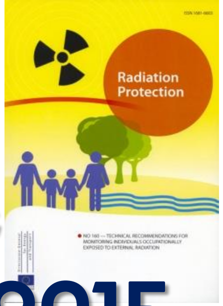
EURADOS Training course

Passive dosemeter detectors

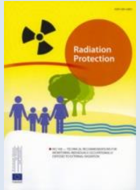
Types of detectors
Basic principles

Janwillem van Dijk
Phil Gilvin, PHE

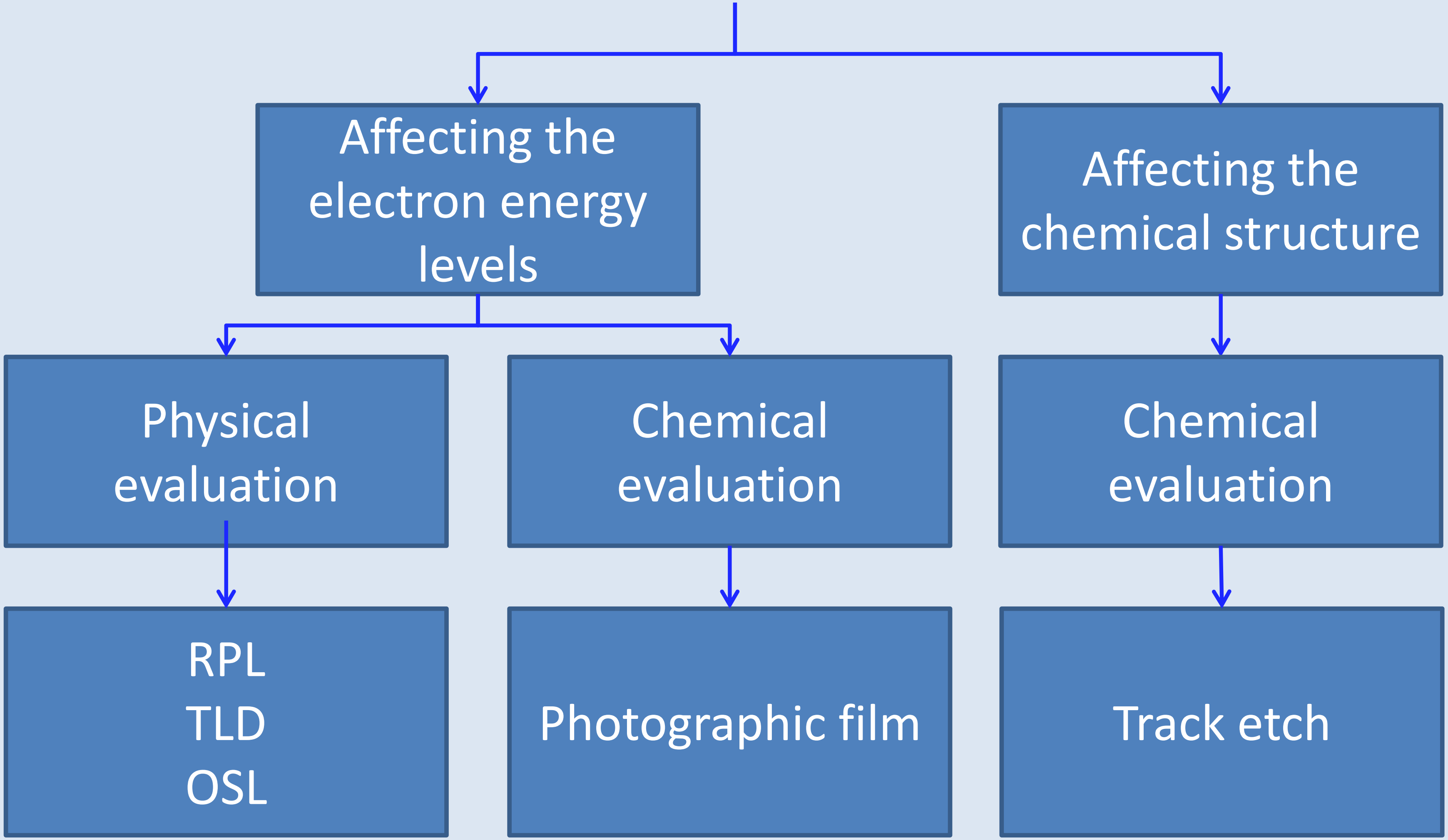


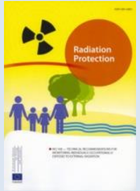
Eurados Training Course
Lisbon, Portugal, 18-22 May 2015

