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THE EFFECTS OF LEAD RADIOISOTOPES FORMED DURING THE DECAY OF RADON ON THE HUMAN BODY AND ASSOCIATED HEALTH RISKS

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Abstract*. The work shows the pattern of formation of radiation load on red bone marrow under the influence of radon. The study is based on the process of radiation decay of radon with the formation of a lead radioisotope (210Pb). The calculation of the dose load was carried out in the following sequence: inhaled radon, radon entering the blood, distribution of the formed lead isotope, localization of lead-210 in the bones and irradiation of the red bone marrow with this radioisotope as the main hematopoietic system. The issue of the significance of the accumulation of radioactive lead in flat bones as a factor in chronic irradiation of the hematopoietic system and the associated health risks is considered.*

Key word*: radon, Lead-210, red bone marrow.*

Radon is a radioactive gas that forms as a result of the decay of uranium and radium present in rocks and soil. Being a gas of geophysical origin, it is one of the most common factors of radiation exposure in urban areas. According to the World Health Organization, it, along with tobacco smoking, is considered one of the main causes of lung cancer [1]. Based on numerous scientific studies, it has been established that the landscapes of Georgia are characterized by a high content of this gas [2]. Urban buildings are no exception [3]. Studies conducted in various residential and office premises have shown significant variations in radon content and the associated different levels of risk for the urban population [4,5]. As is known, radon is an alpha emitter. Alpha particles have high energy, but relatively low penetration ability. Therefore, radon is most dangerous when inhaled, when it enters the lungs. Moreover, the risk increases with an increase in radon concentration and duration of exposure. This is the reason why the main focus of researchers in the field of biomedicine is directed to evaluate the damaging radiobiological effect on the lungs [6,7].

However, the chain of radiation transformation of radon does not stop there. In particular, when radon enters the blood through the pulmonary alveolar mechanism, and therefore into other internal organs. However, in the scientific literature less attention is paid to the secondary effects of radon after it enters the body. In our study, we analyzed and calculated the radiation dose of critical organs, in particular, the hematopoietic system. In this regard, one of the key processes is associated with a long-lived product of radon decay – radioactive lead (^{210}Pb), which tends to accumulate in bone tissue. During the decay of ^{210}Pb, polonium-210 (^{210}Po) is formed, emitting alpha particles with an energy of 5.3 MeV. And if we take into account the fact that the main hematopoietic organ, the bone marrow, is concentrated in flat bones, and then the radiation impact on this system can be of great importance in predicting risks for the population in the case of high doses of radon exposure.

Calculating the effect of radon on critical human organs is complicated by the fact that radon itself is practically not involved in the formation of the radiobiological effect. The main radiation threat to the body is its decay products. Thus, it is precisely the calculation of the level of radiation exposure to decay products that is the main task in predicting health risks caused by elevated radon levels in urban areas. Unfortunately, today it is not completely clear with which specific types of radon decay (as well as its progens) can be adequately associated with indicators in becquerels. Therefore, the calculation was performed under the assumption that the above activity values (e.g., 100 Bq/m3) really belong to radon, although it is not possible to veri-

fy this experimentally, since counting the number of decays is not an a priori targeted process indicating their origin. In our opinion, to resolve this problem, it would be necessary to switch to an energy (spectral) analysis of radon decay products or to proceed from the well-known process of its decay. At the same time, it seems more rational to experimentally (hardware) determine the number of lead nuclei ^{210}Pb in a biological object exposed to radon and, based on this, determine the amount of radon, as well as the dose of radiation absorbed by this object.

The main objective of our study was to calculate the level of radiation exposure to the hematopoietic system of the body under conditions of the alveolar mechanism of radon intake. For this purpose, we compared the received radiation doses and the amount of ^{210}Pb arising during the decay of radon with a given activity. The calculations were carried out, on the one hand, by calculating them by estimating the decay of radon atoms based on their number, and on the other hand, based on their specific activity. The calculations were carried out for the initial specific volumetric activity of 100 Bq/m3, while it is assumed that the radon concentration remains unchanged due to its balancing from external sources. A radon dose of 100 Bq/m3 is the maximum permissible level for household conditions.

As a result of the calculations presented in Tables 1 and 2, it can be concluded that at a dose of 100 Bq/m3 (the average human weight is 70 kg blood with its volume of 5 liters), up to 6.9 x 1010 radon nuclei will enter. Later, during its decay and distribution of the formed radioactive lead in the organs (table 2), approximately 5.7% of this isotope in the flat bones (4-5 kg) (2.37), as a result the red bone marrow located in the flat bones is chronically irradiated with a dose of 2.36 nGy. However, in reality, based on the conditions of the urbanized environment, the values of radon exposure can vary widely [4,8]. And under these conditions, when determining the proportion of radioactive lead entering the body, it naturally increases in proportion to the level of inhaled radon. In this case, the most important factor is the degree of cumulativeness of a particular radioisotope mostly in bone tissue.

