Dosimetry of the lens of the eye

Dosimetric units and quantities for eye lens monitoring, standards, type testing, calibration procedures and phantoms

R. Behrens

13th EURADOS Winter School
"Eye lens dosimetry"
30th January 2020
Introduction: Why the lens?
Dosimetry in general
Which quantity for the lens of the eye?
Practical and formal aspects
Reactions of international organisations
Conclusions / Challenges
Introduction: Why the lens?

ICRP 103 (2007) vs. 118 (2012): Tissue reactions

Threshold dose for the induction of cataract at irradiations
- acute: 2 Gy
- protracted: 5 Gy

Definition of threshold dose:
- effect for 1% of exposed;
- not necessarily cataract!

More shall be prevented ➔
- 500 mSv / 25 years ➔ limit: 20 mSv/a
- 75% “normal” cataract in public; can be operated
- 1% per 200 mSv

Death by cancer:
- 5% per 1 Sv
- death for 1% of exposed ➔ 1% per 200 mSv

If more should be prevented ➔
- 200 mSv / 25 years ➔ limit: 8 mSv/a !?
- 20% “normal” mortality in public by cancer
Contents

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Which quantity for the lens of the eye?
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Reactions of international organisations
Conclusions / Challenges
Terms: Sievert (H) vs. Gray (D)

- Low doses ($\lesssim 0.5$ Sv) $\rightarrow$ DSB
  - Effect: cancer, hereditary disease
  - Depends on radiation type $\rightarrow w_R \rightarrow$ Sv
  - Probability of effect
  - Stochastic effects
  - Long after irradiation (years to decades)
  - Strength of effect
  - Use e.g. for effective dose (risk of cancer) and in epidemiological studies; in therapy only for secondary cancer!

- High doses ($\gtrsim 0.5$ Gy) $\rightarrow$ cell dead
  - Effect: e.g. erythema, organ-fail or -dead, dead (e.g. tumor therapy)
  - Independent of radiation type $\rightarrow$ Gy
  - Probability of effect
  - Deterministic effects
  - Shortly after irradiation (days to weeks)
  - Strength of effect
  - Use e.g. at radiation accidents, tumor therapy (dose in target volume)

Effect not yet clear for the lens of the eye (ICRP 118)
<table>
<thead>
<tr>
<th>Protection quantities (ICRP 116)</th>
<th>Whole body</th>
<th>Lens of the eye</th>
<th>Local skin</th>
</tr>
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<tbody>
<tr>
<td>ICRP reference voxel phantoms: $E_{\text{eff}} = \sum_{T} w_T \sum_{R} w_R D_{T,R}$</td>
<td></td>
<td>Stylized eye model; whole lens (ICRP 116, Annex F): $H_{\text{lens}} = \sum_{R} w_R D_{\text{lens},R}$</td>
<td>Tissue-equivalent cube (10x10x10 cm³); 1 cm² area at 50 – 100 µm depth (ICRP 116, Annex G): $H_{\text{local skin}} = \sum_{R} w_R D_{\text{local skin},R}$</td>
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### Protection quantities vs. operational quantities

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### Operational quantities: definition: $H = Q(L) \cdot D$

<table>
<thead>
<tr>
<th>Area</th>
<th>Operational quantities (ICRU 51)</th>
<th>Individual</th>
<th>Operational quantities for monitoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICRU 4-element tissue sphere: $\varnothing = 30$ cm: $H^\ast(10) = Q \cdot D(10)_{\text{sph}}$</td>
<td>$H_p(10) = Q \cdot D(10)_{\text{person}}$</td>
<td>$H_p(0.07) = Q \cdot D(0.07)_{\text{person}}$</td>
<td></td>
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<tr>
<td>ICRU 4-element tissue sphere: $\varnothing = 30$ cm: $H'(3;\Omega) = Q \cdot D(3;\Omega)_{\text{sph}}$</td>
<td>$H_p(3) = Q \cdot D(3)_{\text{person}}$</td>
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<td>ICRU 4-element tissue sphere: $\varnothing = 30$ cm: $H'(0.07;\Omega) = Q \cdot D(0.07;\Omega)_{\text{sph}}$</td>
<td></td>
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</table>