jwe.van.dijk@xs4all.nl

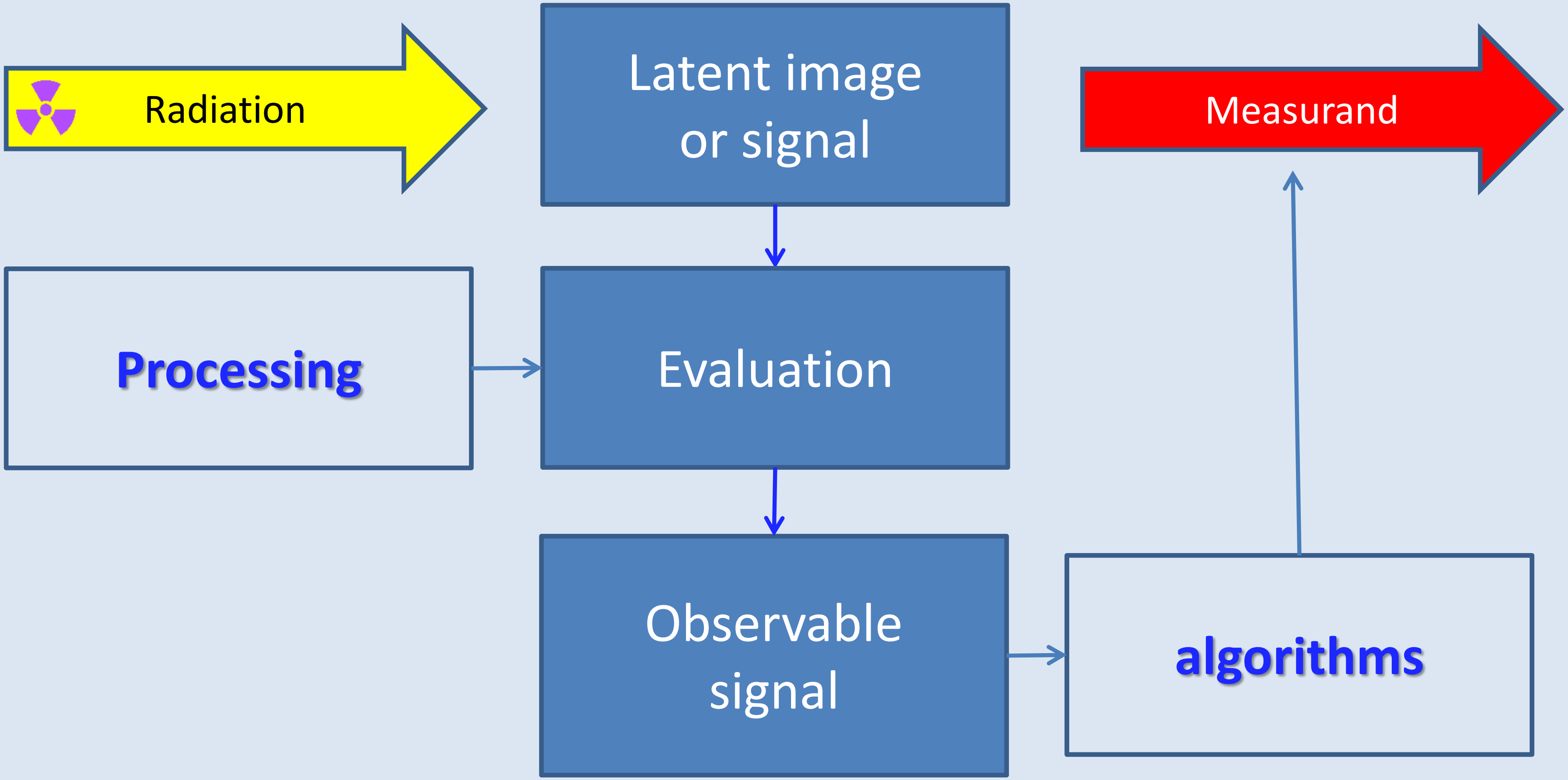


Integrating detector types

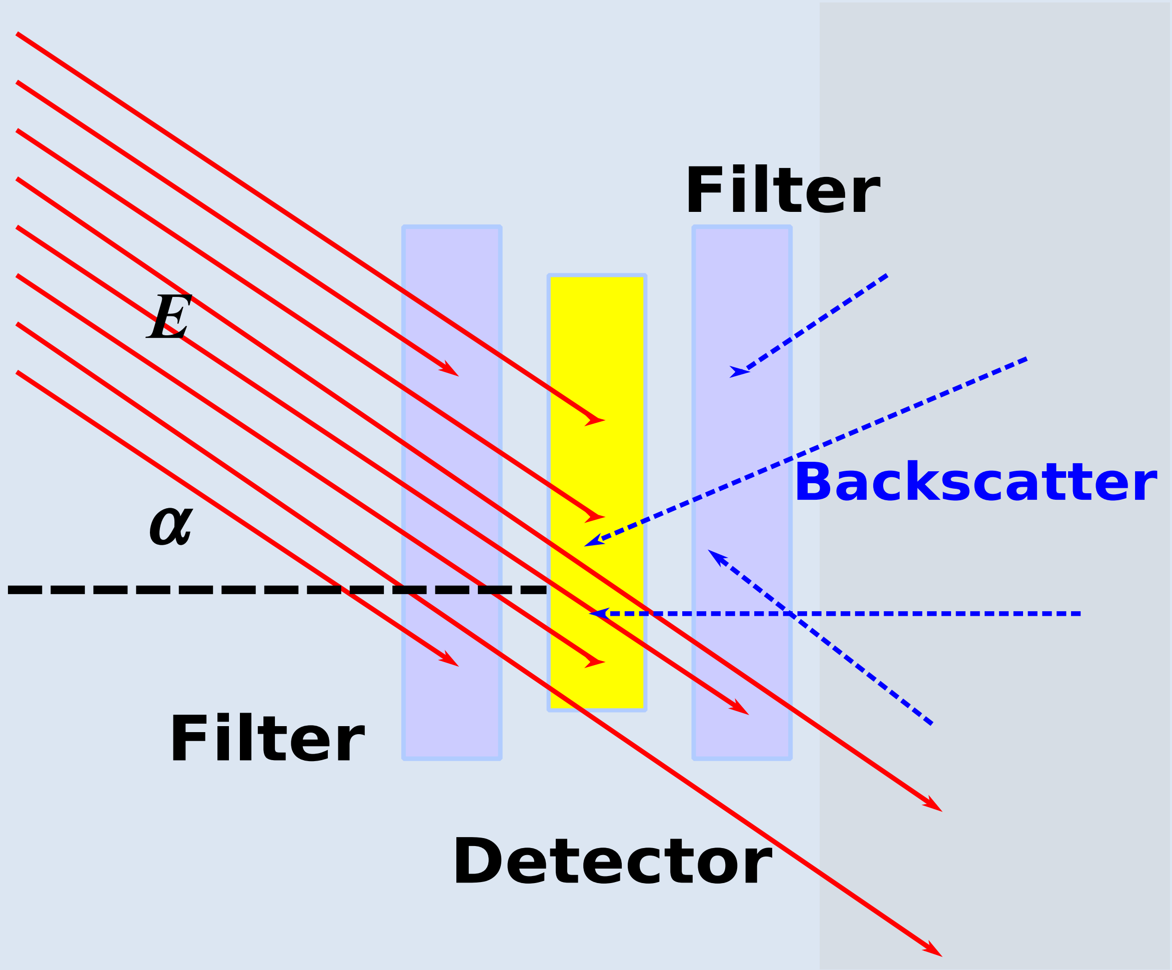


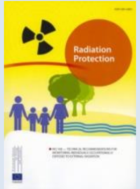


Integrating detector types



Basic design of a dosemeter





Passive dosemeter detectors

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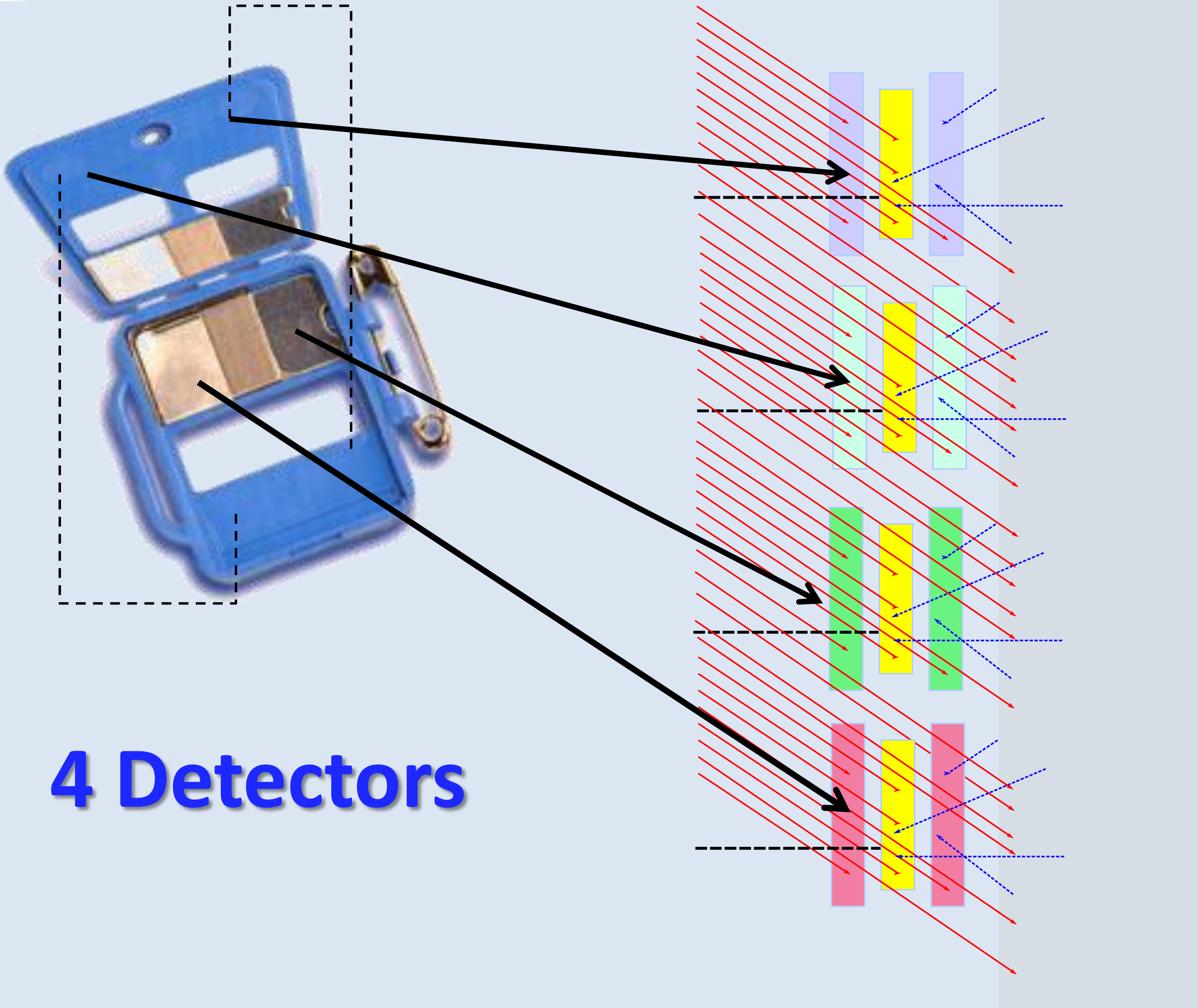
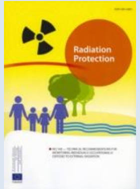


0.5 mm Plastic 3 mm

1 mm Al

0.7 mm Sn 0.3 mm Pb

4 Detectors



Passive dosemeter detectors

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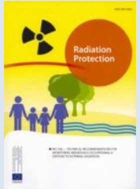
- The response of the detector will depend on the amount of radiation energy absorbed, D
- This is depends on the mass energy attenuation coefficient
- μ_{en}/ρ radiation energy dependent

$$D\left(E\right) \propto \frac{\mu_{\mathrm{en}}(E)}{\rho}$$



Passive dosemeter detectors

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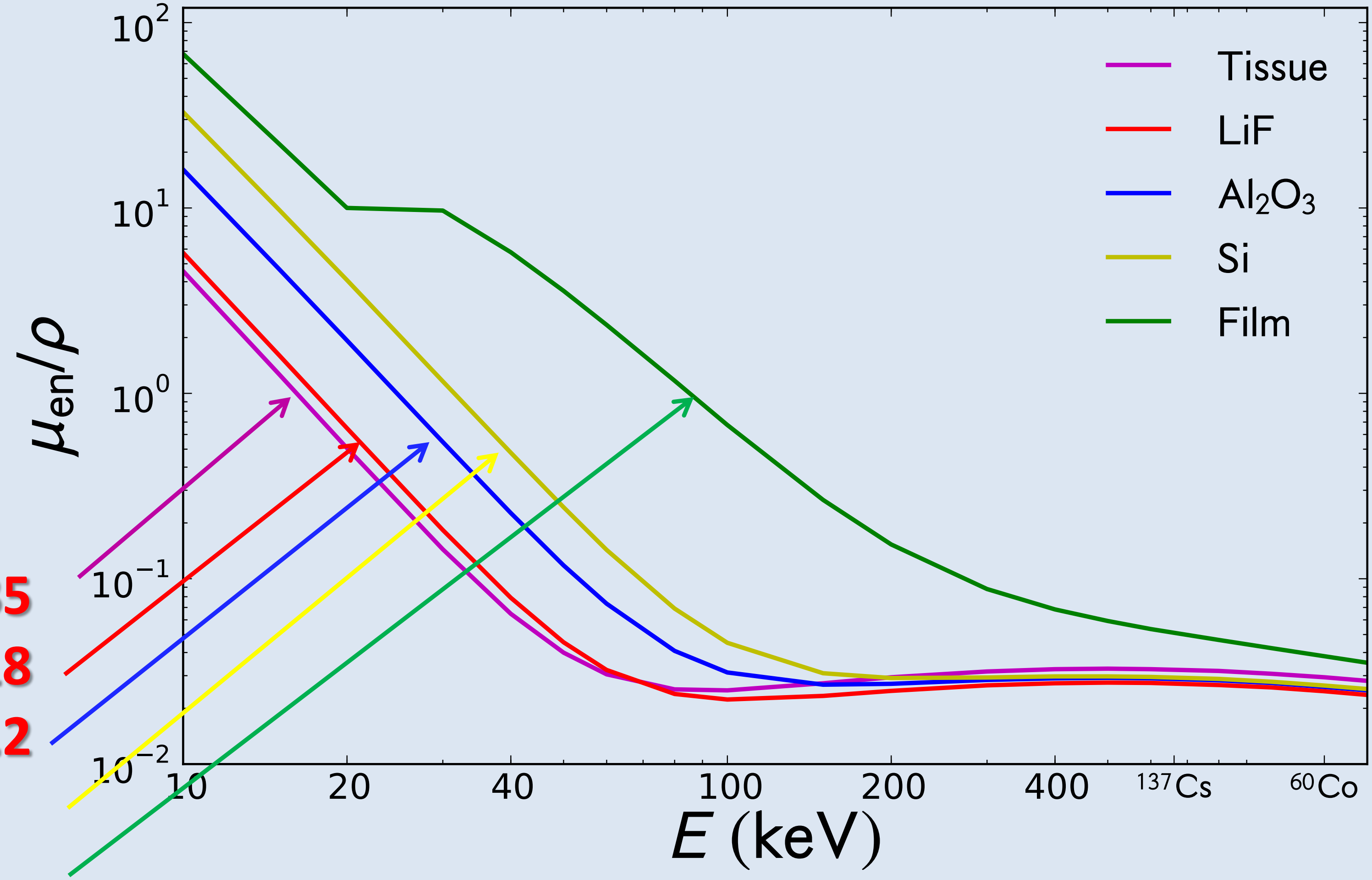


