Journal of Advanced Biomedical Sciences | Winter 2021 | Vol 11 | No 4 | https://doi.org/10.18502/jabs.v11i4.8633

Original Article

Determining the Absorbed Dose of Alpha Radiation due to Inhalation Radon Gas and Its Derivatives in Human Lung Using MCNPX 2.6.0 Simulation Model by Jafari et al. In Khorasan Razavi, Summer 2019

Mohammad Jafari Farhad*, **Bahmani Javad***
Department of Physics, University of Payam Noor, Tehran, Iran

[DOR: 20.1001.1.22285105.2021.11.4.2.5]
[DOI: 10.18502/jabs.v11i4.8633]

Received: 22 Jun 2021 Accepted: 02 Aug 2021

Abstract

Background & Objective: People who work in closed and underground environments such as mines get radioactive gases into their respiratory system due to the concentration in the air. These radioactive substances, after entering the body's respiratory system, with radiating energetic particles, damage most of the live cells. The most damaged parts are in the alveolar air cells of the lung which may lead to cancer.
Materials & Methods: The absorbed energy and annual effective dose due to the emitted alpha beam of radon and derivatives on alveolar air cells of the adult lung using MCNPX 2.6.0 simulation are determined. Color profiles are shown as a result of simulation of absorbed dose in the 27 alveoli of lung due to alpha radiation of radon and its derivatives.
Results: The investigations show that polonium-210 (^{210}Po), as one of the radon derivatives with long life, has the most annual effective absorbed dose in the human lung and as a result can cause the most damage to the living tissue of the alveolar air cells in comparison with the other radon derivatives. After this element, ^{218}Po, ^{222}Rn ,^{214}Po and ^{214}Bi have more the absorbed dose in the human lung, respectively.
Conclusion: Most cancers from radon are generated by radon derivatives. They can play an important role in lung damage. Exposure to radon derivatives rises a person's lifetime risk of lung cancer. The risk increases in direct relationship with the length of exposure and the type of radon derivative. For reduction of ^{210}Po is suggested the use of ventilation. It moves outdoor air into the building, and distributes the air within the building.

Keywords: Radon, alpha, MCNPX 2.6.0, alveolar, lung, radioactive

Introduction

Both natural and artificial alpha-emitting radionuclides in the environment can cause a hazard to human health, but the natural sources currently perform the major contribution to human exposure. Radon is a natural, non-color, non-odor, non-flavor gas with melting point-71 centigrade and boiling point - 61.7 centigrade. Its density is 8 times heavier than air. The atomic number is 86 with 27 isotopes which the most abundant ones are Radon 222, Radon 220 (Thoron) and Radon 219. Radon 222, 220 and 219 arose from radioactive series decay of uranium 238, thorium 232 and actinium 235 alternatively. Also, these isotopes have a half-life of 3.8 days, 55.61 seconds and 3.96 seconds, respectively. Radon is ineffective chemically

***Corresponding Author:**
1. **Mohammad Jafari Farhad,** Department of Physics, University of Payam Noor, Tehran, Iran
Email: F. Mohammadjafari@yahoo.com
https://orcid.org/ 0000 -0003 -4107- 827 X
2. **Bahmani Javad,** Department of Physics, University of Payam Noor, Tehran, Iran

Bahmani Javad: https://orcid.org/ 0000 -0001 -7334- 243 X

and is just soluble in water. Having a short life, it is converted into other products like plutonium, lead, and bismuth (1-2).

