Radiation protection in Nuclear Medicine - Best practice

Sigrid Leide-Svegborn, Assoc. prof., MPE, RPE
Radiation physics
Skåne University Hospital, Malmö
Lund University
SWEDEN

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Disclosure:

I have nothing to disclose and no conflict of interests with respect to this presentation.
Nuclear Medicine

**BENEFIT** - an effect of radioactive substances emitting ionizing radiation

**RISK** - an effect of radioactive substances emitting ionizing radiation

Extravasation of $^{131}$I-MIBG

Bonta et al., J Nucl Med 2011

Tumour diagnostic using $^{18}$F
Radiation Protection in NM – Exposure of whom?

Medical exposure
- Patients (adults, adolescents, children, infants)
- Carers and comforters
- Volunteers in medical and biomedical research

Occupational exposure
- Workers, apprentices and students

Special groups
- Unborn children of pregnant women
- Breastfed newborns and infants

Exposure of the public due to NM practice
- Exposure of individuals excluding any occupational or medical exposure
  (other professionals at the hospital, language interpreters, taxi drivers, individuals in the society etc.)

Radiation protection in NM – The Principles

Justification       Optimization       Dose limitation

No dose limits for medical exposure, dose constraints for carers and comforters
Please follow the recommendations as prescribed by your national authority.

**EU Basic Safety Directive 2013/59/Euratom**

2. The limit on the effective dose for occupational exposure shall be 20 mSv in any single year. However, in special circumstances or for certain exposure situations specified in national legislation, a higher effective dose of up to 50 mSv may be authorised by the competent authority in a single year, provided that the average annual dose over any five consecutive years, including the years for which the limit has been exceeded, does not exceed 20 mSv.

**ICRP 103, Ann ICRP, 2007 and ICRP 118, Ann ICRP, 2012**

Table 6. Recommended dose limits in planned exposure situations.a.

<table>
<thead>
<tr>
<th>Type of limit</th>
<th>Occupational</th>
<th>Public</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective dose</td>
<td>20 mSv per year, averaged over defined periods of 5 years&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1 mSv in a year&lt;sup&gt;f&lt;/sup&gt;</td>
</tr>
<tr>
<td>Annual equivalent dose in:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lens of the eye&lt;sup&gt;b&lt;/sup&gt;</td>
<td>150 mSv 20 mSv</td>
<td></td>
</tr>
<tr>
<td>Skin&lt;sup&gt;c,d&lt;/sup&gt;</td>
<td>500 mSv</td>
<td></td>
</tr>
<tr>
<td>Hands and feet</td>
<td>500 mSv</td>
<td></td>
</tr>
</tbody>
</table>

IAEA. General Safety Guide No. GSG-7 (2018), Occupational Radiation Protection

“For occupational exposure of workers over the age of 18 years, the dose limits are:

(a) An effective dose of 20 mSv per year averaged over five consecutive years<sup>66</sup> (100 mSv in 5 years) and of 50 mSv in any single year;
(b) An equivalent dose to the lens of the eye of 20 mSv per year averaged over five consecutive years (100 mSv in 5 years) and of 50 mSv in any single year;
(c) An equivalent dose to the extremities (hands and feet) or to the skin<sup>67</sup> of 500 mSv in a year.

(a) the limit on the equivalent dose for the lens of the eye shall be 20 mSv per year, but up to 100 mSv in 5 years; and
(b) the limit on the equivalent dose for the skin shall be 500 mSv in a year, this limit shall apply to the dose averaged over any area of 1 cm<sup>2</sup>, regardless of the area exposed;

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Radiation sources
Radiopharmaceuticals
Radiation Protection in NM – **Exposure from what?**

Unsealed radioactive sources

**Radiopharmaceuticals** - liquid, gaseous or solid
- In vials, syringes, containers or if contamination on surfaces or in air
- Within the patient and in the excreta of the patient

Sealed radioactive sources

- Quality control and calibration of equipment or as markers

Radioactive waste (liquid, gaseous and solids)

**Radionuclides**

Characteristics of the radionuclide is of significant importance
- Decay mode and type of radiation emitted
- Energy emitted [keV – MeV]
- Physical half-life [sec – months]
- etc

