Chapter VIII:
Photographic films

Photographic films

- First (integrating) dosimeters to be developed → based on photographic techniques → dosifilms

- Dosifilms were more and more replaced by dosimeters using performing technologies → gradual stopping of production

- Always used in a few number of countries (not Belgium) → Africa

- In the following → only films for dosimetry (not radiodiagnostic)

Properties of photographic films

- Photographic films are relative dosimeters (requiring a calibration) → comparison with calibrated films allows to obtain a dose
- Films allows to measure doses due to X-rays, γ-rays, neutrons and e^-
- Depending on their composition, they allow measurements in the 50 μGy to 10 Gy range

Applications of photographic films

- Qualitative and quantitative dosimetry
- Quality control for equipment in radiotherapy (position of a collimator, radiation dose profile in a phantom,…)
- Films-badges (carried on the chest or on the wrist)

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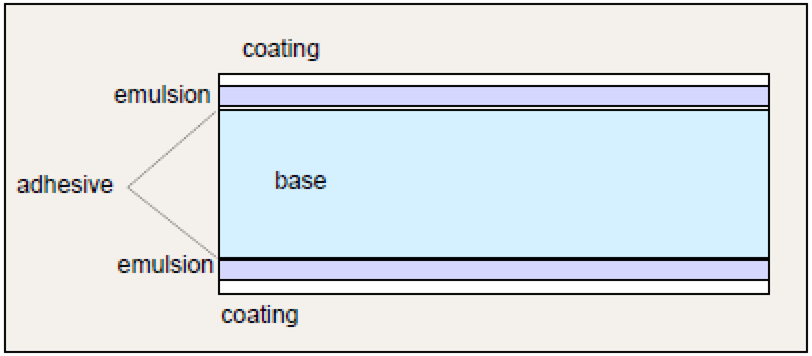
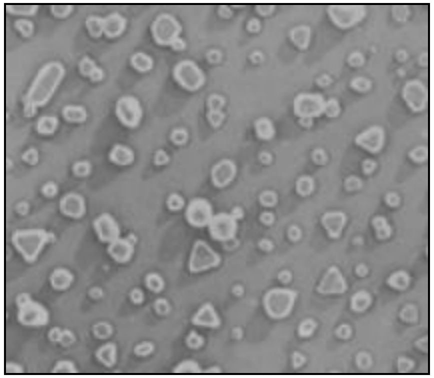
Photographic emulsion

- The emulsion consists of microscopic grains of silver bromide – AgBr – (or another silver halide) dispersed in a gelatin layer (10-20 μm) on either one or both sides of a supporting film
- Incident charged particles produce ion pairs in the grains → conversion of a certain number of Ag^+ ions of the grain (containing typically 10^{10} Ag^+ ions) to Ag atoms → a few such Ag atoms on a grain constitute a **latent image**
- During the development (chemical process) the Ag atoms in the metallic state act as center for a multiplication process → the developer reduces the Ag^+ ions of the grains having a latent image in Ag atoms → only **one** Ag atom in a grain allows the reduction of all of the Ag^+ ions of the grain
- The rest of the silver bromine (non-developed) is removed, leaving behind an opaque microscopic grain of silver
- The presence of this elemental silver may be detected optically and quantitatively related to the absorbed dose

Scheme of a dosimetric film





AgBr micrograins (0.1-3 μm)
in gelatine

Sensitometry – Optical density

- Sensitometry: study of sensitive surfaces → technical discipline that allows to quantify the blackening in photography
- The effect of irradiation is measured in terms of film opacity to the light, determined by a densitometer (sensitometric instrument which measures the density – the blackening - of photographic media)
- The opacity is defined as the ratio between I_0, the light intensity without film, and I, the light intensity transmitted $\perp$ through the film
- The optical density (OD) is defined as the logarithm to the base 10 of the opacity

$$OD = \log_{10}\left(I_0/I\right)$$

Optical density ↔ Fluence ↔ Dose (1)

- With *a* (cm^2/grain), the mean area made opaque per developed Ag grain
- With *n*, the number of developed grains per cm^2
- We have (assuming $n \ll N$, le number of AgBr grains per cm^2) →

$$\frac{I_0}{I} \cong \exp\left(an\right)$$

⇨

$$OD = \log_{10}\left(I_0/I\right) = an\log_{10} e = 0.4343 \times an$$

Optical density ↔ Fluence ↔ Dose (2)

- 3 hypothesis:
  1. The incident ray (X, γ, e^-) gives rise to an electron fluence $\perp$ to the film
  2. A single e^- hit renders a grain developable
  3. All grains have the same projected area *a*

