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GUIDANCE ON PERSONAL DOSIMETRY FOR OCCUPATIONAL EXPOSURE IN INTERVENTIONAL RADIOLOGY

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ABSTRACT

During examinations which involve significant levels of exposure, radiology staff wear protective aprons and move towards various exposure orientations. The resulting body exposure is extremely non-uniform. Under such conditions the partially unshielded organs in the trunk together with tissues and organs in the head and neck region determine the effective dose equivalent[1]. Principally, the same will be true for the newly introduced primary quantity effective dose. New calculations are required for quantitative assessments, because the selection of relevant organs and their weighting factors were changed[2]. In this paper we describe our calculations and we present and discuss conversion factors for the assessment of effective dose in typical exposure situations for radiology staff in interventional radiology.

INTRODUCTION

A particular objective in setting up new calculcations was to examine the ratio between the effective dose and the corresponding operational quantity for depth dose measurements in personal monitoring. Such data is essential to derive correction factors for converting personal dosimetry measurements into effective dose, both with regard to measurements under the protective apron as well as for unshielded measurements. Knowledge of such conversion factors allows for more accurate assessment of the effective dose. This is especially needed in working conditions which involve a high workload of fluoroscopic examinations[3]. On the one hand to avoid excessive overestimation of effective dose, since this could lead to unduly limiting necessary activities. On the other hand, more accuracy may be needed to avoid underestimation which could cause serious problems in complying with regulatory dose limits or with ALARA protection standards. There now is a greater need for appropriate data then before, because lower limits have been recommended for occupational exposure[2].

OPERATIONAL QUANTITIES

For personal monitoring of external radiation, ICRP[2,4] and ICRU[5] recommend assessment of the dose equivalent in soft tissue below a specified point on the body at a reference depth of 10 mm. Recently, ICRU[6] made changes to the name and definition of the related operational quantity. It is now called personal dose equivalent. Since this quantity is defined *in* the body it varies from person to person and values are strongly dependent on the reference location on the body and on the exposure orientation. For the purpose of personal monitoring it is therefore generally recommended to revert to the directional dose equivalent $H'(10,\omega)$ on an appropriate radius in the ICRU tissue equivalent sphere, or a similar approximation for another appropriate phantom.
It is universally known that the directional dose equivalent, when it regards uniform external exposure to photons below 100 keV, gives a significant overestimation of effective dose equivalent[4,5]. The degree of overestimation is even greater for the newly introduced effective dose. Zankl et al.[7] have reported from their model calculations, that for uniform total body exposure, the effective dose is always less than the effective dose equivalent. Lower values occur mostly due to the largely modified concept of the remainder organs and the changes in the weighting factors, especially for shallow organs and breast tissue. Figure 1 gives the calculated ratio of effective dose to directional dose equivalent for mono-energetic photons in the low energy range. The overestimation of effective dose is a factor of 2 or more, for energies below 70 keV and it is most prominent for lateral and posterior-anterior orientations. It is important to recognize that especially these orientations predominantly determine the resulting effective dose in actual practice, depending on the degree of shielding on the sides and the back of the trunk.

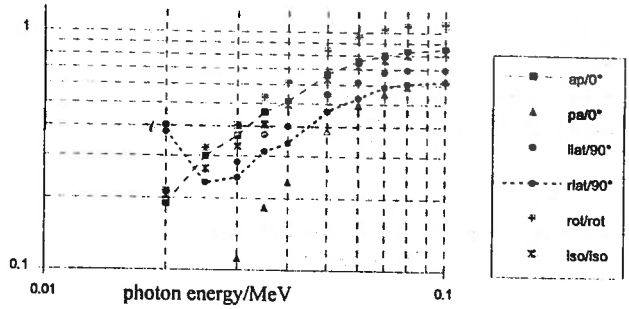

Figure 1
Ratio of effective dose to directional dose equivalent for mono-energetic photons up to 0.1 MeV, in various whole body exposure orientations. Calculations of the effective dose based on data from Zankl et al.[7]. Values for the directional dose equivalent are from ICRU[5] and ICRP[4].

CALCULATING EFFECTIVE DOSE

For our calculations we have adopted the organ dose conversion coefficients per unit kerma-in-air from the work of the German Institute for Radiation Protection GSF[7,8]. These conversion coefficients were calculated by GSF using their mathematical phantoms and applying a Monte Carlo code simulating the photon transport and the energy deposition in relevant organs and tissues which are implied in the ICRP concepts for effective dose and for effective dose equivalent. From the mono-energetic data we evaluated spectral weighted values for the unshielded X-ray spectrum (u) of scattered radiation and for the hardened spectrum (s) after transmission through protective shielding. All our calculations refer to whole body exposure with broad parallel beams in anterior-posterior (AP), posterior-anterior (PA) and left and right lateral (LAT) orientations.For each particular exposure orientation the equivalent dose to organ T is calculated, accounting for the shielded fraction s of that organ and the transmission fraction for scatterd radiation t through the protective device, related to the quantity kerma-in-air. The resulting organ equivalent dose per unit kerma-in-air in a particular exposure geometry is then calculated as the weighted sum over the respective orientations OR, in proportion with the time fraction f in each orientation. The corresponding formula is:

$$H_T = \sum_{OR} f \left\{ (1-s)\left[\frac{H_T}{K_a}\right]_u + s\,t\left[\frac{H_T}{K_a}\right]_s \right\} \qquad (1)$$

