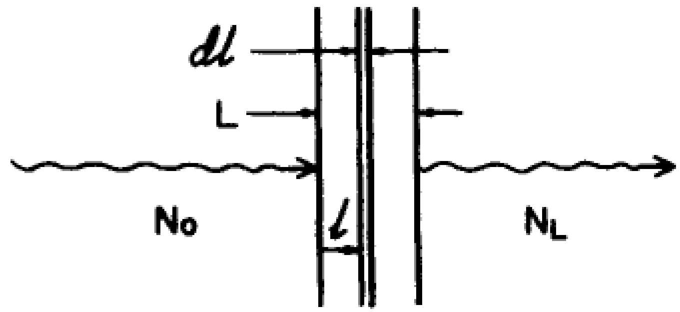
Chapter III: Geometric configurations for uncharged particles

« Simple » exponential attenuation : Ideal case

- Let be a monoenergetic beam of uncharged particles (photons or neutrons) incident ($\perp$) on a target (attenuator) with thickness *L*



$$N_L = N_0 \exp\left(-\mu L\right)$$

- μ: **Linear attenuation coefficient** (unit: m^{-1})
- Ideal case → Each particle is either absorbed during only one interaction (without emission of secondary particles), either crosses the attenuator without change of energy or direction
- Other case valid → particles deviated or possible secondaries but they are not included in N_L

Real beam

- Real beam of uncharged particles → production of secondary particles (charged or not) + deviation of the incident particles (with energy losses or not)
- Behind the attenuator → number of particles larger than the simple number of particles which undergo no interaction → simple exponential attenuation is not valid
- However → charged particles have not to be considered in a beam of uncharged particles (moreover charged particles are less penetrating → are absorbed in the attenuator and detector are often shielded) → *E* given to charged particles is absorbed

Broad beam attenuation

- The deviated primary particles and the uncharged secondaries can reach the detector or not
- The deviated primary particles and the uncharged secondaries can be included in N_L or not
- If yes → simple exponential expression of $N_L \leftrightarrow L$ is not valid
- We have then a *broad beam attenuation*

Effective attenuation coefficient

- We can define an effective attenuation coefficient μ' corresponding to the attenuation observed in the conditions of broad beam attenuation

- More particles are counted in the conditions of broad beam attenuation than in the ideal case of simple attenuation →

