Dosimetry for epidemiologic studies of medical workers

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Agenda

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, Φ
- Kerma, K
- Absorbed dose, D

Measurable

Operational Quantities (ICRU)

- Ambient dose equivalent, H*(d)
- Directional dose equivalent, H'(d,Ω)
- *Personal dose equivalent,* $H_P(d)$

Estimated

Protection Quantities (ICRP)

- *Organ absorbed dose, D_T*
- Organ equivalent dose, H_T
- Effective dose, E

ICRP Publication 74, 1996

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.

d = 10 mm	**d = 3 mm**	**d = 0.7 mm**
Whole Body	Eye lens	Shallow tissues (skin and extremities)
Deep dose equivalent	Lens dose equivalent	Shallow dose equivalent

ICRU Report 51, 1993

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

Annual occupational dose limits for adults

Effective dose, Lens dose equivalent	20 mSv/year over 5 years No single year > 50 mSv
Shallow dose equivalent (skin, hands, feet)	500 mSv

- International Basic Safety Standards (IAEA & WHO)
- Regulations applied by country

ICRP Publication 103, 2007
ICRP Publication 118, 2012

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

- **1st 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

$$D_T = H_P(d) * DF$$

Absorbed dose to the organ or tissue T (Gy)

Personal dose equivalent (Sv)

Dose conversion factor (Gy/Sv)

ICRP Publication 74, 1996

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)

$$DF = \frac{D_T}{H_P(d)} = \frac{D_T}{K_a} \Big/ \frac{H_P(d)}{K_a}$$

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

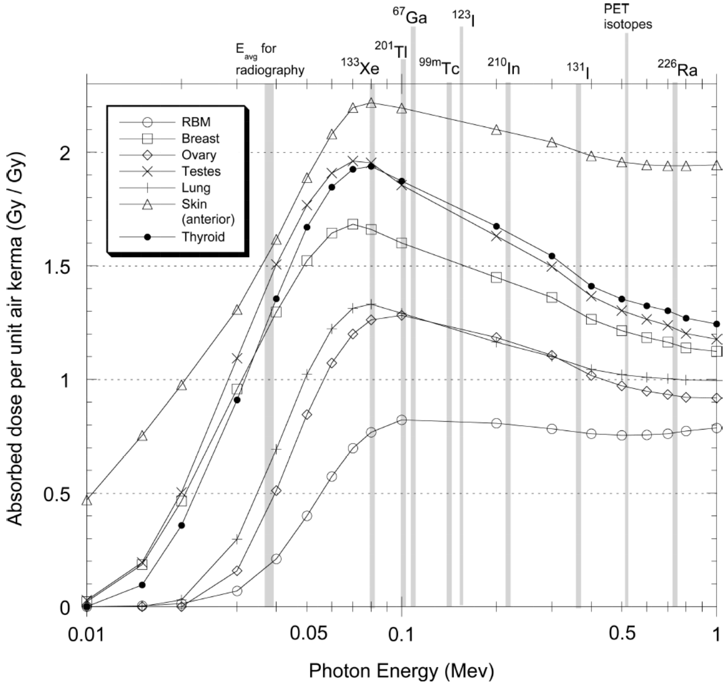
$H_P(d)/K_a$	30 keV	50 keV	80 keV	150 keV	500 keV
d = 0.7 mm	1.230	1.632	1.732	1.518	1.244
d = 10 mm	1.112	1.766	1.903	1.607	1.256

ICRP Publication 74, 1996

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

x 1.38



Influence of energy:

