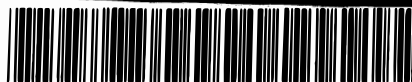CERN-ISR-VA 72-7?

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CERN-ISR-VA/72-47

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STUDY OF A CRYOPUMP FOR POSSIBLE USE ON THE ISR

by

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Geneva, 6th November 1972

ABSTRACT

From the analysis of the two elementary vacuum systems (long and short magnet regions) which constitute the major part of the ISR and neglecting in first approximation special components of unknown outgassing rate and irregular distribution, it seems to be possible to reach pressures not higher than about 4×10^{-12} torr by adding a cryopump to each ion pump in the regions of interest. Such a cryopump, here dimensioned both from the vacuum (pumping speed and ultimate pressure) and from the cryogenic (liquid helium boil-off rate and operational life time) points of view, will help in reducing the background for physics experiments when mounted on the up-stream arms of the intersection regions, and in general, might offer the possibility of increasing the intensities of the circulating beams by reducing beam induced pressure bumps.

1. Introduction

The Intersecting Storage Rings for protons have been designed for circulating proton currents of 20 A in both rings. The original vacuum specification to achieve these intensities was a pressure of 1×10^{-9} torr inside the approximately two kilometres of vacuum chamber constituting the machine. Although the 300 sputter-ion pumps (of 350 ℓ/s pumping speed for N_2) initially mounted provide an average pressure of 1×10^{-10} torr[*] (more than 90% H_2, with traces of water, CO and hydrocarbons), unexpected pressure rises have limited the beam intensities which can be provided for physics runs to 7 A in both rings[1]. These pressure rises are due to ion bombardment of the walls of the vacuum chamber[1] and might be reduced by increasing the pumping speed per unit length of vacuum system (i.e. the number and/or the pumping speed of the pumps) and by better cleaning the bombarded surfaces. An improvement programme is in progress in both these directions, and in particular, about 500 titanium sublimation pumps are now being added. In the regions already modified, pressures of 1 to 4×10^{-11} torr have been achieved.

Only after the completion of this programme will it be possible to decide whether or not this is enough. However, it is already known that for particular regions even lower pressures are desirable; this is the case, for example, of the up-stream arms of the intersection regions, where the beam-gas interactions are a source of spurious events disturbing the nuclear physics experiments.

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[*] all pressures will be expressed in terms of N_2 equivalent, i.e. for H_2, they will be about 3 times lower than the true H_2 pressure; if cold surfaces are present, the quoted pressures are intended to be measured at room temperature.

It is therefore important to study the possibility of ulteriorly improving the vacuum in various points of the machine; we will estimate in this paper the pressures which can be obtained in the magnet chambers when adding on top of each sputter-ion pump a condensation cryopump. An "ad hoc" dimensioned cryopump suitable for reaching pressures in the low 10^{-12} torr pressure range will be presented.

2. The Vacuum System and the Choice of the Pumping Speed

The ISR vacuum system, as already described[2][3][4], consists of about two kilometres of stainless steel pipe of cylindrical (160 mm diameter) or elliptical (50 × 160 mm) cross section. With the exception of the cylindrical straight sections it can be considered as a periodical structure obtained by repetition of the two different elementary units (one for the outer and one for the inner arcs respectively) shown in Figure 1.

Along the path of the beam the pressure increases parabolically from P_{1A}, P_{1B}, to P_{2A}, P_{2B}, which represent therefore the lowest and the highest pressures of practical interest in the two systems A and B. These pressures can be calculated, assuming a H_2 outgassing rate of 2×10^{-13} torr ℓ/s cm^2 (average measured H_2 outgassing for the stainless steel of the ISR vacuum system) as a function of the pumping speed S (for H_2) of the pumping station P. The results, shown in Figure 2, permit us to derive the following interesting observations :

- the vacuum systems A and B are conductance limited at about 3 and 1.5×10^{-12} torr respectively; the ultimate pressure is practically independent of the pumping speed for values of S above 10'000 ℓ/s and it decreases by only 25% for S increasing from 2000 ℓ/s to infinite;

- the highest pressure in both systems does not exceed 4×10^{-12} torr for S = 2000 ℓ/s.

