EVALUATION OF COUNTING EFFICIENCIES OF A WHOLE-BODY COUNTER CONSIDERING THE ICRP BIOKINETIC MODELS

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Abstract

Counting efficiencies of a whole-body counter (WBC), which has been installed at the Japan Atomic Energy Agency (JAEA), have been evaluated for ^{137}Cs and ^{60}Co within a voxel phantom. The distributions of the radionuclides were estimated from the ICRP biokinetic models. The evaluated efficiencies were compared with those for whole-body radionuclide distributions in the voxel phantom in order to study the impact of radionuclide distributions on the counting efficiency evaluations. Consequently, it was found that the efficiencies for ^{137}Cs and ^{60}Co with various distributions have minima at 0.5 days after intake. The efficiencies lead to 20 % (^{137}Cs) and 30 % (^{60}Co) underestimations of activity in comparison with those for the whole-body distributions.

1 Introduction

The International Commission on Radiation Units and Measurements (ICRU) mentions that the acceptable errors for direct measurements with whole-body counters (WBCs) will be less than ± 50 % [1]. The measurements require adequate knowledge of calibrations for the WBCs, such as selections of human surrogates (phantoms) and radioactive source distributions in the human subjects. In particular, the knowledge and its applications are needed for rapid and accurate measurements following an accident. At the Japan Atomic Energy Agency (JAEA), there have been several attempts on the use of voxel phantoms that provide three-dimensional representations of the human bodies in calibrations for a WBC [2, 3]. Monte Carlo simulations with the voxel phantoms have been applied to the calibrations. The purpose of this work is to evaluate counting efficiencies of the WBC considering radioactive source distributions in the voxel phantom for development of a more reliable calibration method for the WBC. Inhaled ^{137}Cs and ^{60}Co were considered as the sources since these nuclides are important for radiation protection in typical nuclear facilities.

2 Materials and methods

2.1 Whole body counter(WBC)

A bed-type WBC, which has three p-type high-purity Ge closed-ended coaxial detectors, has been installed at JAEA. The Ge detectors have approximately 80 % peak efficiencies related to that of a 76.2 mm diameter × 76.2 mm thick NaI(Tl) crystal. A bed and the Ge detectors are located in a shielding room, of which inner size is 2.0 m width × 2.5 m distance × 2.5 m height, to reduce background radiations. The schematic illustrations of the WBC and the Ge detector are shown in

figure 1. The first Ge detector is placed under the thyroid of measured humans at a distance of 30 cm from the bed surface. Second one is at the opposite side of the legs of the humans at 120 cm from the first detector. Last one is in the middle position between the other two detectors above 50 cm from the bed surface. The positions of detectors were determined so that the total counting efficiency is roughly constant along the midline of a measured human.

2.2 Voxel phantom

MAX06 voxel phantom was used. The MAX06 was developed by Kramer *et al.* [4] as the first human phantom which corresponds to the male anatomical data recommended in ICRP publication [5]. Figure 2 shows the images of the MAX06 of (a) entire body and (b) cross sectional slice. The MAX06 has been compiled as a data set of 474 columns × 222 rows × 1461 slices and consequently the total number of voxels are 153,738,108, of which 41,461,410 voxels are filled with human tissues. The voxel size is 1.2 × 1.2 × 1.2 mm^3. Around 90 organ and tissue regions have been specified and it allows to assume variety source distributions in the phantom.

2.3 Biokinetic model

Distributions of ^{137}Cs and ^{60}Co in a human body were estimated using the ICRP biokinetic models [6, 7]. The models are presented as a compartment model, in which transfer of radiological materials are expressed by first-order kinetics as a following equation.

$$\frac{dq_i}{dt} = \sum_j \lambda_{j\to i} q_j - \lambda_i q_i - \lambda_p q_i \tag{1}$$

where q_i, q_j are activities of i- and j-th compartments, λ_i is a transfer coefficient outward from i-th compartment, $\lambda_{j\to i}$ is a transfer coefficient from j-th to i-th compartment and λ_p is a decay constant of the nuclide.

