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D9.117 – Fluence to dose conversion coefficients for non-reference phantoms for photons and neutrons

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Abstract

The goal of the PODIUM project is to develop a software application that allows calculation of the radiation worker doses of interest by combining positioning information from a staff monitoring system and information on the radiation field. The aim is to provide fast dose calculations for workers moving in realistic workplace fields. These calculations will be based on Monte Carlo (MC) methods and need to employ a variety of computational body phantoms, assuming various postures inside the radiation field (e.g., standing, bending over something, hands stretched out into the radiation field) and having different body statures (tall, small, broad). One approach is using a library of pre-calculated conversion coefficients as a first approach of the fast online dosimetry application for workers in the realistic workplaces of WP4 (interventional radiology) and WP5 (neutron fields). For this purpose, a database of pre-calculated fluence to organ and effective dose conversion coefficients was established. This database will cover different relevant phantom postures, statures and positions in the field as well as photons and neutrons of different energies and in different irradiation geometries. Deliverable D9.117 is presenting fluence to dose conversion coefficients for phantoms having non-reference statures, for photons and neutrons.

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I. Introduction: fluence to dose conversion coefficients and their role in PODIUM

The objective of this deliverable of PODIUM WP2 is to provide a library of pre-calculated conversion coefficients as a first approach of the fast online dosimetry application for workers in the realistic workplaces of WP4 (interventional radiology) and WP5 (neutron fields). Especially for neutron dosimetry, it was to be expected that fast (i.e., real-time) Monte Carlo radiation transport would not be feasible within the duration of the PODIUM project. For photons, the database of pre-calculated fluence to dose conversion coefficients can back up the fast Monte Carlo calculations of Task 2.3.

This database covers different relevant phantom statures and positions in the field as well as photons and neutrons of different energies and in different irradiation geometries.

II. Fluence to dose conversion coefficients for photons

The photon conversion coefficients were aimed at serving the needs of the workplaces considered in the frame of the PODIUM project, i.e., interventional radiology. Hence, phantoms with protective lead garment were used for the simulations, and radiation incidence was limited to (a) the upper part of the body and (b) anterior and anteriorly oblique directions of photon incidence. To account for the inhomogeneous radiation incidence on the body, the body was sub-divided into six smaller sections (called “panels”) for which separate conversion coefficients were calculated. There were three panels in height (called “Top”, “Mid”, and “Bottom”), on both sides (left and right). On each of these panels, incidence of parallel mono-energetic photon beams under various angles was considered. Angles in horizontal directions ranged from 60° left-anteriorly oblique (“LAO60”) to 60° right-anteriorly oblique (“RAO60”), in steps of 15°. Anterior radiation incidence is corresponding to 0°. The angles in vertical directions ranged from 30° upward (“Up30”) to 30° downward (“Do30”), also in steps of 15°, where horizontal incidence is corresponding to 90°. All combinations of horizontally and vertically oblique angles were considered. An illustration of the terminology used for the panels and the incidence angles is shown in Figure 1. The photon energies were ranging from 10 keV to 120 keV in steps of 10 keV.

For all six panels, all nine horizontally varying incidence angles were considered, i.e., LAO60, LAO45, LAO30, LAO15, AP, RAO15, RAO30, RAO45, and RAO60. Relevance of the vertically varying incidence angles depended of the location of the panel in height: For the Top panels, only upwards oriented angles were considered; for the Mid panels, upwards and horizontal angles were considered, and downward angles were considered only for the Bottom panels.

Conversion coefficients were calculated for two voxel phantoms representing a large (“Donna2018”, 176 cm, 79 kg) and a slim female (“Irene 2018”, 163 cm, 51 kg), as well as a reference-sized male mesh phantom “RAF”. For details about the phantoms, please see Deliverable D9.104.

