Key issues of occupational radiation protection in interventional procedures

2017 Course of the Nordic Association for Clinical Physics on occupational dosimetry in hospitals

27 September 2017
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Retired member of the ICRP and the IAEA
ICRP has issued reports on protection in interventional procedures including advice on occupational protection.
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Public consultation April-June 2017
Expected publication 2018
Contents of the draft

- Executive summary
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- Application of the principles to occupational protection in interventional procedures
- Dosimetry and exposure assessment
- Radiation protection methods and devices
- Summary of recommendations
- Annexes:
  - Biological effects of radiation
  - Relevant quantities and units
Uses and challenges
Uses

- Interventions are usually guided by fluoroscopy, and radiographic cine-like series of images.
- The number of interventional procedures is increasing greatly in both developed and developing countries.
- New types of interventions are also of increased complexity, require extensive use of x-ray imaging and raise new issues of occupational protection.
Interventions can also be guided by CT imaging (either ordinary CT or CT-fluoroscopy).

Imaging guided Selective internal radiation therapy (SIRT), embolisation with $^{90}$Y-labeled microspheres.

Several hospitals are exploring the use of real-time PET-CT-guidance during interventional procedures.
Challenges: exposure to eye lenses (cont’d)

- Ophthalmological studies were conducted on a sample of interventional cardiologists and nurses attending cardiology congresses (under an IAEA RELID study).
- About 40–50% of interventionalists, an incidence rate which was 4–5 times higher than that of the unexposed individuals in the control group, and 20–40% of technicians and nurses participating in the studies were found to have posterior subcapsular opacities.
The nature of interventional procedures is such that, without protective measures for the eyes, personnel with a medium or high workload could receive eye lens doses above the new annual dose limit, and over time these doses could result in eye lens opacities.
Challenges: extremity doses

- Dose to the interventionalist’s hand that is nearest to the irradiated patient volume can be high and, in some cases, may require specific monitoring.
Challenges: extremity doses

- Values for annual lower extremity doses up to 110 mSv have been found, despite the use of a protective curtain suspended from the patient couch. This exposure is attributed to the gap between the protective curtain and the floor.
Examples of errors in wearing the dosimeters include:

- not using the assigned dosimeter,
- wearing a dosimeter assigned to another person,
- losing a dosimeter,
- wearing a dosimeter over the apron that was intended for use under the apron,
- wearing a ring dosimeter on the incorrect hand.
Occupational exposure monitoring and dose assessment
Purposes of occupational dosimetry

- Verification of compliance with dose limits of
  - Effective dose
  - Equivalent dose to the eye lenses
  - Equivalent dose to the skin
  - Equivalent dose to the extremities
- Optimization of protection
Dosimetry in verification of compliance with dose limits
In most practices, effective dose is assessed from the reading of a personal dosimeter calibrated in terms of personal dose equivalent, $H_p(10)$.

This approximation of the effective dose from $H_p(10)$ is conservative, especially for low penetration of radiation,

but it is acceptable for most practical activities with a relatively homogeneous irradiation.
Determination of effective dose in interventional procedures

- The trunk of the body is shielded by the apron while head, neck and extremities are not.
- Dose distribution is extremely inhomogeneous
The reading of a single dosimeter $H_p(10)$ over the protective apron overestimates effective, while the single dosimeter placed under the apron underestimates effective dose.
If only one dosimeter is used, it should be placed over apron, and the reading should be corrected by a factor lower than 1 (for example 1/10) to account for the protected part of the body.

\[ E \approx 0.1 \, Hp(10) \]
A more accurate approach to effective dose makes use of the readings of two dosimeters, one shielded by the apron and one unshielded above the apron, and combining the reading in a linear form

\[ E = \alpha H_u + \beta H_o \]
Determinación of effective dose

- There is no optimal algorithm for all possible radiation geometries (CONRAD study).
- Therefore, compromises have to be made when making a choice.

