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A NEW TYPE OF LAMP AND REFLECTOR FOR I.R. SIMULATION

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ABSTRACT

The lamps and reflectors used for I.R. Simulation tests at ESTEC did not allow to predict the intensity for test condition with the desired accuracy. This was due to:

- o poor reproducibility of the polar diagrams
- o unknown contribution of the radiation in the long wavelength range in vacuum
- o imperfection in quartz bulb and misalignment of the lamp in the reflector

When using a 1000W coiled spiral type quartz lamp with a diffuse reflector these short comings are overcome and due to the good reproducibility an overall accuracy within $\pm 2\%$ should be obtained.

1. SCOPE

The I.R. simulation (IRSIM) plays a major role in spacecraft testing and considering the ambitious programs both in USA and Western Europe the requirements for such tests will be even more stringent in the future.

At ESTEC numerous IRSIM tests were performed, among them the solar panel tests of Intelsat V and VI; though these tests were all successful, there was often considerable effort required to estimate the intensity of the the I.R. lamps with the desired accuracy for the test condition. Since in addition "Testing for a permanent presence in Space" requires:

- o long term tests (mainly IRSIM)
- o numerous thermal cyclings (also mainly IRSIM)
- o high accuracy (Solar Simulation but also IRSIM)

we felt that some improvement was necessary for IRSIM tests (1).

Of most concern was a more precise prediction of the intensity for the test conditions and as main shortcomings were identified:

- o the polar radiation characteristics of the individual lamps + reflectors differ considerably (in order to simplify the computations for the thermal analysis nearly identical polar diagrams are desired).
- o intensity distribution measurements under test conditions (that is at low I.R. background and under vacuum) are expensive and complicated. Therefore, these measurements are performed at ambient and extrapolated for vacuum and low I.R. background.
- o for the extrapolation for test conditions, however, a good knowledge of the lamp data and lamp parameters is required (the data given by the producer are often idealised, in addition not much is known for non-standard use).

It is purpose of these investigations to find the main characteristics and properties of the lamps (+ reflectors), their shortcomings and if possible an improvement. Measurements were performed on prospective candidates, that is:

- 500 W lamp
- 500 W lamp with metallic reflector
- 500 W lamp with reflecting white strip
- 1000 W lamp
- 1000 W lamp with reflecting white strip
- 1000 W lamp with diffuse reflector

2. GENERAL CONSIDERATIONS

When using a quartz lamp one has to consider for more precise measurements not only the filament as radiator but also the quartz bulb, because it is getting rather hot. For the condition given here in connection with reflecting mirrors this implies - due to the focussing effect of the reflector - that not

only the intensity but also the intensity distribution and the spectrum might change when going from ambient to vacuum.

In order to estimate this effect, the relevant data of the lamps shall be measured and defined first.

2.1 Energy balance of a lamp

For steady state conditions obviously the following equations are valid:

$$1. \quad I_t = I_e + I_{\text{conv}} + I_{\text{abs}}$$

$$2. \quad I_t = \epsilon_f \cdot F_f \cdot \sigma \cdot T^4 + \epsilon_b \cdot F_b \cdot \sigma \cdot (T_b^4 - T_a^4) + C_{ba} \cdot (T_b - T_a)$$

$$3. \quad C_{fb} \cdot (T_f - T_b) + \alpha_b \cdot F_b \cdot \sigma T^4 \\ = \alpha_f \cdot F_f \cdot \sigma \cdot T_b^4 + \epsilon_b \cdot F_b \cdot \sigma \cdot (T_b^4 - T_a^4) + C_{ba} \cdot (T_b - T_a)$$

I_t - total energy of lamp (produced in filament)

I_e - emitted energy of filament directly to ambient (thus not absorbed by bulb)

I_{conv} - energy transferred from filament to bulb by convection

I_{abs} - energy of filament absorbed by bulb (bulb is in the long wavelength range opaque)

T_a - ambient temperature (300°K)

T_f, T_b - temperatures of filament and bulb

C_{fb} - conductivity factor for heat transfer filament-bulb (W/°K)

C_{ba} - conductivity factor for heat transfer bulb-ambient (W/°K)

F_f, F_b - effective surfaces of filament and bulb

$\epsilon_{f, b}$ - emittance of filament, bulb

$\alpha_{f, b}$ - absorptance of filament, bulb

σ - Stefan Boltzmann constant $5.6686 \cdot 10^{-12} \text{ [w/cm}^2 \cdot \text{°K}^4]$

V, A - indicates the operation of the lamp under vacuum or ambient.

- o The first equation means that the energy of the filament is emitted to ambient and a part also transferred to the bulb both by convection and absorbed radiation.
- o The second equation considers that the total intensity is transmitted to ambient by the filament radiation (first term), by the bulb radiation (second term) and the energy transferred to the ambient atmosphere by convection (third term)- which is of course zero when operating the lamp under vacuum.
- o The third equation gives the energy balance of the bulb, the left hand side represents the energy input from filament (both by the filament radiation and by convective heat transfer filament-bulb by the gas in the lamp) and the terms on the right hand side express where the energy is going to (back radiation to filament, radiation to ambient and heat transfer to ambient by convection).

When these factors are known the behaviour of the lamps may be estimated also for non standard conditions.

2.2 1000W lamp

The 1000W lamp was recommended as spectral radiation standard due to its high stability, high colour temperature and ease of handling (2). First quartz iodine lamps were produced which showed within the spectral range (0.25 - 2.5 μ) a smooth curve; the quartz halogene (bromium) lamps show at high resolution small peaks at 308, 309, 393, 395, 586, 587 and 668 nm which, however, may be completely neglected for thermal radiation measurements. The spectrum agrees with that of a black body within the measuring accuracy ($\pm 3\%$).

The filament is a coiled spiral (also named coiled coil) of tungsten wire ($\sim 0.3\text{mm } \phi$); the spiral is $\sim 1.3\text{mm } \phi$ and roled up to 11 coils of 5. mm outer ϕ . Considering the gap between the windings of the spiral one will find for the tungsten wire a length of $\sim 1.0\text{m}$ (length of the spiral $\sim 160\text{mm}$ with ~ 260 windings of $\sim 1.3\text{mm } \phi$). The total surface of this wire is $\sim 9\text{cm}^2$.

For the overall emittance follows then with:

$$I = 1000\text{W} = \epsilon \cdot F \cdot \sigma \cdot T^4$$

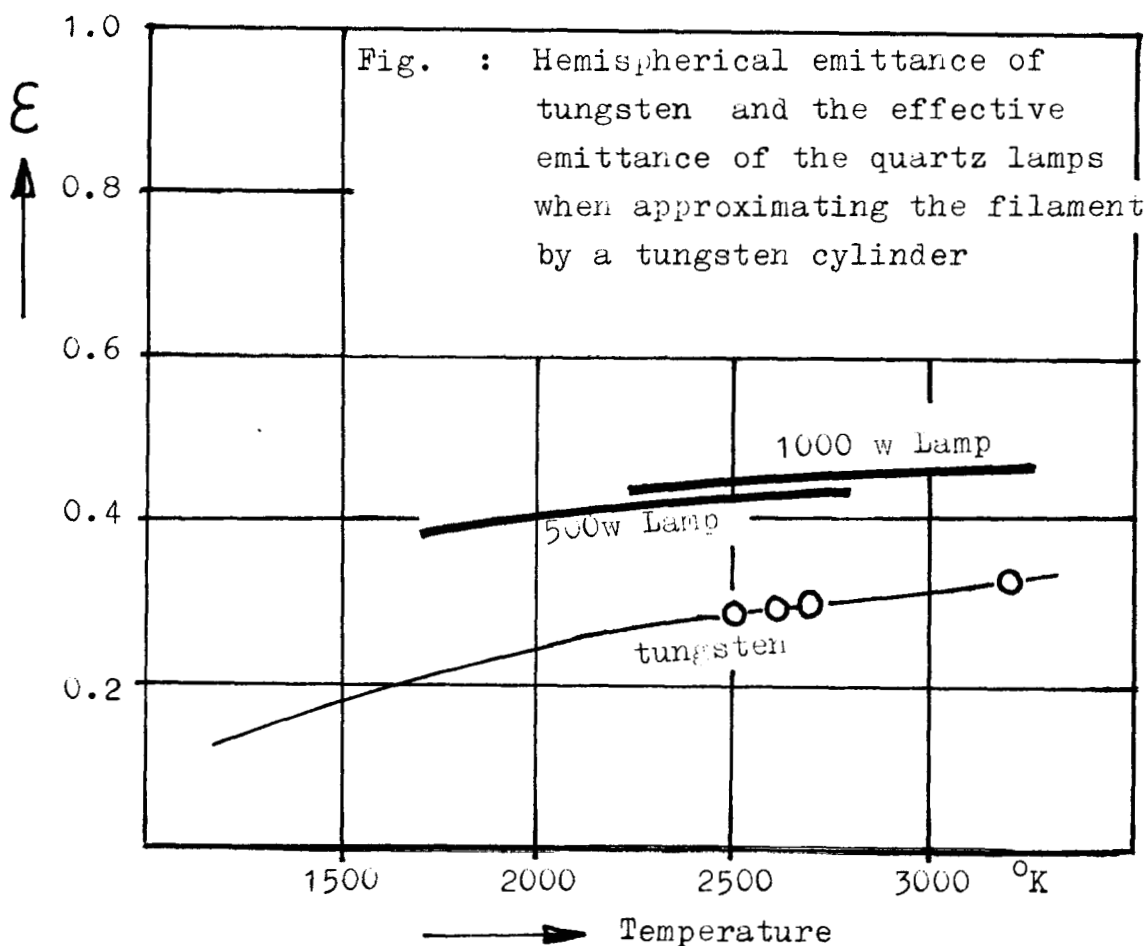
$$\text{where } F = 9 \text{ cm}^2$$

$$T = 3200 \text{ } ^\circ\text{K}.$$

$$\text{for } \epsilon = 0.19.$$

This value is lower than given for tungsten (fig. 1) at this temperature, which is - of course - due to the blockage of the emitting surface. When, however, approximating the emitting filament by a cylinder of 0.5cm ϕ and 2.3cm length (giving an emitting surface of $\sim 3.6\text{cm}^2$) one will find for $\epsilon = 0,467$ which is higher than given and can be attributed to the fact that the surface is rough and no longer smooth for this approximation (3).

The bulb has a surface of 18.8cm^2 (1.5cm ϕ x 3.9cm length, approximated by a cylinder) and absorbs the light beyond $\sim 4\mu$ with a transient range of $\Delta\lambda = 1.5\mu$ (Fig. 2). Measurements with and without quartz plate should eliminate the radiation of the bulb itself (see however annex) (4).