Table 1. Calculation of the amount of radon entering the blood
(with an activity in the air of 100 Bq/m3)

Concentration of radon nuclei in the air, N/м^3	$N_o = \varphi/\lambda$ $N_o = 100/(2{,}1 \times 10^{-6} c^{-1}) = 47.619047619 \times 10^8 =$ $= 4.7619047619 \times 10^9$
Activity in blood, Bq/м^3 (conversion factor 0.23)	0,23 x 100=23
The number of radon nuclei and an equal number of lead nuclei ^{210}Pb that entered the blood (5 liter), exposure-1 year	$1.89257142857 \times 10^8 \times 365 = 690.788571428 \times 10^8$
Decay energy of radon ^{222}Ra to lead ^{210}Pb, MeV	$22.18 \times 690.788571428 \times 10^8 = 15321.6905143 \times 10^8$
Decay energy of ^{222}Rn to lead ^{210}Pb, Joule	$15321.6905143 \times 10^8 \times 1{,}602\ 176\ 634 \times 10^{-19} =$ $= 2{,}45480545353 \times 10^{-7}$
Specific dose absorbed by blood Joule/L (Gy)	$2{,}45480545353 \times 10^{-7}/5 = 0.4909610907 \times 10^{-7}$Gy= $= 4{,}909610907 \times 10^{-8}$Gy =49,09610907 x 10^{-9}Gy = = 49,09610907 nGy
The decay energy of one nucleus ^{210}Pb to ^{206}Pb, MeV	7.404MeV

Table 2. Calculation of the amount of radioactive lead (210Pb) formed as a result of radon decay, as well as the dose load on the red bone marrow of flat bones.

Total lead atoms in blood	$690.788571428 \times 10^8$
Total, lead atoms in hard tissues ^{210}Pb-14,58 %	$690.788571428 \times 10^8 \times 0{,}1458 = 100.716973714 \times 10^8$
In skeletal tissues -8,3%	$690.788571428 \times 10^8 \times 0{,}083 = 57.3354514285 \times 10^8$
Absorbed dose, Ev	$57.3354514285 \times 10^8 \times 7.404 \times 10^6 = 424.511682377 \times 10^{14}$
Specific Absorbed Dose J/кg (Gy)	$680.142993824 \times 10^{-5}/10 = 6.80142993824 \times 10^{-4} =$ $= 0.680142993824$ mGr
Flat bones 5.7% ^{210}Pb	$100.716973714 \times 10^8 \times 0{,}057 = 5.7408675017 \times 10^8$
Absorbed dose, Ev	$5.7408675017 \times 7.404 \times 10^{14}$
Absorbed dose, joule	$425.053829826 \times 10^{-6}$

Specific absorbed dose J/kg (Gy)	42.5053829826 x 10^{-5}/4,5=94.456406628 μGy
Soft tissues. 3.27% lead atoms ^{210}Pb	22.5887862857 x 10^{12}x 690.788571428 x 10^{8}x 0,0327 = =22.5887862857x 10^{8}
Absorbed dose, Ev	22.5887862857 x 10^{8}x 7,404 x 10^{6}=167.247373659 x 10^{14}
Absorbed dose, joule (J)	104.387554691x 10^{14}x10^{-19}= 104.387554691x10^{-5}
Specific absorbed dose J/kg (Gy)	1043.87554691x 10^{-6}/mass
Including bone marrow 0.1308 %Ev	22.5887862857 x 10^{12}x 0,001308 = 2,954613246 x 10^{10}
Absorbed dose, joule (J)	2,954613246 x 10^{10}x1,602 176 634·10^{-19} = = 4.73381436166 x 10^{-9}
Specific absorbed dose J/kg (Gy)	4.73381436166x10^{-9}/2= 2.36690718083 x 10^{-9}= = 2.36690718083 nGy

According to a number of authors [9], in addition to the tendency to accumulate and fix lead ions, partial clearing occurs in parallel, as a result of which some of the lead ions leave the bone tissue. However, with high activity of inhaled radon, an imbalance occurs between the level of radioactive lead clearance and its accumulation in bone tissue. Thus, conditions are created for an increased level of radioactive lead accumulation in flat bones, which in turn causes an increased level of radiation exposure to the hematopoietic system. Indirectly, this position is confirmed by other studies of this process. In particular, it has been shown that with inhalation of increased concentrations of radon in the blood, the level of chromosomal abnormalities increases [10]. It can be concluded that with an increased level of radon in the environment, a high radiation risk is not only irradiation of the lungs, but also the hematopoietic system, leading to chronic irradiation from radioactive lead localized in the flat bones of the body.

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