For calibration: ICRU 4-element tissue slab: 30x30x15 cm³: $H_p(10) = Q \cdot D(10)_{\text{slab}}$

For calibration: ICRU 4-element cylinder: $\varnothing = h = 20$ cm: $H_p(3) = Q \cdot D(3)_{\text{cylinder}}$

For calibration: ICRU 4-el. tissue slab, pillar, rod (Ø = 73, 19 mm): $H_p(0.07) = Q \cdot D(0.07)_{\text{slab, pillar, rod}}$
## Dosimetry of the lens of the eye

### Protection quantities (ICRP 116)

**Whole body**
- ICRP reference voxel phantoms:
  \[ E_{\text{eff}} = \sum T_w \sum R_w D_{T,R} \]

**Lens of the eye**
- Stylized eye model; whole lens (ICRP 116, Annex F):
  \[ H_{\text{lens}} = \sum R_w D_{\text{lens,R}} \]

**Local skin**
- Tissue-equivalent cube (10x10x10 cm³);
  1 cm² area at 50 – 100 µm depth (ICRP 116, Annex G):
  \[ H_{\text{local skin}} = \sum R_w D_{\text{local skin,R}} \]

### Operational quantities: definition

**Whole body**
- ICRP reference voxel phantoms:
  \[ H^* = h_{E,\text{max}} \cdot \Phi \]

**Lens of the eye**
- Stylized eye model; whole lens (ICRP 116, Annex F):
  \[ D'_{\text{lens}}(\Omega) = d_{\text{lens}}(\Omega) \cdot \Phi \]

**Local skin**
- ICRU 4-element tissue slab (30x30x15 cm³) with 2 mm skin cover over 1 cm² at 50-100 µm:
  \[ D'_{\text{local skin}}(\Omega) = d_{\text{local skin}}(\Omega) \cdot \Phi \]

### Quantities: Proposal of ICRU RC26

**Whole body**
- ICRP reference voxel phantoms:
  \[ H_p = h_E \cdot \Phi \]

**Lens of the eye**
- Stylized eye model; whole lens (ICRP 116, Annex F):
  \[ D_p(\Omega) = d_{\text{lens}}(\Omega) \cdot \Phi \]

**Local skin**
- ICRU 4-elements slab, pillar, rod; 2 mm skin cover; 1 cm² area at 50 – 100 µm:
  \[ D_p(\Omega) = d_{\text{local skin}} \cdot \Phi \]
Introduction: Why the lens?
Dosimetry in general
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Is an operational quantity conservative?

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### Operational quantities: definition: $H = Q(L) \cdot D$

**Area**
- ICRU 4-element tissue sphere: $\varnothing = 30$ cm: $H^*(10) = Q \cdot D(10)_{\text{sph}}$
- ICRU 4-element tissue sphere: $\varnothing = 30$ cm: $H'(3;\Omega) = Q \cdot D(3;\Omega)_{\text{sph}}$
- ICRU 4-element tissue sphere: $\varnothing = 30$ cm: $H'(0.07;\Omega) = Q \cdot D(0.07;\Omega)_{\text{sph}}$

**Operational quantities for monitoring Individual**
- For calibration: ICRU 4-element tissue slab: 30x30x15 cm³: $H_{\text{p}}(10) = Q \cdot D(10)_{\text{slab}}$
- For calibration: ICRU 4-element cylinder: $\varnothing = h = 20$ cm: $H_{\text{p}}(3) = Q \cdot D(3)_{\text{cylinder}}$
- For calibration: ICRU 4-el. tissue slab, pillar, rod ($\varnothing = 73, 19$ mm): $H_{\text{p}}(0.07) = Q \cdot D(0.07)_{\text{slab, pillar, rod}}$
Which quantity for the lens of the eye?