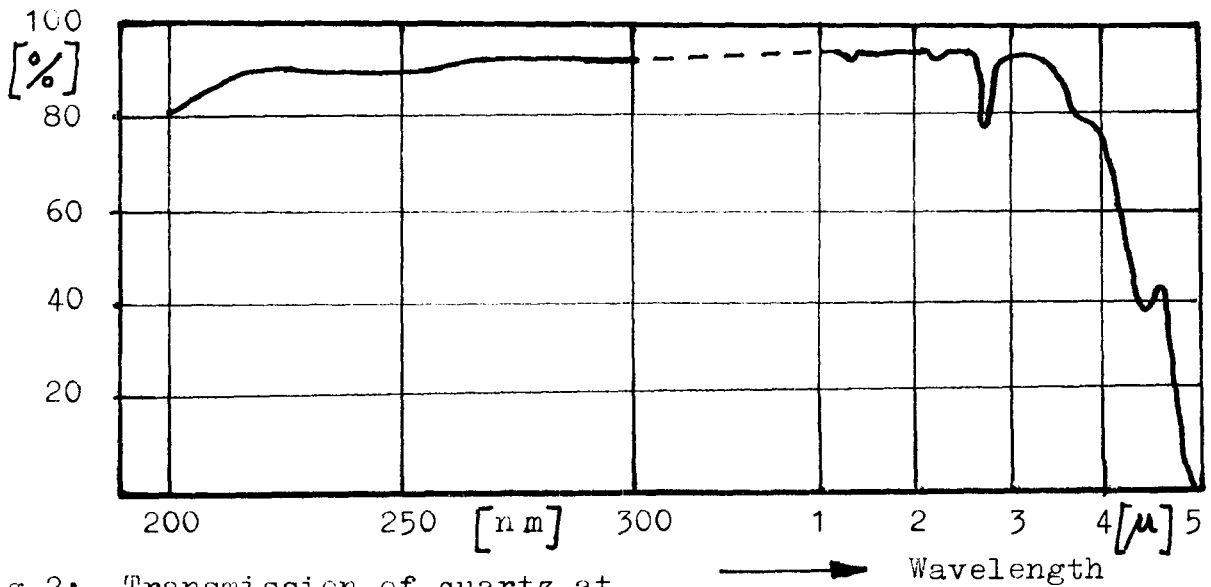


Fig.2: Transmission of quartz at ambient temperature (type Homosil, Herasil, 1mm thick)

Of course one has to consider for such measurements the surface reflection (2x) according to Maxwell relation:

$$R = \left(\frac{n - 1}{n + 1} \right)^2 \quad (n \text{ refraction index here} = 1.45, \text{ or } 6,8 \%)$$

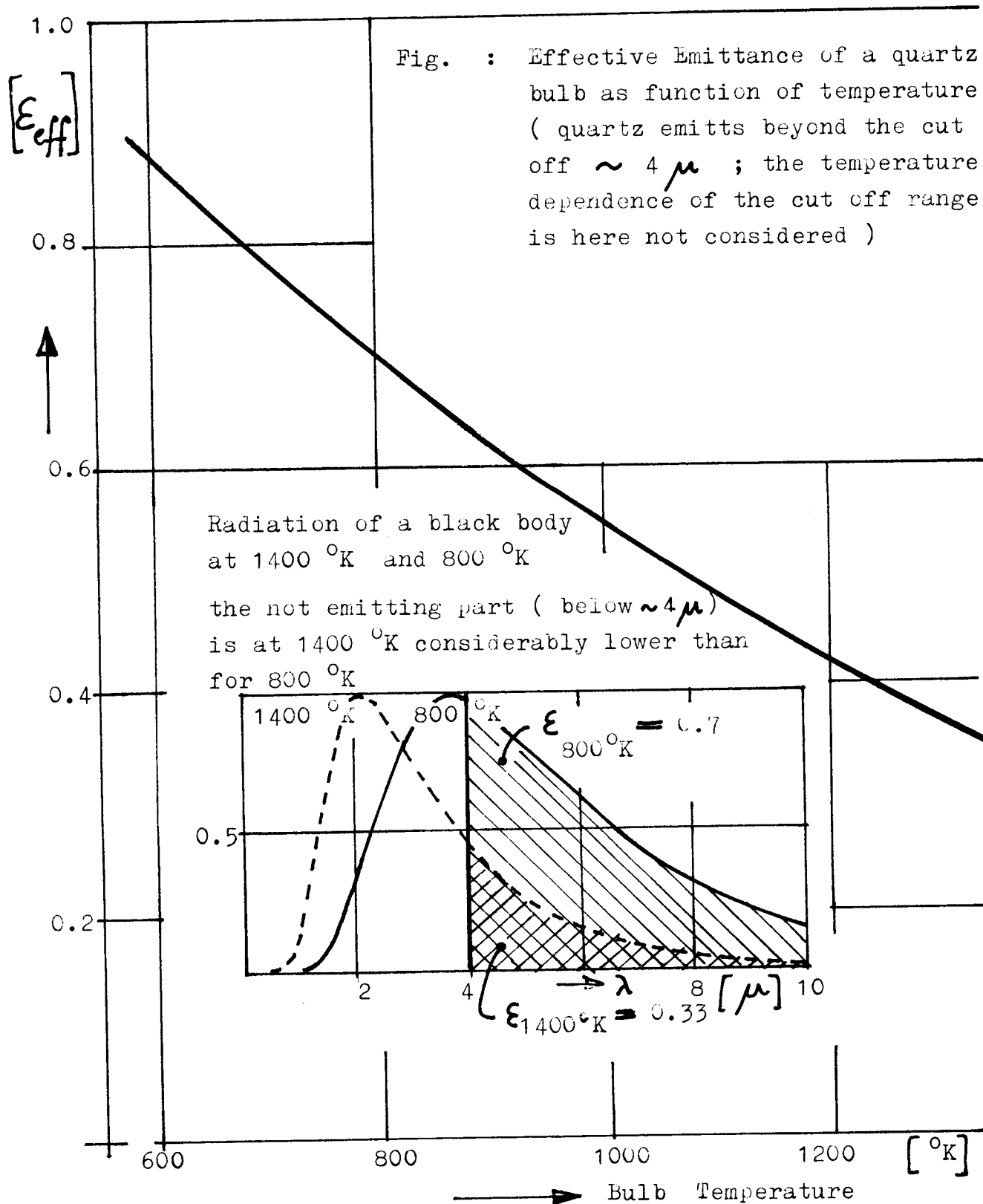
When the radiation intensity of the bulb is known one can estimate the bulb temperature considering the effective emittance (Fig. 3).

2.3 500W lamp

The bulb itself is cylinder of 9.5mm ϕ and 14cm long giving a surface of 4.2cm². The wire is ~ 0.25 mm in ϕ and the length of the filament spiral is 12cm; considering the windings (~ 380) the total length of the wire is thus ~ 1 m and the overall surface is ~ 8 cm².

When assuming the filament temperature given by the producer to 2500°K it would require an effective emittance of $\epsilon = 0.28$ which is too high for this configuration.

Actually a similar value should apply as that found for the 1000W lamp although, the simpler arrangement (simple stretched spiral and not a coiled one) will cause a lower blockage, however this effect should not exceed 10%. It is though that $\epsilon = 0.21$ is a good value leading to a filament temperature of 2685°K - and this value will be used in this report. When approximating the spiral-filament by a cylinder of ~ 1 mm ϕ and 12 cm length the effective overall emittance is $\epsilon = 0.447$.



3. ARRANGEMENT FOR MEASURING THE LAMP DATA

The lamps were investigated for nominal power level (100%) down to 50% power level (lower levels than this are considered not realistic).

In principle it would have been sufficient to perform measurements:

- o with and without quartz plate to separate the radiation coming from filament and from bulb (see however annex).
- o under vacuum (or better the ratio ambient-vacuum) to eliminate the convective cooling by ambient air.

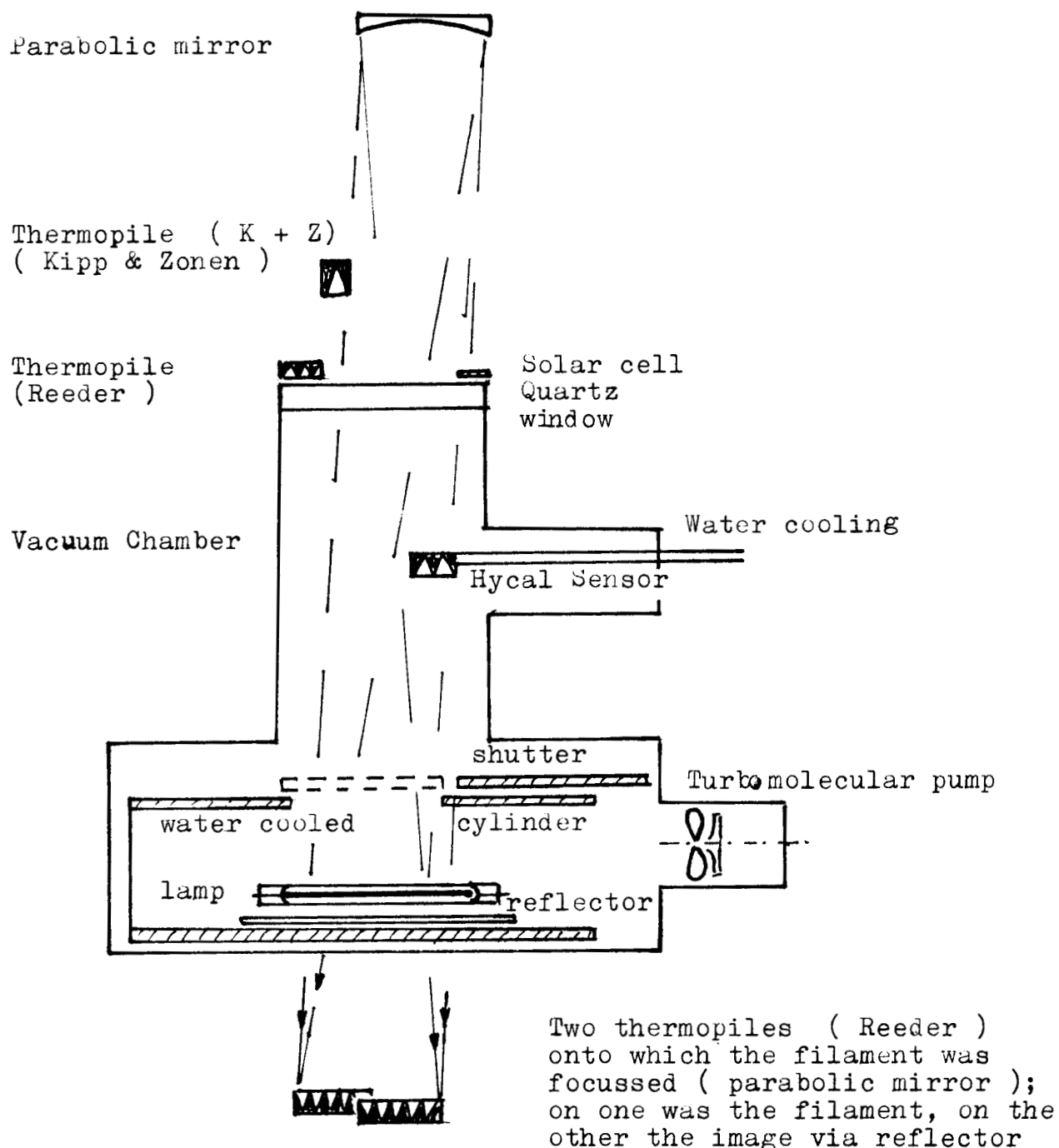
In order to reduce the experimental uncertainties and to gain as much information as possible, additional runs were performed. Since no CaF_2 window with high transmittance in the I.R. range (7μ) was available, a quartz window had to be used.