This value, which refers to the long magnet chamber, is certainly pessimistic because it has been calculated without taking into account the titanium sublimation pump which will be added in the central point of the chamber. It is not possible to foresee the performances of this pump at these pressures; however, the effective pressures P_{1A} and P_{2A} will certainly lie between the curves $P_{1A} - P_{1B}$ and $P_{2A} - P_{2B}$ of Figure 2, respectively.

In conclusion, it seems possible to reduce the pressures corresponding to the final situation, after the installation of the titanium sublimation pumps, by a factor of ten by properly choosing the pumping units. The experience so far gained on cryopumping in our laboratories permits us to state that such an improvement can be obtained by adding on top of each sputter-ion pump a cryopump having a pumping speed for H_2 not lower than 2000 ℓ/s in the low 10^{-12} torr pressure range. Besides the immediate advantage of reducing the background for physics experiments, cryopumping will reduce by a factor of ten the initial rate of ion bombardment to the walls of the vacuum chamber for a given beam current; furthermore, it will offer higher pumping speeds for the majority of the gases released during the pressure rises, and will therefore reduce their importance.

3.   The Determination of the Parameters of the Cryopump

We will base our discussion on the model of cryopump already developed for the ISR[4] (Figure 3). As this figure shows, it is a bath cryopump, much more simple and reliable than a circulation cryopump particularly when, like in our case, the pumps are not accessible because of the radiation hazard and they work at reduced temperature $(2.3^{O}K)$. The choice of operation at $2.3^{O}K$ follows from the need of avoiding periodical regenerating of the pumping surfaces; in fact in our case a normal metal surface might be saturated by H_2 in about 100 days, and the H_2 saturation pressure at $4.2^{O}K$ is about 2×10^{-6} torr. When working at $2.3^{O}K$ the saturation pressure can be as low as 2×10^{-13} torr[4][6] and independent of the quantity of condensed H_2 over several years.

A. Vacuum Considerations

Independently of the nature of the pump, the correlation between the physical quantities describing its performance is given by the formula :

$$S = S^* \left(1 - \frac{P_u}{P}\right) \qquad (1)$$

with P_u = ultimate pressure of the pump

S = pumping speed at the pressure P

S^* = pumping speed at $P \gg P_u$.

The unique feature of a condensation pump is that P_u (in this case equal to $P_o + P_s$, where P_o is the ratio of the H_2 degassing rate from room temperature walls of the cryopump over its pumping speed for H_2 and P_s is the H_2 saturation pressure at $2.3^o K$), can vary over several orders of magnitude since P_s is a function of the quantity and of the energy distribution of the thermal radiation absorbed by the condensing surface[4)5)6)]. Different surfaces give different P_s for the same radiation load: a silver coated surface, (the best we found up to now from this point of view between the materials of practical interest), can yield a P_s value as high as 10^{-9} torr if immersed in a room temperature cavity. When reducing the quantity of thermal radiation by means of liquid nitrogen cooled baffles, P_s decreases proportionally at the beginning, approaching finally an asymptotic value of about 2×10^{-13} torr (due to radiation from $77^o K$) when the $300^o K$ radiation load approaches zero. This implies that the optimization possibilities of this pumping technique consist in finding the substrate yielding the lowest P_s for a given radiation load and the baffle (geometry and material) presenting the maximum value for the ratio of the molecular to the radiation transmission. Independently of this optimization process, for a given choice of pumping surface and baffle, to reduce P_s means to increase the number of baffles, i.e. to reduce S^*. To dimension a condensation cryopump therefore means firstly to choose a P_s value in such a way that S per surface area be maximum at

the operating pressure; after this, the area of the pumping surface must be fixed to give the S value required. Our needs in the present case (Figure 2) are a relatively low pumping speed at very low pressures : therefore, P_u must be in the 10^{-13} torr pressure range.

