The renewed attention for eye lens doses to occupationally exposed workers

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presented by A.L. Lebacq¹

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October 2014, Hobart
Outline

- What is radiation induced cataract?
- Recent evolutions: ICRP statement
- How to measure eye lens doses: formalisms
- Occupational eye lens doses: for who is it relevant?
  - Interventional radiology/cardiology
  - Nuclear medicine
  - Correlation with whole body doses
- Monte Carlo simulations for shielding effects
- Conclusion
What is cataract?

- Cataract: “loss of transparency of the lens of the eye”
  - Starts with lens opacities

- Cataract: most frequent cause for blindness worldwide
  - Genetic component
  - Age related effect
  - Additional risk factors include
    - Sunlight, alcohol intake, nicotine consumption, diabetes, use of corticosteroids AND ionising radiation!

- Types of cataract: nuclear, cortical, posterior subcapsular
  - Damaged cells in lens

- Radiation => mainly posterior subcapsular (but not exclusively)
Radiological risks: Eyes: Lens opacities - Cataract

“A cataract is an opacity of the normally clear lens which may develop as a result of aging, metabolic disorders, trauma or heredity.”

or induced by RADIATION!
Epidemiological studies on humans

- Clinical exposure
  - Chodick et al (2008): 36000 radiation technologists over 19 years:
    - risk of cataract rose by 15%/y

- Atomic bomb survivors
  - Nakashima (2006): estimated threshold 0.6 Gy
  - Neriishi et al (2007): estimated threshold 0.1 Gy
    - both not incompatible with 0 Gy threshold

- Chernobyl data
  - Worgul et al (2007): 8500 liquidators: estimated threshold 0.5 Gy

- Commercial and space flight:
Epidemiological studies on humans

Actually: increased attention for medical occupational exposure

- Studies show increased risk of cataracts for hospital based workers
  - O-Cloc study (Jacob, 2012): IRSN, France
    - 106 cardiologists + control group
    - 17% vs. 5% (p<0.05)
  - Vano et al: 2013:
    - 58 physicians, 69 nurses and technicians during congress
    - 50%, 41% vs. <10%

Overall conclusion:
- Clear increased prevalence in cardiology group
- Lens opacities are induced at much lower doses than supposed
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ICRP previous position

- Cataract induction = **deterministic** effect with definite threshold
  - Acute exposure: 0.5 - 2 Gy
  - Prolonged exposure: 5 Gy (detectable opacities)
  - Prolonged exposure: 8 Gy (visual impairment)

- Latency period that can last for decades

- Occupational dose limit: **150 mSv/year**

- Based on studies:
  - not sufficient follow-up time,
  - few subjects below 2 Gy,
  - longer latency time for lower doses not included,...
ICRP position: recent developments

- Recent studies:
  - Better techniques for dosimetry
  - Findings of radiation induced cataract at lower doses
  - No indication that fractionated is less harmful than acute exposure

- ICRP publication 118 (2012)
  - **New eye lens limit: 20 mSv per year**
    (averaged over 5 years with no more than 50 mSv/y)
  - Threshold dose around 5 Gy for acute or fractionated exposure
  - Not certain there is a threshold
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How to measure the eye lens doses?

**Limiting quantity (dose limit)**

\[ H_{T, \text{eyelens}} < 20 \text{ mSv} \]

Equivalent dose at eye lens

**Operational quantity**

\[ H_p(3) < 20 \text{ mSv} \]

Equivalent dose at 3 mm depth

- But \( H_p(3) \) was never used so:
  - No \( H_p(3) \) tabulation and conversion factors in ICRU and ICRP reports
  - No calibration phantom recommended in ISO series
  - No dosemeters are designed/calibrated for \( H_p(3) \)

- Rolf Berens (PTB, Germany) showed in many publications
  - \( H_p(0.07) \) can be used as a good operational quantity for \( H_{T, \text{eyelens}} \)
    - For gamma’s
    - Not for beta’s!
Recently: regained attention to $H_{p}(3)$

