ESO'S NEW TECHNOLOGY TELESCOPE (NTT)
METALLIC PRIMARY MIRROR PROJECT
Status Report

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Abstract

ESO has investigated the technological feasibility of a metallic primary mirror for the NTT. A brief status report is given indicating that a nickel coated aluminum or aluminum-alloy mirror blank can be manufactured within 15-18 months at costs well below those for a glass or ceramic material of identical shape and dimensions.

ESO's current planning provides a glass type and a metallic version for the NTT's primary mirror. As shown in Fig. 1 a monolithic meniscus shaped blank is foreseen for both versions with a diameter of 3,58 m and a thickness of ca. 240 mm. Each blank weighs approximately 6 metric tons.

The reasons which led to the decision to consider a metallic mirror were based on one of the NTT's fundamental concepts which provides an active optics system. It allows within certain limits for the correction of possible long-wave mirror distortions like those due to thermal expansion or thermal gradients inside the mirror. Further aspects were the high thermal diffusivity of metals allowing to reach temperature equilibrium inside the mirror within a short period of time and the fact that positive experiences have been reported on existing larger metallic mirrors like the two 1,5 m ϕ photometric Catalina mirrors and the 1,4 m ϕ mirror of Merate Observatory in Italy having been in operation since 1968. Optical measurements carried out by ESO in 1982 showed for the latter mirror a total aberration of less than one wavelength which could have been easily corrected by active optics. It is not known whether this aberration was inherent to the new mirror or may have developed with time due to warping. Finally ESO took account of the existing high state of art in treating metals and of cost and lead time aspects which were more favorable than for glass type blanks.

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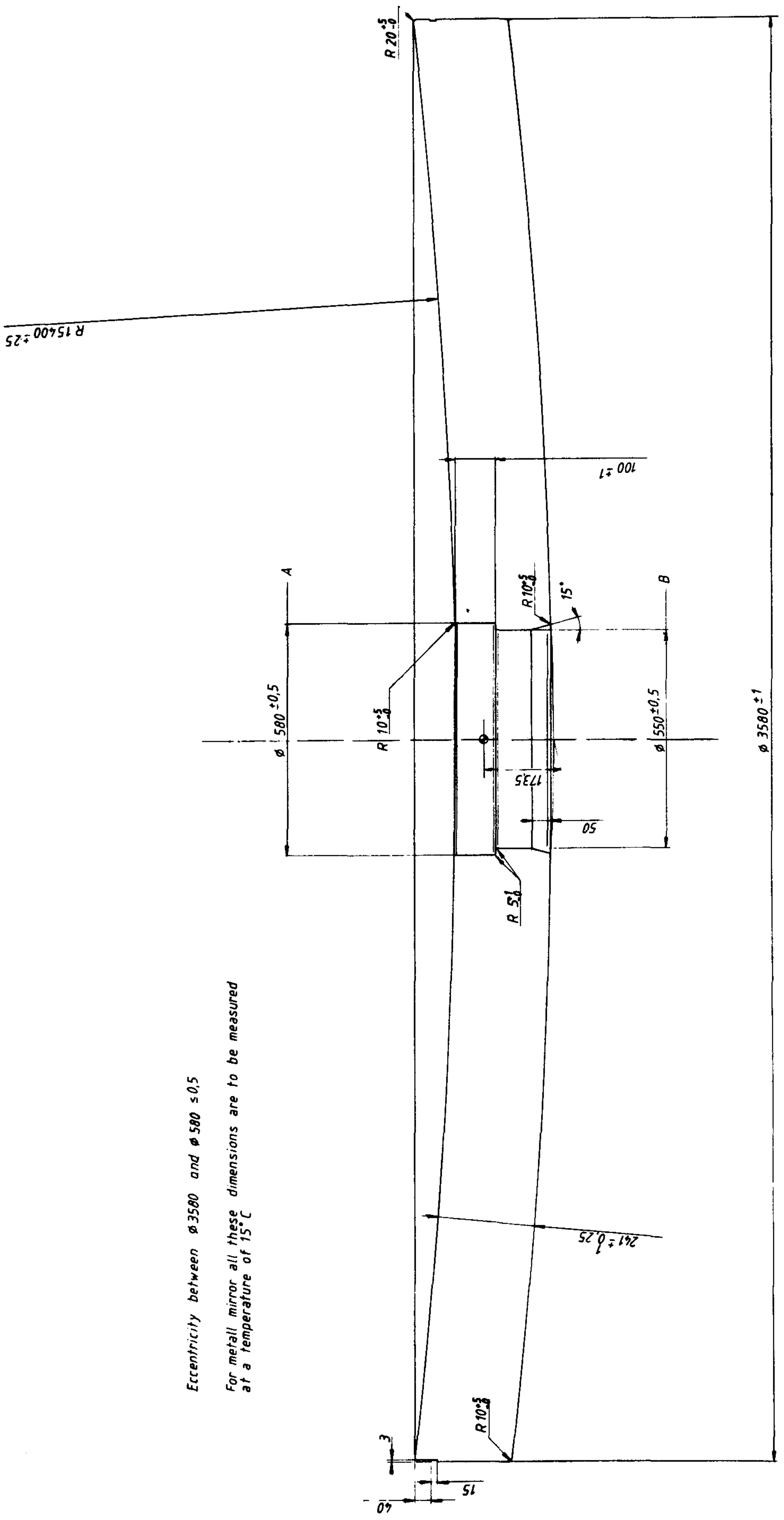