For a P_u value of $3(\pm 1) \times 10^{-13}$ torr we have already obtained[4] (for H_2) $S^* = 5 \pm 0.5$ ℓ/s cm^2 by means of silver plated condensing surface screened by two pairs of 60° chevron baffles coated with aluminium oxide. On this basis we will choose a condensing surface diameter of 250 mm (up to this value the dimensions of the cryopump are compatible with the available room), resulting in a S^* value of 2400 ± 240 ℓ/s for H_2. From this choice and from Figure 2 follows the set of values

$$P_{1A} = 1.5 \times 10^{-12} \text{ torr} \quad P_{2A} = 3.9 \times 10^{-12} \text{ torr}$$

$$P_{1B} = 1.2 \times 10^{-12} \text{ torr} \quad P_{2B} = 2.2 \times 10^{-12} \text{ torr.}$$

As already said, the quoted values of P_{1A} and P_{2A} are probably rather pessimistic because of the effect of the additional titanium sublimation pump in the middle of the long magnet vacuum chamber; the values corresponding to the so modified situation will lie between $P_{1A} - P_{1B}$ and $P_{2A} - P_{2B}$ respectively.

In the previous discussion only H_2 has been considered, and this for two main reasons:

- the outgassing rates from stainless steel are negligible for the other gases (< 1% of the figures for H_2).

- H_2 is the only gas presenting significant P_s values in the operating pressure range.

Nevertheless the gas composition during the pressure rises produced by circulating protons (40% H_2, 40% CO, 20% water vapour and hydrocarbons[1]) is such that the pumping situation for other gases must also be considered.

The S values of the proposed cryopump of $\simeq$ 500 cm^2 pumping surface area will be as follows (P_s is always negligible) :

$$CO - N_2 = 650 \; \ell/s$$

$$CH_4 = 850 \; \ell/s$$

$$A = 550 \; \ell/s$$

$$H_2O = 8500 \; \ell/s$$

(The very high figure for H_2O is due to the pumping of the 77°K baffles). Although the comparison with the corresponding values of Ti sublimation pumps is difficult because they are poorly reproducible, we can state that :

- for CO - N_2 the pumping speed increase is small, approximately 20%.

- for CH_4 and A the increase should be of $\simeq$ 400% at high pressures and practically infinite in the 10^{-12} torr pressure range, where the pumping speed of the sputter ion pumps is practically zero (these gases are not pumped by sublimation pumps).

- for H_2 the increase will be of $\simeq$ 50% at high pressures, and will increase to a much larger figure in the 10^{-12} torr pressure range, where the operation of sublimation pumps becomes problematic.

B. Cryogenic Considerations

Since the silver coating used for the condensing surface was also found to supply the lowest radiation absorption rate between all the materials tested in our experimental cryostat[4), the whole liquid helium container of the cryopumps already made has been silver plated. The ratio of absorbed to the total impinging radiation measured for 5 different silver coated surfaces and various radiation loads was 1.15 ± 0.15% (maximum error for all the measurements). This means that such a surface surrounded by a closed liquid nitrogen cooled screen absorbs $2.6 \pm 0.3 \times 10^{-3}$ mW/cm^2.

On this basis it is possible to determine, as shown in Figure 4, the liquid helium consumption as a function of the height h of its container for different efficiencies of the screens. Since each centimeter of height (see Figure 3) presents the same quantity of liquid He container surface to the liquid nitrogen temperature, the helium boil-off rate increases proportionally to h. The straight line does not cross the origin because when h = 0 the conduction losses (a in Figure 4) and the 77°K radiation losses (b in Figure 4) on the top and bottom of the liquid helium container are still present. Any radiation filtering through the screens introduces an additional constant, i.e. produces a translation of the line towards higher consumptions; for example, for a room temperature radiation transmission of 1/100, the additional constant (c in Figure 4) is equal to b (h = 0). The line corresponding to the efficiency of the chosen screen (the aluminium oxide coated double chevron has a radiation transmission of about 5×10^{-5}) practically overlaps the one corresponding to zero transmission.

