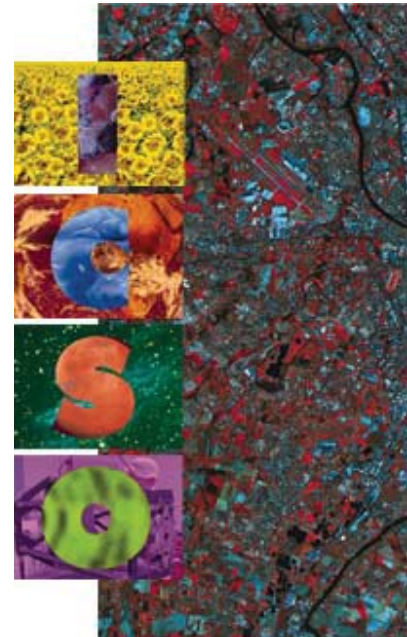# International Conference on Space Optics—ICSO 2000

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Towards a better control of optics cleanliness

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TOWARDS A BETTER CONTROL OF OPTICS CLEANLINESS

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RESUME – La contamination des optiques peut considérablement dégrader les performances en transmission et en diffusion des instruments spatiaux. Prévenir la contamination efficacement demande à intervenir dès la conception des instruments, par des exigences sur les matériaux et par l'ajout de protections (couvercles…). La phase d'intégration et d'essais requiert ensuite des précautions contraignantes (salle blanche, tenues adaptées, capots…) et un suivi permanent par mesure fine du niveau de contamination de l'environnement et des surfaces critiques de l'instrument considéré. Des bilans de contamination sont actualisés le long du projet, d'abord bilans prévisionnels basés sur l'analyse et éventuellement la modélisation, pendant la phase de conception de l'instrument, puis bilans basés sur les mesures de contamination effectuées pendant la phase d'intégration et essais. Enfin, un risque subsiste de contamination accidentelle, qui peut impliquer un nettoyage délicat, voire un démontage.
L'ingénierie propreté développée à ASTRIUM Toulouse et les méthodes généralisées sur les instruments d'optique est présentée ici, y compris la méthode de contrôle de propreté de l'environnement ou des surfaces optiques à l'aide de témoins mesurés par spectrométrie IR et de compteurs en temps réel. ASTRIUM porte actuellement son effort sur le nettoyage sans contact des surfaces et ne nécessitant pas de démontage des optiques, comme la prometteuse méthode UV-ozone.

ABSTRACT – The contamination of optics can considerably degrade the transmission and scattering of spacecraft optics. To prevent efficiently optics from contamination involves introducing since design phase requirements on materials and protections (covers…). Then, integration and test phase demands to implement heavy and stringent means (clean room, specific garment, covers…) and a permanent monitoring by fine contamination measurement of instrument environment and surfaces. Contamination budgets are drawn the project along, first prediction budgets based on analysis and potentially modeling, during design phase, then actual budgets based on contamination measurement during integration and test phase. Finally, the risk still exists to have to clean optics because of hazardous contamination, furthermore to dismount them.
The cleanliness engineering set at ASTRIUM Toulouse is presented here, including the contamination monitoring via witness samples measured by IR spectrometry and via counters. ASTRIUM is presently focusing attention on no contact cleaning like the promising UV-ozone process.

1. INTRODUCTION

The contamination of surfaces can considerably degrade optics transmission and scattering. Generally, transmission is particularly sensitive to molecular contamination and scattering is mainly generated by particles.

The cleanliness of space instrument requires end-to-end care, from design phase to launch campaign. During the engineering phase, protection devices have to be designed (covers, housing, potential purging…), and a decontamination mode may be defined for cryogenic instruments. During integration and test phases, heavy and stringent means have to be implemented (clean room, specific garment, limited access…), the environment has to be controlled, thus to be monitored by measurement using samples and sensors. The optical cleaning is as far as possible avoided, not to damage the surface, as the main general cleaning process is a wipe with solvent, which can scratch the optical surface.

