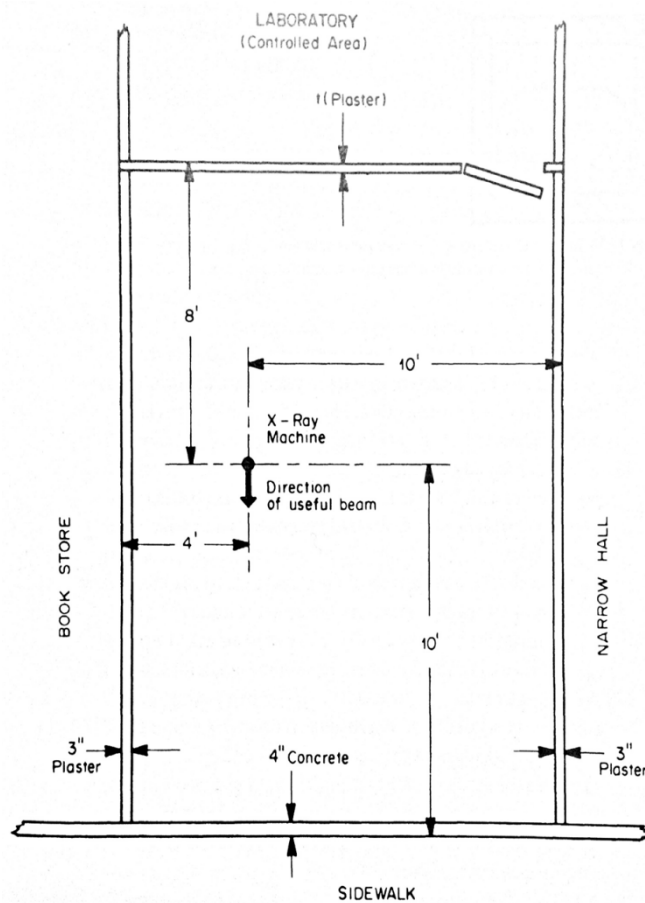


Your Name: _____

Q1. Design of the primary X-ray shielding (40 points)

For the X-ray facility shown in the figure below, please calculate the thickness of concrete shielding needed for the primary protective barrier.



Note:

1. The diagnostic X-ray source is operated at 200 kVp with a maximum current of 60 mA. It is used for 12 mins/day and 4 days/week.
2. The horizontal beam is *always* pointed toward the sidewalk that has an occupancy factor of 0.75.
3. The maximum exposure rate allowed for the sidewalk is 0.01 R/week.
4. The thickness of shielding needed can be estimated using the following figure.

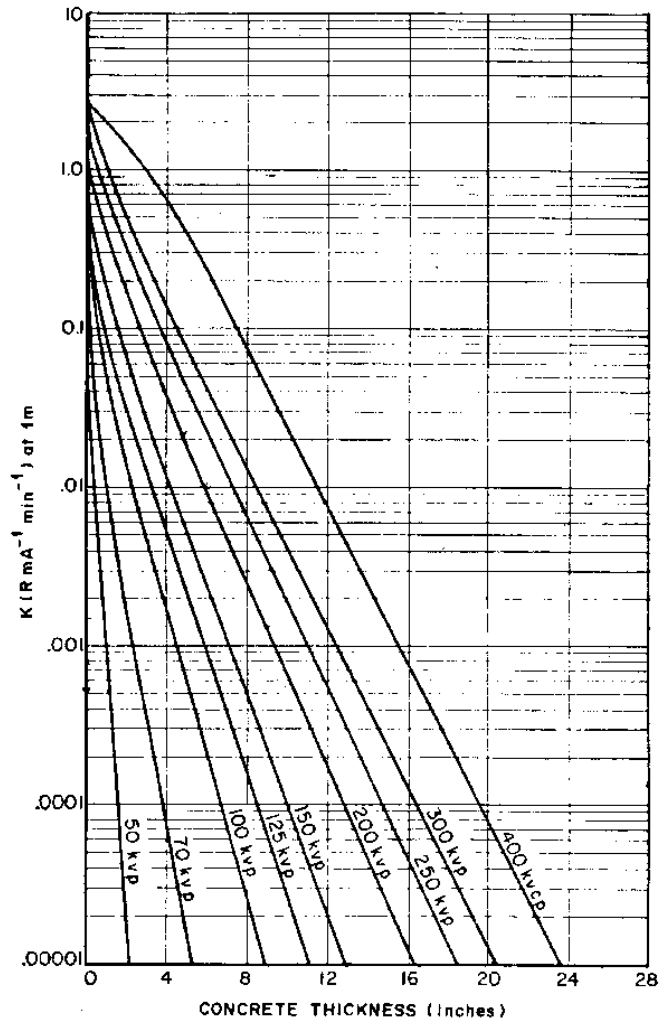


FIGURE 15.6. Attenuation in concrete of X rays produced with (peak) potential differences from 50 kVp to 400 kVp. (*National Bureau of Standards Handbook 76, 1961, Washington, DC*)

Q2: Neutron shielding design (60 points)

For a ^{210}Po -Be point source that emits 7.5×10^7 neutrons/second placed in a spherical water tank of 35 cm radius, please estimate the dose rate at the surface of the shielding.