<table>
<thead>
<tr>
<th>Radiation field</th>
<th>$H_p(0.07)<em>{rod}$ / $H</em>{lens}$</th>
<th>$H_p(0.07)<em>{slab}$ / $H</em>{lens}$</th>
<th>$H_p(3)<em>{slab}$ / $H</em>{lens}$</th>
<th>$H_p(10)<em>{slab}$ / $H</em>{lens}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-ray mean $E &lt; 30$ keV</td>
<td>0.9 – 5</td>
<td>1 – 5</td>
<td>≈ 1</td>
<td>0.01 – 0.9</td>
</tr>
<tr>
<td>X-ray mean $E &gt; 30$ keV</td>
<td>0.8 – 0.9</td>
<td>≈ 1</td>
<td>≈ 1</td>
<td>0.9 – 1.2</td>
</tr>
<tr>
<td>Beta max. $E &lt; 0.6$ MeV and X-rays</td>
<td>1 – 100</td>
<td>1 – 100</td>
<td>≈ 1</td>
<td>see above</td>
</tr>
<tr>
<td>Beta max. $E ≈ 1$ MeV and X-rays</td>
<td>1 – 500</td>
<td>1 – 500</td>
<td>≈ 1</td>
<td>2x10^{-4} – 1</td>
</tr>
<tr>
<td>Beta max. $E &gt; 1.5$ MeV and X-rays</td>
<td>1 – 60</td>
<td>1 – 60</td>
<td>≈ 1</td>
<td>2x10^{-4} – 1</td>
</tr>
</tbody>
</table>

$H_p(0.07)_{slab}$ is ONLY adequate for photon radiation.

$H_p(3)$ is NECESSARY for beta radiation.

$H_p(10)$ is NOT adequate for $E_{ph} < 40$ keV & $\beta$. 

Contents

Introduction: Why the lens?
Dosimetry in general
Lens of the eye: anatomy and dose
Which quantity for the lens of the eye?
Practical and formal aspects
Reactions of international organisations
Conclusions / Challenges
Are extremity dosemeters (for photons for $H_p(0.07)$) appropriate?

**Calibration on**
- Rod phantom
- Slab phantom

... yield the same results!

*R. Behrens et al.*:
Routine measurements

- **D**: $H_p(3)$- and $H'(3)$-dosemeters
- **D**: alternatively until end of 2021 (§ 197 (1) and § 90 (2) StrlSchV): $H_p(0.07)$- and $H'(0.07)$-dosemeters in photon fields

![Monitoring of the lens of the eye: practice in Germany](image-url)
Monitoring of the lens of the eye: practice in Germany

Routine measurements

- D: $H_p(3)$- and $H'(3)$-dosemeters
- D: alternatively until end of 2021 (§ 197 (1) and § 90 (2) StrlSchV): $H_p(0.07)$- and $H'(0.07)$-dosemeters in photon fields

Future: goggles with integrated $H_p(3)$-dosemeter
Irradiations and type tests in $H_p(3)$ and $H'(3)$ possible

- Photon spectra:
  - Conversion coefficients for $K_a \Rightarrow H_p(3)_cyl$:
  - Conversion coefficients for $K_a \Rightarrow H'(3)$:
    \[ \text{J. Radiol. Prot. 37 (2017) 354} \]

- Beta radiation:
  - Extensions to the Beta Secondary Standard BSS 2 incl. conversion factors from $H_p(0.07) \Rightarrow H_p(3)$ and $H'(3)$:
    \[ \text{J. Instrum. 6 (2011) P11007 and Erratum and Addendum} \]
  - Available for old instruments via SW update
Use cylinder or slab phantom for $H_p(3)$?

**Response on slab above 45° significantly different!**

Eye-D: Response on Slab / Response on Cylinder

- Calibration (0°) on slab or cylinder
- Type test ONLY on cylinder!