- ORAMED: European project 2008-2011
  - Development of type test criteria
  - Development of eye lens dosemeter
  - Proposal of calibration phantom: cylindrical phantom
    - Better reproduction of angular dependence of head
    - Conversion factors calculated for $H_{p}(3)$ and cylindrical phantom

1- ISO (30x30x15cm$^3$) slab calibration phantom
2- Reduced (15x20x20cm$^3$) slab calibration phantom
3- Cylindrical calibration phantom (20 cm diameter, 20 cm height)

- IEC 62387(2012): includes testing for $H_{p}(3)$
FINAL VERSION: COMMERCIALLY AVAILABLE

EYE-D™ dosemeter
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Measurements of eye lens doses: for who is it important?

- No routine measurements are done...

- **Nuclear workers:**
  - UK Central Index of Dose Information, 2004, more than 3 mSv:
  - If $H_p(3)$ similar to $H_p(10)$...
    - nuclear reactor operators, nuclear reactor maintenance, nuclear fuel fabrication, nuclear decommissioning, radioactive waste treatment

- **Air crew:**
  - Effective doses: normally below the annual dose limit of 20 mSv.
  - Due to the homogeneity of the radiation field: dose to the lens of the eyes assumed to be similar to $E$.

- **Hospital staff:**
  - largest groups of workers potentially affected by the reduction in the dose limit for the lens of the eye:
    - image-guided interventional procedures,
    - nuclear medicine: preparation of sources/radiopharmaceuticals, PET/CT,
    - manual brachytherapy,
    - CT-guided biopsy,
    - Cyclotron engineers.
ORAMED: Optimization of Radiation Protection for Medical Staff: European FP7 project (02/2008-02/2011)

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11°. Radcard, Poland
    S. Wach, P. Kocjan

12°. MGP Intruments (MGPi), France
    P. Martin, JL. Barrère

www.oramed-fp7.eu
Medical staff involved in **interventional procedures**

- **Work close to the X-ray beam**
- **Exposed to the radiation scattered by the patient**
Measurement campaign for interventional procedures

- 6 different countries
- 3 hospitals per country
- 8 types of procedures
- 10 measurements/type of procedure/hospital

**Interventional Cardiology:**
- CA and PTCA
- RF Ablations (RFA)
- Pacemakers and Cardiac Defibrillator Implantations (PM/CD)

**Interventional Radiology:**
- Angiography (DSA)/Angioplasty (PTA)
  - Lower limbs (LL)
  - Carotids and Brain (C/B)
  - Renal
- Embolisations
- Endoscopic retrograde cholangiopancreatography procedures (ERCP)

3 Cardiology
5 Radiology
>1300 measurements
TL dosemeters were placed at 8 measurements positions:

- Two measurements for eye lens dose
  - Between eyes
  - Left/right eye (tube location)
- TLD in bag
- Calibrated in $H_p(0.07)$
Statistics in interventional **cardiology** with the use of the personal protective equipment

- **36%** used protective glasses in IC

![Diagram showing the use of personal protective equipment in interventional cardiology](image-url)
Statistics in interventional radiology
Personal and Room protective equipment

Percentage of personal protection

- Lead apron, lead collar, glasses: 25%
- Lead apron: 12%
- Lead apron, lead collar: 62%
- None: 1%

25% used protective glasses in IR
ORAMED results:
Comparison of different procedures

- Highest eye lens doses in embolisations
- Median around 60 $\mu$Sv/per procedure

$H_p(0.07)$ (mSv)
ORAMED results: Comparison of different procedures

- L/R eye always higher than between eyes
- Some very high values/procedure
Eye lens dose per KAP (Kerma in Air Product)

- Highest eye lens doses in PM (per KAP)

![Box plot showing eye lens dose per KAP for different procedures.](image)
Extrapolation to annual eye lens doses

- Use of annual workload (# procedures)
  - From logbook
  - From personal contact

