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Dust contamination and in-situ cleaning of ground-based telescope optics: The VLT approach.

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ABSTRACT

It seems to be a fundamental law of nature that optical surfaces become dirty. On-site contamination has been recorded at the ESO La Silla Observatory and at the VLT site over a period of 6 years. Measured data will be presented, and the efforts made at ESO since 1990 to define suitable on-line monitoring and preventive maintenance will be detailed. In-situ cleaning techniques, existing equipment and procedures will be reviewed. Emphasis will be put on the CO_2 snowflake cleaning technique and the integrated cleaning device of the 3.5 m NTT telescope will be described. The preliminary cleaning and protection test conducted on the first finished 8 m mirror at the optical manufacturer's site will be presented as well, and plans for the in-situ cleaning of the VLT mirrors will be explained.

Keywords: Dust contamination, in-situ cleaning, CO_2 snowflake, Peel-off technique, UV laser cleaning.

1. INTRODUCTION

Reflective surfaces of astronomical mirrors degrade as soon as they are exposed to telescope environment. Contamination is mainly dust, molecular contaminants (e.g. oil layers, lubricants,) natural contaminants (e.g. pollens, water marks, bird droppings ...) and a combination of those pollutants with water humidity. All those effects reduce reflectivity and increase light scattering. The light scattered from optical surface irregularities degrades optical performances in several ways.

- it reduces optical throughput since some of the scattered radiation will not even reach the focal plane
- wide-angle scatter will produce a veiling glare which reduces image contrast or signal-to-noise ratio
- the small-angle scatter will decrease resolution by producing an image blur.

To maintain performance goals of the large mirrors, early studies were carried-on at ESO Garching to select *in situ* cleaning techniques adapted to our requirements. Traditional cleaning techniques such as washing, electrostatic annealing, liquid solvents, adhesive roller and various other approaches were already envisaged and sometimes tested with unsatisfactory results or found to be inappropriate to large telescopes.

2. THE AGEING of COATINGS in the OPEN AIR

A long term survey of airborne particles was initiated in 1992 at the VLT observatory of Cerro Paranal to establish the cleanliness of the telescope area before the start of construction works [1]. In parallel with the aerosol survey, an analysis of the damaged caused to mirror coatings was conducted by periodically exposing a set of mirrors to external conditions. This second experiment was initiated at the beginning of January 1993. Intermediate results of this survey were published, beginning of February 1996 [2]. This experiment is still going on, but is now dedicated to evaluating the cleanings techniques selected by ESO for the VLT and their efficiency.

2.1 Experimental set-up

A unit composed of two aluminium coated mirrors with a diameter of 40 mm was installed at 10 m above ground on the meteorological tower at Paranal. One of the mirrors was faced upwards and the second downwards, reproducing the respective positions of primary and secondary mirrors of a telescope.

After an exposure of two weeks, in the open air, the samples were send back to ESO Garching for surface characterisation (reflectivity, scattering and surface roughness). The second set was in the mean time installed on the mast giving opportunity for a continuous survey of dust contamination.

Measuring Tools

The dust contamination of the mirrors was evaluated at ESO Garching by using the µScan™ scatterometer/reflectometer from T.M.A . This device measure the quantity of light scattered by surface irregularities (Bi-directional Reflectance Distribution Function, BRDF) indifferently due to surface micro-defects or dust contamination. Another information provided by this instrument is the surface reflectivity (R expressed in %) at the wavelength of 670 nm. From the specular and scattered light measurements the equivalent micro-roughness of the surface is computed (RMS value expressed in Å).

