

Lead containers for natural radioactive samples with 20 mm walls

The attenuation by a factor of 1 048 576 (i.e. 2^{20}) through 20 mm of lead containing 3% antimony is based on the exponential relationship between the material thickness and the half-value layer (HVL: Half-Value Layer) for γ radiation, as well as on the maximum range for β particles.

For γ radiation, attenuation follows the law $I = I_0 \times (1/2)^{(x/HVL)}$, where x is the material thickness (here, $x = 20$ mm and HVL the half-value layer). An attenuation factor¹ of 1 048 576 implies that $I/I_0 = 1/1\,048\,576 = (1/2)^{20}$, which requires that $x = 20 \times \text{HVL}$.



Using tabulated HVL values for pure lead (e.g.: 0.068 cm at 200 keV and 0.42 cm at 500 keV), a calculation shows that to obtain 20 HVL in 20 mm thickness (i.e. HVL = 1 mm), the γ energy is around 250–300 keV. The addition of 3% antimony, although it slightly decreases the overall density, also decreases the effective atomic number of the material. This slightly increases the HVL, thus reducing the maximum γ energy attenuated by a factor of 1 048 576 to ≈ 240 –280 keV (compared to 250–300 keV for pure lead).

For β particles, whose attenuation is not exponential but related to their maximum range in matter, 20 mm of lead are sufficient to completely stop β particles with energy ≤ 4.5 MeV, thus covering all β emissions from natural uranium/thorium isotopes (e.g.: ^{210}Bi , $E_{\text{max}} = 1.16$ MeV) and even more energetic emissions (e.g.: ^{208}Tl , $E_{\text{max}} = 1.8$ MeV).

Thus, for a shielding of 20 mm of lead + 3% Sb, the maximum energies attenuated by a factor of 1 048 576 are:

- ≈ 240 –280 keV for γ ,
- ≤ 4.5 MeV for β .

This corresponds to the energies frequently encountered in natural radioactive samples, including complex decay chains such as those of U-Thorianite (^{235}U , ^{232}Th and their daughter elements).

Whatever the case, for accurate values concerning the attenuation of gamma rays in materials, please consult the NIST website (<https://www.nist.gov/>):

<https://www.nist.gov/pml/xcom-photon-cross-sections-database>

¹ Note on the terminology of attenuation factors

When it is stated that a shield 'attenuates by a factor of X', this means that the intensity of the radiation is divided by X, i.e. $I/I_0 = 1/X$. An attenuation factor of 1024 (10 HVL, since $2^{10} = 1024$) reduces the intensity to 1/1024 of its initial value. In this case, 20 mm of lead + 3% Sb corresponds to 20 HVL for γ -rays of 240–280 keV, producing an attenuation factor of $2^{20} = 1,048,576$, or approximately one millionth of the initial intensity.