The resulting effective dose per unit air-kerma is calculated as the weighted sum over relevant organs with their assigned weighting factor, according to the definiton in ICRP Publication 60[1]. It is obvious that a similar calculation applies for the effective dose equivalent. However, the selection of organs as well as their weighting factors is then conform the previous definition in ICRP Publication 26[9].

CALCULATING DEPTH DOSE EQUIVALENT

Our calculations for the related operational quantity in personal monitoring refer to the dose equivalent at 10 mm tissue depth at the front side of the trunk. For this depth dose equivalent we use the simplified notation HP. Personal dosimeters are usually calibrated in AP orientation only, and the actual angular response in LAT and PA orientation is then neglected when worn at the front of the body. Under these assumptions we have calculated unshielded HP_u values for depth dose measurements outside the apron, and shielded HP_s values which apply under the protective apron. Our method for calculating HP per unit kerma is similar to equation (1), but with use of conversion coefficients for the directional dose equivalent $H'(10,\omega)$ in the ICRU sphere[4,5].

CONVERSION FACTORS

As is obvious, the unshielded HP_u values always significantly overestimate the effective dose, while it is underestimated by shielded HP_s values at the front side under the apron. The ratio between calculated values for the unshielded depth dose equivalent and the corresponding effective dose with use of a protective apron is further described as the divider. It represents the division factor for converting unshielded HP_u values at the front side of the body into the effective dose, in a particular exposure situation. Similarly, we use the name multiplier for the calculated multiplication factor for deriving the effective dose from shielded HP_s values for the depth dose equivalent at the front side under the apron. Additional to the divider and the multiplier we have calculated the protection factor, which describes the actual protective effect of a particular apron in a particular exposure situation. The protection factor is defined as the ratio between the calculated effective dose without and with use of an apron respectively. Values for the protection factor, divider and multiplier have been calculated for a variety of exposure situations which were modelled to simulate actual exposure conditions of staff in interventional radiology.

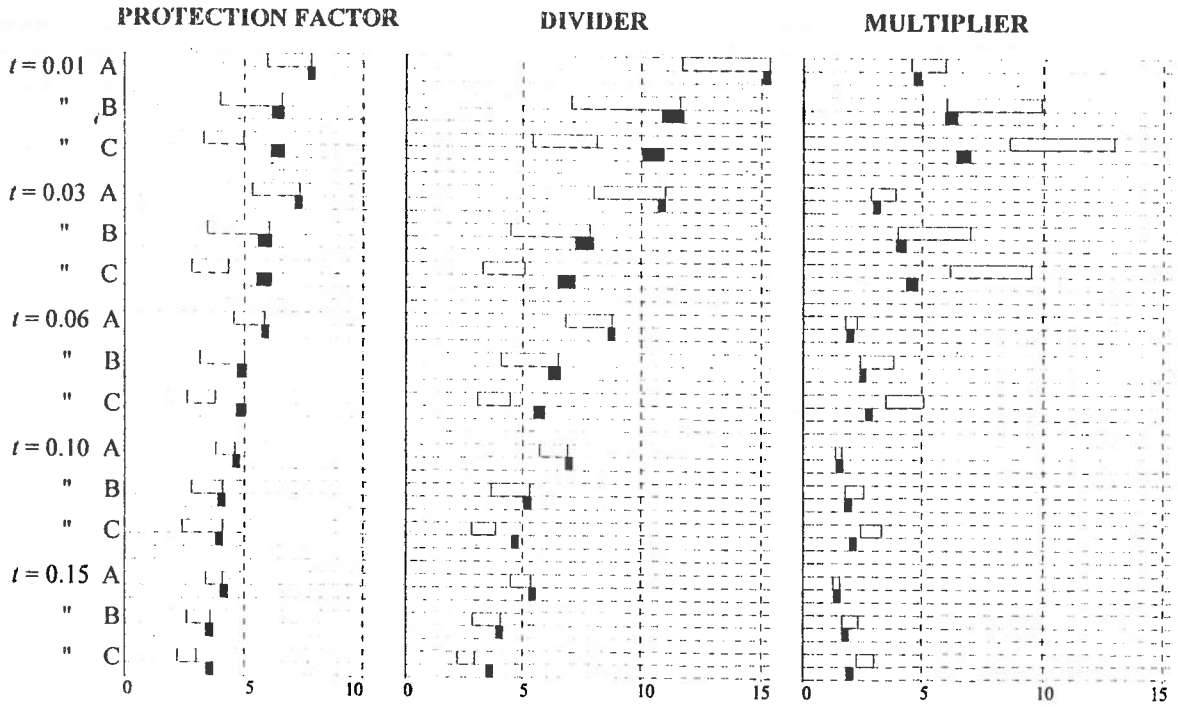

Figure 2 *Calculated values for conversion factors. Open bars refer to frontal apron; filled bars refer to wrap-arounds. Further explanation is given in the text.*

