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Investigation the Effect of Radon Pollution on Hair Structure

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ABSTRACT

In this article, it has been tried to determine equivalent dose of hair, the number of track and the amount of damage or secondary elements produced in hair by radon and progeny alpha particles using Monte Carlo N Particle Version Extended (MCNPX) code and Geometry and Tracking 4 (Geant4) toolkit. The hair was put in the air of Tehran city with a Radon concentration of 104 Bq/m3 for 20 h irradiation time. The results show that during this period, 65 track/cm are created in hair with depths between 2 - 43 µm. Also, the 12C, 18O, 14N and 32S elements are produced in the hair with the number of 36, 135, 11, and 0.2, respectively, which indicates the breaking of hair composition. Also, Proton, Alpha and Gamma ray are generated in the hair structure with the number of 4590, 550 and 4790 respectively during this period. The secondary particles that produce by interaction of alpha with hair (such as 12C, 18O, 14N and 32S) usually have high energy during production and they can be damage the hair structure. The 36Cl and 18F radioactive elements with the number of 1.19 and 0.8 are created in the hair structure during this period. The equivalent dose of Radon and progeny in hair in this period is equal to 63 pGy (1.21 mSv as effective dose).

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INTRODUCTION

The external parts of the human body are always exposed to environmental radiation (Maier., 2020) such as Alpha activity of Radon and progeny (Vaupotič., 2024). Human skin and hair are more exposed to these radiations. Gamma and Neutrinos pass through the human body, but some of other radiations such as Alpha caused by Radon and progeny have a short range and stop at a short depth of the human body (Falkenbach., 2002). The outer surface of the human body is mostly covered with clothes, but human hair is always exposed to Alpha radiation caused by Radon and progeny (Olszewski., 2019). Hair is mainly composed of Carbon, Oxygen, Nitrogen, Hydrogen, Sulfur and a small percentage of other elements (Girault., 2019; Saiki., 1998). Hair can be damage by three ways: a) the Alpha radiation of Alpha radioactive elements such as Radium that is present in the hair structure. b) Alpha radiations caused by the decay of aerosols with Radon and its progeny that sit on the hair surface and c) Alpha particles caused by the decay of Radon and its progeny in the air that reach to the hair surface (Jung., 2016;

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Kunchi., 2019). In this article, was tried to study the effect of Alpha radiation by Radon and its progeny present in the air on the hair structure. Alpha radiation reaching the hair structure damage the hair component and affects its quality and strength that is very important for humans. Previously, potentially toxic metals in irrigation water, soil, and vegetables and their health risks was investigated using Monte Carlo models(Orosun.,2023). In this article, using MCNPX code and GEANT4 toolkit that based on Monte Carlo principles (Agostinelli,.2003; Waters., 2007; Pelowitz., 2011;Bednarz., 2011), was tried to calculate the amount of damage (secondary elements produced in hair), the track created in different parts of hair and the amount of radioactive elements produced in hair due to Radon and progeny Alpha particles in the air. Finally the main aim of this research is a calculation the alpha damage and secondary elements produced in human hair due radon and progeny activity in air that is explained in next sections.

MATERIAL AND METHODS

Description of input file for the MCNPX simulation

First, an input file for the MCNPX simulation is prepared, which includes three main sections: cell card, geometry card, and data card. According to Figure 1, the cell card contains five cells, three of which pertain to the structure of hair. The first cell corresponds to the medulla, the second cell corresponds to the cortex, and the third cell corresponds to the cuticle or outer protective covering of the hair. The fourth cell represents the air surrounding the hair, and the fifth cell is the outermost cell, consisting of a vacuum. The length of the hair for the simulation, as shown in Figure 1, is considered to be 1 cm. The dimensions of the air surrounding the hair are determined based on the range of the most energetic alpha particle from radon and progeny (7.69 MeV), which is 7.5 cm (Rezaie.,2013). The reason for this choice is that no alpha particles resulting from radon and progeny activity will reach to hair from a distance greater than this value.

In Figure 1, the diameter of the medulla is 12 μm. The diameter of the cortex is 101 μm, and the thickness of the cuticle is 2.5 μm (Kunchi., 2019; Sehrani, .,2019).