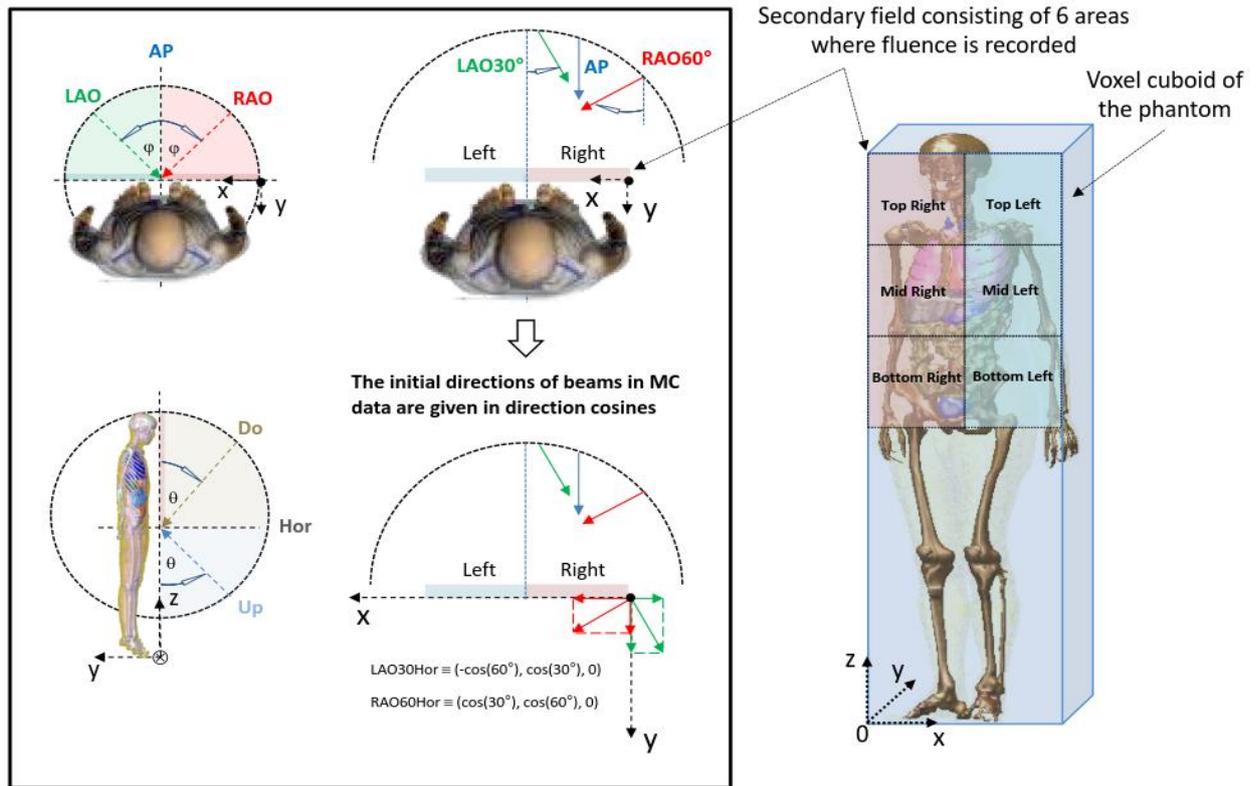


Figure 1: Terminology used for field panels and angles of incidence

Conversion coefficients were calculated for effective dose (ICRP 2007) and for all organs contributing to this quantity. Examples of fluence to effective dose conversion coefficients for selected panels, incidence angles and photon energies are shown in Figures 2-5.

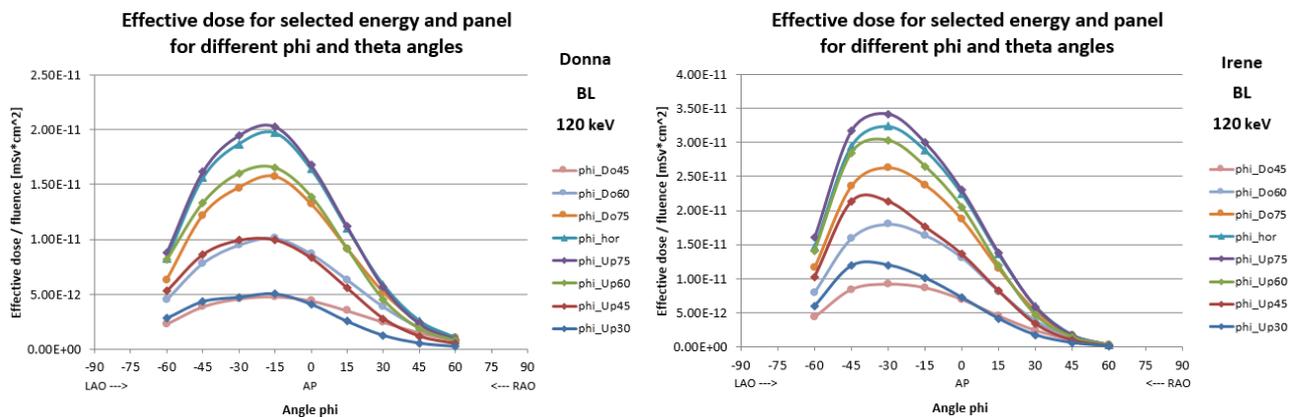


Figure 2: Effective dose per fluence conversion coefficients for photons of energy 120 keV for the Bottom left (BL) panels of Donna2018 (left) and Irene2018 (right). The x-axis is representing different horizontal angles, and each vertical angle is represented by a different curve.

