Comparison of internal and external dose conversion factors using ICRP adult male and MEET Man voxel model phantoms.

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Abstract

The dose conversion factors enter directly in the evaluation of the effective dose in case of external irradiation of a body or in case of internal exposure. They can be calculated only making use of Monte Carlo methods and (voxel) model phantoms. In this work the differences in anatomy and in resolution among two voxel model phantoms, the MEET Man voxel model phantom and the reference ICRP adult male are considered to account for the different values of the dose conversion factors.
MCNPX Monte Carlo code is employed with each voxel model phantom.
Dose conversion factors are calculated for whole body irradiation with monoenergetic photon beams in anterior-posterior, posterior-anterior and left- and right-lateral direction. Those factors are calculated as a function of the photon energy, from 30 keV to 10 MeV, in terms of the KERMA.
For the internal exposure scenarios, several organs are taken as source and the dose conversion factors are evaluated in the neighbouring organs. The source organs emit photons of fixed energy, in the energy range from10 keV to 10 MeV.
Discrepancies in the dose conversions factors are observed and explained in term of anatomical differences. Thus this investigation gives an impression to inter-individual variations of the dose conversion factors.

1. Introduction

In radiation protection the quantities that need to be limited, as the equivalent dose in the body, are not directly measurable. Therefore there is a necessity to relate those ones, the protection quantities, with some quantities that can be measured, the operational quantities. In order to assess doses, conversion coefficients are employed. The definition of those factors depends on the irradiation scenarios, whether the irradiating source is placed outside the body or if the source is an organ itself.
If the body is irradiated from outside, in order to calculate the organ effective dose, dose conversion factors are given in terms of absorbed dose normalized to air KERMA, being this latter a measurable quantity by using proper instrument. The dose conversion factors are dependent on the anatomy of the phantoms, on the kind and the energy of the radiation, and also on the direction where the radiation comes from. Four different irradiation scenarios are considered here: anterior-posterior, posterior-anterior and left- and right-lateral direction of mono-energetic photons emitted from a surface as big as the phantom itself. The whole body is therefore homogenously irradiated.
Differently, in case of ingestion or inhalation the incorporated radionuclide decays in one or more specific organs, the source organs. The emitted energy will be partly absorbed from the target organs. Specific absorbed fraction SAF is defined as the fraction of energy emitted from the source organ S absorbed from the target organ T, normalized to the mass M_t of the target organ:

$$SAF(T \leftarrow S) = \frac{1}{M_t} \frac{Energy\ absorbed\ in\ T}{Energy\ emitted\ from\ S}$$

These coefficients depend on the anatomical model of the voxel phantom, the type and the energy of the radiation.
The calculation of the specific absorbed fraction is necessary for the assessment of the organ doses, being this latter proportional to the specific absorbed fraction.
In both kinds of scenarios, internal contamination and external irradiation, the dose conversion factors can be calculated only making use of Monte Carlo radiation transportation codes and of (voxel) model phantoms.
In the present work two voxel phantoms have been used for the calculation of dose conversion factors and the obtained result are compared. The observed differences are explained in terms of anatomy or density of the organs in the two models. Some relevant examples are reported in detail.