Z

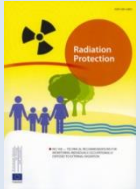
7.35

8.18

10.2

14

42



From absorbed dose in detector to $H_\mathrm{p}(10)$

Rough estimate of relative response of a detector

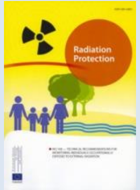
$$D\left(E\right)_{\mathrm{det}} \propto \left(\frac{\mu_{\mathrm{en}}(E)}{\rho}\right)_{\mathrm{det}}$$

$$D\left(E\right)_{\mathrm{tissue}} \propto \left(\frac{\mu_{\mathrm{en}}(E)}{\rho}\right)_{\mathrm{tiss}}$$

NIST
J.H. Hubbell

ICRU 57

$$R_{\mathrm{det},H_\mathrm{p}(10)} = \frac{D(E)_{\mathrm{Det}}}{H_\mathrm{p}(10)} \approx \frac{D(E)_{\mathrm{det}}}{D(E)_{\mathrm{tiss}}} \frac{h_{\mathrm{pk}}(0,E)}{h_{\mathrm{pk}}(10,E)}$$



Passive dosemeter detectors

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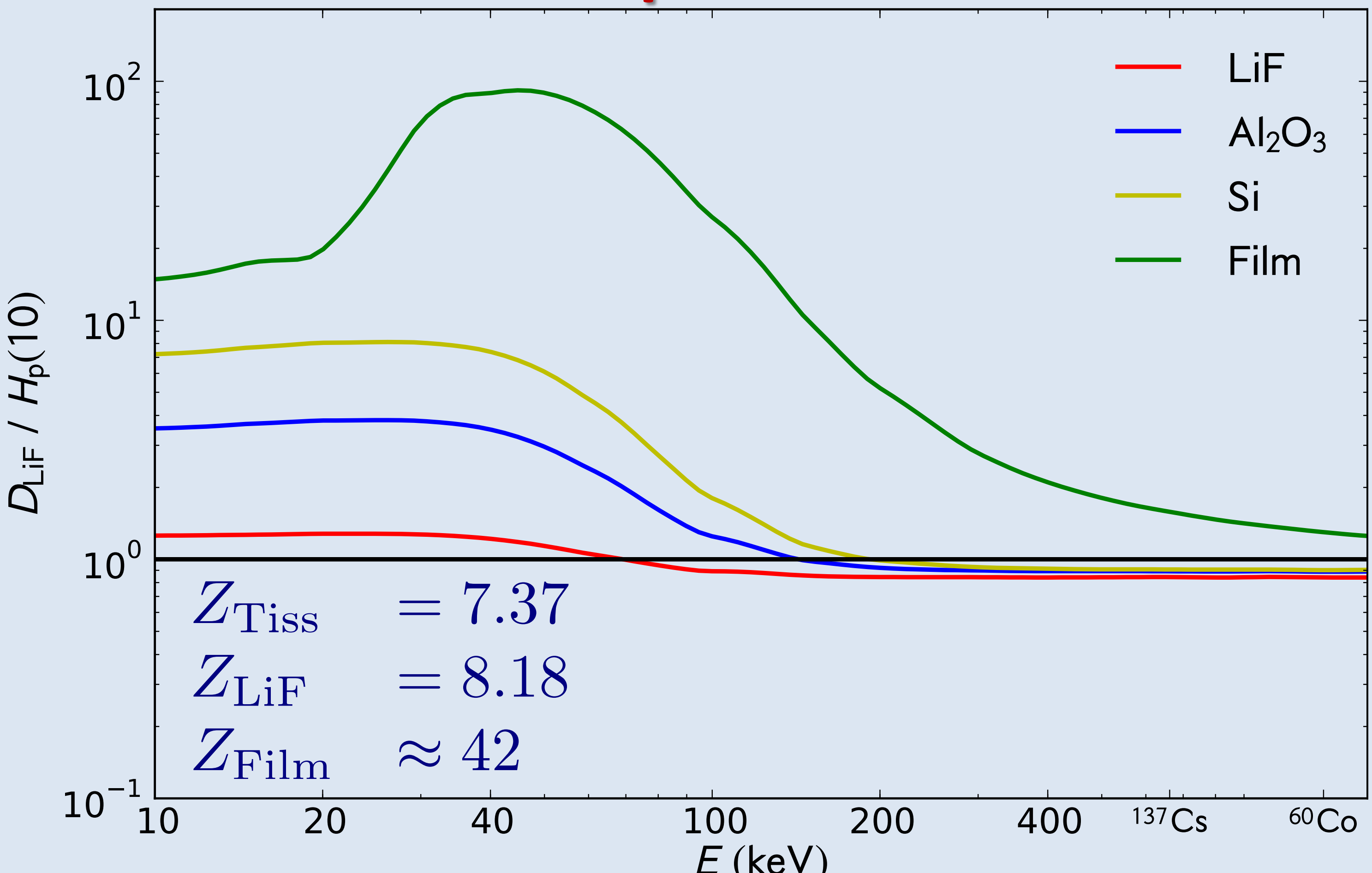
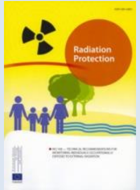
Tissue equivalence



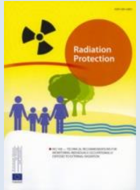
The more the effective atomic number Z approaches that of tissue, the better the absorbed dose in the detector approximates the dose in tissue.



From detectors to dosemeter

We need filters over the detector

1. **To emulate 10 mm tissue measuring** $H_{\mathrm{p}}(10)$
2. **To correct for energy dependence because of non-tissue-equivalence**



Passive dosemeter detectors

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Detector with filters

Conversion coefficients

$$R_{\mathrm{det},H_\mathrm{p}(10)} \approx \frac{D(E)_\mathrm{det}}{D(E)_\mathrm{tiss}} \; \frac{h_\mathrm{pk}(0,E)}{h_\mathrm{pk}(10,E)} \; e^{-\sum d_i \rho_i \left(\frac{\mu_{en}(E)}{\rho}\right)_i}$$

