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New techniques in external dosimetry: current status, developments and future trends

Seminar of the Federal Commission on Radiation Protection (KSR)
25 March 2022

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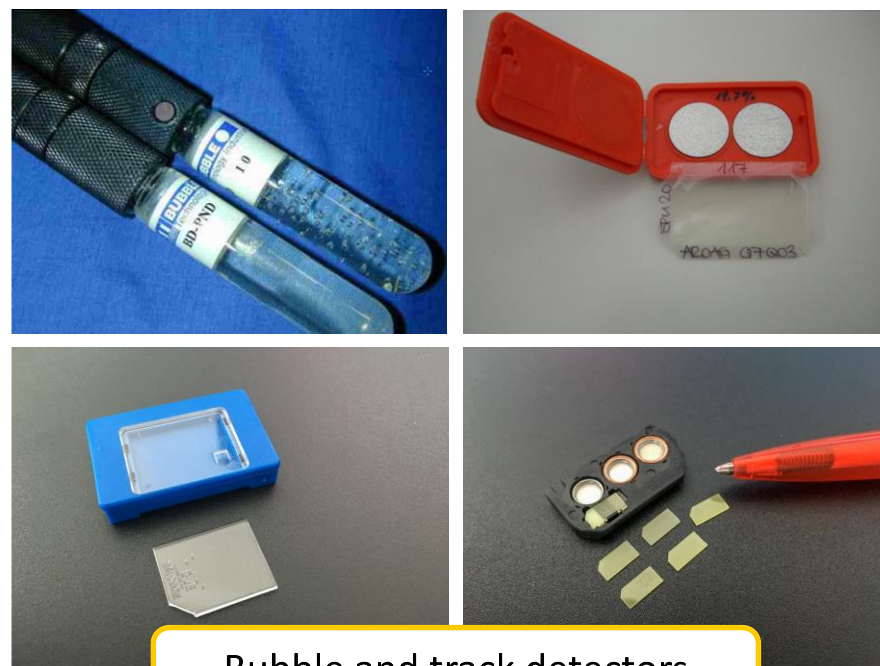
Personal dosimetry technologies

Luminescesce dosimeters

Electronic dosimeters

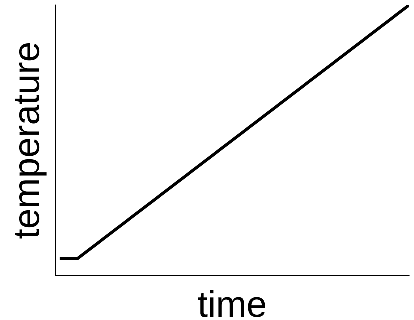


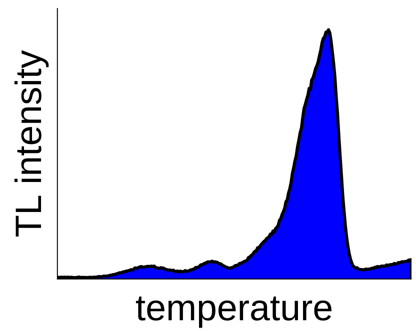
Bubble and track detectors

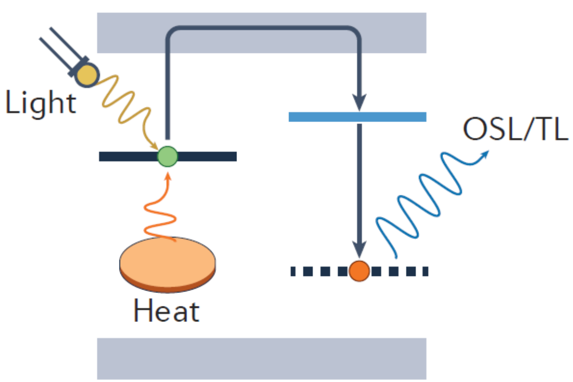
Outline

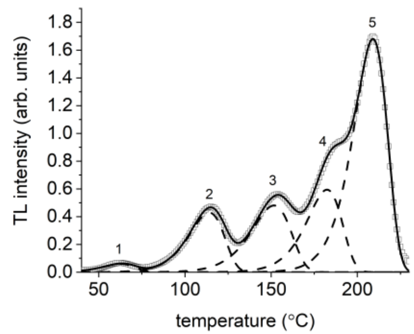
- ***Personal photon dosimetry***
  – Luminescence dosimeters (TL, OSL, RPL)
  – Direct-ion-storage (DIS) dosimeters
  – D-Shuttle dosimeters
- ***Neutron dosimetry***
  – PADC detectors
  – Fluorescent Nuclear Track Detectors (FNTD)
- ***Computational methods***

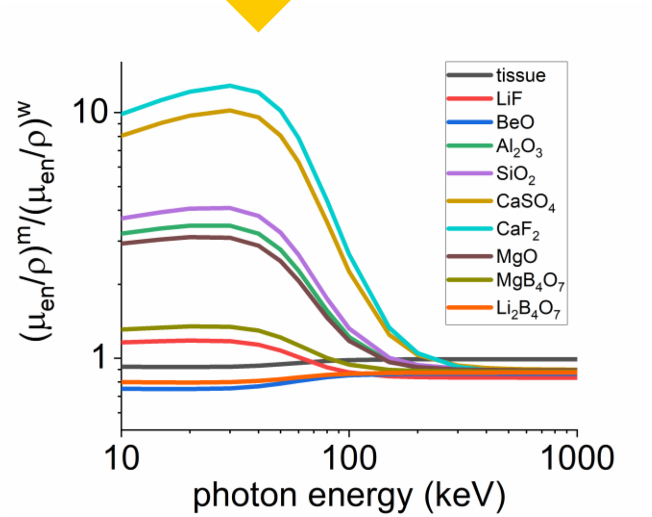
Thermoluminescence (TL)





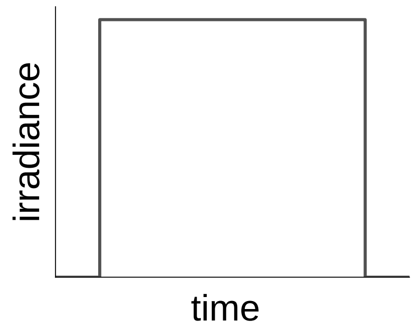


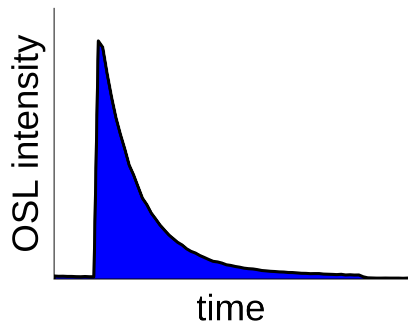


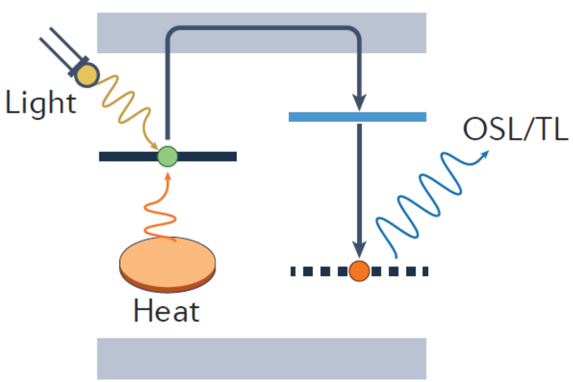


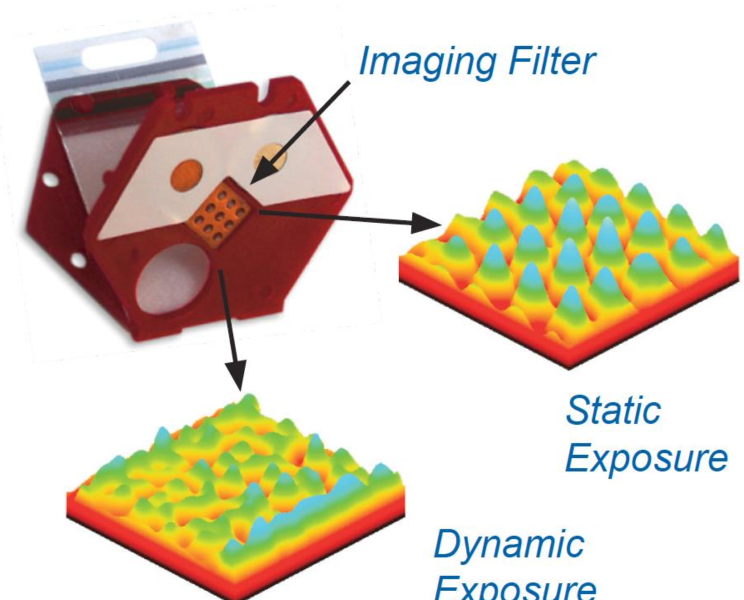
- $H_p(10)$ and $H_p(0.07)$
- Photons and beta

Optically Stimulated Luminescence (OSL)