The measurements were performed with the following objectives and conditions:

1. In order to guarantee utmost reproducibility for all measurements constant current setting was applied; (simultaneously the voltage was measured for additional check).
2. The total intensity was measured inside the vacuum chamber by means of a water cooled Hycal sensor (without window).
3. In order to eliminate I.R. absorption by water vapour in natural air also measurements were performed at dry GN_2 atmosphere. (5, 6).
4. For rough information about the spectral distribution, the following were used:
 - o a solar cell for the short wave length range (till 1.1μ)
 - o a glass plate for the range till 2.7μ .
 - o a quartz plate for the range till 4μ .
5. A Reeder thermopile was placed close to the quartz window to get an indication of scattered light (mainly I.R.).
6. At some distance, where stray light is expected to be negligible a K + Z - thermopile was installed for additional indication and cross check.
7. For studying the filament itself a parabolic mirror was used to focus the filament image onto Reed thermopile(s).

The experimental mock up is shown in fig. 4.

Fig.4: Experimental mock up for the measurements at ambient and under vacuum (eliminating the cooling effect of air and estimating the temperatures of bulb and filament). For assessment of the absorption effect of water vapor - assuming 65 % relative humidity - also measurements under dry GN_2 atmosphere were performed.



4. EVALUATION OF THE MEASUREMENTS

The measurements allow to calculate the unknown factors for the 1000W and the 500W lamp.

4.1 Heat loss to ambient air by convection

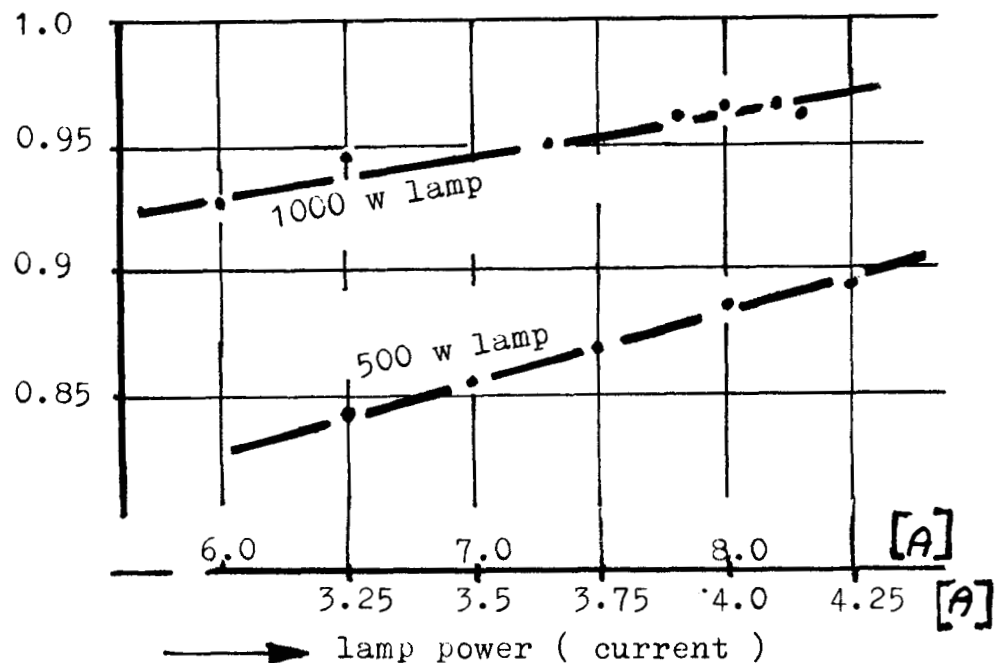
Obviously the cooling effect of the ambient air is eliminated when measuring under vacuum:

$$I_t = I_a + C_{ab} (T_b - T_a), \text{ or}$$

$$\frac{I_a}{I_t} = 1 - C_{ab} (T_b - T_q) \cdot \frac{1}{I_t}$$

The ratio of the output of the lamps as measured with the Hycal sensor in air and vacuum is given in Fig. 5. During these measurements it was observed that the power remained rather constant, the small correction will be considered in § 4.2.

Fig. 5: Ratio of the output of the lamps obtained at ambient and under vacuum for the 500 w lamp and the 1000 w lamp; both lamps without reflector. (measured with the Hycal sensor, no window)



Measurements with and without quartz plate - as already mentioned - were performed in order to eliminate the radiation of the bulb itself from which the bulb temperatures are found when considering:

$$\frac{\text{signal with quartz plate}^*}{\text{signal without quartz plate}} = \frac{\epsilon_f \cdot F_f \cdot \sigma \cdot T_f^4 - \epsilon_b \cdot F_b \cdot \sigma \cdot (T_b^4 - T_a^4)}{\epsilon_f F_f \cdot \sigma \cdot T_f^4}$$

(* corrected for surface reflections)

The emitted and absorbed energy is given for different lamp power in Fig. 6 a, b for the 500W lamp, and in fig. 7 a, b for the 1000W lamp.

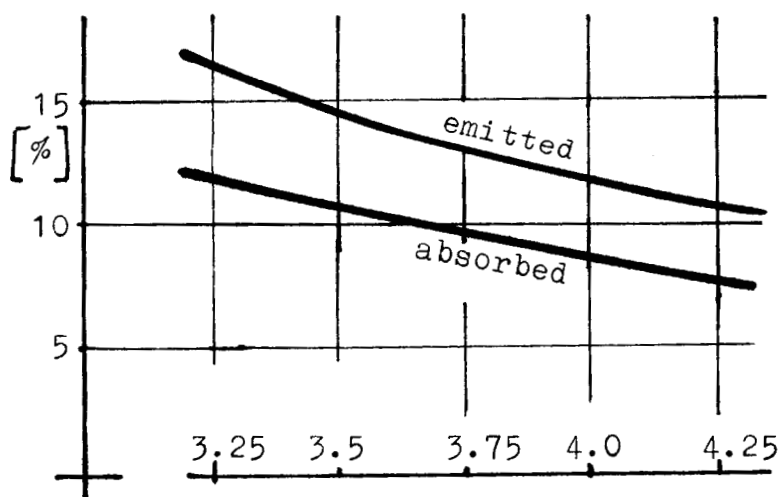


Fig. 6a :

The emitted and absorbed energy of a quartz bulb (500 w) decreases compared with the total lamp output for high power level (at ambient)

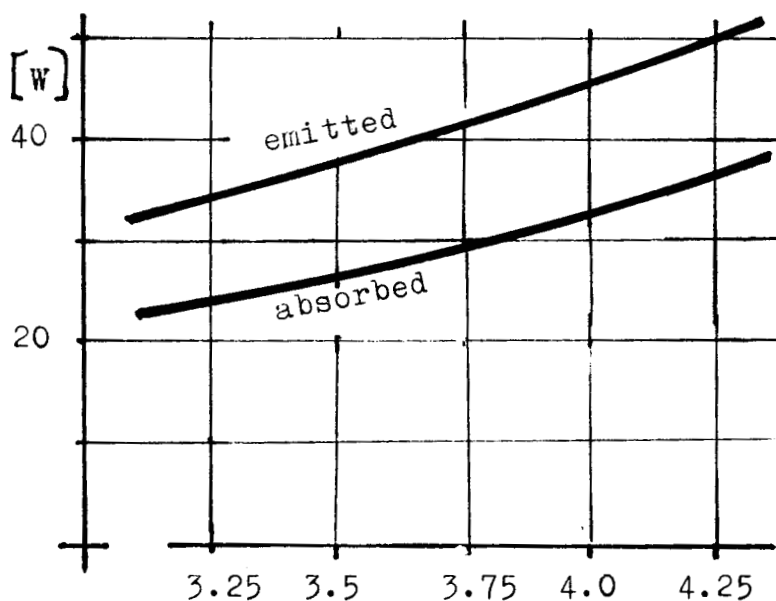


Fig. 6b :

The emitted (and absorbed) energy of a 500 w lamp is 50 w at ambient and nominal power; the difference between absorbed and emitted energy is due to convective heat transference filament-bulb

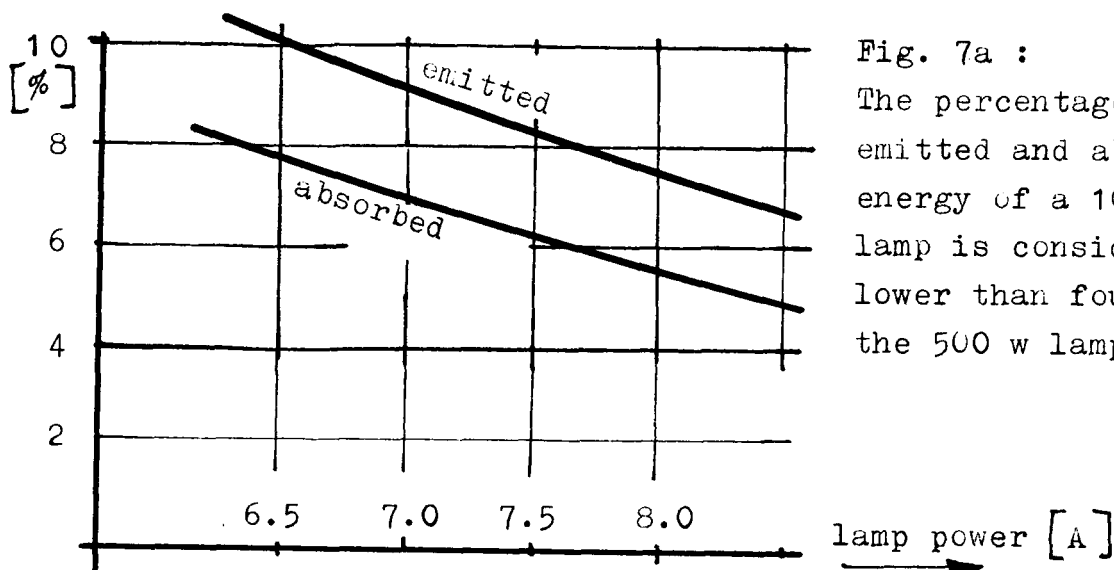


Fig. 7a :

The percentage of emitted and absorbed energy of a 1000 w lamp is considerably lower than found for the 500 w lamp.