30 x 30 x 15 cm³

VS. $\frac{R_{\text{Slab}}}{R_{\text{Cylinder}}}$

$\varnothing = 20 \text{ cm}$

$\text{h} = 20 \text{ cm}$

Uncertainty bars: standard deviation of the mean values

R. Behrens and O. Hupe
**$H_p(3)$ eye lens dosemeters: Calibration and characterization.**

<table>
<thead>
<tr>
<th>Calibration (0°)</th>
<th>Characterization (0°.. $\alpha$)</th>
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</thead>
<tbody>
<tr>
<td><strong>Area monitoring</strong></td>
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</tr>
<tr>
<td><strong>Individual monitoring</strong></td>
<td><strong>Individual monitoring</strong></td>
</tr>
<tr>
<td>Eye lens dosemeters on water cylinder, water slab or PMMA rod phantom</td>
<td>Eye lens dosemeters on water-cylinder phantom</td>
</tr>
</tbody>
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*free in air*
### Calibration, characterization and measurement

<table>
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<tr>
<td><strong>Calibration (0°) and characterization (0° .. ( \alpha ))</strong></td>
<td></td>
</tr>
<tr>
<td>free in air</td>
<td></td>
</tr>
<tr>
<td><strong>Measurement</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>whole body-, eye lens-, ring-dosem. on Water slab-, water-cyl.-, PMMA-rod-phantom (water-pillar not in Germany)</td>
<td></td>
</tr>
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<td><strong>Individual monitoring</strong></td>
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<td>whole body-, eye lens-, ring-dosem. at the person at representative part of the body behind / below protection</td>
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Calibration (0°) and characterization (0°..α)

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<td>Whole body-, eye lens-, ring-dosem. at the person at representative part of the body behind / below protection</td>
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Procedures unchanged – “only” new conversion coefficients

➤ Calibration coefficient and energy dependence change!
Dose rate constants for the quantity $H_p(3)$ for frequently used radionuclides in nuclear medicine

Table 1

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Dominant emissions</th>
<th>Radiation</th>
<th>$E_\gamma$; $E_{\beta,max}$ keV</th>
<th>Geometry</th>
<th>$k_{\text{nuclide}}$</th>
<th>$\Gamma (H_p(3))$ in (mSv·m$^2$)/(GBq·h)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>This work</td>
</tr>
<tr>
<td>Tc-99m</td>
<td>$\gamma$</td>
<td>141</td>
<td>0.89</td>
<td>5 ml solution in 10 ml syringe</td>
<td>0.71 ± 0.04</td>
<td>0.021 ± 0.006 0.025 $^d$</td>
</tr>
<tr>
<td>I-131</td>
<td>$\beta^-$</td>
<td>606</td>
<td>0.90</td>
<td>Capsule in applicator</td>
<td>0.66 ± 0.03</td>
<td>0.071 ± 0.021 0.069 $^d$</td>
</tr>
<tr>
<td>F-18</td>
<td>$\beta^+$</td>
<td>634</td>
<td>0.97</td>
<td>5 ml solution in 10 ml syringe</td>
<td>0.60 ± 0.03</td>
<td>0.169 ± 0.049 0.169</td>
</tr>
<tr>
<td></td>
<td>photons</td>
<td>511 $^a$</td>
<td>1.94 $^b$</td>
<td></td>
<td></td>
<td>0.169 ± 0.049 0.169</td>
</tr>
<tr>
<td>Ga-68</td>
<td>$\beta^+$</td>
<td>1899</td>
<td>0.89</td>
<td>5 ml solution in 10 ml syringe</td>
<td>1.00 ± 0.05</td>
<td>0.499 ± 0.146 0.155</td>
</tr>
<tr>
<td></td>
<td>photons</td>
<td>511 $^a$</td>
<td>1.78 $^b$</td>
<td></td>
<td></td>
<td>2.566 ± 0.762 2.566 ± 0.762</td>
</tr>
<tr>
<td>Y-90</td>
<td>$\beta^-$</td>
<td>2280</td>
<td>0.99</td>
<td>Microspheres in 5 ml syringe</td>
<td>1.00 ± 0.05</td>
<td></td>
</tr>
</tbody>
</table>