- Multiplied with average doses measured

- Often underestimation, because they perform other procedures that are not measured
### Annual doses ERCP:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Procedure</th>
<th># procedures</th>
<th>Annual dose [mSv]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ERCP</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>ERCP</td>
<td>107</td>
<td>3,9</td>
</tr>
<tr>
<td>3</td>
<td>ERCP</td>
<td>30</td>
<td>0,3</td>
</tr>
<tr>
<td>4</td>
<td>ERCP</td>
<td>70</td>
<td>0,6</td>
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<tr>
<td>5</td>
<td>ERCP</td>
<td>110</td>
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<tr>
<td>6</td>
<td>ERCP</td>
<td>100</td>
<td>0,2</td>
</tr>
<tr>
<td>7</td>
<td>ERCP</td>
<td>300</td>
<td>0,4</td>
</tr>
<tr>
<td>8</td>
<td>ERCP</td>
<td>1281</td>
<td>17</td>
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<td>9</td>
<td>ERCP</td>
<td>689</td>
<td>6</td>
</tr>
<tr>
<td>10</td>
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<td>70</td>
<td>0,7</td>
</tr>
<tr>
<td>11</td>
<td>ERCP</td>
<td>107</td>
<td>5</td>
</tr>
<tr>
<td>12</td>
<td>ERCP</td>
<td>250</td>
<td>2</td>
</tr>
<tr>
<td>13</td>
<td>ERCP</td>
<td>125</td>
<td>1,2</td>
</tr>
<tr>
<td>14</td>
<td>ERCP</td>
<td>150</td>
<td>1,4</td>
</tr>
<tr>
<td>15</td>
<td>ERCP</td>
<td>230</td>
<td>2</td>
</tr>
<tr>
<td>16</td>
<td>ERCP</td>
<td>36</td>
<td>3,4</td>
</tr>
<tr>
<td>17</td>
<td>ERCP</td>
<td>150</td>
<td>9</td>
</tr>
</tbody>
</table>
## Annual doses CA/PTCA:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Procedure</th>
<th># procedures</th>
<th>Annual dose [mSv]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CA/PTCA</td>
<td>260</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>CA/PTCA</td>
<td>230</td>
<td>28</td>
</tr>
<tr>
<td>3</td>
<td>CA/PTCA</td>
<td>750</td>
<td>47</td>
</tr>
<tr>
<td>4</td>
<td>CA/PTCA</td>
<td>1200</td>
<td>69</td>
</tr>
<tr>
<td>5</td>
<td>CA/PTCA</td>
<td>1000</td>
<td>46</td>
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<td>6</td>
<td>CA/PTCA</td>
<td>710</td>
<td>10</td>
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<td>7</td>
<td>CA/PTCA</td>
<td>900</td>
<td>26</td>
</tr>
<tr>
<td>8</td>
<td>CA/PTCA</td>
<td>600</td>
<td>11</td>
</tr>
<tr>
<td>9</td>
<td>CA/PTCA</td>
<td>630</td>
<td>11</td>
</tr>
<tr>
<td>10</td>
<td>CA/PTCA</td>
<td>630</td>
<td>12</td>
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<tr>
<td>11</td>
<td>CA/PTCA</td>
<td>500</td>
<td>5</td>
</tr>
<tr>
<td>12</td>
<td>CA/PTCA</td>
<td>1000</td>
<td>27</td>
</tr>
<tr>
<td>13</td>
<td>CA/PTCA</td>
<td>500</td>
<td>30</td>
</tr>
<tr>
<td>14</td>
<td>CA/PTCA</td>
<td>600</td>
<td>9</td>
</tr>
<tr>
<td>15</td>
<td>CA/PTCA</td>
<td>1100</td>
<td>9</td>
</tr>
</tbody>
</table>