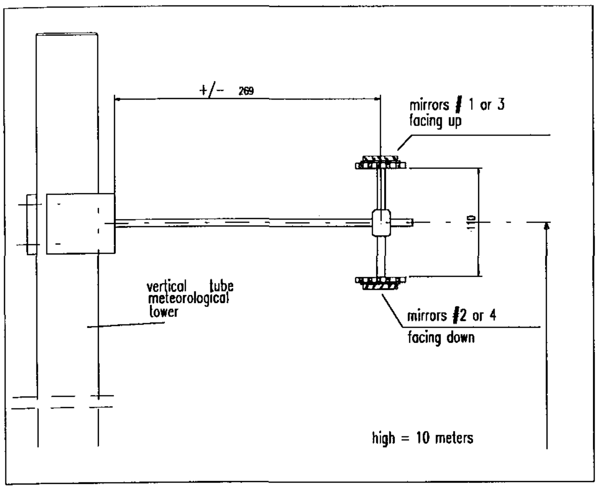

Fig.1 Experiment set-up

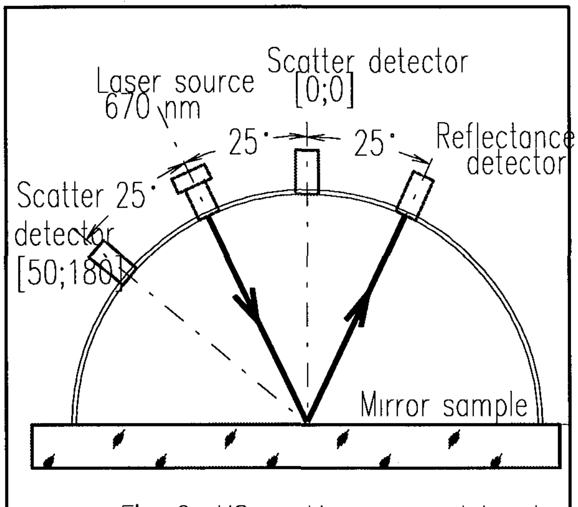

Fig. 2 UScan Measurement head

2.2 Environmental Characteristics

A chemical characterisation of dust samples collected from the Paranal and La Silla sites was carried-out in April-May 1993 just before starting excavations at Paranal [3].

From this report it comes out " The Diorites form the essential part of the rocky mass of Cerro Paranal. A diorite is generally composed of feldspars [1] and amphiboles [2]. Some diorites - and this is valid for Paranal - contain quartz. Quartz and feldspar may represent alone 80% of the rocky volume of Cerro Paranal. The main characteristic of quartz (formula SiO_2) is its resistance to deterioration and its very strong tenacity. Its resistance to all mechanical and chemical action is particularly high which explains that it can be found in nearly all dusts of mineral origin up to the extremely low size of one micrometer. However, one particular phenomenon has to be emphasised: all the slopes exposed to the prevailing wind are carpeted with a more or less thick coat of very fine dust. It is this irregular impalpable powder layer that supplies the whirlwinds in summer time. "

Natural pollution

From airborne particle measurements [1] carried-out at Paranal during the period December 1992- May 1993, before construction work, we can conclude that the site was better than class 30 000 (pc. per CFM)[3] for particles larger than 1 µm and around class 100 000 for particles down to 0.5µm. Measurements performed in La Silla domes showed cleanliness classes ranging between 16 000 to 65 000 (Particles equal to or larger than 0.5 µm at flow rate one cubic foot per minute).

Induced pollution

The actual intensive dust pollution has been generated by the concrete and gravel loading plant as well as the cement silos adjacent to meteorological mast. Also, digging and blasting works should be mentioned.

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[1] Mineral composition based on Si, but more liable to deterioration than quartz.

[2] Amphiboles are silicates having a complex formula associating Al, Fe, Mg, Ca and Na.

[3] According to Fed-Std-209D : Clean Room and Work Station Requirements, Controlled environment, June 15, 1988.

Two periods can be easily identified with different levels of dust contamination: (See graph.1)

1. " Normal " period with moderate contamination ranging from January 1993 to August 1994.
2. " Intense" period with important induced contamination mainly from August' 94 to December' 95

The combination of natural and induced pollution is manifest, especially since April 1994. Induced pollution, during this survey, should be considered as exceptional and as <u>unusual</u> for an observatory site.

