Internal contamination and dosimetry for personnel in nuclear medicine

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Sources of occupational exposure in nuclear medicine:

1. *External irradiation*
   - Whole body, extremities, hands, fingers and eye lens when working with radioactive sources

   - Whole body irradiation from patients
Sources of occupational exposure in nuclear medicine:

2. *Internal irradiation*
   Valid for all radionuclides and specially for iodine
Inhaled material cleared from the lungs often enters the gastrointestinal tract and then a secondary ingestion type of exposure occurs.
Monitoring for internal contamination

- Few monitoring programs going – mostly not done
- Few systematic studies
- Screening measurements should be possible
  - Simple, fast, inexpensive, frequent
  - Directly at the workplace by local staff
“In nuclear medicine, the exposure due to internal contamination shall be monitored. It should be done by external monitoring of the thyroid for individuals handling large activities of radioiodine. Note that a gamma camera with no collimator mounted can be used as a whole body counter.”

Monitoring & optimization of occupational RP
BSS:

• Monitoring equipment must be provided – However, strong evidence that many professionals using radiation in medicine are not consistently monitored

• Need to improve compliance – monitoring must be seen as adding value

(John Le Heron, IAEA, at International Conference on RADIATION PROTECTION IN MEDICINE Setting the Scene for the Next Decade, 3-7 December 2012, Bonn, Germany)
INTERNATIONAL STANDARDS AND RECOMMENDATIONS
ISO 20553 [3-1; 2006]

Depending on the level of exposure, the standard recommends:

– monitoring at the workplaces, including the measurement of surface and air contamination levels, or nasal mucus sample collection, when the likely committed effective dose level may exceed 1 mSv

– individual monitoring, including *in vivo* measurements and *in vitro* analyses when the likely committed effective dose level may exceed 6 mSv
Article 41

Individual monitoring

1. Member States shall ensure that category A workers are systematically monitored based on individual measurements performed by a dosimetry service. In cases where category A workers are liable to receive significant internal exposure or significant exposure of the lens of the eye or extremities, an adequate system for monitoring shall be set up.

2. Member States shall ensure that monitoring for category B workers is at least sufficient to demonstrate that such workers are correctly classified in category B. Member States may require individual monitoring and if necessary individual measurements, performed by a dosimetry service, for category B workers.

3. In cases where individual measurements are not possible or inadequate, the individual monitoring shall be based on an estimate arrived at from individual measurements made on other exposed workers, from the results of the surveillance of the workplace provided for in Article 39 or on the basis of calculation methods approved by the competent authority.
Thyroid Monitoring for $^{123}\text{I}$, $^{124}\text{I}$, $^{125}\text{I}$ and $^{131}\text{I}$

A simple method of monitoring radioactive iodine uptake in the thyroid is by using a radiation protection instrument. Following any procedure with iodine, allow 24 hours for accumulation in the thyroid. Then: Position the probe end onto the surface of the neck as shown in Fig. Move the probe slowly up and down noting the maximum reading. Repeat on the other side of the midline and note the maximum reading. Subtract the background reading for the monitor from both readings. Add the left and right side readings together.

This method is capable of detecting approximately 1kBq of iodine in the thyroid, which equates to less than 1% of the annual limits on intake [ALI].
Table 1. Screening procedures for most commonly used radionuclides in nuclear medicine with the method of measurement, the screening interval, the threshold value and the minimum detectable annual $E_{50}$ ($E_{50,\text{min}}$).