What is more relevant in our case is the dependence of the life time of a filling on the height of the liquid helium container, as shown by Figure 5. Observe that the slope of this curve (i.e. the life-time increase per unit of height increase) decreases with h, and becomes zero for h → ∞. This means that L approaches an asymptotic

value (71 $\pm$ 8 days) when the vertical surface of the helium container is much bigger than the surface of the top and bottom, and that the situation is more favourable for small h values. For example, when h = 2 (1 litre volume) L $\simeq$ 8 days, whilst when h = 10 (5 litre volume), L = 27 days only. It is therefore important to choose the minimum value of h compatible with the life time requirements. Since we need at least L = 34 days (at 4.2, corresponding to 24 days at the operational temperature of 2.3°K) we have chosen h = 200 mm (10 litre volume), supplying a calculated life time of 40 $\pm$ 5 days at 4.2°K.

4. Conclusions

The calculated pressure distributions for the two vacuum systems considered (short and long magnet chambers, which together constitute about 85% of the ISR vacuum system) show that pressures lower than $\simeq 4 \times 10^{-12}$ torr can be obtained everywhere when pumping with pumping speed $\simeq$ 2000 ℓ/s for H_2. This pumping speed can be obtained by means of the condensation cryopump described above which is shown in Figure 6 in the proposed position. It has the following characteristics :

Ultimate pressure P_u after H_2 saturation at 2.3°K : $3(\pm 1) \times 10^{-13}$ torr

Pumping speed S^* (for H_2) : 2400 $\pm$ 240 ℓ/s

Liquid helium consumption (cm^3) : 250 $\pm$ 30 per day

Life time at 4.2°K : 40 $\pm$ 5 days

The pressure situation obtained by means of this cryopump could represent an improvement of about a factor of ten with respect to the situation already obtained by means of titanium sublimation pumps. Although the most immediate consequence of this improvement is probably the possibility of strongly reducing the background from up-stream arms disturbing the nuclear physics experiments, cryopumping could eventually help in increasing the intensities of the circulating proton beams by reducing beam induced pressure rises in critical regions.

5. <u>Acknowledgements</u>

6. <u>References</u>

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2) E. Fischer, Two Kilometers at 10^{-10}, the CERN Intersecting Storage Rings for Protons, J. Vac. Sci. Technol. <u>9</u>, 1208 (1972).

3) B. Angerth, Equipment for total and partial pressure measurements in the ISR Ultrahigh Vacuum System, Vacuum, vol. 22, pp. 7-14 (1972).

4) C. Benvenuti, R.S. Calder, An Application of Cryopumping to Colliding Beam Physics Experiments, Supplement to the Review "Le Vide", No. 157, pp. 29-37.

5) C. Benvenuti, A cryostat for the experimental optimization of very low pressure condensation cryopumping, CERN 72-3.

6) C. Benvenuti and R.S. Calder, The desorption of condensed hydrogen from various substrates by infrared thermal radiation, Physics Letters, vol. 35 A, pp. 291-292.

