J. Appl. Environ. Biol. Sci., 5(8S)609-613, 2015

ISSN: 2090-4274
Journal of Applied Environmental and Biological Sciences
www.textroad.com

The Calculation of the Annual Effective Dose Due to Exhalation of Radon Progeny in Iran

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Received: March 8, 2015
Accepted: May 10, 2015

ABSTRACT

Ramsar, in northern Iran, is among the world's well-known areas with highest levels of natural radiation such as Radon which is the second leading cause of lung cancer. It can get into any type of building, homes, offices, and schools and result in a high indoor radon level. Some radioisotopes of Radon progeny deposited in the human lungs emit α and β particles followed by γ rays. While γ and β rays are comparatively less damaging to the respiratory system than α, they store their energy in the other organs because the high penetrating photons can travel through the whole human body without being absorbed. In order to establish a quantitative estimate of the hazards caused by such radiation, this paper studies the annual effective dose due to Radon progeny in Ramsar. The results show the photon absorbed dose in some organs such as lungs, heart, esophagus, thymus and breasts are remarkable especially for the maximum concentration of radon in Iran, and the contribution of such great organ doses should be studied for lung, esophagus, and breast cancers. Also the effective dose of these photons and electrons per year was 2.6 $mSvWLM^{-1}$ in Ramsar.The dosimetry of photons and electrons are important, particularly in situations with high levels of exposure to Radon because all organs received the photon and electron absorbed dose from radon progeny. Also the value of the effective dose per year is more than the annual allowable effective dose (1 mSv), so one cannot ignore the photon and electron dose, and high concentrations of radon.

KEYWORDS: Dosimetry, Lung Cancer, ORNL Phantom, Radon Progeny, Ramsar, MCNPX

1. INTRODUCTION

Humans, animals and plants have been exposed to natural radiation since the creation of life. More than 3.5 billion years ago, when the living organisms appeared on the Earth, the level of natural radiation was about three times higher than its current level. The U.S. Environmental Protection Agency (US EPA) and the Surgeon General's Office have estimated that as many as 20,000 lung cancer deaths are caused each year by Radon. Inhabited areas with high levels of natural radiation are found in different areas around the world including Yangjiang, China; Kerala, India; Guarapari, Brazil and Ramsar, Iran. The relationship between radon exposure and lung cancer has already been demonstrated in epidemiological studies performed on cohorts of miners [1]. Radon comes from the natural (radioactive) breakdown of uranium in soil, rock and water and gets into the air we breathe. The high background radiation in the "hot" areas of Ramsar is primarily due to the presence of very high amounts of ^{226}Ra and its decay products which were brought to the earth's surface by hot springs.^{220}Rn, or thoron from the ^{232}Th series, and ^{219}Rn from ^{235}U have very short lives (55.6 s and 3.96 s, respectively), and they are of minor significance compared with ^{222}Rn in ^{238}U series. The half-life of ^{222}Rn (3.82 day) is long enough to diffuse into and build up in homes [2]. The natural level of ^{222}Rn in open space is usually below 10 $Bq.m^{-3}$ [3]. In the closed space, ^{222}Rn can accumulate due to poor air ventilation. The primary routes of potential human exposure to radon are inhalation and ingestion.

Although high concentrations of radon in groundwater may contribute to radon exposure through ingestion, the inhalation of radon released from water is usually more important**.**

The organ that receives the highest dose from the inhaled radon progeny is the lungs [4]. ^{218}Po and ^{214}Po decay by the emission of alpha particle, which damage the surrounding tissues and are responsible for relatively high dose in the lungs. ^{214}Pb and ^{214}Bi decay through beta emission followed by gamma radiation.

A lot of work has been done to determine the doses in the human lungs due to short-lived radon progeny. Many papers deal with the determination of dose delivered by alpha particles in the lungs [5,6] because of their low range and relatively high and discrete energy (6 MeV for ^{218}Po and 7.69 MeV for ^{214}Po). On the other hand, β particles emitted by radon progeny have continuous spectra with electron energies up to 3 MeV. γ radiation has a discrete energy spectrum but there are many lines with maximal energy of 3 MeV. β and γ are much more penetrating than alpha particles and their mean free paths in tissue are from few millimeters for low energy electrons to a few tens of centimeters for high-energy photons. High-penetrating photons can travel throughout the human body without being absorbed [7]. Former Studies have shown that despite the fact that Ramsar is an area with one of the highest background radiation in the world [8], serious research and studies about the exact calculations of radon progeny absorbed dose have not been conducted. So there is an important question. Is it possible that the absorbed dose of photons and electrons from radon progeny has a fundamental contribution in the annual permissible dose?