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Method</th>
<th>Interval</th>
<th>Threshold</th>
<th>$E_{50,\text{min}}$ (in mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{11}$C</td>
<td>DRM$^{a}$</td>
<td>4 h</td>
<td>1 $\mu$Sv h$^{-1}$</td>
<td>5.0</td>
</tr>
<tr>
<td>$^{15}$O</td>
<td>DRM$^{a}$</td>
<td>by alarm$^{c}$</td>
<td>1 $\mu$Sv h$^{-1}$</td>
<td>2.9</td>
</tr>
<tr>
<td>$^{18}$F</td>
<td>DRM$^{a}$</td>
<td>4 h</td>
<td>1 $\mu$Sv h$^{-1}$</td>
<td>4.8</td>
</tr>
<tr>
<td>$^{67}$Ga</td>
<td>LM$^{b}$</td>
<td>7 d</td>
<td>5500 Bq</td>
<td>1.0</td>
</tr>
<tr>
<td>$^{68}$Ga</td>
<td>DRM$^{a}$</td>
<td>4 h</td>
<td>1 $\mu$Sv h$^{-1}$</td>
<td>7.1</td>
</tr>
<tr>
<td>$^{90}$Y</td>
<td>HCM$^{c}$</td>
<td>each use</td>
<td>3000 Bq cm$^{-2}$</td>
<td>1.6</td>
</tr>
<tr>
<td>$^{99m}$Tc</td>
<td>DRM$^{a}$</td>
<td>12 h</td>
<td>1 $\mu$Sv h$^{-1}$</td>
<td>5.3</td>
</tr>
<tr>
<td>$^{111}$In</td>
<td>LM$^{b}$</td>
<td>7 d</td>
<td>5000 Bq</td>
<td>1.0</td>
</tr>
<tr>
<td>$^{123}$I</td>
<td>SCM$^{d}$</td>
<td>1 d</td>
<td>1400 Bq</td>
<td>1.0</td>
</tr>
<tr>
<td>$^{124}$I</td>
<td>SCM$^{d}$</td>
<td>7 d</td>
<td>3000 Bq</td>
<td>11.5</td>
</tr>
<tr>
<td>$^{125}$I</td>
<td>SCM$^{d}$</td>
<td>30 d</td>
<td>1300 Bq</td>
<td>1.0</td>
</tr>
<tr>
<td>$^{131}$I</td>
<td>SCM$^{d}$</td>
<td>7 d</td>
<td>2000 Bq</td>
<td>10.5</td>
</tr>
<tr>
<td>$^{153}$Sm</td>
<td>HCM$^{c}$</td>
<td>each use</td>
<td>3000 Bq cm$^{-2}$</td>
<td>0.4</td>
</tr>
<tr>
<td>$^{169}$Er</td>
<td>HCM$^{c}$</td>
<td>each use</td>
<td>10 000 Bq cm$^{-2}$</td>
<td>0.7</td>
</tr>
<tr>
<td>$^{177}$Lu</td>
<td>HCM$^{c}$</td>
<td>each use</td>
<td>3000 Bq cm$^{-2}$</td>
<td>0.3</td>
</tr>
<tr>
<td>$^{186}$Re</td>
<td>HCM$^{c}$</td>
<td>each use</td>
<td>3000 Bq cm$^{-2}$</td>
<td>0.9</td>
</tr>
<tr>
<td>$^{188}$Re</td>
<td>HCM$^{c}$</td>
<td>each use</td>
<td>3000 Bq cm$^{-2}$</td>
<td>0.8</td>
</tr>
<tr>
<td>$^{201}$Tl</td>
<td>LM$^{b}$</td>
<td>14 d</td>
<td>55 000 Bq</td>
<td>1.0</td>
</tr>
</tbody>
</table>

DRM=Dose rate monitor
LM=Lung monitor
HCM=Hand contamination monitor
SCM=Surface cont. monitor

e) By alarm, air contamination at workplace above 4000 Bq/m$^3$

Baechler et al.
Rad Prot Dosim
144, 464–467, 2011
(i) ‘screening measurements’ performed at the workplace by local staff to detect whether potential intake has occurred; and

(ii) ‘intake measurements’ performed by a medical physicist to determine the committed effective dose, $E_{50}$, in the case of positive screening results.
Whole body monitoring using a gammacamera without a collimator

$99^m$Tc

$111^m$In

$123^m$I

MDA < 1 kBq $99^m$Tc

(Max finding 25 kBq after work with $99^m$Tc-Technegas; $E = 0.1$ mSv/year, $D_{\text{lung}} = 0.6$ mGy/year)

If > 1 MBq make a whole body scan with collimator

(Larsson et al., 2016)
ICRP Publication 134 (Part 2 of 5)

To be used for dose estimates after ingestion and inhalation of:

1. HYDROGEN
2. CARBON
3. PHOSPHORUS
4. SULPHUR
5. CALCIUM
6. IRON
7. COBALT
8. ZINC
9. STRONTIUM
10. YTTRIUM
11. ZIRCONIUM
12. NIOBIUM
13. MOLYBDENUM
14. TECHNETIUM

Electronic Annex – OIR DATA VIEWER
Electronic Annex – OIR DATA VIEWER
A cyclotron man was found to have 385 kBq $^{65}$Zn in his body. There was a suspicion that contamination occurred a year ago.

**Dose per content function**

In this series of reports, a set of tabulated values $z(t) = \frac{E(50)}{m(t)}$, where $E(50)$ is the effective dose coefficient, and $m(t)$ is the reference bioassay (retention or excretion) function. Values of $z(t)$ represent the committed effective dose per predicted activity content in the body or in a given organ (Sv Bq$^{-1}$), or per daily excretion.

1 year – whole body – $5.3 \times 10^{-8}$ Sv/Bq

Committed effective dose = $5.3 \times 10^{-8} \times 3.85 \times 10^5 = 20$ mSv
$^{99m}$Tc-pertechnetate

(Effective dose coefficient for oral intake)

- ICRP Publication 128: 0.013 mSv/MBq ($w_T$ from ICRP 60)

- IDACDose2.1: 0.014 mSv/MBq ($w_T$ from ICRP 103) (+8 %)
  (http://www.idac-dose.org/about-idac/)

- Highest dose to thyroid (and only 1% uptake)
$^{99m}\text{Tc}$

Hand contamination

2.40 $10^{-4}$ $\mu$Sv/MBq, min

$1$ m

2.09 $10^{-3}$ $\mu$Sv/MBq, min

$^{18}\text{F}$

1.82 $10^{-3}$ $\mu$Sv/MBq, min

$1$ m

1.68 $10^{-2}$ $\mu$Sv/MBq, min

$^{18}\text{F}$ give an 8 times higher doserate than $^{99m}\text{Tc}$
$^{131}$I-iodide

