Radiation Safety for X-ray Imaging Procedures Outside Imaging Departments

Ingvar A J Fife

2017 Canadian Imaging Winter School Quality Improvement and Radiation Safety
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  – Safety Culture: *Training Challenges*
Part I

Introduction

Thanks, who am I and what is the talk about?
Presenter Disclosure

- **Faculty Member**: Dr. Ingvar Fife  
  Assistant Professor, Radiology  
  Adjunct Professor, Physics and Astronomy

- **Medical Physicist**, Medical Physics Division

- **Regulator**, Manitoba Radiation Protection Act and X-ray Safety Regulations

- **Relationships with commercial interests:**  
  - None to report
Reference materials used for this presentation

- International Commission on Radiological Units (ICRU) 2005: Patient dosimetry for X-rays Used for Medical Imaging. ICRU Report 74. ICRU Bethesda, MD.
  - www.imagegently.org
  - www.imagewisely.org
  - http://www.xrayrisk.com
Web sites for info’ on radiation sources and effects

- European Commission (radiological protection pages): europa.eu.int/comm/environment/radprot
- International Atomic Energy Agency: www.iaea.org
- International Commission on Radiological Protection: www.icrp.org
- World Health Organization: www.who.int
Radiological Protection in Fluoroscopically Guided Procedures Performed Outside the Imaging Department

ICRP Publication 117

Authors on behalf of ICRP

Authors on behalf of ICRP
Manitoba and Quebec

- Great Grey Owl
- Prairie Crocus
- White Spruce
- “Gloriosus et liber”

- Snowy Owl
- Blue Flag
- Yellow Birch
- “Je me souviens”
IAEA and WHO

Radiation Protection in Medicine, 2012

Setting the scene for the next decade

• Indicate gaps in current approaches to radiation protection in medicine
• Identify tools for improving radiation protection in medicine
• Review advances, challenges and opportunities in the field of radiation protection in medicine
• Assess the impact of the international Action Plan for the Radiation Protection of Patients, in order to prepare new international recommendations, taking into account newer developments
Bonn Call-for-Action aims

• strengthen the radiation protection of patients and health workers overall
• attain the highest benefit with the least possible risk to all patients by the safe and appropriate use of ionizing radiation in medicine
• aid the full integration of radiation protection into health care systems
• help improve the benefit / risk-dialogue with patients and public
• enhance the safety and quality of radiological procedures in medicine
Proposed Actions I

- Enhance the implementation of the principle of justification
- Enhance the implementation of the principle of optimization of protection and safety
- Strengthen manufacturers’ role in contributing to the overall safety regime
- Strengthen radiation protection education and training of health professionals
- Shape and promote a strategic research agenda for radiation protection in medicine
Proposed Actions II

• Increase availability of improved global information on medical exposures and occupational exposures in medicine
• Improve prevention of medical radiation incidents and accidents
• Strengthen radiation safety culture in health care
• Foster an improved radiation benefit-risk-dialogue
• Strengthen the implementation of safety requirements globally
# X-ray tube registrations

<table>
<thead>
<tr>
<th>Type of X-ray tube</th>
<th>2001</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiographic</td>
<td>488</td>
<td>586</td>
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<tr>
<td>Fluoro</td>
<td>116</td>
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<tr>
<td>CT</td>
<td>12</td>
<td>23</td>
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<tr>
<td>Dental</td>
<td>1102</td>
<td>1491</td>
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<tr>
<td>Mammo</td>
<td>18</td>
<td>20</td>
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<tr>
<td>Others</td>
<td>12</td>
<td>28</td>
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<tr>
<td><strong>Total</strong></td>
<td>1748</td>
<td>2238 (2570 in 2017)</td>
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</table>

<table>
<thead>
<tr>
<th>Type of X-ray tube</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chiropractic: urban / rural</td>
<td>55 / 22</td>
</tr>
<tr>
<td>Industrial: urban / rural</td>
<td>57 / 45</td>
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</table>
## Fluoroscopy registrations