Corresponding author: Shila Banari Bahnamiri, Assistant Professor of nuclear physics, Tabari University of Babol, Iran. Radon in the ground, groundwater, or building materials enters working and living spaces and disintegrates into its decay products.

In this work, the absorbed organ doses from radon progeny were investigated [9]. Besides, the effect of different radioactive decay data from web-based library ENDF/IV table of radioactive isotopes [10] on organ dose values was analyzed.

2. MATERIAL AND METHODS

2.1.ORNL modified phantom

The direct measurement of the absorbed dose in a human body is generally not possible. Therefore, anthropomorphic phantoms coupled with Monte Carlo simulations are most commonly used for estimating the absorbed dose. The analytical models of the human body (called human phantoms) were described in ORNL publications [11]. These phantoms are basically solid-geometry models that describe the exterior and interior anatomical features of a human body using analytical equations. For example, each lung is represented by half an ellipsoid with a section removed. The section removed from the left lung is larger than that removed from the right lung because of the position of the heart.

However, during primary phantom implementations, the lost particles were traced. Two overlaps are seen at the area where the transverse colon of upper large intestine meets the ascending colon of upper large intestine or the descending colon of lower large intestine, and another one at the meeting region of the esophagus and the spine. The geometry errors, which almost took place in too small areas of these organs, were removed with a minor displacement of meeting surfaces [20].

According to figure 1, human phantom consists of three types of tissues: skeletal, lung and soft, with different densities and elemental compositions [12,13].

All the equations for organs of all phantoms, with other relevant information (elemental compositions, volumes, masses, etc.), were programmed in input files for MCNP-4B code. By combining surfaces through Bull algebra, MCNP-4B forms cells representing various organs [7].

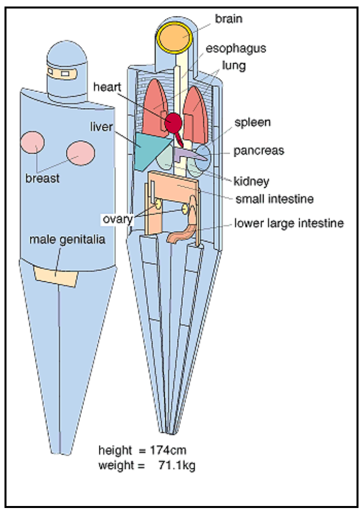

Fig.1. Mathematical model of the human body

To calculate doses in other organs when the source is in the lungs, ORNL phantom of the human body was applied. This model does not give almost any detail of human lungs. Tree structure of Trachea-Bronchial (**T-B**), T-B was completely neglected and whole respiratory tract is given with two asymmetrical ellipsoids representing two (left and right) lungs.

2.2.Dose Calculation

Uniform distribution means the uniform random sampling of initial photons and electrons points in objects, which represents lung in the ORNL model.

In order to calculate the doses in other sensitive organs when the source is in the lungs, the ORNL phantom of the human body was used. Since the radon progeny attached to the aerosols in the air enters the lungs through inhalation and decay in the lungs, one can define the lungs as the main radiation source for input file of Monte Carlo N-Particle (MCNP) code. Due to the high penetrability of γ, it is assumed as the uniform source of radiation.

Also according to figure 2, the human lung contains a large number of air tubes with different diameters, which are distributed across the lung volume. In fact, the particles are inhaled into the airways. The alpha particles emitted from radon products, are short-range. So they are not removed from the air tube. These particles deposit their energy in the airways. However, due to the low density ($0.296\, g/cm^3$) of lung tissue, the electron range in the lungs is amount of approximately centimeters that is larger than the airways diameter, especially for the ^{214}Bi isotopes can also be a few centimeters. Thus a good approximation (as suggested by Markovic et al 2009) as the source of human lung uniform emitting electrons was considered.