The cleanliness budget method, set on SPOT5 project with CNES collaboration and systematically applied at ASTRIUM Toulouse is presented hereafter, from contamination prediction budget to actual budget based on measurement. The budget is drawn for on-ground phase at delivery step and for in-flight phase at spacecraft end-of-life. The contamination monitoring means are then presented and the cleaning possibilities are discussed.

2. CLEANLINESS ENGINEERING RATIONALE

The outcomes of cleanliness engineering are requirements about spacecraft design (venting routing, covers), materials (out gassing), integration and test environment control and measurement, contamination monitoring of sensitive instruments. One main activity is also to draw contamination budgets like follows. The corresponding logic is depicted by the block-diagram in figure 1.

The on-ground contamination budget is built from the instrument configuration and from the integration and test plan. The instrument configuration, i.e. geometry and potential coverage, allows us to take cavity protection effects into account. The integration and test plan defines the environmental conditions and the duration of each activity during the instrument integration and test. The working environment is characterized by unitary contamination rates, from ESA PSS-01-201 for particles and from ASTRIUM clean rooms internal measurement for molecular contamination, as detailed in section 3 here after. The unitary rates have then to be multiplied by durations.

The in-flight contamination budget is mainly derived from on-ground one in adding the effect of out gassing phenomenon and potential thruster plume impingement effect. Each organic material (resin, glue, paint, MLI…) induces out gassing under vacuum of volatile molecules, which may condensate on surfaces, depending on their temperature. Water is one of the most common out gassed molecule. Thus, porous materials (like foam) and high out gassing materials (like rubber) are forbidden. The level of out gassing can be modeled using dedicated software, as presented in section 4 here after.

The prediction budget is drawn by addition of the contributors here above, on-ground up to launch and in-flight. Would the prediction budget be out of compliance, should some inputs be tighter. The main degrees of freedom are about the application of space conditioning by bake-out to equipment pieces, the addition of covers and the tightening of integration and test environmental conditions.

Finally, the prediction budget obtained by analysis before any hardware activity will be replaced by an actual budget, which takes measurement into account, as long as they are performed along integration and test activities. Therefore, the contamination budget frozen at instrument delivery results from an iterative process.

The diagram in figure 1 hereafter summarizes the working logic and the sequence of activities from cleanliness engineering to demonstrate the compliance of instrument cleanliness at delivery.
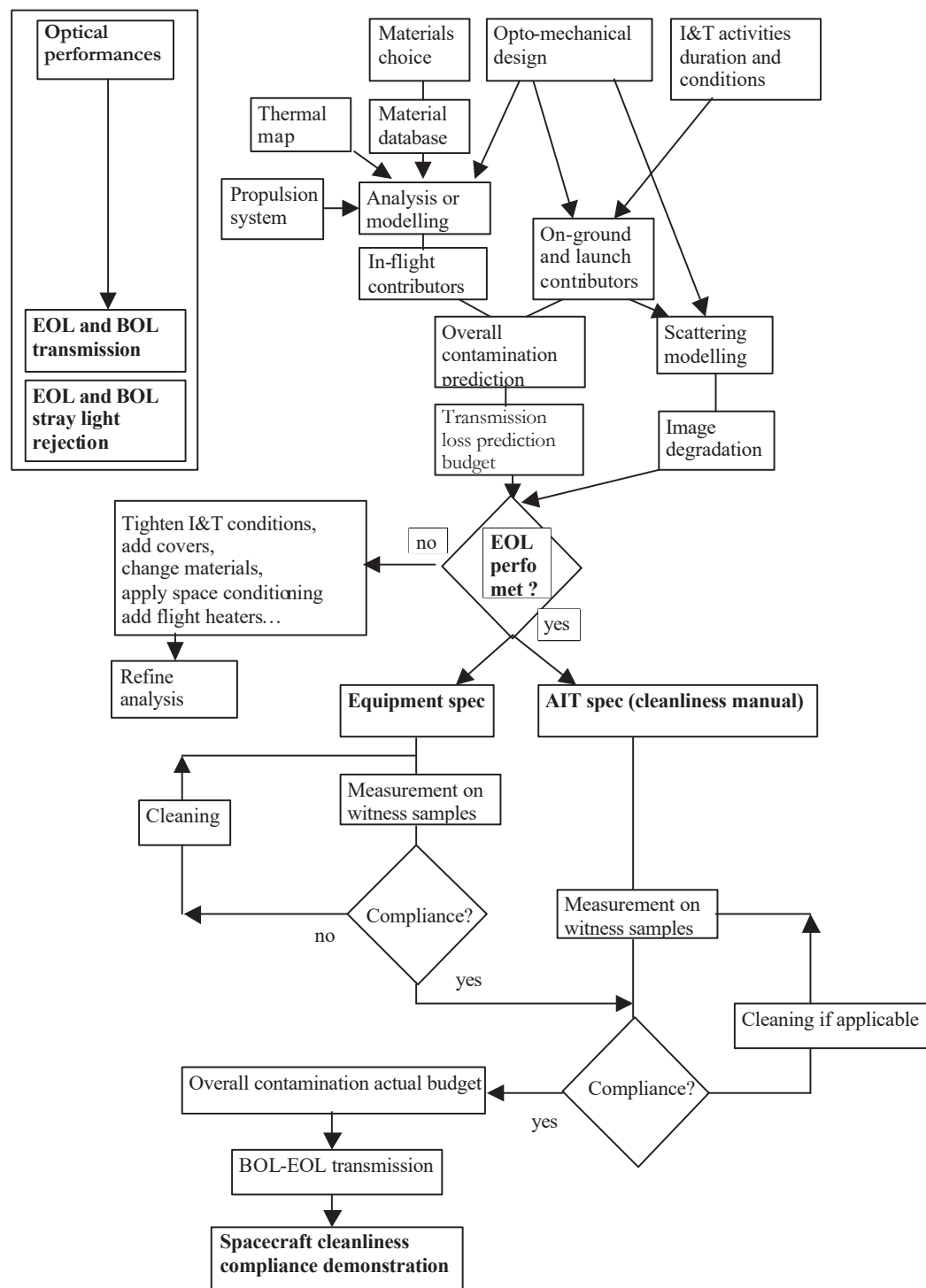
Figure 1 : Cleanliness engineering rationale