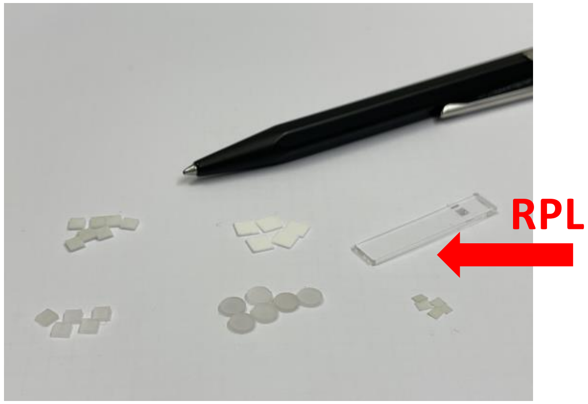


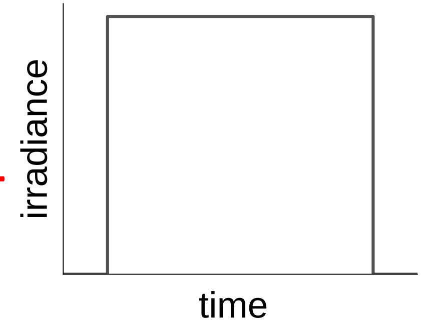


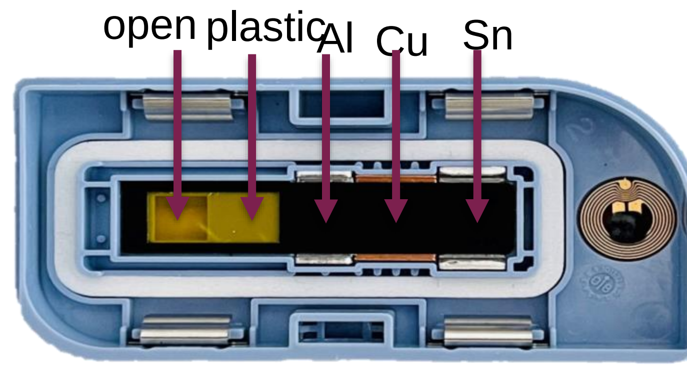


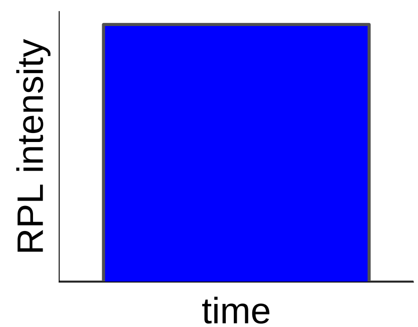


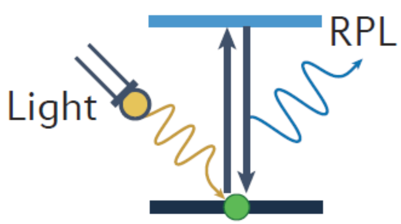
Radiophotoluminescence (RPL)

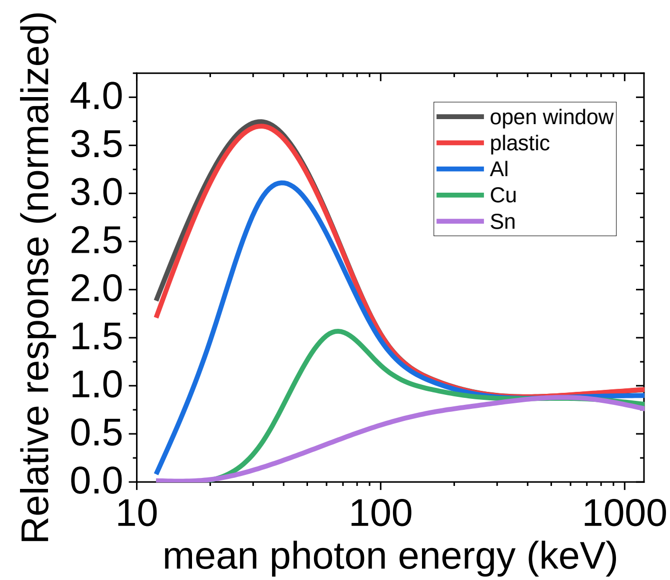






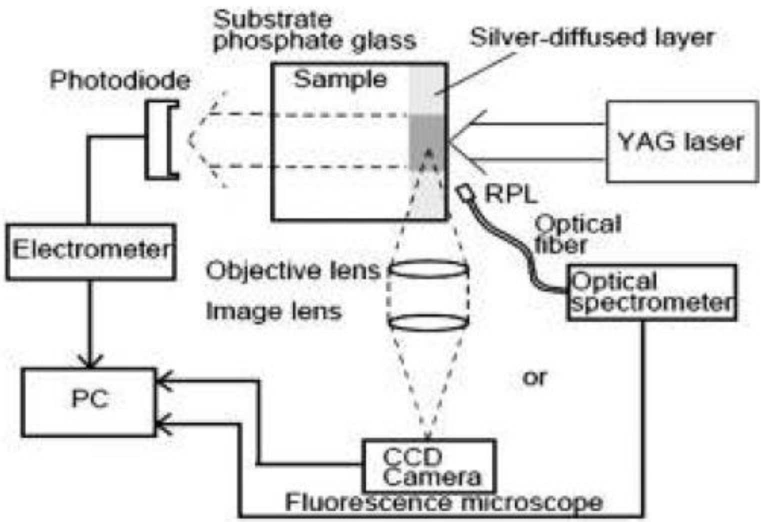


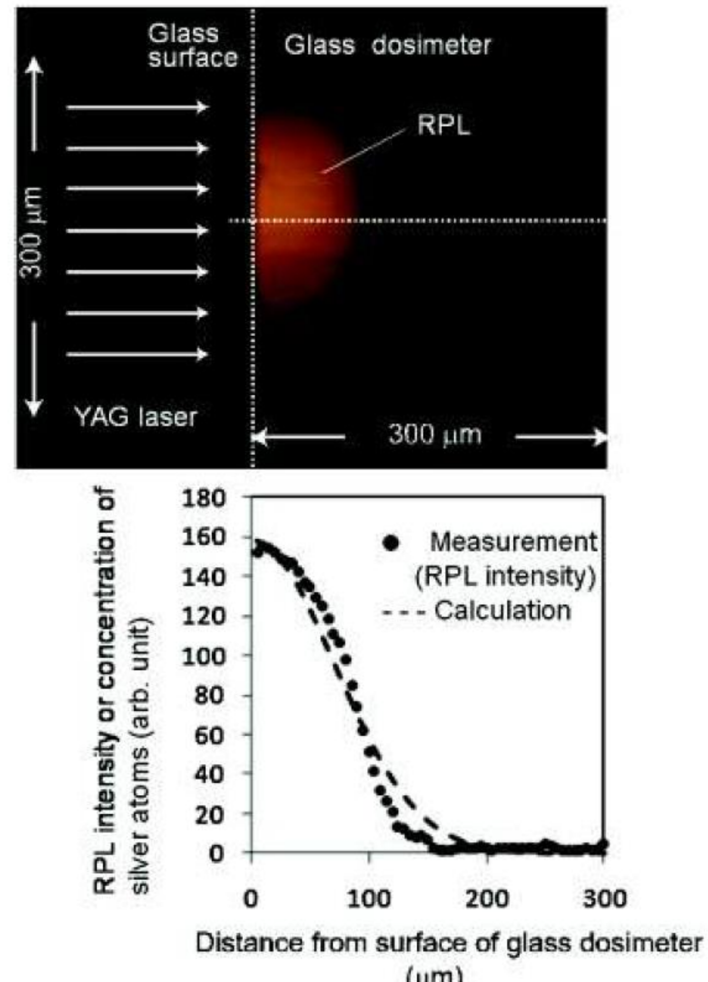




- $H_p(10)$ and $H_p(0.07)$
- Photons and beta

Spatial information using RPL (Ag⁺-doped phosphate glass)





Yamamoto et al. Radiat. Meas. 46, 1544-1559 (2011)

Comparison of luminescence dosimetry

TL	OSL	RPL
• Requires heating • Not re-readable • TL curve • Many materials available	• All-optical readout • Partially re-readable • 2D information • Al_2O_3:C, BeO	• All-optical readout • Fully re-readable • 3D information • Ag^+-doped phosphate glass, Al_2O_3:C,Mg

Luminescence dosimetry

Advantages

- Small and passive (always on)
- Diagnostic signals
- Relatively cheap
- Point, 1D and 2D measurements

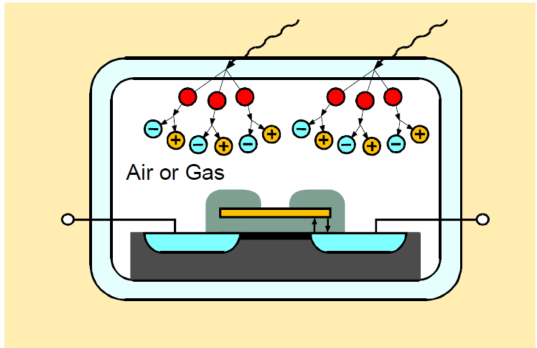
Disadvantages

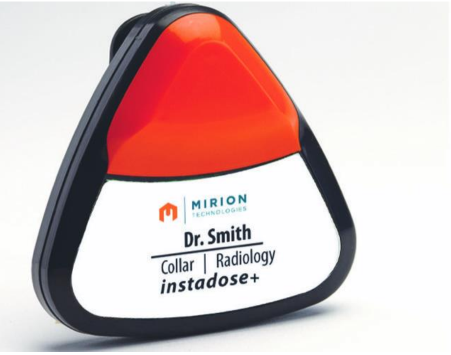
- Off-line readout
- Limited availability (OSL, RPL)

