Beta Shielding
Chapter 7: External Radiation Protection

Beta Ray Shielding

辐射与β发射体相关的
- 电子或正电子
- Bremsstrahlung x-rays
- 在正电子的情况下，湮灭光子

β屏蔽由低Z物质组成，厚度足以阻止β射线，外层为高Z材料以衰减Bremsstrahlung x-rays。
Beta Ray Shielding – An Example

Example 10.10

Fifty milliliters of aqueous solution containing $37 \times 10^4$ MBq (10 Ci) carrier-free $^{90}$Sr in equilibrium with $^{90}$Y is to be stored in a laboratory. The health physics requires the dose-equivalent rate at a distance of 50 cm from the center of the solution to be no greater than 0.1 mSv (10 mrems) per hour. Design the necessary shielding to meet this requirement.

The maximum and mean beta-ray energies of $^{90}$Sr and $^{90}$Y are as follows:

<table>
<thead>
<tr>
<th></th>
<th>$E_{\text{max}}$, MeV</th>
<th>$E_{\text{mean}}$, MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{90}$Sr</td>
<td>0.54</td>
<td>0.19</td>
</tr>
<tr>
<td>$^{90}$Y</td>
<td>2.27</td>
<td>0.93</td>
</tr>
<tr>
<td>Sum</td>
<td></td>
<td>1.12</td>
</tr>
</tbody>
</table>
Serial Transformation

In many situations, the parent nuclides produce one or more radioactive offsprings in a chain. In such cases, it is important to consider the radioactivity from both the parent and the daughter nuclides as a function of time.

\[ ^{90}\text{Kr} \xrightarrow{\beta} ^{90}\text{Rb} \xrightarrow{\beta} ^{90}\text{Sr} \xrightarrow{\beta} ^{90}\text{Y} \xrightarrow{\beta} ^{90}\text{Zr}. \]

Due to their short half lives, \(^{90}\text{Kr}\) and \(^{90}\text{Rb}\) will be completely transformed, resulting in a rapid building up of \(^{90}\text{Sr}\).

\(^{90}\text{Y}\) has a much shorter half-life compared to \(^{90}\text{Sr}\). After a certain period of time, the instantaneous amount of \(^{90}\text{Sr}\) transformed per unit time will be equal to that of \(^{90}\text{Y}\).

In this case, \(^{90}\text{Y}\) is said to be in a **secular equilibrium**.
Secular Equilibrium: $T_A >> T_B \ (\lambda_A << \lambda_B)$

$$\lambda_A N_A = \lambda_B N_B \ and \ Q_A = Q_B$$
Part 1: Beta Shielding Considerations

The range of the beta particles with the max. energy of 2.27 MeV is 1.19g/cm². If polyethylene is used as the shielding material, the wall thickness of the shielding is chosen to be equal to the range,

\[
t_{\text{wall}} = \frac{1.19 \text{ g/cm}^2}{0.959 \text{ g/cm}^3} = 1.26 \text{cm}
\]
Part 2: Extra Shielding for Bremsstrahlung X-rays

The rate of beta energy emitted by the source is

\[ \dot{E}_\beta = A \cdot E_\beta = 3.7 \times 10^{11} Bq \times 1.12 \text{ MeV/t} \]

The fraction of beta energy being converted to bremsstrahlung is

\[ f = 3.5 \times 10^{-4} \cdot z_{\text{eff}} \cdot E_{\text{max}}(\text{MeV}) \]

where \( Z_{\text{eff}} \) is the effective Z of the absorbing material

\[ Z_{\text{eff}} = \frac{\sum N_i Z_i^2}{\sum N_i Z_i} = 6.6 \text{ for polyethylene} \]

\( N_i \): number fraction of the i’th element
\( Z_i \): atomic mass number of the i’th element.

So

\[ f = 3.5 \times 10^{-4} \cdot 6.6 \cdot 2.27 = 5.24 \times 10^{-3} \]
Part 2: Extra Shielding for Bremsstrahlung X-rays

Assuming all X-rays are emitted from a point, the dose rate at a distance \(d\) is

\[
\dot{D} = \frac{f \cdot \dot{E}_\beta \left(\frac{MeV}{s}\right) \cdot 1.6 \times 10^{-13} \left(\frac{J}{MeV}\right) \cdot \mu_{en} \left(\frac{1}{cm}\right) \cdot 3.6 \times 10^3 \left(\frac{S}{h}\right)}{\rho_{air} \cdot (k g/m^3) \cdot 4\pi \cdot d^2 (m^2) \cdot 10^{-3} (Gy/mSv)} = 1.14 \text{ mSv/h}
\]

Suppose all bremsstrahlung photons having the maximum beta particle energy, 2.27 MeV. The linear attenuation coefficient for 2.27 MeV photons in lead is 0.51 cm\(^{-1}\). The thickness of lead needed to bring the dose at 0.5 m away to 0.1 mSv is given by

\[
0.1 = 1.14 \cdot e^{-0.51(cm^{-1}) \cdot t(cm)}
\]

\[
t = -\frac{1}{0.51} \ln \frac{0.1}{1.14} = 4.8 \text{ cm}
\]