Eccentricity between ø 3580 and ø 580 ≤ 0,5

For metall mirror all these dimensions are to be measured at a temperature of 15°C

Figure 1: Dimensions of the NTT primary mirror blank

It is of course well known that some other existing larger metallic mirrors showed a poor long-term dimensional stability. Unfortunately there is very limited quantified information available which would allow for the analysis as to whether those mirrors failed due to poor design, poor fabrication or insufficient maintenance.

With all these aspects in mind ESO decided to investigate from scratch the metal mirror question, concentrating mainly on two basic problems:

a) to find out whether an NTT size component for visible optics was technologically feasible;

b) to carry out basic quantitative investigations on the warping behavior of metallic mirrors in order to predict possible distortions of an NTT size blank under operating conditions.

After a review of potential substrate materials, a decision was taken in favor of aluminum/al-alloy for the following reasons:

- exchangeability of an al and a glass-type mirror without significant modification of the mirror support system (densities: glass 2,5 g/cm^3, al 2,7 g/cm^3)

- positive experiences with some existing larger size aluminum mirrors

- excellent thermal diffusivity

- analogy and similarity to glass (density, Young's modulus, specific heat)

- good compatibility of al/nickel substrate/layer combinations

- high corrosion resistance

- promising chances to solve the critical aspects (homogeneity, dimensional stability)

- cost and lead time aspects

As far as plating was concerned, ESO decided in favour of nickel since the major part of the existing mirrors had been coated with this material.

With this first blank concept, ESO then contacted competent manufacturers. Various fabrication procedures, cost and lead time estimations were discussed for an NTT-size blank and also the availability of fabrication facilities. Based on the finally agreed techniques, orders were then placed for a total of 18 515 mm ϕ test mirrors. The blanks of these mirrors, which are currently being investigated for warping, were manufactured by the following techniques:

7 blanks by classical sandcasting
1 blank by melt-in-place casting
3 blanks by open mold casting
3 blanks by rolling
3 blanks by forging
1 blank by pure machining (without applying any kind of mechanical
deformation
18

The test mirror blanks were nickel plated in layer thicknesses between 100 μ and 500 μ by applying the following coating techniques:

13 blanks plated electroless
4 " " electrolytic
1 blank " chemical vapor deposit
18

The principles of the three casting techniques are shown in Fig. 2. Figures 2a and 2b illustrate the classical sandcasting technology. The blank is cast surface down in a sand-lined iron mold. Chilling is provided via iron plates which may have an additional water cooling via a coil system. Fig. 2c shows the basic principle of the melt-in-place technology: an iron mold is filled with material rocks and the mold content then melted in an oven. Modifications of this concept led to the open mold techniques (Fig. 2d and 2e). It turned out that the most promising results may be expected by making use fo the technique under 2e which provides extensive chilling and proper balance between flow rate and cooling.