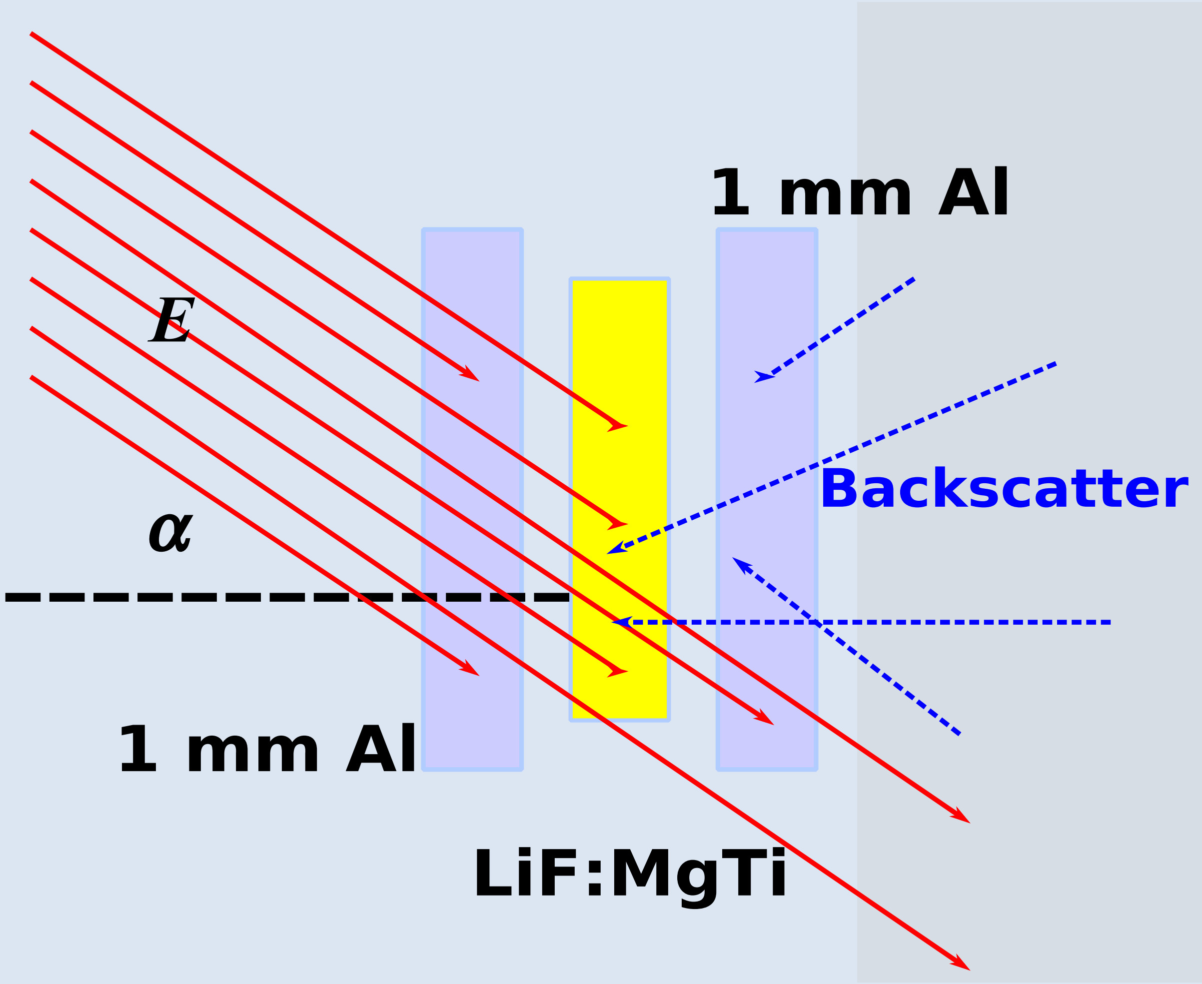
Response

Absorbed dose

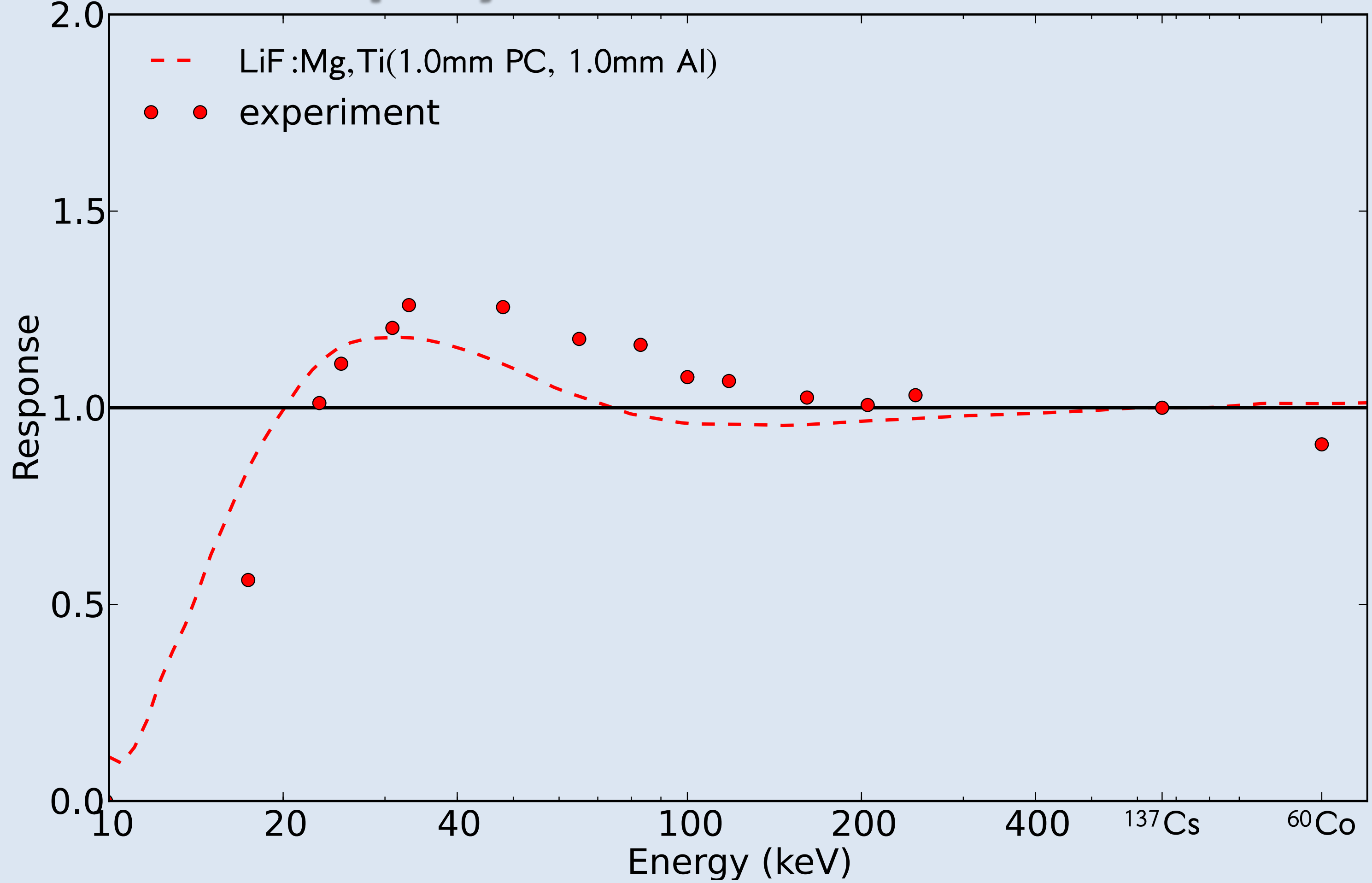
ICRU57

Filter attenuation

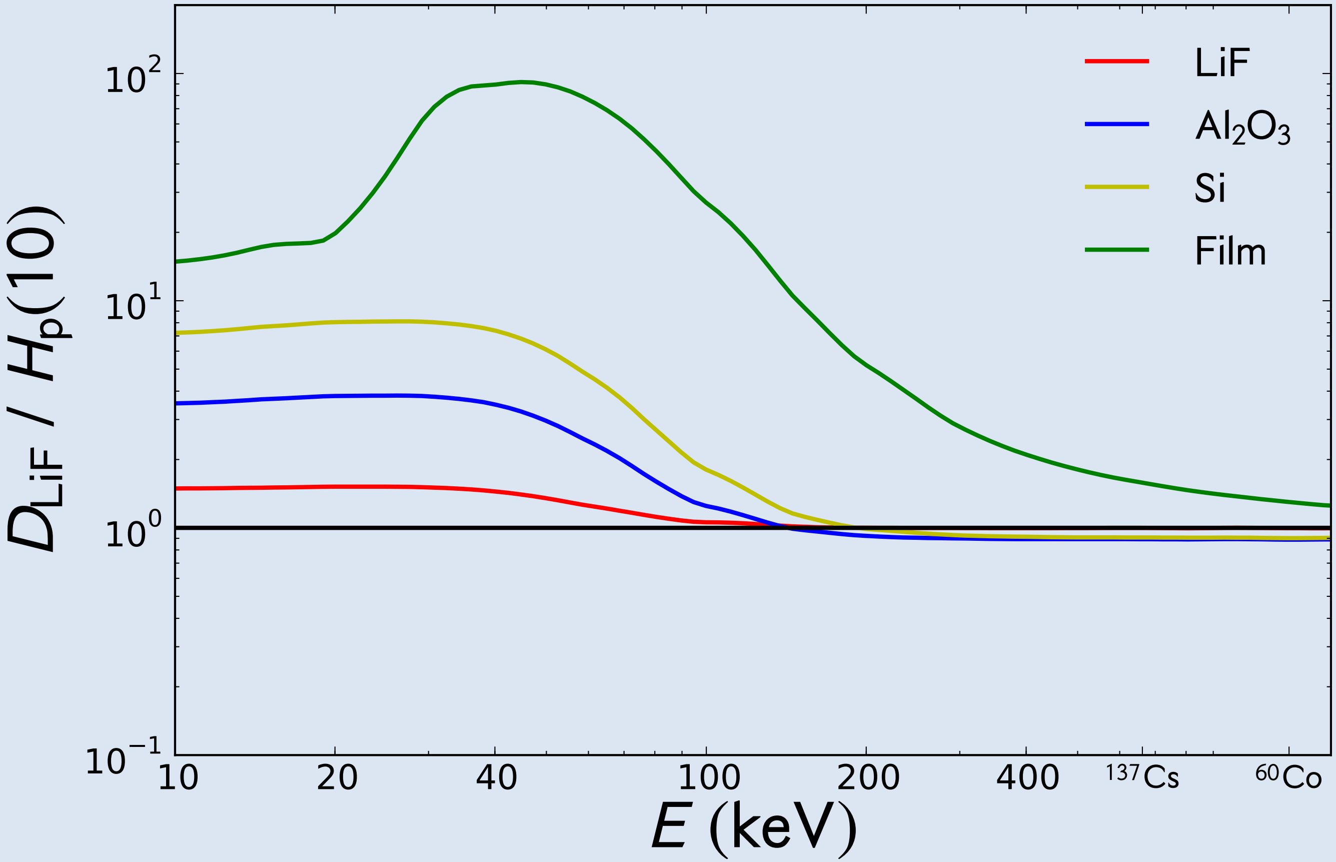
Passive dosemeter detectors

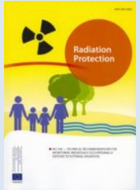


Calculated and observed response LiF:MgTi Filter 1 mm polycarbonate + 1 mm Al



With photographic film the discrepancy detector material and tissue is very large





