Biokinetic Models and Dose Coefficients for Internal Exposure

ICRP Symposium on Radiological Protection Dosimetry

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Topics

• Publications providing internal dose coefficients
• Biokinetic models and developments
• New Publications and data
• Inhaled radon as a special case
• Scientific application of ICRP biokinetic models
ICRP Recommendations

Publication 26  ICRP 1977
Publication 60  ICRP 1991
Publication 103  ICRP 2007
ICRP dose coefficients, Sv/Bq

Committed equivalent and effective dose

- Inhalation or ingestion
- Workers and public
- Adults, children, fetus, breast-fed infant
Occupational exposures

Dose coefficients relating to the 1977 Recommendations
(Publication 26)

*Publication 68* (ICRP, 1994)
Revised dose coefficients following 1990 Recommendations
(Publication 60) with some revised models

*Publications 54 and 78* (ICRP, 1988, 1997)
Bioassay data for interpretation of measurements
Public exposures


*Publication 88 and 95 (ICRP, 2001, 2004)* Dose coefficients for the embryo and fetus, and breast-fed infant following intakes by the mother
Recent Publications

**Publication 119** Compendium of Dose Coefficients based on ICRP Publication 60. Ann ICRP 41 (Supp1) 2012

Biokinetic models

• Respiratory tract
• Alimentary tract
• Systemic models for each element / group
  - simple eg. tritium, caesium-137
  - complex eg. strontium-90, plutonium-239
Human Respiratory Tract Model

Extrathoracic airways

Bronchial

Bronchiolar

Alveolar interstitial
Particle transport model

- **Anterior nasal**
  - Naso-oro-pharynx-larynx
  - L\textsubscript{ET}
  - ET\textsubscript{seq}
  - ET\textsubscript{1} 1 d
  - GI tract

- **Extrathoracic**
  - ET\textsubscript{2}' 10 min

- **Thoracic**
  - LN\textsubscript{TH}
  - LN\textsubscript{ET}
  - BB\textsubscript{seq}
  - BB\textsubscript{2}
  - BB\textsubscript{1}
  - Al\textsubscript{3}, Al\textsubscript{2}, Al\textsubscript{1}

- **Alveolar interstitial**
  - 20 yr 2 yr 30 d

**Clearance half-times**
Al Retention: new data

![Graph showing lung retention over time for different groups.](image)

- Cobalt-60 group
- PuO₂ group
- New HRTM
- Kuempel
- ICRP 66
Human Alimentary Tract Model

Publication 30 (ICRP 1979)
Human Alimentary Tract Model

Publication 100 (ICRP 2001)
Systemic model for Iodine

Figure 5-2. Structure of the biokinetic model for systemic iodine used in this report.
Systemic model for Plutonium
Plutonium-239 on bone surface
Biokinetic and Dosimetric models

Biokinetic models: Transformations in source organs / tissues

Dosimetric models: Energy deposition in and committed dose to target organs / tissues per transformation in source organs / tissues
Planned publications

**Phantoms and radiations transport calculations**
- Radiation Transport for Adult Phantoms (Adult SAFs)
- Pediatric Reference Computational Phantoms + SAFs
- Pregnant Female and Fetus Reference Computational Phantoms + SAFs

**Internal dose coefficients**
- Occupational Intakes of Radionuclides, Parts 1 - 5
- Internal Dose Coefficients for Members of the Public, Pts 1 & 2
- *In utero* Dose Coefficients for Maternal Intakes
- Breast-feeding Infant Dose Coefficients for Maternal Intakes

**External dose conversion coefficients**
- External Dose Coefficients for Members of the Public

**Radiopharmaceutical dose coefficients**

**Use of Effective Dose**
# Occupational Intakes of Radionuclides (OIR)

<table>
<thead>
<tr>
<th>Part</th>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part 1</td>
<td><em>Publication 130 (2015)</em> Introduction</td>
</tr>
<tr>
<td>Part 2</td>
<td>H, C, P, S, Ca, Fe, Co, Zn, Sr, Y, Zr, Nb, Mo, Tc</td>
</tr>
<tr>
<td>Part 3</td>
<td>Ru, Sb, Te, I, Cs, Ba, Ir, Pb, Bi, Po, Rn, Ra, Th, U</td>
</tr>
<tr>
<td>Part 4</td>
<td>Lanthanides and Actinides</td>
</tr>
<tr>
<td>Part 5</td>
<td>F, Na, Mg, K, Mg, Ni, Se, Mo, Tc, Ag</td>
</tr>
</tbody>
</table>

*ICRP*  
INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION
## OIR dose coefficients for cobalt

<table>
<thead>
<tr>
<th>Inhaled particulate materials (5 µm AMAD aerosols)</th>
<th>Effective dose coefficients (Sv Bq(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( ^{57}\text{Co} )</td>
</tr>
<tr>
<td>Type F, cobalt nitrate, chloride</td>
<td>3.3E-10</td>
</tr>
<tr>
<td>Type M, all unspecified forms</td>
<td>1.0E-09</td>
</tr>
<tr>
<td>Type S, cobalt oxide, FAP, PSL</td>
<td>2.4E-09</td>
</tr>
</tbody>
</table>

| Ingested materials                                 |                             |                             |                             |
| \( f_A = 0.1 \), all chemical forms               | 2.4E-10            | 1.2E-09            | 7.6E-09            |
| \( f_A = 0.05 \), insoluble oxides                | 1.7E-10            | 9.8E-10            | 4.8E-09            |
Bioassay data for $^{60}$Co : inhalation of 1 Bq Type M
Dose conversion convention for inhaled radon-222 + progeny

ICRP *Publication 65* (1993)