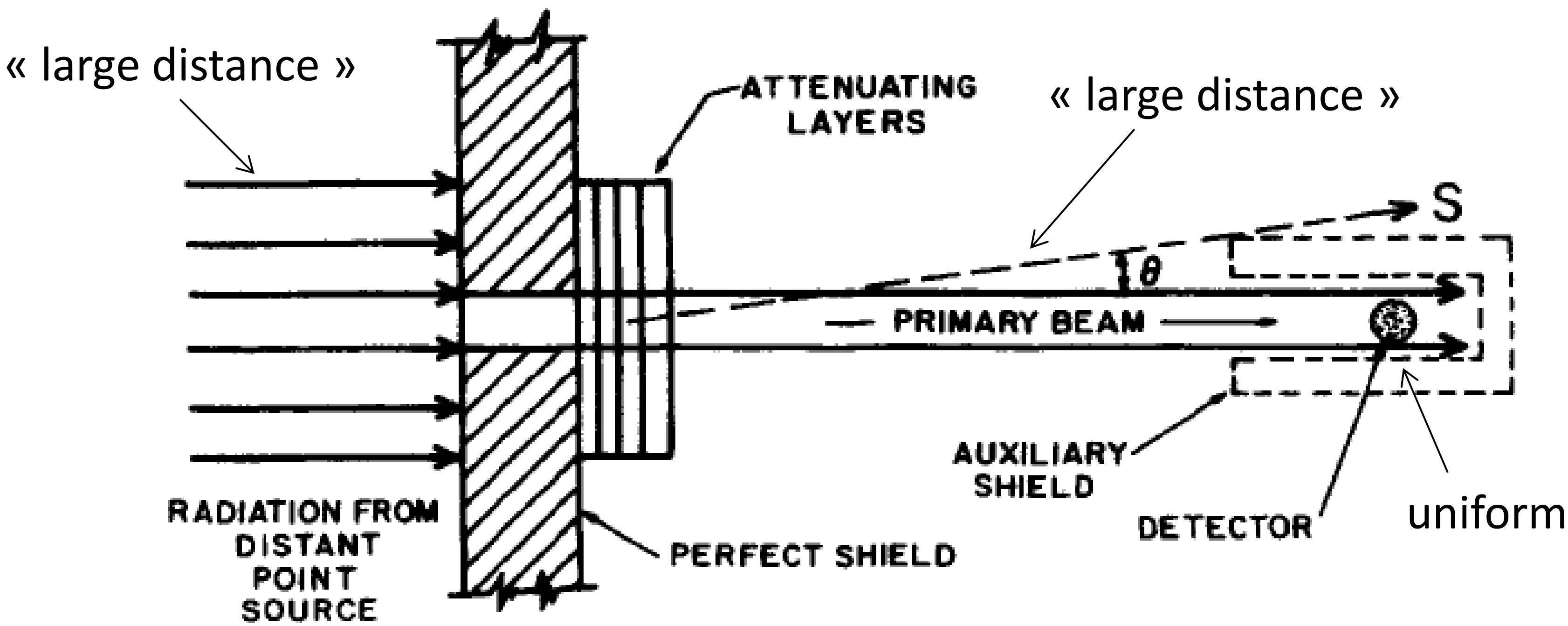
$$\mu' < \mu$$

Narrow beam attenuation (1)

- If the deviated primary particles and the uncharged secondaries reach the detector but are not included in N_L → We have then a *broad beam geometry* but a *narrow beam attenuation*
- The exponential equation of the ideal case stays valid in these conditions for a real beam
- In practice → discrimination against the deviated primaries and the secondaries which reach the detector by considering their energy, their direction, their flying time, etc.

Narrow beam attenuation (2)

- Another way to obtain a narrow beam attenuation → to use a *narrow beam geometry* to avoid that the deviated primaries and the secondaries reach the detector



Narrow beam geometry

Narrow beam geometry: Characteristics

- Large distance between the source and the attenuator → particles have a normal incidence on the attenuator
- Large distance between the attenuator and the detector → each particle deflected inside the attenuator will miss the detector (intensity of the primaries at the detector independent on the distance of the attenuator ↔ intensity of the deviated primaries and of the secondaries ↘ as a function of the square of this distance) → the relative intensity of the primary beam ↗ as a function of this distance
- The beam is collimated so as to uniformly cover the detector → ↘ of the number of the deviated primaries and of the secondaries generated inside the attenuator

Narrow beam geometry : Shields

- The shield in front of the attenuator has to stop all the incident radiations except those passing through the opening

- The shield around the detector has to stop all the radiations except those passing through the opening ($\theta \approx 0°$)
  - Lead if radiations to be stopped are X-rays or γ (advantage: small thickness)
  - Hydrogenated materials if they are neutrons

Narrow beam geometry : In practice

- In practice → not difficult to achieve an experiment with a narrow beam geometry → narrow beam attenuation is correct
- Values of the attenuation coefficients published in literature have been obtained in these rigorous conditions of narrow beam geometry
- However in some practical cases → no narrow beam geometry → it is thus necessary to define other contexts: ideal broad beam geometry and ideal broad beam attenuation

Ideal broad beam geometry

- In an *ideal broad beam geometry*, every scattered or secondary uncharged particle reaches the detector, but only if generated in the attenuator by a primary particle on its way to the detector, or by a secondary charged particle resulting from such a primary
- Attenuator thin enough → escape of the uncharged particles resulting from first interactions by the primaries, plus the X-rays and annihilation γ-rays emitted by the secondary charged particles that are generated by primaries in the attenuator
- Multiple scattering is excluded