$^a$ Calculated  $^b$ Measured  $^c$ Otto [19]  $^d$ Average

Monitoring of the lens of the eye: nuclear medicine

Dose rate per activity at 1 m

Dose rate constants for the quantity $H_p(3)$ for frequently used radionuclides in nuclear medicine

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<th>$\gamma$</th>
<th>5 ml solution in 10 ml syringe</th>
<th>$E_{\gamma}$</th>
<th>$E_{\text{max}}$</th>
<th>$P$</th>
<th>$\Gamma(H_p(3))$ in (mSv·m²)/GBq·h</th>
<th>$\nu$</th>
<th>$\mu$</th>
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<td>Capsule</td>
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<td>0.169</td>
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<td>0.035</td>
<td>0.035</td>
<td>5.0</td>
<td>0.021 ± 0.006</td>
<td>0.026</td>
<td>0.026</td>
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<tr>
<td>I-131</td>
<td>$\beta^{\gamma}$</td>
<td>Capsule</td>
<td>1.78 $^{10}$</td>
<td>0.169</td>
<td>0.169 ± 0.116</td>
<td>0.035</td>
<td>0.035</td>
<td>2.566</td>
<td>0.85 ± 0.172</td>
<td>0.085</td>
<td>0.085</td>
</tr>
</tbody>
</table>

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Figure 2: Dose rate constants divided by the average value of the dosimeters on the phantom’s eyes.
Impact of radiation protection means on the dose to the lens of the eye while handling radionuclides in nuclear medicine

Iris Bruchmann®, Bastian Szermerski®, Rolf Behrens®, Lilli Geworaki®

®Department for Radiation Protection and Medical Physics, Medical School Hannover, Carl-Neuberg-Str. 1, 30625 Hannover
®Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig

Figure 1. Set-up with four alderson head phantoms (above) and protection glasses (below); laboratory glasses (left) and X-ray goggles (right).

Figure 2. Nuclide-depending mean reciprocal attenuation factors determined for laboratory glasses and X-ray goggles with $H_p(3)$-dosimeters.
*not investigated

Figure 3. Nuclide-depending mean reciprocal attenuation factors determined for laboratory glasses and X-ray goggles with $H_p(0.07)$-dosimeters.
*not investigated
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Introduction: Why the lens?
Dosimetry in general
Which quantity for the lens of the eye?
Practical and formal aspects
Reactions of international organisations
Conclusions / Challenges
International documents with $H_p(3)$ and / or $H'(3)$

IEC 61331-3: Requirement to medical protective equipment (2014)


IAEA TecDoc 1731: Dosimetry in practice (2013)

IEC 62387: Requirements to dosemeters (passive) (2020)
IEC 61526: Requirements to dosemeters (active) (2010 – in rev.)

ISO 14146: Routine test for dosemeters (2018)
Radiation protection of medical staff from cataract

Frequently asked questions by the health professionals
- Which part of the eye does cataract affect?
- Is cataract caused by ionizing radiation different from that caused by age?
- Is it possible to diagnose radiation-induced eye lens injuries?

Related resources
- Retrospective evaluation of lens injuries and dose study
- Radiation doses in interventional

https://rpop.iaea.org/RPOP/RPoP/Content/InformationFor/HealthProfessionals/6_OtherClinicalSpecialities/radiation-cataract/Radiation-and_cataract.htm
IAEA activities

https://rpop.iaea.org/RPOP/RPoP/Content/InformationFor/HealthProfessionals/6_OtherClinicalSpecialities/radiation-cataract/Radiation-and_cataract.htm

Radiation protection of patients with cataract

Health professionals

- RPOP Home
- Radiology
- Responsibilities of health professionals
- Children
- Pregnant women

Frequently asked questions by the health professionals

- Which X-ray procedures and clinical conditions are associated with elevated eye lens doses to the patient?
- What are typical eye lens doses to patients associated with diagnostic and interventional procedures?
- How can I manage eye lens dose and prevent injuries in patients?
- Which X-ray procedures and clinical conditions are associated with elevated eye lens doses to the patient?
EURADOS activities: ORAMED

https://www.oramed-fp7.eu/en

ORAMED, Optimization of Radiation Protection of Medical Staff

ORAMED aims at the development of methodologies for better assessing and reducing exposures to medical staff for procedures resulting in potentially large doses or complex radiation fields, such as Interventional radiology, nuclear medicine and new developments. We want to concert our efforts to improve and consolidate not only research in this area but also to foster technological transfer and to ensure a good dissemination of our findings.