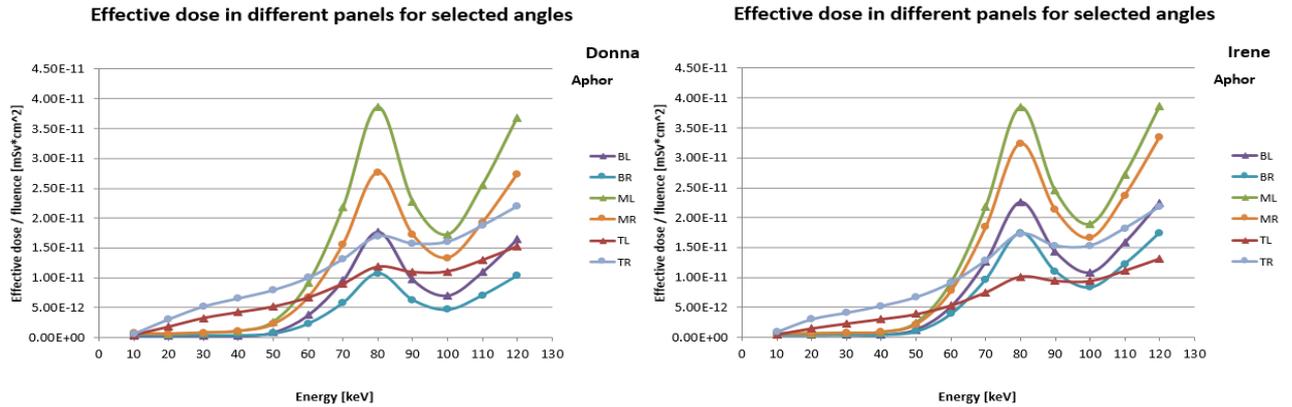


Figure 3: Effective dose per fluence conversion coefficients for AP horizontal radiation incidence for Donna2018 (left) and Irene2018 (right). The x-axis is representing photon energy, and each panel is represented by a different curve.

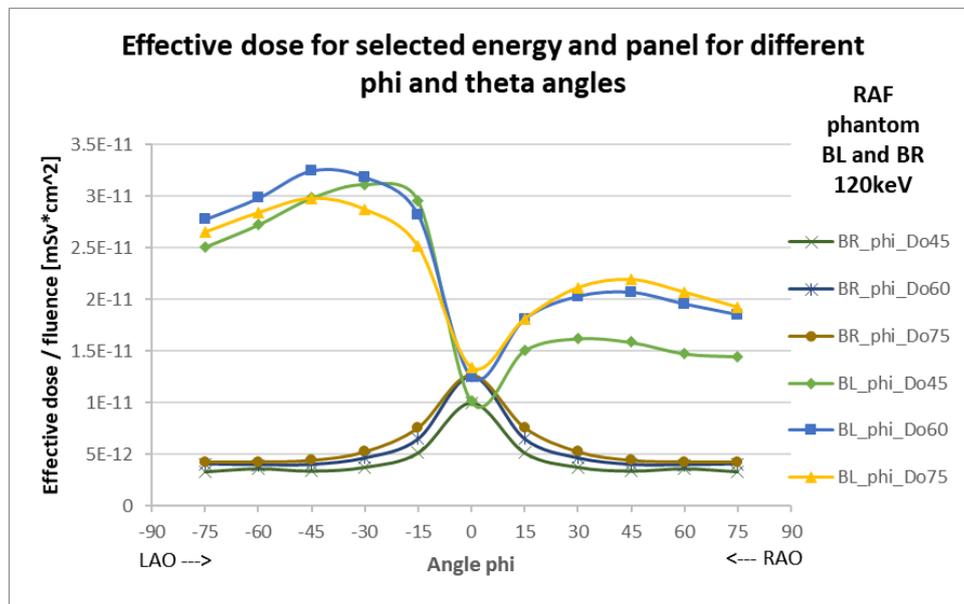


Figure 4: Effective dose per fluence conversion coefficients for photons of energy 120 keV for the Bottom left (BL) and Bottom right (BR) panels of the RAF phantom. The x-axis is representing different horizontal angles, and each vertical angle is represented by a different curve.