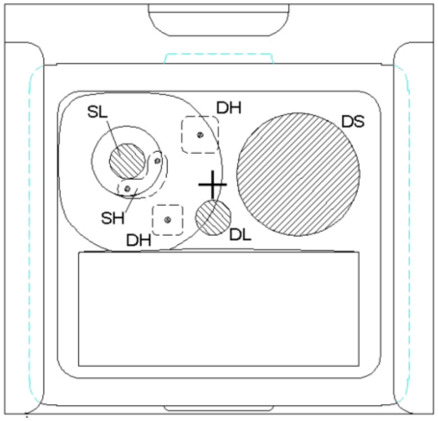
Potential advances

- New materials
- Introduction of new systems for OSL dosimetry
- More sophisticated badge designs/readout modes

Direct Ion Storage (DIS)







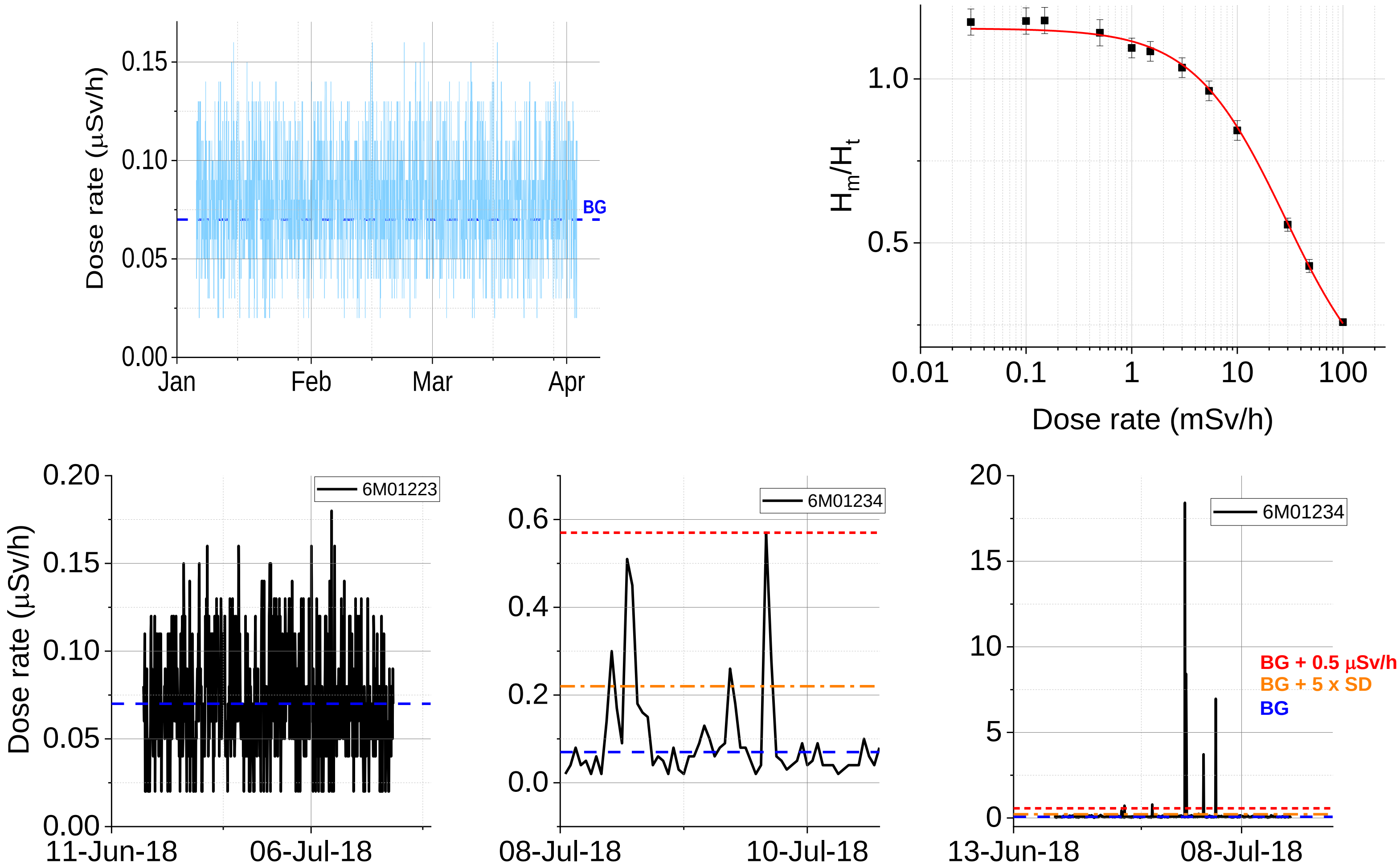
- Charge in the floating gate of the MOSFET
- Conductivity of drain-source is measured (non destructive)
- Three “DIS” chambers: DS, DL, SL
- Two MOSFET-detection elements: DH, SH

- $H_p(10)$ and $H_p(0.07)$
- Photons and beta
- No reader required (up to 100 mSv)
- No need to return dosimeter

D-Shuttle dosimeter

- Gamma rays dosimeter
- Used in Japan after Fukushima accident
- Semiconductor-based
- Lightweight
- Indication: $H_p(10)$

D-Shuttle dosimeter



Musto, E., Assenmacher, F., Hofstetter-Boillat, B., Mayer, S. and Yukihara, E. G. Radiat Meas. 129, 106208 (2019).

D-Shuttle dosimeter

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Journal of Radiation Research

OXFORD

Measurements and determinants of children's exposure to background gamma radiation in Switzerland

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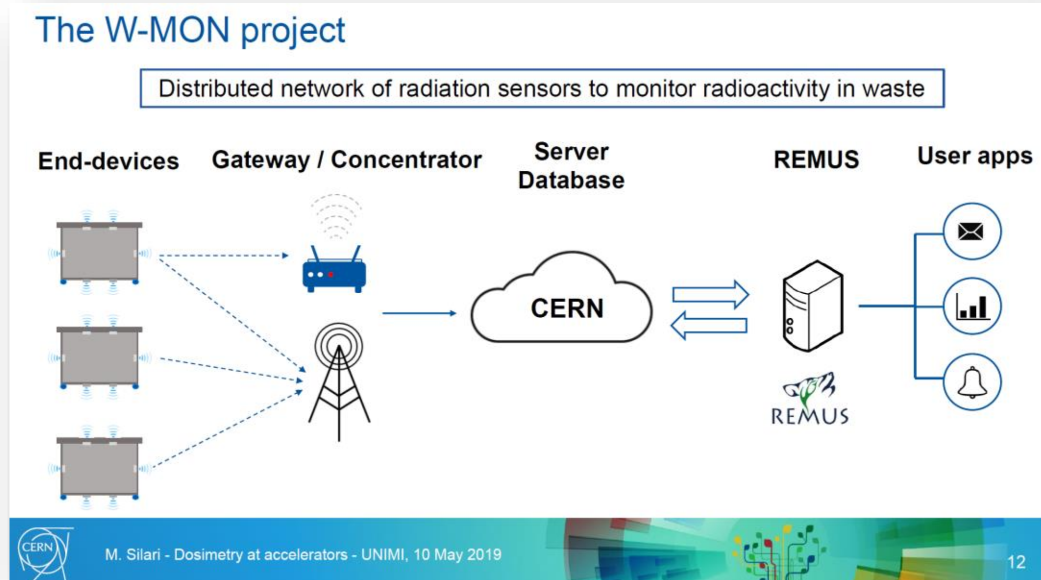
ABSTRACT

Epidemiological studies of children's cancer risks associated with background gamma radiation exposure have used geographic exposure models to estimate exposure at their locations of residence. We measured personal exposure to background gamma radiation, and we investigated the extent to which it was associated with children's whereabouts. We collected data on whereabouts and exposure to background gamma radiation over a 5-day period among children aged 4–15 years in Switzerland. We used D-Shuttle dosimeters to measure children's exposure, and we asked parents to write their children's activities in diaries. We used Poisson mixed-effects and linear regression models to investigate the association of hourly and overall doses, respectively, with children's reported whereabouts. During the observed time, 149 participating children spent 66% indoors at home; 19% indoors away from home; and 15% outdoors. The mean personal exposure was 85.7 nSv/h (range 52.3 nSv/h–145 nSv/h). Exposure was 1.077 (95% CI 1.067, 1.087) times higher indoors than outdoors and varied by building material and (predicted) outdoor dose rates. Our study provides detailed information about children's patterns of exposure to background gamma radiation in Switzerland. Dwelling building materials and outdoor dose rates are important determinants of children's exposure. Future epidemiological studies may benefit from including information about building materials.