*Hybrid Imaging – includes CT*

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Design of a Nuclear medicine facility
Radiation protection starts already in the design of a Nuclear medicine facility

- Design of facilities
- Shielding
- Monitoring
- Recording

Workers designation

Monitoring

Area designation

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The patient
Justification and optimization
Radiopharmaceuticals
Radiation protection of the patient - justification and optimization

**Justification**
- Risk versus benefit

**Optimization**
- Radiation exposure versus diagnostic quality or therapeutic outcome
Optimization of a diagnostic procedure

• The relation between the activity and the diagnostic accuracy is dependent on the type of examination. It is important to know whether the diagnosis is based on quantitative information or on visual evaluation. Both for a simple uptake measurement and in connection with imaging, the amount of activity needed will depend on the type of equipment used, the body constitution of the individual patient, the patient’s metabolic characteristics and clinical condition.

• Image quality is dependent on technical factors and on patient related factors

• Equipment must be operated within the limits and conditions established in the technical specifications and in the license requirements, ensuring that it will operate satisfactorily at all times. Thus, an extensive QA program is needed.

https://www.iaea.org/resources/rpop/health-professionals/nuclear-medicine/
Diagnostic reference level, DRL in Nuclear medicine

DRL is a level used in nuclear medicine imaging to indicate whether, in routine conditions, the amount of activity (MBq or MBq/kg) of radiopharmaceuticals administered in a specified procedure for medical imaging is unusually high or unusually low for that procedure.

**DRLs is a practical tool to promote optimization.**

DRLs are general guideline for clinical operations and do not apply directly to individual patients and examinations.

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The blue boxes represent different NM practices.
Examples of different radiopharmaceuticals for diagnostic use

\[ ^{99m}\text{Tc}} \text{-diphosphonates} \]

\[ ^{111}\text{In}} \text{-octreotide} \]

\[ ^{18}\text{F}} \text{-FDG} \]

\[ ^{99m}\text{Tc}} \text{-MIBI} \]

\[ ^{123}\text{I}} \text{-ioflupane} \]

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Internal dosimetry – The dose to the Nuclear medicine Patient

Table. Absorbed dose per unit A [mGy/MBq]
Optimization in radionuclide therapy

- In nuclear medicine therapy radiopharmaceuticals are used to cure, mitigate or control a disease, such as a benign thyroid condition or various malignant, such as lymphomas or bone metastases. It can be used either on selective targets or throughout the entire body.

- The goal of therapy with radiopharmaceuticals, is to optimise the relationship between e.g., tumour control probability and potential complications in normal organs and tissues.

- Treatment with radiopharmaceuticals requires administration protocols that justify and optimise the treatment. **Individual absorbed dose estimates** should be performed for treatment planning and for post-administration verification of doses to tumours and normal tissues.
Optimization for paediatric patients

- **Bone scintigraphy**
  - $^{99m}$Tc-MDP

- **Renal scintigraphy**
  - $^{99m}$Tc-DMSA

- **Neuroblastoma scan**
  - $^{123}$I-MIBG

**Justification and optimization**

- Patient – benefit from the radiation is expected

- Children are more radiation sensitive

- Longer expected life time

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Figure 2 Adapted from ICRP Publication 60 (1990)
Breastfeeding patient