- In these conditions →

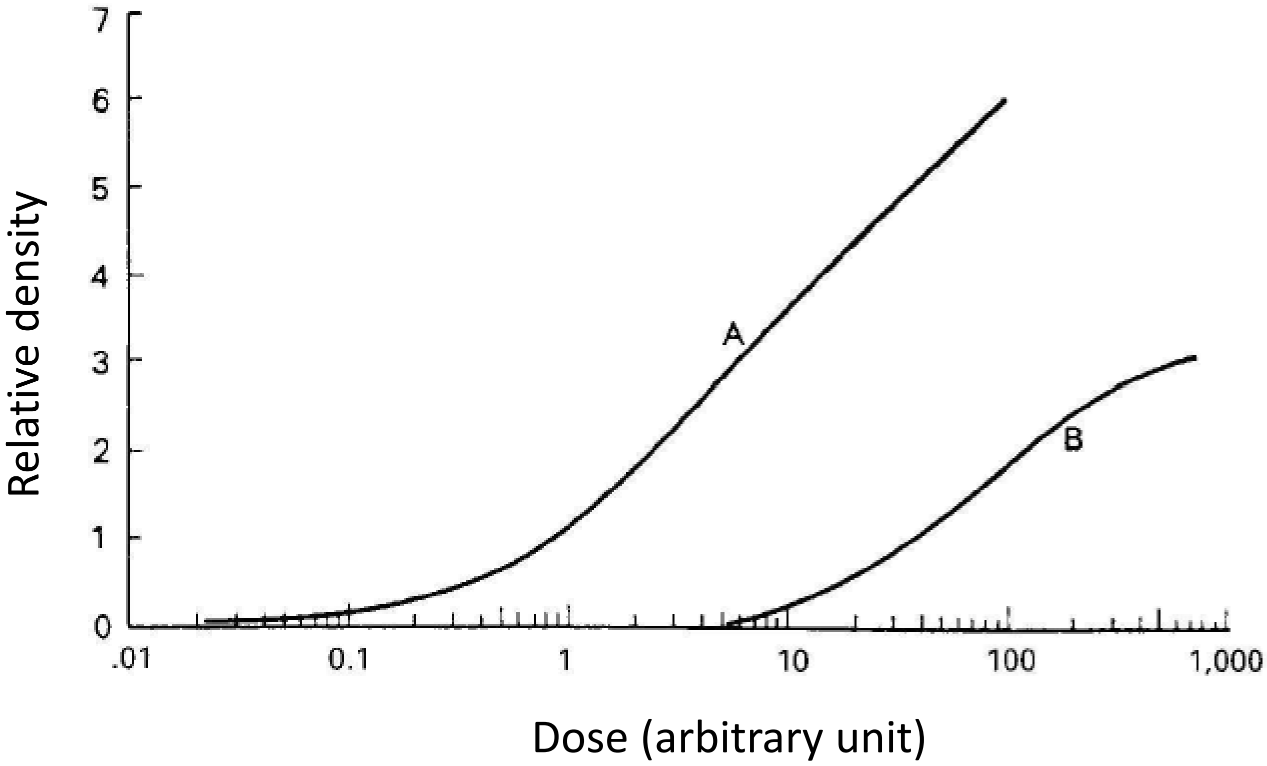
$$\frac{n}{N} \cong a\Phi$$

➡ $$OD = 0.4343 a^2 N \Phi$$

- OD is thus $\propto$ to Φ and thus to *D*

Examples of relations between exposition and optical density

By comparison to a film irradiated with an unknown amount of radiation and a film irradiated with a known quantity → determination of the dose



Characteristics of a OD-Dose curve

- Ideally → the relation between OD and dose has to be linear
- Practically → it can be linear, linear for a given range of dose or non-linear (depending on the film)
- For each type of film the OD-Dose curve has to be determined before the use of the film
- The OD-Dose curve is called the sensitometric curve, the characteristic curve or the H&D curve (Hurter and Driffield, pioneers of sensitometry)

