Monitoring occupational radiation doses in fluoroscopy applications

CIRMS

October 2010

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Introduction

- Medical environments where fluoroscopy is routinely used offer unique challenges for monitoring and reporting of occupational radiation doses. While exposures to personnel may be quite substantial, they are reduced by the use of protective garments such as lead aprons and thyroid shields.
- Protective garments shield a large portion of an individual's body, whereas unshielded areas may receive significant dose. Appropriate assessment of these non-uniform exposures has been a continuously debated topic among radiation experts (1).

Placement of dosimeters

Early experimental data on the radiation dose received by radiologists performing fluoroscopy was based on the readings registered by dosimeters placed at different locations of the body.

These data indicated that information on the location should be an integral part of personnel monitoring record (2). The most commonly used locations were waist or chest area under the lead apron and the outside of the collar.

Other locations included: forehead, eye area (clipped to eyeglasses), wrist, and fingers.

Arguments in favor of placement of dosimeters inside the protective apron

- the trunk represents a location consistent with that employed in situations when protective garments are not used;

- realistic measurements are best made by placement representative of the dose of the bulk of the body organs;

- placement at waist level inside the lead apron enables monitoring embryo/fetus dose in case of an undeclared or unknown pregnancy in female workers (1).

Arguments for collar placement of the dosimeter

- once shielded, the trunk of the body is no longer a critical organ;
- eyes and thyroid become more important since the doses can be significant;
- it is desirable to conservatively monitor the region of highest radiation doses to be able to detect potential accidents, particularly involving eyes;
- the use of shielded dosimeter may not produce dose information of notable magnitude;
- collar badge placement enables a reproducible measurement and assessment of radiation environment (1).

National Council on Radiation Protection and Measurements (NCRP)

Over the years, international and national radiation protection expert bodies expressed varied opinions and made inconsistent recommendations much to disappointment of professionals entrusted with implementing personnel dosimetry in medical environments. In the US, the advisory body, NCRP:

- in its 1966 Report 32, suggested that dosimeters be worn in location representing the part of body most likely to receive highest exposure;
- in its next report in 1968 (Report 33), recommended that whole-body dosimeters be worn on the chest or abdomen, and recognizing the difficulties for situation when protective garments are worn, suggested that the opinions of qualified experts be sought for such cases;
- in 1971, in its Report 39, the council suggested that separate dosimeters be worn on the trunk, eyes and extremities;

NCRP (cont)

- in Report 48, in 1976, an explicit recommendation was made that dosimeters be worn outside the lead apron, and an ambiguous statement was added that they be carried in a pocket or pinned to clothing;
- in 1978, in Report 57, a recommendation was made that a dosimeter be worn under protective garments, with a second one to be worn if the thyroid or the eye is considered the dose-limiting organ;
- the same year, Report 59 recommended that in diagnostic radiology dosimeters are best positioned on the collar when protective garments are used since the monitoring device should be worn at the body part most likely to receive the greatest proportion of dose equivalent;
- in 1981, Report 68 suggested again that one dosimeter be used inside the lead apron (for bone marrow dose) and another outside the apron to represent the dose to unshielded thyroid and eyes.

ICRP & State Agencies

- Introduction of EDE (Effective Dose Equivalent) in the ICRP Report 26 in 1977, and then a related quantity ED (effective dose) in the ICRP Report 60 in 1992, and subsequent adoption of this dose quantity in State and Federal regulations somewhat altered the debate about the placement of dosimeters for the purpose of monitoring of occupational exposures in medical environment (3). However, no firm resolution has been reached thus far.
- Some State agencies have taken positions concerning dosimeter placement i.e. on the chest or abdomen, while requiring separate dosimetry for the lens of the eye. Historically, nearly all State regulations have recommended collar placement as well (4).

Determination of EDE in Fluoroscopy

EDE represents a weighted summation of the dose equivalents to various body parts. This representation of radiation dose influenced decisions regarding the choice and optimal placement of a single or multiple dosimeters accounting for the anticipated contributions of equivalents to various portions of the body. The issue of how best to compute the individual's total EDE became a challenge, particularly in medical environments in which fluoroscopy is used. From the viewpoint of EDE, the most important tissues/organs would be:

- whole body (weighting factor $w_T = 1.0$), with dose to the major portion of the body best estimated by a dosimeter placed under the lead apron;
- red bone marrow, $w_T = 0.12$, outside of shielded area of the body i.e. arms and legs, which would not be included in the whole body dose estimate;

Determination of EDE in Fluoroscopy (cont)

- the testes, $w_T = 0.25$ (ICRP 26, 1977) or $w_T = 0.20$ (ICRP 60, 1992);
- the thyroid, $w_T = 0.03$ (ICRP 26, 1977) or $w_T = 0.05$ (ICRP 60, 1992;
- lungs, $w_T = 0.12$, dose accounted for by whole body estimate.

