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Internal dosimetry of inhaled iodine-131

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ABSTRACT

In this paper, the dose assessment for the iodine inhalation exposure in 19 aerosol sizes and three gas/vapor forms at three levels of thyroid uptake, was performed. Two different modes of work (light vs. heavy) and breathing (nose vs. mouth) for aerosol inhalation were investigated. In order to calculate the cumulated activities per unit of inhaled activity, a combined model which included the latest models of both human respiratory and alimentary tract was developed. The S values for ^{131}I were computed based on the ICRP adult male and female reference voxel phantoms by the Monte Carlo method. Then, the committed equivalent and committed effective dose coefficients were obtained (The data are available at http://www.um.ac.ir/~mirihakim). In general, for the nonzero thyroid uptakes, the maximum cumulated activity was found in the thyroid. When the thyroid is blocked, however, the maximum depends on the work and breathing mode and radioisotope form. Overall, the maximum CED coefficient was evaluated for the inhalation of elemental iodine at thyroid uptake of ~27% (2.8×10^{-8} Sv/Bq). As for the particle inhalation per se, mouth breathing of 0.6 nm and 0.2 μm AMTD particles showed to have the maximum (2.8×10^{-8} Sv/Bq) and minimum (6.4×10^{-9} Sv/Bq) CED coefficients, respectively. Compared to the reference CED coefficients, the authors found an increase of about 58% for inhalation of the aerosols with AMAD of 1 μm and 70% for 5 μm.

1. Introduction

Iodine-131 (^{131}I) is an important contributor to the overall exposure in the early period after a nuclear accident. Inhalation is one of the main pathways of radioiodine exposure. Therefore, the study of the population's health risks caused by inhalation exposure to radioiodine dispersed in the environment is necessary to improve the radiation protection of the members of public and workers. To evaluate the committed dose coefficients, three steps should be preceded (Loevinger and Berman, 1976). The first step is the calculation of the cumulated activity of ^{131}I, which requires the solution of a first order differential equations of all compartments in the combined biokinetic model which included models of both human respiratory and alimentary tract. The calculation relies on the input values of fractional deposition in the respiratory tract reported in ICRP Publication 66 (ICRP, 1994a). The second step is the Monte Carlo calculation of S values for all source-target pairs by using the computational phantoms. The final step is the calculation of committed equivalent and committed effective dose coefficients based on the results of the previous two steps.

The International Commission on Radiological Protection (ICRP) has published, among other dosimetric data the committed effective dose (CED) coefficients of the inhaled radioiodine in Report 119 (Eckerman et al., 2012). The following assumptions have been made:

The ICRP results are reported for iodine, inhaled as elemental iodine (I_2), methyl iodide (CH_3I), and aerosols with sizes of 1 and 5 μm. The values are only applicable for a reference person with normal thyroid uptake and normal nose breathing and an average breathing rate of 1.2 m^3/h during 8 h of light work. Radioiodine as an aerosol, however, may be breathed in a variety of various sizes, especially in submicron sizes near the release location of the nuclear accident (Lebel et al., 2016), through the nose and mouth during the light and heavy work. Although different deposition patterns in the respiratory tract caused by different aerosol sizes and physiological parameters (e.g. type of work and breathing) (ICRP, 1994a) may change dose coefficients, no report of these parameters was found in studies on the inhalation dose.

The results in ICRP Publication 119 are based on biokinetic models of human respiratory and alimentary tract in ICRP's Reports 30, 56, and 68 (ICRP, 1979, 1990a, 1994b). Both human respiratory and alimentary tract models and the absorption parameter values have been updated since then (ICRP, 2015; Leggett, 2010), but the cumulated activities and the inhalation doses based on a combined model which included both new models have not been computed. Leggett indicated that some changes in only alimentary tract model can lead to substantially higher dose coefficients compared to the values based on the previous model in most organs (like thyroid) (Leggett, 2010).

The stylized version of phantoms is used by the ICRP task group to

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compute internal doses of radioisotopes. The simple anatomy of these phantoms results in significant discrepancies in the radiation dose when compared with the realistic anatomy of human body, i.e. voxel phantoms (Leggett, 2010). Therefore, The ICRP has suggested that the stylized phantoms should be replaced by the voxel ones in the radiation dosimetry (ICRP, 2007). Finally, the reference CED coefficients are estimated based on tissue weighting factors, w_T values, in ICRP Publication 60. The changes to the w_T values in ICRP Publication 103 may also influence the CED coefficients.

The aim of this study is to do a dose assessment for all possible states that may be encountered in the radioiodine inhalation exposure, based on the updated biokinetic models, computational phantoms, and tissue weighting factors. These include 19 aerosol sizes (with Activity Median Thermodynamic and Aerodynamic Diameters (AMTD and AMAD) from 0.6 nm to 20 μm) and three gas/vapor forms (I_2, CH_3I, and Ethyl iodide (C_2H_5I)) at three levels of thyroid uptake (0, 5, and ~27 percent). Two different modes of work (light vs. heavy) and breathing (nose vs. mouth) for aerosol inhalation were investigated.

2. Materials and methods

2.1. Computation of dose coefficients

In this study, the general method of dose assessment, approved by MIRD committee, was applied (Loevinger and Berman, 1976). The absorbed dose coefficient in units of Gy.Bq^{-1}, $D(r_T, T_D)$, is calculated as the sum of dose to each source region (Bolch et al., 2009). The absorbed dose coefficient refers to the mean absorbed dose in target region, r_T, per unit of inhaled activity in each source region, r_S, during the residence time in the body.

$$D(r_T, T_D) = \sum_{r_S} S(r_T \leftarrow r_S)\widetilde{A}(r_S, T_D) \quad (1)$$

where $S(r_T \leftarrow r_S)$ (the so-called S value in Gy.(Bq.s)$^{-1}$), defined as the absorbed dose in r_T per nuclear transformation in r_S (described in section 2.3) and $\widetilde{A}(r_S, T_D)$ (in seconds) is the cumulated activity per unit of inhaled activity in r_S over the specified time, T_D, (see section 2.2).