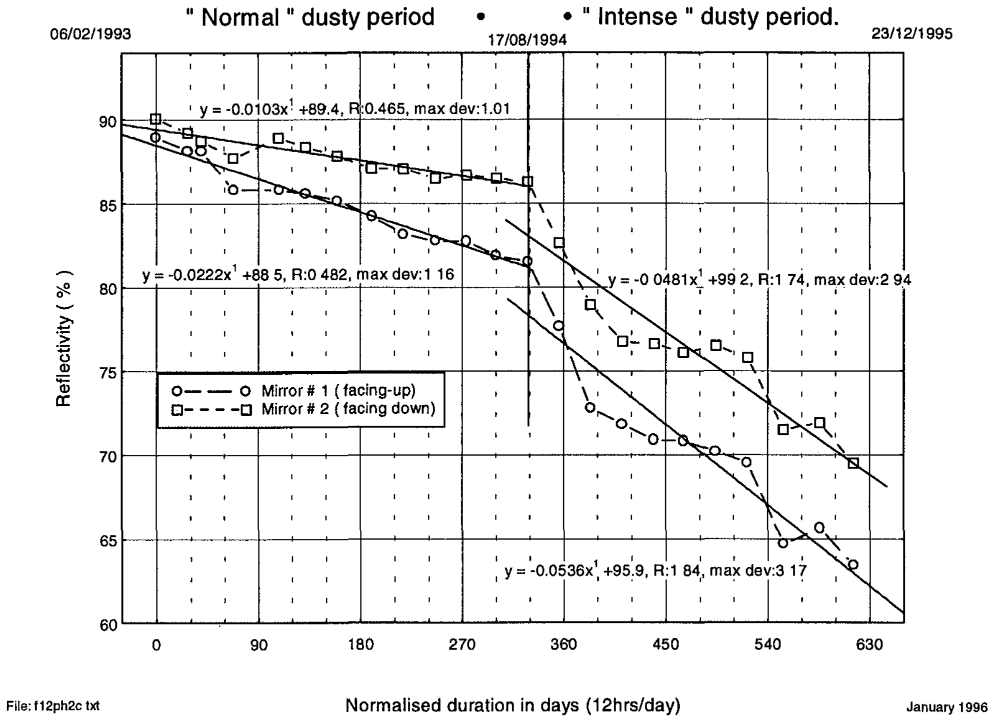
2.3 Presentation of the results

Survey conditions

Due to the construction works the external conditions, and specially the "intense" period, are obviously worse than when the VLT will be in operation. The results are shown to be interpreted as those of <u>accelerated ageing cycles</u>. They will be used to test cleaning efficiency and to optimise the cleaning periodicity.

Evolution law for dust contamination

On graph 1, all the periods corresponding to the exposure of the samples in the open air were joined together and their duration extended by a factor 2. We normalised to an exposure duration of 12 hours per day. The duration of the "normal "period of this survey is likely corresponding to the operation of a telescope at Paranal during one year.



Graph. 1 : Reflectivity evolution for mirrors # 1 and # 2 during the whole survey.

Evolution law: " Normal " period

- By fitting the curve of mirror #2, during the "normal "dusty period, we obtain:

$$R_{m2} \cong R_0 - D/100 \qquad (a)$$

where R_0 is the initial reflectivity after coating (e.g. 90%) and D is the duration in days.

The loss of reflectivity for **mirror # 2** (facing down) is of the order of **3.65 %** per year.

- By applying the same approach to mirror #1, we obtain :

$$R_{m1} \cong R_0 - D/45 \qquad (b)$$

or a loss of reflectivity for **mirror #1** (facing up) of **8 %** per year.

For a three-mirror telescope (e.g. Nasmyth) and assuming that the primary and tertiary mirrors have the same contamination rates, the total loss of reflectivity per year will be around **15 %** .