<table>
<thead>
<tr>
<th>Type of fluoroscopy unit</th>
<th>2001</th>
<th>2017</th>
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<tbody>
<tr>
<td>Mini C-arm</td>
<td>6</td>
<td>8</td>
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<tr>
<td>Mobile C-arm</td>
<td>21</td>
<td>38</td>
</tr>
<tr>
<td>Interventional (Special)</td>
<td>8/9</td>
<td>18</td>
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</table>
There are many procedures with potential to impart skin doses exceeding 1 Gy

- Endovascular aneurysm repair
- Renal angioplasty
- Iliac angioplasty
- Ureteric stent placement
- Therapeutic endoscopic retrograde cholangiopancreatography
- Bile duct stenting and drainage
- Orthopaedics and joints
- Pain management
- Obstetrics and gynaecology
- Cardiac angiography
Background and motivation

• An increasing number of medical specialists are using fluoroscopy outside imaging departments, and expansion of its use is much greater today than at any time in the past.

• There has been general neglect of radiological protection coverage of fluoroscopy machines used outside imaging departments.
Background and motivation

• Lack of radiological protection training of workers using fluoroscopy outside imaging departments can increase the radiation risk to workers and patients.

• Recent reports of opacities in the eyes of workers who use fluoroscopy have drawn attention to the need to strengthen radiological protection measures for the eyes.
Background and motivation

• Although tissue reactions among patients and workers from fluoroscopy procedures have, to date, only been reported in interventional radiology and cardiology, the level of fluoroscopy use outside imaging departments creates potential for such injuries.
Fluoroscopy use outside imaging departments is increasing

- Fluoroscopy in endovascular repair is increasing
- Radiation levels are similar to interventional and cardiology procedures
- Procedures may be prolonged and complex
- Extended periods where entrance radiation is fixed increasing risk of skin injury
- Use of more complex endovascular devices is likely to increase
Part II

Medical X-ray exposures

The Patient Journey and exposure parameter
Roentgen and an early radiograph
X-actly So!

The Roentgen Rays, the Roentgen Rays,
What is this craze?
The town’s ablaze
With the new phase
Of X-ray’s ways.

I’m full of daze,
Shock and amaze;
For nowadays
I hear they’ll gaze
Thro’ cloak and gown—and even stays,
These naughty, naughty Roentgen Rays.

(WILHELMA, in Photograp

Roentgen craze – Electrical Review, April 1896
WONDERFUL NEW RAY SEES THROUGH HAND!

X-Ray Studio...
110 East Twenty-Sixty Street,
...New York C
The Patient Journey

How does someone get an X-ray?
The patient journey

Patient visits clinician
The patient journey

Patient visits clinician

X-ray request generated
The patient journey

Patient visits clinician

X-ray request generated

Patient has X-ray
The patient journey

Patient visits clinician

X-ray request generated

Patient has X-ray

X-ray read
The patient journey

1. Patient visits clinician
2. X-ray request generated
3. Patient has X-ray
4. X-ray read
5. Report sent to referring clinician
Outcome of patient journey

Results of X-ray affect management of patient
Radiological technique

• Method of obtaining the image
• No. of views/radiographs per examination
• Choice of equipment and X-ray rooms for particular examinations
Fundamental radiographic exposure parameters

- Beam energy (kilovoltage) - kV
- Tube current - mA
- Exposure time - s
Transmission of monoenergetic photons

Transmission vs. Tissue thickness (cm)
Radiographic technique

- Fundamental exposure parameters kV/mAs
- Filtration
- Focal spot size - broad/fine
- Geometry - FFD/FSD
- Reduction of scatter
- Collimation
- Shielding of radiosensitive organs
- Compression
- Image receptor
- Processing
- QA
Fundamental fluoroscopy screening parameters

- Screening energy (kilovoltage) - kV
- Screening current - mA
- Screening time - s
Fluoroscopy technique

- Fundamental screening parameters kV/mA/s
- Filtration
- No of views/images per examination
- Choice of imaging device
- kV / mA characteristics
Choice of imaging device

- Pulsed fluoroscopy
- Automatic dose-rate options
- Magnification options
- TV frame store options
- Video tape recording
- 100/105mm cameras
- Laser imagers
Compression