Research has shown that exposure to high concentrations of radon gas is a major cause of lung cancer. It is the second leading cause of cancer in the United States after smoking. Research in the United States shows that radon kills between 15,000 and 22,000 people a year, and the average death rate from radon-induced lung cancer is higher than in other disasters (3). Danaei and et.al have calculated absorbed dose from short-lived radionuclides of the radon (^{222}Rn) decay chain in lung tissue. The results are shown that short-lived radionuclides of radon decay chain, especially alpha emitter products, can be considered as dangerous internal radiation sources (4). Hunter and et.al have determined the lifetime lung cancer risks associated with radon exposure, based on various models and exposure scenarios (5). Radon and toron gas were measured near active faults in northeastern Iran by Jafari and et al in 2013 (6). The results show that residential areas close to active faults often had higher concentrations of radon and toron gas than other residential areas. In most residential areas, the density of toron was two to three times that of radon. About 20% of the residential areas were exposed to radon and toron gas more than the acceptable limits of radon. Most human exposure to radon occurs in residential homes. Radon usually enters homes from various directions, with soil and crustal rocks beneath the building generally being the main source of radon production and entry into residential environments. The first major source of radon gas is primarily uranium and then thorium in soil and rock. The World Health Organization (WHO) has also set a base limit on the permissible annual dose of radon in homes for reducing the risks of radon exposure to 100Bq/m^3 regardless of the radioactive derivatives (7). Among the natural sources, inhaled ^{222}Rn (the only long-life isotope of radon) and its decay products indoors have the main contributor to population exposure and might be responsible for a large number of lung-cancer deaths each year (8-13). These elements are the radioactive substances that after the decay of uranium-238 (^{238}U) come to the surface from the depths of the earth and through particles in the air such as dust that can enter the respiratory system of a person. Moreover, radon derivatives can also enter the respiratory tracts, and after decay, they produce a destructive effect on the body tissues, especially the lung's internal organs, by producing the energetic beams of alpha. Each member of the body, according to its structure and dimensions, can absorb the fraction of energy beam emission. Radon is a radioactive gas but radon derivatives are solids and can deposit in different parts of the lung where the most accumulated place of them are in the alveolar air cells (a tiny sac for holding air in the lungs; formed by the terminal dilation of tiny air passage ways) of the lung. The alveoli in the lung are the last place of the gas exchange of the body, and in most studies, it has been introduced as the main deposition place. The amount of energy deposited in the lung depends on parameters such as the density of radon gas in the location and exposure time of persons (14). The isotopes and their atomic masses are shown within the boxes; the main decay processes are demonstrated by arrows, with the type of decay and half-life indicated. The ^{206}Pb represents the end of chain and is not a radioactive nuclide. It should be noted that the $^{222}Rn$is produced by alpha decay of radium-226 (^{226}Ra) in the uranium-238 (^{238}U) decay chain. As can be seen the ^{214}Po and ^{218}Po are short-life derivatives of ^{222}Rn and long with ^{210}Po are alpha emitters. The ^{214}Pb, ^{210}Bi,^{210}Pb and 214Bi (with the decay probability of 99.979%) are beta emitters. As radon decays, it produces radioactive derivatives and releases significant amounts of alpha radiation along with low values of beta and gamma radiation from various energies. Despite their restricted tissue penetration potential, alpha particles can cause important biological damage in exposed tissue due to their high relative biological effectiveness (RBE) (15). Beta and gamma-radiation is also emitted from the decay of radon derivatives, therefore the RBE is minimal in comparison here the only alpha-emitting derivatives are considered.

In order to evaluate the health hazards imposed by radon and its decay derivatives, it is necessary to investigate the effects of radon exposure and to obtain the absorbed energy and dose due to alpha beam of ^{222}Rn and derivatives on alveolar air cells of adult lung by MCNPX 2.6.0 simulation. This issue is being examined considering the importance of the subject.

Radon derivatives (^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po) with a short half-life, have high energy beams that cause serious damage to the lung structure after transpiration through the lung. These radionuclides (radioactive nuclei) are not cumulative and sufficient in the environment. For example, ^{214}Pb is a beta emitter that has less importance in dosimeters, but ^{214}Po is a high-energy alpha emitter. Therefore, after the decay of radon, the concentration of the derivatives in the environment has particular importance. Radon with its derivatives can balance in an environment after a special time. Equilibrium factors are important in the amounts of the absorbed dose due to the radon derivatives and it expresses the effect of each derivative nucleus on the absorbed dose in the lung by inhalation of radon gas. Therefore, a knowledge of the radioactive equilibrium factor between radon and its derivatives is important to calculate the dose accurately and it must be determined in each radon monitoring. This factor is defined as the ratio between the activity of all short-life radon derivatives and the activity that would be at equilibrium with the radon parent.