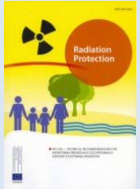
Multiple detectors and filters

Dose calculation algorithms

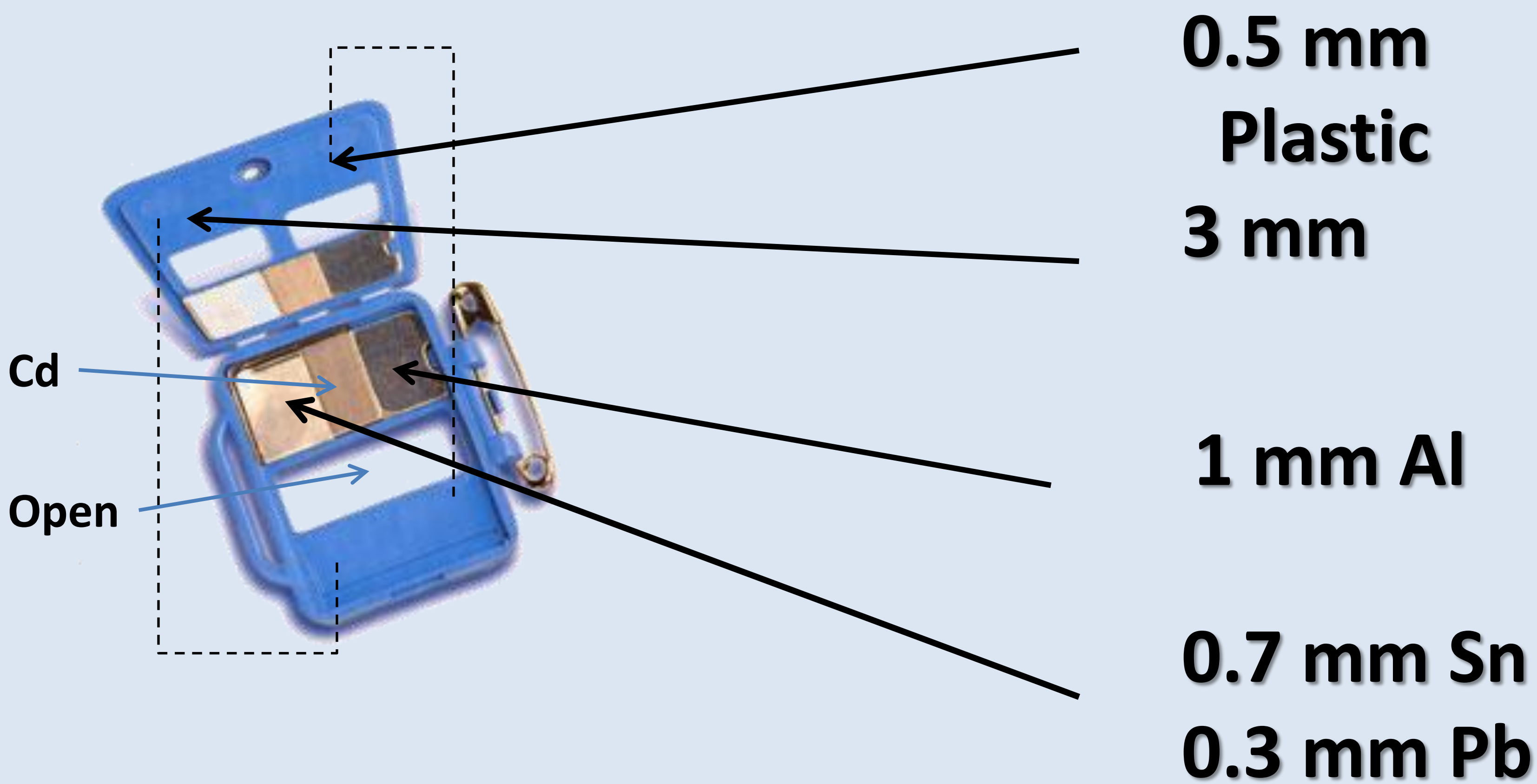
- Linear combination of detector signal
- Branching algorithms

E.g.:

$$
\begin{aligned}
&\textbf{if } \frac{D_1}{D_2} > Q : \\
&\qquad H = a_1 D_1 + a_2 D_2 \\
&\textbf{else} : \\
&\qquad H = b_1 D_1 + b_2 D_2
\end{aligned}
$$



NRPB/AERE R236 multi element film dosemeter



Passive dosemeter detectors

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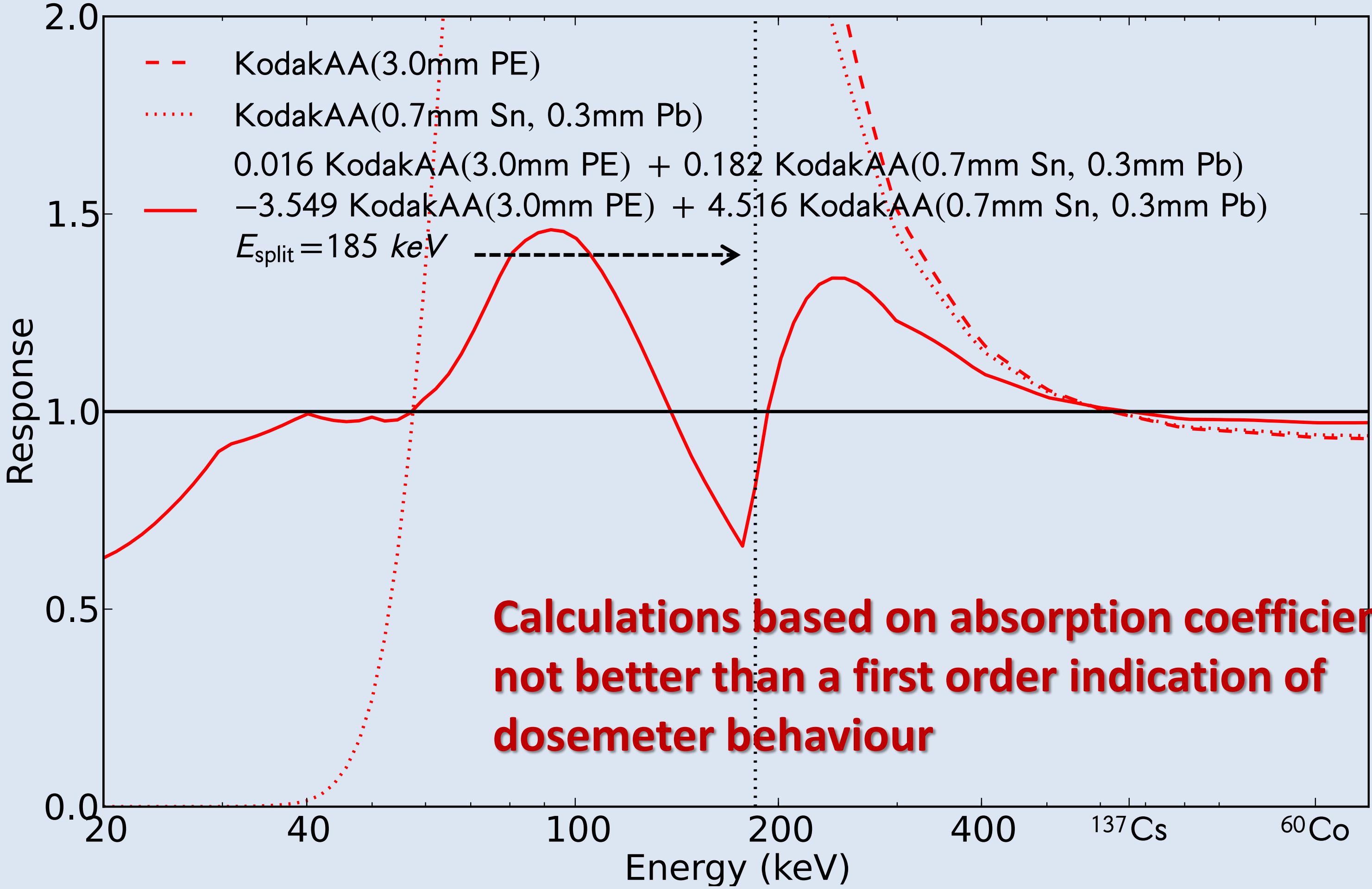
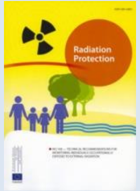


Calculations based on absorption coefficients not better than a first order indication of dosemeter behaviour