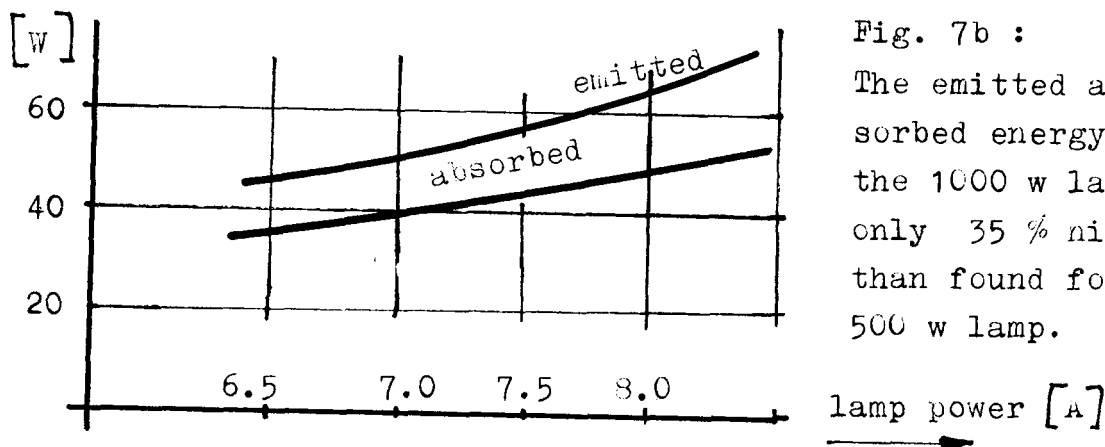


Fig. 7b :

The emitted and absorbed energy of the 1000 w lamp is only 35 % higher than found for the 500 w lamp.

For simplicity T_a was not considered here; in worst case it will contribute only $\sim 5\%$ of the bulb radiation which is again only 20% of the total lamp radiation, hence it will be not more than 1%, of the total lamp intensity; for nominal power and for the 1000W lamp the error will be always negligible.

For these data, the bulb temperature T_b for both ambient and vacuum may be calculated; since ϵ_b , however, also depends on temperature (fig. 3) an iteration procedure had to be applied (fig. 8).

The conductivity factor C_{ba} of the heatflow from bulb to ambient air remains - as to be expected - constant (fig. 9). One may assume that the cooling of the bulb by ambient air is in first approximation proportional to the bulb surface, and when comparing the 1000W lamp and the 500W lamp it agrees within $\pm 5\%$ with their surface ratio. (Of course this is no longer valid in case the lamps are cooled e.g. by a fan).

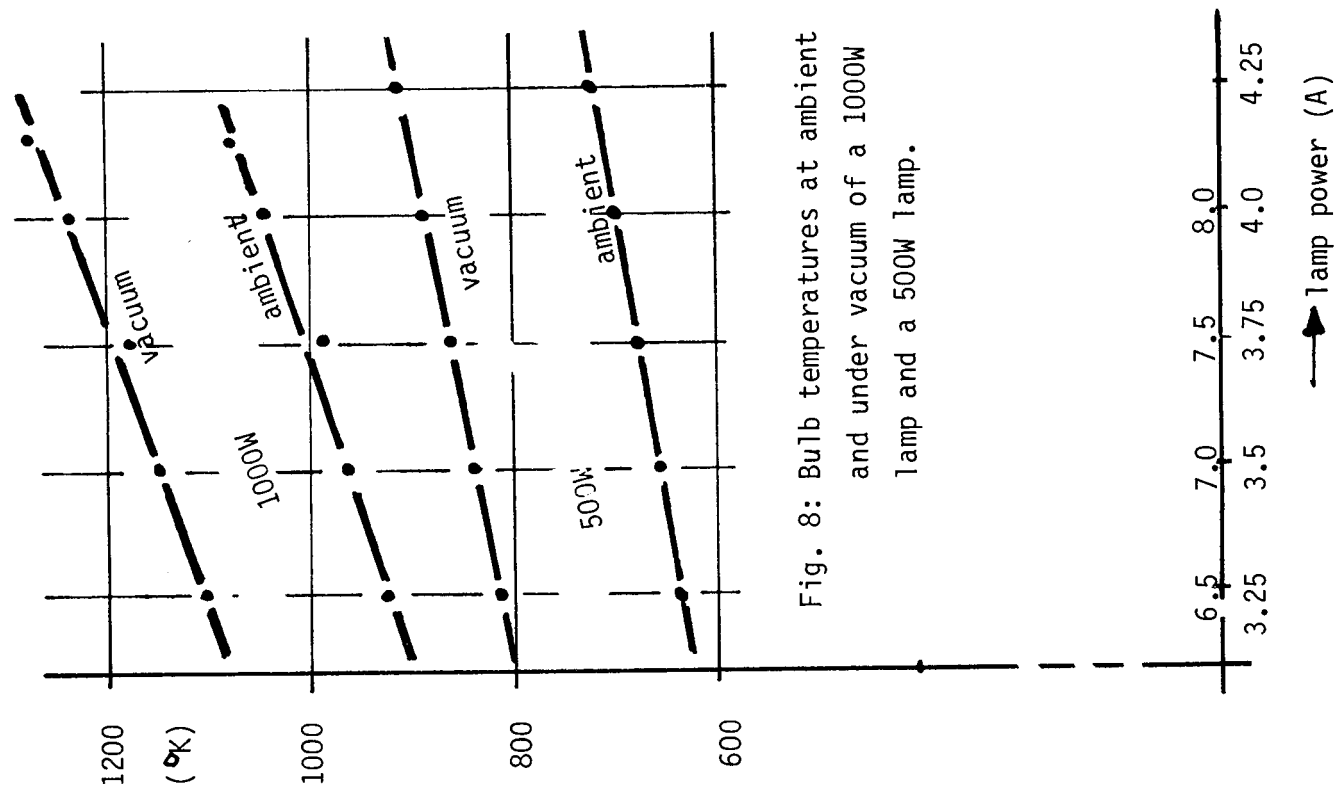


Fig. 8: Bulb temperatures at ambient and under vacuum of a 1000W lamp and a 500W lamp.

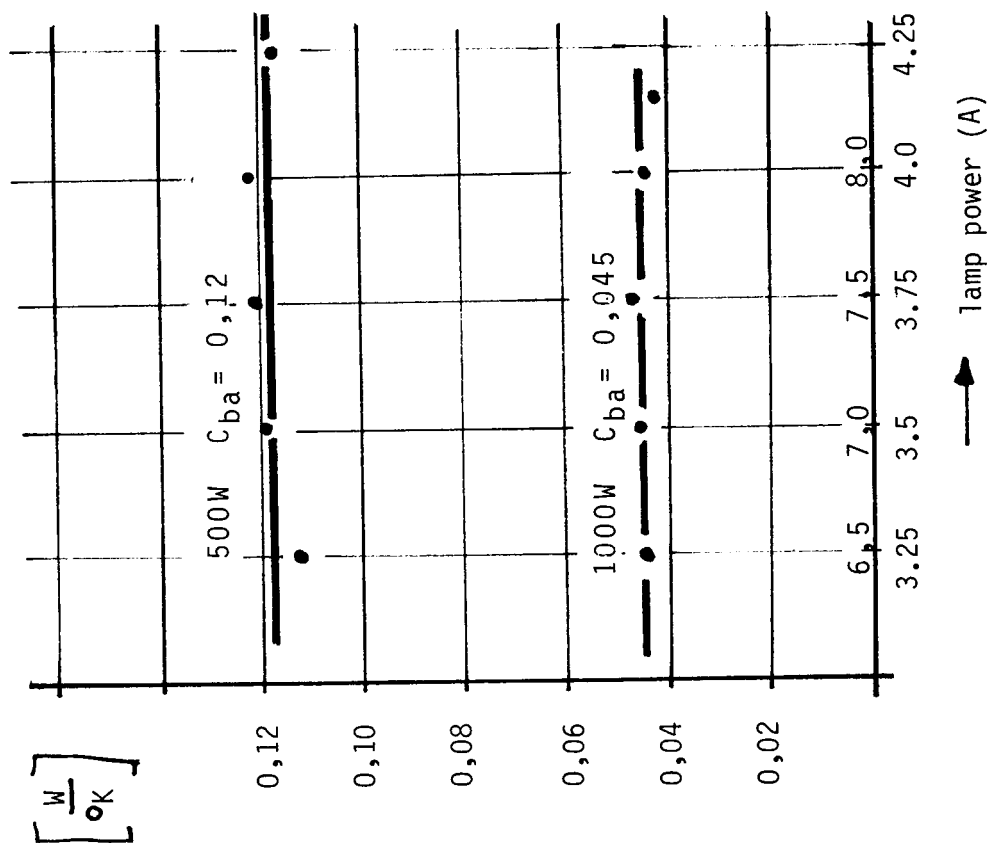


Fig. 9: Conductivity factor for heat transfer bulb-ambient
 $(H_{ba} = C_{ba} (T_b - T_a))$
 for a 500W lamp and a 1000W lamp.

4.2 Heat transfer from filament to bulb

Since the boundary conditions of the lamps are known the inner parameters may be studied here - referring to the second equation - in particular:

- o the absorbed radiation energy by the bulb due to the opaqueness beyond 4μ .
- o the conductivity constant C_{fb} .
- o the back radiation bulb-filament.

The percentage of absorbed radiation by the bulb is increasing for lower filament temperatures due to the shift to longer wavelengths. (Fig. 10). When considering the back radiation bulb-filament one should know the effective absorptance for the configuration given (coiled spiral) as function of the temperature. It is assumed that in the first approximation the ratio of the effective absorptances at the temperatures T_1 and T_2 is the same as the ratio of the absorptances of tungsten for the same temperatures, or:

$$\frac{\alpha_{\text{eff}}(T_1)}{\alpha_{\text{eff}}(T_2)} = \frac{\alpha_{\text{tungst}}(T_1)}{\alpha_{\text{tungst}}(T_2)}$$

For nominal power ($T = 3200^\circ\text{K}$) both effective absorptance ($\alpha = \epsilon = 0.467$) and absorptance of tungsten ($\alpha = \epsilon = 0.31$) is given.