Figure 1

The two elementary vacuum units of the ISR Vacuum System :
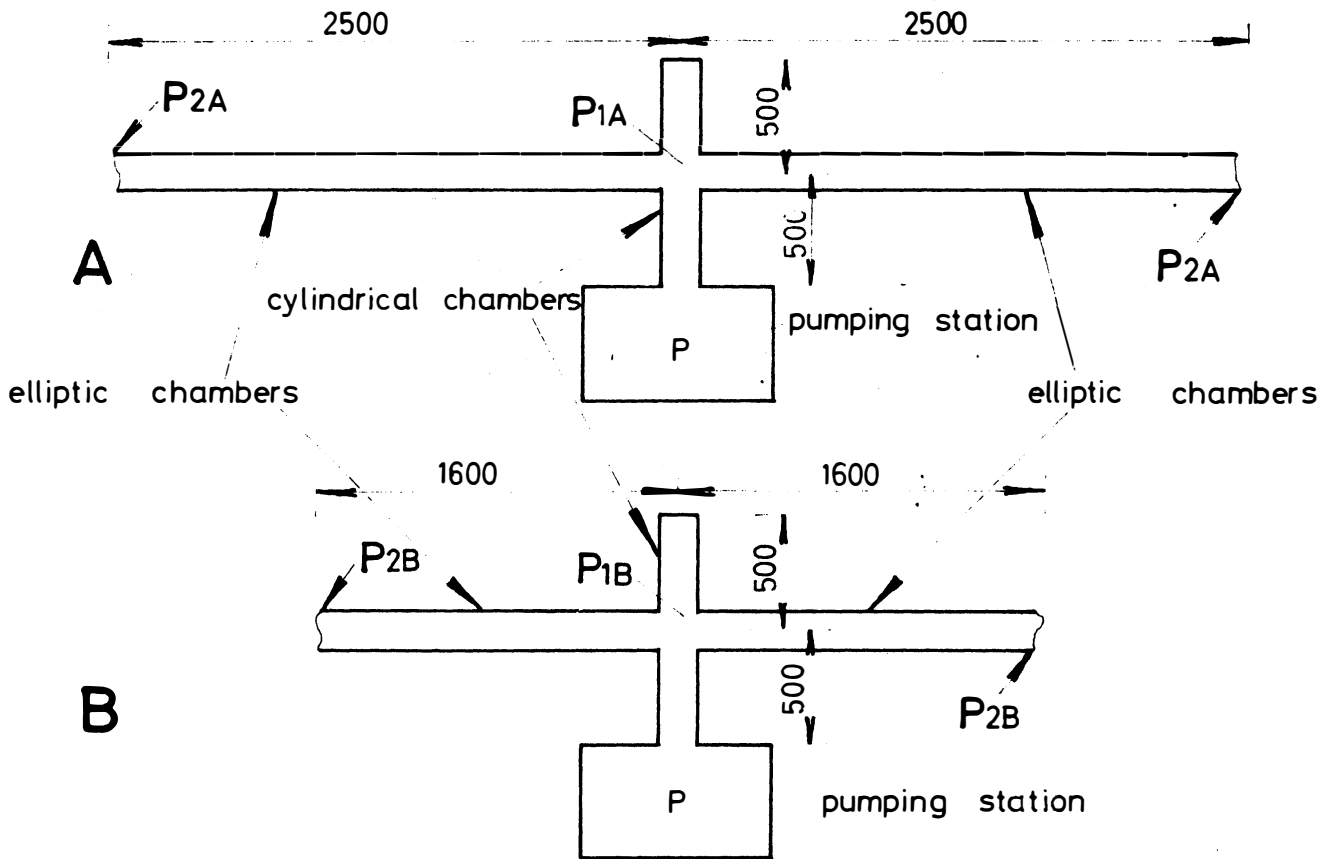
A : outer arcs

B : inner arcs.