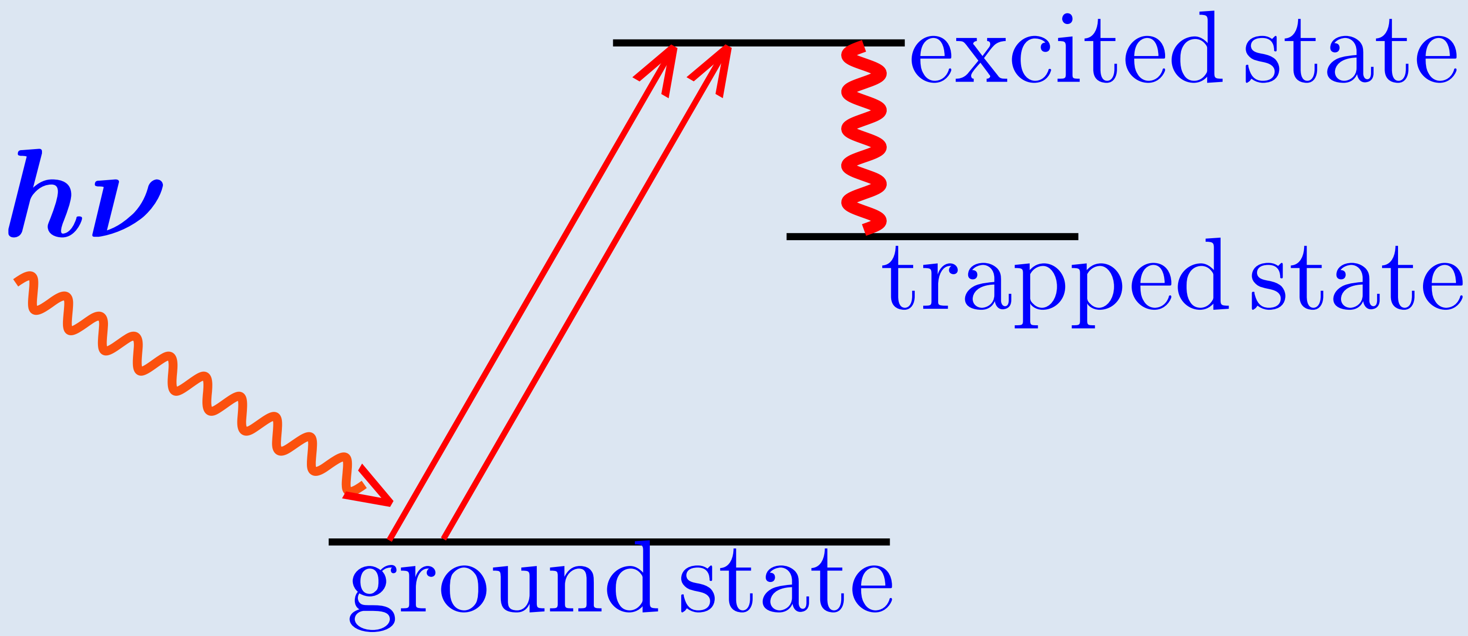


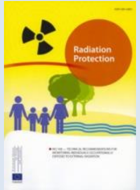
The trap model

Solid sate detectors

What happens on an electronic level

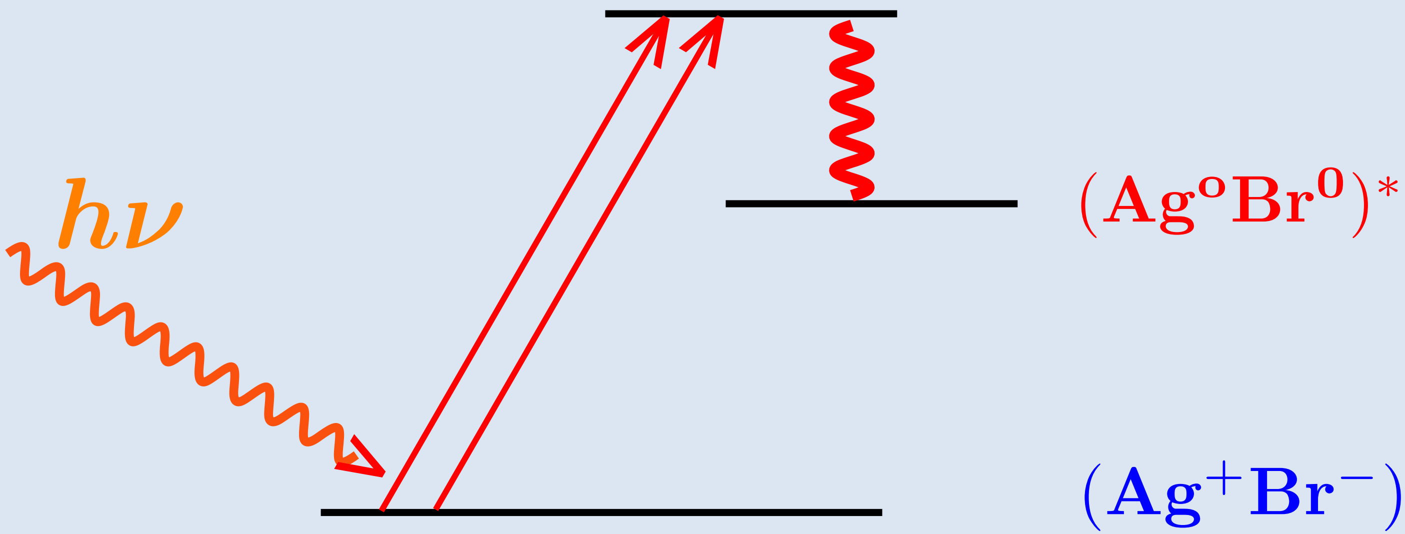
The trap model

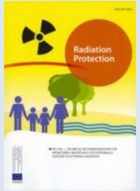




The trap model

Excitation in photographic film
Much simplified

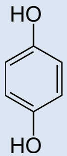




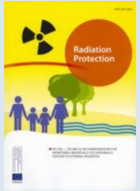
Film chemistry

$$\mathbf{Ag^{(+)}Br^{(-)} + h\nu \rightarrow (Ag^{o}Br^{o})^{*}}$$

$$\mathbf{Ag_2^+, Ag_2^o, Ag_3^+, Ag_3^o, Ag_4^+, Ag_4^o}$$

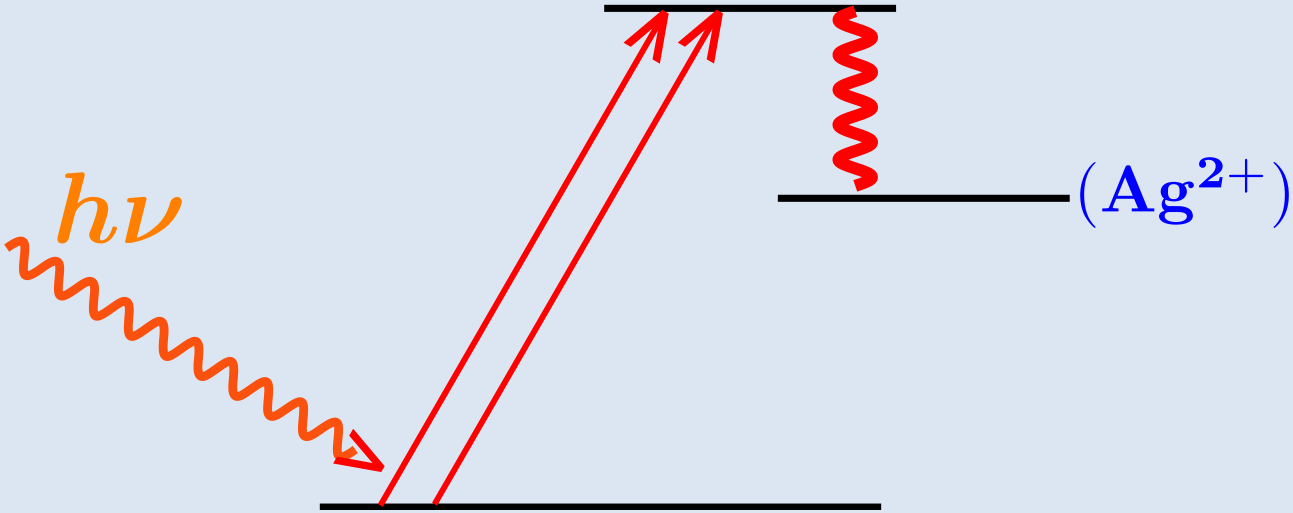

hydrochinon

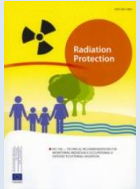
$$\mathbf{C_6H_4(OH)_2 + Na_2SO_3 + 2AgBr^{*} + NaOH \rightarrow}$$
$$\mathbf{C_6H_3(OH)_2SO_3Na + 2NaBr + H_2O + 2Ag}$$



The trap model

Excitation in silver doped phosphate glass (RPL)
Much simplified





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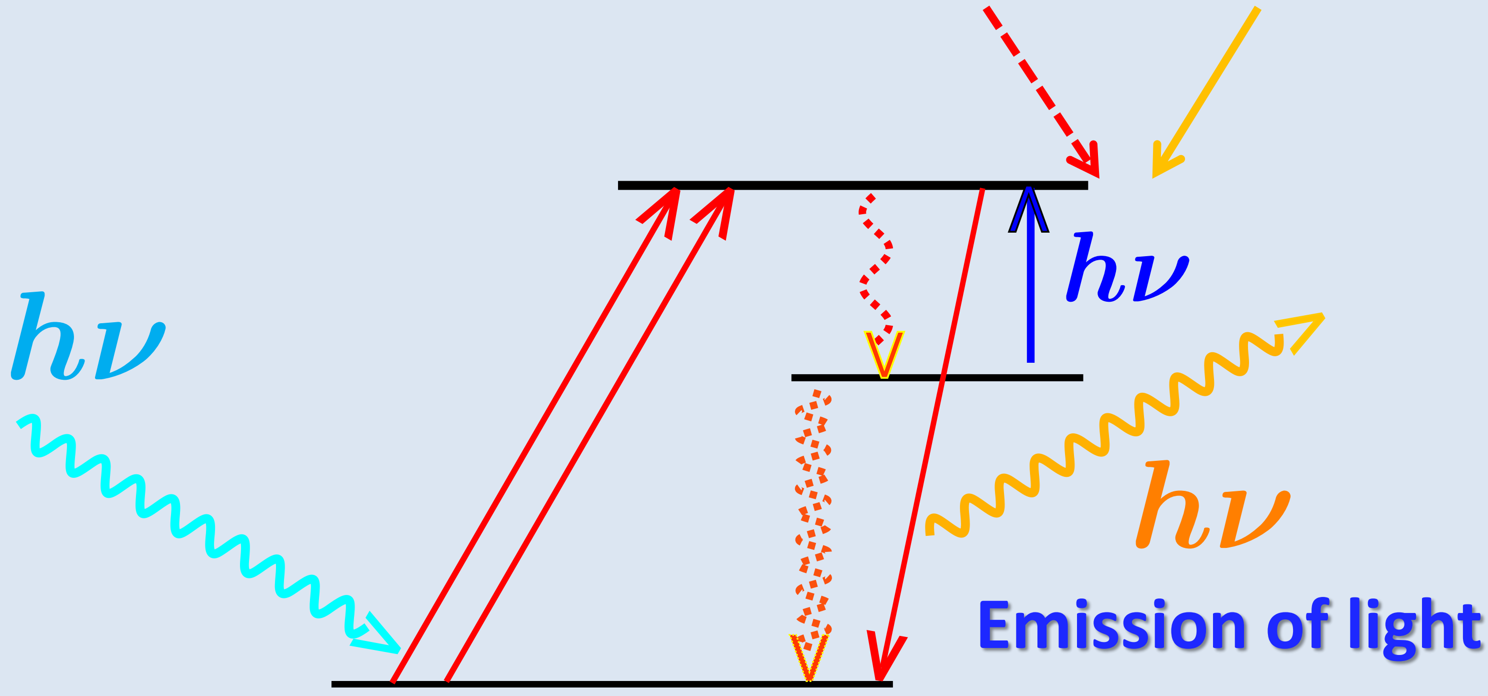
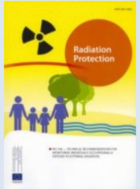
RPL Ag^{+} doped phosphate glass

On irradiation with near UV

- **Not irradiated:**
  Fluorescence in near UV
- **Irradiated:**
  Phosphorescence in orange