Half are above 20 mSv !!!
## Annual doses both PM&ICD and RF ablations:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Procedure</th>
<th># procedures</th>
<th>Annual dose [mSv]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PM&amp;ICD+RF abl</td>
<td>150+60</td>
<td>88+63</td>
</tr>
<tr>
<td>2</td>
<td>PM&amp;ICD+RF abl</td>
<td>190+190</td>
<td>24+13</td>
</tr>
<tr>
<td>3</td>
<td>PM&amp;ICD+RF abl</td>
<td>90+190</td>
<td>25+7</td>
</tr>
<tr>
<td>4</td>
<td>PM&amp;ICD+RF abl</td>
<td>110+50</td>
<td>0.8+1.5</td>
</tr>
<tr>
<td>5</td>
<td>PM&amp;ICD+RF abl</td>
<td>40+20</td>
<td>4+0.1</td>
</tr>
<tr>
<td>6</td>
<td>PM&amp;ICD+RF abl</td>
<td>40+20</td>
<td>7+0</td>
</tr>
<tr>
<td>7</td>
<td>PM&amp;ICD+RF abl</td>
<td>80+350</td>
<td>1+5</td>
</tr>
</tbody>
</table>
### Annual doses Embolizations and DSA:
often combinations different type of procedures

<table>
<thead>
<tr>
<th>Operator</th>
<th>Annual dose [mSv]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27</td>
</tr>
<tr>
<td>2</td>
<td>23</td>
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<tr>
<td>3</td>
<td>6</td>
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<tr>
<td>4</td>
<td>4</td>
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<td>5</td>
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<td>11</td>
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<td>14</td>
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<td>13</td>
<td>20</td>
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<tr>
<td>14</td>
<td>49</td>
</tr>
<tr>
<td>15</td>
<td>85</td>
</tr>
<tr>
<td>16</td>
<td>9</td>
</tr>
</tbody>
</table>
Influence factors for eye lens doses
Shielding: room protective equipment

Ceiling suspended shield

Transparent in arc shape
ERCP: ceiling shield important for tube above: Factor 5 to 8 dose reduction

Effect of ceiling suspended shield to the eyes

- median
- average

ERCP: ceiling shield important for tube above: Factor 5 to 8 dose reduction
Embolisations: ceiling shield important: Factor 3 to 7 dose reduction
CA/PTCA: ceiling shield important: Factor 1.5 to 2.5 dose reduction

Positioning of the shield is difficult but has a big influence on the shield effectiveness
Effect of “going out during image acquisition” for IR procedures (ERCP not incl.)

There is a significant effect of the “going out” parameter in reducing the doses in all dosimetric positions examined.
Eye lens doses in nuclear medicine

• Very few data available
  • Large individual variability
  • Largely dependent on workload and procedural technique

  • Ratio $H_p(10)/H_p(3)$:
    • Scintigraphy: $1,1 \pm 0,2$
    • PET: $0,9 \pm 0,5$

  • Typical yearly workload: (Tc-$99m$ and I-$131$):
    • around $4,5 \text{ mSv}$

  • Typical yearly workload: (Tc-$99m$ and I-$131$):
    • around $8 \text{ mSv}$
Eye lens doses in nuclear medicine
In Belgium (measurements still ongoing)

- 6 hospitals
- 25 operators (preparation + administration)
- Mainly Tc-99m, F-18 (also Ga-68, I-123, I-131,...)
- 1 working week measurements -> extrapolation to annual dose

Eye lens dose (Headband or glasses)
  • Left/right eye

Whole-body dose
  • chest
Yearly eye lens dose in nuclear medicine

Weekly dose extrapolated to **annual** dose based on annual workload

European BSS: monitoring when risk exists to get a dose > 3/10th of dose limit
Radiation workers: too many dosemeters?

- Interventionalists: need to wear..
  - Legally:
    - Whole body dosemeter above lead apron
    - Whole body dosemeter under lead apron
    - Extremity (ring) dosemeter
  - Optional:
    - Feet dosemeter
    - Active dosemeter
  - Now extra: eye lens dosemeter..
  - Like a Christmas tree full of dosemeters...