2. The voxel phantoms

The MEET Man [1] was segmented in 1990s at the Institute of Biomedical Engineering (IBT) of the University of Karlsruhe (Germany) from image data from the Visible Human Project [2]. The Visible Human Project wants to create a complete data set of photographs of human bodies, a man and a woman. The MEET Man phantom comes from the segmentation of the CT scan of the whole body of the man, only the head and the neck were scanned with MRI. The cadaver was 180 cm high and had a weight of 92 kg. He was photographed in 1-mm-transersal slices. Six versions with as many cubical voxel resolutions are available, from 6 mm^3 down to 1 mm^3. Through this work the voxel phantom with a cubic voxel resolution of 4 mm^3, corresponding to 5.9 million voxels, will be used, if not differently specified. The two models with voxel resolutions of 2 mm^3 and 6 mm^3 are used only for checking the effect of different resolutions on the organ dose conversion factors. Density and material compositions were taken from the reference male adult [3] and [4] when possible.
The ICRP reference adult male phantom [5] was constructed modifying an already existing voxel model, whose height and mass resembled the reference data. The reference adult male represents a man with a height of 176 cm and a mass slightly below 70 kg. The voxel size is 8 mm in height with an in-plane resolution of 2.08 mm.
The phantom models have been converted into MCNPX voxel format using Voxel2MCNP [6], an in-house software that allows to set up radiation protection scenarios with voxel model and to generate the corresponding input files for MCNPX.

3. Validation of the method

All the results presented in the following have been obtained with MCNPX Version 2.6.0, running 1 million histories in mode p e for each scenario.
The tally *f8 has been required to calculate the energy deposited in the target organ while the f6 tally has been used for the calculation of the KERMA in a box filled of air. The box, both when filled of air for the KERMA evaluation and when containing the voxel phantom, is always placed in void.
Calculated dose conversion factors for the reference adult male have been firstly compared with the published value, in order to validate the method.
Two examples are shown in fig.1(a) and 1(b), for two different scenarios and two different organs. The blue full squares are the values obtained in this work using the ICRP reference man phantom; the red dots are from M. Zankl [7]. The error bars on the blue squares refer only to the statistical uncertainties given from the simulations. The statistical uncertainties on the KERMA

calculation have been considered negligible, being below per-mille level, even for low energy photons. The results here obtained are perfectly in agreement with the published ones.

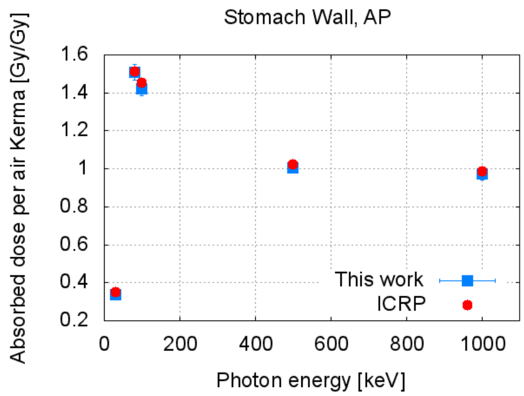

Fig. 1(a): Dose conversion factor for the stomach wall in the AP irradiation scenario, calculated with the ICRP reference man (blue squares) compared with the values from [7] (red dots).

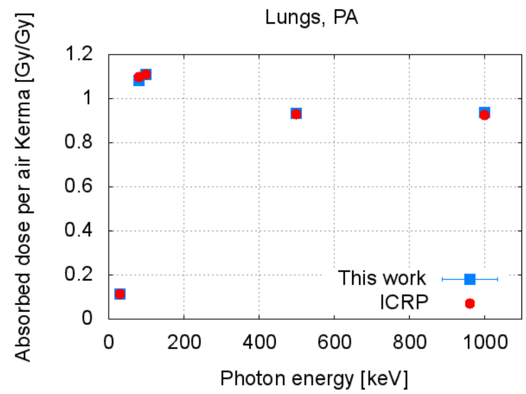

Fig. 1(b): Dose conversion factor for the lungs in the PA irradiation scenario, calculated with the ICRP reference man (blue squares) compared with the values from [7] (red dots).

4. Irradiation from external source

Four different scenarios have been considered for the whole body irradiation, anterior-posterior (AP), posterior-anterior (PA), left- and right-lateral direction (LLAT and RLAT).
The dose conversion factors are calculated as a function of the photon energy, from 30 keV to 10 MeV, in terms of air KERMA. As expected different results are obtained using MEET Man and ICRP reference man phantoms. Some examples are given in fig. 2(a) and 2(b).