The conductivity constant for the convective heat transfer of the gas in the lamp depends on the molecular velocity of the gas, which again depends on the root of the temperature.

It is:

$$C_{\text{gas}} = A \cdot n \cdot \bar{v} \cdot \bar{l} \cdot \frac{S_h}{N_1}$$

- \bar{v} - mean molecular velocity
- \bar{l} - mean free path
- A - form factor
- S_h - specific heat
- N_1 - Avogadro's Number
- n - density

Here is only \bar{v} a function of temperature (even \bar{l} is temperature independent). Hence follows:

$$C_{\text{gas}} = \text{const} \sqrt{\frac{T}{T_0}}$$

Since C_{fb} increases with temperature, it compensates partly the influence of decreasing temperature difference ($T_{fil} - T_{bulb}$) when going from ambient to vacuum; in addition the back-radiation of the bulb will increase as well (T^4) and the decreasing emissivity ϵ_b of quartz is also partly compensated in this case by the increasing effective absorptance $\alpha_f = \epsilon_f$.

Both effects have the consequence that the filament temperature - and hence the electrical power of the lamp when operated on constant current setting - will remain nearly constant when going from ambient to vacuum (difference $\sim 1\%$).

This result also means that no remarkable influence is to be expected when lamps without reflector are operated in a chamber with warm or cooled (LN_2) shrouds.

4.3 Discussion of the results for nude lamps

The measurements performed on nude lamps allow the following conclusions:

- o When going from ambient to vacuum the additional heat input may easily be considered. (5 - 10% for the 1000W lamp and 10 - 17% for the 500W lamp).
- o The lamps may be operated nearly at nominal power level with warm or cooled (LN_2) shrouds also under vacuum).
- o In order to reduce the contribution of the bulb radiation the lamps should be operated nearly at nominal power level (e.g. it is better to use a few lamps at high power than numerous lamps at low power).

5. LAMPS WITH REFLECTOR

Naturally for IRSIM tests the radiation of the lamps to the rare side (to the shrouds) should be reduced as much as possible which means a reflector should be used. Commercially available were two types of lamp + reflector.

5.1 Lamp with reflecting white strip

The lamps with reflecting white strip (actually a TiO coating on the rare side of the quartz bulb) have the advantage that lamp and reflector are one radiation unit and thus simpler. The transparency of the reflecting strip was however still $\sim 30\%$ and that was considered too high; these lamps were therefore rejected for IRSIM test. The polar diagrams are shown in fig. 11.

5.2 Lamp with metallic reflector

The lamps provided with a metallic reflector showed no radiation to the back and were therefore chosen for IRSIM tests. Though all the IRSIM tests at ESTEC were performed with this type of lamp + reflector with good success, there is a disadvantage which cannot be overlooked: the polar radiation characteristics differ for the individual lamps considerably (see fig. 12).

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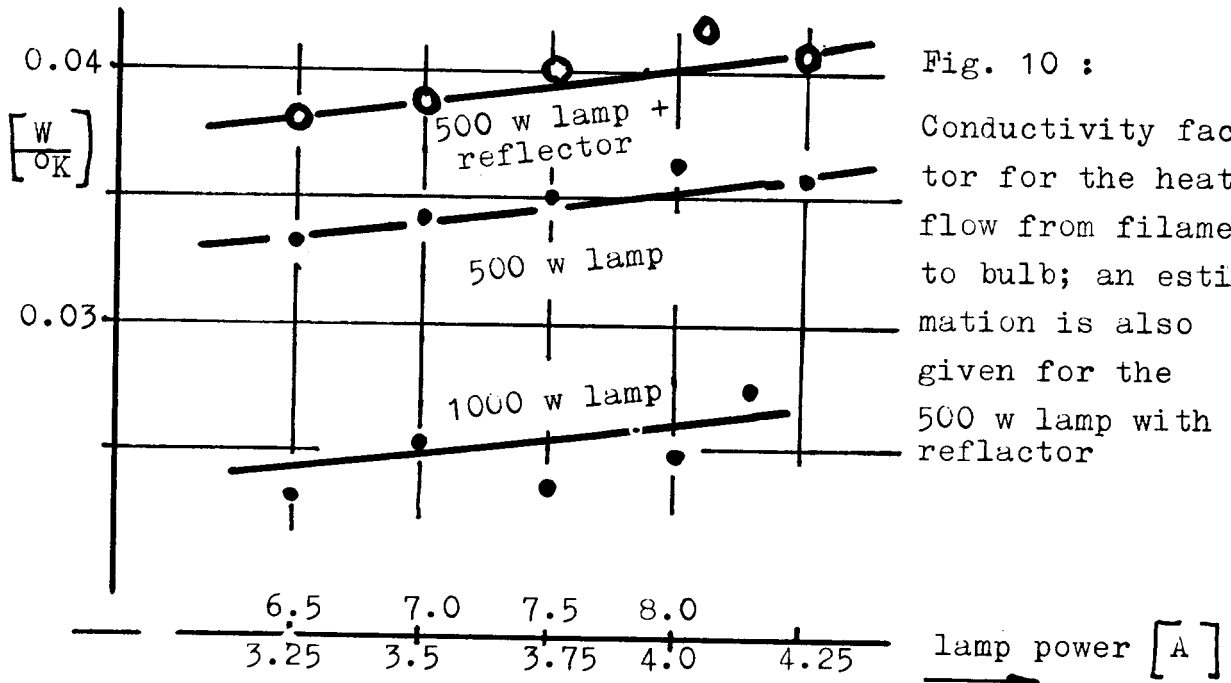
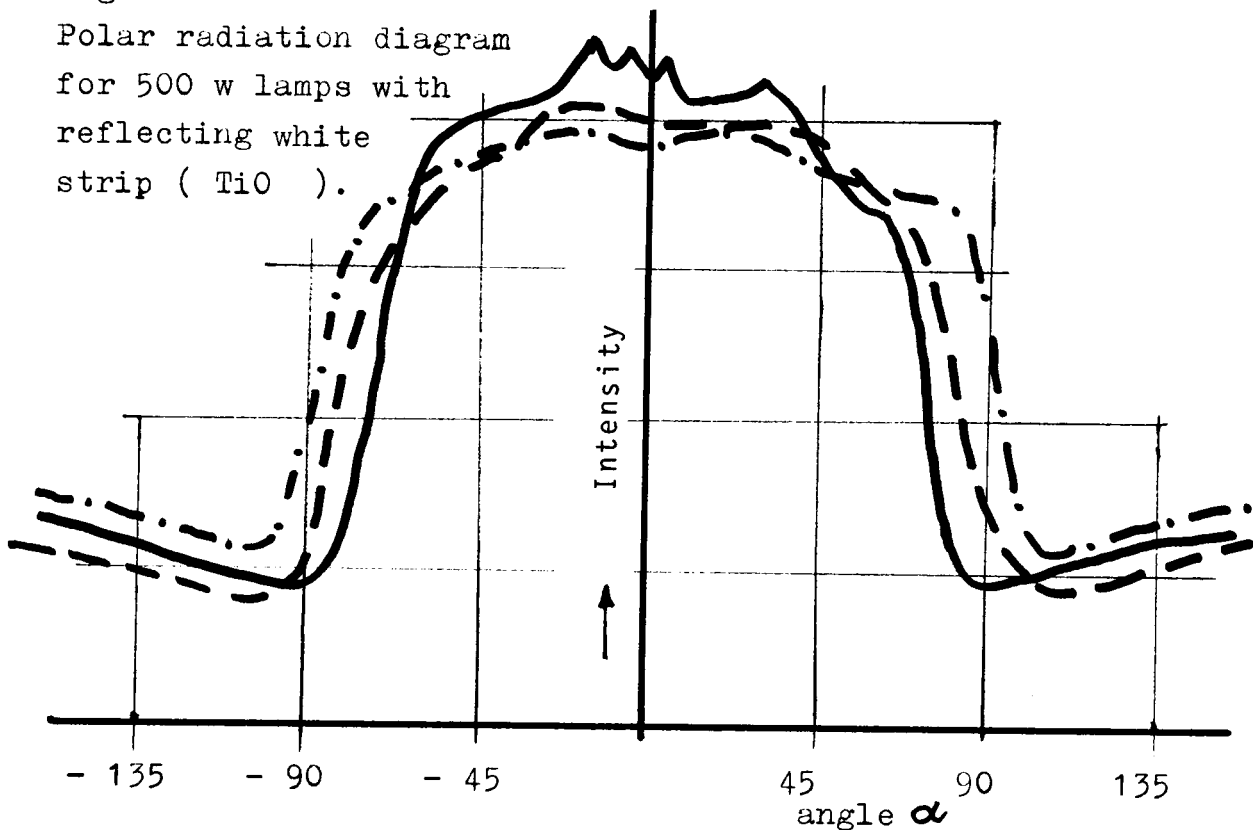


Fig. 11 :

Polar radiation diagram
for 500 w lamps with
reflecting white
strip (TiO_2).