Figure 2

Pressure variation as a function of the pumping speed S
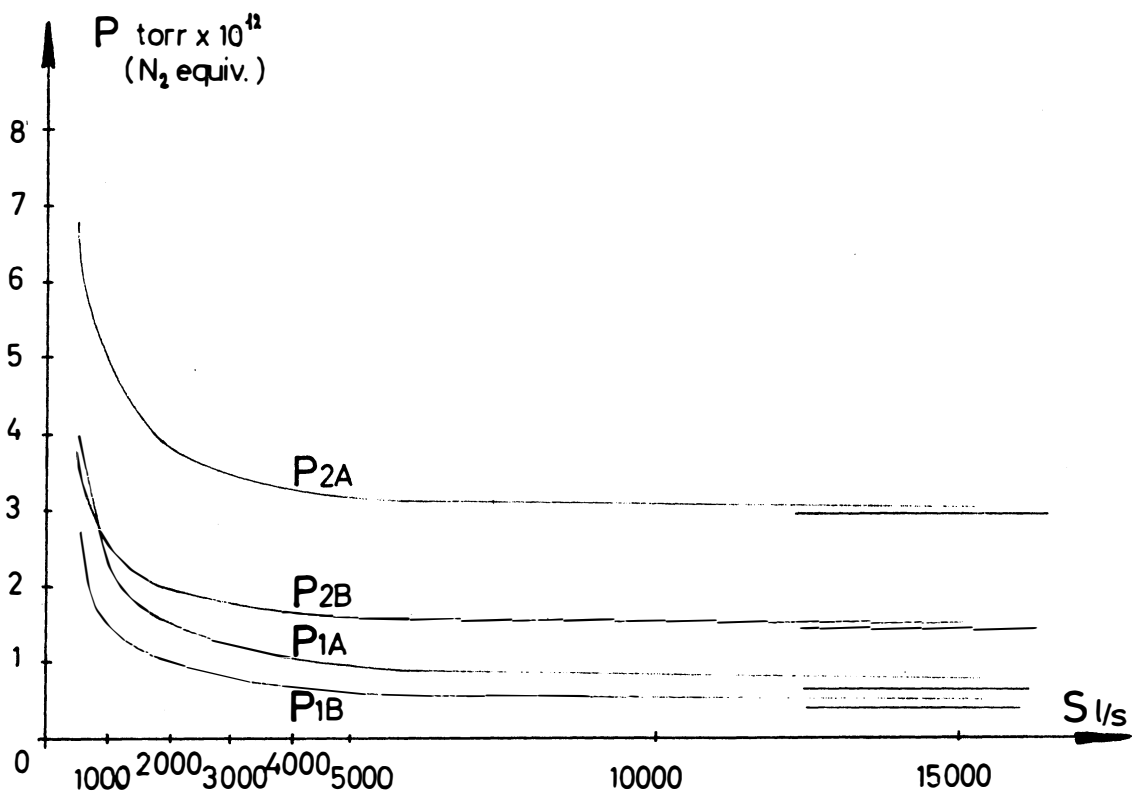at the different points of the vacuum units shown in Fig. 1
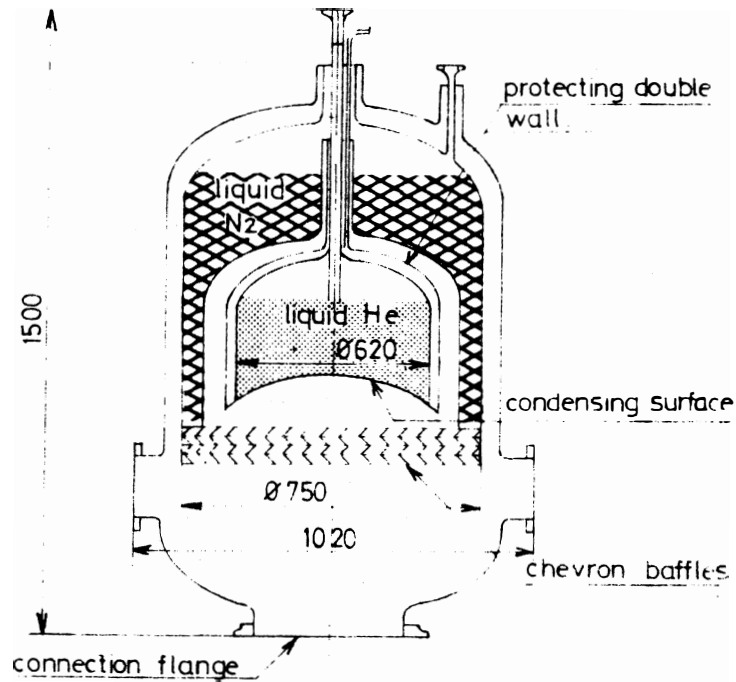
Figure 3

The existing cryopump

Figure 4

Liquid helium boil-off rates Q (for various 300°K radiation transmissions of the 77°K cooled baffles) as a function of the height h of the liquid helium container. Error $\pm$ 11%.

