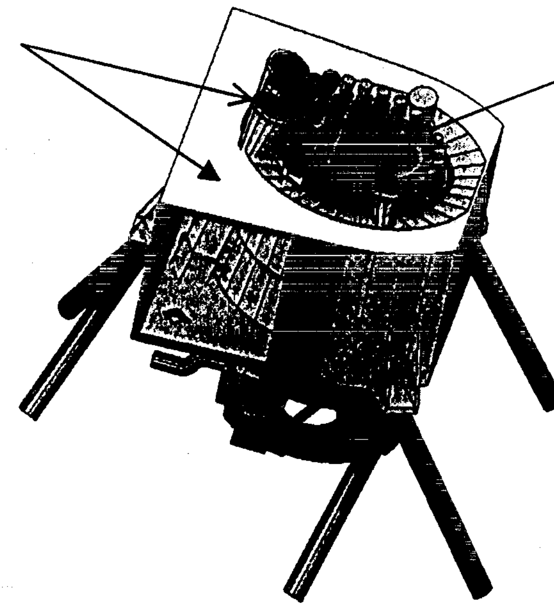
HFI Cleanliness

1- Cryostat details (FPU): *"Russian doll"*



Layout: JJ Fourmond IAS

2- Cryostat interfaces with LFI



Before integration with LFI

↳ Cleaning of:

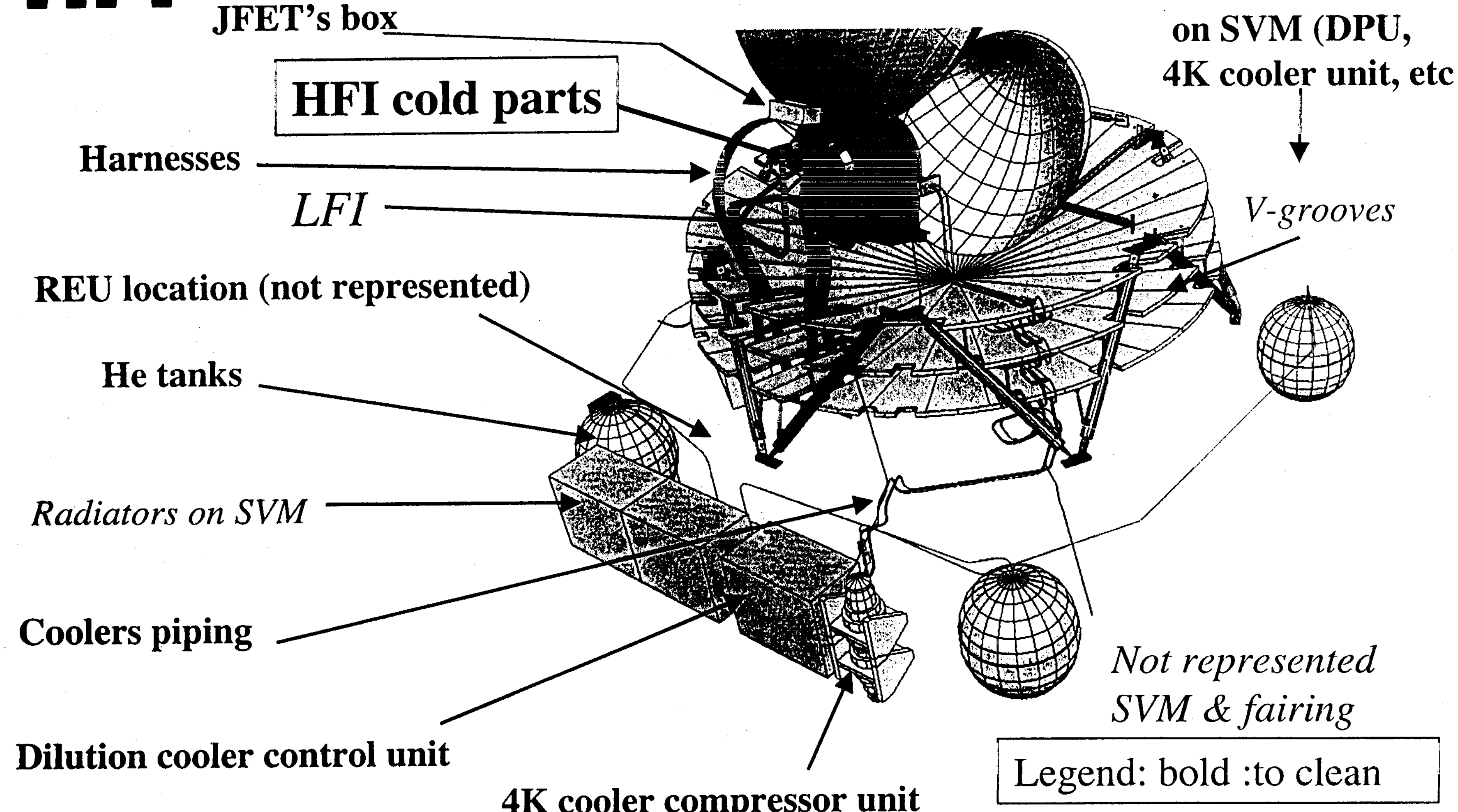
- connectors,
- coolers cold tips and pipes,
- harnesses.