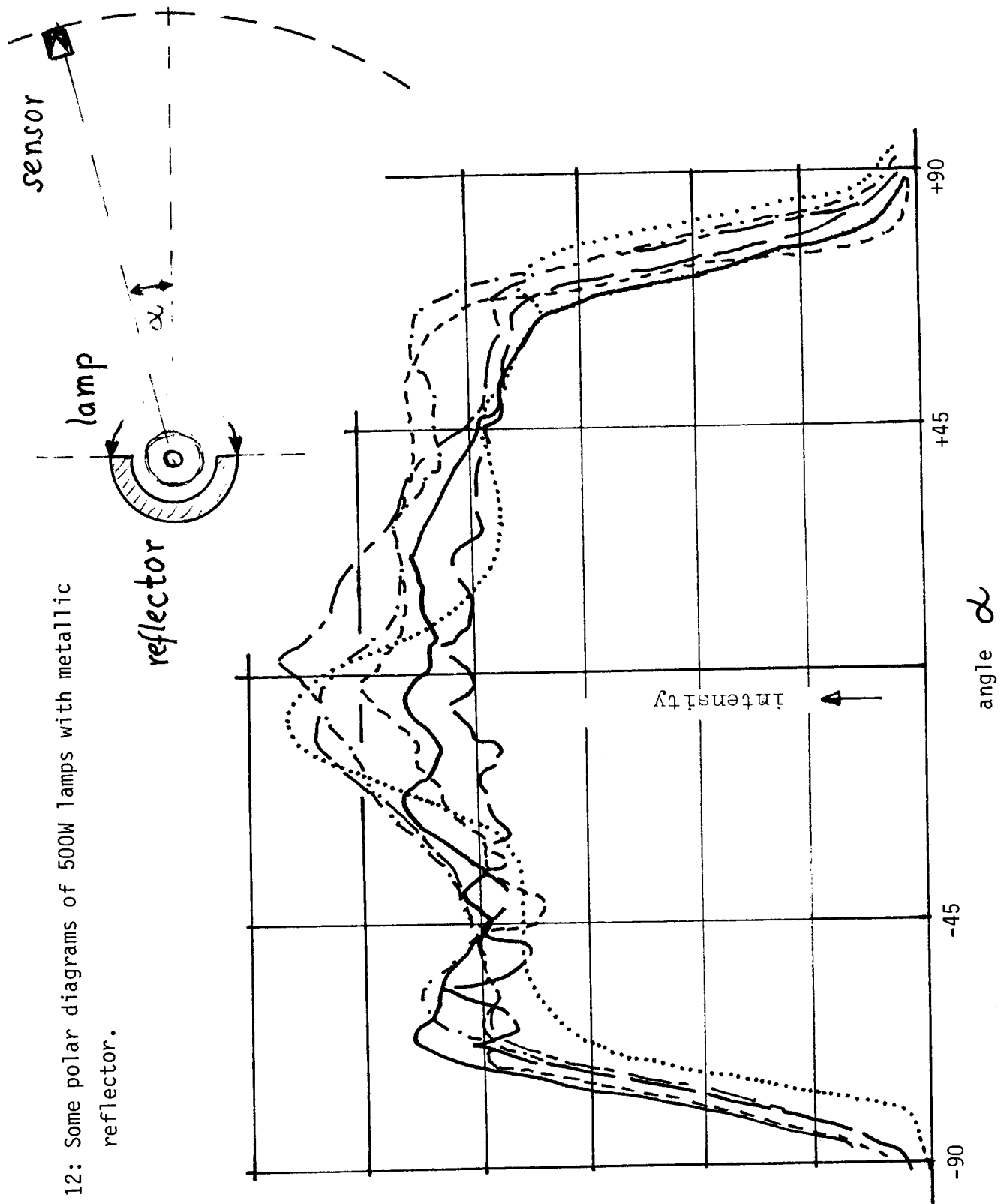


Fig. 12: Some polar diagrams of 500W lamps with metallic reflector.

5.3 Discussion of the results of the polar diagrams

The polar diagrams of both types, show sharp peaks and valleys being superimposed to a more smooth slope. Since even nude lamps show occasionally these sharp peaks they are obviously due to imperfections of the quartz bulb itself (actually due to bubbles in the quartz, acting as focussing or defocussing lens). The irregularities showing the more smooth slope are due to imperfections of the reflector and/or misalignment of the filament in the reflector. In order to overcome these shortcomings one should:

- o use a lamp with larger filament diameter so that the peaks are more spread out and furthermore
- o use a diffuse reflector.

Both requirements may be met when using a 1000W quartz lamp (coiled spiral filament) with e.g. MgO coating on the rare side (7). The 1000W lamp has in addition the advantage that the radiation of the bulb itself is relatively low in comparison with the filament intensity. Unfortunately lamps with coated MgO back are delicate to handle because the MgO layer shows poor adherence. Numerous attempts with other coatings were performed (8, 9) and the investigations are still in progress, at present, however, as the most practical solution is considered a 1000W lamp in combination with a small stainless steel reflector coated with MgO.

6. 1000W LAMP WITH MgO COATED REFLECTOR

Reflector + lamp are shown in fig. 13. The reflecting surface was coated with MgO smoke; since here the coating was on an inner surface the poor adherence of the MgO did not affect the handling seriously.

6.1 Polar diagrams

As already mentioned it is highly desirable for the analysis to have for all lamp-reflector units an identical polar diagram. Even for a diffuse reflector a fair adjustment of the lamp is necessary in order to achieve reproducible polar diagrams. Since the position of the filament in the quartz bulb varies from lamp to lamp each filament had to be positioned to the centre line of the reflector individually by bending slightly the lamp holder.

For the NOSAT-IRSIM test 20 lamp + reflector units were prepared. For a complete analysis is of course necessary to know the radiation characteristics for the hemispherical space. Therefore for each lamp the polar diagrams were measured for: 90° (\triangle lamp vertical), for the tilted positions 75° , 60° , 45° , 30° , 15° and for 0° (lamp horizontally, the filament is in the measuring plane). For the 0° position both the light intensity coming from the filament and that coming via the reflector should follow the cosine distribution; (except around $10^\circ \pm 4^\circ$ - the inclination angle of the spirals of the filament - a somewhat lower intensity is found because of the higher blockage effect for the back part of the filament). The result is shown in fig. 14.

Fig. 13:

Lamp in a reflector (MgO coated; this reflector has a low blockage factor).

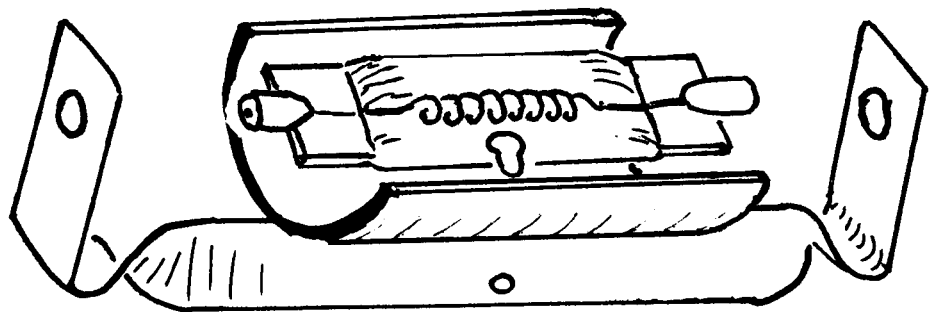
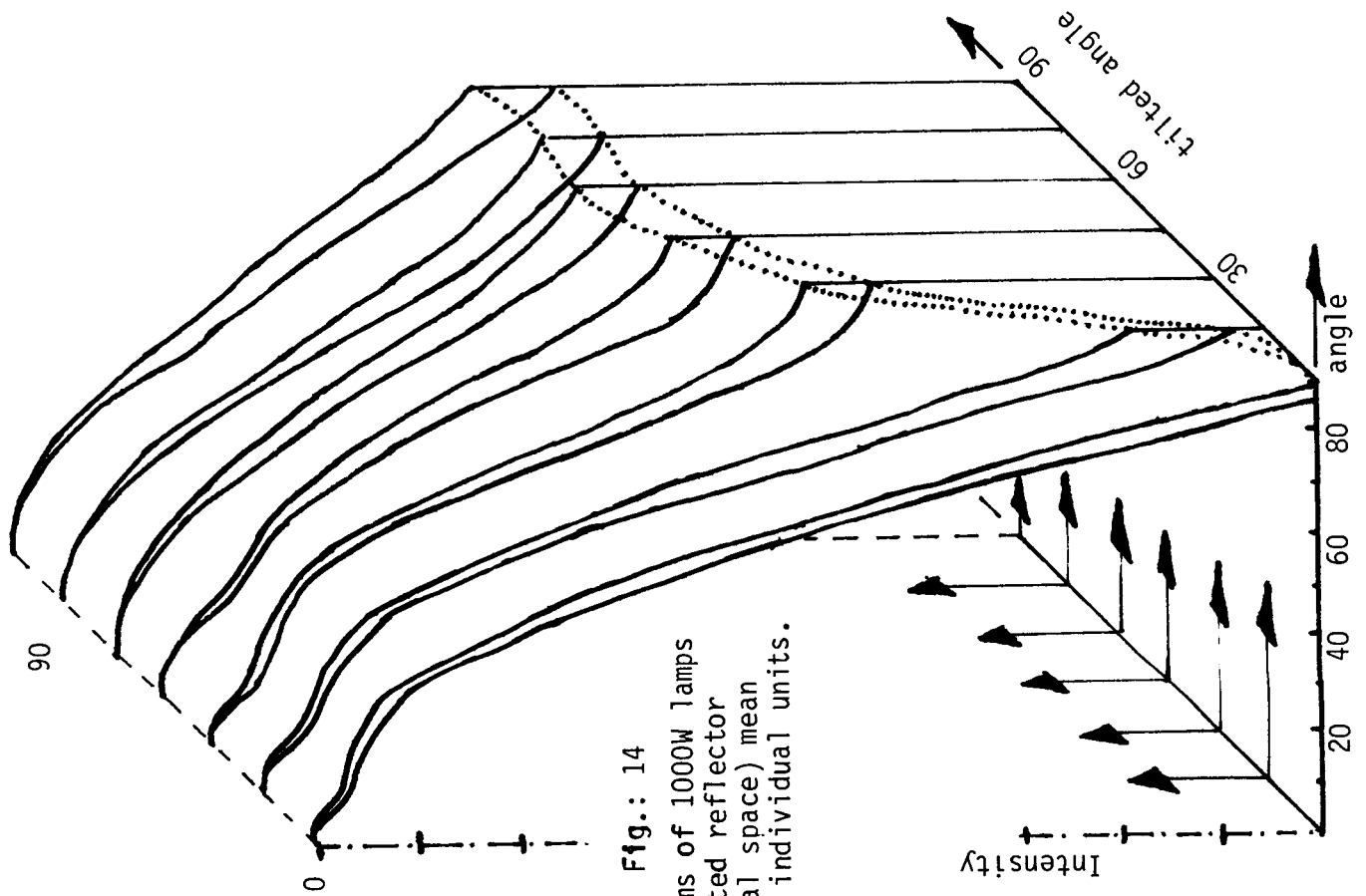


Fig.: 14

Polar diagrams of 1000W lamps with MgO coated reflector (hemispherical space) mean spread of 20 individual units.



For the 90° position (lamp axis perpendicular to measuring plane) only the light intensity via the reflector should obey in first approximation the cosine law; that from the filament directly should be independent from the angle; hence for the angular intensity distribution one should in first approximation expect a cosine superimposed to an independent value. For the tilted lamp positions one should of course expect a gradual change between these two polar radiation diagrams.

Naturally the total light output for the same power setting varies for the individual lamps slightly ($\sim \pm 1\%$). It is, however, easy to adapt the lamp power for each lamp such that the same maximum intensity - perpendicular to lamp + reflector - is achieved and to normalise in this way the polar diagrams. This was done for these lamps; the lamp current varied between 7.78 and 7.95 A. The scatter for the individual lamps is indicated.

