Organ doses determined using a RANDO phantom for different radionuclide depositions and photon energies

Hörnlund, Mikael; Bernhardsson, Christian

Published in:
Medical Physics in the Baltic States

2013

Document Version:
Publisher's PDF, also known as Version of record

MEDICAL PHYSICS IN THE BALTIC STATES 11 (2013)

Proceedings of International Conference "Medical Physics in the Baltic States"
10 - 12 October 2013, Kaunas, Lithuania

ORGAN DOSES DETERMINED USING A RANDO PHANTOM FOR DIFFERENT RADIONUCLIDE DEPOSITIONS AND PHOTON ENERGIES

Mikael HÖRNLUND, Christian BERNHARDSSON
Medical Radiation Physics, Department of Clinical Sciences, Malmö, Lund University, Skåne University Hospital, SE-205 02, Malmö, Sweden

***Abstract*:** Dose conversion coefficients relating the kerma free-in-air to effective dose have been studied. In order to do so a sampling scheme encompassing all the risk organs and tissues was developed for the Alderson RANDO phantom. Preliminary results are shown for some specific organs irradiated with a point source in the laboratory.

***Keywords*:** RANDO phantom, dose conversion factors, TLD

1. Introduction

The international Commission on radiological protection (ICRP) has introduced the effective dose (*E*) for the management of stochastic effects, *i.e.*, in order to implement the principle of limitation[1] and the principle of optimization[2] in radiological protection [1]. The effective dose is calculated from the equivalent dose to a set of risk organs and tissues in the human body. Summation of the equivalent organ doses, multiplied by the appropriate tissue weighting factors, yields the effective dose [2]. Obviously, effective dose cannot be measured. However, by estimation of the dose distribution in the human body (due to external exposure) the risk quantity can be related to physical, measurable quantities. The coefficient relating the two quantities is called a conversion coefficient (CC) [3]. Conversion coefficients have been published by several authors *e.g.* [4, 5] as well as the ICRP [3]. In order to determine CCs, associated with external exposure to gamma radiation, one can either use computational methods on mathematical phantoms [6] or experimental *in situ* measurements with anthropomorphic phantoms [7]. As pointed out by Golikov *et al.* (2007), the number of experimental efforts to derive conversion coefficients is steadily exceeded by those based upon mathematical methods. One drawback in trying to perform an experiment where the goal is to derive CCs from measurements on contaminated soil is to find a proper location where experiments are allowed, either by the environment (*e.g.* heavily contaminated soil) or by artificially contaminating a surface.

In 2011 a dedicated mobile system for dispersion of activity (financially supported by the Swedish radiation safety authority) was acquired at the Medical Radiation Physics group in Malmö. This system allows simulating surface contamination of various size and types of radionuclides *in situ*.

The long-term aim of the present work is to determine conversion coefficients from contaminated plane quadratic surfaces, as well as for point-sources using an anthropomorphic phantom (Alderson RANDO phantom). Conversion coefficients relating the effective dose to kerma free-in-air will be investigated for a set of photon energies. As a first step to do so, an appropriate sampling scheme encompassing all the risk organs and tissues (as defined in ICRP report 103) for the widely used Alderson RANDO phantom was established and the experimental set-up was tested. Here we report on our first results from this study.

2. Material and methods

The anthropomorphic Alderson RANDO phantom[3] is a commercially available, well-known and widely used phantom for obtaining dose distributions from external irradiation (Fig. 1).

The phantom (male) consists of natural human skeleton enclosed in tissue-simulating plastic (mass density = 0.985 g cm-3, effective atomic number = 7.30), molded to resemble a human adult. The RANDO phantom also accounts for the lungs (Fig. 2). The lung-simulating tissue has the same effective atomic number as the tissue-simulating plastic, but a lower mass density of 0.32 g cm-3.

[1] Radiation exposure due to handling of radiation must be kept as low as reasonably achievable.

[2] Exposure of individuals of the public and radiation workers must not exceed the dose limits.

[3] The RANDO® phantom. The Phantom Laboratory. P.O. Box 511, Salem, NY 12865-0511 United States.

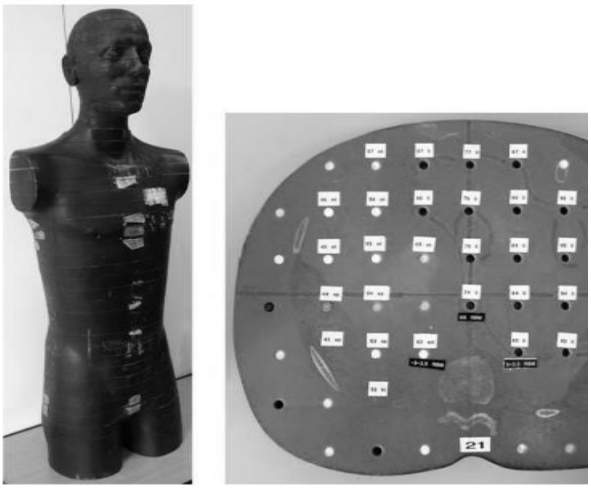

Fig. 1. The Alderson RANDO Phantom (left) consisting of 36 slabs with TLD insertions. Top side of slab number 21 of the RANDO Phantom (right). White (or black) labels correspond to sampling points for organs identified to be located in the current slab. Sampling points corresponding to the part of the liver in slab 21 is encompassed by red markings.