Figure 2:

PRINCIPLES OF VARIOUS CASTING TECHNOLOGIES

2a & 2b : classical sand casting with chills or water cooled mold bottom

2c : melt in place (MIP) casting

2d : open mold casting with chills

2e open mold casting with water cooled chilling block

Fig. 2a

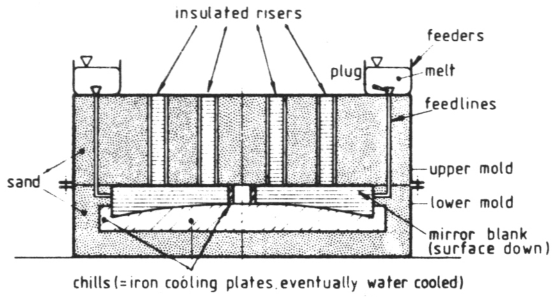


Fig. 2b

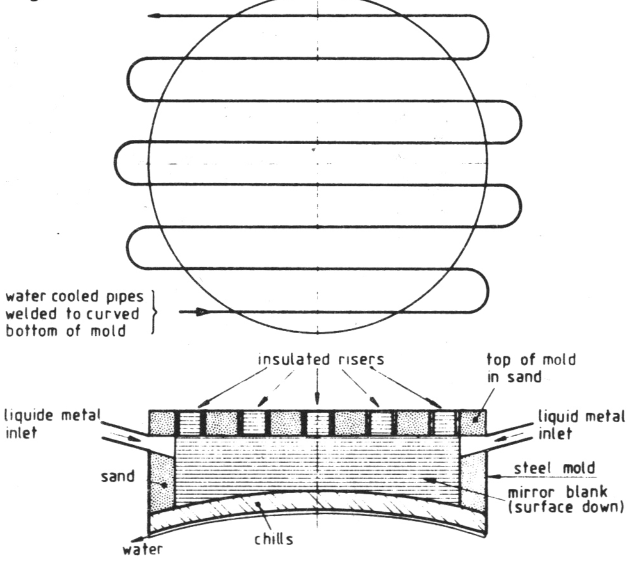


Fig. 2c

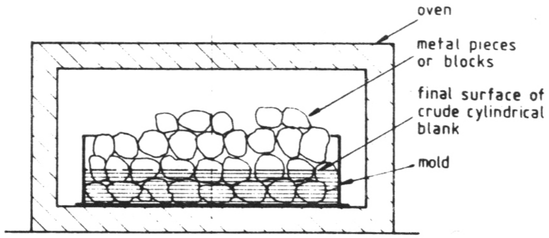


Fig. 2d

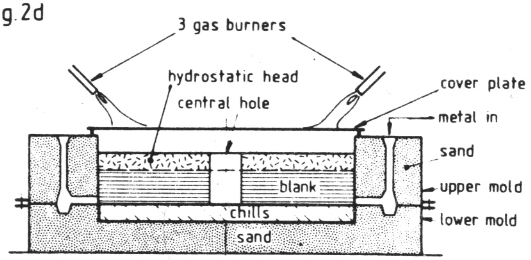
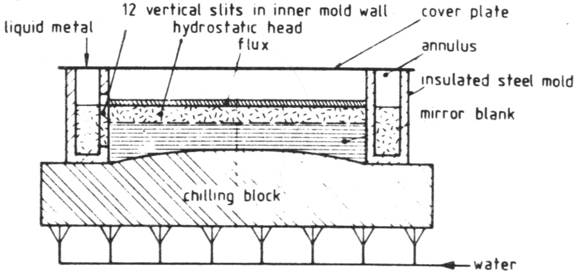


Fig. 2e



The sketches in Fig. 3 illustrate the manufacture principles of a blank starting off from string cast ingots of various shapes. In the first two techniques a cylindrical disc is worked out from the ingot either by rolling plus machining or forging plus machining. Subsequent pressing is necessary in both cases to obtain the crude meniscus shape. The technique already mentioned before which avoids application of any kind of mechanical deformation by rolling, forging or pressing is shown in Fig. 3.3. A specially shaped large size quadratic ingot is required. However, this method is not considered for manufacturing the NTT blank (at least for the time being) since it is expensive and major development work is needed to produce the ingot.