(Effective dose coefficient for oral intake)

ICRP Publication 128: 22 mSv/MBq ($w_T$ from ICRP 60)
IDACDose2.1: 16.3 mSv/MBq ($w_T$ from ICRP 103) (-25 %)

$w_T$ for thyroid has been changed from 0.05 to 0.04

Highest dose to thyroid. 90 % of all decays will occur in the thyroid and 97.5% of all contributions to effective dose comes from the thyroid

Absorbed dose to thyroid: $430 \text{ mGy/MBq} \rightarrow (364+437)/2 = 400 \text{ mGy/MBq}$

Contributions to Effective dose:

Earlier estimate $430 \text{ mGy/MBq} \times 0.05=21.5 \text{ mSv/MBq}$

New estimate $(364+437)/2 \text{ mGy/MBq} \times 0.04=16.0 \text{ mSv/MBq}$
$^{131}$I-iodide
(oral intake)

Biokinetic model from ICRP Publication 128

1.06 $10^{-3}$ $\mu$Sv/MBq,min

16.3 mSv/MBq

$\mu$J/cm$^3$/MBq,min
Effective dose, Sv

- Enables the summation of all radiation exposures by risk adjustment using simplified weighting factors.

- Applies to sex-averaged reference persons, and relates to nominal risk coefficients for uniform external low LET radiation exposure.

- Applied without uncertainties, assumes LNT dose-response, chronic exposure = acute exposure, internal = external.

- Relates to fatal cancer risk of 5% per Sv.
How to avoid internal contamination?

- Protection begins with the prevention of contamination of the environment in which people work and live.

- Limitation of open sources and processes that can cause radioactive contamination of surfaces or air.

- Only work in specific areas (fume hoods or other areas with air extraction).

- Monitoring of localities, laboratory benches, equipment, wards, etc.
EXAMPLE: MONITORING THERAPY WARD

<table>
<thead>
<tr>
<th>Area or item</th>
<th>Initial (Bq/cm²)</th>
<th>After cleaning (Bq/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toilet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Washroom floor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sink and Faucets</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shower</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Armchair</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bedroom floor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TV/Telephone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bedside table</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doorknobs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lamp switches</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Derived limit: 3 Bq/cm²

METHODS
• wipe test
• area monitor

IAEA Educational material
WIPE TEST

Wipe a known surface area with an absorbent material moistened with water or alcohol. Put the sample in a tube and measure the activity in a well counter or a liquid scintillation counter.

\[
\frac{\text{cps-BG}}{E_c E_w A} = \text{contamination (Bq/cm}^2)\]

cps: counts per second for sample
BG: instrument background
\(E_c\): counter efficiency (cps/Bq)
\(E_w\): swipe efficiency (assumed to be 0.1)
A: area swiped (cm\(^2\))
What can the individual do?

• Adopt clean operating conditions
• Adopt good laboratory practices
• Do not eat, drink, smoke, etc., ...
• Use protective gloves and clothing
• Wash your hands frequently (water with a neutral hand soap)
Greatest risk of contamination of the worker

- Spills
- Labelling, iodinations
- Handling of cyclotron targets
- Improper radiopharmaceutical administration
- Emergency surgery or autopsy of therapy patient
- Experimental work with animals
- *In vitro* analyses
Table 2. The mean activity ± SD and the range of $^{125}$I in the thyroid and the corresponding average annual absorbed dose to the thyroid for the four staff categories investigated.

<table>
<thead>
<tr>
<th>Category</th>
<th>Mean activity ± SD (range) (Bq)</th>
<th>Yearly average absorbed dose ± SD (range) (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1977–1990</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemists</td>
<td>1,470 ± 680 (20–7,400)</td>
<td>10.4 ± 4.8 (0.1–53)</td>
</tr>
<tr>
<td>Laboratory staff</td>
<td>140 ± 155 (0–4,030)</td>
<td>1.0 ± 1.1 (0–29)</td>
</tr>
<tr>
<td>Nuclear medicine staff</td>
<td>30 ± 10 (10–90)</td>
<td>0.2 ± 0.07 (0.07–0.6)</td>
</tr>
<tr>
<td>Administrative staff</td>
<td>25 ± 15 (0–100)</td>
<td>0.2 ± 0.1 (0–0.7)</td>
</tr>
<tr>
<td>1991–1996</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemists</td>
<td>381 ± 159 (3–1,690)</td>
<td>2.7 ± 1.1 (0.02–12)</td>
</tr>
<tr>
<td>Laboratory staff</td>
<td>15 ± 7 (0–480)</td>
<td>0.1 ± 0.05 (0–3.4)</td>
</tr>
</tbody>
</table>

Jönsson and Mattsson, Health Physics 1998

$^{125}$I content in thyroids of personnel working with $^{125}$I in hospitals
Internal contamination and dosimetry for personnel in nuclear medicine

Thank you for listening!
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