Dosimetry for epidemiologic studies of medical workers

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1. Background
   - Dosimetric quantities
   - Occupational dose limits
   - Monitoring devices

2. Dose reconstruction
   - Badge dose reconstruction
   - Organ dose reconstruction

3. Existing dosimetry studies

4. Conclusions
Background
Dosimetric quantities

- Operational quantities ≠ protection quantities

**Physical quantities**
- Fluence, $\Phi$
- Kerma, $K$
- Absorbed dose, $D$

**Operational Quantities (ICRU)**
- Ambient dose equivalent, $H^*(d)$
- Directional dose equivalent, $H'(d,\Omega)$
- Personal dose equivalent, $H_P(d)$

**Protection Quantities (ICRP)**
- Organ absorbed dose, $D_T$
- Organ equivalent dose, $H_T$
- Effective dose, $E$

Measurable

Estimated
Dosimetric quantities (2)

- **Operational quantities**
  - *Personal dose equivalent, $H_p(d)$* for *individual monitoring*

Dose equivalent in ICRU (soft) tissue at an appropriate depth, $d$, below a specified point on the human body.

<table>
<thead>
<tr>
<th>$d = 10 \text{ mm}$</th>
<th>$d = 3 \text{ mm}$</th>
<th>$d = 0.7 \text{ mm}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole Body</td>
<td>Eye lens</td>
<td>Shallow tissues</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(skin and extremities)</td>
</tr>
<tr>
<td>Deep dose equivalent</td>
<td>Lens dose equivalent</td>
<td>Shallow dose equivalent</td>
</tr>
</tbody>
</table>
Occupational dose limits

- As Low As Reasonably Achievable (A.L.A.R.A. principle)
  - Time
  - Distance
  - Shielding

- Radiation protection: monitoring the individual radiation dose to ensure the radiation exposure remains A.L.A.R.A.

- Administrative controls: focus on the exposure (usually) over 10% of the established occupational regulatory limits
Occupational dose limits (2)

- Recommendations from the International Commission on Radiological Protection

<table>
<thead>
<tr>
<th>Annual occupational dose limits for adults</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective dose, Lens dose equivalent</td>
</tr>
<tr>
<td>Shallow dose equivalent (skin, hands, feet)</td>
</tr>
</tbody>
</table>

- International Basic Safety Standards (IAEA & WHO)

- Regulations applied by country
Monitoring devices (1)

- Individual passive dosimeters
  - No direct readout
  - No external source of energy needed to operate
  - Estimate an exposure received over time

- Types of passive dosimeters
  - Dosifilms, also called film badges (< 2000s)
  - Thermoluminescent dosimeters (TLD)
  - Optically stimulated luminescent dosimeters (OSL) (> 2000s)
Monitoring devices (2)

- Various minimum detection levels
  - Below these limits, the readings are reported as zero

- Different providers
  - Landauer, DosiLab, Mirion, IRSN, etc.

- Various locations
  - Chest/waist/collar for deep-dose equivalent
  - Finger for shallow-dose equivalent (ring dosimeters)
  - Over/underneath the lead apron
Dose reconstruction
Badge dose reconstruction

- **1\textsuperscript{st} challenge:** badge dose records not always available

Different scenarios:

1. No badge doses for the whole cohort
   ⇒ imputation only based on literature and work history

2. Badge doses missing for some subjects among the cohort
   ⇒ imputation based on work history and badge dose records from other subjects

3. Most of badge doses available but some records missing
   ⇒ imputation based on work history and badge dose records from the same subject
Badge dose reconstruction (2)

- **2nd challenge:** work history not always available or detailed enough
  - High uncertainty on the literature-based dose estimates
  - Difficult identification of missing badges or badges not worn
  - No information on the type of procedures performed
    - Main photon energies, geometry of irradiation
  - No information on the usage of a protective apron
Badge dose reconstruction (3)

- Remaining uncertainties
  - Were the dosimeters worn during all periods of radiation exposure? (workers’ compliance)
    - Specific issue observed with FGI staff, mostly
  - Were the dosimeters worn at the point of highest exposure?
  - Were the dosimeters worn underneath or over the protective apron?
  - How much exposure below the limits of detection?
  - Uncertainty on the dose estimates obtained through interpolation
Organ dose reconstruction

\[ D_T = H_P(d) \times DF \]

Absorbed dose to the organ or tissue \( T \) (Gy)

Personal dose equivalent (Sv)

Dose conversion factor (Gy/Sv)
Organ dose reconstruction (2)

- Dose conversion factors

  - Depend on various parameters:
    - Dominant photon energy
    - Geometry of irradiation
    - Badge location
    - Apron usage

  - Use of tables of pre-computed dosimetry values
Organ dose reconstruction (3)

Tissue absorbed dose per unit of air kerma free-in air (Gy/Gy)

\[
DF = \frac{D_T}{H_P(d)} = \frac{D_T}{K_a} \left/ \frac{H_P(d)}{K_a} \right.
\]

Personal dose equivalent per unit of air kerma free-in air (Sv/Gy)
Organ dose reconstruction (4)

1. Tables of pre-computed values of personal dose equivalent per unit of air kerma free-in air (Sv/Gy), for various energies and geometries of exposure

Example: for an antero-posterior exposure, without apron

<table>
<thead>
<tr>
<th>$H_p(d)/K_a$</th>
<th>30 keV</th>
<th>50 keV</th>
<th>80 keV</th>
<th>150 keV</th>
<th>500 keV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d = 0.7 \text{ mm}$</td>
<td>1.230</td>
<td>1.632</td>
<td>1.732</td>
<td>1.518</td>
<td>1.244</td>
</tr>
<tr>
<td>$d = 10 \text{ mm}$</td>
<td>1.112</td>
<td>1.766</td>
<td>1.903</td>
<td>1.607</td>
<td>1.256</td>
</tr>
</tbody>
</table>
Organ dose reconstruction (5)