Keywords: natural background radiation; terrestrial radiation; dosimetry; exposure measurements; low dose ionizing radiation

D-Shuttle dosimeter



Radiation Measurements 139 (2020) 106488

Contents lists available at ScienceDirect

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Radiation Measurements

journal homepage: www.elsevier.com/locate/radmeas

A distributed and interconnected network of sensors for environmental radiological monitoring

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Manzano et al. Radiat. Meas. 139, 106488 (2020)

Manzano et al. IEEE Trans. Instrum. Meas. 70, 6008512 (2021)

Slides courtesy of Dr. Marco Silari (CERN)

On-demand/active dosimetry

Advantages
- No shipping (Instadose)
- Periodic dose recording (D-Shuttle)

Disadvantages
- Control of the data?
- D-Shuttle not available anymore

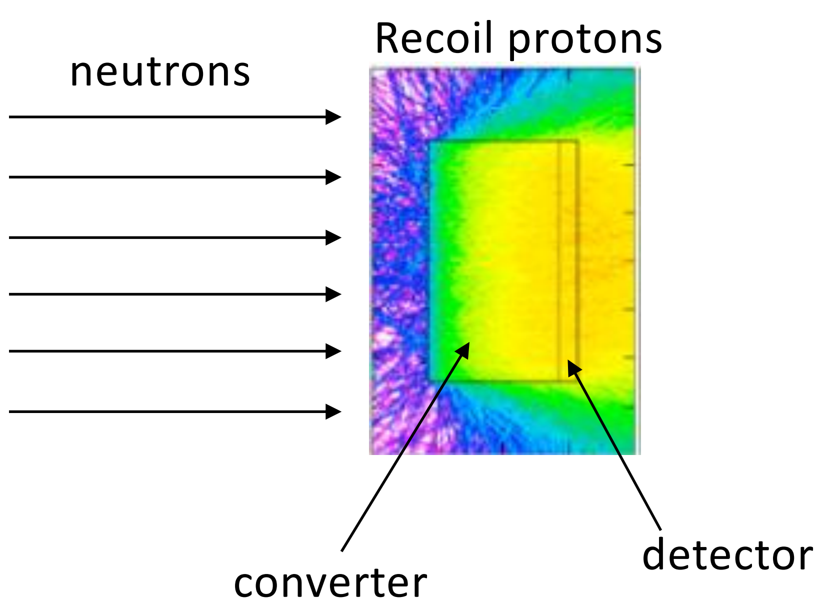
Potential advances
- Networked dosimeters
- Development of low-cost dosimeters

Neutron dosimetry detection principles

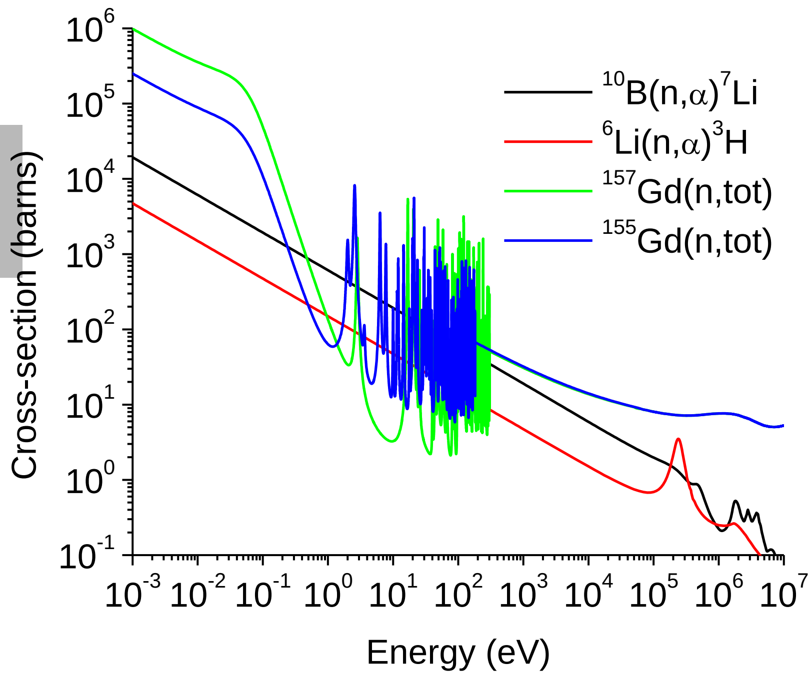
Inelastic scattering

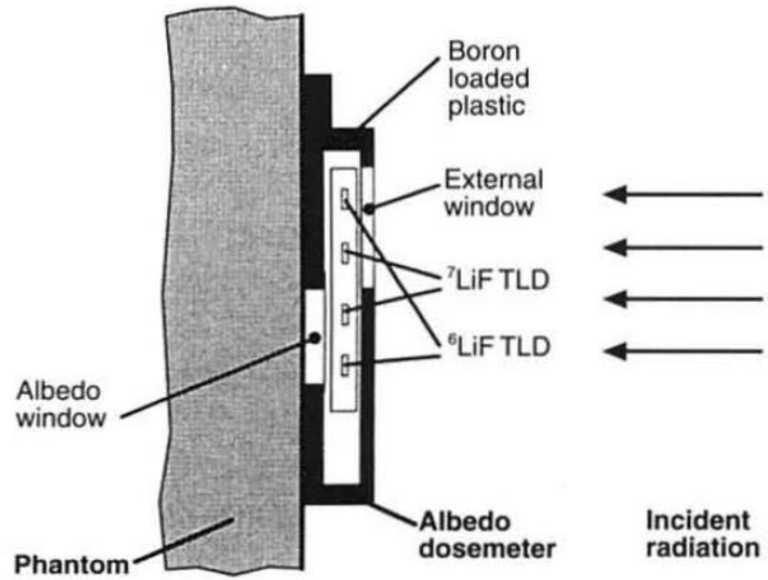
$$^{6}\mathrm{Li} + \mathrm{n} \rightarrow {}^{3}\mathrm{H} + \alpha \quad \begin{cases} E(^{3}\mathrm{H}) = 2.73\,\mathrm{MeV} \\ E(\alpha) = 2.05\,\mathrm{MeV} \end{cases}$$

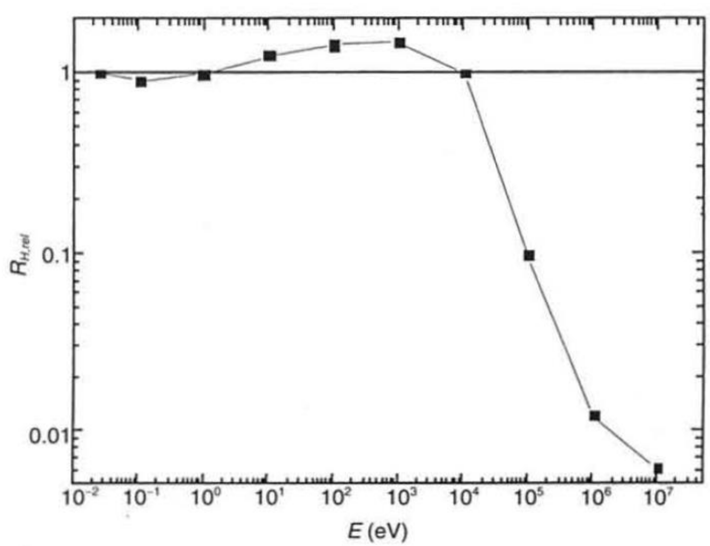
Elastic scattering (recoil protons)



Albedo neutron dosimetry







- Require neutron moderation
- Strongly influenced by the geometry

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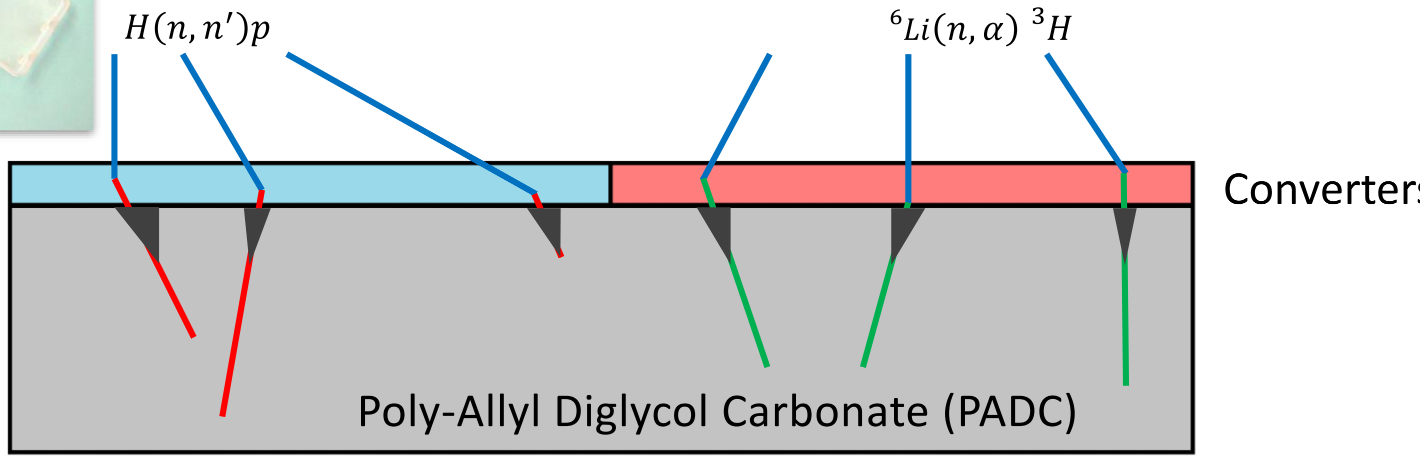
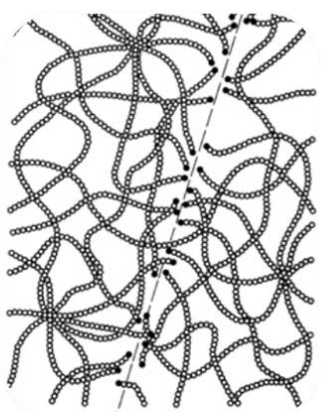
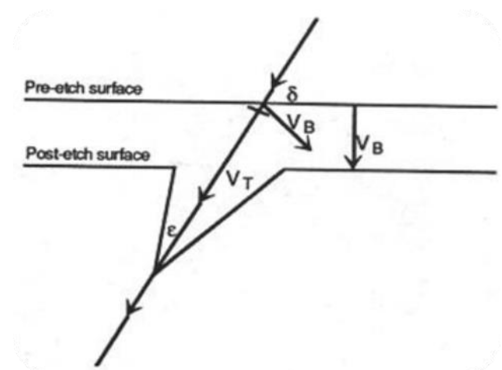
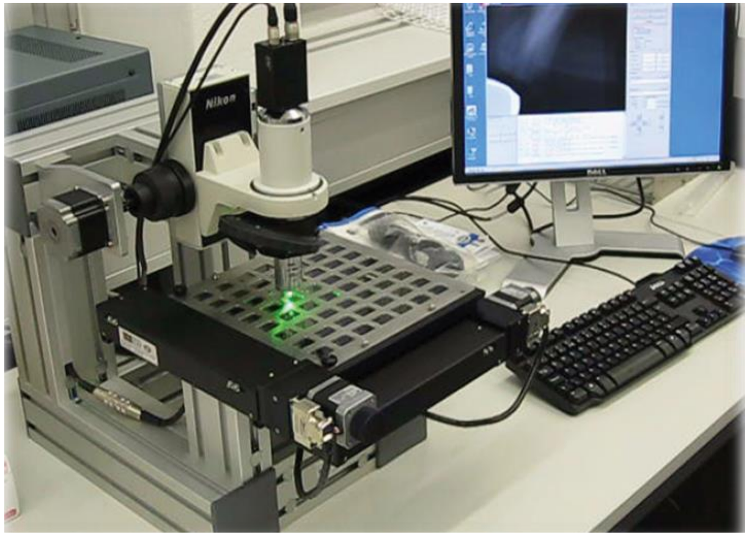
Neutron dosimetry using Plastic Nuclear Track Detectors (PNTDs)