In figure 3, the biokinetic models of ^{137}Cs and ^{60}Co are shown. The radionuclides are deposited in the respiratory organs by inhalation and then absorbed into blood and moved to some organs with specific rates of the materials. The source distributions vary with time. The equations for each compartment of the models were calculated to obtain the source distributions at given days after an intake by inhalation.

2.4 Monte Carlo calculations

Counting efficiencies of the WBC were evaluated with the EGS4 code [8] in conjunction with UCWBC code [2]. The photon source organs of the MAX06 and emission fractions were assumed to be the source distributions derived from the biokinetic models. Photon energies of 662 keV (^{137}Cs) and 1333 keV (^{60}Co) were simulated. The MAX06 was assumed to be on the bed at the same position with humans in actual measurements. The counting efficiencies were evaluated by dividing the sum of total absorption peaks of the three Ge detectors by the number of histories. The number of histories was set 10 millions so that statistical uncertainties were below 3 %. The cross section data for photons were taken from PHOTX [9], and for electrons from ICRU report 37 [10].

3 Results and discussion

3.1 Source distributions

Table 1 shows the fractions of activity in the source organs for ^{137}Cs and ^{60}Co at 0.5, 3, 10 and 365 days after an intake. At 0.5 days, the nasal passage is one of the main source organs for both

nuclides because it is the entrance of the inhaled materials.

It can be also seen in table 1 that the distributions of ^{60}Co are different from homogeneity over the period of a year. The nasal passage and the colon are dominant source organs at 0.5 and 3 days. Following removal of the activities from these organs, the lungs become a significant source organ. On the other hand, ^{137}Cs is almost homogeneously distributed in the whole body because of rapid absorption into blood and circulation to the whole body. These fractions of activity were assigned into the MAX06 for the simulations. Figure 4 illustrates the source distributions on frontal view of the MAX06.

3.2 Counting efficiency

Figure 5 shows the counting efficiencies of the WBC for ^{137}Cs and ^{60}Co with various source distributions. For both nuclides, the efficiencies at 0.5 days after an intake are the lowest and the discrepancies with those for the homogeneous sources are approximately 20 % and 30 % for ^{137}Cs and ^{60}Co, respectively. This is due to the retention of the activity in the nasal passage, which is at relatively large distance from the detectors. The results indicate that measurements with the WBC following intakes by inhalation of ^{60}Co and ^{137}Cs can lead to underestimations of the body activity.

For ^{137}Cs, the counting efficiency at 3 days after an intake is consistent with that for the homogeneous source. It is due to the rapid circulation of Cs to the whole body. The efficiency for ^{60}Co at 3 days after an intake is inconsistent with that for the homogeneous source. This means that the activities in the other organs than the nasal passage only slightly affected the efficiency of the WBC.

4 Conclusions

The counting efficiencies of the WBC at JAEA for ^{137}Cs and ^{60}Co were evaluated using the voxel phantom and the ICRP biokinetic models. The fractions of the radionuclides in the organs at 0.5, 3, 10 and 365 days after an intake were estimated. It was found that the efficiencies at 0.5 days after an intake are the lowest for both radionuclides. The differences of the counting efficiencies between that for the specific source distributions at 0.5 days after an intake and that for the homogeneous source distribution are 20 % and 30 % for ^{137}Cs and ^{60}Co, respectively. The results show that the calibration of the WBC taking into account the biokinetic models may be necessary for measurements following an accident.