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>With thyroid shielding</th>
<th>Without thyroid shielding</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>$\alpha$</td>
<td>$\beta$</td>
</tr>
<tr>
<td>Swiss Ordinance [2008]</td>
<td>1</td>
<td>0.05</td>
</tr>
<tr>
<td>McEwan [2000]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Von Boetticher et al. [2010]</td>
<td>0.79</td>
<td>0.051</td>
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Table 4.1. Values of $\alpha$ and $\beta$ [adapted from Järvinen et al. (2008)] of the algorithms that best meet the criteria of no underestimation and minimum overestimation for the typical geometries, and an algorithm based on Publication 103.
The two-dosimeter approach

With information of \( Hp(10) \) under the apron, the approach provides reassurance that an apron with sufficient attenuation has been regularly worn.
In summary, for assessing effective dose

• The ICRP continues to recommend the use of **two dosimeters**, over and under apron

• If for a given institution, it can be reliably assumed that all professionals wear protective aprons with sufficient attenuation during all interventions, **the under-apron dosimeter** could be omitted for the majority of staff members

• However, two dosimeters are still recommended for the **interventionalist** performing the procedure, who **typically** receives the highest occupational doses
In addition

• The dosimeter over the apron, if placed at collar level, provides a reasonable estimation of the dose to the parts of head and neck, not protected by the apron.
Eye lens
The operational quantity is $H_p(3)$.

However, $H_p(0.07)$ can be used as an approximation to $H_p(3)$ for photon radiation of all energies used in radiology;

$H_p(10)$ could be also used for this purpose, but only if the photon spectrum has a mean energy above 40 keV.
Assessment of eye lens doses

- If the over apron dosimeter is placed on at collar level, the $H_p(0.07)$ reading, provides a reasonable estimate of eye lenses exposure, when no eye glasses are worn.
- But, when eye glasses are worn …the dose read from the collar dosimeter would need to be divided by a DRF.
Dosimeter for eye lenses and glasses are worn

- When using protective lead glasses or face masks, the dosimeter shall be worn behind them (ISO 15382).
Extremities
Exposure monitoring to the extremities

- Assessment of dose to the hands in some specific complex interventional procedures, with hands close to the irradiated volume of the patient, needs more attention in the future (wrist or ring dosimeters).
Hand close to or in the radiation beam

- When part of the hand is very close to the direct x-ray beam, the wrist dosimeter may underestimate the actual doses to the part of the hand placed at the border of the beam.

- In the case that a finger is introduced in the beam, especially a CT slice not even the ring dosimeter may not provide a good estimate of the dose to the part of the finger in the CT beam (finger tip doses)
Similarly, assessment of exposure to the lower extremities, including the feet, will also require increased attention, especially when protective curtains are not available or there is a gap between the curtains and the floor. A gap may be present, depending on the height of the table during the intervention.
To the future

- Research efforts should pursue the development of computational technologies with personnel position sensing, to assess personnel doses, including eye doses (IAEA, 2014b; NCRP, 2016).
Dosimetry in optimization tasks
Dosimetry for optimisation

- When optimization tasks are focused on one particular type procedure or one particular protective action, direct reading active dosimeters may be more useful.
- If an optimisation task affects globally all procedures and activities, then the regular TLD dosimetry can be used to compare and assess the effectiveness of the action, for example a dose reduction.
Protective measures and devices
Methods and devices for occupational protection

- Relationship between patient and occupational exposure
- Use of investigation levels
- Protection of embryo and fetus
- Use of protective aprons
- Use of ceiling suspended screens
- Use of lead glasses
- Protection of the hands
- Protection of the feet
Most actions to protect the patient protect also the staff

- Reduction of fluoroscopy time, number of acquisition runs and number of images per run,
- Use of lower-dose mode fluoroscopy and acquisition, lower pulse frequency,
- Last image hold and image loops,
- Image receptors close to the patient, collimation to the required field of view (FOV),
- Cautious use of steep oblique projections,
- etc
There are, however, additional actions and devices that protect the staff only. These are:

- These are: protective apron and collar, ceiling-suspended shield and leaded eye glasses, tabletop-suspended leaded curtains, stepping back to increase distance from the patient and staying on the image receptor side rather than on the side of the x-ray tube.

But, the use of occupational protection devices should not interfere with the procedure and not jeopardize the clinical result, nor increase patient exposure.
In summary:

- Occupational protection is very much linked to patient protection, is dependent on the procedures and should be managed in an integrated approach with patient protection.
An investigation level for a monthly dose should be such that when extrapolated to a year, it can approach but not exceed the relevant dose limit.