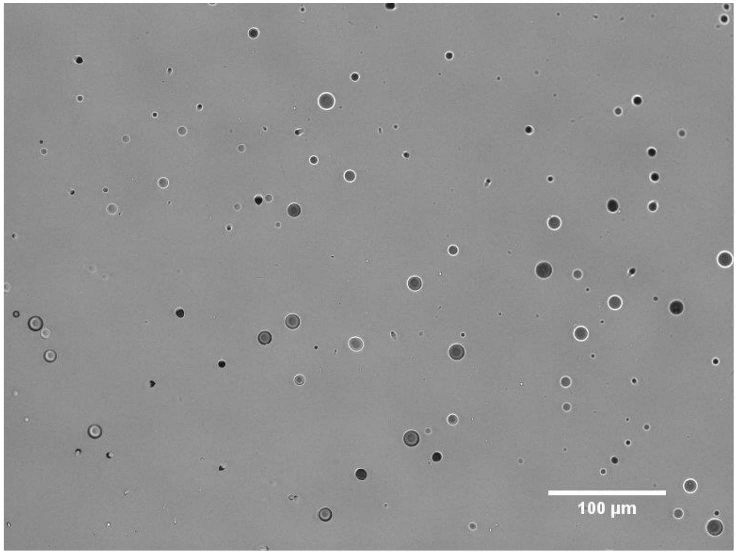


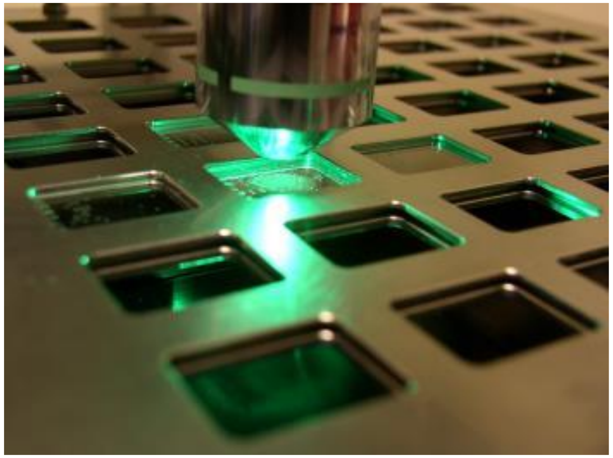




Plastic Nuclear Track Detectors (PNTDs)



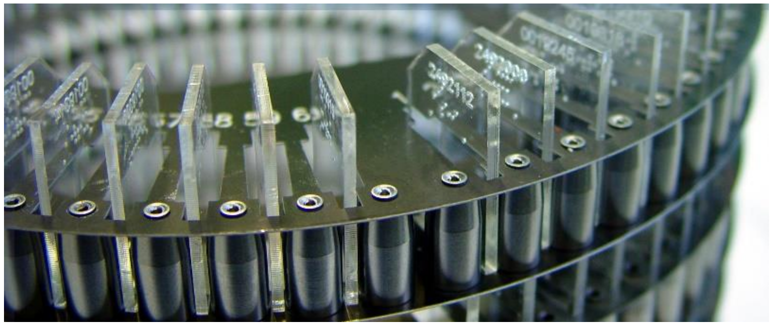




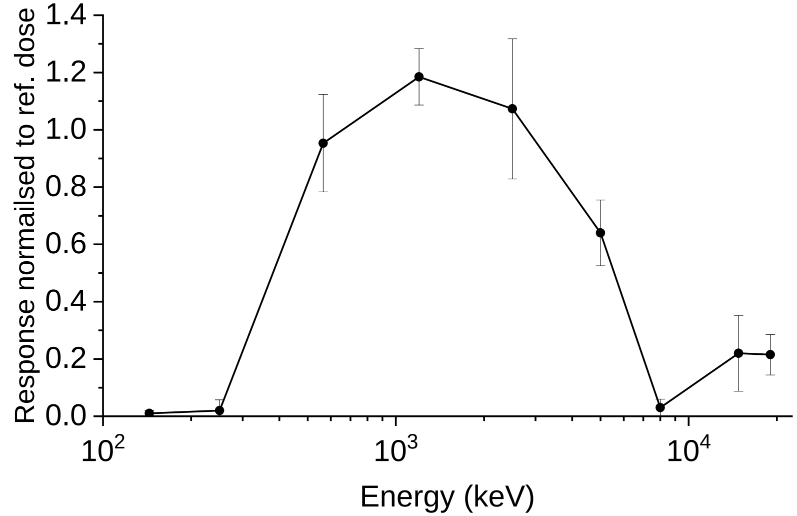
$$Dose = \frac{tracks}{mm^2} C_{cal}$$

Plastic Nuclear Track Detectors (PNTDs)

