PRINCIPLES OF RADIATION SHIELDING

Arthur B. Chilton
Professor of Nuclear and Civil Engineering
University of Illinois at Urbana-Champaign

J. Kenneth Shultis
Professor of Nuclear Engineering
Kansas State University

Richard E. Faw
Professor of Nuclear Engineering
Kansas State University

PRENTICE-HALL, INC., Englewood Cliffs, NJ 07632

2. If the source is a neutron emitter of S_p neutrons per second, r in the denominator is given in centimeters, and the detector response is the phantom-related dose equivalent rate in units of cSv s^{-1}, then $\hat{R}$ is given by the appropriate value of the response function $\mathcal{R}_{H_p}$ from Table 5.4, divided by 4π, with units of cSv cm^2.
3. If the source is a photon emitter of S_p photons per second, r in the denominator is given in centimeters, and the detector response is the phantom-related dose equivalent rate in units of cSv s^{-1}, then $\hat{R}$ is the appropriate value of the response function $\mathcal{R}_{H_p}$ from Table 5.3, divided by 4π, with units of cSv cm^2.
4. If the source is a radioactive element of strength S_p, expressed indirectly by the activity in curies, r in the denominator is given in meters, and the detector response is expressed as exposure rate in units of R h^{-1}, then $\hat{R}$ for the given photons of energy E_i is given by the expression $19.5 n_i E_i (\mu_{en}/\rho)_i^{air}$, where E_i is given in MeV, n_i is the number of photons of energy E_i emitted per disintegration (see Appendix 5), and $(\mu_{en}/\rho)_i^{air}$ is the appropriate value taken from tables in Appendix 3.[6] The units for $\hat{R}$ here are R m^2 Ci^{-1} h^{-1}. The expression given for $\hat{R}$ is readily derived from Eq. (5.27).

In case an initial buildup factor is to be used to account approximately for scattered radiation, the examples above must be modified by multiplication of $\hat{R}$ by this factor.

Although isotropic emission is typical of most sources encountered in shielding analyses, occasionally situations will arise in which the source emission will be anisotropic in direction. Equation (6.16) or (6.17) may still be used;

[6] $\hat{R}$ for this situation has been called the "partial specific gamma-ray constant" and given the symbol Γ_i. The "specific gamma-ray constant" is the sum of the partial constants for all photon energies, and is simply designated as Γ. Table 6.2 gives values of this constant

TABLE 6.2 Values of the Specific Gamma-Ray Constant (Γ) for Certain Radioisotopes

Radioisotope	Γ $\frac{\text{R m}^2}{\text{Ci h}}$	Γ $\frac{\text{R cm}^2}{\text{GBq h}}$
^{60}Co	1.30	351
^{137}Cs—^{137m}Ba	0.32	86
^{192}Ir	0.500	135
^{198}Au	0.232	62.7
^{226}Ra + daughters	0.825[a]	223[a]

[a]Assumes source encapsulated in platinum with 0.5-mm wall thickness.

Source: *Ref. 2.*

for certain radioisotopes. These are most useful in the present context for radioisotopes ^{137}Cs and ^{60}Co, emitting monoenergetic or nearly monoenergetic photons. Then $\hat{R}$ simply equals Γ.

use the associated half-value layer (HVL) or tenth-value layer (TVL) (see Section 6.2). In Table 7.1 values of the HVL and TVL are presented for a wide range of x-ray tube voltages with lead, iron, or concrete shields.

For radiological protection of personnel from medical, dental, and industrial x-ray machines which operate only intermittently, the average exposure over some period of time (usually a week) is of interest rather than the instantaneous exposure rate, which is zero when the machine is idle. To obtain such an average weekly exposure X, Eq. (7.27) is integrated over the time that the machine is in operation during the week to give

$$X = \frac{W}{r^2} B_f, \tag{7.29}$$

where the weekly workload is now defined as $W = it$ (with t being the weekly operating time of the x-ray unit) and is usually expressed in units of mA min.

TABLE 7.1 Half-Value and Tenth-Value Layers[a]

Peak Voltage (kV)	Attenuation Material: Lead (mm) HVL	Lead (mm) TVL	Concrete (cm) HVL	Concrete (cm) TVL	Iron (cm) HVL	Iron (cm) TVL
50	0.06	0.17	0.43	1.5		
70	0.17	0.52	0.84	2.8		
100	0.27	0.88	1.6	5.3		
125	0.28	0.93	2.0	6.6		
150	0.30	0.99	2.24	7.4		
200	0.52	1.7	2.5	8.4		
250	0.88	2.9	2.8	9.4		
300	1.47	4.8	3.1	10.4		
400	2.5	8.3	3.3	10.9		
500	3.6	11.9	3.6	11.7		
1,000	7.9	26	4.4	14.7		
2,000	12.5	42	6.4	21		
3,000	14.5	48.5	7.4	24.5		
4,000	16	53	8.8	29.2	2.7	9.1
6,000	16.9	56	10.4	34.5	3.0	9.9
8,000	16.9	56	11.4	37.8	3.1	10.3
10,000	16.6	55	11.9	39.6	3.2	10.5
Cesium-137	6.5	21.6	4.8	15.7	1.6	5.3
Cobalt-60	12	40	6.2	20.6	2.1	6.9
Radium	16.6	55	6.9	23.4	2.2	7.4

[a]Approximate values obtained at high attenuation for the indicated peak voltage values under broad-beam conditions; with low attenuation these values will be significantly less.

Source: *Ref. 15; by permission of the National Council on Radiation Protection and Measurements.*