Effective dose, E, is a quantity defined for the gender-averaged reference person to assess the overall radiation detriment (ICRP, 1990b). It is quantified as follows:

$$E = \sum_T w_T H_T = \sum_R w_R D(r_T, T_D) \quad (2)$$

where H_T is the equivalent dose in tissue or organ, T, and w_T is the weighting factor for the tissue T. In this study, the effective dose was estimated using the w_T values of ICRP Publication 103 (ICRP, 2007). For photons and electrons, the corresponding equivalent dose is equal to the absorbed dose, i.e. $w_R = 1$.

2.2. Cumulated activity calculation

Cumulated activity is the total number of disintegrations in the source region during a specified time and should be evaluated based on the biokinetic models. In the present work, using the values of absorption parameters in ICRP Publication 130, two systemic biokinetic models were combined together into one complete model with 30 compartments to describe the behavior of the inhaled ^{131}I in the human body (Fig. 1). The models include the ICRP model of the respiratory tract as described in ICRP Publication 130 (ICRP, 2015), and the Leggett's systemic biokinetic model (Leggett, 2010).

The structure of the compartmental biokinetic model can be characterized mathematically by a set of differential equations for each compartment as follows (Bolch et al., 2009):

$$\frac{df_i^*(t)}{dt} = \sum_{\substack{j=1 \\ j\neq i}}^{n} k_{ij}(t) f_j^*(t) - k_{ii}(t) f_i^*(t) - \lambda f_i^*(t) + U_i^*(t), \; i = 1, \ldots, n \quad (3)$$

where $f_i^*(t)$ is the amount of radioactive substance in the compartment i at time t. $K_{ij}(t)$ is the transfer coefficient, defined as the fraction of substance in the compartment j transferred to the compartment i per unit time. Here the asterisk denotes the radioactive tracer, $U_i^*(t)$ is its input function in terms of the activity taken from ICRP (ICRP, 1994a, 2012) for all exposure conditions, and λ is the physical decay constant

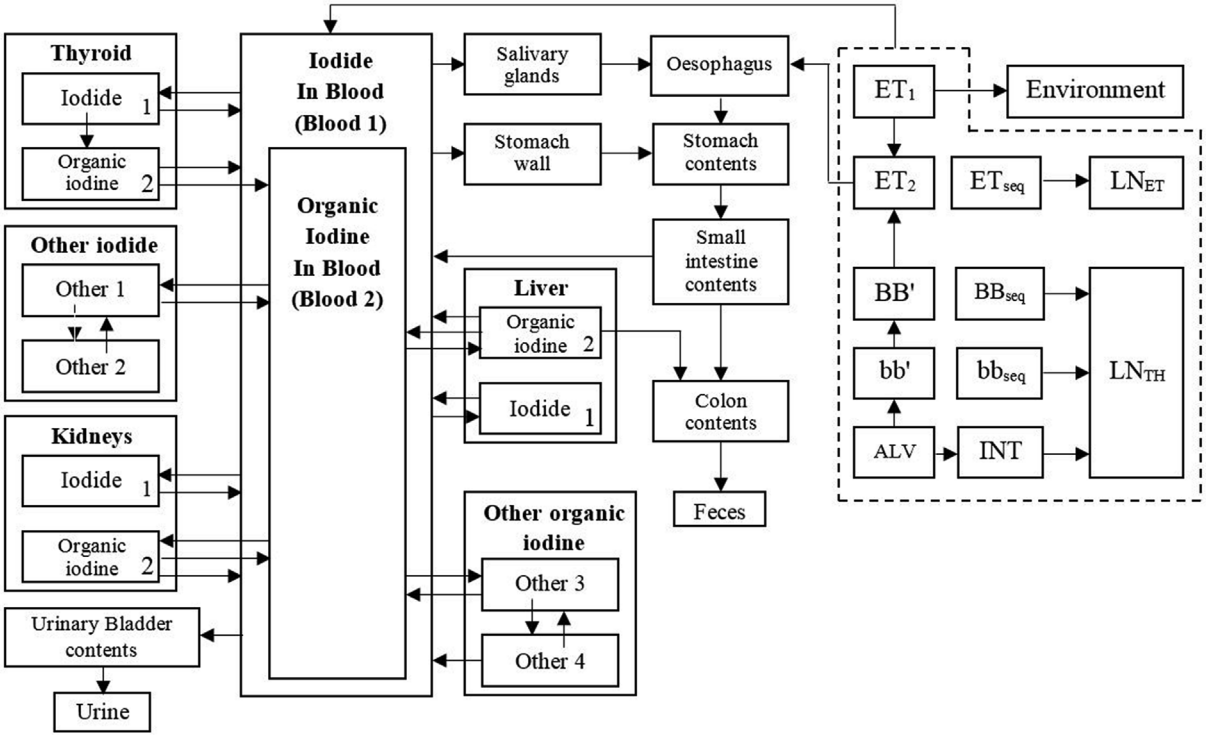

Fig. 1. Biokinetic model for iodine inhalation dosimetry. A combination of the human respiratory and alimentary tract models (ICRP, 2015; Leggett, 2010).