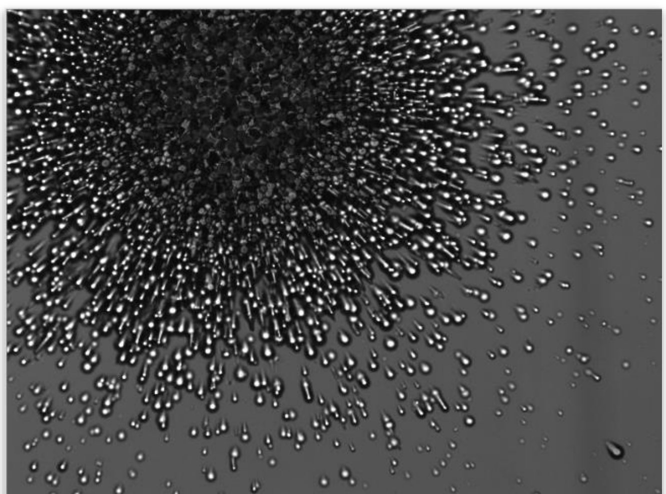
- Need chemical etching
- Not re-usable



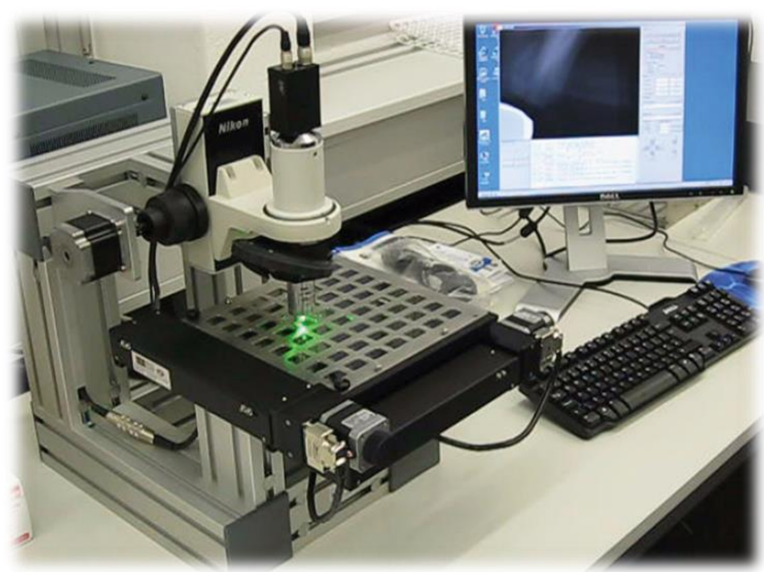
- Narrow sensitivity range



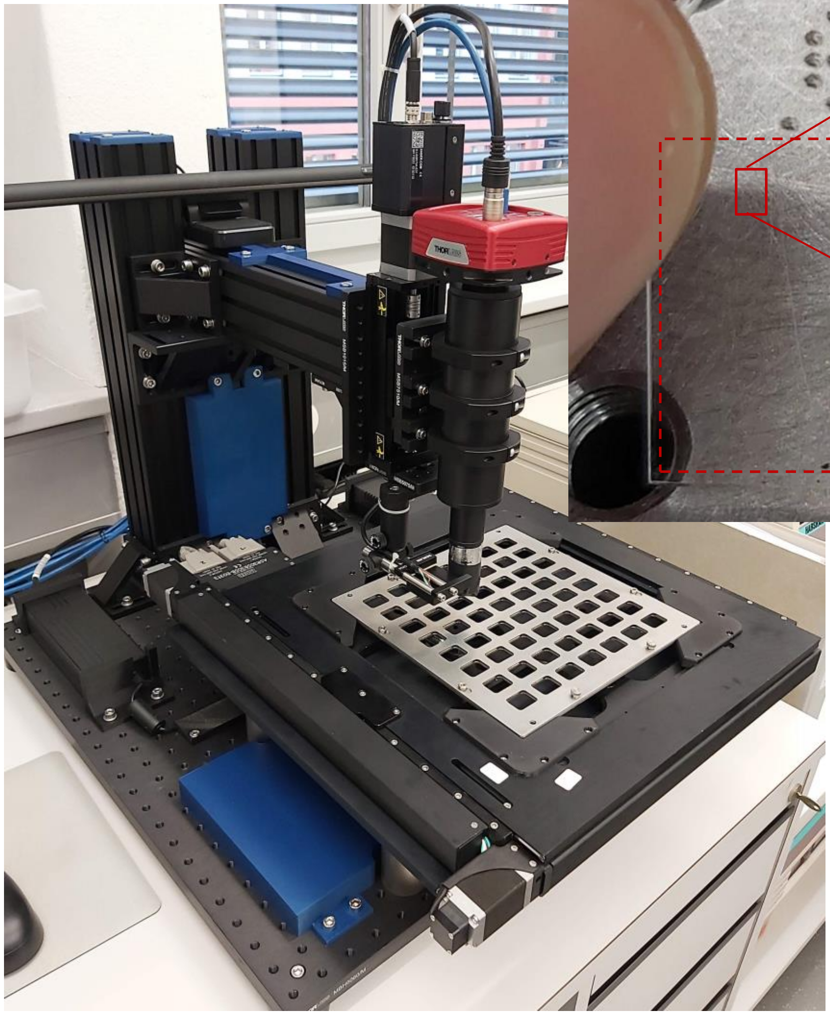
- Frequent material problems



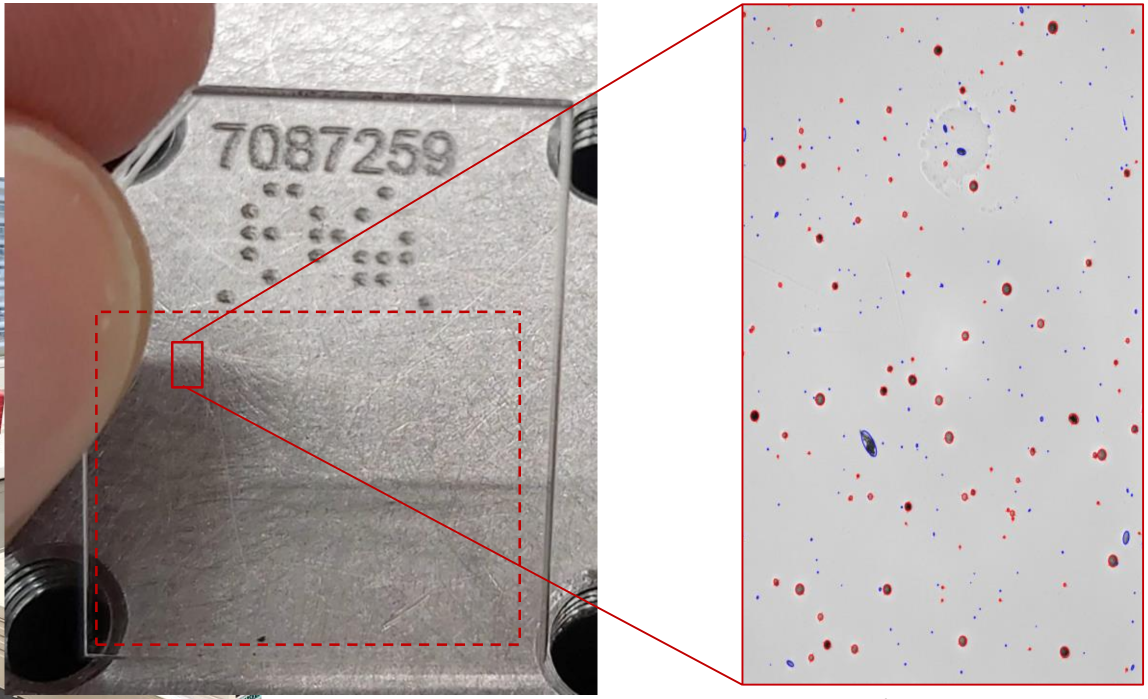
- Black box



Plastic Nuclear Track Detectors (PNTDs)

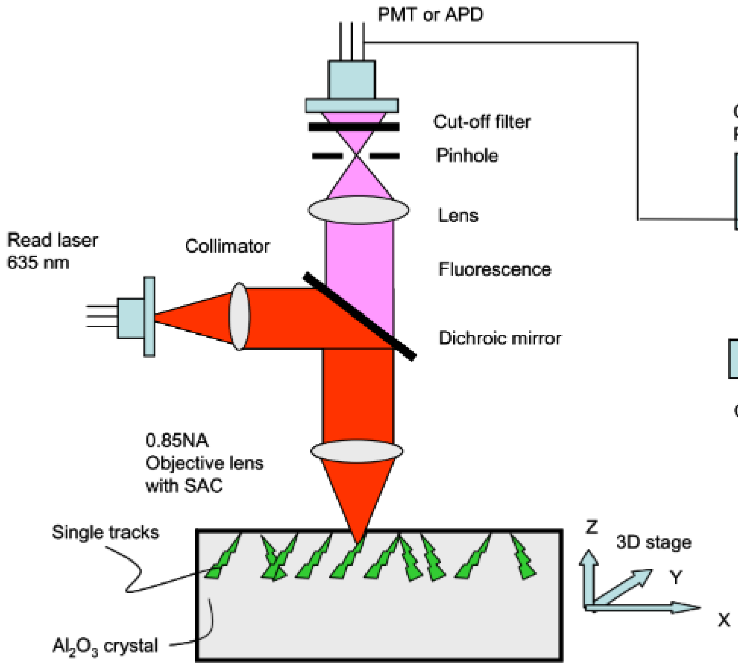


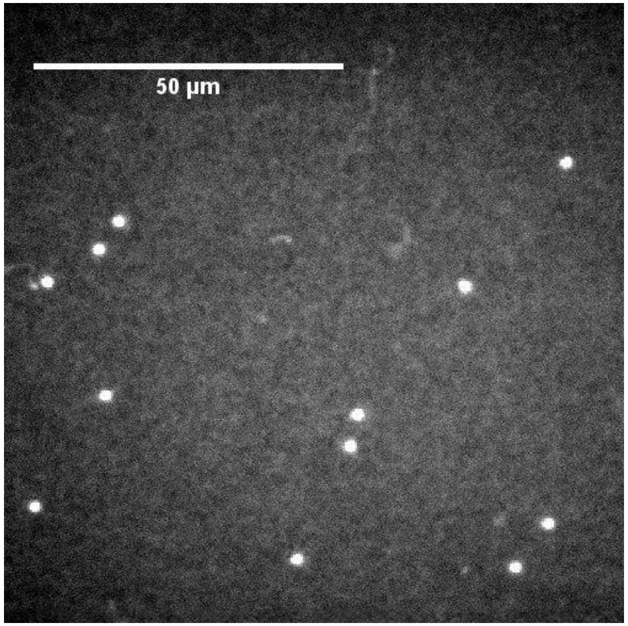
PADC reader developed at PSI

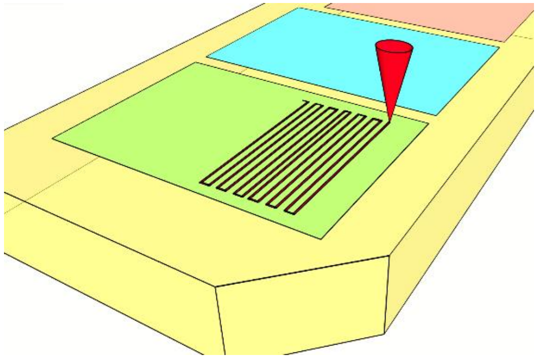


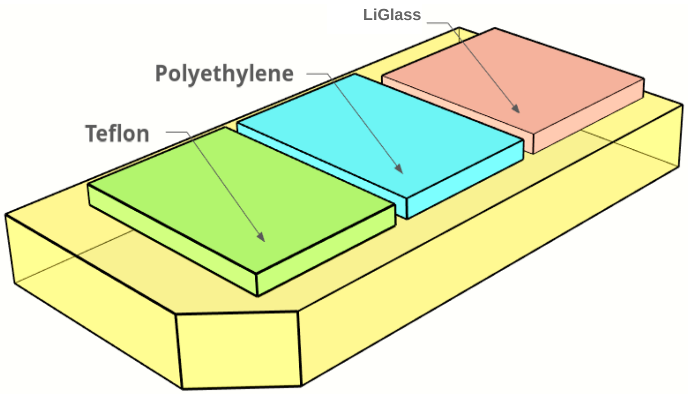
Red = accepted / Blue = rejected

Fluorescence Nuclear Track Detectors (FNTDs)