Evolution law: " Intense " period

When looking at graph.1, we notice that the two curves have similar slopes. The variation law will be identical for the two mirrors (turned upwards and downwards). In this special case of intense contamination, the pollution originating from ground level affects in a similar way the two optical surfaces.

The variation law is :

$$R_{m1m2} \cong R_0 - D/20 \qquad (c)$$

or a loss of reflectivity of **18.25 %** per year and per mirror.

3.- IN-SITU CLEANING TECHNIQUES

After several preliminary tests performed in our laboratory, three cleaning techniques emerged and were more intensively investigated. In our selection preference was given to a "dry " cleaning process allowing its application without constraints to delicate telescope environment.

3.1 UV Laser cleaning

A feasibility study was performed by the Laser Laboratorium Göttingen (LLG) on a number of samples previously exposed to natural dust at Paranal. The various U.V. laser parameters (wavelength, pulse length and fluence) were investigated to achieve surface cleaning without damaging the Al coating and mirror substrate. An optimum arrangement was found well below the material damage threshold.

Cleaning effects are comparable to the peel-off technique and a VLT M1 mirror (52 m^2) could be cleaned within 10 hours using a standard excimer laser.

This approach was not chosen, by ESO, for the following technical reasons:

- Spraying of water close to the laser impact was needed to achieve a maximum cleaning efficiency.
- The risks to damage the Al coating and perhaps the mirror substrate were not fully rejected.
- The cleaning duration (10 hours) was too long and limiting, for safety reasons, the dome access to other activities. (U.V. laser beam reflections)
- Skilled technicians were needed for operation and maintenance of excimer laser.
- Complicated optical beam relays would be necessary to scan the whole mirror surface.
- The concept was based on heavy equipment, difficult to move from telescope to telescope.

3.2 CO_2 snow flake sweeping

From the various cleaning techniques already investigated by ESO, the use of jet spray cleaning technology for removing particles from mirror surface was very soon selected. A prototype was installed in October 1993 on a telescope in operation (NTT) giving promising results.

Liquid CO_2 is expanded through specially designed nozzles producing a mixture of fine solid CO_2 particles or "snowflakes" and gas. These fine particles form a jet stream directed to the surface to be cleaned. The cleaning action comes primarily from momentum transfer from snowflakes to particles contamination. These collisions loosen the dust particles from the surface and then the CO_2 sublimate directly to the gas phase.

However, the method has certain constraints and limitations. In order to avoid leaving any residue on the mirror surface it is important to use very pure CO_2 (e.g. 99.995 % in vol. or class 4.5).

3.3 Peel-off product

To remove tiny particles that stick tenaciously on dirty mirrors the " peel-off " technique is certainly the most efficient one. The peel-off product **XL Clean 5** used in this experiment and more generally at the ESO observatory was developed following a close collaboration between Bayer AG, IRSA GmbH [4] and ESO.

The XL Clean 5 is a polyurethane dispersion in water of white coloration. The material is poured or sprayed onto the optical surface, allowed to dry, and then stripped off from the surface. This product is well suited for cleaning both small and large Al coated mirrors but an appropriate masking of mechanical surroundings is advisable.

A good adhesion of the Al layer on the blank substrate is of paramount importance.

4.- CLEANING PRACTICES at LA SILLA OBSERVATORY.

Two cleaning techniques are used at La Silla, the CO_2 snowflake and the peel-off based on the XL Clean 5.

CO_2 snowflake technique :

Optical Maintenance at La Silla

Since the beginning of 1992 the main telescopes at La Silla received a periodical cleaning (on an average of 1.5 months) by a manual scanning of the mirrors with a CO_2 snowflake spray gun.

On graph. 2 are reported the curves corresponding to the regular cleaning of the main mirrors of the 2.2 m, 1.54 Danish and 3.6 m ESO telescopes. In general, slopes indicating the reflectivity degradation are, at least, 4 times less inclined than the dusty evolution law § 2.3 (b).

When considering the 2.2 M telescope regularly cleaned with CO_2 snowflake technique immediately after recoating we observed a decrease of reflectivity, for a two years period, of about only 4% .