- Is there a correlation between whole body dosemeter (above apron) and eye lens doses?
  - Could be option for monitoring
NM: Correlation eye lens - whole body dose
(weekly dose)

$H_p(10) = H_p(3)$

$R^2 = 0.3809$

Poor correlation!
Whole-body dose to monitor eye dose not recommended
IC procedures: Correlation whole body dose and eye lens doses

Assessment of eye lens doses from whole body doses?
ELDO project: DoReMi funded project

- Extensive measurement campaign
  - Considering all typical clinical conditions for cardiology procedures (beam energy, projection, position operator, ...)
  - Without protection equipment
  - For different positions of the whole body dosimeter (above lead apron)

Result:
ratio [eye lens dose/whole body dose] and associated uncertainty
## Results ELDO project

### Assessment of eye lens dose from whole body dose?

- Ratio of average left eye lens dose and whole body dose measured at different locations, considering all projections and access routes:

<table>
<thead>
<tr>
<th>Left eye</th>
<th>Collar</th>
<th>Collar</th>
<th>Collar</th>
<th>Chest</th>
<th>Chest</th>
<th>Chest</th>
<th>Waist</th>
<th>Waist</th>
<th>Waist</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L</td>
<td>M</td>
<td>R</td>
<td>L</td>
<td>M</td>
<td>R</td>
<td>L</td>
<td>M</td>
<td>R</td>
</tr>
<tr>
<td>Ratio</td>
<td>3.3</td>
<td>2.1</td>
<td>11.5</td>
<td>0.8</td>
<td>1.2</td>
<td>2.5</td>
<td>1.5</td>
<td>1.8</td>
<td>8.0</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>42%</td>
<td>48%</td>
<td>81%</td>
<td>90%</td>
<td>73%</td>
<td>100%</td>
<td>159%</td>
<td>143%</td>
<td>147%</td>
</tr>
</tbody>
</table>

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**Best correlation**

Extensive *simulation campaign*: correction for
- different types of lead glasses
- different types and positions of ceiling shields
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Why use Monte Carlo simulations

- During IR procedures many parameters influence operators’ doses.

- In clinical practice it is impossible to study each parameter separately, as many of them change simultaneously.

- Assessing the influence of each parameter is very important in order to provide specific guidelines concerning the radiation protection of the staff involved in IR procedures.
Methodology Monte Carlo study

- Simulation study (MCNP-X), considering
  - Different models of lead glasses
    - Lead thicknesses
    - Sizes of the glasses
    - How they fit on the face
  - Different exposure conditions typical for FGI procedures
    - Variation in beam energy
    - Variation in beam projections, including mono and bi-plane configurations
    - Position of the operator (distance from radiation field AND rotation of the body)
  - Investigation of the origin of the scattered photons reaching the eyes

- Image intensifier
- Lead apron
- Operator
- Patiënt
Methodology Monte Carlo study

- 2 basic models

  L1
  ‘Wrap around’ model with 0,5 mm Pb

  L2
  ‘square’ model with 0,75 mm Pb (front) + 0,3 mm Pb (side)

  L2’
  Glasses 10° tilted towards the head
Results of the Monte Carlo study

1. Protection efficiency = \[
\frac{\text{eye lens dose with lead glasses}}{\text{eye lens dose without lead glasses}}
\]

=> smaller value = better protection efficiency

<table>
<thead>
<tr>
<th></th>
<th>Left eye</th>
<th>Right eye</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>0,13</td>
<td>0,76</td>
</tr>
<tr>
<td>L2</td>
<td>0,56</td>
<td>0,64</td>
</tr>
<tr>
<td>L2'</td>
<td>0,43</td>
<td>0,54</td>
</tr>
</tbody>
</table>

- Left eye closer to the beam
- Averaged over all beam projections
- Operator at 70 cm of X-ray field
2. **Origin of scattered radiation: Proportion through unprotected parts**