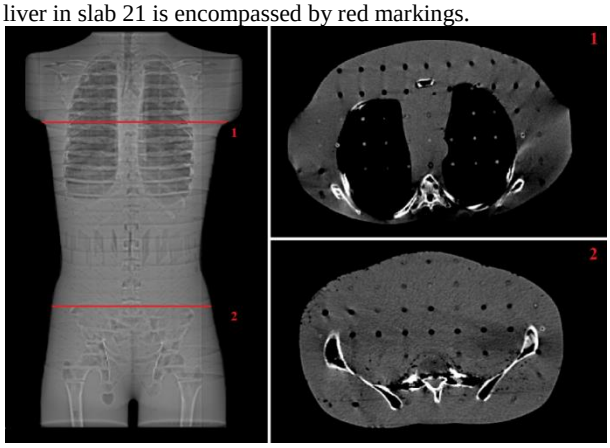

Fig. 2. Anterior-posterior *(*AP*)* view of the Alderson RANDO Phantom (left) (head not included). Slab 15 of the RANDO phantom (upper right). Slab 28 of the RANDO phantom (lower right). Approximate location of slab 15 and 28 are marked out on the AP image (left image).

The male RANDO phantom consists of 36 slabs, each with a thickness of 2.5 cm, except for the lower pelvic section which is 9 cm thick. Each section contains a grid of holes, separated by 30 mm and 5 mm in diameter, where thermoluminescent (TL) dosimeters may be inserted (see Fig. 1). The male RANDO phantom corresponds to a complete body of 175 cm and 73.5 kg (a female version of the RANDO phantom is also available, but this will not be included in the present work). The sampling points and the mass fractions for the various risk organs and tissues in the Alderson RANDO phantom were determined with the help of clinical expertise, data from the literature and CT-images of the phantom

In order to evaluate the compiled sampling scheme, a test irradiation of the RANDO phantom with TLDs inserted into a limited number of organs was undertaken in the laboratory. For this purpose, 84 TL-dosimeters were annealed at 240 ˚C for 10 min, thereafter rapidly cooled and inserted into the organ sampling points corresponding to the urinary bladder, liver and prostate, respectively. Two sampling-schemes, partially overlapping in sampling points, were used for the liver in order to assess the impact of the number of TLDs used on the determined (mean) organ dose. The number of dosimeters and the sampling schemes are shown in Table 1.

Table 1: Organs exposed during test-irradiation. The number in parenthesis corresponds to the number of overlapping sampling points for the two sampling schemes.

Organ	# TLDs	Sampling Scheme
Liver	71 (14)	Golikov and Nikitin (1989)
Liver	19 (14)	Scalzetti et al. (2008)
Prostate	2	Scalzetti et al. (2008)
Bladder	6	Scalzetti et al. (2008)

For the purpose of achieving rotational invariant exposure geometry the phantom was positioned on a table rotating with one revolution per eight seconds. A ^{60}Co point-source of 74.9 MBq was mounted on a chain, hanging from the roof perpendicular to the table, at a distance of 1.6 m from the center of rotation (Fig. 3).

Fig. 3. Experimental setup during irradiation. 1: ^{60}Co-source mounted on a chain; 2: distance between ^{60}Co-source and personal dosimeter (1.5 m); 3: distance between ^{60}Co-source and the center of rotation.

By positioning a dose rate meter at the center of rotation, the dose rate was determined to 14 μSv h^{-1}, at the height of the phantoms chest. Irradiation was carried out during 48 hours and then the source was removed and the TLDs retrieved. Mean organ doses were calculated as the mean from the TL-response of each dosimeter in the organ.

3. Results and discussion

A sampling scheme containing the mass fractions and sampling positions for risk organs and tissues, as defined by the ICRP (2007), has been compiled for the male Alderson RANDO phantom [8]. The mass of the organs and tissues used as the basis for the sampling scheme agree within ±4% with the reference values published by the ICRP, Publication 89 (2002), except for the salivary glands, eyes and prostate, for which the discrepancy in mass is 24%, 6% and 7%, respectively. Other sampling schemes of the RANDO phantom have been compiled by *e.g.* [9 - 11]. However, none of the authors have compiled a sampling scheme with sufficient information to allow the calculation of effective dose, *i.e.* sampling positions and mass fractions for some important risk organs have not been included. Most notably, the sampling positions for the

red bone marrow (RBM) have not been included. An attempt to provide this information has been performed in the present work. However, the precision and the accuracy of the sampling scheme have not yet been fully evaluated in the present work. Field measurements and comparisons with published data on the dose distribution in the RANDO phantom is required in order to assess the usefulness of the sampling scheme.

The results from the first indoor experiments on the RANDO phantom are presented in Tables 2 and 3. The experimental setup was as in Fig. 3 using a ^{60}Co point-source.