The 1.54 Danish mirror was cleaned 16 times in the operational period between two coatings. Before renewing the coating its reflectivity, at 670 nm, was still 82% or a decrease in reflectivity of about 7%.

Automated Build-in NTT In-situ Cleaning Device

A new concept, the in-situ cleaning, was installed on the NTT in October 1993. The choice of the NTT for developing this prototype installation was also guided by the wish to replace the cleaning system, based on a wet process, originally foreseen and partially implemented, but never completed.

Two arms with CO_2 injectors are connected to a turntable fixed under the M3 unit of the telescope. In rest position they are in the shadow of M3 spiders. During the cleaning operation, on day time, the telescope is tilted by around 60 degrees. Each arm is successively powered, starting the ejection of CO_2 snowflakes from the upper part of the mirror to downwards. The cleaning process was adjusted to last in total 90 seconds.

Results:

On graph 2 was reported the curve corresponding to the evolution law at Paranal during the "normal "dusty period : § 2.3 (b) .

Until the installation of the automated in-situ cleaning device, NTT M1 mirror received 8 manual CO_2 cleanings and its reflectivity was following this evolution law. A large improvement was due to the automatised cleaning period with 11 cleanings, reaching the end of second year of coating with a reflectivity better than 80%. During the third year, the decrease in reflectivity is less than the evolution law. For technical reasons (Big Bang) the NTT main mirror is still not re-coated but automated in-situ cleanings are maintained, limiting in the same time its decrease in efficiency.

Peel-off technique :

On the 3.6 m Telescope

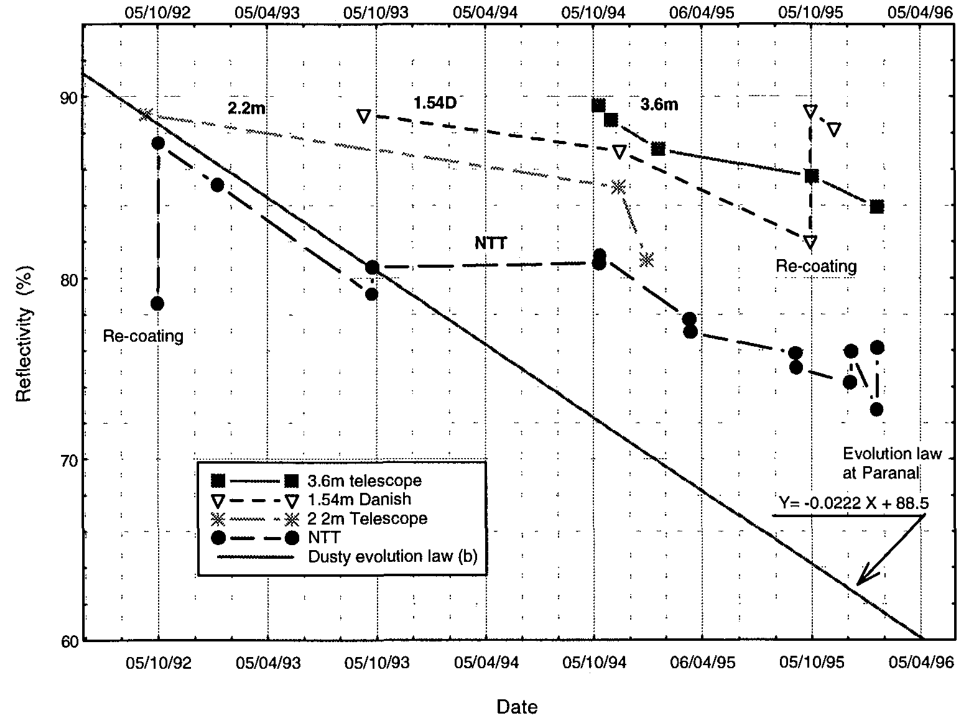
After initial tests on small mirrors, the promising results encouraged us to rapidly experiment on larger mirrors. The in-situ cleaning of the 3.6m mirror, in Oct. 1994, prior to its re-coating, was a significant apprenticeship. The success of the operation was depending of practical aspects as trivial as the easy access in front of the mirror and the possibility to protect the mechanical surroundings. Also was important for the spraying of product the very low relative humidity of the air. The final removal of the dried film in one single piece without breakage was obtained thanks to an uniform spraying. But the in-situ cleaning would be a success if, and only if, the Al coating adheres strongly on the mirror. The removal force exerted on the dried film is less severe than the " adhesive test " described in MIL-M-13508C.