The time required for the radon equilibrium with its derivatives is about 30 minutes in a relatively closed and quiet environment with low airflow. The equilibrium state significantly depends on the airflow and the physical processes that may be removed the fraction of the derivatives. The equilibrium factor is defined as the ratio the to the actual radon gas concentration according to the following formula (17).

$$F = \frac{EEC_{Rn}}{C_{Rn}}$$

which $EEC_{Rn} = 0.105C_1 + 0.515C_2 + 0.380C_3$ is a radon equilibrium equivalent concentration (in Bqm^{-3}or pCiL^{-1}) and is defined as the activity concentration of radon that is resulted if the radon derivatives were in equilibrium with the radon. C_{Rn},C_1,C_2 and C_3 are the activity concentration for ^{222}Rn ,^{214}Po,^{214}Pb and ^{214}Bi, respectively (Bqm^{-3}). In calculations assume that ^{214}Po due to the very short half-life is always in equilibrium with ^{214}Bi. The equilibrium factor depends strongly on the environment conditions (hours and mode of ventilation, humidity etc.) (18). According to the ICRP (international commission on radiological protection) recommendations value of 0.4 for the equilibrium factor is considered (19).

When radon gas, ^{222}Rn, decays in the atmosphere, the first product of ^{218}Po is formed in the form of a charged positive ion. The charge of the ion is neutralized quickly and began to grow at the atomic level, which absorbs available gases and vapor molecules in the pathway. On the other hand, polonium atom is also combined with oxygen or other materials, such as nitrate and sulfate, to become a simple structure. In a relatively short period of time, this molecule, with the surrounding water vapor shell, turns into a particle in the air. While this connection method tends to be removed from this collection, with the continuous decay of radon in the atmosphere, the equilibrium factor always remains constant and there is a small percentage of ^{218}Po that is not connected to the hazes in the air. Therefore,^{218}Po and the next derivatives have been seen to be connected in the atmosphere.

The alpha emission from ^{218}Po provides the necessary ejection energy due to decay to the ^{214}Pb atoms which makes the fraction of these atoms separate from particles and follows the general behavior pattern of distinction of ^{218}Po. But the subsequent beta decays of ^{214}Pb and ^{214}Bi do not release the ejection energy required to separate the atoms. The alpha emission from ^{214}Po can release some of the atoms of the 210 series, but their life is long, so they are less considered. A small fraction of separated

[DOR: 20.1001.1.22285105.2021.11.4.2.5]

[DOI: 10.18502/jabs.v11i4.8633]

particles with a size of 2-20nm is quickly spreading and this diffusion process is the most important physical factor for removing them from the atmosphere and deposition in the respiratory system (15). The deposit rate in the internal spaces for the separated radon derivative s in the surfaces is almost 7mh^{-1}. In the mines, the residual and quiet air can affect the relative concentrations of radon and its derivatives (20).

Materials and Methods

The effect of radon gas is investigated on the lungs, which is one of the most sensitive parts of the human body. Since it is not possible to study the effect of this gas on a living organism, it is decided to simulate this limb and obtain the effect of radon gas on it. Using the Monte Carlo N-Particle (MCNPX 2.6.0) simulation code (21, 22), first the person's lung is designed based on the ICRP66 publication (23). This code can measure a problem with high accuracy. Due to the cathartic nature of the nuclear interactions, MCNPX 2.6.0 code simulation is very real and with little error. In this method, all processes are followed according to what happens in the real world. The probability of each event is determined according to the experimental data in the form of cross section. The shape of the lung geometry is divided into three parts: the main bronchial tubes, the Rt&Lt lung along the subunit bronchial tubes and the alveoli (considering the heart under the Lt lung). Because of the heart placed under the Lt Lung volume is considered to be less than the Rt lung, so that it would match with the adult lung. Subsidiary bronchial tubes are shown separately in each ventricle and three generations of its subfolds are drawn. Empty spaces in the lung are considered as small cubes which alveolar air cells are inside them. The thickness of the walls and the length of the bronchial tubes and the alveoli are defined under the actual standards in the code. Because the number of alveolar air cells is three hundred million (24) and if all of them are placed as source, it is possible to run the program very hard, then the lungs are initially divided into several parts, and the sources are placed there, and their effect to each other investigated carefully. Then the overall result is analyzed.