HFI cleanliness budget will be coordinated with LFI budget

Alcatel view

HFI Cleanliness

3-Planck: HFI items



ALCATEL design

PLANCK HFI

HFI Cleanliness

- ESA requirements PT-RQ-04410 for Planck

"At delivery to ESA:

1- Particulate contamination:

Less than 300 ppm inside the cold instrument

Less than than 100 ppm on the outside of these units

2- Molecular contamination:

Less than $2x10^{-7}$ g/cm^2 "

- IAS proposition:

Budget established in function of real needs for HFI (or other items) and appropriated with budget of other instruments:

➩ ESA requirements look too severe

HFI cleanliness requirements Specification (1)

1 - The driver for HFI particulate cleanliness is the scattering by dust, that induces straylight.
Parts that relevant are the telescope mirrors and the horns.
Parts internal to the FPU are also, in a lesser amount, sensitive to dust.

2 - The driver for molecular contamination is the transmission of the telescope and horns. Internally to the FPU, the bolometers are also sensitive to any kind of molecular contamination.

HFI cleanliness requirements Specification (2)

1 - Particulate contamination on optical parts:

- Telescope: less than 1200 ppm (TBC)
This requirement comes from the studies of P.d.M. (Meeting of Sept. 13, 2000), that shows that scattering by dust is the main source of straylight at high frequency. Ideally, lower scattering levels should be wished. Compromises may be necessary.

- 4K Horns: less than 1200 ppm (TBC)
For the same reasons

- Parts internal to HFI-FPU (filters,   ): less than 1200ppm

PLANCK HFI

HFI Cleanliness

HFI cleanliness requirements Specification (3)

2- Molecular contamination on optical parts:

- Telescope: Less than $3x10^{-6}$ g/cm^2 (TBC)

This makes a layer of $0.03 \mu m$ of contaminant, i.e. 10^{-4} wavelength. There is no absorbing material known to be an effective absorber in the sub millimeter domain at this thickness. Numbers still to be given.

- 4K Horns: Less than $3x10^{-6}$ g/cm^2 (TBC)

For the same reasons

- Parts internal to HFI-FPU (filters,): Less than $3x10^{-6}$ g/cm^2 (TBC)

HFI Cleanliness

Budget determination: Concerns and responses

1-Molecular and particulate deposition onto spiderweb bolometers and into contacts:

The *Russian doll* FPU architecture constitutes a succession of protecting screens against molecular contamination: each element is a trap preventing *condensate produces* from arriving up to bolometers.