Cleaning performance

The XL Clean 5 film was removed in a single piece but Al coating adhesion on the mirror was poor. On areas where the coating was preserved the cleaning efficiency was :

	Ref. %	RMS in Å
On dusty mirror	78.7	149
After 1st Peel-off	85.4	126
After 2nd Peel-off	86.8	124
On fresh coated mirror	89.5	63

Graph. 2 La Silla Survey : NTT, 3.6m tel, 2.2m tel and 1.54 Danish



Tests on the 8.2 m mirror at REOSC.

Before applying this challenging cleaning technique on a piece as large as our 8.2m mirror blank several qualification tests were performed to validate the product (XL Clean 5) .

- ✔ Climatic tests with and without humidity
- ✔ Physical characterisation (e.g. elasticity, plasticity, induced stresses,)
- ✔ Abrasive tests
- ✔ Resistance to chemicals
- ✔ Long term behaviour

This phase completed, a test bench was installed in our laboratory in order to define the parameters for an optimum application of XL Clean 5 on the large mirror. The following parameters were defined and adjusted:

- ✔ Product viscosity and spraying flow.
- ✔ Type of application (i.e. single layer, multilayers, drying time between layers,....)
- ✔ Projection rate
- ✔ Thickness uniformity and layer overlapping

All the parameters established in the laboratory were transferred on the REOSC CNC polishing machine. The first application, using the computer facilities, was used as demonstrative test. The film removal was conform to our expectations, easy and in one piece. The film resulting from the second application stayed as a protective layer during packing and transportation and will be removed before cleaning the mirror prior to its Al coating at Paranal.

The XL Clean 5 application summarised by numbers

M1 mirror area	52 m^2
Quantity of XL Clean 5 consumed	18 litres
Viscosity	105 s (DIN 4)
Spraying time	1h 22 min
Ambient temperature	19°C
Relative humidity of the air	increasing from 40 to 47 %
Thickness of the dried film	150 µm ± 40 µm
Dried film weight	7.2 kg.

We should admit that the application conditions are far better at the Optical Workshop than could be expected at the observatory.

5. PLANS FOR THE VLT IN-SITU CLEANING

Based on the results of the Paranal Dust Survey, the procured experience by the automated cleaning device installed on the NTT, the CO_2 snowflake technique already extended to most of the telescopes at La Silla, it is possible to seriously envisage the transfer of this cleaning technology to a mirror of larger dimension as our VLT main mirror.

At the first stages of VLT project, various proposals were envisaged to integrate an automated in-situ cleaning device in the M1 Cell. But higher priority was given to a light-weight telescope structure, at the cost of a possible decrease in cleaning efficiency and certainly an heaviness optical surface maintenance.

At the present time, the in-situ cleaning of the VLT mirrors, will be carried-on manually by using an independent lifting device (Cherry Picker) as shown in figure 3. This lifting device will also be used to access all the telescope parts for optical alignment and during the general maintenance of the Telescope structure and enclosure.

Interlocks and safety requirements, as well as collision protection, were included in the Cherry picker specifications to procure a save operational device.