1. zero transmission
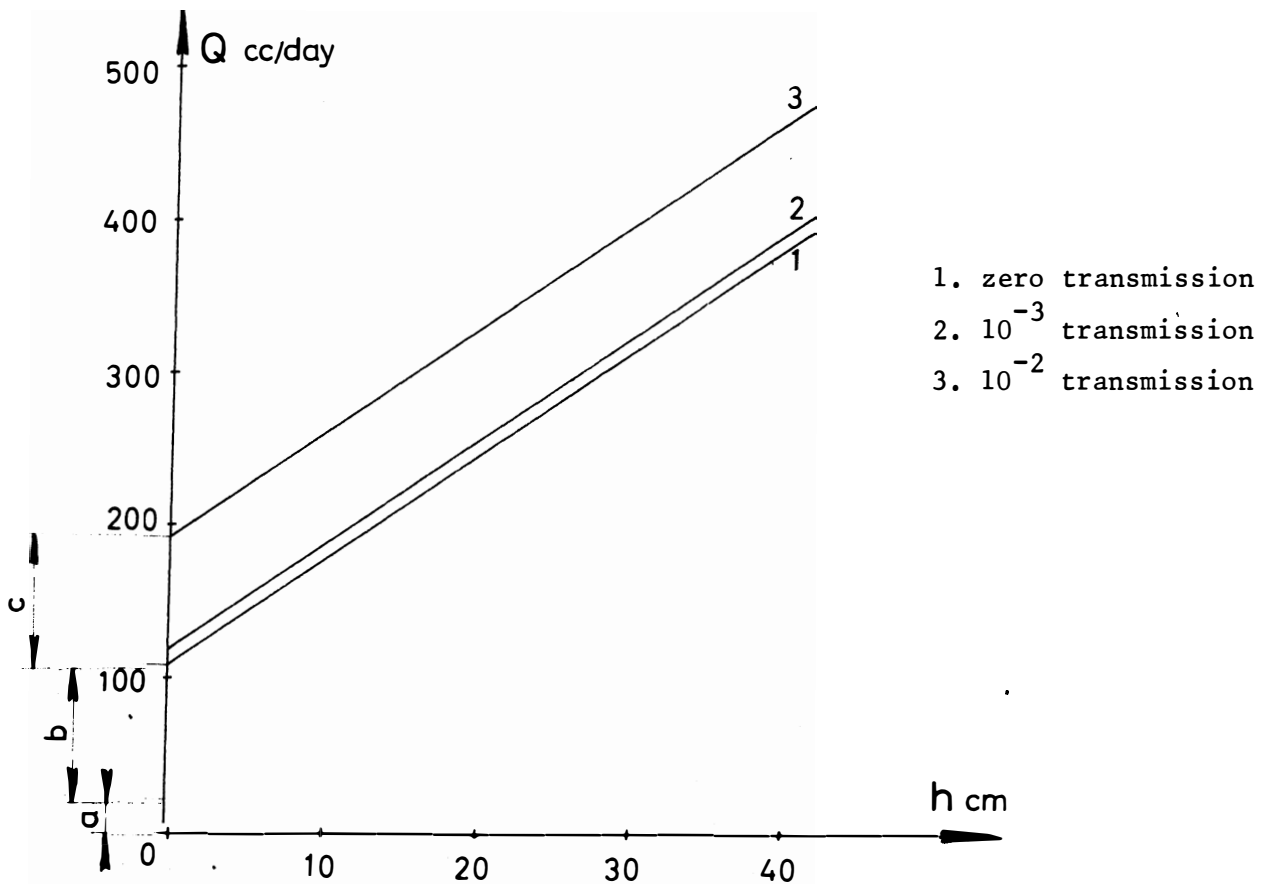2. 10^{-3} transmission
3. 10^{-2} transmission