3. CONTRIBUTORS

On-ground, the molecules come from environmental vapors, air conditioning and from materials off gassing. A limit is reached thanks to the design of clean rooms and air conditioning system (active carbon filters) and to the working rules (allowed/forbidden materials and processes).

The particles come mainly from the operators (clothes, skin, hair), even if dedicated garments are worn. This is highlighted by the particles counter recording, which shows a contrast of levels between day and night (as evidenced in figure 4). The best is met in clean rooms class 100, pending a cost increase of activities by a factor more than 2 with respect to class 100 000 or 10 000 one[1], due to wearing time, hardware cleaning time and limitation of personal number.

A clean room class 100 (resp.100 000) as per FED-SDT-209 generates on the surfaces a particles deposition rate of 2 PPM (resp.225) per day, knowing that 1 PPM means a surface obstruction ratio of 10^{-6}. A molecular contamination rate of 1 mg/m² per year is assumed for class 100 rooms, 2 mg/m² is assumed for class 100 000 rooms, from measurement at ASTRIUM Toulouse on witness samples exposed over one year (while companies take up to 10 mg/m² into account).

For particles, the relation considered between room class and surface deposition is the following empiric one:

$$\text{Surface daily deposition in PPM} = 0.07 \, (\text{class})^{0.7}$$

During launch campaign, the environment under fairing depends on launcher type. The quality is not better than class 100 000 and out gassing of fairing materials during ascent is strong. With ARIANE launcher, class 100 000 and 4 mg/m² during ascent is assumed (ARIANE manual).

In-flight, organic materials and porous bodies, if any, will generate out gassing and the contamination deposited on-ground will be spread again. To minimize the mass of organic materials, to forbid the use of porous materials, to select authorized ones from ESA or NASA lists is required to each project. Materials are specified by their out gassing rates, the total mass loss (TML) or the recovery mass loss (RML) and the collected volatile condensable material (CVCM), taken from ESA or NASA data bases or measured on a project request. The general requirement of TML <1% and CVCM <0.1% is generally specified to suppliers, and ratio 10 times lower are specified for parts close to sensitive surfaces like optics and detectors. To apply a space conditioning by a bake-out above 65°C over 48h under a vacuum of 1 mPa (10^{-5} mbar) is recommended, and is required each time a part is used in optics vicinity with not compliant ratio.