In breast milk
10-20% of $A_{mother}$

Thyroid scintigraphy
$^{99m}$Tc-pertechnetate, 200 MBq

In breast milk
0.07% of $A_{mother}$

Lymphoma PET/CT
$^{18}$F-FDG, 277 MBq

S. Leide Svegborn, Radiat Prot Dosim 2010
### Recommendation on breastfeeding interruption – IAEA cont’d

<table>
<thead>
<tr>
<th>Radiopharmaceutical</th>
<th>Most common clinical use</th>
<th>Typical adm. activity (MBq)</th>
<th>Feeding interruption time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{99m}$Tc-pertechnetate</td>
<td>Thyroid scan, Meckel’s diverticulum</td>
<td>100-400</td>
<td>12 h (2)</td>
</tr>
<tr>
<td>$^{99m}$Tc-MAA</td>
<td>Lung perfusion imaging</td>
<td>40-150</td>
<td>12 h</td>
</tr>
<tr>
<td>$^{99m}$Tc-HMPAO WBC</td>
<td>Infection imaging</td>
<td>180-400</td>
<td>12 h</td>
</tr>
<tr>
<td>$^{99m}$Tc-labelled RBC</td>
<td>Radionuclide ventriculography</td>
<td>800</td>
<td>12 h</td>
</tr>
<tr>
<td>$^{99m}$Tc-mebrofenin and other iminodiacetic acid derivatives</td>
<td>Hepatobiliary imaging and function</td>
<td>300</td>
<td>4 h (1)</td>
</tr>
<tr>
<td>$^{99m}$Tc-human albumin nanocolloidal particles</td>
<td>Sentinel nodes</td>
<td>5-120</td>
<td>4 h (1)</td>
</tr>
<tr>
<td></td>
<td>Liver scanning</td>
<td>120-200</td>
<td></td>
</tr>
<tr>
<td>$^{111}$In-octreotide</td>
<td>Neuroendocrine tumours</td>
<td>100-200</td>
<td>60 h (2.5 d)</td>
</tr>
<tr>
<td>$^{123}$I-MIBG</td>
<td>Neuroblastoma imaging</td>
<td>400</td>
<td>&gt; 3 weeks or complete cessation (3)</td>
</tr>
<tr>
<td>$^{123}$I-Nal</td>
<td>Thyroid imaging and function</td>
<td>20</td>
<td>&gt; 3 weeks or complete cessation (3)</td>
</tr>
<tr>
<td>$^{123}$I-ioflupane (FP-CIT)</td>
<td>Dopaminergic neurotransmission (D1) in movement disorders</td>
<td>150-250</td>
<td>&gt; 3 weeks or complete cessation (3)</td>
</tr>
</tbody>
</table>

1) One meal discarded, if free pertechnetate + external exposure  
2) > 400 MBq 24 h  
3) risk of iodine impurities  
4) normal renal function  
6) incl. external exposure

Cont’d
Radiation related effects on fetus or embryo

- Early effects (failure to implant or miscarriage)
- Effects on embryo/fetus during growth
  - Lethal effects – threshold dose 100 mGy
  - Malformation – threshold dose 100-200 mGy or higher
  - Mental retardation – threshold dose 100 mGy
    - Higher risk 8-15 w post-conception
    - Somewhat less risk 16-25 w p.c.
- Cancer (leukemia and solid tumours) – No threshold dose

**Stochastic effects**

**Deterministic effects**
Fetal exposure in Nuclear medicine

Irradiation of the embryo/fetus from radiopharmaceuticals administered to the pregnant patient

- The embryo/fetus may be irradiated **externally** from activity in the mother.

- Some radiopharmaceuticals may cross the placenta and concentrate in fetal tissue i.e. **internal exposure** of the fetus.

Figure 1. Gamma camera examination 6 days after administration of 3 700 MBq 131-I in Case 2. Note small uptake in the thyroid bed, uptake in mammary glands, and uptake in the fetal thyroid and fetal body/amniotic fluid.

Assessment of the dose to the embryo/fetus

Stabin MG. *J Nucl Med* 2018;1005-1006

An example of a pregnant female computational phantom.

Rensselaer Polytechnic Institute pregnant female models for 3 mo (left), 6 mo (middle), and 9 mo (right) of gestation.


![Image of pregnant female computational phantom](image)