Introducing of air and hair components

The components of hair include oxygen, nitrogen, hydrogen, carbon, sulfur, and a small percentage of other elements. After calculating the percentages of these elements, the elemen composition of hair is calculated and result was shown in Tables 1 (Mussabekova and

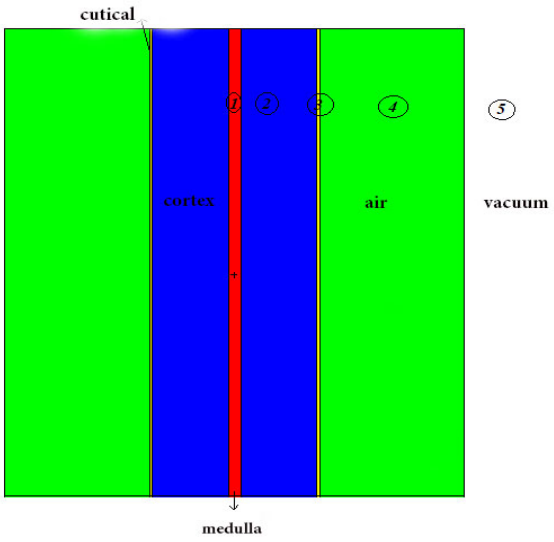

Fig. 1. A view of the hair structure in the input file of the MCNPX code

Table 1. The elements percentage of hair

Element	percentage	Element	percentage
Al	1.37×10^{-5}	Mg	5.45×10^{-5}
As	2.20×10^{-5}	Mn	3.59×10^{-4}
Br	2.6×10^{-6}	Na	4.1×10^{-6}
Ca	4.57×10^{-4}	Sb	2.56×10^{-5}
Cd	1.72×10^{-4}	Sc	1.53×10^{-6}
Cl	2.57×10^{-4}	Se	4.25×10^{-4}
Co	2.59×10^{-5}	V	5.42×10^{-5}
Cr	1.635×10^{-3}	Zn	1.578×10^{-4}
Cu	1.49×10^{-5}	C	0.44763
Fe	1.40×10^{-5}	O	0.28
Hg	1.16×10^{-6}	S	0.05
K	3.50×10^{-6}	N	0.15
H	0.07		

Mkhitaryan., 2021; Werner et al., 2018) .Also the density and elemental composition of Air around hair is taken from ICRP reports (Hassan ., 2014;ICRP.,2016) .

Definition of the radiation source

One of the important parameters in the MCNPX input file is the definition of the radiation source, which in this study is the alpha radiation from radon and progeny with energies of 5.49, 6, and 7.69 MeV, with equilibrium factors of 1, 0.723, and 0.217, respectively (Rezaie.,2013). The concept of the equilibrium factor is that after radon entering to environment, it initially decay to ^{218}Po due to alpha activity, and then ^{218} Po decays to ^{216} Po via alpha emission. After a short period, radiation equilibrium is established between radon and progeny, with equilibrium factors of 1, 0.723, and 0.217, respectively.

Radon concentration in Tehran city

According to research achievements, the average radon concentration in Tehran city is 104 Bq/m^3(Shahbazi.,2019). Maximum and minimum concentrations are 460.2 (Shahid Baqeri in west) and 31 Bq/m^3 (Shahid Araqi in north), respectively (Shahbazi.,2019).

Description of the Geant4 simulation process

Geant4 toolkit was used to check the number of secondary particles produced in hair due to the interaction of Radon and progeny Alpha particle with hair components. The Geant4 has many capabilities for extracting data related to the decay products of compound nuclei (Allison.,2016). The decay products of composite nuclei created by Alpha interaction with hair are extracted with the GetParticleType()(Collaboration., 2019) command in the Geant4 toolkit.

RESULTS AND DISCUSSION

The skin and hair form the first barrier exposed to air pollution and use as biodosimeter (Çam.,2014; Çolak.,2011). Large suspended particle, small airborne particles, smoke and gaseous pollution as radon causing hair damage (Rajput.,2015; Trüeb.,2015). Hair loss can be caused by air pollution, environmental and medical radiation (Nogueira.,2004; Nogueira.,2006; Dario.,2015). Also pollution, environmental and medical radiation can be change the DNA, stem cell, color, oxidant stress etc. in human hair(Sieber.,1986). Previously changes in Human Hair Induced by UV- and Gamma Irradiation was investigated (Palma.,2016). In this paper was tried to investigate the effect of alpha radiation on Hair with Monte Carlo simulation Result based on MCNPX code and Geant4 toolkit.