4. ANALYSIS AND BUDGET

As explained before, the on-ground budget for both molecular and particulate contamination is a sum of contributors, and each contributor is the multiplication of the environment contamination rate by the task duration. The contributors correspond to equipment delivery, instrument integration and test up to delivery, satellite integration and test up to delivery and launch campaign.

Out gassing under vacuum is modeled using OUTGASSING software, ASTRIUM developed software founded by ESA and internally upgraded, which takes into account instrument geometry, temperature map and materials data (TML, CVCM, out gassing kinetic…). However, it has to be kept in mind that the modeling is presently limited by the lack of materials data from technological measurement (particularly about the materials reemission phenomenon). To save cost, an analysis by similarity with another instrument can be performed when the cleanliness requirement is not stringent as much. About thruster plume impingement effect, a dedicated modeling is run using CONTAMINE software co-founded with CNES, to check that thrusters generate low condensation on optics or solar arrays and are therefore satisfactorily located. While measured data are introduced in the actual on-ground budget, in-flight contributors remain theoretical data from analysis.

From the contamination budget, the impact on optical performances is assessed. The loss of transmission factors is computed assuming a full obscuration factor for particles, and assuming absorption factors for molecular deposits. A sample measurement campaign founded by CNES allowed us few years ago to collect spectral absorption data about the absorption of contaminants generated at various level by paints, glues and resins… An example of absorbance measurement is shown in figure 2. About the contamination induced by clean room environment, measurement was performed at ASTRIUM Toulouse on witness samples exposed over one year. The transmission loss is an input to performance engineers, who compute the electronics gain setting range or the increase of signal to noise ratio.
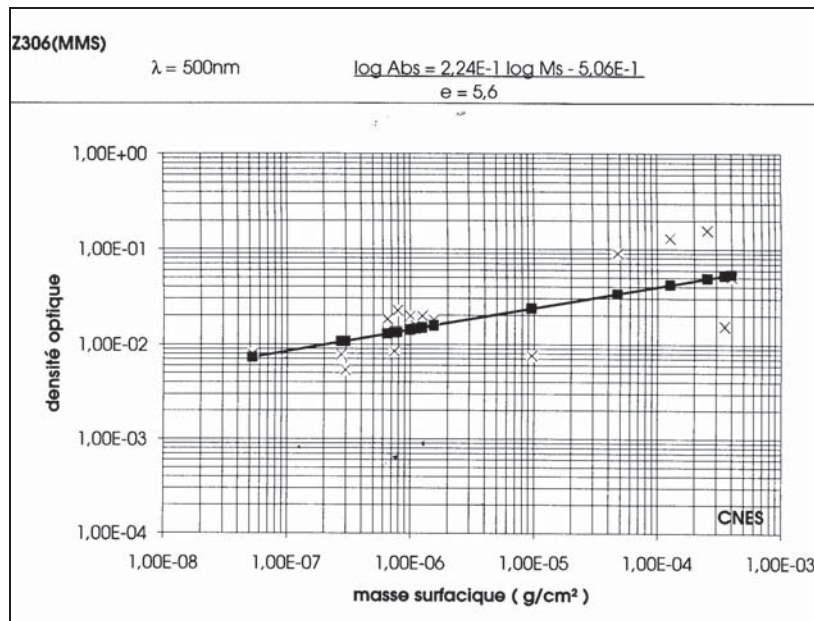

Figure 2 : Example of absorbance measurement versus contamination level for the contamination induced by Z306 black paint out gassing (CNES data)

The generation of stray light by scattering is roughly analyzed by ray tracing method using ASAP software, or more deeply using APART from Breault Research Organization. Nevertheless, the software analysis is limited to particles generated scattering. A sample measurement campaign of CNES allowed us few years ago to collect scattering data about the scattering (BRDF) of contaminants generated at various level by paints, glues and resins... An example of scattering measurement is shown in figure 3. The stray light level is then an input to performance engineers, who computes, e.g. for an imaging instrument, the degradation of image contrast, i.e. of modulation transfer function (MTF).