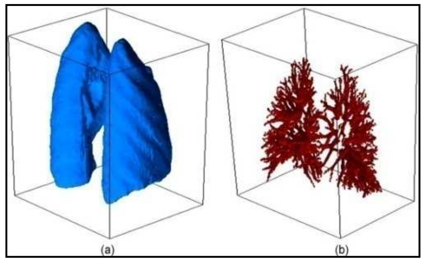

Fig. 2: Airways of the respiratory system

The yields $(Bq\text{-}s)^{-1}$ versus energy (MeV) of radon progeny was taken from ENDF/VI decay data[10] The spectrum of beta is obtained from ref. [23]. The output files of MCNP code were obtained from the mean absorbed dose (in MeV/g per one particle of radiation) in the 'main' organs and the 'remainder' tissue of the human body. The averaged absorbed dose (MCNP output), $\overline{{}_T D_R^n}$, is the quotient of deposited energy due to radiation of type R in the volume of specific organ or tissue T by its mass from nuclide n (^{214}Pb or ^{214}Bi). The mean absorbed dose per particle of radiation (in μGy WLM^{-1}) from the whole lung as a source was calculated using Equation (1)[7]. WLM is a working level month that is exposed to the radon progeny of 1 WL ($2.08\times10^{-5}\,Jm^{-3}$) during 170 h.

$$ {}_T D_R^n = \overline{{}_T D_R^n} . A_n . Y_R^n \tag{1} $$

where, A_n is the activity of each isotope (n) and Y_R^n is the yield of radiation. Since $\overline{{}_T D_R^n}$ obtained in the simulation is given per quantum or per particle of radiation, and activities per disintegration to derive absorbed dose per 1 WLM, one needs to know the yield of certain type of radiation.

These are the results from the program LUNGDOSE.F90. This program includes calculation working level month deposition of aerosols in different deposition regions of the Human Respiratory Tract Model (HRTM) according to the algebraic model of ICRP Publication 66 and equilibrium activities of radon progeny in different clearance regions of the HRTM and the total number of emitted particles for given exposure conditions and exposure time. The input parameters for the program LUNGDOSE.F90 are such as breathing rate of $0.78\,m^3h^{-1}$, equilibrium factor(The radon equilibrium factor[26] is the ratio between the activity of all short-period radon progenies (which are responsible for most of radon's biological effects) of 0.395 and these are very important parameters for calculating photon and electron activities [7].The absorbed doses were reported per 1 WLM in $\mu GyWLM^{-1}$ using Equations (2) and (3).

$$ {}_T D_R^{214Pb} = {}_T D_\gamma^{214Pb} + {}_T D_{X-ray}^{214Pb} + {}_T D_\beta^{214Pb} + {}_T D_{ce}^{214Pb} \tag{2} $$

$$ {}_T D_R^{214Bi} = {}_T D_\gamma^{214Bi} + {}_T D_{X-ray}^{214Bi} + {}_T D_\beta^{214Bi} + {}_T D_{ce}^{214Bi} \tag{3} $$

Photon and electron absorbed doses were estimated for 24 main organs. The equivalent dose H_T is one of the radiobiological protection quantities that is defined as a weighed mean absorbed dose, in some organ T, from γ, x-ray, β and conversion electron and was obtained using Equation 4.

$$ H_T = \sum_n \sum_{X-ray,\gamma,\beta,Ce} w_R \; {}_T D_R^n \tag{4} $$

Where, W_R is the radiation weighting factor which depends on the radiation type and energy whose values for photon and electron radiations are equal to 1.

The effective dose, which is the main radiation protection quantity, is obtained using equation 5[7,25]. The sex averaged effective dose was calculated as:

$$ E_{eff} = \sum_T w_T \frac{H_{TM} + H_{TF}}{2} \tag{5} $$

Where, W_T is the tissue weighting factor taken from recent ICRP publication 103 [23]. H_{TM} and H_{TF} are the equivalent doses for male and female respectively.

3. RESULTS AND DISCUSSION

The entire organ dose estimations in this work have an uncertainty less than 0.5%. Table 1 lists the absorbed doses, ${}_T D_R^n$ per WLM , in 24 main organs of the human body. As expected, some of the photon particles emitted by radon

progeny have enough energy to leave the lungs and deposit their energies in different organs, for which the organ doses cannot be disregarded. But the absorbed doses of the electron are less than photon. So except for lungs one can overlook the electron absorbed dose compared with photon absorbed dose, because the photon dose is more than 5% of electron absorbed dose.
As expected, the results show that the lungs are the sources that receive the highest absorbed dose than other organs.