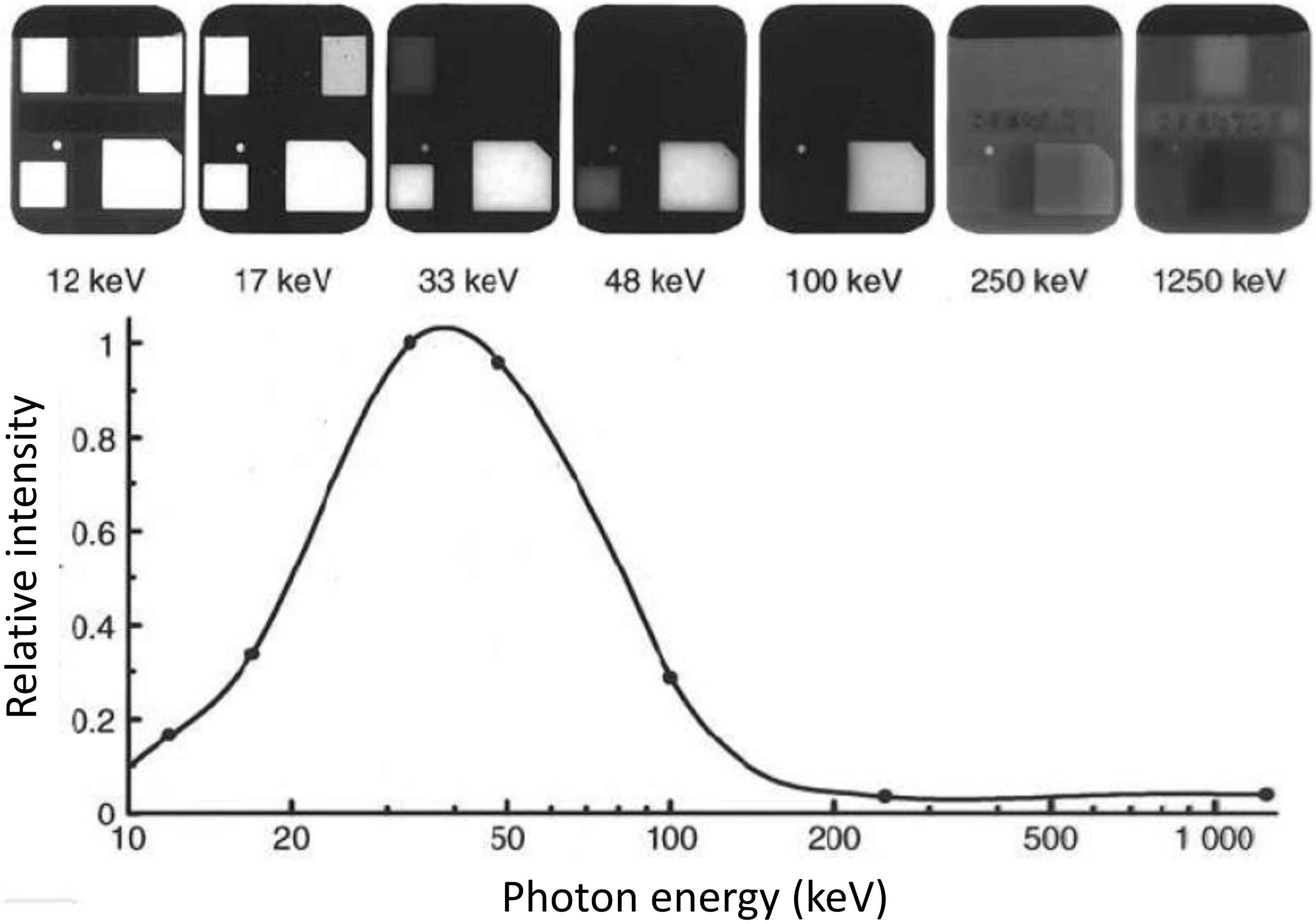
Parameters of H&D curve

- Gamma: slope of the linear part
- Latitude: range of doses for which the H&D curve is linear
- Fog: OD of a non-exposed film
- Speed: exposition necessary to produce OD = Fog +1