About both performances, transmission and stray light, the need is strongly dependent on mission parameters (wavelength) and operation constraints (parasitic sources like sun within field-of-view). For instance, UV instruments are much more sensitive than visible instruments to both molecular and particular contamination. A transmission loss of about 10 % per surface is assessed[2] in UV band for a molecular contamination level of 2.5 mg/m², while 0.5 % to 2 % is generally lost over visible spectrum for the same contamination level.

Note finally that, for cryogenic instruments, the concern is also to prevent optics and detectors from contaminants icing. The impact is again on transmission and stray light and can evolve dramatically. Therefore, if a decontamination mode by heating is not possible, a low contamination level is required to the instrument.
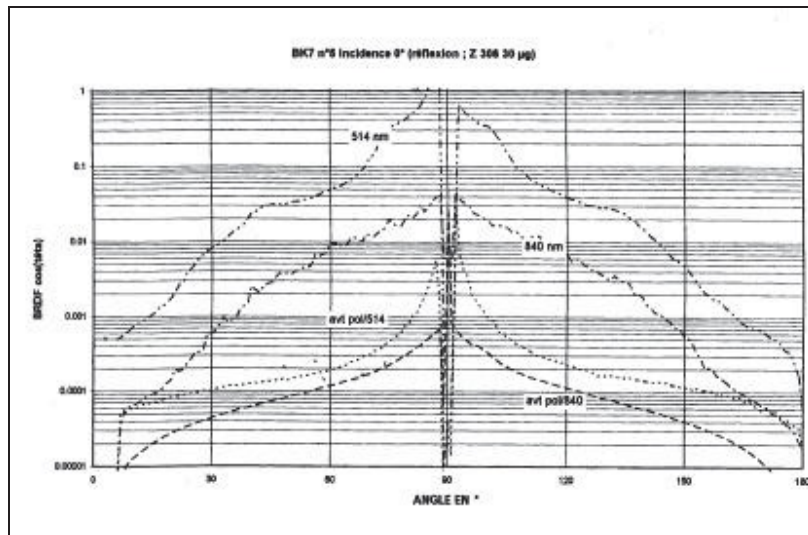
Figure 3 : Example of scattering measurement (BRDF) versus angle, wavelength and contamination level for the contamination induced by Z306 black paint out gassing (CNES data)

5.   CLEANLINESS MONITORING

At ASTRIUM Toulouse, the particulate contamination of integration and test environment is continuously monitored within each clean room by MET-ONE particles counters. The counters are connected to a network, which also records temperature and humidity. See a particles counter record in figure 4, where day/night alternation is obvious. A sampling can be applied onto instrument surface, by tape-lift test method. Particle fall out (PFO) witness samples can also be used and red by the dedicated counter URAMEC. Nevertheless, it is sufficient in most cases to check the environment only and to use the empiric relation given in section 3 here above to derive the surface contamination. The sampling of particles and the use of witness samples are only necessary for the local measurement of instruments submitted to tighten contamination requirement, i.e. for which scattering is very critical.
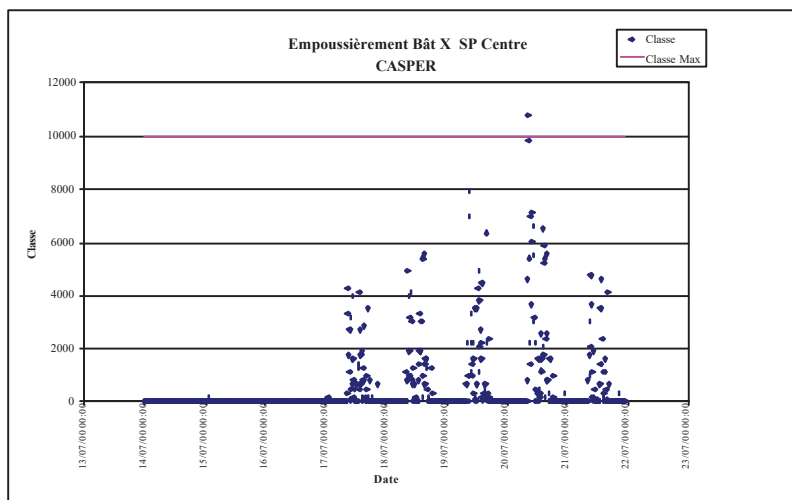