The diameter and thickness of the alveoli are considered 200 and 2 micrometers, respectively (25). Therefore, for solving the problem in the MCNPX 2.6.0 code, the alveoli are defined as spherical centers with radius of 0.01cm and 0.0098 cm. It is located in the area between the two soft tissue spheres and the smaller butter of the air. At first, the problem is selected for an alveolus, and then a cubic section of 0.06 × 0.06 × 0.06 as the sample of the lung tissue. Which has 27 alveoli and now it has selected 27 spheres as springs and simulations. Empty spaces inside the lung were considered as small cubes with alveolar sacs inside them. Due to program limitations, it was not possible to use 300 million sources simultaneously, and an ideal and generalizable model was defined.

Inside each sphere, a homogeneous source of alpha is placed and then, using the MCNPX 2.6.0 code, the dose of sources in all spheres is measured. Depending on the absorption dose form, it is indicated that the dose of each air cell is due to the dose of the cell itself and the other adjacent sticking cells to them. It means that the dose of each cell is influenced by the dose of 10 sticking cells to it. So, it cannot affect the bronchial tubes and other parts of the lung. The reason is the short range of alpha beams. Therefore, in the lung simulation and calculation of absorbed dose, it is possible to ignore the effect of the sources in the alveoli over other respiratory components of the lung. After placing alpha-homogeneous sources in all of the main bronchial tubes and their branches, the absorbed dose is calculated using MCNPX 2.6.0 code and its graphical form is plotted using the Tecplot software. To reduce the error in the calculations, this code is implemented for 5 million particles. Due to the high color of the Mesh Tally software, the absorption value of the entire main bronchial tube and its splits cannot be displayed in a single shape, but can be plotted separately. Its reason is a large difference in the absorption dose of the primary and secondary bronchial tubes. Because radon derivatives have high energy beams, they can play the main role in damaging the human respiratory system. Due to the solid form of these elements, the absorption doses are investigated separately in this study. Radon derivatives are deposited in the last inhalation process in alveoli. Considering the deposition of these materials in the alveoli, a very thin layer of nanometers in the air can be formed that can be used as a source. In this paper, each spherical air cell to be an internal layer as the place of the deposition of derivatives and an outer layer as the cell's genus is considered. To study the effect of others on the inside, the cube contained 27 cells in one shape, each with two layers of membrane shaped with genus and source is considered. The source is considered only by the alpha beams, and the effects of other beams are ignored. Among the radon derivatives, the only high-energy alpha beams emitting including ^{214}Po, ^{218}Po, ^{214}Bi and ^{210}Po are considered. In the calculations, these derivatives are used as sources within the cell membrane. In the respiratory tract, the deposition occurs only in alveoli (including millions of alveolar air cells), therefore, the effect of the radon derivative nucleus is ignored in the main and secondary bonscials.

Results

The values of the absorbed energy and dose due to high energy alpha beam of ^{222}Rn,^{214}Po,^{214}Bi,^{210}Po and ^{218}Po as a result MCNPX 2.6.0 simulation are given in Tables1 to 6, respectively.

Table1. The values of absorbed radiation energy and dose due to alpha beams of ^{222}Rn on the membrane of ever alveolar air cell with mass of 6.1160×10^{-8} gr

Cell No.	Absorbed energy of ^{222}Rn (MeV).10^5	Absorbed dose of ^{222}Rn (mSv)	Amount of computational error in code
1	7.67640	0.828882137	0.0072
2	7.60844	0.82496419	0.0072
3	7.67154	0.826999946	0.0072
4	7.55046	0.8080032259	0.0073
5	7.5731	0.818790242	0.0072
6	7.38998	0.795206789	0.0072
7	7.42490	0.7967737667	0.0072
8	7.47895	0.803105321	0.0072
9	7.38728	0.793604452	0.0072
10	7.62380	0.820831049	0.0072
11	7.48244	0809274218	0.0073
12	7.42239	0.793385216	0.0073
13	7.41822	0.796690921	0.0073
14	7.50055	0.804064096	0.0072
15	7.38232	0.792363802	0.0072
16	7.33200	0.788781276	0.0072
17	7.43740	0.789343003	0.0072
18	7.28609	0.798666059	0.0072
19	7.48357	0.787570935	0.0073
20	7.43605	0.808655914	0.0072
21	7.26764	0.788781276	0.0072
22	7.36462	0.778429733	0.0073
23	7.38245	0.778990054	0.0072