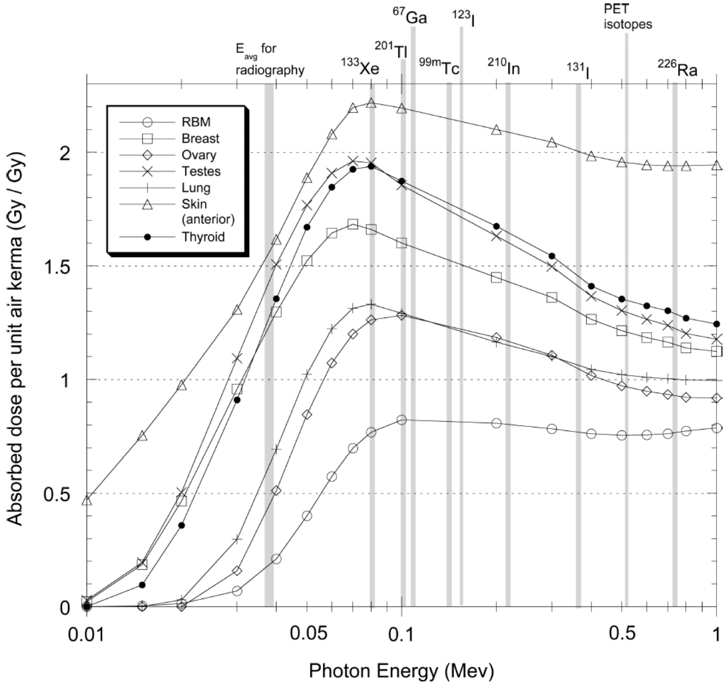
- D_{Skin}/K_a for ^{67}Ga

Simon et al. *Health Phys*, 2011
ICRP Publication 74, 1996
ICRP Publication 118, 2010

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

x 1.75



Influence of energy:

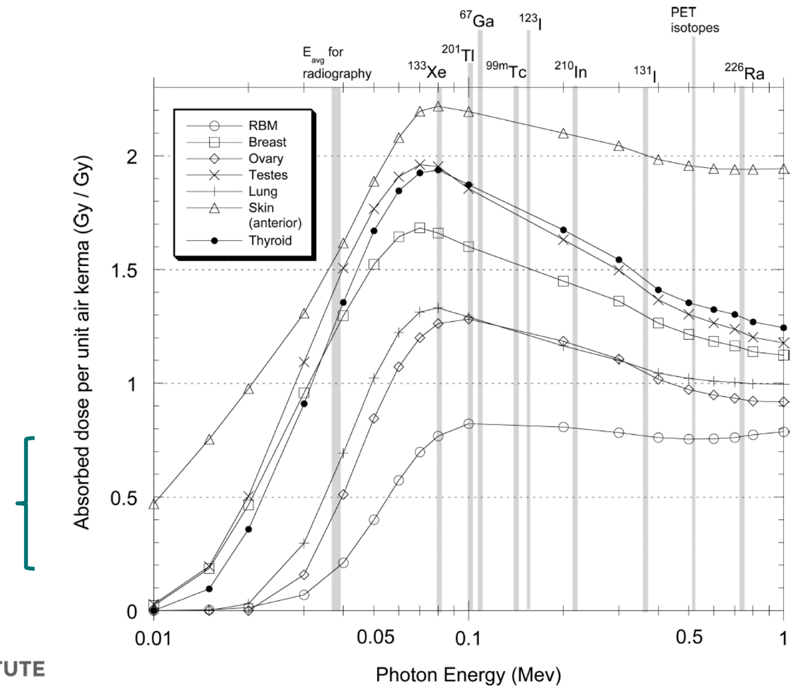
- D_{Skin}/K_a for ^{67}Ga
- D_{Lungs}/K_a for ^{99m}Tc

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

x 4



Influence of energy:

- D_{Skin}/K_a for ^{67}Ga
- D_{Lungs}/K_a for ^{99m}Tc
- D_{RBM}/K_a 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

Zielinski et al. *Int J Occup Med Environ Health*, 2009
Ashmore et al. *Am J Epidemiol*, 1998
Sont et al. *Am J Epidemiol*, 2001

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

Simon et al. *Radiat Res*, 2006
Simon et al. *Radiat Res*, 2014

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

Choi et al. *J Prev Med Public Health*, 2016
Choi et al. *Radiat Prot Dosimetry*, 2018
Lee WJ et al. *Environ. Health*, 2019

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

Zhang et al. *Radiat Prot Dosimetry*, 1998
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. *Radiat Prot Dosimetry*, 1998
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

Preston et al. *Br J Cancer*, 2016

Take home message

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

Detailed work history	+	**Comprehensive badge dose records**
Types of procedures		Annual dose records
Types of radionuclides for NM		Number of readings
Precise badge location		⬇
Radiation safety practices		Monthly dose records

Quiz

Quiz (1)

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

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

Quiz

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

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

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)

- Organan 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

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