The two cleaning techniques (CO_2 snowflake and XL Clean 5 peel-off product) will be complementary applied:

- The CO_2 snowflake technique will be the baseline and carried on **every 2 weeks** on M1 and M3 mirrors and 3 months on M2.
- Moreover the XL Clean 5 peel-off product will used at least every 6 months on M3 (the most exposed and critical mirror) and locally on M1, to repair severe injuries (fingerprint, oil spots,...).
- A whole cleaning of M1 by using the peel-off product, will be carried on for the first time, just before a scheduled re-coating of the M1 mirror.

A frequent monitoring of optical surface quality (reflectivity and equivalent micro-roughness) will be the main indicator for adjusting the cleaning frequency.

Consumption and cost evaluation

Based on recent tests performed, in our laboratory, on an advanced CO_2 snow-gun equipment, we can estimate the liquid CO_2 consumption was around 1kg/m^2 ± 0.3 . The uncertainty is depending of the technician skill and the level of contamination.

The surfaces to be cleaned for each VLT unit summed 54 m^2 and two cylinders of 35 liters will probably be consumed during the cleaning operation. Considering the actual cost of liquid CO_2 in Santiago (Chile) when delivered by cylinders, each cleaning operation can be estimated to cost less than **200 DM**. Applying a cleaning periodicity of two weeks we have to consider almost 25 operations during one year and the annual cost per VLT Unit would be around 5000 DM.

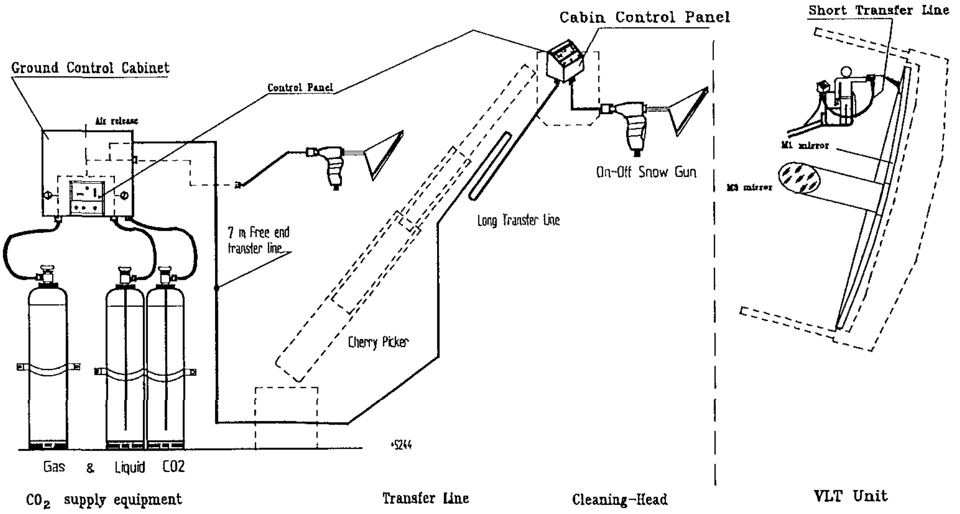


Fig. 3 Layout of the CO2 Cleaning Module

6. CONCLUSION

It is evident that any loss of light at the various reflections bringing photons to Cassegrain, Nasmyth and Coudé foci can be directly translated into a smaller effective aperture of the telescope or in an increase of integration time. Tools are existing and already tested to limit this reduction in efficiency of large and expensive telescopes. A regular and effective dust removal including appropriate surface monitoring will be implemented at Paranal for the Optical Maintenance of the VLT .

7. ACKNOWLEDGEMENT

We wish to acknowledge the considerable contribution of the many people involved in the Site Evaluation Team of Paranal without them this investigation would not have been possible. Many thanks also to M.Sarazin for his very helpful comments.

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ESO Internal report.

[3] Chemical analysis of dust samples from Paranal and La Silla sites.
Doc: VLT-TEL-94/0001 dated 07/01/1994. Dolomieu Institute Grenoble (France)

[4] The XL Clean 5 peelable product is commercially available at :
IRSA lackfabrik Irmgard Sallinger GmbH Contact person : Mr Schlinder
An der Günz 15
D- 8909 Deisenhausen Germany