Notes:

1. Assuming that the Po-Be neutron source emits fast neutrons of around 4 MeV, and each thermal neutron capture by hydrogen leads to the emission of a gamma-ray of 2.26 MeV energy.
2. For a point source of fast neutrons placed at the center of a spherical shielding of nT (cm) radius, the fast neutron flux emerging from the surface of the shielding is given by

$$\dot{\phi} = \frac{BS}{4\pi(nT)^2} \frac{1}{2^n} \text{ (neutrons/cm}^2\text{/s)},$$

where $B=5$ is the build-up factor, S is the source strength in neutrons per second, and $T = 3.7$ cm is the half-value layer (HVL) for fast neutrons in water.

3. For a point source of thermal neutrons of strength S neutrons/second at the center of a spherically-shaped non-multiplying medium of radius R , the flux of thermal neutrons escaping from the surface of the medium is

$$\dot{\phi} = \frac{S}{4\pi R D} e^{-R/L} \text{ (neutrons/cm}^2\text{/sec)},$$

where $L = 2.88$ cm is the thermal diffusion length in water, and $D = 0.16$ cm is the diffusion coefficient.

4. For a spherical volume of radius R , filled with a uniform gamma-ray activity of C ($\text{Bq} \cdot \text{cm}^{-3}$), the dose rate induced by the gamma-ray activity at the surface of the spherical volume is

$$\dot{D} = \frac{1}{2} \cdot C \cdot \Gamma \cdot \frac{4\pi}{\mu} \cdot (1 - e^{-\mu r}) \cdot \left(34 \frac{\text{J/kg}}{\text{Coulomb/kg}} \right) \cdot \left(\frac{\mu_{\text{water}}/\rho_{\text{water}}}{\mu_{\text{air}}/\rho_{\text{air}}} \right),$$

where $\mu = 0.046 \text{ cm}^{-1}$ is the linear attenuation coefficient of water for gamma rays of 2.26 MeV, and $\left(\frac{\mu_{\text{water}}/\rho_{\text{water}}}{\mu_{\text{air}}/\rho_{\text{air}}} \right) = 1.1$. $\Gamma = 7.2 \times 10^{-5} \left(\frac{\text{C}}{\text{kg}} \cdot \text{cm}^2 \cdot \text{MBq}^{-1} \cdot \text{h}^{-1} \right)$ is the specific gamma-ray constant for 2.26 MeV gamma-rays.

5. You may estimate the dose rate induced by fast and thermal neutrons using the table below.

TABLE 9.5. Values of Neutron Fluence Rates Which, in a Period of 40 H, Result in a Maximum Dose Equivalent of 1 mSv

| Neutron Energy, MeV | Neutron Fluence Rate, cm ⁻² s ⁻¹ | |
|------------------------|---|---|
| | Adapted from NCRP Report No. 38 (NCRP, 1971) ^a | Adapted from Cross and Ing, 1985 ^a |
| 5 × 10 ⁻⁸ | 270 | 280 |
| 10 ⁻⁷ | 340 | — |
| 10 ⁻⁶ | 280 | 280 |
| 10 ⁻⁵ | 280 | 280 |
| 10 ⁻⁴ | 290 | 290 |
| 10 ⁻³ | 340 | 280 |
| 5 × 10 ⁻³ | — | 310 |
| 10 ⁻² | 350 | 300 |
| 2 × 10 ⁻² | — | 250 |
| 5 × 10 ⁻² | — | 110 |
| 10 ⁻¹ | 58 | 40 |
| 3 × 10 ⁻¹ | — | 20 |
| 3.8 × 10 ⁻¹ | — | 16 |
| 4.4 × 10 ⁻¹ | — | 13 |
| 5 × 10 ⁻¹ | 14 | 16 |
| 6 × 10 ⁻¹ | — | 15 |
| 8 × 10 ⁻¹ | — | 14 |
| 9 × 10 ⁻¹ | — | 13 |
| 1.0 | 10 | 9.7 |
| 1.20 | — | 12 |
| 2.00 | — | 11 |
| 2.30 | — | 12 |
| 2.50 | 10 | 11 |
| 3.00 | — | 11 |
| 3.50 | — | 8.5 |
| 4.50 | — | 9.9 |
| 5.00 | 8.0 | 9.7 |
| 6.25 | — | 9.2 |
| 7.00 | 8.5 | 9.0 |
| 10.0 | 8.5 | 8.0 |
| 14.0 | 6.0 | 6.8 |
| 14.7 | — | 6.5 |
| 20 | 5.5 | — |
| 40 | 5.0 | — |
| 60 | 5.5 | — |
| 100 | 7.0 | — |
| 200 | 6.5 | — |
| 300 | 5.5 | — |
| 400 | 5.0 | — |

^aThe fluence rates presented here have been obtained from the cited references by dividing the respective reference values for thermal neutrons by 2.5 and the respective values for all other energies by 2.0. These adjustments have been made to reflect recommendations of the NCRP (1987) to increase the effective quality factors for thermal neutrons and more energetic neutrons by 2.5 and 2.0, respectively. SOURCE: From NCRP Report No. 112. By permission.