A consortium of 12 partners from 9 European countries, including research institutes, metrology laboratories, regulator bodies, hospitals and manufacturers, is in charge of the development of the Project, with the collaboration of several hospitals and professional organizations.

This website is one of the main tools to share the new knowledge of the project with end-users and stakeholders and to provide a communication channel to receive comments and proposals from them.

Project start date: February 1, 2006 - Duration: 36 Months

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Physikalisch-Technische Bundesanstalt - Braunschweig and Berlin
Dosimetry of the lens of the eye

13th EURADOS Winter School "Eye lens dosimetry" 2020-01-30 Firenze, Italy

National Metrology Institute of Canada Dr. R. Behrens 28
### Design quantity a) Institution Type Detector type and material Photograph

<table>
<thead>
<tr>
<th>Institution</th>
<th>Type</th>
<th>Detector type and material</th>
<th>Photograph</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMGU</td>
<td>Eye-D™</td>
<td>TLD-100: nat.LiF:Mg,Ti</td>
<td><img src="image" alt="TLD-100" /></td>
</tr>
<tr>
<td>KIT</td>
<td>Augenlinsen-dosimeter</td>
<td>TLD-700: ³LiF:Mg,Ti</td>
<td><img src="image" alt="TLD-700" /></td>
</tr>
<tr>
<td>HMGU</td>
<td>Eye-D™ b)</td>
<td>MCP-Ns: nat.LiF:Mg,Cu,P</td>
<td><img src="image" alt="MCP-Ns" /></td>
</tr>
<tr>
<td>HMGU</td>
<td>AWST-TL-TD 60 (Typ W)</td>
<td>TLD-100: nat.LiF:Mg,Ti</td>
<td><img src="image" alt="TLD-100" /></td>
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<td>HMGU</td>
<td>AWST-TL-TD 70 (Typ X)</td>
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<th>Institution</th>
<th>Type</th>
<th>Detector type and material</th>
<th>Photograph</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPS</td>
<td>LPS-TLD-TD 03</td>
<td>TLD-700: ³LiF:Mg,Ti</td>
<td><img src="image" alt="TLD-700" /></td>
</tr>
<tr>
<td>MPA</td>
<td>MPA-TKD-01 d)</td>
<td>TLD-100: nat.LiF:Mg,Ti</td>
<td><img src="image" alt="TLD-100" /></td>
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<tr>
<td>PDGB</td>
<td>BE-TLD-TD Brille 4)</td>
<td>TLD-100: nat.LiF:Mg,Ti</td>
<td><img src="image" alt="TLD-100" /></td>
</tr>
<tr>
<td>PDMB</td>
<td>BE-TLD-TD Brille</td>
<td>MCP-7s: ³LiF:Mg,Cu,P</td>
<td><img src="image" alt="MCP-7s" /></td>
</tr>
<tr>
<td>PDMB</td>
<td>BE-TLD-TD Photonen 01</td>
<td>MCP-7s: ³LiF:Mg,Cu,P</td>
<td><img src="image" alt="MCP-7s" /></td>
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<tr>
<td>PDMB</td>
<td>BE-TLD-TD Beta-Photonen 3)</td>
<td>MCP-7s: ³LiF:Mg,Cu,P</td>
<td><img src="image" alt="MCP-7s" /></td>
</tr>
</tbody>
</table>

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R. Behrens et al.: *Intercomparison of eye lens dosemeters.*


[https://doi.org/10.1093/rpd/ncw051](https://doi.org/10.1093/rpd/ncw051)
Betas often overestimate (up to a factor of 5000!)