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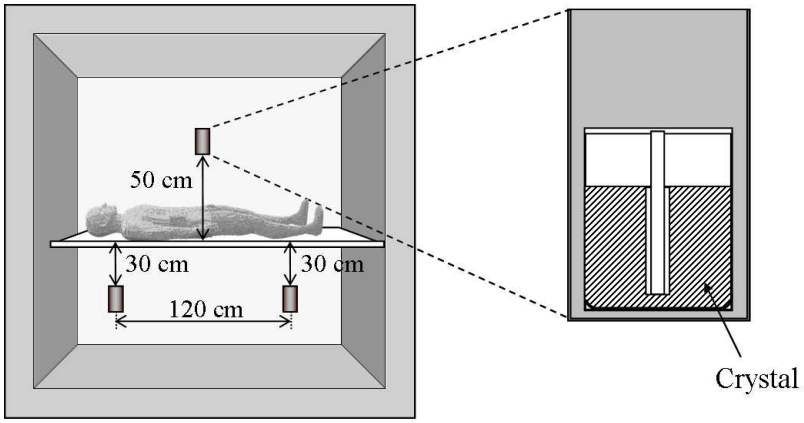
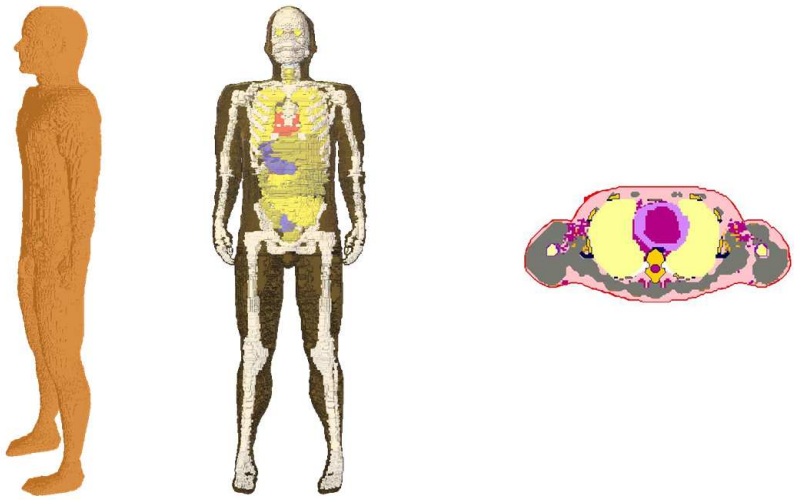
Table 1: Fractions of activity in the specified source organs.

Elapsed days	^{137}Cs				^{60}Co			
from intake	0.5	3	10	365	0.5	3	10	365
Whole body (blood)	68	96	100	100	8	18	27	60
Nasal passage	32	4			32	11		
Lungs					9	36	69	33
Small intestine					3			
Colon					48	33	1	
Liver						2	3	7



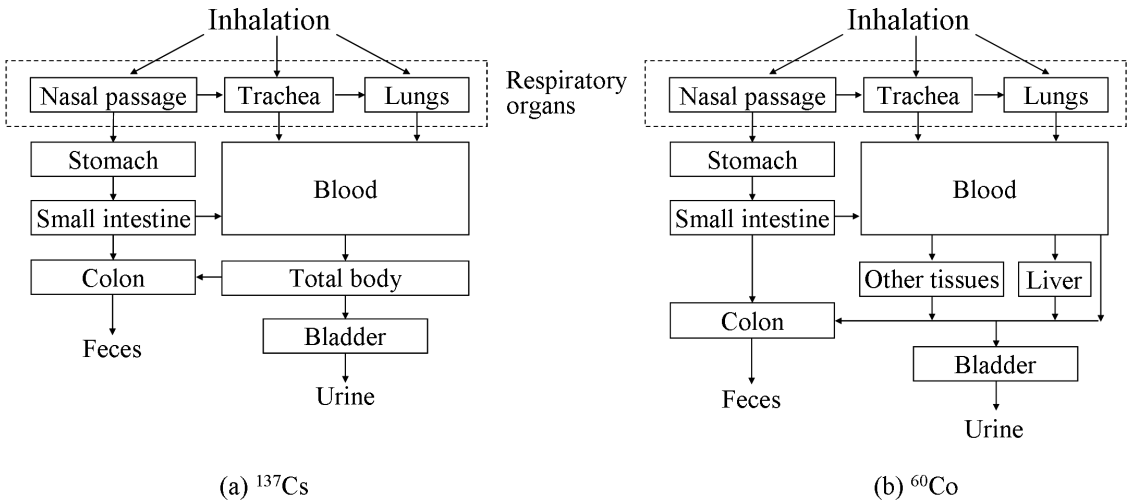
(a) Whole-body counter (b) Ge detector

Figure 1: Geometrical models of the whole-body counter and the Ge detector.