6.2 I.R. contribution when going from ambient to vacuum

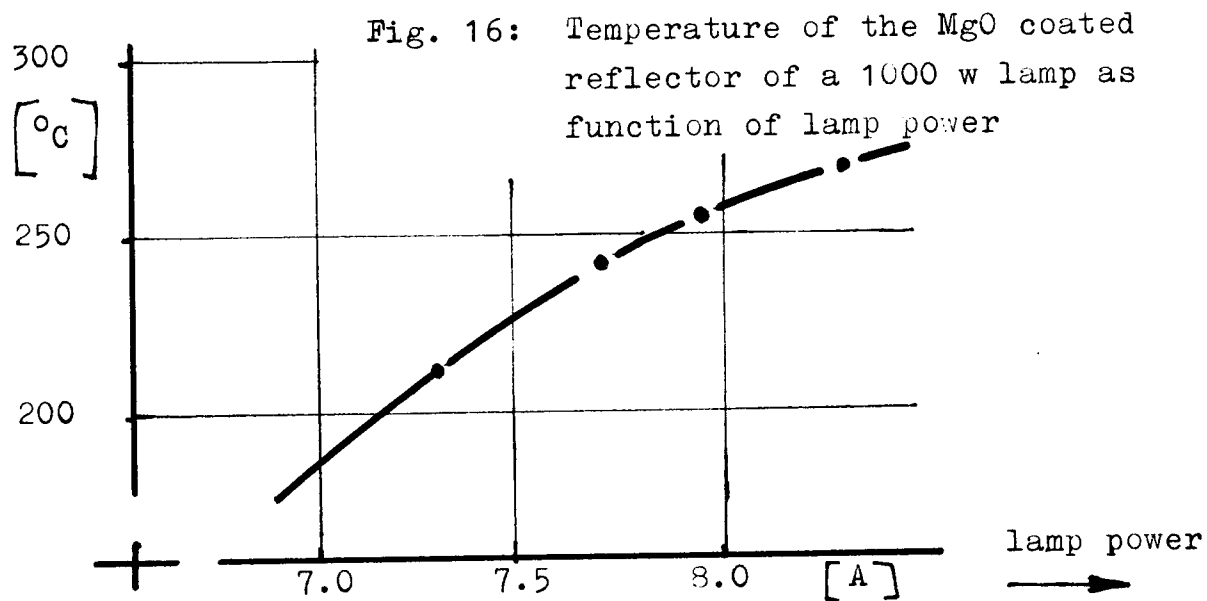
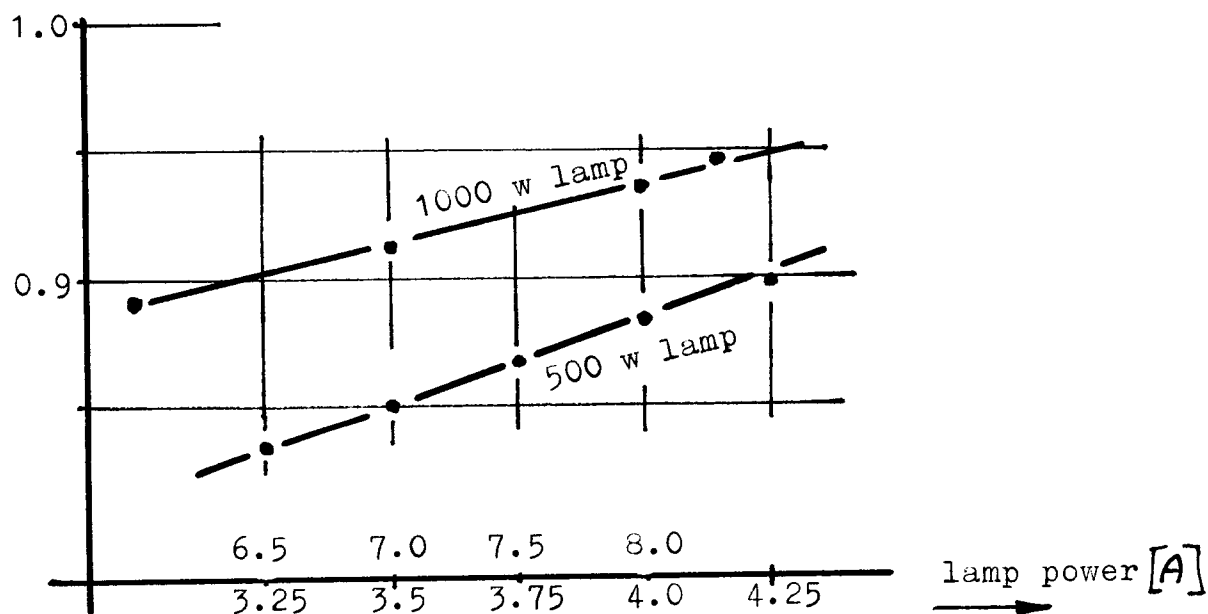
As already mentioned it is common practice to measure the intensity of a lamp array at ambient and to extrapolate or calculate the intensity for vacuum conditions. Previous measurement on the 500W lamp showed for the intensity obtained at ambient and under vacuum the ratio 0.9 for nominal power level which decreased with decreasing power level and for 50% power level 0.84 was found; for the lamps with metallic reflector approximately the same ratio was found. Therefore also for the 1000W lamp with reflector a similar ratio is expected as found for the nude lamps (fig. 15). That actually a slightly higher effect was found is possibly due to the diffuse reflector. Irrespective, however, the cooling effect is also here only halve the value found for the 500W lamp + reflector.

The temperature of the reflector itself was measured (see fig. 16) and for nominal power only 270°C were measured; no problems are anticipated concerning heat input onto uncooled shrouds and structure when calibrating the lamp array at ambient.

6.3 Experience on 1000W lamp + reflector

As described in §4.3 the vacuum has little effect on the filament temperature. The reflector, however, blocks off nearly halve the radiation, hence a stronger influence is to be expected. Since for the 1000W lamp bulb and specially the filament temperatures are considerably higher than found for the 500W lamp the reliability had to be checked. Several lamps were tested for ~ 400 h at nominal power - and occasionally even a few percent higher. All lamps survived, only on one lamp the filament sunk slightly down with the consequence that due to the dense filament spirals the quartz bulb reached the softening temperature on the reflector side and formed a small bubble. Long term tests are not yet performed at reduced power level; however at 90% power the filament temperature would be reduced by $\Delta T = \sim 85^\circ\text{K}$ and at 80% even by 180°K so one may conclude that long test periods may be performed in case the lamp power is restricted to $\sim 80\%$ of nominal power.

Fig. 15: Ratio of the output of a 1000 w lamp and a 500 w lamp with reflector obtained at ambient and under vacuum



The reflectors survived the test as well though here by protective coating with a noble metal improvements are feasible.

7. DISCUSSION AND EXPECTED ACCURACY OF THE 1000W LAMP + MgO REFLECTOR

Previous investigations showed that a good solution is obtained for the lamp array given in fig. 17 and when the mutual distance of the lamps is approximately the same as to the test plane. In the following for this configuration reproducibility, intensity distribution and accuracy shall be discussed. (10).

7.1 Reproducibility

Referring to the polar diagrams and the scatter in intensity given in fig. 14 the achievable reproducibility was calculated for the central point (perpendicular to the central lamp); it is assumed that this represents the reproducibility of the whole lamp array. The calculated contribution to the total intensity of the individual array parts (central lamp, 1. lamp square, 2. lamp square, 3. lamp square) is shown in fig. 18, and for the overall reproducibility follows 0.5%. Not included is here a geometrical misalignment of the lamps; irrespective, however, it is considered that an overall reproducibility of within $\pm 0.5\%$ should be achieved.

7.2 Intensity distribution

In figs 19, 20 the calculated intensity distribution for the Y-axis is given for the distance to the test plane 30, 50, 70 and 90cm; the mutual distance of the lamps was always 70cm. It demonstrates that also for this polar diagram for ~ 70 cm distance (\sim same distance of the lamps) an optimum is achieved; larger distances cause mainly a sharper fall off towards the corner. The intensity drop between the lamps is only $\pm 2\%$.

7.3 Expected accuracy of the intensity for test conditions

When calibrating a lamp array at ambient and extrapolating for vacuum the following uncertainties and corrections are to be considered; for lamp power was assumed 75% of nominal power (~ 7.5 A).

1. Accuracy of primary standard fluxmeter	:	$\pm 1\%$
2. Reproducibility of lamp array	:	$\pm 0.5\%$
3. Contribution of bulb when going into vacuum (no longer air cooling) + 7%	:	$\pm 0.2\%$
4. I.R. absorption by water vapour + 1%	:	$\pm 0.2\%$
5. Correction for higher filament temperature under vacuum (in case lamps are operated at constant current) + 2%	:	$\pm 0.2\%$

The overall accuracy is still within $\pm 1.5\%$.

Fig. 17:

Lamp array
of 49 lamps
schematic.