Monte Carlo simulation Result based on MCNPX code
The location, length, angle of radon and progeny alpha tracks on Hair

Using the PTRAC card of MCNPX code (Hendricks.,2008), the location, length, angle of tracks, the hair cortex surface in the hair were calculated that the results are shown in Table 2. In Table 2, 65 particles due to the alpha effect caused by the activity of 104 Bq/m^3 Raden and progeny reach to hair with length of 1 cm (Rezaie.,2013; Rezaie.,2012). According to the simulated results in Figure 3, the probability of an alpha particle with an energy of 5.49 MeV reaching the hair tissue is equal to 1.46×10^{-04}. According to the equilibrium factor between

Table 2. Angle, length and location of Alpha particles track in hair due to 104 Bq/m^3 Radon concentration in air of Tehran city

Track number	Track location (cm)	Track length (cm)	Track angle (degree)	Track number	Track location (cm)	Track length (cm)	Track angle (degree)
1	7.22E-02	7.57E-04	0.867599	**34**	0.23147	0.000148	2.138574
2	-5.48E-03	3.32E-04	2.199529	**35**	0.02087	0.000235	2.137021
3	-0.00082	0.003145	2.489524	**36**	0.001879	0.000143	1.733068
4	0.059964	0.001348	0.7681	**37**	-0.0024	0.000733	1.289439
5	-0.02494	0.000383	-0.77015	**38**	0.079842	0.000127	1.558946
6	-0.00583	0.00076	2.843267	**39**	-0.01208	0.000168	0.875191
7	0.25791	0.00013	1.314117	**40**	0.008241	0.00014	1.963632
8	-0.00771	0.000239	0.837126	**41**	0.18803	0.000315	2.332963
9	-0.00185	0.000182	2.122607	**42**	-0.0038	0.000144	1.26175
10	0.002977	0.000208	0.987725	**43**	0.000556	0.00014	1.428729
11	-0.00221	0.000248	1.312452	**44**	0.14164	0.000132	1.640327
12	0.001562	0.000146	2.071098	**45**	0.44621	0.000254	0.597277
13	-0.00185	0.001797	2.417137	**46**	-0.35046	0.000298	2.575569
14	0.019164	0.000135	1.551782	**47**	0.020986	0.000202	2.042472
15	-0.03723	0.000169	1.926255	**48**	0.28145	0.000134	1.407714
16	0.30801	0.000172	0.997017	**49**	-0.00788	0.0048	2.295468
17	-0.04489	0.000141	1.897539	**50**	0.011789	0.002225	1.544576
18	0.1852	0.000235	0.623089	**51**	0.005374	0.000276	1.450476
19	-0.00941	0.000266	2.406129	**52**	0.00319	0.00017	2.311246
20	9.84E-05	0.004668	1.414339	**53**	0.010376	0.000203	1.396637
21	-0.43417	0.000163	1.647576	**54**	-0.0048	0.00022	1.850978
22	0.004389	0.000164	0.877378	**55**	0.13883	0.000366	2.187734
23	0.10639	0.000261	0.557784	**56**	0.2149	0.000395	2.644851
24	0.014373	0.00013	1.401418	**57**	0.004036	0.000239	0.548764
25	-0.0013	0.00195	2.496992	**58**	-0.02833	0.000159	2.233639
26	0.00366	0.000127	1.640479	**59**	0.093579	0.000371	1.239711
27	0.4303	0.000366	0.383395	**60**	-0.00668	0.000223	1.764179
28	0.021191	0.000138	1.937339	**61**	0.10733	0.000206	0.675315
29	-0.09617	0.00024	0.804419	**62**	-0.22983	0.000163	1.92393
30	-0.06464	0.000206	2.401654	**63**	-0.01701	0.000428	2.566901
31	0.042755	0.000234	0.606707	**64**	-0.00447	0.000162	1.248379
32	-0.04441	0.000173	2.24287	**65**	0.00648	0.000181	0.920829
33	0.17728	0.000173	1.873917				