The results of the feasibility investigations for a nickel coated aluminum or al-alloy NTT blank can be summarized as follows:

- the coated blank is technologically feasible;

- all facilities exist already for manufacturing the uncoated blank;

- coating, although feasible, represents the greatest risk. Further tests are likely to be needed to identify the optimal process conditions for obtaining the desired layer quality;

- existing facilities for nickel plating are not large enough to allow for the application of the merging technique for which they have to be extended or newly built. The costs and lead times required for these facilities are included in the figures given above.

It seems to be worthwhile to mention that the techniques outlined before or combinations thereof allow also for the fabrication of Very Large Telescope (VLT) blanks in the 8 m diam. class. Segment welded designs would lead to acceptable solutions particularly if steel were the selected material.

This paper describes briefly the results of the investigations carried out so far. The comprehensive report covering the results in more detail is available on request.

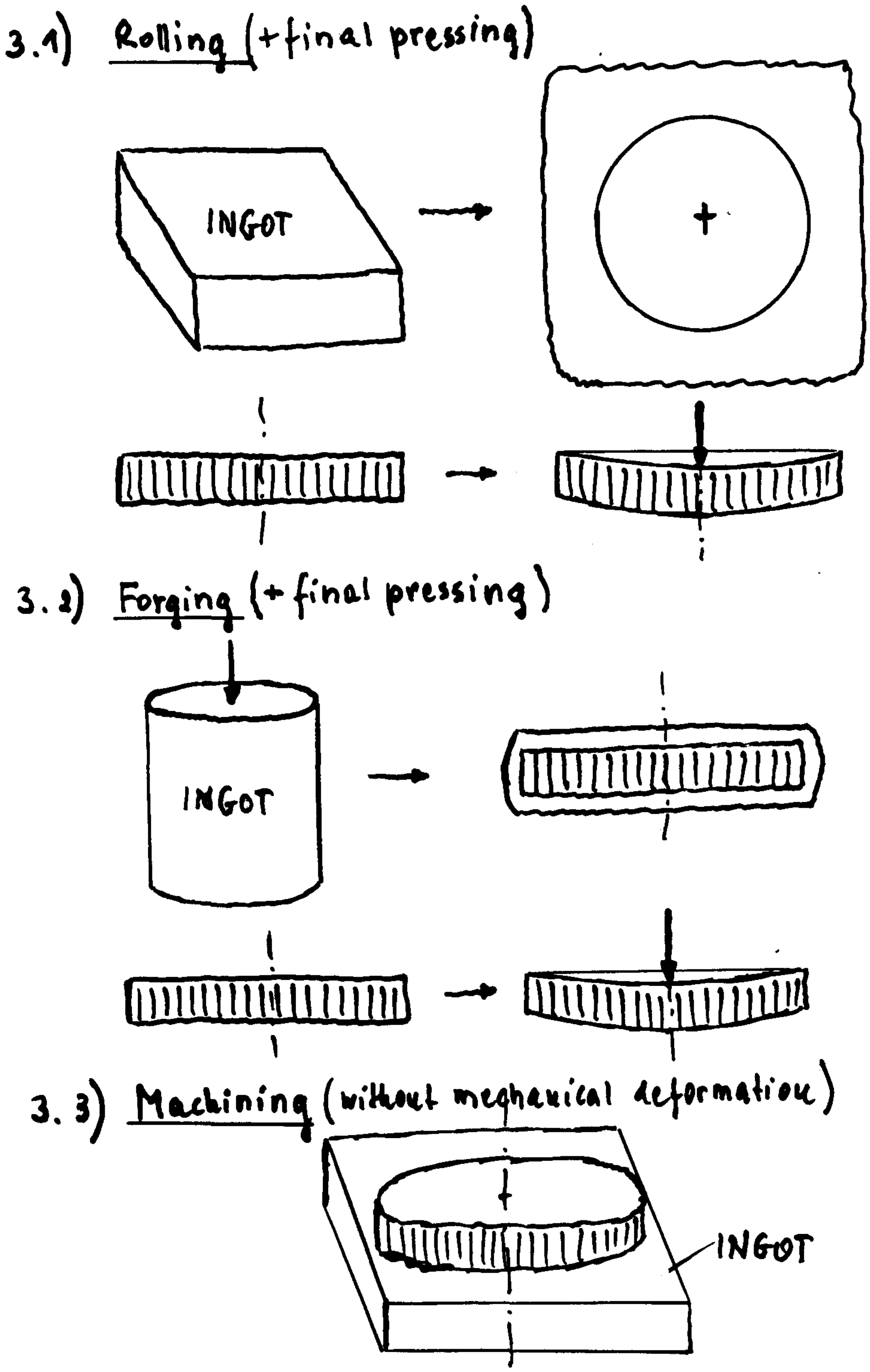


Figure 3: String cast ingots for blanks

Acknowledgement

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DISCUSSION

H. Smith: How sensitive do you expect your metal mirror to be to denting from any accidents of bumping while being handled?

K.N. Mischung: No quantitative answer can be given now. The effect will be investigated as part of our 515mm ϕ test mirror program. Due to the high thickness of our massive NTT al mirror it may be assumed that the diameter of the deformed surface zone would be 2-3 times the denting diameter. This is my personal feeling. Verification is however necessary.

I. Appenzeller: As Roger Angel earlier this morning demonstrated the merits of honeycomb mirrors, could you please comment on the possibilities of metallic honeycomb blanks? Secondly, could you please compare the thermal properties of your metallic mirrors to Roger Angel's honeycomb glas mirrors?

K.N. Mischung: Question 1 - Almost any kind of metallic mirror shape can be worked out from a crude cast, forged or rolled blank by milling, drilling, turning. Thus it is no problem to work in a honeycomb or any other type of mirror bottom side. The fabrication accuracies are high, dimensional tolerances of ca 1/300mm can be obtained. Pieces up to 100t in diameter of approx. 8m can be processed.