TLD and OSL
Excitation of the traps by heat or light





Passive dosemeter detectors

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$$I\,(t) \propto \frac{\partial y}{\partial t} = sye^{-\frac{E_{Act}}{kT(t)}}$$

$$t = 0 \rightarrow y = y_0$$

I : light intensity

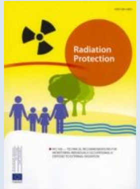
y : number of filled traps at t

s : frequencyfactor

E_{Act} : activation energy

k : Bolzmann constant

T : temperature



Passive dosemeter detectors

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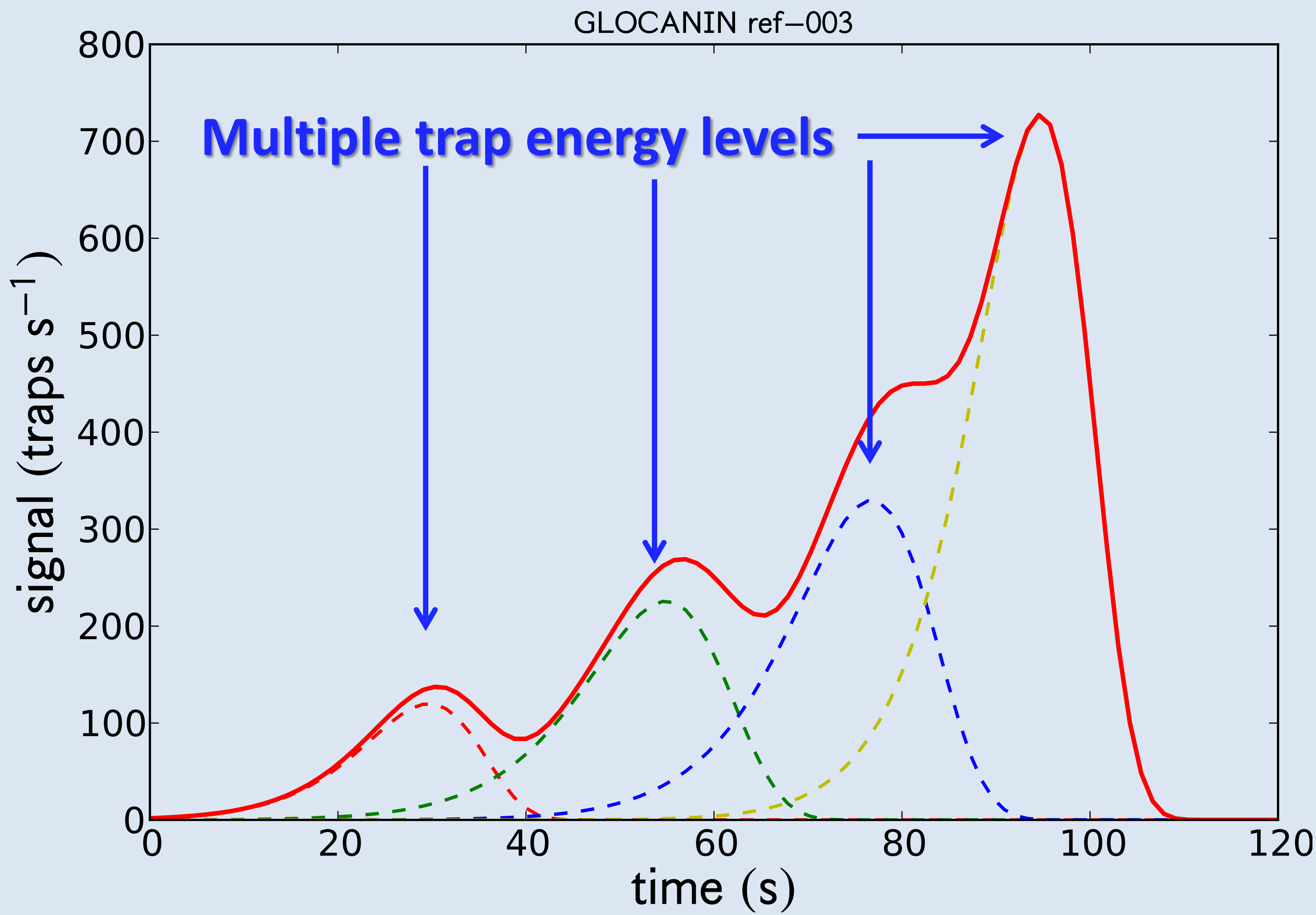
TLD:Mg,Ti glow curves with deconvolution



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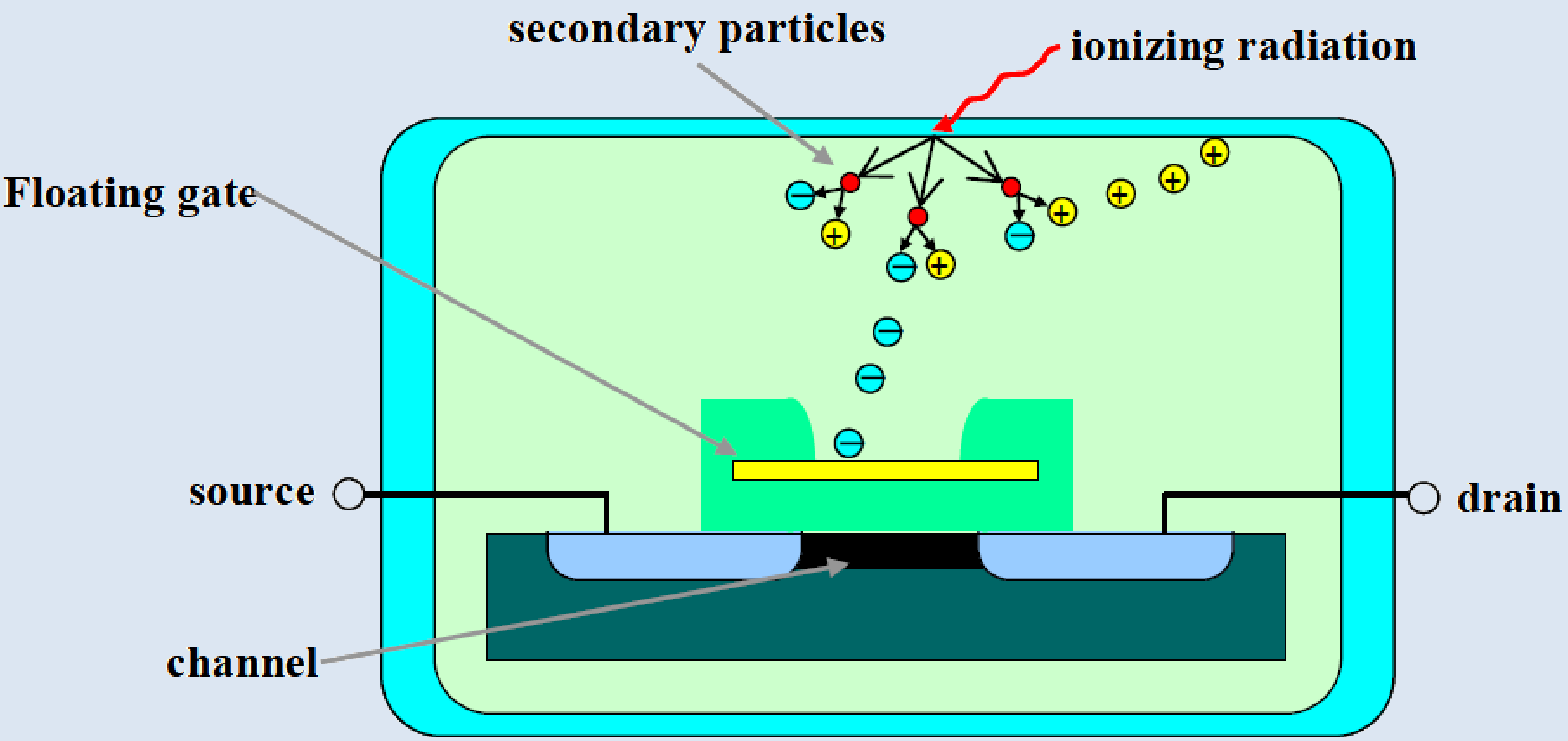
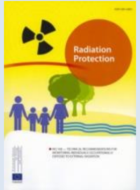
Direct Ion Storage dosemeter
DIS

Ionization chamber with the Floating gate of a MOSfet as anode





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Designing a New TLD Holder

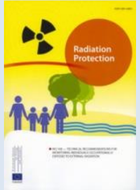
2001 – 2005: UK NRPB/HPA switching to Harshaw TLD.

- **2-element card**
- **LiF:Mg,Cu,P material – higher sensitivity, negligible fading**

Also decided to retain thin foil wrapper

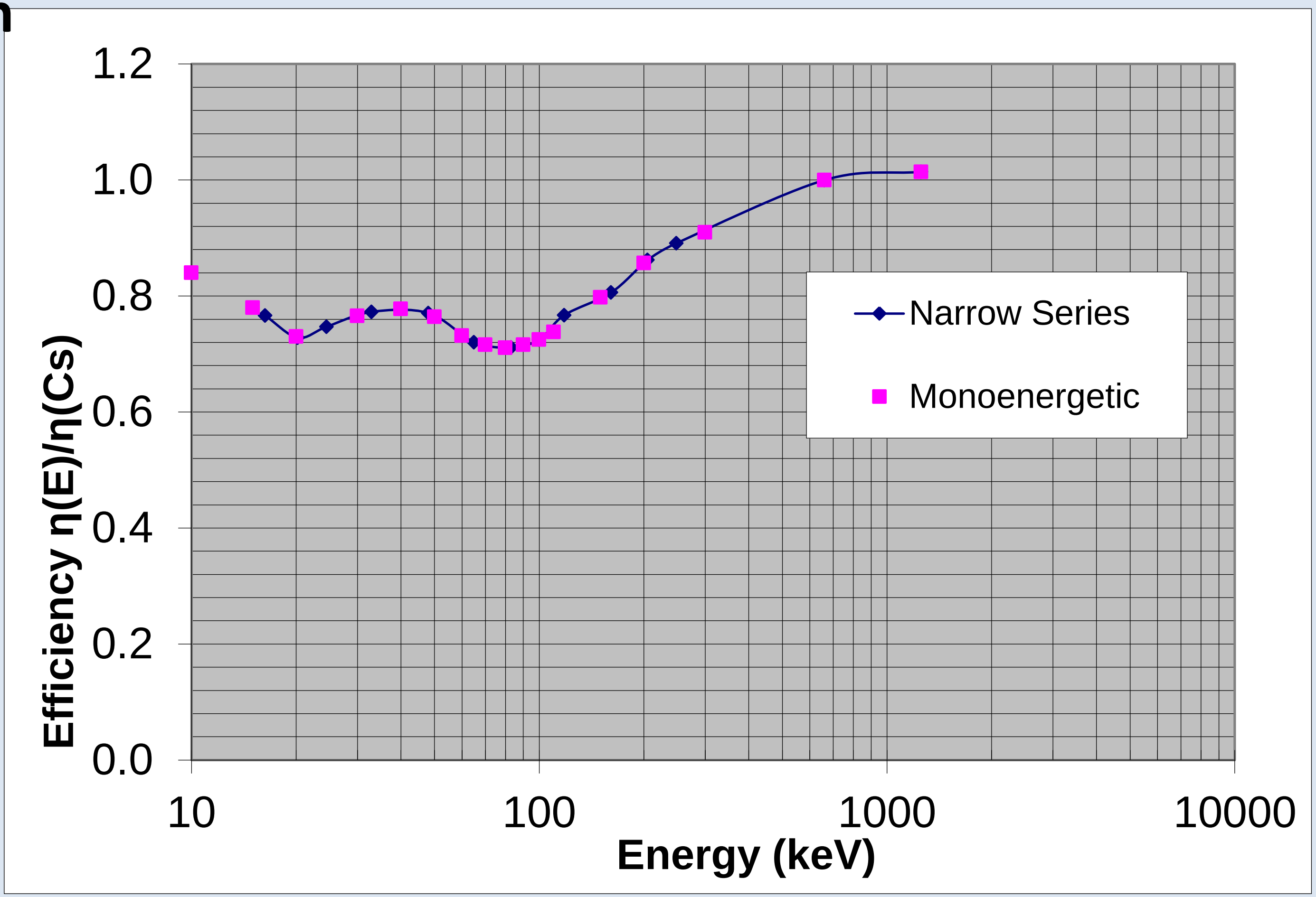
Q. What should the filters be like?