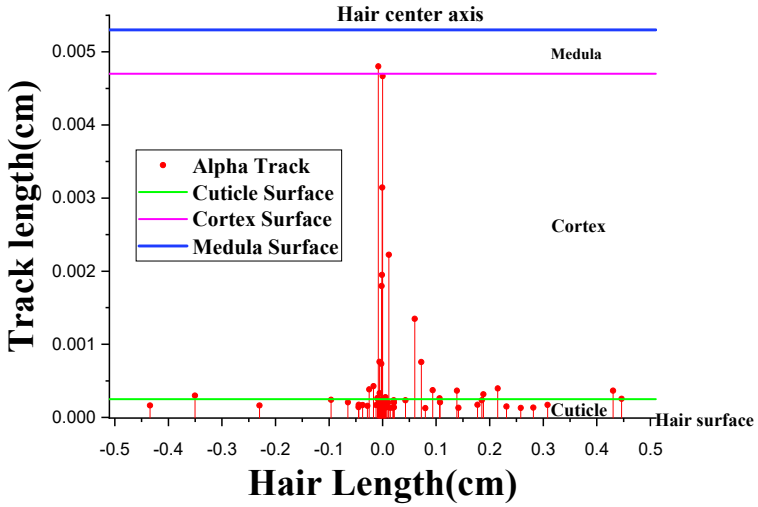

Fig. 2. Alpha tracks per day created in hair with 1cm length by alpha activity of Radon and progeny in air of Tehran city

Table3. The number of tracks, the number of Radon particles in the hair in 20 hours

Total track length (cm)	Number of Radon	Number of Alpha particle	Number of track	probability of Alpha collision (P)
3.39E-02	15000	30000	65	2.1E-03

Roden and girls (^{218}Po and ^{214}Po) which is equal to 1: 0.76: 0.216, it is concluded that for every alpha radiation with energy 5.49 MeV, one alpha from progeny is also radiated. As a result, the number of alpha with energy 5.49 MeV is equal to 65/2 = 32.5 particles. In order for this amount of alpha to reach the hair, the number of Radon around the hair must be equal to $32.5/1.46\times10^{-04} = 22414$, so the number of alpha irradiated around the hair in this case will be equal to 44828 particles.

The path of 65 Alpha particle tracks in hair space due 104 Bq/m^3 Radon concentration in air of Tehran city is shown in Figure 2. The largest and the smallest track lengths are 43μm and 2μm respectively.

Table 3 shown the number of track, number of Radon particles, total length of tracks and number of Alpha particle at 20 h for 104 Bq/m^3 Radon concentration in air of Tehran city. Radiation time is calculated as 20 h according to the amount of Radon concentration, which is proportional to the number of irradiated Alpha particles caused by Radon in the air around the hair.

The Alpha dose rate in different parts of the Hair

The dose rate in different parts of the hair was calculated by using the *f6 and *f8 tallies (Shahbazi-Gahrouei.,2015) caused by Alpha Radon particles and progeny in the air of Tehran city with a Radon concentration of 104 Bq/m^3(Yang, Wang, and Meyers., 2017)., that result is shown in Table 4

According to the information in Table 4, there is a 99.9% agreement between the dose rate calculations with *f8 tally and the dose calculations with *f6 Tally. The energy spectrum of Radon and progeny alpha particle at the surface of Cuticle, Cortex and Medulla is shown in Figure 3. As it is clear in the figure, with the penetration of Alpha particles into the hair, the energy spectrum of Alpha particles shifts to lower energies and the probability value also decreases. Alpha particles reach the Medulla with very low probability and energy and reach the Cortex with more energy and probability.

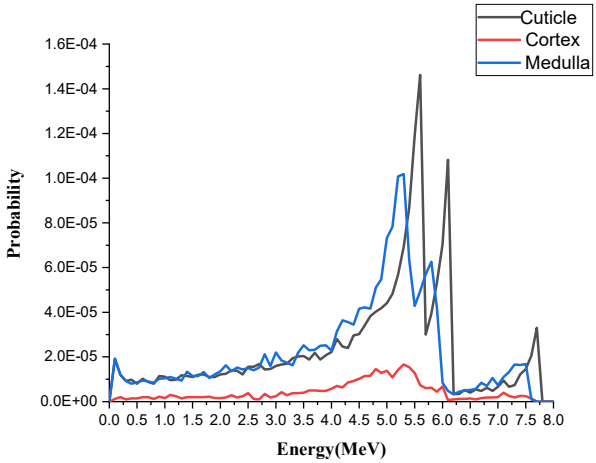

Fig. 3. The energy spectrum of Radon and progeny Alpha particle at the surface of Cuticle, Cortex and Medulla.