24	7.30116	0.789447064	0.0072
25	7.29482	0.774208696	0.0073
26	7.33533	0.776853664	0.0072
27	7.29053	0.786427275	0.0072

Table2. The values of absorbed radiation energy and dose due to alpha beams of ^{214}Po on the membrane of ever air cell with a mass of 6.1160×10^{-8} gr

Cell No.	Absorbed energy of ^{214}Po (MeV).10^{5}	Absorbed dose of ^{214}Po (mSv)	The amount of computational error in code
1	7.83157	0.791224183	0.0067
2	7.44014	0.751677977	0.0066
3	7.42598	0.750247391	0.0066
4	7.34659	0.742226612	0.0067
5	7.39743	0.747362982	0.0067
6	6.94819	0.701976226	0.0067
7	6.95304	0.702466222	0.0066
8	6.99762	0.706940144	0.0066
9	6.94240	0.70139126/0	0.0067
10	7.45410	0.75308836	0.0067
11	7.36583	0.744170431	0.0067
12	6.99983	0.707193420	0.0067
13	6.98487	0.705682010	0.0066
14	7.00625	0.7078452033	0.0066
15	7.05498	0.712765229	0.0067
16	6.88824	0.695979473	0.0067
17	6.92707	0.699842471	0.0067
18	6.92659	0.699793977	0.0067
19	7.06664	0.713943240	0.0064
20	6.51710	0.658423167	0.0064
21	6.43788	0.650419564	0.0065
22	6.51606	0.658318096	0.0065
23	6.59409	0.666201473	0.0065
24	6.54246	0.660985290	0.0065
25	6.49242	0.655929745	0.0065
26	6.55147	0.661895571	0.0065
27	6.44997	0.651641017	0.0065

Table3. The values of absorbed radiation energy and dose due to alpha beams of ^{214}Bi on the membrane of ever air cell with a mass of 6.1160×10^{-8} gr

Cell No.	Absorbed energy of ^{214}Bi (MeV).10^{6}	Absorbed dose of ^{214}Bi (mSv)	The amount of computational error in code
1	1.711600	0.172923094	0.0070
2	1.167270	0.117929387	0.0070

[DOR: 20.1001.1.22285105.2021.11.4.2.5]

[DOI: 10.18502/jabs.v11i4.8633]

3	1.174130	0.118622454	0.0070
4	1.152600	0.116447276	0.0071
5	1.173720	0.118581031	0.0071
6	1.149370	0.116120949	0.0071
7	1.52920	0.116479606	0.0071
8	1.158530	0.117046384	0.0071
9	1.139730	0.115147019	0.0071
10	1.165690	0.117769760	0.0071
11	1.144900	0.115669344	0.0071
12	1.14540	0.116138124	0.0071
13	1.147460	0.115927981	0.0071
14	1.164590	0.117658627	0.0070
15	1.141330	0.115308667	0.0070
16	1.142020	0.115378378	0.0071
17	1.149290	0.116112866	0.0071
18	1.134410	0.114609539	0.0071
19	1.155180	0.116707934	0.0071
20	1.156440	0.116835232	0.0071
21	1.136110	0.114781290	0.0070
22	1.143900	0.115568314	0.0071
23	1.154850	0.116674594	0.0071
24	1.148560	0.116039114	0.0071
25	1.148240	0.116006785	0.0070
26	1.142490	0.115425862	0.0071
27	1.145660	0.115746127	0.0071

Table4. The values of absorbed radiation energy and dose due to alpha beams of ^{210}Po on the membrane of ever air cell with a mass of 6.1160×10^{-8}gr