Requirement to meet IEC 61066

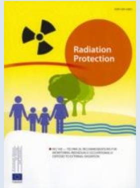


Passive dosemeter detectors

Intrinsic Efficiency of the material: the ratio, η, of **light energy emitted** during heating to **energy absorbed during gamma irradiation**



Calculated using MCNP

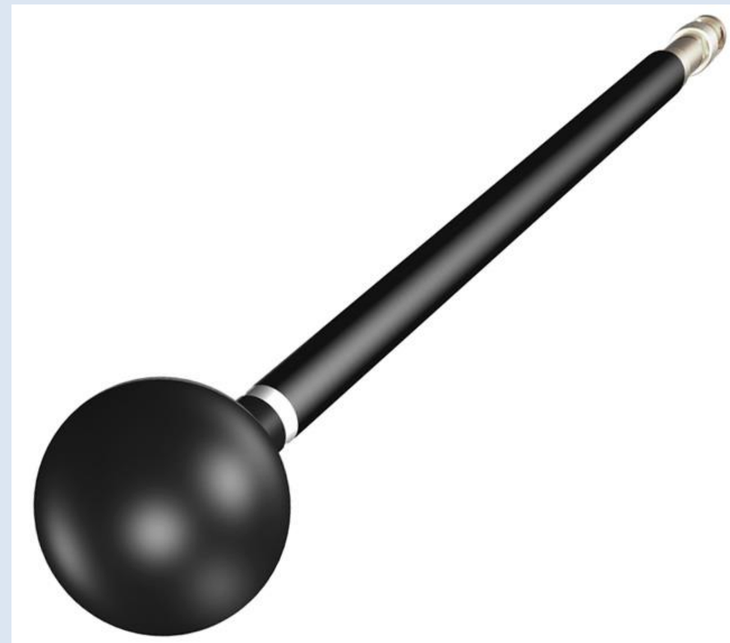


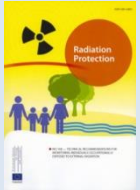
How is the System Calibrated?

Reference to secondary standards

Measure AIR KERMA, K_{air}

Need to know how that relates to LiF





Passive dosemeter detectors

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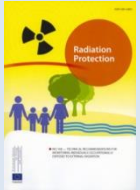
Steps

1. Convert from K_{air} to K_{LiF}
2. Convert from K_{LiF} to $H_{\mathrm{p}}(\mathrm{d})$
3. Account for intrinsic efficiency
4. Normalise as required



Passive dosemeter detectors

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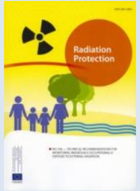
Steps

1. Convert from K_{air} to K_{LiF}
2. Convert from K_{LiF} to $H_{\mathrm{p}}(d)$
3. Account for intrinsic efficiency
4. Normalise as required

$$R = \left(\frac{K(\theta,E)_{\mathrm{LiF}}}{K(\theta,E)_{\mathrm{Air}}} \right) \left(\frac{K(0,\mathrm{Cs})_{\mathrm{Air}}}{K(0,\mathrm{Cs})_{\mathrm{LiF}}} \frac{h(0,\mathrm{Cs})}{h(\theta,E)} \right) \left(\frac{\eta(E)}{\eta(\mathrm{Cs})} \right)$$

. . . calculations carried out using Monte Carlo package (MCNP-4C2)



Passive dosemeter detectors

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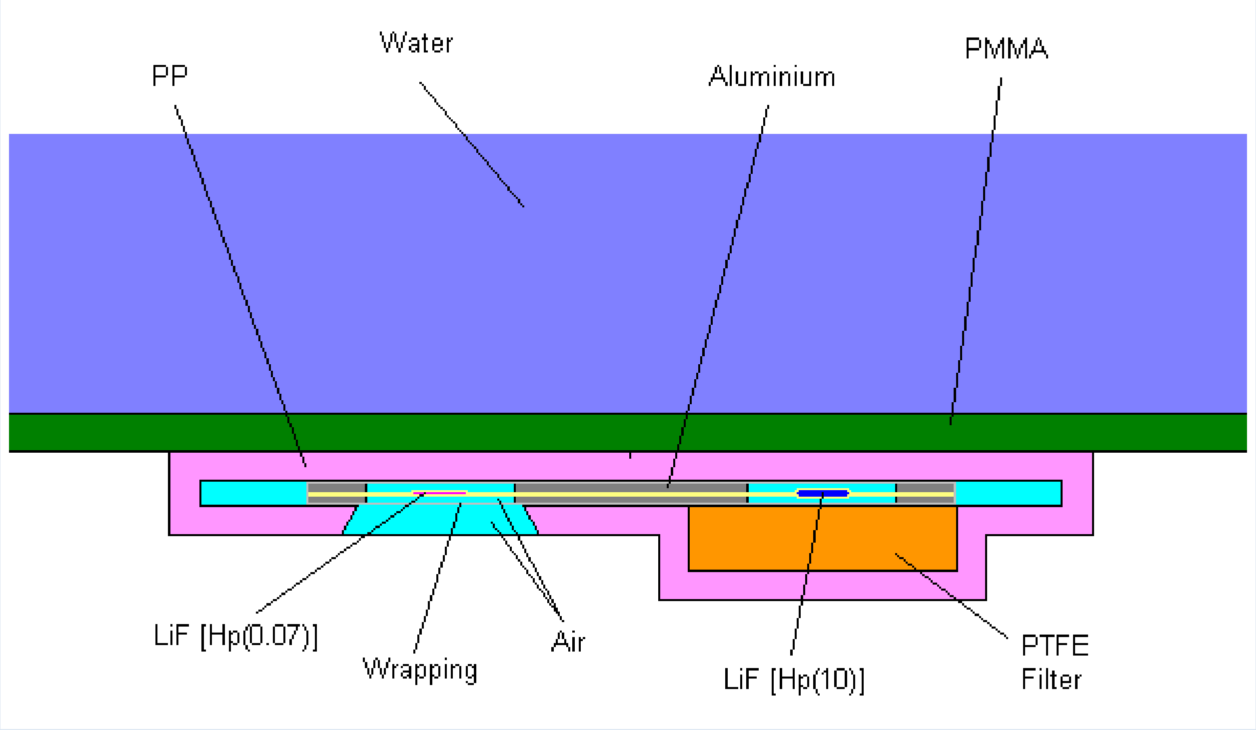
Various filters simulated using MCNP:

- aluminium, various thicknesses
- carbon
- encapsulated in polypropylene



Passive dosemeter detectors

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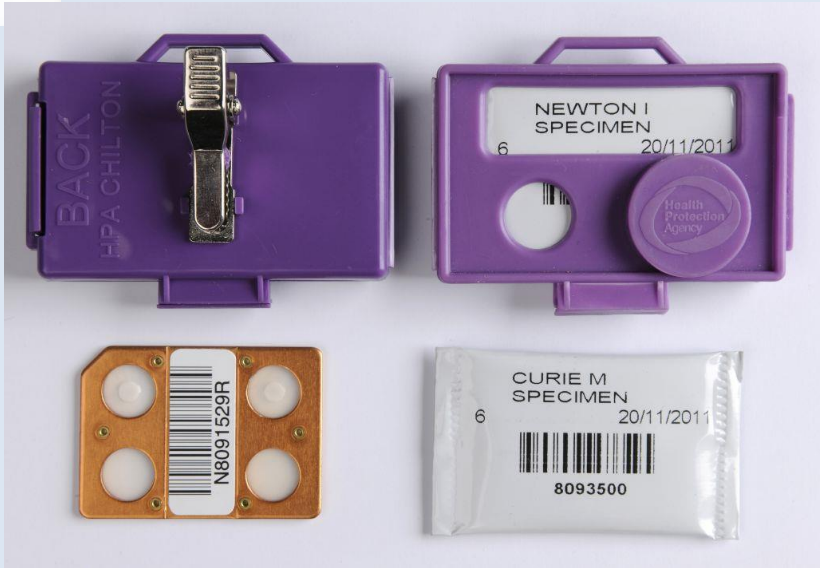

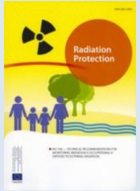

Passive dosemeter detectors

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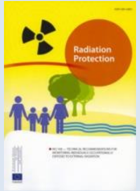
LiF: Mg,Cu, P has a nearly tissue-equivalent efficiency function

So, just cover the TLD element with tissue-equivalent material => dosemeter with nearly tissue-equivalent response

Use PTFE – closely tissue-equivalent but denser than most plastics

House in polypropylene

Cylindrical filter extending far enough to give correct response at 60°



Passive dosemeter detectors

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