- Reduced tissue depth - reduced thickness range
- Reduced scatter - improved contrast
- Softer spectrum - improved contrast
- Reduced geometric unsharpness
- Reduced movement blur
- Reduced tissue overlap - improved visualisation
Image Quality and Dose

In the context of clinical optimization discussions
Image Quality

**OBJECTIVE**
- modulation transfer function (MTF)
- noise power spectrum (NPS)
- detective quantum efficiency (DQE)
- signal-to-noise ratio
- threshold contrast-detail methods
- limiting spatial resolution
- alternative forced choice methods
- receiver operating characteristic methods

**SUBJECTIVE**
- clinical images
Image Quality

• **Contrast sensitivity**
  – Spectrum, scatter and receptor characteristics

• **Blur/unsharpness**
  – Sharpness of edges and boundaries reduced and contrast reduced

• **Noise**
  – Visibility of low contrast objects reduced

• **Geometry**
  – Viewing perspective
  – Field of view
  – Distortion

• **Artefacts**
Image Quality

• Semi-quantitative measures
  – test objects
  – quick and easy assessment
  – non-invasive (field measurements)
  – subjective

• These test objects are used to assess the following Image Quality Parameters:
  – Contrast [Contrast-detail test object]
  – Limiting Spatial Resolution [Line pair test object]
  – Dynamic Range
Contrast-detail Test Object

Schematic drawing

Fluoroscopy image
Contrast-detail Curve
Effect of Dose/image

Low dose rate

High dose rate
Effect of Dose/image

![Graph showing the effect of dose on threshold contrast and detail diameter. The graph includes lines for low, medium, and high dose, with the x-axis representing detail diameter (mm) and the y-axis representing threshold contrast (%).]
Effect of XRII field size on c-d curve

- Change XRII field size
  - image magnified
  - dose rate increased

- Resolution of smaller details improved

- Higher dose rate = less quantum noise

- Resolve lower contrasts

- But patient skin dose rate higher
- smaller field of view
Spatial Resolution

• Resolution of fine detail in a radiological image is important
  – catheter tips
  – guide wires
  – vessel diameter
Limiting Resolution

Line Pair Test Object
ICRP Publication 60 and 103

1990 and 2007 Recommendations of the ICRP

- Dose quantities used in radiological protection
- Biological aspects of radiological protection
- Conceptual framework of radiological protection
- System of protection
Hierarchy of Dose Quantities

Absorbed Dose
energy imparted by radiation to a unit mass of tissue

Equivalent Dose
absorbed dose weighted for harmfulness of different radiations

Effective Dose
equivalent dose weighted for susceptibility to harm of different tissues

Collective Effective Dose
effective dose to a group from a source of radiation
Radiation quantities used in radiation protection

**SOURCE QUANTITIES**
- Tube current (mA), exposure time, kV, filtration

**FIELD QUANTITIES**
- Absorbed dose in air
- Dose-area product

**PATIENT DOSE QUANTITIES**
- Entrance surface dose
- Absorbed dose
- Equivalent dose
- Effective dose

X-ray tube

Dose-area product meter

Image receptor (film or image intensifier)
Effective Dose, $E$

- Sum of the equivalent doses to all organs and tissues in the body multiplied by their $w_T$
  \[ E = \sum_T w_T H_T \]

  Unit: Sievert (Sv) (=Jkg\(^{-1}\))

- $E$ gives information on overall risk of \textbf{stochastic effects} and can be used to compare risk from different types of exposure
Effective dose calculation

Effective dose = 

\[ H_{\text{lung}} \times 0.12 + H_{\text{breast}} \times 0.05 \]
\[ + H_{\text{thyroid}} \times 0.05 + H_{\text{liver}} \times 0.05 \]
\[ + H_{\text{gonads}} \times 0.2 + \ldots \ldots \text{etc for all named organs with } w_t \]

Organs without \( w_t \) counted in 'remainder'

Allows risks of different exposures to be compared
Practical considerations in the clinical setting

Factors affecting patient dose
Factors affecting patient dose

Patient dose will depend on

- the patient
- equipment specification
- operator technique
- equipment performance
Controlling dose to patients