Table 1: Organ doses from γ radiation, x-ray, β and conversion electron from radon progeny nuclides, distributed in the human lungs (in μGy WLM^{-1})

Organs	Total photon absorbed dose	Total electron absorbed dose	Total absorbed dose
Kidneys	3.16E-01	9.08E-05	3.16E-01
Pancreas	6.65E-01	6.30E-04	6.66E-01
Small Intestine	9.87E-02	7.44E-05	9.88E-02
Adrenals	8.94E-01	1.67E-03	8.96E-01
Gall bladder	3.26E-01	5.08E-04	3.26E-01
Heart	1.63	6.18E-03	1.64
Skin	1.96E-01	4.29E-03	2.0E-01
Thyroid	4.48E-01	2.55E-03	4.50E-01
Stomach	4.87E-01	3.68E-03	4.90E-01
Bone surfaces	3.14E-01	2.61E-03	3.14E-01
Lungs	4.54	49.31	53.85
esophagus	1.59	4.42E-03	1.59
Bladder	2.51E-02	5.86E-05	2.52E-02
Thymus	1.12	8.16E-04	1.12
Liver	7.72E-01	8.79E-03	7.81E-01
Brain	5.31E-02	2.74E-05	5.31E-02
Colon	8.22E-02	1.08E-04	8.23E-02
Red Bone Marrow	3.48E-01	8.98E-04	3.49E-01
Muscle	3.72E-01	8.33E-03	3.8E-01
Spleen	6.40E-01	1.41E-03	6.41E-01
Breast	9.84E-01	1.41E-02	9.98E-01
Uterus	4.63E-02	1.89E-04	4.65E-02
Ovaries	4.92E-02	3.04E-04	4.95E-02
Testes	8.78E-02	1.49E-04	1.03E-03

After lungs, the second and the third highest doses are received by heart and the esophagus respectively because both of them are located close to the lungs. The bladder receives less absorbed dose than other organs, as it is located farthest from the source compared with other organs.

Based on these data (table 1), the whole body effective dose was obtained according to ICRP103 recommendation. Therefore, the total Sex averaged effective dose was calculated to be about 7.50 μSvWLM^{-1}.

The results showed the maximum concentration of radon is more than 31000 Bq/m^3. Based on these data, the annual organ absorbed dose in maximum concentration of radon was shown in figure (3). The results show the absorbed dose in some organs such as lungs, heart, esophagus, thymus, and breast are notable, so the effective dose of total photons and electrons is equal to 2.596 mSv. Therefore, this value is comparable with 1mSv (The annual allowable effective dose) [20].

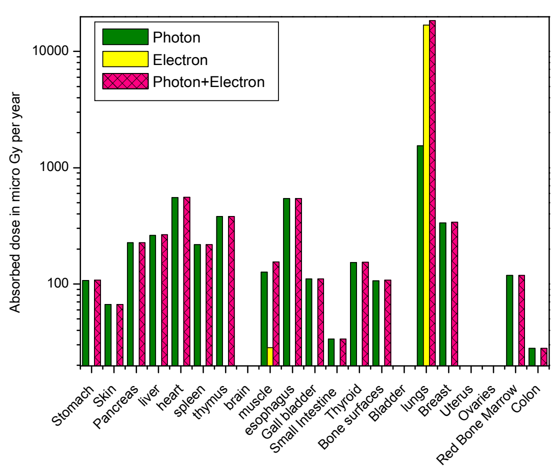

Fig. 3. The annual absorbed dose of photon emitted from radon progeny based on UNSCEAR 2006 radon concentration measurement in Iran

4.Conclusions

Although the contribution of alpha particles (emitted from radon progeny) in the effective dose is about 15 $mSvWLM^{-1}$ [21], just lungs receive the absorbed dose and alpha particles which cannot be exhaled out of the lungs because of their short range. Photons contribution in the effective dose is important because all organs receive the photon absorbed dose from radon progeny. The average concentration of radon in outdoor air is usually low due to the large volume of the air so that this concentration is generally safe. However, in the environments with high concentration of radon such as Ramsar, the risk may be obtained from the photon and electron dose increases. This value is more than the annual allowable effective dose. The contribution of such great organ doses should be studied for lung, esophagus, and breast cancers

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