### Left eye

- **PA**: 62%
- **LLAT L1**: 64%
- **RLAT**: 65%
- **PA**: 12%
- **LLAT L2**: 8%
- **RLAT**: 71%

### Right eye

- **PA**: 34%
- **LLAT L1**: 63%
- **RLAT**: 13%
- **PA**: 11%
- **LLAT L2**: 58%
- **RLAT**: 52%

- **Gap beneath the glasses**
- **Scattered from head**
- **Gap between the glasses**
### Results of the Monte Carlo study

- **Space between glasses and head**
  - *L1*
    - 0.5 cm gap
    - 1.0 cm gap
    - 1.5 cm gap
  - Reference

<table>
<thead>
<tr>
<th>Left eye</th>
<th>PA</th>
<th>0.15</th>
<th>0.27</th>
<th>0.47</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LLAT</td>
<td>0.12</td>
<td>0.32</td>
<td>0.55</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Right eye</th>
<th>PA</th>
<th>0.41</th>
<th>0.77</th>
<th>0.96</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LLAT</td>
<td>0.75</td>
<td>0.94</td>
<td>0.98</td>
</tr>
</tbody>
</table>
Results of the Monte Carlo study

- **Rotation of the body**

<table>
<thead>
<tr>
<th>Thorax irradiation; operator at 70 cm</th>
<th>Dose with/without glasses</th>
<th>Left eye</th>
<th>Right eye</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>L1</strong></td>
<td><strong>PA</strong></td>
<td>Towards tube</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Away from tube</td>
<td>0.42</td>
</tr>
<tr>
<td><strong>L2</strong></td>
<td><strong>LLAT</strong></td>
<td>Towards tube</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Away from tube</td>
<td>0.81</td>
</tr>
</tbody>
</table>

- Protection efficiency of glasses decreases if turned away from tube

- Rotation also influences eye lens dose without protection:
  - Eye lens dose decreases if turned away from tube
# Results of the Monte Carlo study

- **Thickness of lead**

<table>
<thead>
<tr>
<th></th>
<th>L1</th>
<th></th>
<th>L2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PA</td>
<td>LLAT</td>
<td>PA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0,35 mm</td>
<td>0,35 mm</td>
<td>0,75/0,3 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0,5 mm</td>
<td>0,5 mm</td>
<td>0,35/0,35 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0,35 mm</td>
<td>0,5 mm</td>
<td>0,75/0,7 mm</td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>0,17</td>
<td>0,13</td>
<td>0,63</td>
<td>0,66</td>
</tr>
<tr>
<td>Right</td>
<td>0,91</td>
<td>0,97</td>
<td>0,77</td>
<td>0,82</td>
</tr>
</tbody>
</table>

- **Minimal effect for variation of thickness of lead glasses**

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SCK-CEN
Conclusion

- Considering ALL parameters, the average protection efficiency:
  - L1:
    - Left eye: 0.26 +/- 63%
    - Right eye: 0.79 +/- 30%
  - L2:
    - Left eye: 0.60 +/- 39%
    - Right eye: 0.69 +/- 39%

- Difference in protection of left and right eye for L1
  BUT actual dose received by right eye is also lower than left eye

- Protection of the eye depends on
  - Type of lead glasses (shape, how it fits, thickness)
  - The working procedure (beam projections, positions of the operator)
Renewed attention to eye lens doses
- Clear evidence that there is a risk at lower doses
- Dose limit has been reduced to 20 mSv/year

Several professional groups at risk
- Mainly data on interventional radiologists and cardiologists

New BSS:
- Need for protection and monitoring
- Need for $H_p(3)$ dosemeters

Correlation with whole body dosemeter is not best solution

Eye lens doses dependent on work load and protection measures
- There are effective ways of reducing the doses
- Well positioned ceiling shield reduces the eye lens doses significantly
- Tube below gives lower eye lens doses

Lead glasses reduce with factor 3 to 8: not zero!
Exceptional extension abstracts deadline for ARPS: Monday 3rd of November 2014 - 6.00pm