Cell No.	Absorbed energy of of ^{210}Po (MeV).10^6	Absorbed dose of ^{210}Po (mSv)	The amount of computational error in code
1	1.43667	1.451438613	0.0068
2	1.44601	1.460905132	0.0067
3	1.45153	1.466481993	0.0067
4	1.42555	1.440234377	0.0068
5	1.45342	1.468391462	0.0068
6	1.42292	1.437577286	0.0068
7	1.43160	1.446346697	0.0068
8	1.43756	1.452368090	0.0067
9	1.41572	1.430303120	0.0067
10	1.43772	1.452529738	0.0068
11	1.41853	1.433142065	0.0068
12	1.43133	1.446073916	0.0068
13	1.43066	1.445397014	0.0068

14	1.44022	1.455055491	0.0068
15	1.41457	1.429141474	0.0068
16	1.42040	1.435031328	0.0068
17	1.42525	1.439931287	0.0068
18	1.41210	1.426645831	0.0068
19	1.43707	1.451873043	0.0068
20	1.44117	1.456015276	0.0068
21	1.42011	1.434738340	0.0068
22	1.42004	1.434667619	0.0068
23	1.43803	1.452842932	0.0068
24	1.42902	1.443740121	0.0068
25	1.42200	1.436647809	0.0068
26	1.42599	1.440678909	0.0068
27	1.41724	1.4131838777	0.0068

Table 5. The values of absorbed radiation energy and dose due to alpha beams of ^{218}Po on the membrane of ever air cell with a mass of 6.1160×10^{-8} gr

Cell No.	Absorbed energy of ^{218}Po (MeV).10^5	Absorbed dose of ^{218}Po(mSv)	The amount of computational error in code
1	7.667640	0.775547345	0.0072
2	7.608844	0.768681340	0.0072
3	7.67154	0.775056337	0.0072
4	7.55046	0.762823616	0.0072
5	7.57317	0.765118009	0.0073
6	7.38998	0.746610308	0.0072
7	7.42490	0.750138278	0.0072
8	7.47895	0.755598954	0.0072
9	7.38728	0.745428256	0.0073
10	7.62380	0.770233162	0.0073
11	7.48244	0.755951549	0.0073
12	7.42239	0.749884693	0.0072
13	7.41822	0.749463397	0.0072
14	7.50055	0.757781204	0.0073
15	7.38232	0.745836417	0.0072
16	7.33200	0.740752583	0.0072
17	7.43740	0.751401154	0.0073
18	7.28609	0.736114292	0.0073
19	7.48357	0.7560655713	0.0072
20	7.43605	0.751264764	0.0072
21	7.26764	0.734250287	0.0072
22	7.36462	0.743037884	0.0072
23	7.38245	0.745849551	0.0072

24	7.30116	0.737636816	0.0072
25	7.29482	0.736996285	0.0072
26	7.33533	0.741089014	0.0072
27	7.29053	0.736562866	0.0073

By assuming that the space within the cells is similar room, radon gas reaches the equilibrium with its derivatives after 30 minutes. The values of absorbed annual effective dose are calculated (see Table.6) considering the half-life of all elements (radon as a unit factor) and the equilibrium factor of radon and its derivatives in the environment. If the decay time of radon is considered one unit, the ratio of the decay time of the other derivative nuclei to radon is calculated. Using the concentration relation and substituting the concentration of each of the derivative nuclei and the output of simulation results, the following table is completed.

Table6. The values of the average absorbed annual effective dose resulting from alpha beams of radon and its derivative by applying equilibrium factors

Sample cell as spaces within the alveoli of the lung	Average dose (mSv)	Equilibrium factors
^{222}Rn	0.751300	0.7513000
^{218}Po	0.798410	0.0000475
^{214}Po	0.655200	0.0000001
^{210}Po	1.444450	8.1832368
^{214}Bi	0.118430	0.0001643
The average total	3.767790	8.9347487

A similar study has shown that alpha decay has more share to the lung absorbed dose in comparison with the beta and gamma decay (26). The other research has indicated that alpha emitter radionuclides had almost a different contribution in the lung dose at the deposited state inside the lung's air sacs (27). The results of this paper are similar to both studies.

