doi:10.46793/ICCBI21.141Z

OVERVIEW OF PHANTOMS IN DOSIMETRY AND RADIATION PROTECTION

Milena P. Živković[1], Dragoslav Nikezic[1,2], Tatjana B. Miladinović[3], Dragana Ž. Krstić[1]

[1] University of Kragujevac, Faculty of Science, R. Domanovica 12, 34000 Kragujevac, Republic of Serbia
e-mail: milena.zivkovic@pmf.kg.ac.rs, dragana.krstic@pmf.kg.ac.rs, nikezic@kg.ac.rs
[2] The State University of Novi Pazar, Novi Pazar, Serbia
e-mail: nikezic@kg.ac.rs
[3] Institute for Information Technologies, University of Kragujevac, Jovana Cvijića bb, 34000 Kragujevac, Serbia
e-mail: tanja.miladinovic@uni.kg.ac.rs

Abstract:

In this paper, the characteristics of phantoms from their origin to the latest species are considered. With the development of technique and technology, the characteristics of phantoms have also been improved, whose importance in monitoring human health is extremely important.
The first species were adapted to certain nations and precisely constructed so that sizes such as the height and mass of the phantoms were appropriate and represented the real inhabitants of those areas, that is, the inhabitants of America and Japan.
Later, female, children's phantoms were formed, as well as phantoms of pregnant women in different stages of pregnancy. The latest generations of phantoms, voxel, and mesh phantoms, represent realistic presentations of the human body and are applied in dosimetry and radiation protection in different areas, as well as in different irradiation conditions.
The International Commission on Radiation Protection - ICRP continuously studies data on radiation doses and effects and issues appropriate protection recommendations and promotes phantoms that represent the human body and organs of great importance for the occurrence of cancer.

Key words: radiology, medical physics, male and female phantom, voxels

1. Introduction

Phantoms are physical or virtual representations of the human body that are used to determine various physical quantities in radiation protection and dosimetry for organs and tissues, mostly the absorbed dose, to protect against ionizing radiation. Although it is not possible to make such a physical phantom or a mathematical model of a phantom that would accurately simulate the human body, it is possible to make phantoms or models that are used as approximate surrogates. The simplest phantoms are constructed from tissue material equivalent to tissue material with cavities in the organs to set up dosimeters for measurements (in situ). Such phantoms have a density corresponding to the lungs, muscles, or bone structure [1]. Recommendations for the design of human body models and phantoms used in radiation protection are given in ICRP89 [2]. These reports provide an overview of human anatomical, physiological, and metabolic characteristics, and suggest “typical” or reference values for phantoms. Each of the models includes a description of the model, a diagram or photograph, external dimensions, densities of the tissues considered, applications and references.

The aim of this paper is to present the development of phantoms in radiation physics and dosimetry.

2. The development of phantoms

2.1. First phantoms

In radiation protection, one of the first is the physical model of the Alderson-Rando phantom [3]. This phantom has the shape of a human body with a skeleton that is inserted into a material equivalent to tissue.

2.1.1 Mird phantom

Snyder et al. [4] introduced a mathematical phantom, in which the size and shape of bodies and organs are described by mathematical equations. This phantom was further developed in accordance with the recommendations in the ICRP and is known as MIRD5 (MIRD - Medical Internal Radiation Dose). It was initially intended to calculate the absorbed dose from internal irradiation and was later modified and applied to calculate the absorbed dose from external irradiation.

The original MIRD phantom is hermaphroditic and includes gonads of both sexes and breasts for the female and was the basis for the development of future phantoms.

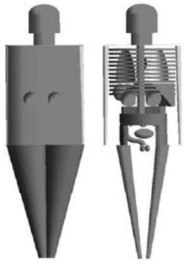

Fig. 1. MIRD phantoms.

The first pediatric models were developed in the Oak Ridge National Laboratory by proportional downsizing of the "adult phantom" model [5].

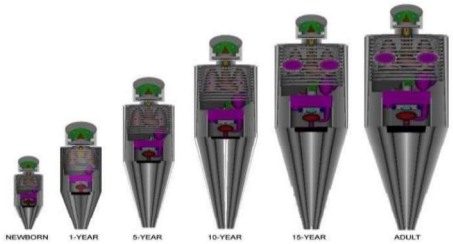

Fig. 2. Oak Ridge phantom family.

Later modifications were improved and considered knowledge of pediatric anatomy and growth. In the latest pediatric models, the organs are quite like the real ones.

2.2 The ORNL phantom

The ORNL series includes phantoms for newborns, individuals aged 1, 5, 10, 15 and phantoms of adult males [6]. The 15-year-old phantom represents both genders, male and female. Each phantom consists of three large sections: (1) the elliptical cylinder represents the torso and arms; (2) two fringed cones represent the legs and feet; and (3) a circular cylinder, together with an elliptical cylinder and half of the ellipsoid representing the neck and head. The female phantom is accompanied by breasts, which are represented by two ellipsoids.