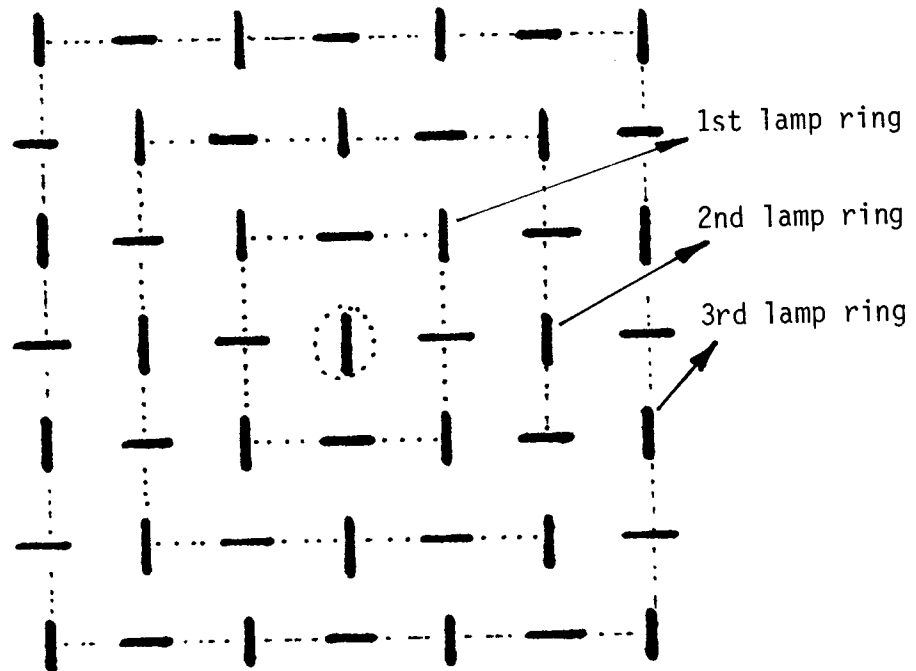
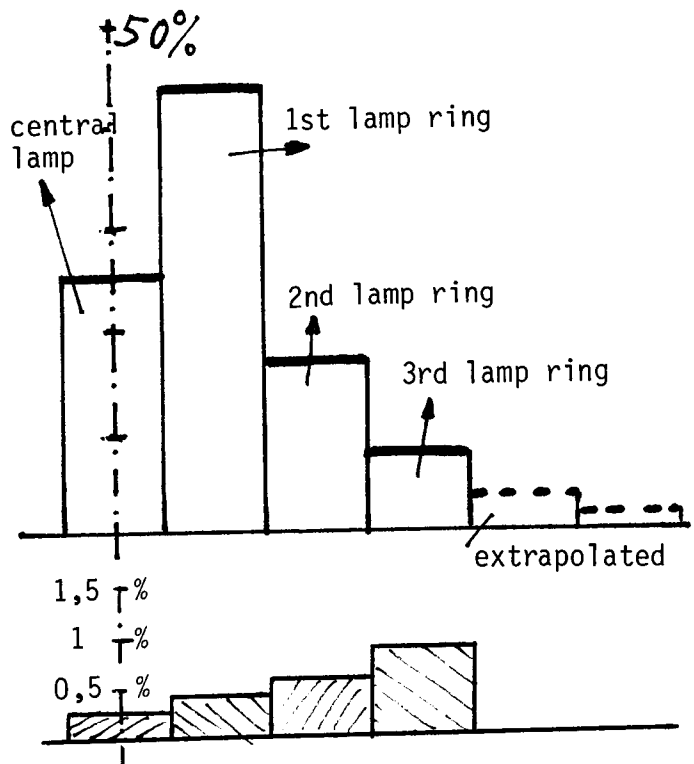
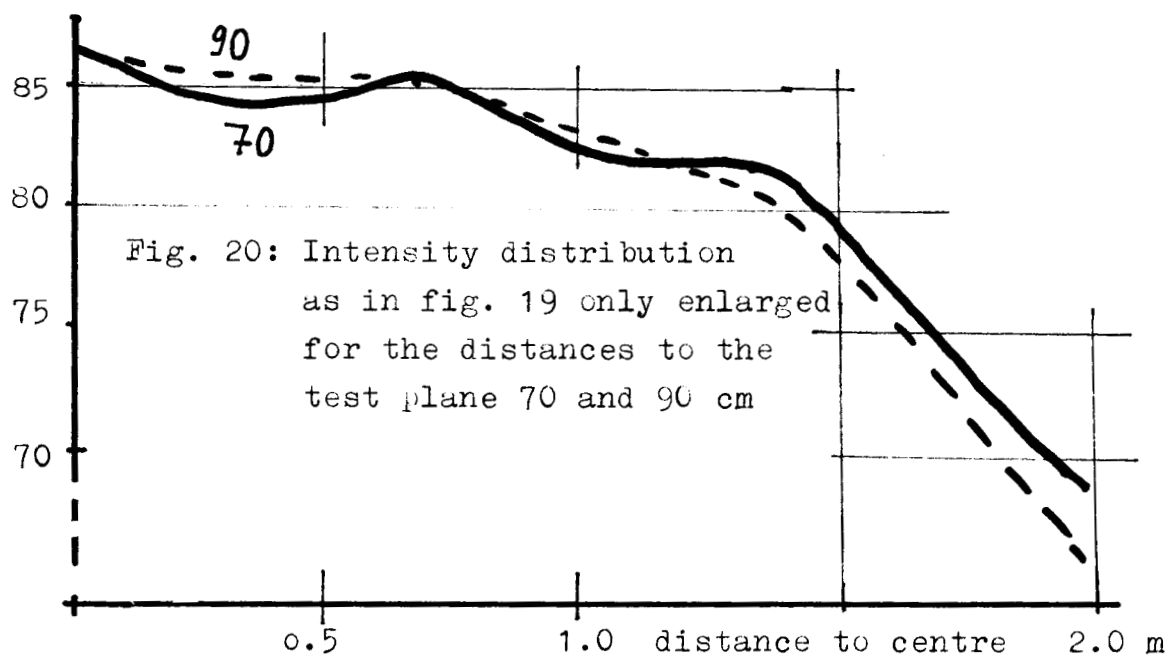
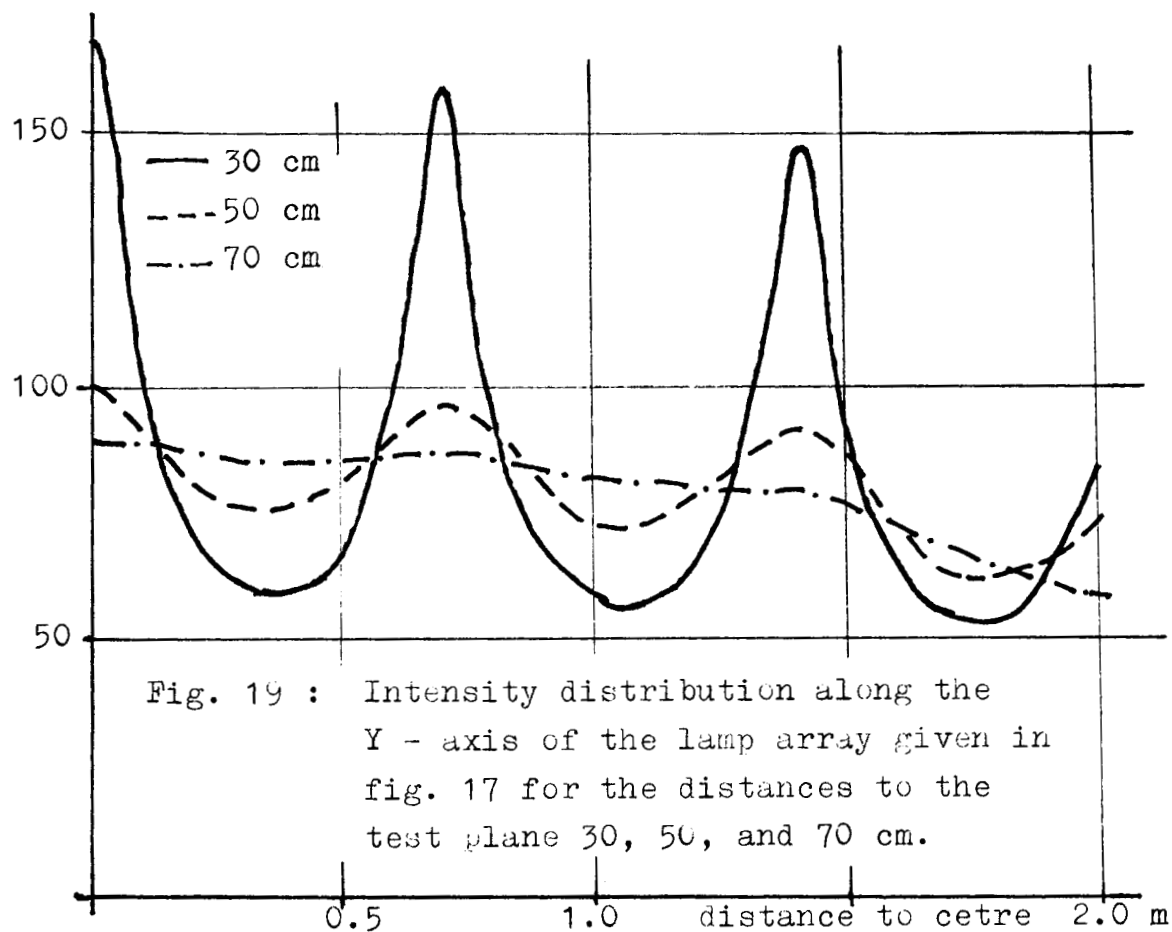


Fig. 18:

Calculated intensity at
the central point (opposite
central lamp).
Contribution of the individual
lamp rings.
The calculated scatter of
the intensity for the
individual lamp rings is
given below.
It is below 1% for the
worst case.





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ANNEX

The absorption of the quartz bulb of a lamp was measured by means of a monochromator. One lamp 1000W was placed before the entrance slit of the monochromator (filament off axis) and the light of a second 1000W lamp was focussed onto the monochromator slit, passing the bulb (only) of the first lamp. The quartz was heated up by operating this first lamp at the power level concerned, and the ratio to the transmittance at ambient (no lamp power) is measured.

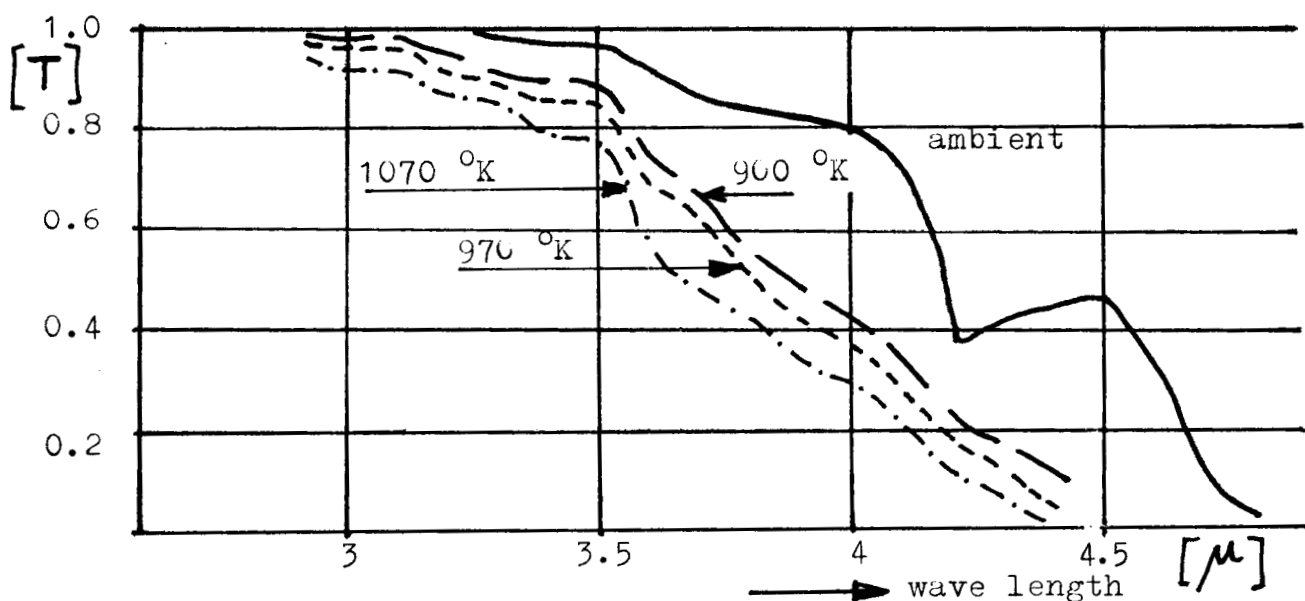


Fig. : Transmission of quartz around the cut off range ($3 \div 5 \mu$) at ambient and at the operational temperatures of the quartz lamp (1000 w Lamp) operated at 8.30; 7.0; and 6.0 Amp. The surface reflection is not considered.