• Routine straight forward procedures can become high-dose with poor technique
• Controlling dose to patients helps control dose to staff
Controlling patient dose I

• Keep beam on time to minimum
• Dose rates are higher and accumulate faster for larger patients
• Keep tube current (mA) as low and tube potential (kVp) as high possible
• Keep X-ray tube at a maximum and II at minimum distance from patient
Controlling patient dose II

• Collimate to area of interest
• For prolonged procedures change angulation to reduce skin dose
• Minimize fluoro’ time and high dose mode use
• Don’t overuse magnification modes
• Remove grid for small patients
Controlling dose to staff

- Wear protective apparel and use shielding devices
- Establish protocol for procedures (positioning etc.)
- Horizontal beam: Operator stands on II side
- Vertical beam: X-ray tube under patient
Controlling dose – general

• Ensure all staff have appropriate training
• Use appropriate equipment set up for the imaging task
• QA programs confirmed and in place
• Review protocols and procedures
Imaging Department

• Home of radiological expertise
• Protocol and procedure established by those with competence
• Provides radiological resource to clinical colleagues
• Backup and contingency support
Outside of Imaging Department

• Responsibilities tend not to be well established
• Procedures not consistent
• Ownership of procedures is not well understood
• May not be well supported
• Far from resources
Part III

Safety and Responsibilities

Radiation Safety - Justification and Optimization
# Three key things?

<table>
<thead>
<tr>
<th>Principles</th>
<th>Practicalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Justification</td>
<td>• Time</td>
</tr>
<tr>
<td>• Optimisation</td>
<td>• Distance</td>
</tr>
<tr>
<td>• Limitation</td>
<td>• Shielding</td>
</tr>
</tbody>
</table>
1. No practice involving exposures to radiation should be adopted unless it produces at least sufficient benefit to offset the radiation detriment it causes.

2. In relation to any particular source of radiation .... all reasonable steps should be taken to adjust the protection so as to maximise the net benefit, economic and social factors being taken into account.

3. A limit should be applied to the dose (other than from medical exposures) received by any individual...
The patient journey

1. Patient visits clinician
2. X-ray request generated
3. Patient has X-ray
4. X-ray read
5. Report sent to referring clinician
DUTY HOLDERS

• Employer and / or Owner of equipment
• Referrer
• Practitioner – the person that reads the images
• Operator
• Medical Physics Expert
EMPLOYER / OWNER

• Must ensure that framework to comply is in place, e.g.
  – Written policies for compliance
  – Written standard operating procedures
  – Record of trained staff
  – Establish diagnostic reference levels
  – Carry out clinical audit
REFERRER

• Must provide sufficient medical data for justification of exposure to be made
  – referral criteria must be provided to referrer
  – requests without sufficient data should be rejected
PRACTITIONER

• Clinical responsibility for the exposure
• Responsible for justification of individual medical exposures (with referrer)
  – Judge benefits against risk from dose
  – Consider alternative techniques

• Ensure clinical evaluation of exposure
Justification

• Based on data from referrer
• Objectives of the exposure
• Benefit to individual from exposure
• Risk to individual from exposure
• Use of other lower dose or no dose techniques
OPERATOR

• Range of operators and duties, e.g
  – ‘Pressing the button’
  – Optimising exposure (ALARP)
  – Checking patient ID
  – Checking pregnancy status

• Calibration of equipment is also an operator function
MEDICAL PHYSICS EXPERT

• Medical physicist with experience in diagnostic radiology, nuclear medicine or radiotherapy
  – Closely involved in therapy
  – Available for consultation in diagnostic procedures
Typical duty holders

• ** Employer:** Hospital Chief Executive
• **Referrer:** GP (family doctor), hospital doctor, etc
• **Practitioner:** radiologist, radiation technologist (radiographer), cardiologist
• **Operator:** radiologist, radiation technologist (radiographer), cardiologist
Diagnostic Reference levels (DRLs)

• No ‘dose limits’ for patients, but good practice expected, so:
• DRLs - dose not normally exceeded for each examination
  – can be specified as DAP or screening time
  – Further justification if certain levels exceeded on individual patient?
• Review initiated when DRLs consistently exceeded
DRLs and dose contraints