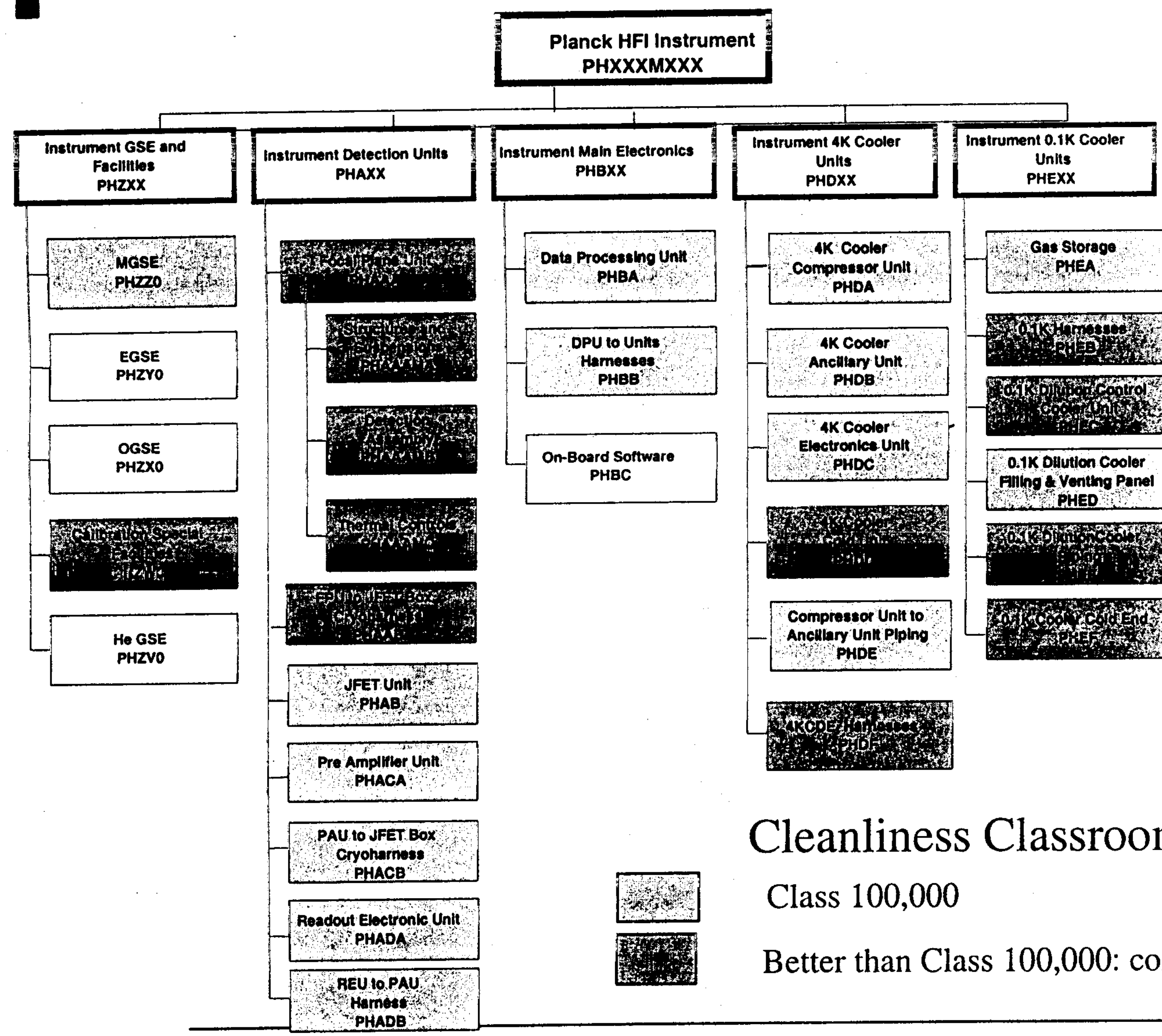
- Bolometers are protected by filters into the 4K box,
- Bolometers are bound to exterior only by a porous dust proof plug for pressure equilibrium,
- No direct visibility between bolometers and exterior feedhorns.