Question 2 - The attached table compares all relevant thermal data of glass and other substrate materials. The principal physical property which affects the time constant of a material is thermal diffusivity which is more than two orders of magnitude better for Al than for glass.

The results of calculations carried out for a flat concrete wall of 0,4m thickness are given by E. Schmidt (Thermodynamik, 8 Aufl.). Its thermal properties are almost identical with those for glass. The isothermal lines as a

	Thermal Conductivity λ Kcal/mh°C	Specific heat c Kcal/Kg°C	Density ρ Kg/m³	Thermal Diffusivity a m²/h	Young's modulus E Kg/m²	Specific Stiffness E/ρ m	Thermal Elongation α m/m°C	Hardness H Kg/mm²	Tensile Strength σ Kg/mm²	Yield strength σ0,2 Kg/mm²	Micro-yield Strength MYS kg/mm²
Glass	0,6-0,9	0,20	2500	$0,014 \cdot 10^{-1}$	$1 \cdot 10^{10}$	$4 \cdot 10^{6}$	$(0 \div 10) \cdot 10^{-6}$	≥200	3÷9	3÷9	3÷9
Aluminium/ low Al alloys	150(-200)	0,22	2700	$2,5 \cdot 10^{-1}$	$0,7 \cdot 10^{10}$	$2,6 \cdot 10^{6}$	$23 \cdot 10^{-6}$	≥ 20	4÷50	2,5÷30	0,6¹⁾
(Low alloy) Carbon Steel	42	0,11	7800	$0,49 \cdot 10^{-1}$	$2,1 \cdot 10^{10}$	$2,7 \cdot 10^{6}$	$11 \cdot 10^{-6}$	≥100	30÷90	20÷60	5¹⁾
Alloy steel 18/8 (18% Cr, 8% Ni)	18	0,12	7800	$0,19 \cdot 10^{-1}$	$2,0 \cdot 10^{10}$	$2,6 \cdot 10^{6}$	$16 \cdot 10^{-6}$	200	60	30	7¹⁾
Beryllium	140	0,24	1840	$3,2 \cdot 10^{-1}$	$3,0 \cdot 10^{10}$	$16,3 \cdot 10^{6}$	$12 \cdot 10^{-6}$	≥200	25	18	3
Copper Beryllium (98% Cu, 2% Be)	300¹⁾	0,1¹	8260	$3,6 \cdot 10^{-1}$	$1,27 \cdot 10^{10}$	$1,54 \cdot 10^{6}$	$17 \cdot 10^{-6}$¹⁾	≥200	>90	>80	?
Titanium (90% Ti, 6% Al, 4% V)	6	0,13	4500	$0,1 \cdot 10^{-1}$	$1,1 \cdot 10^{10}$	$2,54 \cdot 10^{6}$	$9 \cdot 10^{-6}$	30	90	80	?
Carbon Fibre Type I ∥ to fibre ⊥ to fibre	 3,6 0,6	 0,2 0,2	 1550 1550	 $0,12 \cdot 10^{-1}$ $0,02 \cdot 10^{-1}$	 $1,3 \cdot 10^{10}$ $0,85 \cdot 10^{10}$	 $8,4 \cdot 10^{6}$ $5,5 \cdot 10^{6}$	 $0,2 \cdot 10^{-6}$ $35 \cdot 10^{-6}$	 ? ?	 170 55	 ? ?	 ? ?
Type II ∥ to fibre ⊥ to fibre	4,7 1,1	0,2 0,2	1550 1550	$0,16 \cdot 10^{-1}$ $0,04 \cdot 10^{-1}$	$2,26 \cdot 10^{10}$ $0,73 \cdot 10^{10}$	$13,6 \cdot 10^{6}$ $4,7 \cdot 10^{6}$	$-0,88 \cdot 10^{-6}$ $32,5 \cdot 10^{-6}$	? ?	120 32	? ?	? ?
Kanigen Nickel Coating	4-12	0,1	7900	$0,1 \cdot 10^{-1}$	$1,4 \cdot 10^{10}$	$1,77 \cdot 10^{6}$	$13 \cdot 10^{-6}$	500-1000	40-80	?	?