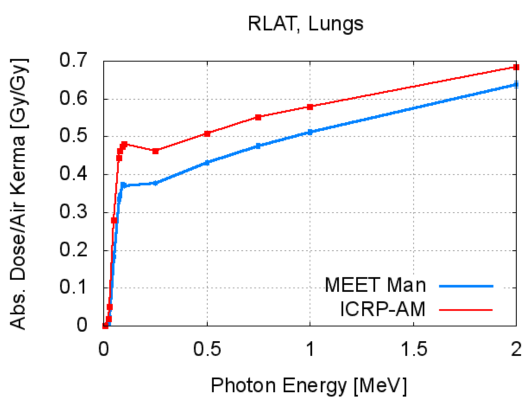

Fig. 2(a): Dose conversion factors for the lungs in a RLAT scenario calculated using the MEET Man (blue line) and the ICRP reference man (red line).

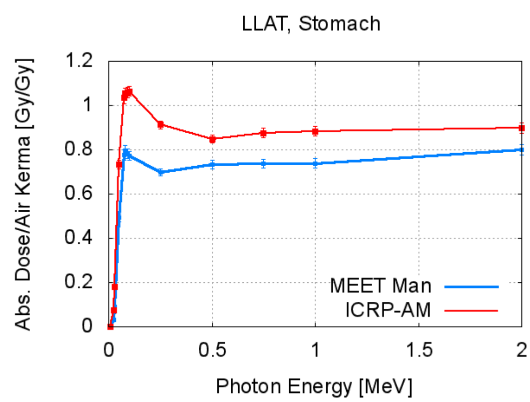

Fig. 2(b): Dose conversion factors for the stomach wall in a LLAT scenario calculated using the MEET Man (blue line) and the ICRP reference man (red line).

The difference between the two is explained mainly with the thicker layer of adipose tissue for the MEET Man phantom. Given the attenuation coefficient of the adipose tissue, 100 keV photon beam is attenuating of 15% when crossing 1 cm of adipose. Also the position of the arms seems to be responsible for the fact that in MEET Man the dose conversion factors are lower than in

ICRP reference man. Fig. 3(a) and 3(b) show that in the case of the MEET Man the radiation coming from the side (LLAT and RAT) is more shielded than for ICRP reference man.

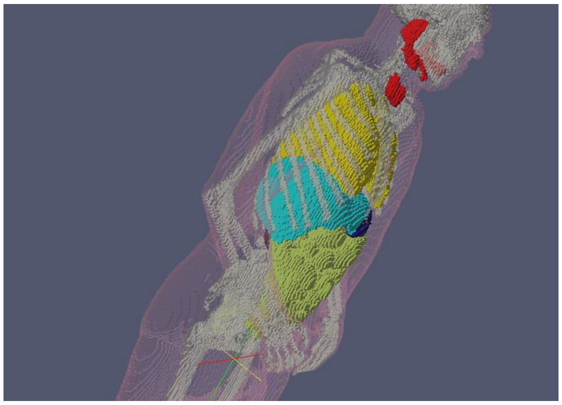

Fig. 3(a): Side view of the MEET Man voxel phantom.

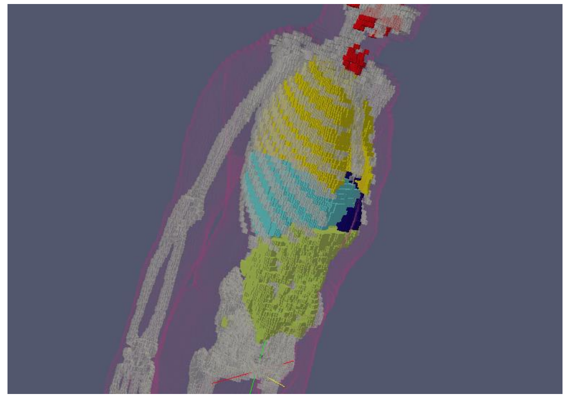

Fig. 3(b): Side view of the ICRP reference man voxel phantom.