Conclusion

Color profiles are investigated, resulting from simulation of absorbed dose of alveoli due to alpha beams of radon and decay products using mesh tally software. The values of absorbed radiation energy and dose due to alpha beams on the alveolars air cell of the human lung are determined. All short-period radon derivatives are responsible for most of radon's biological effects. Therefore, when radon and derivatives are exposed to inhale, the resulting radiation dose to the lung is primarily due to the radon derivative. The most considerable doses to the lung are primarily from the decay of alpha-emitting derivatives. The derivatives of beta particles and gamma-ray emitter have contributed to a small percentage of the total absorbed dose to the lung. Investigations indicate that with considering equilibrium factors the average absorbed annual effective dose of the alpha beam is maximized due to ^{210}Po. This derivative has more effect on the tissues of the air cell and the impact factor is almost ten times that of other radon derivatives. After this element, ^{218}Po, ^{222}Rn , ^{214}Po and ^{214}Bi have more absorbed doses, respectively. So, they have less biological effect on the human respiratory system. The maximum permissible limit of annual dose for radon and its derivatives should not be more than 200Bq/m^3 because the risk of tissue damage would be very high. The tissue of air cells is very thin and delicate, and the lack of gas exchange in them leads to premature death. In estimating the absorbed dose of alpha radiation due to inhaled radon gas and its derivatives in the human lung, the role of radon girls is about 80% of the total absorbed dose in the lungs. However, this dose should be adjusted based on the half-life and balance factor, the rate of which is reduced to about 30%.

Radon arrives homes via gaps in the bottoms or at floor-wall connections, gaps around tubes or cables, small holes in hollow-block walls, or sinks or drags. Radon levels are generally higher in undergrounds, storerooms or living areas in contact with soil. Radon concentrations vary between adjacent homes, and can change within a home from day to day and from hour to hour.

For reduction of ^{210}Po is suggested the use of ventilation. It moves outdoor air into a building and distributes the air within the building. The general aim of ventilation in buildings is to provide healthy air for breathing by diluting the pollutants originating in the building and removing the pollutants from it. Also, radon levels in available homes can be decreased by increasing under-floor ventilation, installing a radon sink system in the underground, avoiding the crossing of radon from the basement into living rooms, terminating floors and walls and improving the ventilation of the house.

Acknowledgment

This article is extracted from a research project at Payam Noor university with the code 2215 and therefore this university is thanked and appreciated.

Conflict of Interests

The authors have no conflict of interest.