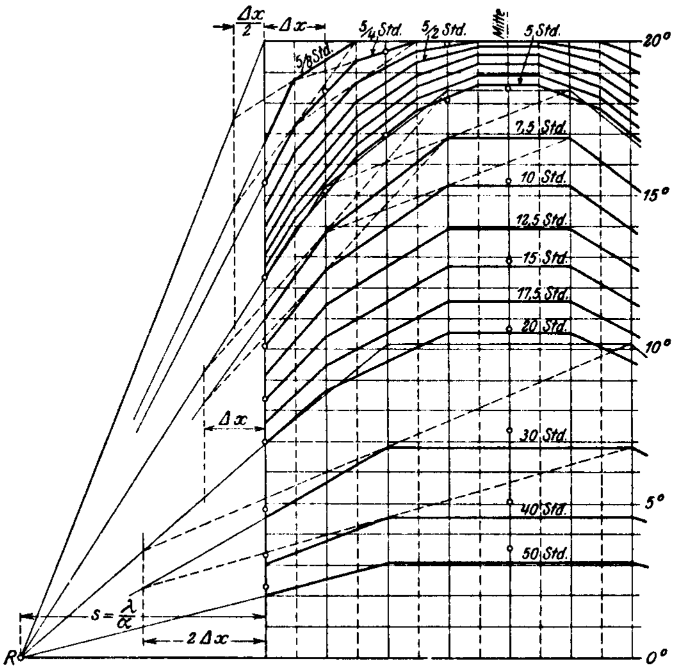
1) estimated value

Table 1: Physical properties of mirror materials at ambient temperature

function of time will be reached in a 0.4m thick Al blank in less than 1/100 of the periods of time shown in the graph. Extrapolation to the 0.24m thick massive Al NTT blank would lead to more or less identical isothermal lines.

Since both NTT mirror versions are massive blanks we have done no calculations to compare thermal behaviour of a massive Al blank and a honeycomb glass blank. The heat transfer and the time constant in a honeycomb structure depend heavily on its geometry. A mathematical solution is a very complex problem.

I would estimate that the time constant of a honeycomb type glass mirror with ribs of approx. 10-20mm thickness is in the same order of magnitude as that for a massive Al NTT blank.



Calculated time variant isothermal lines inside a 0.4 m thick concrete wall which had initially a constant temperature of 20° C and was then suddenly exposed to a surrounding air temperature of 0° C. (Taken from E. Schmidt, Thermodynamik, 8th edition.)