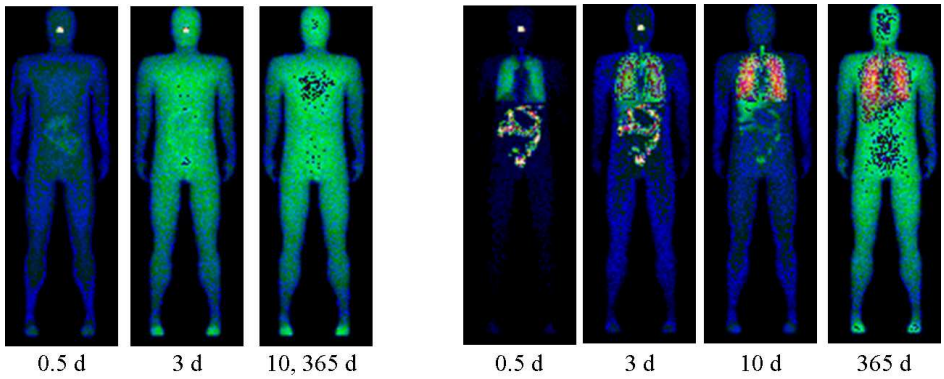
(a) Whole body (b) Cross-sectional image

Figure 2: MAX06 phantom.



(a) ^{137}Cs (b) ^{60}Co

Figure 3: ICRP biokinetic models.



(a) ^{137}Cs (b) ^{60}Co

Figure 4: Variation of source distributions displayed on frontal view of the MAX06 phantom.

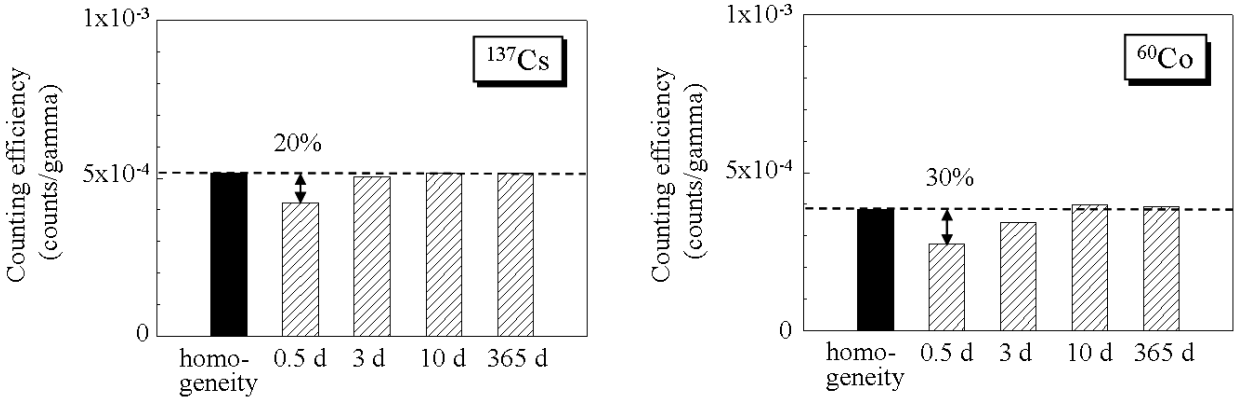


Figure 5: Counting efficiency evaluated for ^{137}Cs and ^{60}Co with homogeneous activity and actual source distributions derived from the biokinetic models.

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