A *dose constraint* is a restriction on the prospective doses received by individuals whereas *DRLs* are for retrospective comparison with the average doses received by typical groups of patients.
DRLs for radiodiagnostic examinations

• medical diagnosis and treatment
• occupational health surveillance
• health screening programmes
• medico-legal procedures
National DRLs

Levels being established by Health Canada

COMP 2017 Winter School

Health Canada: Safety Codes and DRLs, Narine Martel

Diagnostic Reference Levels (DRLs): Concepts, Canada and Constraints, Graeme Wardlaw
Alternatives

• fundamental exposure parameters
• delivered mAs and kV or radioactivity used/injected
• control panel displays
• nomograms
Establish DRLs

- Audit techniques
- Review
- Set level
- Record and report
- Review
Incidents

• If patient receives dose ‘greater than intended’ due to clinical or procedural error then report to Regulator

• Guideline of 3x ‘intended dose’ for high dose diagnostic examinations
Part IV

Safety Culture

Training Challenges
Radiation Protection Engagement

- Health and Safety Committees
- Quality Committees
- Radiation Protection Committees
- Incident recording and reporting systems
- In service training
- X-ray department interactions
- Any opportunity
Why are we here?

- ICRP publication 33

No person shall operate radiological equipment without adequate technical competence, or perform radiological procedures without adequate knowledge of the physical properties and harmful effects of ionizing radiation
Manitoba Regulation 341/88R

Section 5(1)

No person shall use or prescribe the use of X-ray equipment for the irradiation of human subjects who is not authorized to do so by an Act of Legislature.
Manitoba Regulation 341/88R

Section 5(2)......

a) is registered as a radiological technologist......
b) Is in training to be a radiological technologist......
c) Possesses training and experience commensurate with radiological work he is called upon to do, and is authorized by the minister to do that work...........may operate X-ray equipment for the irradiation of human subjects.......
Training requirements

*Training is compulsory and should be commensurate with the work done*
The Manitoba Quality Assurance Program (MANQAP) Pursuant to The Medical Act, the Council of the College of Physicians and Surgeons of Manitoba has established a Program Review Committee which oversees the operation of the Manitoba Quality Assurance Program (MANQAP). The objective of MANQAP is to establish standards for diagnostic facilities, to investigate and inspect diagnostic facilities for accreditation and to monitor compliance with established standards.
College of Physicians and Surgeons of Manitoba

Manitoba Diagnostic Imaging Standards pursuant to By-Law No. 3 of the College of Physicians and Surgeons of Manitoba, Council has established standards governing diagnostic imaging facilities
6.0 Fluoroscopy

6.1 General

6.1.1. A facility must:

6.1.1.1 limit the performance of fluoroscopy procedures to:

1. a radiologist.
2. a radiology technologist student or medical student under the direct supervision of a radiologist.
3. a radiology resident physician approved by the facility director.
4. a physician who has satisfactorily completed didactic training by Radiation Protection and Imaging Physics Division of Manitoba.
5. a radiology technologist delegated by the facility director.

6.1.1.2 establish and maintain:

1. a list of procedures which may be done during non-core hours.
2. for referring physicians, a list of procedures performed at the facility.

6.1.1.3 provide protective lead aprons to all persons present in the fluoroscopy room during exposure.

6.1.1.4 use lead curtains on a stationary radioscopic unit during fluoroscopy.

6.1.1.5 provide a radiologist interpretive report on all fluoroscopic examinations.

6.1.1.6 provide the operator with a clear line of sight to the output display at all times.
Manitoba Diagnostic Imaging Standards

6.1.1. A facility must:

6.1.1.1 limit the performance of fluoroscopy procedures to:

......

......