Table 4. Radon and progeny alpha particle dose rate in different parts of hair in the air of Tehran city with 104Bq/m^3 Radon concentration of

Hair structure	*f6 Jerk/g	*f8 MeV	Mass g	Dose rate (*f6) Gy/h	Dose rate (*f8) Gy/h
Medulla	3.23E-20	3.03E-04	1.50E-06	4.84E-05	4.83E-05
Cortex	1.96E-20	0.01274	0.000104	2.94E-05	2.93E-05
Cuticle	2.18E-20	0.000716	5.26E-06	3.27E-05	3.27E-05

Monte Carlo simulation Result based on Geant4 Toolkit

The elements produced in the hair tissue by radon and progeny alpha particle

Using the Geant4 toolkit, the elements produced in the hair tissue were calculated for alpha particles with 5.49, 6 and 7.69 MeV energy per million Alpha particles, and the results are shown in Table 5.

Table 5 contains three kinds of particles. The first kind of particles are S, N, O and S particles that are present in the composition of hair. But according to the energy of these particles, it is concluded that these particles are separated from the hair tissue, therefore, the hair structure is destroyed. The second kind of particles are particles that do not exist in the composition of hair, such as ^{34}S, ^{36}S, Gamma, Alpha and Proton. The third kind of particles are particles that are radioactive such as ^{36}Cl and ^{18}F. Some particles are produced only with 7.69 MeV Alpha particle. The number of particles produced with 7.69 MeV Alpha particle is more than the number of particles produced with 5.49 MeV alpha particle. Most of the produced particle's energy is in the MeV range, which automatically damage other structure of the hair by stopping in it. The production probability of Proton, Gamma, Alpha, ^{12}C, ^{16} O and ^{14}N is also more than other particles.

Human hair is more exposed to Alpha radiation than other parts of the body due to the decay of Radon and progeny. The Alpha that reaches to the hair, produce a track in it and cause the damage of the hair structure. In this article using the MCNPX code and Geant4 toolkit, the number and depth of track and the dose rate in hair caused by the decay of Radon and progeny around it was calculated. The 44828 Alpha particles with energy of 5.49, 6 and 7. 69 MeV related to 104 Bq/m^3 Radon concentration in the air of Tehran city was simulated at 20 h time of irradiation. The equilibrium factor between Radon and progeny was assumed 1, 0.723, 0.217. During this period, 65 tracks with a minimum depth of 2 μm and a maximum of 43μm are created in 1 cm of hair.

Using the Geant4 toolkit, the yield of produced elements in hair structure was calculated due

Table 5. Particles produced in hair tissue due to one million Alpha radiation by Radon and progeny

Element	7.69 MeV			6 MeV			5.49 MeV		
	Number	Energy	Half life	Number	Energy	Half life	Number	Energy	Half life
^{36}Ar	3	0.710	-	-	-	-	-	-	-
^{38}Ar	1	0.770	-	-	-	-	-	-	-
^{12}C	1558	1.27	-	632	0.675	-	418	0.549	-
^{35}Cl	1	0.873	-	-	-	-	-	-	-
^{36}Cl	1	1.1930	4.35e5 y	-	-	-	-	-	-
^{18}F	1	0.543	2.64h	1	0.358	2.64h	-	-	-
^{19}F	2	0.184	-	1	0.203	-	1	0.2	-
^{22}Ne	-	-	-	1	0.635	-	-	-	-
^{21}Ne	-	-	-	-	-	-	1	0.055	-
^{24}Mg	1	0.562	-	-	-	-	-	-	-
^{14}N	398	0.834	-	212	0.722	-	139	0.708	-
^{23}Na	1	0.187	-	-	-	-	-	-	-
^{16}O	988	0.799	-	844	0.845	-	677	0.842	-
^{18}O	3	0.459	-	2	0.128	-	1	0.256	-
^{32}S	19	0.113	-	3	0.02	-	-	-	-
^{34}S	2	0.075	-	1	0.388	-	-	-	-
^{36}S	1	1.95e-5	-	-	-	-	-	-	-
alpha	633	4.049	-	89	3.21	-	31	2.56	-
e	1	0.105	-	1	0.303	-	-	-	-
gamma	1101	5.54	-	1142	5.66	-	911	5.72	-
proton	1461	1.48	-	1006	1.16	-	921	1.034	-
neutron	-	-	-	-	-	-	1	0.336	14.67 min