Ideal broad beam attenuation

- If, in addition to having ideal broad beam geometry, we require the detector to respond in proportion to the radiant energy *R* of all the primary, scattered and secondary uncharged radiation incident upon it → Ideal broad beam attenuation

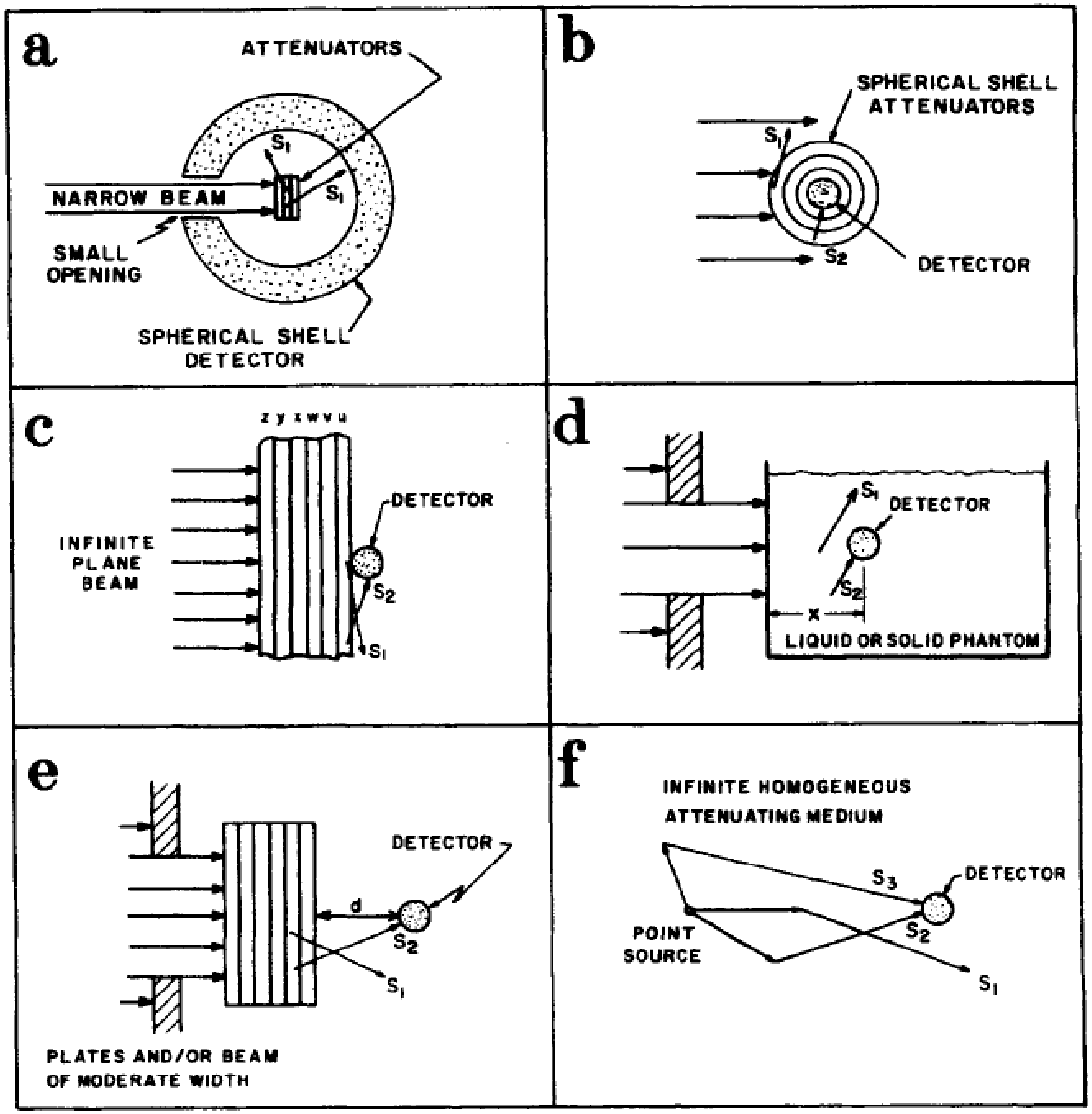
$$\Rightarrow \quad R_L = R_0 \exp\left(-\mu_{en} L\right)$$