Figure 4 : Particles counter measurement record versus time (one week) in a class 10 000 clean room (note the day/night alternation)

The molecular contamination is monitored via optical witness samples in zinc selenide (ZnSe) crystal, which are fixed close to sensitive surfaces and protected together with them if possible when coverage is placed. Samples have to be placed in representative areas while remaining accessible. The transmission of the samples is analyzed with the FTIR spectrophotometer Magna 750 from NICOLET, shown in figure 5, over 400-4000 cm^{-1} according to ESA PSS-01-705 (standard absorption peaks). The sensitivity with such method and mean is 0.3 mg/m² for hydrocarbon species. See in figure 6 the curves of the raw measurement at various exposure steps of a cumulative sample. It has to be highlighted that the absolute accuracy of the method is highly dependent on the spectrophotometer calibration quality (type of reference material, mass and uniformity of deposit).

Note that new sensors using surface acoustic waves should be promising to monitor the molecular environment of a clean room, and potentially of an instrument in-flight, with high accuracy.

Figure 5 : ASTRIUM Toulouse contamination laboratory with FTIR spectrophotometer
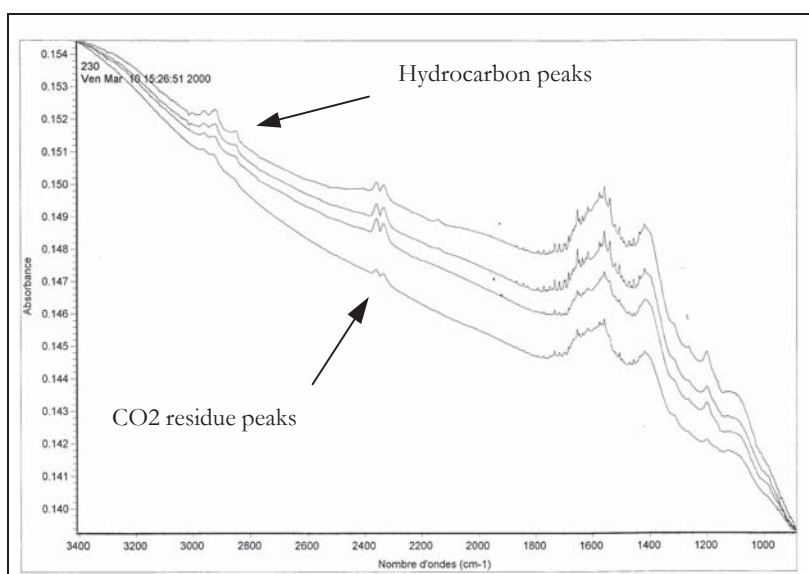

Figure 6 : FTIR transmission raw measurement of ZnSe optical witness sample
(with cumulative exposure measured at various steps)

6. CLEANING MEANS

Against particles, the general method is to remove them using a vacuum cleaner. The method can easily be applied, but the efficiency is limited to big particles. The molecular contamination is difficult to remove and the decision, when optics are concerned, has to be discussed in the frame of a material review board (MRB), which involves the manufacturer of the components. An overall small pollution can be partly removed by heating under vacuum, but the associated cost is very high. A local pollution such as a fingerprint can be removed by a wipe with solvent like alcohol, or acetone then alcohol, pending the risk to scratch the surface (particularly with metal coated mirrors). In any case, a wipe method has to use high purity solvents (spectrometry grade) and high quality dried wipes, and it has to be applied by experimented personal.