Minimum dose values for the over-apron and hand dosimeters can be established to provide an alert for possible poor compliance on wearing dosimeters.
Protection of embryo and fetus

- The working conditions of a pregnant worker, after the declaration of pregnancy, should be such as not to exceed about 1 mSv to the conceptus during the remainder of pregnancy.
- Unnecessary discrimination against pregnant workers should be avoided. Currently, available data do not justify automatically excluding pregnant interventionalists or other workers from performing procedures in the interventional room.
- If the under apron dosimeter is placed on the abdomen and shows a value for personal dose equivalent, Hp(10)< 0.2 mSv per month, the equivalent dose to the conceptus would be below the dose limit.
Use of protective devices
Shielding aprons should be worn by all interventional staff working inside the x-ray room.
Avoidance of musculo-skeletal problems: attention to apron weight

- There are reports of musculo-skeletal injuries among interventionalists (Papadopoulos et al., 2009; NCRP, 2010; Klein et al., 2015)
Lighter aprons

- Lighter-weight aprons that contain composite layers or bi-layers of high atomic number elements such as tin or bismuth, instead of lead.
- Characterisation in terms of “lead equivalence” can be misleading, since photon attenuation varies significantly over the photon energy spectrum, with the largest variations occurring in the imaging range.
- The specification of the protective value of garments should be accompanied with an indication of the characteristics of the radiation beams used to measure the attenuation.
- The combination of measurements made at different beam qualities should reflect the conditions under which the garment is used.
Uncovered parts of the body

- Aprons shield the trunk against scattered radiation, but parts of the body including the head, arms, hands and legs are not protected by the apron.
Thyroid protection: cancer incidence thyroid vs. age at exposure

![Graph showing the risk of exposure-induced cancer incidence per Sv (Sv) against age at exposure (y). The graph compares female and male data.](image)
A close fit of leaded glasses to the facial contours, particularly around the sides and underside of the glasses, is important because the clinician is looking up at the image monitor during exposures. As a result, the eyes may be irradiated from the side and below directly by the radiation scattered by the patient.
Use of ceiling-suspended shielding

- Apart from the apron, the most important element in protection of the head is the proper use of ceiling suspended lead acrylic shields.

- They should always be included in interventional installations, as they can reduce doses to the whole head and neck by a factor of 2–10, depending on how efficiently they are positioned.
The interventionalist can reduce doses received during the use of high-dose acquisition modes, such as image acquisition series and DSA, and during injection of contrast media using an automatic injector, and by stepping back to increase the distance to the patient.
Hands particularly close to the beam, such as in percutaneous biliary drainage, nephrostomy tube placement, and gastrostomy placement.
Use of protective drapes

- Disposable lead drapes and pads can be effective in protecting the hands in some procedures. This type of protection should be considered for procedures where the operator needs to be close to the source of scattered radiation (i.e., the irradiated volume of the patient).

- When placing disposable drapes on the patient, attention is required to avoid placing the drapes in the primary beam, which might increase patient and operator exposure.
Quality assurance programme

• Quality assurance with regular documented checks to confirm that professionals involved in interventions guided by radiological imaging always wear their dosimeters and protective equipment including eyewear is very important.

• Acceptance tests for protective devices are crucial; some supplies of defective protective clothes have been documented. In addition, handling protective devices with care (e.g. avoid folding) and regular testing are required as part of the quality assurance.

• The radiological protection programme should include audits of occupational doses, investigation of abnormal exposure, reporting and recording results as well as corrective actions if appropriate.
Expensive lead aprons sent to the cleaning service of the hospital without the appropriate instructions.
Education and training

- Initial and continuing education and training of professionals is required.
- Imaging equipment, procedures and use of radiological protection tools, such as ceiling suspended shields and/or leaded eyewear and shielding curtains.
- Use of real-time active dosimeters not only helps in optimising protection of specific high dose procedures but also contributes to education of professionals on the level of doses being received.
Radiation protection specialists need not only knowledge of general radiological protection but also …

- of the clinical practice,
- the x-ray equipment used in interventions,
- strategies for occupational exposure assessment,
- the protection methods and
- selection and testing protective garments.
Thank you for your attention