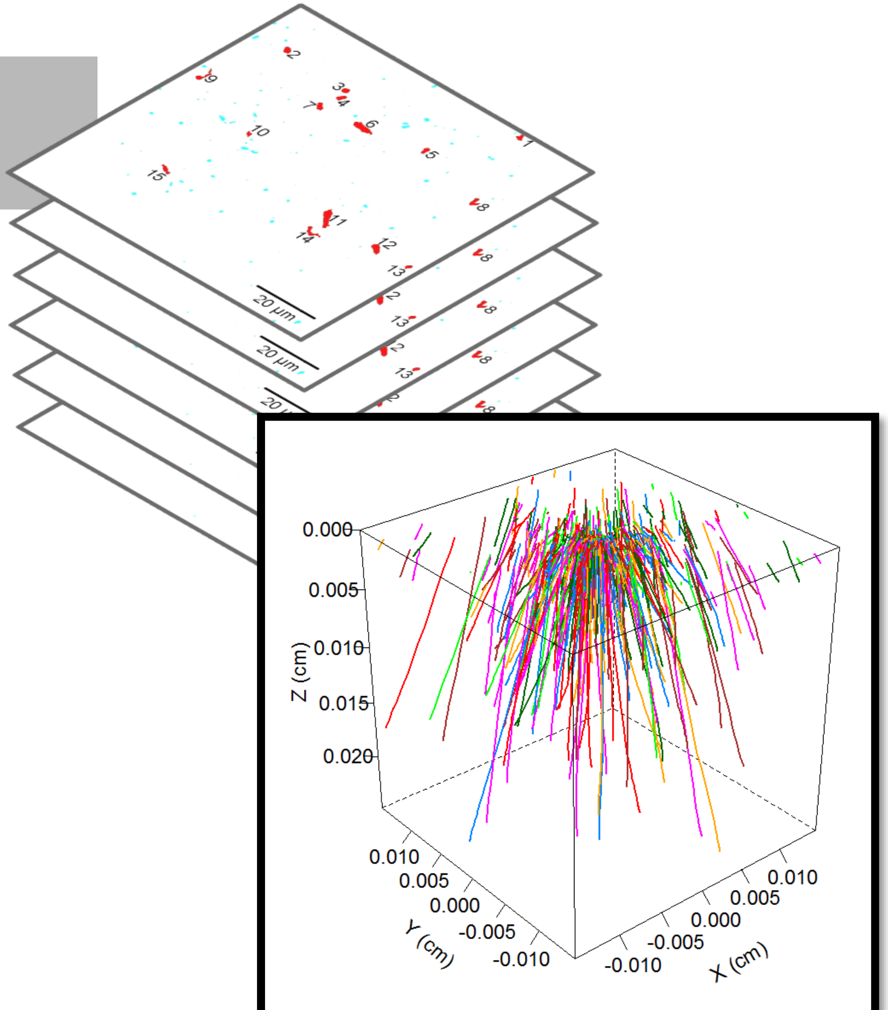


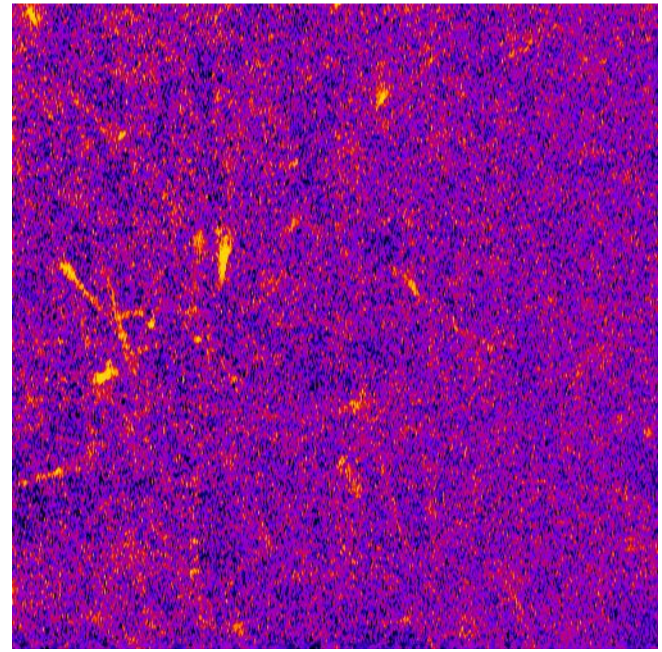




Akselrod, M. S. and Kouwenberg, J. Radiat Meas. **117**, 35-51 (2018).

Fluorescence Nuclear Track Detectors (FNTDs)





See various papers by Alberto Stabilini

Neutron dosimetry

Advantages PADC

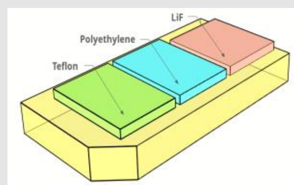
- Tissue equivalent and “self-converter”
- Simple readout

Disadvantages PADC

- Requires chemical etching
- Not re-usable
- Inconsistency in material quality
- QA is time-consuming

Advantages FNTD

- Re-usable
- 3D track information



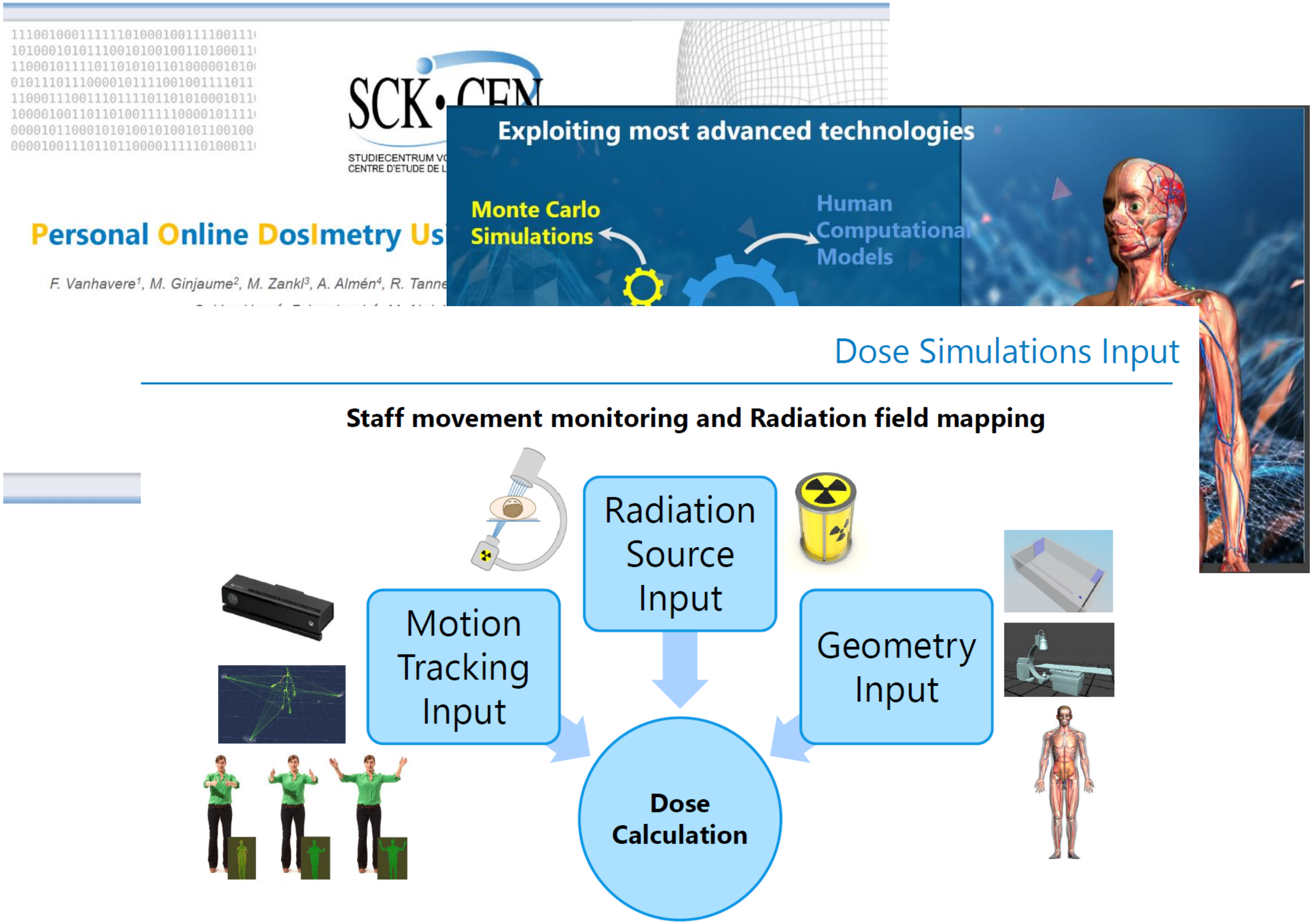
Disadvantages FNTD

- Requires complex equipment
- Requires external converters
- More energy dependent

Potential advances

- Improvement in PADC material manufacturing
- More control of the individual processes (away from the “black box”?)
- Further development of new optical techniques

Computational methods



Slides courtesy of Dr. Filip Vanhavere (SCK-CEN, Belgium)

Computational methods

- Results show the validity of the method in interventional radiology and some neutron workplaces
- Important aspect of visualisation of radiation (ALARA, training tool)

Slides courtesy of Dr. Filip Vanhavere (SCK-CEN, Belgium)

Overlook

- **Short term**
  – Parallel developments in passive (OSL/RPL) and active dosimetry
  – Slow improvements in PADC neutron dosimetry
- **Medium term**
  – Adaptations/developments motivated by the ICRU Report 95
  – Improvement of new techniques for neutron dosimetry
  – Development of cheaper, networked dosimeters
- **Long term**
  – Greater emphasis in computational methods

Thank you for your attention!

