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manufactured by Enraf, Rigaku-Denki, and Siemens, these lifetimes are about the same as the lifetime of the filament under good vacuum conditions, that is, of the order of 1000 h.

Phillips (1985) has written a review article on stationary and rotating-anode X-ray tubes that contains many important practical details.

4.2.1.3.1. *Power dissipation in the anode*

The allowable power loading of X-ray tube targets is determined by the temperature of the target surface, which must remain below the melting point. Müller (1927, 1929, 1931) first calculated the maximum loading both for stationary and for rotating anodes. His calculations were refined by Oosterkamp (1948) who considered, in particular, targets of finite thickness, and who also treated pulsed operation of the tube. For normal conditions, Oosterkamp's conclusions and those of Ishimura, Shiraiwa & Sawada (1957) do not greatly differ from those of Müller, which are in adequate agreement with experimental observations.

For an elliptical focal spot with axes f_1 and f_2, Müller's formula for the maximum power dissipation on a stationary anode, assumed to be a water-cooled block of dimensions large compared with the focal-spot dimensions, can be written

$$W_{\rm stat} = 2.063(T_M - T_0)Kf_1\mu(f_1,f_2), \qquad (4.2.1.12)$$

where K is the specific thermal conductivity of the target material in W mm^{-1}, T_M is the maximum temperature at the centre of the focal spot on the target, that is, a temperature well below the melting point of the target material, and T_0 is the temperature of the cold surface of the target, that is, of the cooling water. The function μ is shown in Fig. 4.2.1.4. For copper, K is 400 W m^{-1} and, with $T_M - T_0 = 500$ K,

$$W_{\rm stat} = 425\mu f_1. \qquad (4.2.1.13)$$

For $f_2/f_1 = 0.1$, and $\mu = 0.425$, this equation becomes

$$W_{\rm stat} = 180f_1. \qquad (4.2.1.14)$$

In these last two equations, f_1 is in mm.

For a rotating target, Müller found that the permissible power dissipation was given by

$$W_{\rm rot} = 1.428\,K(T_M - T_0)f_1(f_2\rho Cv/2K)^{1/2}, \qquad (4.2.1.15)$$

where f_2 is the short dimension of the focus, assumed to be in the direction of motion of the target, v is the linear velocity, ρ is the density of the target material, and C is its specific heat.

For a copper target with f_1 and f_2 in mm and v in mm s^{-1},

$$W_{\rm rot} = 26.4f_1(f_2v)^{1/2}. \qquad (4.2.1.16)$$

Equation (4.2.1.16) shows that for very narrow focal spots rotating-anode tubes give useful improvements in permissible loading only if the surface speed is very high (see Table 4.2.1.3). The reason is that with large foci on stationary anodes the isothermal surfaces in the target are planar; with fine foci, these surfaces become cylindrical and this already makes for very efficient cooling without the need for rotation. Rotating anodes are thus most useful for medium-size foci (200 to 500 μm) since for the larger focal spots it becomes very expensive to construct power supplies capable of supplying the permissible amount of power.

Table 4.2.1.3 shows the recommended loading for a number of commercially available X-ray tubes with copper targets, which will be seen to be in qualitative agreement with the calculations. Some of the discrepancy is due to the fact that the value of $K(T_M - T_0)$ for the copper–chromium alloy targets used in actual X-ray tubes is appreciably lower than the value for pure copper used here. To a good approximation, the permissible loading for other targets can be derived by multiplying those in Table 4.2.1.3 by the factors shown in Table 4.2.1.4. It is worth noting that the recommended loading of commercial stationary-target X-ray tubes has increased steadily in recent years. This is largely due to improvements in the water cooling of the back surface of the target by increasing the turbulence of the water and the effective surface area of the cooled surface.

In considering Table 4.2.1.3, it should be noted that the linear velocities of the highest-power X-ray-tube anode have already reached a speed that Yoshimatsu & Kozaki (1977) consider the practical limit, which is set by the mechanical properties of engineering materials. It should also be noted that much higher specific loads can be achieved for true micro-focus tubes, *e.g.* 50 kW mm^{-2} for a 25 μm Ehrenberg & Spear tube and 1000 kW mm^{-2} for a tube with a 1 μm focus (Goldsztaub, 1947; Cosslett & Nixon, 1951, 1960).

Some tubes with focus spots of less than 10 μm utilize foil or needle targets. These targets and the heat dissipated in them have been discussed by Cosslett & Nixon (1960). The dissipation is less than that in a massive target by a factor of about 3 for a foil and 10 for a needle, but, in view of the low absolute power, target movement and even water-cooling can be dispensed with.

4.2.1.4. *Radioactive X-ray sources*

Radioactive sources of X-rays are mainly of interest to crystallographers for the calibration of X-ray detectors where they have the great advantage of being completely stable with time, or at least of having an accurately known decay rate. For some purposes, spectral purity of the radiation is important; radionuclides that decay wholly by electron capture are particularly useful as they produce little or no β or other radiation. In this type of decay, the atomic number of the daughter nucleus is one less than that of the decaying isotope, and the emitted X-rays are characteristic of the daughter nucleus. In some cases, the probability of electron capture taking place

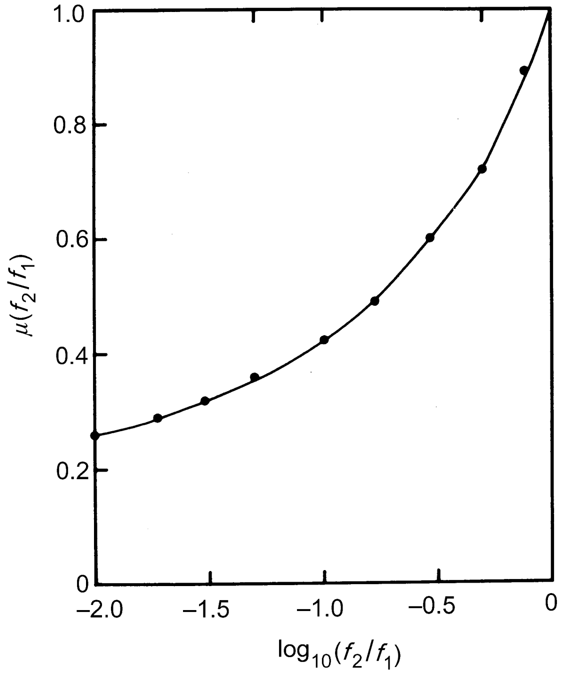

Fig. 4.2.1.4. The function μ in Müller's equation (equation 4.2.1.12) as a function of the ratio of width to length of the focal spot.