Figure 5

Operational life time L at 4.2°K as a function of the height h of
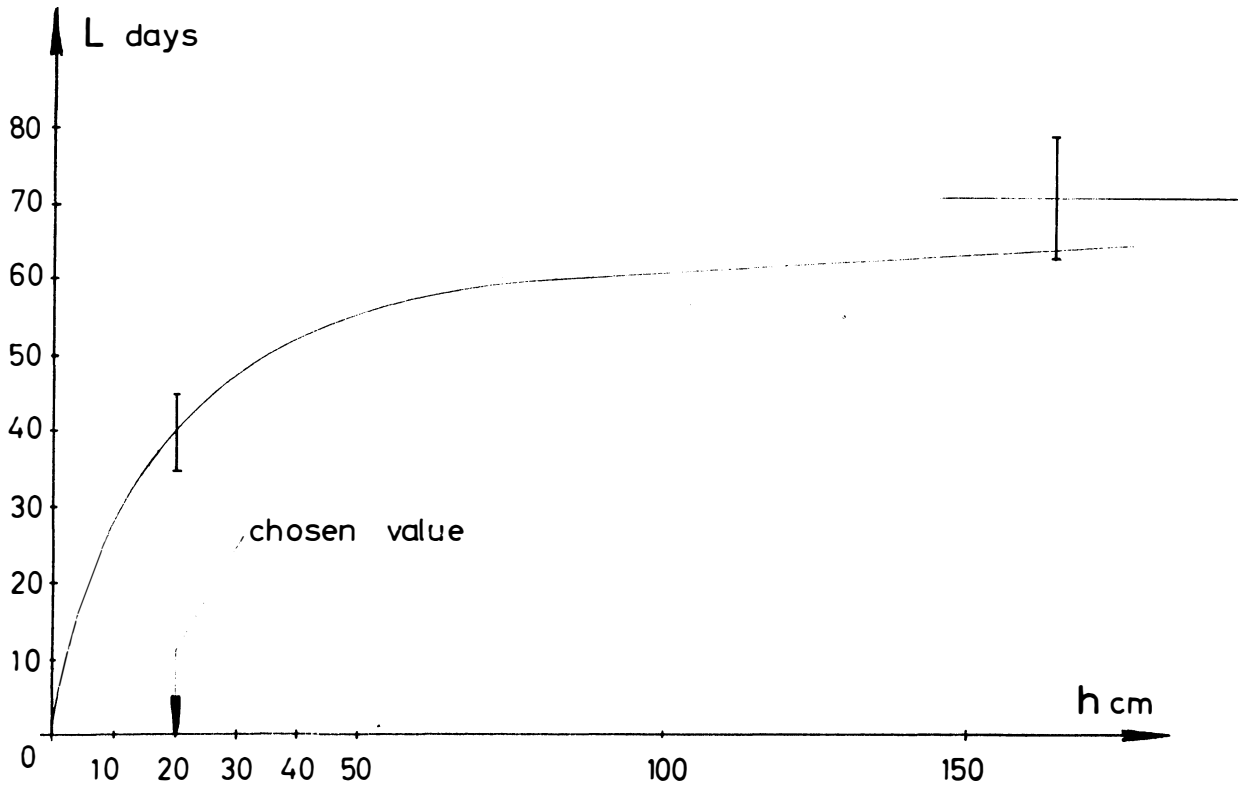The liquid helium container (Error ± 11%).

Figure 6

The new cryopump in the proposed position