Evidence of the shielding effect of the arm on the side can be checked by looking at the thyroid and the salivary glands. In fig.4 the dose conversion factors are given for these two organs in the two phantoms. The plot shows that the values are pretty similar for the two phantoms. This organs have been chosen because they have very similar shape in the two voxel phantoms from the LLAT side (in the MEET Man the two sides are not symmetric) and the adipose tissue on the neck is not so thick. For low energy photons MEET Man predicts lower values even for these organs, but from 500 keV photons on the two phantoms give the same results.

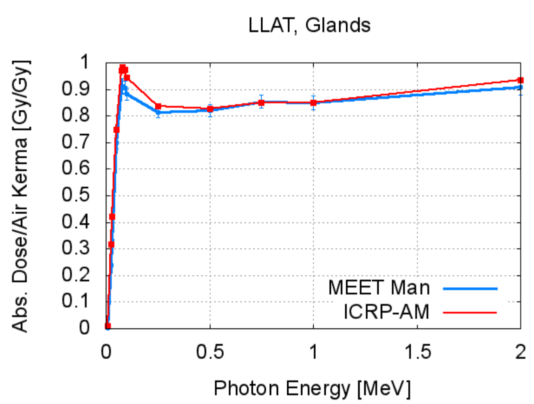

Fig. 4: Dose conversion factors for the thyroid and the salivary glands for MEET Man (blue line) and the ICRP reference man (red line).

5. Internal exposure

In case of internal exposure more parameters play a role in the evaluation of the SAF and it is more difficult to make prediction just looking at the shape of the phantoms. Several organs, both as source and as targets have been investigated and in the most of the case an appreciable disagreement has been found using the two voxel phantoms. Two examples are given in fig. 5(a) and 5(b). In the first one the SAF from the liver to the lungs is shown. The lungs of the ICRP reference are composed by a blood part and from a tissue part, whose density are 1.06 g·cm^{-3} and 0.38 g·cm^{-3} respectively. Weighting these two values with the voxel number related to each tissue, one obtains an average density of 0.41 g·cm^{-3}. The lungs of MEET Man have a density of 0.32 g·cm^{-3}, around 20% less than ICRP reference man. For this reason the lungs of the ICRP reference man absorb more energy than those of MEET Man, giving therefore higher value of the SAF as shown in fig. 5(a). On the other hand we observe the opposite effect when the lungs are the source organ. Being higher the density of the lungs of ICRP reference man, there is a bigger effect of self-absorption, with the final effect the energy deposited in stomach wall, for example, is less in ICRP reference man than in MEET Man, as shown in fig. 5(b).

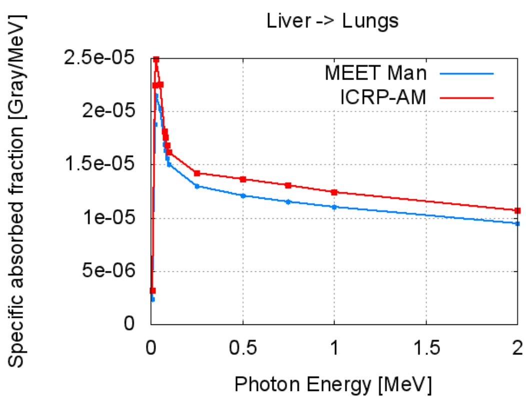

Fig. 5(a): Specific absorbed fraction for source region liver and target region lungs. Phantom used are MEET Man (blue line) and the ICRP reference man (red line).