4. a physician who has satisfactorily completed didactic training by Radiation Protection and Imaging Physics Division of CancerCare Manitoba.
Training

• Compulsory required by legislation
• Initial induction with update and refresher sessions
• Appropriate to the tasks and responsibilities commensurate with the level of radiation use
• Evaluation of knowledge and competence
• Evaluation of competence by appropriate groups
• Didactic and practical
Training

• Training programs should be oriented towards the type of procedures in which target audience is involved

• A worker’s competency to carry out a particular function should be assessed by individuals who are suitably competent themselves
Training course

• Fluoroscopy for the non-Radiologist
• Dedicated to work undertaken
• Practical hands-on equipment training is appreciated
• Provided by team of radiological professionals
• RP training for medical staff promoted by health authorities, regulatory groups and professional bodies
• Enables professional development
ICRP PUBLICATION 113
Education and Training in Radiological Protection for Diagnostic and Interventional Procedures

EDUCATIONAL SLIDES (E. Vano and C. Martin)
Version 12th March 2015
Table 3.1. Recommended radiological protection training requirements for different categories of physicians and dentists.

<table>
<thead>
<tr>
<th>Training area</th>
<th>Category 1 DR</th>
<th>Category 2 NM</th>
<th>Category 3 CDI</th>
<th>Category MDI</th>
<th>Category 4 MDX</th>
<th>Category 5 MDN</th>
<th>Category 6 MDA</th>
<th>Category 7 DT</th>
<th>Category 8 MD</th>
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<tr>
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<td>Typical doses from diagnostic procedures</td>
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<td>Suggested number of training hours</td>
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<td>30–50</td>
<td>20–30</td>
<td>15–20</td>
<td>15–20</td>
<td>8–12</td>
<td>8–12</td>
<td>10–15</td>
<td>5–10</td>
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</table>

Medical RP, radiological protection; DR, diagnostic radiology specialists; NM, nuclear medicine specialists; CDI, interventional cardiologists; MDI, interventionalists from other specialties; MDX, other medical specialists using x-ray systems; MDN, other medical specialists using nuclear medicine; MDA, other medical doctors assisting with fluoroscopy procedures such as anaesthetists and occupational health physicians; DT, dentists; MD, medical doctors referring for medical exposures and medical students; l, low level of knowledge indicating a general awareness and understanding of principles; m, medium level of knowledge indicating a basic understanding of the topic, sufficient to influence practices undertaken; h, high level of detailed knowledge and understanding, sufficient to be able to educate others.
Table 3.2. Recommended radiological protection training requirements for categories of healthcare professionals other than physicians or dentists.

<table>
<thead>
<tr>
<th>Training area</th>
<th>9 MP</th>
<th>10 RDNM</th>
<th>11 ME</th>
<th>12 HCP</th>
<th>13 NU</th>
<th>14 DCP</th>
<th>15 CH</th>
<th>16 RL</th>
<th>17 REG</th>
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<tr>
<td>Atomic structure, x-ray production, and interaction of radiation</td>
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<tr>
<td>Nuclear structure and radioactivity</td>
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<tr>
<td>Radiological quantities and units</td>
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<tr>
<td>Fundamentals of radiation detection</td>
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<tr>
<td>Principle and process of justification</td>
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<td>l</td>
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<tr>
<td>Fundamentals of radiobiology, biological effects of radiation</td>
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<td>Risks of deterministic effects</td>
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<tr>
<td>Particular patient RP aspects</td>
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<td>Particular staff RP aspects</td>
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<td>Risks from fetal exposure</td>
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<tr>
<td>National regulations and international standards</td>
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</tbody>
</table>

RP, radiological protection; MP, medical physicists specialising in RP, nuclear medicine, and diagnostic radiology; RDNM, radiographers, nuclear medicine technologists, and x-ray technologists; HCP, healthcare professionals directly involved in x-ray procedures; NU, nurses assisting in x-ray or nuclear medicine procedures; DCP, dental care professionals including hygienists, dental nurses, and dental care assistants; ME, maintenance engineers and applications specialists; CH, chiropractors and other healthcare professionals referring for, justifying, and delivering radiography procedures (amount of training depends on range of tasks performed); RL, radiopharmacists and radionuclide laboratory staff; REG, regulators; l, low level of knowledge indicating a general awareness and understanding of principles; m, medium level of knowledge indicating a basic understanding of the topic, sufficient to influence practices undertaken; h, high level of detailed knowledge and understanding, sufficient to be able to educate others.
Training content

• Relevant to the imaging tasks and procedure objectives
Thanks for your kind attention
END OF PRESENTATION