**Shaded rows indicate consideration of placental crossover in the fetal dose estimates**

<table>
<thead>
<tr>
<th>Radiopharmaceutical</th>
<th>Estimated fetal dose (mGy/MCi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Early pregnancy</td>
</tr>
<tr>
<td>99mTc-X</td>
<td>2.3 x 10^-2</td>
</tr>
<tr>
<td>18F-FDG</td>
<td>2.6 x 10^-2</td>
</tr>
<tr>
<td>18F-fluoride</td>
<td>3.1 x 10^-2</td>
</tr>
<tr>
<td>18F-phosphate</td>
<td>8.7 x 10^-3</td>
</tr>
<tr>
<td>123I-Ga-citrate</td>
<td>9.4 x 10^-3</td>
</tr>
<tr>
<td>133Xe-hypervan</td>
<td>4.9 x 10^-3</td>
</tr>
<tr>
<td>131I-IMP</td>
<td>2.2 x 10^-2</td>
</tr>
<tr>
<td>125I-mIBG</td>
<td>2.2 x 10^-2</td>
</tr>
<tr>
<td>123I-Nal</td>
<td>2.3 x 10^-2</td>
</tr>
<tr>
<td>123I-HSA</td>
<td>2.4 x 10^-2</td>
</tr>
<tr>
<td>123I-mIBG</td>
<td>3.2 x 10^-2</td>
</tr>
<tr>
<td>131I-hypervan</td>
<td>9.8 x 10^-2</td>
</tr>
<tr>
<td>131I-mIBG</td>
<td>1.2 x 10^-1</td>
</tr>
<tr>
<td>111In-DTPA</td>
<td>7.6 x 10^-3</td>
</tr>
<tr>
<td>111In-pentetreotide</td>
<td>9.4 x 10^-3</td>
</tr>
<tr>
<td>111In-glutethemate</td>
<td>1.1 x 10^-2</td>
</tr>
<tr>
<td>111In-RBCs</td>
<td>1.7 x 10^-2</td>
</tr>
<tr>
<td>111In-WBCs</td>
<td>2.2 x 10^-3</td>
</tr>
<tr>
<td>81Kr</td>
<td>1.2 x 10^-2</td>
</tr>
<tr>
<td>177Lu-DOTATATE (J)</td>
<td>1.9 x 10^-2</td>
</tr>
<tr>
<td>186Rb</td>
<td>9.5 x 10^-3</td>
</tr>
<tr>
<td>125I-EDTMP (2)</td>
<td>3.6 x 10^-3</td>
</tr>
<tr>
<td>177Lu-chloride</td>
<td>8.4 x 10^-3</td>
</tr>
<tr>
<td>131I-disofenin</td>
<td>1.9 x 10^-2</td>
</tr>
<tr>
<td>131I-DMSA</td>
<td>5.9 x 10^-3</td>
</tr>
<tr>
<td>131I-DTPA</td>
<td>1.7 x 10^-2</td>
</tr>
<tr>
<td>131I-DTPA aerosol</td>
<td>7.6 x 10^-3</td>
</tr>
<tr>
<td>131I-glucoprotein</td>
<td>1.6 x 10^-2</td>
</tr>
<tr>
<td>131I-HMPAO</td>
<td>1.0 x 10^-1</td>
</tr>
<tr>
<td>131I-MAA</td>
<td>3.2 x 10^-2</td>
</tr>
<tr>
<td>131I-MAG3</td>
<td>2.6 x 10^-2</td>
</tr>
<tr>
<td>131I-MOP</td>
<td>8.1 x 10^-2</td>
</tr>
<tr>
<td>131I-MIBI rest</td>
<td>1.7 x 10^-2</td>
</tr>
<tr>
<td>131I-MIBI stress</td>
<td>1.4 x 10^-2</td>
</tr>
<tr>
<td>131I-terechtechne</td>
<td>1.4 x 10^-2</td>
</tr>
</tbody>
</table>

**99mTc-X: 1-10 mGy
18F-FDG: 10 mGy
111In-pentetreotide: 20 mGy

**131I-Nal: High doses to embryo/fetus
Risk of significant fetal thyroid harm**

Cont’d
Occupational exposure

Dose limitation

Monitoring
Radiation Protection in NM – Occupational exposure - When?

- Production of the radionuclide incl. QC
- Preparation of the radiopharmaceutical incl. QC
- Transportation (external and internal)
- Receiving and unpacking the radionuclide
- Quality and activity control of the delivered radionuclide
- Administration of the radiopharmaceutical to the patient or a phantom (QC of the equipment)
- Taking care of the patient during the NM procedure (e.g. imaging or treatment)
- Taking care of the radioactive waste (short-term and long-term)
- Storage of radiation sources
- Accidental and unintended exposure
- .......
Please follow the recommendations as prescribed by your national authority.