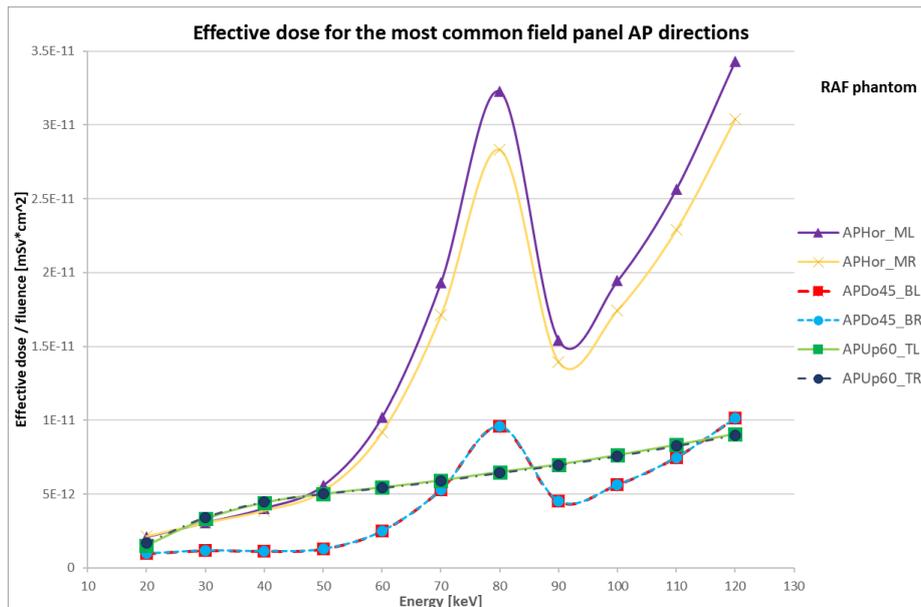


Figure 5: Effective dose per fluence conversion coefficients for the most common AP horizontal radiation incidence of the RAF phantom. The x-axis is representing photon energy, and each panel is represented by a different curve.

It can be seen that generally the conversion coefficients for Irene2018 are higher than those for Donna2018 and RAF phantom, due to her smaller body resulting in reduced self-shielding. The lead apron has relatively less attenuating effect below its 88 keV K-edge, which accounts for the fall in the effective dose contributions behind the lead apron, which give minima at 100 keV.

III. Fluence to dose conversion coefficients for neutrons

For neutron workplaces, the fields are much more homogeneous than the photon fields in interventional radiology. Hence, only broad parallel beams incident on the whole body had to be considered. Also, lead aprons are not effective in workplaces where neutrons contribute significantly to the effective dose, so no modelling of the neutron conversion coefficients was performed with a lead apron in the model. The absence of the lead apron also mitigated against the use of the panel approach that was favoured for photons.

The conversion coefficients that are required are largely available in ICRP Publication 116 (ICRP 2010), but additional angles were required for the workplace calculation because it was considered that the published data were too coarse in direction resolution for the purpose of online dosimetry.

The additional angles of incidence are horizontal and 45° upwards: along the vertical axis and along the horizontal axis, it is from 0° to 315°, in steps of 45° with the 0° being from the right side of the phantom to the left side of the phantom. To derive effective dose coefficients, two phantom calculations needed to be done: the Adult Female and Adult Male phantom. The Adult Female is the slimmer phantom compared to the Adult Male, with less mass and height. The (pseudo) effective dose per neutron fluence conversion coefficients are calculated for the Adult Female and Adult Male phantom and the ratio is derived: $E_{pseudo,AF}/E_{pseudo,AM}$, for the various 45° upward beams: this is shown

in Figure 4. The ratio of (pseudo) effective dose ratio between Adult Female and Adult Male is always between 1.00 ± 0.20 and this is well between the ± 0.30 needed for personal dosimetry. Where the ratio is above 1.0 the neutron effective dose conversion coefficients are higher for the smaller body, as is the case with the photons above. This is especially the case for the PA direction of the 45° upwards beam. As most sensitive organs are more oriented towards the front side of the phantoms, and the neutron beam is entering from the back side of the phantom, there will be more tissue attenuating the neutron beam for the bigger phantom resulting in a lower neutron energy and therefore a smaller dose.