Table 2. Experimental setup during the laboratory irradiation.

Isotope	Time (h)	Point source activity (MBq)	Ambient dose rate, $H^*(10)$	Personal dose equivalent, $H_p(10)$
^{60}Co	48	74.8	762	480

Table 3. Mean organ dose and calculated conversion coefficients for the RANDO phantom when irradiated from a 74.8 MBq ^{60}Co point-source at a distance of 1.5 m during 48 h.

Organ	Mean organ dose, D (μGy)	$D/H^*(10)$ (Gy Sv^{-1})	$D/H_p(10)$ (Gy Sv^{-1})
RBM	310	0.41	0.65
Liver	350	0.46	0.73
Bladder	313	0.41	0.65
Prostate	302	0.40	0.63

The conversion coefficients in Table 3 relate the ambient dose and personal dose, respectively, to the mean organ dose for four different risk organs (RBM, liver, bladder and prostate[4]). Conversion coefficients relating protection quantities to operational quantities are not published in ICRP 74 (1996). However, the operational quantities are indirectly related to the mean organ dose by conversion coefficients between the operational quantities and kerma free-in-air. The reason for presenting the CCs in terms of a protection quantity through an operational quantity is that most dosemeters and radiation monitoring devices are calibrated in terms of the operational quantities rather than kerma free-in-air. Thus, CCs as given in Table 3, would likely facilitate the usage of conversion coefficients in radiation protection in practice. Unfortunately, a direct comparison with the values published by ICRU could not be done since kerma was not measured during this experiment.

Conversion coefficients resulting from combining the calculated kerma with the mean organ dose in Table 3 is numerically equal to the values presented in the column for $D/H_p(10)$. These values are approximately 25% larger than the corresponding CCs published by the ICRP (1996). No obvious reason for this discrepancy has been found by the author. The numerical values for the conversion coefficients, in a given column, in Table 3 have an absolute difference lower than 15% from each other. No direct comparison with the literature can be done since CCs are not usually published as in Table 3. However, the absolute difference is larger than the corresponding absolute difference for the CCs in terms of mean organ dose to kerma free-in-air, for the same organs, as published by the ICRU, Report 57 (1998). For ^{60}Co-photons the CCs differs no more than 5%.

[4] Part of the remainder.

4. Conclusions

A complete sampling scheme with mass fractions and positions of the risk organs for the Alderson RANDO phantom is now available. With this sampling scheme it will be possible to calculate the organ doses or effective dose to the organs at risk as defined by the ICRP (2007). These are the first results from this project on conversion coefficients which will be extended to cover all organs and tissues of the RANDO phantom. Different point sources with various gamma energies will be investigated in the laboratory. Finally, conversion coefficients for different homogenously dispersed radioactive surfaces will be determined *in situ* using a dedicated dispersion device.

Acknowledgments

This project was financially supported by the Swedish Radiation Safety Authority (SSM).

5. References

1. Menzel H-G. and Harrison J. Effective dose: a radiation protection quantity. Annals of the ICRP, 2012;41(3-4):117-123.
2. International Commission on Radiological Protection. The 2007 Recommendations of the International Commission on Radiological Protection. 2007, ICRP Publication 103. Ann. ICRP 37 (2-4), p. 1-332.
3. International Commission on Radiological Protection. Conversion Coefficients for use in Radiological Protection against External Radiation. 1996, ICRP Publication 74. Ann. ICRP 26 (3-4), p. 1-205.
4. Eckerman K. and Ryman J. External Exposure to Radionuclides in Air, Water, and Soil. 1993, Federal Guidance Report No. 12, U.S. Environmental Protection Agency, Washington, D.C.
5. Lee J.S., Dong S.L. and Wu T.H. Estimation of organ dose equivalents from residents of radiation-contaminated buildings with Rando phantom measurements. Applied Radiation and Isotopes 1999; 50(5): 867-873.
6. Jacob P., Paretzke H., Rosenbaum H. and Zankl M. Effective dose equivalents for photon exposures from plane sources on the ground. Radiation Protection Dosimetry 1986; 14(4): 299-310.
7. Golikov V., Wallström E., Wöhni T., Tanaka K., Endo S. and Hoshi M. Evaluation of conversion coefficients from measurable to risk quantities for external exposure over contaminated soil by use of physical human phantoms. Radiation and Environmental Biophysics 2007; 46(4):375-382
8. Hörnlund M. Estimation of dose conversion factors – conversion factors from measurable to risk related quantities [MSc thesis]. Malmö: Göteborg University; 2013
9. Golikov V. and Nikitin V. Estimation of the mean organ doses and the effective dose equivalent from Rando phantom measurements. Health Physics 1989; 56(1):111-115.
10. Huda W. and Sandison G. Estimation of mean organ doses in diagnostic radiology from Rando phantom measurements. Health Physics 1984; 47(3): 463-467.
11. Scalzetti E., Huda W., Bhatt S. and Ogden, K. A method to obtain mean organ doses in a Rando phantom. Health Physics 2008; 95(2):241-244.