Table 6. The yield, the number and the energy of produced elements with the highest abundance in the hair structure placed in Tehran with 104 Bq/m^3 Radon concentration

Elements	The percentage of the element in the composition of the hair	The yield of produced element (Y) ($\times 10^{-3}$)	The number of particles produced in 1 cm hair for 104 Bq/m^3 Radon concentration in Tehran	Maximum energy of produced element (MeV)
C	0.44763	1.21	2920	1.27
O	0.28	1.50	3630	0.85
S	0.05	0.01	24.2	0.11
N	0.15	0.38	910	0.83
Alpha	0	0.23	550	4.05
Gamma	0	1.98	4790	5.72
Proton	0	1.97	4590	1.48

to interaction of 5.49, 6 and 7.69 MeV Alpha particle of Radon and progeny in the condition of that the hair was put 20 h in the air of Tehran with 104 Bq/m^3 Radon concentration. The produced elements with the highest yield were shown in Table 6.

The number of produced element (Np) in 1 cm hair for C= 104 Bq/m^3 Radon concentration in Tehran at t = 20 h = 72000 s was calculated as following.

Np =Y×P×C×V×t =Y×2.1E-03×104×153.86 ×72000 = 2.42E6×Y

That P is probability of Alpha collision with hair (2.1E-03). V is the air volume around the L=1 cm hair that is (V= πr^2 L). R=7 cm is the range of 7.6 MeV Alpha particle in air. Therefore V=3.14×7 ^{2} ×1=153.86 cm^3.

The energy of Carbon, Oxygen, Nitrogen and Sulfur shows that these particles have been

Table 7. The yield, energy and half-life of radioactive elements produced with the highest abundance in hair structure placed in Tehran with 104 Bq/m^3 Radon concentration.

Radioactive Elements	Production yield ($\times 10^{-5}$)	The number of particles produced due to 104 Bq/m^3 of Radon concentration in Tehran	Energy of produced particles (MeV)	Half-lives
^{36}Cl	3.33	0.03	1.19	4.35e5 y
^{18}F	5.74	0.05	0.8	2.64h

separated from the hair structure, which means that the hair structure has been damaged. The abundance of separated Oxygens is more than Carbon and Nitrogen. In addition to primary Alpha particles, 550 secondary Alpha particles with energy of4.05MeV are also produced in the hair structure. As a result of Alpha interaction with hair, 4790 Gamma particles with energy of 5.72 MeV are produced, which can cause radiation hazards in the human body due to its high energy. Also, 4590 protons with energy of 1.48 MeV are produced in the hair. Therefore, the proton and another hair can cause secondary damage in the hair structure.

Radioactive elements production in the hair structure

Also, the ^{36} Cl and ^{18} F radioactive elements was produced in the hair structure with a very small amount that their energy, abundance and half-life are given in Table 7.

Due to the low abundance of the ^{36} Cl and ^{18} F radioactive elements produced in the hair structure, their secondary effects can be ignored.

CONCLUSION

Human hair is exposed to alpha radiations due to radon concentration in air. In this article, it has been tried to determine the alpha damage and secondary elements produced in human hair due radon and progeny activity in air of Tehran city using MCNPX code and Geant4 toolkit. The results show that 65 Track/cm per day are created in hair with depths between 2 - 43 μm. Also, the ^{12}C, ^{18}O, ^{14}N and ^{32}S elements are produced in the hair, which indicates the breaking of hair composition. Due Radon concentration in air, the ^{36}Cl and ^{18}F radioactive elements are created in the hair structure that indicate the hair becomes slightly radioactive. For people who work in mines and other places where the concentration of Radon is high, the rate of hair loss is also significant.

GRANT SUPPORT DETAILS

The present research did not receive any financial support.

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research

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