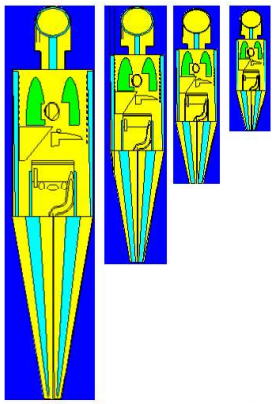

Fig. 3. ORNL phantoms [7].

Three types of tissue were determined: soft tissue, lungs and the whole skeleton, densities (kg m^{-3}): 1040, 296 and 1400, respectively. The physical dimensions of the ORNL phantom are shown in Table 1.

Table 1. Physical dimensions of the ORNL series of mathematical phantoms

Phantom	Mass (*kg*)	Height (*cm*)	Arms and core (*cm*)	Transverse diameter (*cm*)
Newborn	3.60	51.5	12.7	9.8
1 y	9.72	75.0	17.6	13
5 y	19.8	109.0	22.9	15
10 y	33.2	139	27.8	16.8
15 y	56.8	164	34.5	19.6
A grown man	73.7	179	40.0	20.0

2.4 Voxel and Mesh phantoms

Voxel and mesh are the latest generation of phantoms. Voxel phantoms are used in many different simulations such as X-ray dose estimates, from internal irradiation, determination of conversion factors in microdosimetry, as well as when using other irradiation sources.
Many shortcomings have been overcome by the introduction of so-called mesh phantoms. These are adult MRCPs (Mesh-type Reference Computational Phantoms) of male and female phantoms that are constructed starting from a voxel reference phantom [8] taking into account the micrometer dimensions of tissues and the high risk of these tissues for cancer.

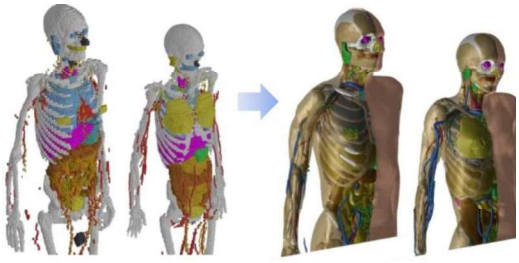

Fig. 4. Voxel (left) and mesh (right).

Figure 5 shows voxel and mesh phantoms. Organs that can be identified by different surface colors are chest, bones, colon, eyes, lungs, liver, pancreas, small intestine, stomach, teeth, thyroid, bladder. Muscle and adipose tissue are shown as transparent [9].

3. Conclusions

In this paper, the characteristics of phantoms from their origin to the latest species are considered. As shown with the development of technique and technology, the characteristics of phantoms, whose importance in monitoring human health is extremely important, have also been improved.

The first species were adapted to certain nations and precisely constructed so that sizes such as the height and mass of the phantoms were appropriate and represented the really real inhabitants of those areas, that is, the inhabitants of America and Japan. Later, female, children's phantoms were formed, as well as phantoms of pregnant women in different stages of pregnancy.

The latest generations of phantoms, voxel, and mesh phantoms, represent realistic presentations of the human body and are applied in dosimetry and radiation protection in different areas, as well as in different irradiation conditions.

References

[1] ICRP, *Data for Use in Protection against External Radiation. ICRP Publication 51.* Ann. ICRP 17 (1987).
[2] ICRP, *Basic Anatomical and Physiological Data for Use in Radiological Protection Reference Values*. ICRP Publication 89. Ann. ICRP 32 (2002) 3-4.
[3] S.W. Alderson, L.H. Lanzl, M. Rollins, J. Spira, *An instrumented phantom system for analog computation of treatment plans,* The American Journal of Roentgenology, 87 (1962) 185.
[4] Snyder W. S., Ford M. R., Warner G. G., Watson G. G., Revision of MIRD Pamphlet No. 5 *Entitled Estimates of absorbed fractions for monoenergetic photon sources uniformly distributed in various organs of a heterogeneous phantom*. ORNL-4979, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1974.
[5] M. Cristy, *Mathematical phantoms representing children of various ages for use in estimates of internal dose.* U.S. Nuclear Regulatory Commission Rep. NUREG/CR-1159 (also Oak Ridge National Laboratory Rep. ORNL/NUREG/TM-367). 1980.
[6] D. Krstić, D. Nikezić. *Input files with ORNL—mathematical phantoms of the human body for MCNP-4B.* Computer Physics Communications, 176 (1): 33-37, 2007.
[7] T. Goorley, MCNP Medical Physics Geometry Database. Los Alamos National Laboratory. https://mcnp.lanl.gov/pdf_files/la-ur-07-6618.pdf. 2007.
[8] ICRP, *Adult reference computational phantoms. ICRP Publication 110.* Ann. ICRP 39 (2009).
[9] ICRP, *Adult mesh-type reference computational phantoms*. *ICRP Publication 145*. Ann. ICRP 49 (2020).