International Tables for Crystallography (2006). Vol. C, Table 4.2.1.5, p. 196.

Table 4.2.1.4. *Relative permissible loading for different target materials*

Cu	Cr	Fe	Co	Mo	Ag	W
1.0	0.9	0.6	0.9	1.2	1.0	1.2

from some shell other than the K shell is very small and most of the photons emitted are K photons. The number of photons emitted into a solid angle of 4π, uncorrected for absorption, is given by the strength of the source in Curies ($1\,\text{Curie} = 3.7 \times 10^{10}$ disintegrations s^{-1}), since each disintegration produces one photon. A list of these nuclei (after Dyson, 1973) is given in Table 4.2.1.5.

Useful radioactive sources are also made by mixing a pure β-emitter with a target material. These sources produce a continuous spectrum in addition to the characteristic line spectrum. The nuclide most commonly used for this purpose is tritium which emits β particles with an energy up to 18 keV and which has a half-life of 12.4 a.

Radioactive X-ray sources have been reviewed by Dyson (1973).

4.2.1.5. *Synchrotron-radiation sources*

The growing importance of synchrotron radiation is attested by a large number of monographs (Kunz, 1979; Winick, 1980; Stuhrmann, 1982; Koch, 1983) and review articles (Godwin, 1968; Kulipanov & Strinskii, 1977; Lea, 1978; Winick & Bienenstock, 1978; Helliwell, 1984; Buras, 1985). Project studies for storage rings such as the European Synchrotron Radiation Facility, the ESRF (Farge & Duke, 1979; Thompson & Poole, 1979; Buras & Marr, 1979; Buras & Tazzari, 1984) are still worth consulting for the reasoning that lay behind the design; the ESRF has, in fact, achieved or even exceeded the design parameters (Laclare, 1994).

A charged particle with energy E and mass m moving in a circular orbit of radius R at a constant speed v radiates a power P into a solid angle of 4π, where

$$P = 2e^2c(v/c)^4(E/mc^2)^4/3R^2. \qquad (4.2.1.17)$$

The orbit of the particle can be maintained only if the energy lost in the form of electromagnetic radiation is constantly replenished. In an electron synchrotron or in a storage ring, the circulating particles are electrons or positrons maintained in a closed orbit by a magnetic field; their energy is supplied or restored by means of an oscillating radio-frequency (RF) electric field at one or more places in the orbit. In a synchrotron, designed for nuclear-physics experiments, the circulating particles are injected from a linear accelerator, accelerated up to full energy by the RF field and then deflected into a target with a cycle frequency of about 50 Hz. The synchrotron radiation is thus produced in the form of pulses of this frequency. A storage ring, on the other hand, is filled with electrons or positrons and after acceleration the particle energy is maintained by the RF field; the current ideally circulates for many hours and decays only as a result of collisions with remaining gas molecules. At present, only storage rings are used as sources of synchrotron radiation and many of these are dedicated entirely to the production of radiation: they are not used at all, or are used only for limited periods, for nuclear-physics collision experiments.

In equation (4.2.1.17), we may substitute for the various constants and obtain for the radiated power

Table 4.2.1.5. *Radionuclides decaying wholly by electron capture, and yielding little or no γ-radiation*

Nuclide	Half-life	X-rays		Remarks
		Element	$K\alpha_1$ (keV)	
^{37}Ar	35 d	Cl	2.622	–
^{51}Cr	27.8 d	V	4.952	γ at 320 keV
^{55}Fe	2.6 a	Mn	5.898	–
^{71}Ge	11.4 d	Ga	9.251	–
^{103}Pd	17 d	Rh	20.214	Several γ's; all weak
^{109}Cd	453 d	Ag	22.16	γ at 88 keV
^{125}I	60 d	Te	27.47	γ at 35.4 keV
^{131}Cs	10 d	Xe	29.80	–
^{145}Pm	17.7a	Nd	37.36	γ's at 67 and 72 keV
^{145}Sm	340 d	Pm	38.65	γ's at 61 keV; weak γ at 485 keV
^{179}Ta	600 d	Hf	55.76	–
^{181}W	140 d	Ta	57.52	γ at 6.5 keV; weak γ's at 136, 153 keV
^{205}Pb	5×10^7a	Tl	L only ($L_{\alpha_1} =$ 10.27 keV)	–

$$P = 0.0885\,E^4I/R, \qquad (4.2.1.18)$$

where E is in GeV (10^9 eV), I is the circulating electron or positron current in milliamperes, and R is in metres. Thus, for example, at the Daresbury storage ring in England, $R = 5.5$ m and, for operation at 2 GeV and 200 mA, $P = 51.5$ kW. Storage rings with a total power of the order of 1 MW are planned.

For relativistic electrons, the electromagnetic radiation is compressed into a fan-shaped beam tangential to the orbit with a vertical opening angle $\psi \simeq mc^2/E$, *i.e.* ~ 0.25 mrad for $E = 2$ GeV (Fig. 4.2.1.5). This fan rotates with circulating electrons: if the ring is filled with n bunches of electrons, a stationary observer will see n flashes of radiation every $2\pi R/c$ s, the duration of each flash being less than 1 ns.

The spectral distribution of synchrotron radiation extends from the infrared to the X-ray region; Schwinger (1949) gives the instantaneous power radiated by a monoenergetic electron in a circular motion per unit wavelength interval as a function of wavelength (Winick, 1980). An important parameter specifying the distribution is the critical wavelength λ_c: half the total power radiated, but only $\sim 9\%$ of the total number of photons, is at $\lambda < \lambda_c$ (Fig. 4.2.1.6). λ_c is given by

$$\lambda_c = 4\pi R/3(E/mc^2)^3, \qquad (4.2.1.19)$$

from which it follows that λ_c in Å can be expressed as

$$\lambda_c = 18.64/(BE^2), \qquad (4.2.1.20)$$

where B ($= 3.34\ E/R$) is the magnetic bending field in T, E is in GeV, and R is in metres.

Synchrotron radiation is highly polarized. In an ideal ring where all electrons are parallel to one another in a central orbit, the radiation in the orbital plane is linearly polarized with the electric vector lying in this plane. Outside the plane, the radiation is elliptically polarized.

In practice, the electron path in a storage ring is not a circle. The 'ring' consists of an alternation of straight sections and bending magnets and beam lines are installed at these magnets.

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