EU Basic Safety Directive 2013/59/Euratom

2. The limit on the effective dose for occupational exposure shall be 20 mSv in any single year. However, in special circumstances or for certain exposure situations specified in national legislation, a higher effective dose of up to 50 mSv may be authorised by the competent authority in a single year, provided that the average annual dose over any five consecutive years, including the years for which the limit has been exceeded, does not exceed 20 mSv.


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(a) the limit on the equivalent dose for the lens of the eye shall be 20 mSv in any single year and 100 mSv in any five-year period; and
(b) the limit on the equivalent dose for the skin shall be 500 mSv in a year; this limit shall apply to the dose averaged over any area of 1 cm², regardless of the area exposed;
Detection of ionizing radiation - human inadequacy

- Can not see it
- Can not hear it
- Can not feel it
- Can not smell it
- Can not taste it

Can easily detect it with a radiation detector

Table 2.4. Operational quantities for monitoring external exposures.

<table>
<thead>
<tr>
<th>Task</th>
<th>Operational dose quantities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Area monitoring</strong></td>
<td><strong>Individual monitoring</strong></td>
</tr>
<tr>
<td>Control of effective dose</td>
<td>Ambient dose equivalent</td>
</tr>
<tr>
<td></td>
<td>$H'(10)$</td>
</tr>
<tr>
<td>Control of doses to the skin, hands, wrist, and feet</td>
<td>Directional dose equivalent</td>
</tr>
<tr>
<td></td>
<td>$H'(0.07, \Omega)$</td>
</tr>
<tr>
<td>Control of dose to the lens of the eye*</td>
<td>Directional dose equivalent $H'(3, \Omega)$</td>
</tr>
<tr>
<td></td>
<td>Personal dose equivalent</td>
</tr>
<tr>
<td></td>
<td>$H_p(10, \Omega)$</td>
</tr>
<tr>
<td></td>
<td>Personal dose equivalent</td>
</tr>
<tr>
<td></td>
<td>$H_p(0.07, \Omega)$</td>
</tr>
<tr>
<td></td>
<td>Personal dose equivalent</td>
</tr>
<tr>
<td></td>
<td>$H_p(3, \Omega)$</td>
</tr>
</tbody>
</table>

Radiation Protection in NM – Monitoring

Personal monitoring
Continuously and periodically
Whole body (PED, TLD), extremity dose and eye lens dose (TLD)

Workplace monitoring
Source related and task related
Continuously or periodically

Monitoring for contamination

External contamination
Internal contamination
Minimize the radiation dose - T D S

Minimize the TIME of exposure

Use DISTANCE tools e.g. forceps

Use various SHIELDING

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Minimizing external exposure, by using SHIELDING

20 min @ 1 m from source

<table>
<thead>
<tr>
<th></th>
<th>Without</th>
<th>With</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>400 MBq $^{99m}$Tc</td>
<td>2.7 μSv</td>
<td>0.6 μSv</td>
<td>Good!</td>
</tr>
<tr>
<td>400 MBq $^{18}$F</td>
<td>12 μSv</td>
<td>11 μSv</td>
<td>use Distance and Time</td>
</tr>
</tbody>
</table>

Radiation protection apron 0.5 mmPb

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Minimizing external exposure, especially finger doses by using both SHIELDING AND DISTANCE

Anniqa Rastbäck, Malmö 2022

Automatic dispensing- and infusion robots for PET-substances

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Avoid contamination

Use protective paper

Use laboratory clothing

Use gloves nitrile or vinyl

Do not eat, drink or smoke in the lab.

Wash and measure hands

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Safety culture in NM
Accidental and unintended medical exposure

The SAFRON Reporting system also for Radionuclide therapy

Safety in Radiation Oncology (SAFRON)

QUANUM3.0
The Quality Management Audits in Nuclear Medicine programme

IAEA HUMAN HEALTH SERIES
No. 33
QUANUM 3.0: An Updated Tool for Nuclear Medicine Audits
Third Edition

Sigrid Leide Svegborn 2022
Thank you for your attention

Sigrid.Leide_Svegborn@med.lu.se