- R_0: radiant *E* of the primaries incident on the detector for $L = 0$, R_L: radiant *E* of uncharged particles striking the detector when the (thin) attenuator is in place and μ_{en}: energy-absorption coefficient
- μ_{en} is often considered as an approximation of μ' (« straight-ahead approximation ») even if the conditions are not ideal → good results for attenuator with small Z

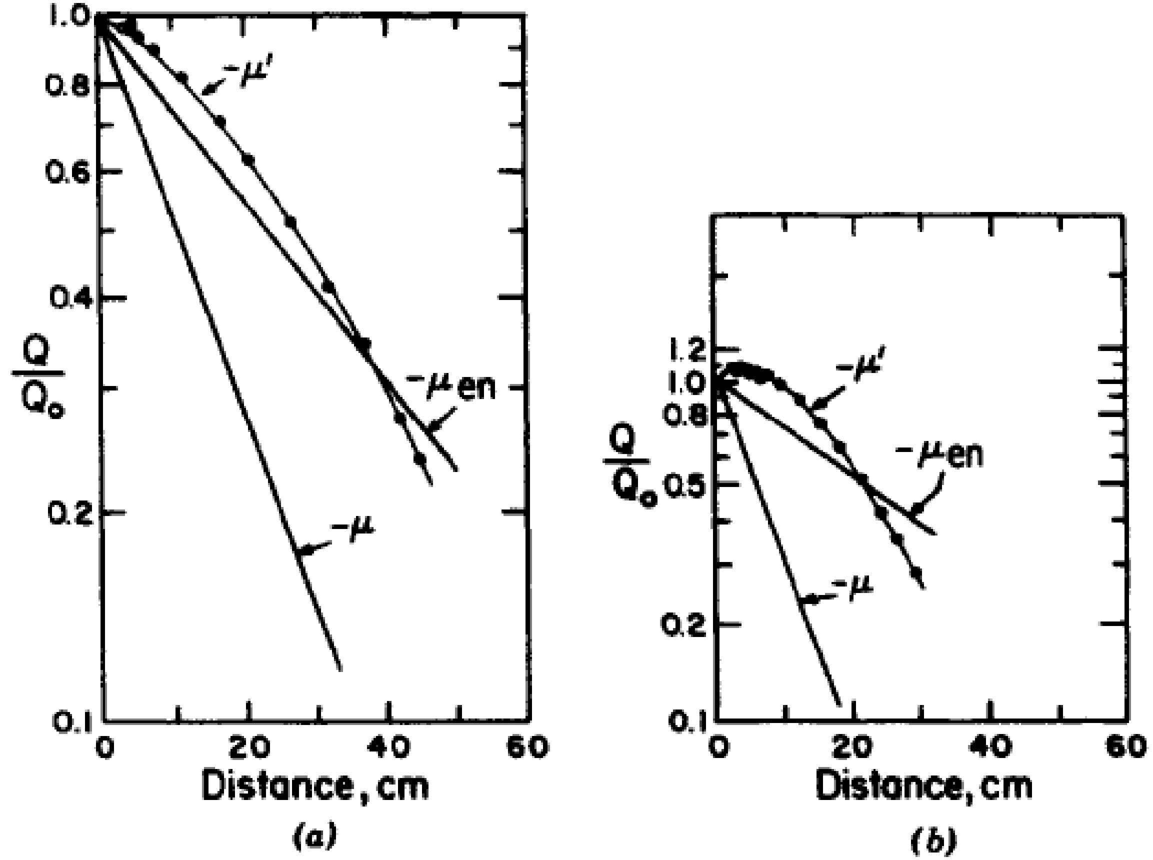
Out-scattering ↔ in-scattering

- In practice → often scattered particles or uncharged secondaries generated in the attenuator supposed to reach the detector fail to arrive → loss called « out-scattering »
- However scattered particles or secondary uncharged particles generated in the attenuator that are aimed at the detector sometimes strike it → increase called « in-scattering »
- Ideal broad beam geometry → in-scattering replaces perfectly (in type and energy) out-scattering
- Generally in-scattering < out-scattering → $\mu_{en} < \mu' < \mu$
- If in-scattering > out-scattering → $\mu_{en} > \mu'$

Ideal broad beam geometry: Examples



Examples of attenuation curves



Broad beam attenuation for γ-rays of (a) ^{60}Co (1.25 MeV) and (b) ^{203}Hg (0.279 MeV) as a function of the distance for a point source in a infinite H_20 medium (f case)

Examples of attenuation curves: Comments

- μ' is not constant
- $\mu' < \mu$ → but when L ↗ → the slopes of μ' and μ become = → for L< → deviated + secondaries > absorbed + out-scattering. When L ↗ → deviated + secondaries striking the detector ↘ and absorbed + out-scattering ↗ → equilibrium → similar evolution of μ' and μ