That is why no contact methods are investigated for few years, like ozone cleaning generated by UV source[3], or smooth contact methods, like CO_2 snow jet flushing using a gun[4,5], which could complete themselves. Both methods are under investigation at ASTRIUM Toulouse. UV-ozone methods, from usual sources or excimer laser, were compared in 1998-99 to the classical wipe method in the frame of the CNES program named "Groupe conseil pour la qualité des mécanismes du spatial" (GCQMS). See in figure 7 the evolution of CaF_2 sample transmission over IR and visible bands before and after cleaning using UV-ozone method, as efficient as a wipe method.
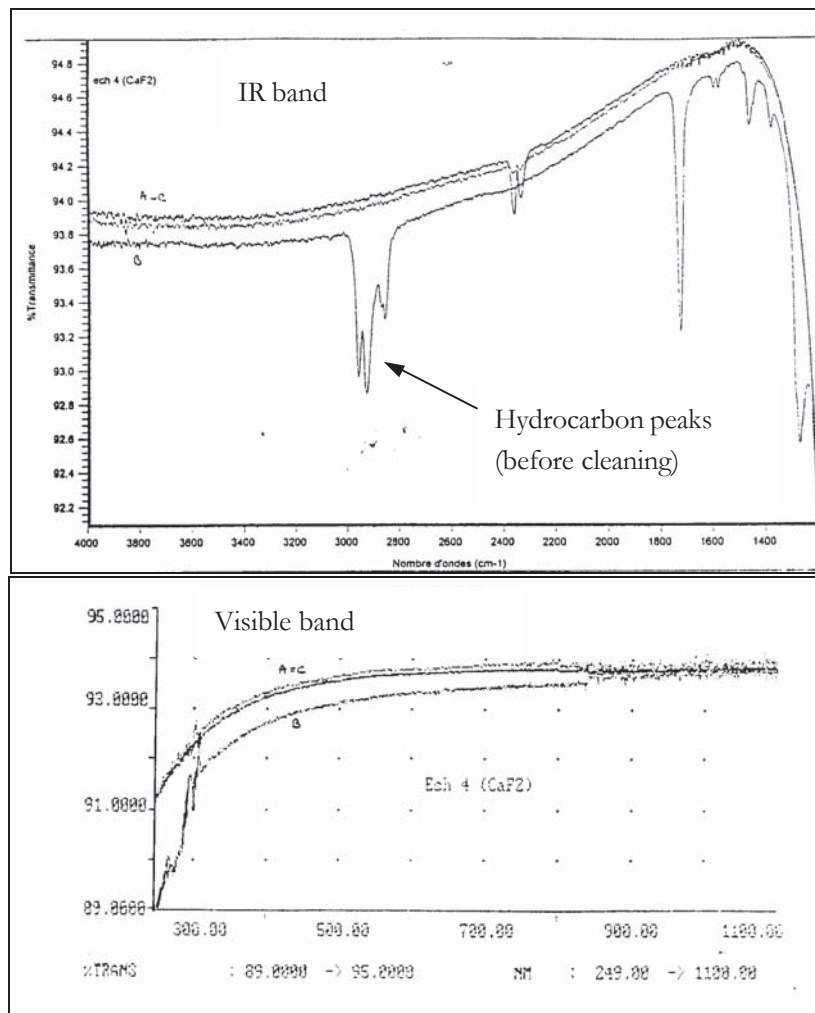

Figure 7 : Evolution of the transmission over IR and visible bands of an optical sample in CaF_2 cleaned by UV-ozone method

MOBIDIC project (Mobile Breadboard Illuminator Dedicated to Instruments' Cleaning), co-founded by CNES and ASTRIUM, is presently running as one following of GCQMS program. It aims at developing dedicated UV-ozone equipment, able to clean local or spread molecular pollution inside an integrated telescope. A breadboard is under test at ASTRIUM Toulouse at the date. The limits and drawbacks of the method have to be clearly identified, like the thermal impact and the safety of surrounding surfaces and components. Note that the equipment has to include an air extraction device with an active carbon filter, to remove both attacked contaminants and ozone residue.

7. CONCLUSION

The cleanliness engineering presented here above allows ASTRIUM Toulouse to control the cleanliness of optical instruments for spacecrafts, thanks to end-to-end process from design engineering to integration and test quality control. Investigations are running now about no contact cleaning methods, like UV generated ozone exposure. MOBIDIC project co-founded by CNES and ASTRIUM is presently running about the development of UV-ozone equipment for the cleaning of integrated telescope.

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