Energy dependence for incident X-rays

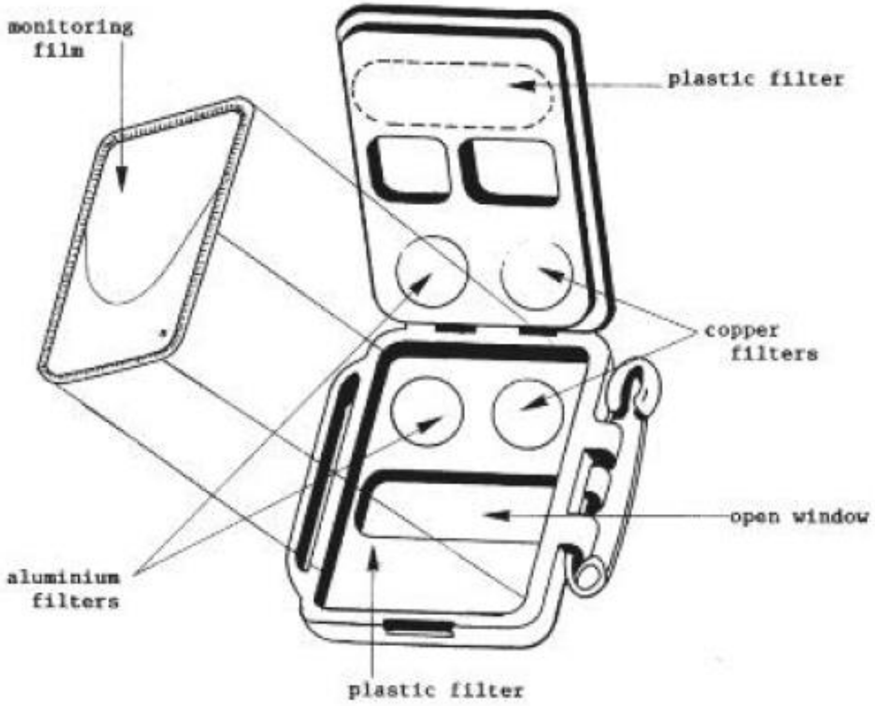
- Dosifilms show a very important dependence on the energy of the incident X-rays for small energies ($E < 200$ keV)
- This energy dependence is due to the cross section of the photoelectric effect of Ag increasing largely faster than the cross section of air o tissue for $E < 200$ keV
- A maximum sensitivity is observed for ≈ 30-40 keV
- Below 30 keV, this sensitivity of the film decrease because of the attenuation of the radiation inside the film envelope
- For $E < 200$ keV → accurate calibration is necessary at an energy corresponding to the radiation to be measured

Energy dependence: Example



Filters (1)

The support of the film is made in such a way that radiation can reach the film directly trough a free aperture or through various filters ≠ (Al, Cu, Cd, Sn, Ag, Pb, plastic,…)



Filters (2)

- The choice and the design of the filters is determined as a function of radiation to be measured
- The evaluation of exposure is made by considering the OD behind each filter
- For β radiation, blackening of the film occurs only behind the free aperture
- It is possible to estimate the energy repartition for the photons responsible of the dose by measuring the blackening behind each filter

Nuclear emulsions: Fast neutrons

- For neutrons with $E > 0.5$ MeV → Nuclear track films are used (Eastman KodaK NTA) → used of a thicker emulsion layer (a few μm → ≈ 1mm)
- In these films → concentration in hydrogen close to the one of tissue (→ tissue-equivalent for fast neutrons)
- The elastic collision of neutrons with protons makes protons in motion → energy is deposited in the film along the trajectory of the proton → track
- Tracks are counted → The number of tracks per unit of area of the film is $\propto$ to the absorbed dose
- For E< 500 keV → tracks are not identifiable

Nuclear emulsions: Thermal neutrons (1)

- In the film, thermal neutrons also produce protons (and thus measurable tracks) after their capture by nitrogen via the reaction $^{14}N(n,p)^{14}C$
- However → nitrogen concentration in the film $\ll$ hydrogen concentration → small sensitivity for thermal neutrons (but can be used)
- Practically → the field of neutrons is composed of thermal and fast neutrons → the 2 components have to be measured separately → addition of 2 filters (Cd and Sn)
- Cd has a very large cross section for the reaction $^{113}Cd(n,\gamma)^{114}Cd$ → 2500 barns for $E_n = 0.025$ eV and 7400 barns for $E_n = 0.179$ eV
- On the other side the capture of neutron by Sn is extremely weak

Nuclear emulsions: Thermal neutrons (2)

- Result for a field of thermal neutrons → « large» density of tracks in the film behind the Sn filter and nothing behind the Cd filter
- For a field of fast neutrons → same density of tracks behind the 2 filters
- Moreover → due to the reaction (n,γ) in Cd → blackening more important behind Cd than behind Sn (without neutrons → same blackening behind the 2 filters)
- Finally → the tracks counting and the determination of blackening allow to obtain separately the fluxes of thermal and fast neutrons
- Attention → film non-sensitive to epithermal neutrons (0.5 eV < E < 1 MeV)

Advantages and disadvantages of dosifilms (1)

Advantages

1. Excellent 2D spatial resolution → information on the spatial distribution of dose
2. Archival storage → the reading does not perturbs the film → permanent recording allowing rereading (checking)
3. Studied in details in labs,…
4. Flexible geometry
5. Linearity (almost) between OD and dose
6. Independent on the dose rate

Advantages and disadvantages of dosifilms (2)

<u>**Disadvantages**</u>

1. **Very weak sensitivity** → The dosimeter C.B. Kodak does not measure the absorbed doses below ≈ 200 µGy → with a dose rate of 200 µGy/h → 5 hours to reach the maximum annual dose acceptable (1mSv)
2. The development process has to be controlled with a huge accuracy → big expertise is needed
3. Large energy dependence for photons
4. Very sensitive to environment → T, humidity