The non-stochastic dose limitations should be considered as well. Since the weighting factor for the thyroid is small (and thyroid shield may be worn), it is anticipated that the eye will represent a more significant tissue than other areas to be monitored by a dosimeter outside the protective garments at collar level.

Many numerical relationships between monitoring data and EDE have been proposed to derive at more accurate dose estimates. Three most common and well accepted relationships are found in the publication by Webster in 1989 (5), and recommendations of the CRCPD (Conference of Radiation Control Program Directors) in 1995 (6) and the NCRP in 1995 (7).

Dose estimates with multiple dosimeters

The original empirical formula (5) for computation of EDE when two dosimeters are worn (one under lead apron, another unshielded at The collar) was:

[1] $$EDE = 1.5\ H_1 + 0.04\ H_2$$

where H_1 represents dose equivalent measured by a dosimeter at waist level under the lead apron and H_2 represents dose equivalent measured using a dosimeter at collar level outside the protective shields.

The use of this formula in fluoroscopy environment met with criticism from medical physics community as it resulted in substantial errors (8). Then came alterations in the recommended values of tissue weighting factors; they were followed by re-evaluation of the EDE formula [1] and derivation of an empirical formula for ED (9):

[2] $$ED = 0.5\ H_1 + 0.025\ H_2$$

Multiple dosimeters (cont.)

While having some practical merit, the above formula applies only to conditions similar to those for which the equation was developed. The investigators have warned that extensive use of it as it may underestimate of up to 2%. At the same time, the use of thyroid shields may reduce the effective dose by at least a factor of 2.

Further work in this area produced additional formula: (10)

[3] $$ED = H_1 + 0.06\ (H_{2,shallow} - H_1)$$

Analysis of the above equation (1) reveals that for high dose scenarios underestimation of less that 30% may be expected, and for low dose scenarios underestimate would vary from 20 to 36%.

Dose estimates with a single dosimeter

It has been shown that for the EDE, use of a single dosimeter at the waist under the lead apron underestimates the dose by a factor as high as 65(11).

When a single dosimeter is worn unshielded at collar level, Webster (5) recommends the measured deep dose equivalent (DDE) to be multiplied by 0.3 to derive at the value of EDE for external radiation. This is a conservative approach thus the derived EDE value is overestimated (12).

In 1995, the NCRP issued Report 122 (7) that states the following:

> *When a single personal monitor worn at the neck outside and above a protective apron is used, dividing the personal dose equivalent (i.e. deep dose equivalent by 5.6 to obtain a conservatively high estimate of EDE is recommended.*

Discussion of methodologies & regulations

Also in 1995, the CRCPD issued a document (6) with model regulations for voluntary use by state authorities with applicable provisions:

> *When a protective apron is worn while working with medical fluoroscopic equipment and monitoring is conducted as specified, the EDE for external radiation shall be determined as follows:*
>
> – *When only one individual monitoring device is used and it is located at the neck outside the protective apron, the reported deep dose equivalent shall be the EDE for external radiation; or*
>
> – *When only one individual monitoring device is used and it is located at the neck outside the protective apron, and the reported dose exceeds 25 percent of the limit specified, the reported deep dose equivalent value multiplied by 0.3 shall be the EDE for external radiation."*

In 2002, the US NRC issued a Regulatory Issue Summary,RIS2002-06.

It lists the CRCPD guidance as *acceptable alternative method for Compliance with 10CRF Part 20 with occupational exposure to medical X-ray radiation when protective apparel is used.*

Conclusion

- State regulations are lacking consistent requirements
- CO: For <145 kVp
  - When apron & no thyroid collar used: DDE=0.06(collar dose-waist dose) + waist dose
  - When apron & collar used: DDE=0.02(collar dose-waist dose) + waist dose
- University of CO Hospital Program requested and received approval to follow CRCPD guideline.

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