- $\mu_{en} \approx \mu'$
- For L< → $\mu_{en} > \mu'$ → excess of in-scattering
- For L> → $\mu_{en} < \mu'$ → excess of out-scattering
- For L ≤ 10 cm → positive slope → more radiations detected in the presence of H_2O than without H_2O → excess of in-scattering (example: backscattered radiation coming from medium *behind* the detector)

Buildup factor

- B: **Buildup factor** → Factor describing quantitatively broad beam attenuation → can be applied to all quantities in radiological physics, all geometries, all attenuators :

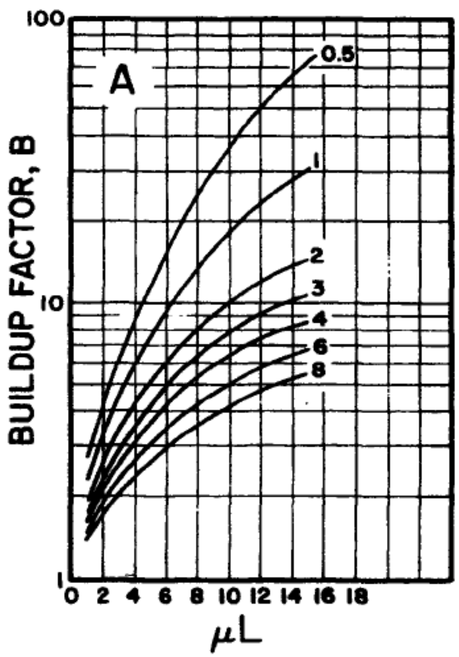
$$B = \frac{\text{quantité due au primaire + au diffusé et au secondaire}}{\text{quantité due au primaire}}$$

- For a narrow beam geometry → *B* = 1
- Example: effect on the energy fluence:

$$\frac{\Psi_L}{\Psi_0} = B \exp\left(-\mu L\right)$$

Typical buildup factors

- When $L = 0 \rightarrow B = B_0 = \Psi_L/\Psi_0$
- Generally $B_0 = 1$ (ex: previous Fig.: geometries a, b, c, e)
- For cases d or f → backscattered radiations can strike the detector → $B_0 > 1$ (B_0 is then called: backscattered factor)



Photons in semi-infinite H_2O

- B ↗ when L ↗
- B ↗ when E ↘ (only for this case)

Mean effective attenuation coefficient

- $\bar{\mu}'$: **Mean effective attenuation coefficient** → alternative concept to the buildup:

$$\frac{\Psi_L}{\Psi_0} = B \exp\left(-\mu L\right) = \exp\left(-\bar{\mu}' L\right)$$

$$\bar{\mu}' = \mu - \frac{\ln B}{L}$$

- Computational advantage