References

1. Bem H, Długosz-Lisiecka M, Janiak S, Mazurek D, Szajerski P. Fast determination of indoor radon (222 Rn) concentration using liquid scintillation counting. Journal of Radioanalytical and Nuclear Chemistry. 2017;312(2):337-42.
2. Harrison JD, Marsh JW. Effective dose from inhaled radon and its progeny. Annals of the ICRP. 2012;41(3-4):378-88.
3. Hahn EJ, Gokun Y, Andrews Jr WM, Overfield BL, Robertson H, Wiggins A, Et al. Radon potential, geologic formations, and lung cancer risk. Preventive medicine reports. 2015; 2:342-6.
4. Danaei Z, Baghani HR, Mowlavi AA. Absorbed Dose Assessment from Short-Lived Radionuclides of Radon (222Rn) Decay Chain in Lung Tissue: A Monte Carlo Study. Iranian Journal of Medical Physics. 2020;17(2):66-74.
5. Hunter N, Muirhead CR, Bochicchio F, Haylock RG. Calculation of lifetime lung cancer risks associated with radon exposure, based on various models and exposure scenarios. Journal of Radiological Protection. 2015;35(3):539.
6. Molavi A, Mohmmad Jafari. F, Binesh, A. Measurement of radon and toron gas near active faults in northeastern Iran. Journal of Radiation Assessment and Safety.2013;2(4):1-8.
7. Sethi TK, El-Ghamry MN, Kloecker GH. Radon and lung cancer. Clin Adv Hematol Oncol. 2012;10(3):157-64.
8. Forkapić S, Mrđa D, Vesković M, Todorović N, Bikit K, Nikolov J, Et al. Radon equilibrium measurement in the air. In Paper presented at the First East European Radon Symposium–FERAS 2012; 5(2):1021-1025.
9. Conde-Sampayo A, Lorenzo-González M, Fernández-Villar A, Barros-Dios JM, Ruano-Ravina A. Exposure to Residential Radon and COPD: A Systematic Review. International Journal of Chronic Obstructive Pulmonary Disease. 2020; 15:939.
10. Stanley FK, Irvine JL, Jacques WR, Salgia SR, Innes DG, Winquist BD, Et al. Radon exposure is rising steadily within the modern North American residential environment, and is increasingly uniform across seasons. Scientific reports. 2019;9(1):1-7.
11. Gaskin J, Coyle D, Whyte J, Krewksi D. Global estimate of lung cancer mortality attributable to residential radon. Environmental health perspectives. 2018;126(5):057009.
12. Messina MJ. Legumes and soybeans: overview of their nutritional profiles and health effects. The American journal of clinical nutrition. 1999;70(3):439s-50s.
13. Martin K, Ryan R, Delaney T, Kaminsky DA, Neary SJ, Witt EE, Et al. Radon from the Ground into Our Schools: Parent and Guardian Awareness of Radon. SAGE Open. 2020;10(1):2158244020914545.
14. Field RW, Steck DJ, Smith BJ, Brus CP, Fisher EL, Neuberger JS, Et al. Residential radon gas exposure and lung cancer: the Iowa Radon Lung Cancer Study. American Journal of Epidemiology. 2000;151(11):1091-102.
15.Kendall GM, Smith TJ. Doses to organs and tissues from radon and its decay products. Journal of Radiological Protection. 2002;22(4):389.
16. Nilsson R, Tong J. Opinion on reconsideration of lung cancer risk from domestic radon exposure. Radiation Medicine and Protection. 2020;1(1):48-54.
17. Leung SY, Nikezic D, Yu KN. Passive monitoring of the equilibrium factor inside a radon exposure chamber using bare LR 115 SSNTDs. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers,

Detectors and Associated Equipment. 2006;564(1):319-23.
18. Jilek K, Thomas J, Tomášek L. First results of measurement of equilibrium factors F and unattached fractions fp of radon progeny in Czech dwellings. Nukleonika. 2010; 55:439-44.
19.vFerry C, Richon P, Beneito A, Cabrera J, Sabroux JC. An experimental method for measuring the radon-222 emanation factor in rocks. Radiation Measurements. 2002;35(6):579-83.
20. Morgan WF, Sowa MB. Non-targeted effects induced by ionizing radiation: mechanisms and potential impact on radiation induced health effects. Cancer letters. 2015;356(1):17-21.
21. Goorley JT, James MR, Booth TE, Brown FB, Bull JS, Cox LJ, et al. Initial MCNP6 release overview-MCNP6 version 1.0. Los Alamos National Lab. (LANL), Los Alamos, NM (United States); 2013.
22. Shultis JK, Faw RE. Department of Mechanical and Nuclear Engineering, Kansas State University, Manhattan, KS, USA jks@ ksu. edu fawre@ triad. rr. com.
23. Paquet F, Bailey MR, Leggett RW, Etherington G, Blanchardon E, Smith T, et al. ICRP Publication 141: Occupational Intakes of Radionuclides: Part 4. Annals of the ICRP. 2019;48(2-3):9-501.
24. Ochs M, Nyengaard JR, Jung A, Knudsen L, Voigt M, Wahlers T, et al. The number of alveoli in the human lung. American journal of respiratory and critical care medicine. 2004;169(1):120-4
25. ICRU-48. Phantoms and computational models in therapy, diagnosis and protection ICRU-48. Bethesda: International Commission on Radiation Units and Measurement, 1992.
26. Hofmann W, Li WB, Friedland W, Miller BW, Madas B, Bardiès M, et al. Internal micro dosimetry of alpha-emitting radionuclides. Radiation and environmental biophysics. 2020;59(1):29-62.
27. Kozak K. Radon—The Element of Risk. The Impact of Radon Exposure on Human Health. 2000; 10(12): 125-220