EXPOSURE SITUATIONS

Each exposure situation describes a particular combination of the characteristic features of the chosen apron and the assumed exposure orientations. Results of our calculations are summarized in Figure 2, repeatedly for three geometries. Geometry A refers to 100% AP orientation; geometry B refers to 70% AP with 30% LAT orientation and geometry C implies 60% AP with 10% PA and 30% LAT orientation. Results are presented for different values of the transmission fraction t, which correspond to apron thickness in combination with the energy spectrum of scattered X-rays. Without explanation we note that transmission values of 0.03, 0.06 and 0.10 correspond to an apron thickness of 0.5 mm, 0.35 mm and 0.25 mm lead equivalence respectively. This correlation applies to usual mean energies of scattered X-rays around 50 keV. For significantly higher or lower scattered energies the transmission fraction shifts to the next higher or lower value. The results in Figure 2 are given separately for wrap-around aprons and for frontal ones, both without shielding of the neck region. The presented range of calculated values in each case is correlated to variations in adopted values for the shielded fractions of trunk organs. These variations account for differences in size and fit of an apron in a particular exposure orientation.

PROTECTION FACTOR

Observation of the calculated protection factors draws attention to the fact that increasing the shielding thickness of an apron does not imply that the protective capacity improves significantly. It is noteworthy that doubling the lead thickness of frontal aprons above 0.25 mm doubles the weight of the apron but hardly reduces the effective dose in practice. This is trivial because of the dominating influence of unshielded organs and tissues. In particular, the unshielded tissues in the neck region account for roughly half or more of the resulting effective dose under the apron. Additional neck shielding with 0.25 mm lead equivalence therefore doubles the protection factor. The displayed results clearly show that the protection factor is predominantly dependent on the size and fit of the apron in combina-

tion with the exposure orientation. Wrap-around aprons provide much better protection in LAT and PA orientation. For geometry C the protection factor on the whole is a factor 1.5 better than for frontal aprons of equal thickness. A more striking feature is that the protection factor for wrap-arounds is less sensitive to body rotation in the scattered field around the patient and also less variable with differences in the fit of an apron. The composite uncertainty due to orientation and fit together, is small for good fit wrap-arounds but goes up to a factor 2 or more for frontals.

DISCUSSION ON PERSONAL MONITORING

Calculated values for divider and multiplier clearly show that a reasonably accurate estimation of effective dose from single badge depth dose measurements requires knowledge of the shielding thickness of the apron. However, what appears to be more critical are the size and the fit of an apron. For the good fit wrap-arounds reliable estimates are possible. For exposure situations as they occur in fluoroscopic interventional practice we conclude a reduction factor of 5 for converting unshielded HP_u measurements at the front of the body into an estimate for the effective dose. Our study shows that this in fact is a prudent figure for the divider which was calculated for a good fit wrap-around apron of 0.25 mm lead equivalence, accounting for a substantial LAT and AP exposure. More precise choices only can be made with detailed knowledge of the actual exposure conditions. For general conclusions some conservatism is justified to avoid unwarranted underestimation. A multiplier of 3 seems adequate for estimating the effective dose from shielded depth dose measurements where it regards wrap-around aprons with 0.25 and 0.35 mm lead equivalence. However, for greater shielding thickness the multiplier goes up to 5 and above.
Our calculations show a wide range of uncertainty for divider and multiplier when frontal aprons are used. This hampers the allocation of a generally applicable correction factor. Especially where it regards thick frontal aprons, shielded HP_s measurements may excessively underestimate the effective dose. Our findings certainly argue against single badge monitoring with placement of the dosemeter under aprons. In high exposure working conditions it then will be difficult to demonstrate compliance with recommended dose limits without unduly limiting occupational activities. Additionally, substantial levels of effective dose may remain unassessable due to the considerable enhancement of the lower detection limit. The complete lack of any dosimetric information then makes it highly speculative to assess equivalent doses for the head and neck region and for organs that are only partially shielded. Single badge dosimetry above the apron more adequately meets to these objections. It must be recognized however, that unshielded HP_u measurements show a wide dispersion according to the chosen position on the body. From our experience[10] we know that there is a variation of a factor 2 between left and right at the body and also a factor of 2 between high and low. The recommendable position for a dosemeter in the practice of interventional radiology is at "collar level" above the apron. At that position minimal angular variations occur.
As a final remark we wish to emphasize that particularly in situations where occupational doses may reach recommended dose limits, single badge monitoring is often not sufficient. Accurate assessment of effective dose in such situations is very complex and requires special expertise in dosimetry for the organization and interpretation of additional monitoring and calculations.

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