For the AP direction, the 45° upwards beam the ratio above and below 1.0 occurs, depending on the neutron energy. However, where the effective dose conversion coefficient ratio is below 1.0, the opposite is true, and the smaller body supplies the lower effective dose conversion coefficients. This is especially true for both lateral 45° upwards beam directions. Looking at more detail to the difference of the phantoms shows that the difference in the lateral dimension is only 2%, whereas the difference in the front back dimension is 12% and in the height 5%. This makes that for the lateral dimensions the Adult Male intersects with more neutrons than the Adult Female and the attenuation properties are not that dissimilar compared to the lateral dimensions and therefore the Adult Male phantom absorbed more energy than the Adult Female and dividing by the phantoms mass results apparently in the higher neutron effective dose per fluence conversion coefficient for the Adult Male phantom.

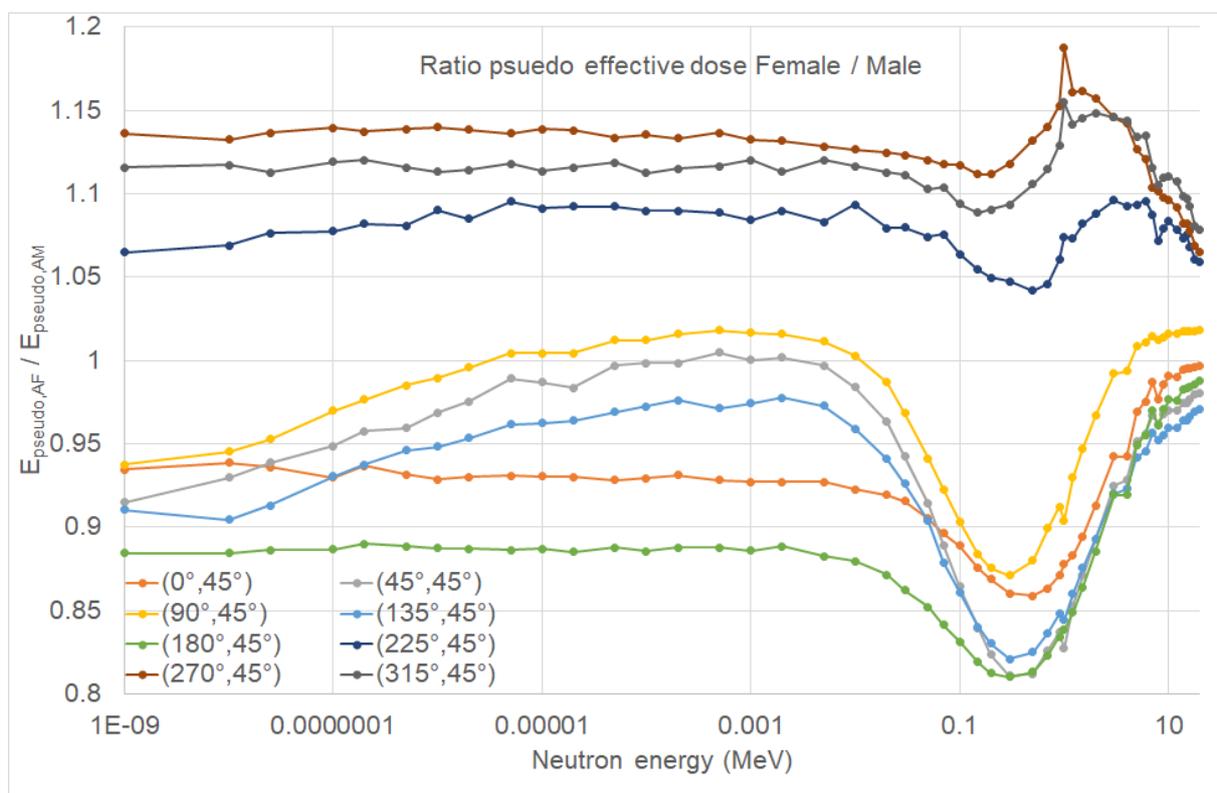


Figure 4: Ratio of the pseudo effective dose per fluence conversion coefficient for the Adult Female / Adult Male phantom for various neutron energies, and various horizontal angles (first in legend) and the vertical 45° upwards (second in legend) direction.

IV. Conclusions

With this deliverable, WP2 provides a library of pre-calculated fluence to dose conversion coefficients for phantoms having various statures that can be used as a first approach of the fast online dosimetry application for workers in realistic workplaces. The numerical data of the conversion coefficients were uploaded in the STORE database and can be found at [DOI:10.20348/STOREDB/1156](https://doi.org/10.20348/STOREDB/1156).

V. References

- ICRP (2007). The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. I. C. o. R. Protection. Oxford, UK, Elsevier.
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