2. Pre-computed values of organ/tissue absorbed dose per unit of air kerma free-in-air (Gy/Gy), for various energies

\[ D_{\text{Skin}}/K_a \text{ for } ^{67}\text{Ga} \]

Influence of energy:
- \( D_{\text{Skin}}/K_a \) for \(^{67}\text{Ga}\)
2. Pre-computed values of organ/tissue absorbed dose per unit of air kerma free-in-air (Gy/Gy), for various energies

Influence of energy:
- \( D_{\text{Skin}}/K_a \) for \(^{67}\text{Ga}\)
- \( D_{\text{Lungs}}/K_a \) for \(^{99m}\text{Tc}\)

Simon et al. *Health Phys*, 2011
ICRP Publication 74, 1996
ICRP Publication 118, 2010
Organ dose reconstruction (6)

2. Pre-computed values of organ/tissue absorbed dose per unit of air kerma free-in-air (Gy/Gy), for various energies

- DRBM/Ka for PET isotopes
- DLungs/Ka for 99mTc
- DSkin/Ka for 67Ga

Influence of energy:
- DSkin/Ka for 67Ga
- DLungs/Ka for 99mTc
- DRBM/Ka for PET isotopes

Simon et al. *Health Phys*, 2011
ICRP Publication 74, 1996
ICRP Publication 118, 2010
Existing dosimetry studies of medical workers
Existing dosimetry studies of medical workers

Most of the epidemiologic studies of medical workers do not report individual dosimetry, except from:

- Canadian medical workers
- U.S. radiologic technologists
- Korean medical workers
- Chinese x-ray technologists
- Danish radiation therapy workers
- Japanese radiologic technologists
Existing dosimetry studies of medical workers (2)

- Canadian cohort study of medical workers
  - 67,562 workers
  - Time period: 1951–1987
  - Badge dose records from the National Dose Registry of Canada
  - No work history
  - Annual and cumulative whole body dose ($H_p(10)$)
  - No organ doses

Existing dosimetry studies of medical workers (3)

- U.S. radiologic technologists cohort study
  - 110,374 workers
  - Time period: 1916–1997
  - Badge dose records from Landauer, Inc. (mostly)
  - Work history from 3 surveys
  - Statistical simulation of various configurations
  - Annual and cumulative personal dose equivalents
  - Doses to 12 organs and tissues
Existing dosimetry studies of medical workers (4)

- Korean medical workers
  - 94,396 workers
  - Time period: 1996–2011
  - Badge dose records from the centralized national dose registry
  - Detailed work history from a survey (2012)
  - Dose reconstruction model based on 8,167 medical workers
  - Deterministic dosimetry system (single estimates)
  - Doses to 7 organs and tissues
Existing dosimetry studies of medical workers (5)

- Chinese X-ray technologists
  - 27,011 workers
  - Time period: 1950–1995
  - No badge dose records
  - Occupational history survey (from 3,545 workers)
  - $H_P(0.07)$ and $H_P(10)$ estimates
    - model validated on 10 monitored workers
  - Doses to 5 organs and tissues

Sun et al. *Int. J. Cancer*, 2016
Existing dosimetry studies of medical workers (6)

- Danish radiation therapy workers
  - 4151 workers
  - Time period: 1954–1982
  - Badge dose records (kept locally before 1975 then centralized at the National Institute of Radiation Hygiene)
  - No work history
  - Annual and cumulative skin doses (then converted to $H_p(10)$)
  - No organ doses
Existing dosimetry studies of medical workers (7)

- Japanese radiologic technologists
  - 12,195 workers
  - Time period: 1969–1993
  - Dose reconstruction for 3,461 workers with work history and relatively high doses
  - Dose reconstruction model tested on 1,069 workers with work history and self-reported doses
    - No good correlation between reconstructed and self-reported doses
    - Individual film badge doses proven to be necessary

Yoshinaga et al. *J. Epidemiol*, 1999
Conclusions
Some challenges specific to medical workers

- Non-uniform exposures
  - Various positions of the workers

- Various energies possibly involved

- Higher proportion of women than in other radiation fields
  - Majority of female workers among the U.S. radiologic technologists
  - Additional doses to estimate (breast, reproductive organs, fetus)
  - Dose-response observed for female breast cancer
Take home message

What do we need for a good dosimetry study of medical radiation workers

<table>
<thead>
<tr>
<th>Detailed work history</th>
<th>Comprehensive badge dose records</th>
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<tbody>
<tr>
<td>Types of procedures</td>
<td>Annual dose records</td>
</tr>
<tr>
<td>Types of radionuclides for NM</td>
<td>Number of readings</td>
</tr>
<tr>
<td>Precise badge location</td>
<td>Monthly dose records</td>
</tr>
<tr>
<td>Radiation safety practices</td>
<td></td>
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Quiz (1)

- Personal dose equivalent $H_P(d)$ is:

A. A physical quantity
B. An operational quantity
C. A protection quantity
Quiz

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A. A physical quantity
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Quiz (2)

- Effective dose is used as a surrogate of the personal dose equivalent

A. True
B. False
Quiz (2)

- Effective dose is used as a surrogate of the personal dose equivalent

  A. True
  B. False
Quiz (3)

- Organ dose estimates depend on:

  A. Badge dose records
  B. Photon energy spectrum
  C. Geometry of irradiation
  D. Radiation safety practices
  E. All of the above
Quiz (3)

- Organ dose estimates depend on:
  
  A. Badge dose records  
  B. Photon energy spectrum  
  C. Geometry of irradiation  
  D. Radiation safety practices  
  E. All of the above