Photons well detected


https://doi.org/10.1093/rpd/ncw051
Participant from 12 nations from 22 IMS (individual monitoring services). Bulgaria, Czech Republic, France, Germany, Israel, Italy, Slovakia, Spain, Switzerland, Turkey, United Kingdom, USA

6 Eye-D™ systems (ORAMED European project)
3 Dosemeters with special badge to wear near the eye
11 Dosemeters in a plastic bag
2 Whole body dosemeters

I. Clairand et al.: EURADOS 2016
intercomparison exercise of eye lens dosemeters.
https://doi.org/10.1093/rpd/ncy067
Dosemeter tests: international (EURADOS)

Betas often overestimate
(up to a factor of 5000!)

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I. Clairand et al.: EURADOS 2016
intercomparison exercise of eye lens dosemeters.
https://doi.org/10.1093/rpd/ncy067
Introduction: Why the lens?
Dosimetry in general
Which quantity for the lens of the eye?
Practical and formal aspects
Reactions of international organisations
Conclusions / Challenges
Conclusions / Challenges

Protection and operational quantities

- Equivalent dose to the lens of the eye, $H_{\text{lens}}$
- Personal dose equivalent to the lens of the eye, $H_p(3)$
- Directional dose equivalent to the lens of the eye at 3 mm depth, $H'(3)$

Calibration, characterization and measurement

Personal monitoring:
- Calibration: on cylinder or slab phantom, only at $\alpha = 0^\circ$
- Characterization at $\alpha \neq 0^\circ$: only on cylinder phantom
- Measurements: close to the eye

Area monitoring:
- Calibration, characterization and measurement „free in air“
- $H'(3)$ dosemeters not yet available

Dosemeter comparison in $H_p(3)$

- Betas often overestimated (up to a factor of 5000!), especially with $H_p(0.07)$ dosemeters
- Photons well detected, also with $H_p(0.07)$ dosemeters

Monitoring

- Obligation to measure on the person if $H_{\text{lens}} > 15 \text{ mSv/year possible}$
- Use of $H_p(3)$ and $H'(3)$ as of 2022 (in Germany – different in other countries) until then in photon fielders also $H_p(0.07)$ and $H'(0.07)$ possible
Literature (with links to each work)

- Conversion coefficients for mono-energetic photons: $\Phi \rightarrow H_{\text{lens}}$: Phys. Med. Biol. 56 (2011) 415
- Compilation of conversion coefficients $\Phi \rightarrow H_{\text{lens}}$: Rad. Prot. Dosim. 174 (2017) 348

  J. Radiol. Prot. 32 (2012) 455 & IRPA13 contribution TS7e.3

- Conversion coefficients for photon spectra: $K_a \rightarrow H_{p}(3)_{\text{slab}}$: Rad. Prot. Dosim. 147 (2011) 373
- Conversion coefficients for photon spectra: $K_a \rightarrow H_{p}(3)_{\text{cyl}}$: Rad. Prot. Dosim. 151 (2012) 450

- $H_{p}(0.07)$ photon dosemeters: Calibration on both rod and slab phantom: Rad. Prot. Dosim. 148 (2012) 139
- Type tests only on cylinder phantom: Rad. Prot. Dosim. 168 (2016) 441

- Beta irradiations in $H_{p}(3)$ and $H'(3)$: Extensions to the Beta Secondary Standard BSS 2: J. Instrum. 6 (2011) P11007 & Erratum & Addendum

- Dosemeter tests: Photon fields: $H_{p}(0.07)$ and $H_{p}(3)$ dosemeters perform well
  Beta fields: $H_{p}(0.07)$ dosemeters overestimate $H_{\text{lens}}$ up to a factor of 5000!

- Nuclear medicine:
Dosimetry of the lens of the eye

Dosimetric units and quantities for eye lens monitoring, standards, type testing, calibration procedures and phantoms

R. Behrens

13th EURADOS Winter School "Eye lens dosimetry" 30th January 2020

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