2- Adoption of an assembly sequence preserving the cleanliness of the interior of cryostat (during AIT/AIV and integration).

PLANCK HFI

HFI Cleanliness

HFI Particulate Cleanliness Needs :1st approach



Cleanliness Classroom

- Class 100,000
- Better than Class 100,000: cold units and harnesses

HFI Cleanliness

HFI Particulate Cleanliness Needs : possible approach based on by assembly processes (1/2)

HFI operations	Operation	Institute	Cleanliness Class (FED-STD-209)	Contamination rate (per day)	Duration in days	Instrument proposed budget OF in ppm
Bolometers	- Fabrication	Caltech	100 (TBC)	1.5	TBD	TBD
	- Mounting		100 (TBC)	1.5	TBD	Id
	- Crystal gluing	JPL	1000 (TBC)	12	TBD	Id
	- Test		1000 (TBC)	12	TBD	Id
	- Packaging to delivery to QMW		1000 (TBC)	12	TBD	Id
Feedhorns assembly	- Assembly with feedhorns on 4K plate	QMW	1000 (TBC)	12	TBD	Id
	- Tests		1000 (TBC)	12	TBD	Id
	- Setting of protective cover		1000 (TBC)	12	TBD	Id
Assembly into FPU	- Cleanliness procedure before assembly	[redacted] IAS	1000 (TBC)	12	TBD	TBD
	- 4K box dustproof		1000 (TBC)	12	TBD	Id
Partial budget for cryostat assembly	- **Interior of bolometer**					**better than 1000 ppm**
	- **FPU (4K box)**					**better than 3000 ppm**

Relative humidity 40-50% in cleanrooms and for storage.

HFI Cleanliness

HFI Particulate Cleanliness Needs : 2nd approach based on by assembly processes (2/2)

HFI operations	Operation	Institute	Cleanliness Class (FED-STD-209)	Contamination rate (per day)	Duration in days	Instrument proposed budget OF in ppm
FPU calibration in IAS (without 4K and 20K)	- Separating cable bake-out at 80°C - Protecting cover	IAS	<10,000	60	TBD	TBD
Integration with LFI	- Integration - Global protecting cover	TBD	<10,000 (TBC)	60	TBD	TBD
Delivery to ESA	- Cleaning - Delivery	TBD	<10,000 (TBC)	60	TBD	TBD
Total HFI at delivery to ESA	**All mechanical surfaces**			**<1000 ppm**		

Opening of covers only at ESA . Optical tests made with alignment references on covers (TBC)

Objective: < 5000 ppm at launch ?

Particle Cleanliness strategy

1- Design of HFI:

- Cleaning processes evaluation for reservoirs, tubes, pre-operational feeding on ground (purges) etc..
- Materials chosen generating no particles.

2- Mirrors and baffles cleanable:

3- AIT/AIV:

- Cognizant staff,
- Use of cover for tests and storage in Class 10,000,
- Continuous monitoring of cleanliness on witness samples.

4-Delivery to ESA:

- Cleaning before delivery,
- Visual inspection,
- Packaging according to ESA-PSS-01-202,
- Delivery of validated cleaning procedure.

5- Documentation: List of records.

Particulate Telescope Budget: Proposition (1/2)

1- Remark:

Cleaning of telescope is not in charge of IAS.

2- Proposed budget : (Revisited Alcatel data)

Step/environment	Contamination rate (ppm/day)	Duration days	Obscuration Factor (ppm)
Equipment of telescope after cleaning			500
Dust coming from protective area			400
Integration with LFI/HFI (Class 10,000)	60	5	300
Total at delivery to ESA			1200

Then : tests at ESA, launch preparation for a total budget of 5000ppm