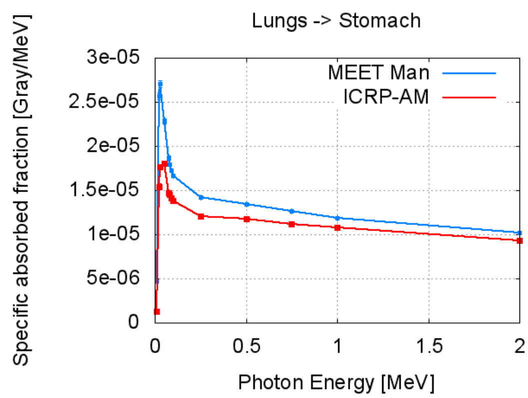

Fig. 5(b): Specific absorbed fraction for source region lungs and target region stomach wall. Phantom used are MEET Man (blue line) and the ICRP reference man (red line).

6. Effect of the voxel resolution

As mentioned above the MEET Man phantom is available in different voxel resolutions. Looking at the single organ the only small difference is in the mass of the organ. A possible border effect could play a role in the calculation of the dose conversion factors, if there is any. Here it is checked that these effects are negligible in the calculation of the dose conversion factors, as shown in fig. 6(a) and 6(b). Two organs have been chosen for this test, the glands and the liver, in order to check the possible effect on a small and on a big organ. Here the LLAT irradiation is shown. The dose conversion factors obtained with the MEET Man in the version of 6×6×6 mm^3 and in the version 2×2×2 mm^3 are perfectly in agreement, both for the glands (thyroid and salivary glands) and for the liver.

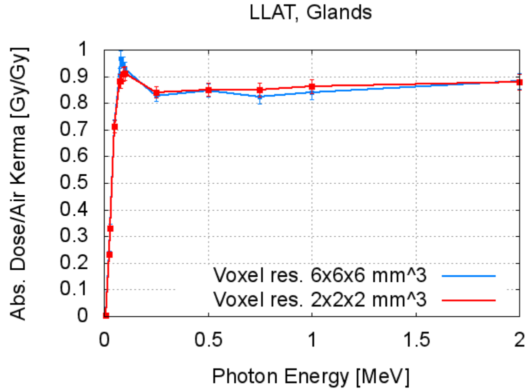

Fig.6(a): Dose conversion factors for the thyroid and the salivary glands in a LLAT scenario from MEET Man in two different voxel resolutions.

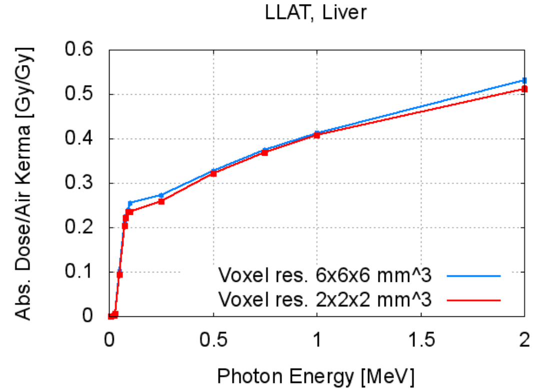

Fig.6(b): Dose conversion factors for the liver in a LLAT scenario from MEET Man in two different voxel resolutions.

7. Conclusion and outlook

In this work dose conversion factors with MEET Man voxel phantoms have been calculated in different exposure scenarios, both considering irradiation coming from inside or outside the body. In the most of the case the dose conversion factors calculated with the MEET Man are lower than the ones obtained with the ICRP reference man, and this assures that the estimates of the organ effective dose is conservative in the most of the case, at least when the measured person is bigger than the ICRP reference man. Smaller reference voxel phantom exist however, which can be used for people smaller than the one represented from the reference phantom.

More scenarios of external irradiation will be considered in the future and the coefficients for more couple source-target organ will be calculated. A further step will be the implementation of the dose conversion factors calculation in the already existing software Voxel2MCNP. Several voxel phantoms can be already loaded in this software; in the next future scenarios for several irradiation of the whole body as well as scenarios of internal contaminations are foreseen to be implemented, with the idea to be used in the evaluation of daily routine measurements.

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