Contributions
- Lily Bossin (PSI)
- Jeppe Christensen (PSI)
- Filip Vanhavere (SCK-CEN)
- Marco Silari (CERN)

Disclaimer
- Mention of commercial products are for illustrative purposes and do not represent endorsement from the part of the speaker or PSI
- Dr. Yukihara’s research was funded by Landauer while at Oklahoma State University (2004 – 2015)

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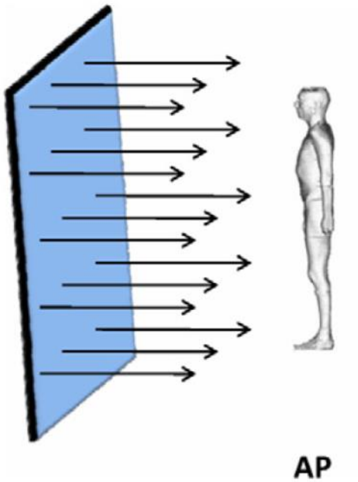
Operational quantities

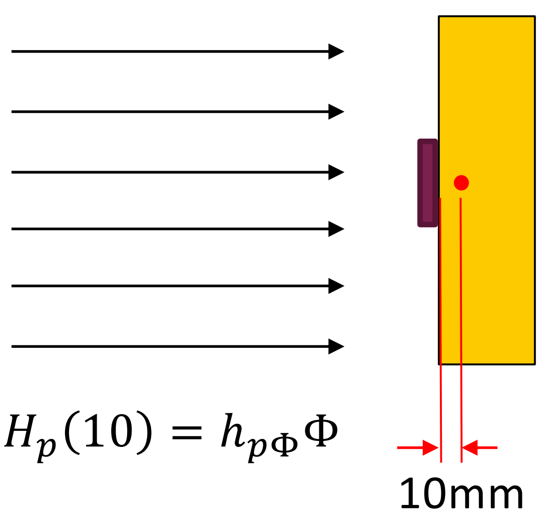


Effective dose: $E = \sum_T w_T \sum_R w_R D_{T,R}$

ICRU Report 51

Personal dose equivalent $H_\mathrm{p}(10)$

$$H_p(10) = Q(L)D$$



$$H_p(10) = h_{p\Phi}\Phi$$

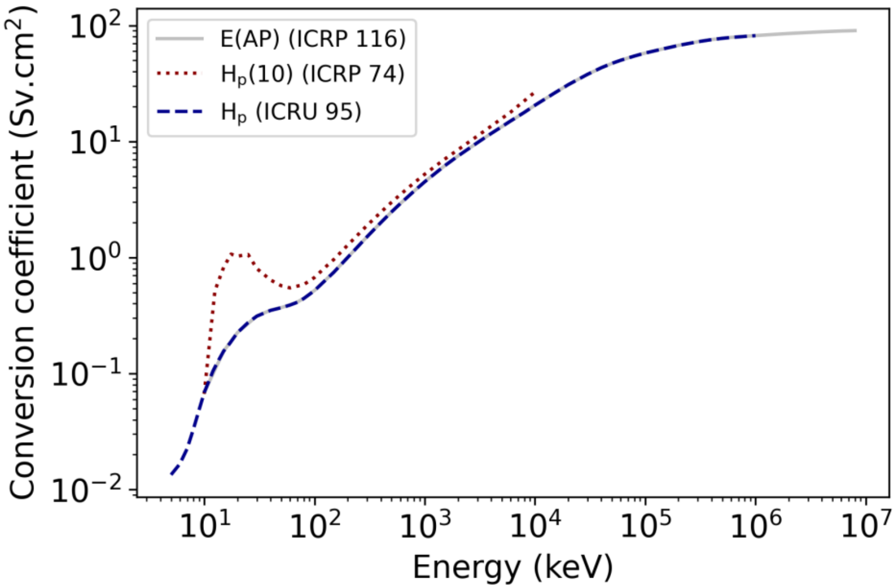
ICRU Report 95

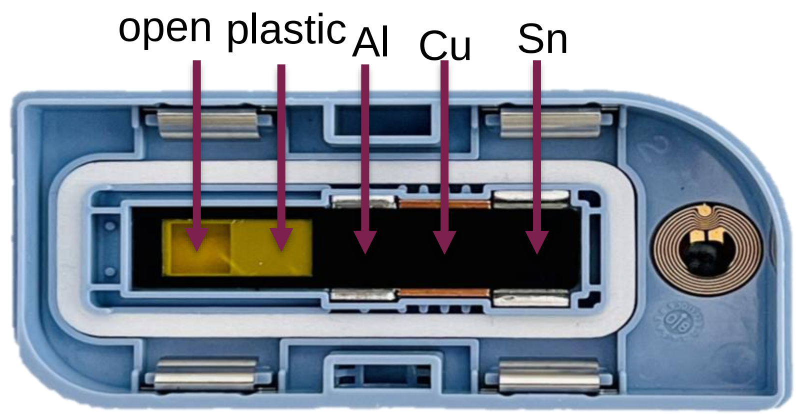
Personal dose equivalent H_p

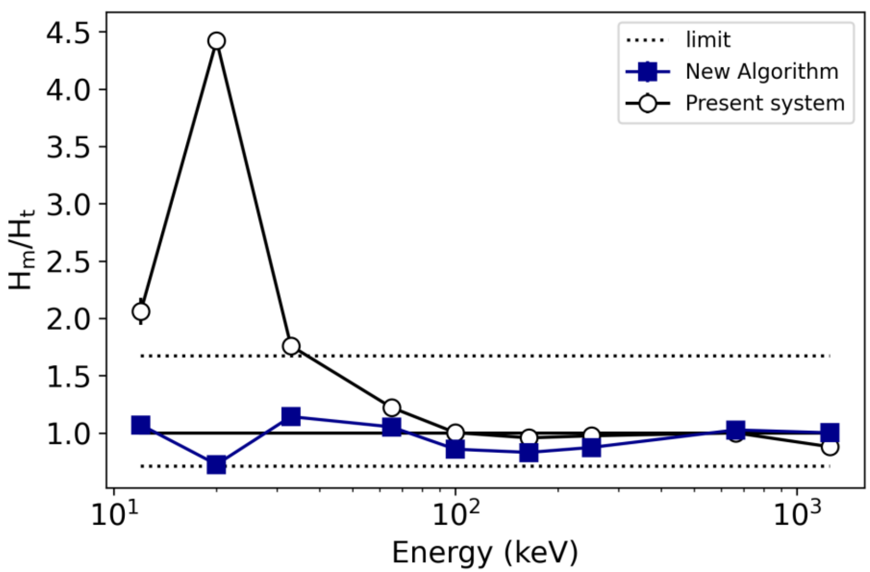
$$H_p = \Phi h_\Phi$$

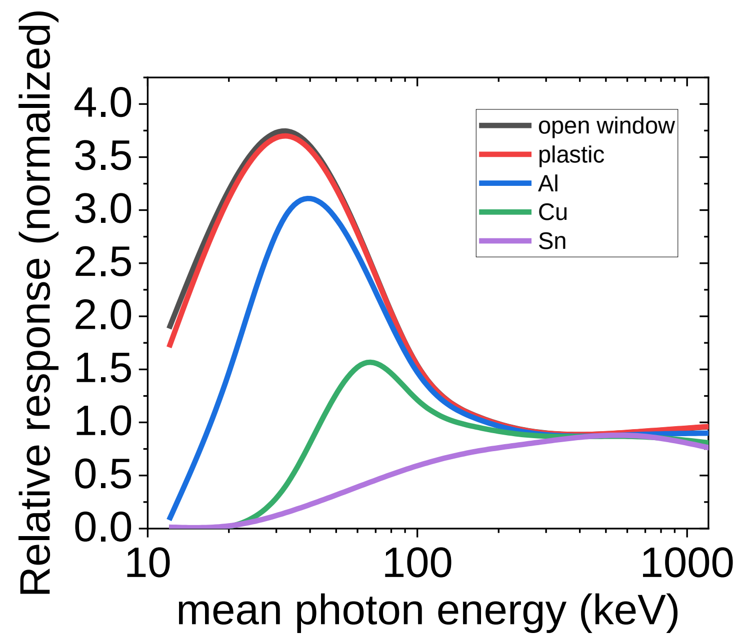
$$h_E = \frac{E}{\Phi}$$

Operational quantities









Bossin et al. submitted to Radiat. Meas. (2021).