Compare lung cancer risk in miners (LEAR)

\[ 2.83 \times 10^{-4} \text{ per Working Level Month (WLM)} \]

with total detriment from cancer and hereditary effects from Pub 60 (1991):

<table>
<thead>
<tr>
<th></th>
<th>Workers</th>
<th>Public</th>
</tr>
</thead>
<tbody>
<tr>
<td>per Sv</td>
<td>$5.6 \times 10^{-2}$</td>
<td>$7.3 \times 10^{-2}$</td>
</tr>
<tr>
<td>mSv per WLM</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>
Revised radon risk coefficient and Statement on Radon
ICRP Publication 115 (2010)

Revised nominal risk coefficient of $5 \times 10^{-4} \text{ WLM}^{-1}$ to replace the Pub 65 value of $2.83 \times 10^{-4} \text{ WLM}^{-1}$

Intention to publish dose coefficients for radon isotopes calculated using biokinetic and dosimetric models

Lowered Upper value of Reference Level for homes from 600 Bq m$^{-3}$ to 300 Bq m$^{-3}$
Epidemiological approach

Using $5 \times 10^{-4}$ per WLM lung cancer risk

<table>
<thead>
<tr>
<th>Group</th>
<th>Risk Rate $\text{Sv}^{-1}$</th>
<th>Equivalent Dose $\text{mSv WLM}^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workers</td>
<td>$4.2 \times 10^{-2}$</td>
<td>12</td>
</tr>
<tr>
<td>Public</td>
<td>$5.7 \times 10^{-2}$</td>
<td>9</td>
</tr>
</tbody>
</table>

Publication 65 values

<table>
<thead>
<tr>
<th>Group</th>
<th>Equivalent Dose $\text{mSv WLM}^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workers</td>
<td>5</td>
</tr>
<tr>
<td>Public</td>
<td>4</td>
</tr>
<tr>
<td>Environment</td>
<td>Equilibrium factor</td>
</tr>
<tr>
<td>-------------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>Home</td>
<td>0.4</td>
</tr>
<tr>
<td>Indoor workplace</td>
<td>0.4</td>
</tr>
<tr>
<td>Mine</td>
<td>0.2</td>
</tr>
</tbody>
</table>

*Note: For the indoor workplace, lower breathing rate is considered.*
OIR 3 dose coefficients for radon

Inhalation or ingestion:
Radon-222 (Radon)          Effective dose
Radon-220 (Thoron)          Organ equivalent doses
Radon-219 (Actinon)

- BUT for inhaled Rn-222 – use **12 mSv per WLM** in most circumstances
- Information provided so that account can be taken of specific information on exposure conditions
  - aerosol characteristics, equilibrium factor
Protection against radon exposures
ICRP Publication 126 (2014)

Upper Reference Level of 300 Bq m\(^{-3}\) applying to all exposures in homes and workplaces

<table>
<thead>
<tr>
<th>Exposure</th>
<th>Effective dose mSv / y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home (≈7000h)</td>
<td>15.8</td>
</tr>
<tr>
<td>Work (≈2000h)</td>
<td>4.5</td>
</tr>
<tr>
<td>Total (8760h)</td>
<td>19.8</td>
</tr>
</tbody>
</table>
Plutonium production plants

Sellafield, Cumbria, UK

Mayak Nuclear Complex, Southern Urals, Russia
Mayak Pu production – early years
Techa River

Radionuclide composition, %
- $^{90}$Sr - 11.6
- $^{89}$Sr - 8.8
- $^{137}$Cs - 12.2
- $^{95}$Zr, $^{95}$Nb - 13.6
- $^{103,106}$Ru - 25.9
- Rare-earth elements - 26.8

Average daily release, TBq

1950 1952 1954 1956
- $^{90}$Sr - 11.6
- $^{89}$Sr - 8.8
- $^{137}$Cs - 12.2
- $^{95}$Zr, $^{95}$Nb - 13.6
- $^{103,106}$Ru - 25.9
- Rare-earth elements - 26.8

Key:
- Iset River
- Zatechenskoye (237 km)
- Mikhaylovsk River
- Borovaya River
- Zyuzelka River
- Kyzyl-Tash Lake
- Irtyash Lake
- Metlino Pond
- Mishelyak River
- Muslyumovo (78 km)
- Brodokalmak (109 km)
Calcium / strontium model for adults

- Rapid turnover (ST0)
- Intermediate turnover (ST1)
- Tenacious retention (ST2)

- Plasma
- Urine
- Urinary bladder contents
- Urinary path
- GI Tract contents
- Faeces
- Other soft tissues

- Skeleton
  - Cortical volume
    - Nonexch.
    - Exch.
  - Trabecular volume
    - Nonexch.
    - Exch.

- Kidneys
  - Other kidney tissue
Calcium / strontium model for adults

Rapid turnover

Intermediate turnover (ST1)

Tenacious retention (ST2)

Urine

Urinary bladder contents

Urinary path

Other kidney tissue

Other soft tissues

Plasma

GI Tract contents

Faeces

Fetus

Cortical volume

Nonexch. — Exch.

Trabecular volume

Nonexch. — Exch.

Cortical surface

Trabecular surface

Skeleton

Kidneys

Cortical volume

Nonexch. — Exch.

Other kidney tissue

Urinary bladder contents

Urine

Urinary path
Calcium/Strontium transfer to the fetus

Maternal plasma

Fetal soft tissue

Fetal blood

Fetal bone surface

Fetal exchangeable bone volume

Fetal non-exchangeable bone volume
ICRP biokinetic models being updated to make best use of current knowledge

Primary purpose is calculation of reference dose coefficients in support of the system of protection

Also used for scientific applications