RADON AND PRODUCTS OF ITS DECAY: DETERMINATION OF VOLUME ACTIVITY OF Β-RADIOACTIVE AEROSOLS

Stefan M. Krustev
Prof. Paraskev Stoyanov Medical University of Varna, 55 Marin Drinov str, 9002 Varna, Bulgaria, Department of Physics and Biophysics, e-mail: krustev@mu-varna.bg

ABSTRACT:

This article deals with radioactivity, radon, and products of its radioactive decay as a basic element of natural irradiation background as well as with human health-related risks. A special attention is paid to the laboratory exercise devoted to this actual topic and elaborated and introduced by the author into the syllabus of practice in biophysics for medical students. Basic physical regularities and processes of radioactivity as well as biophysical foundations of irradiation are considered. Irradiation by radioactive sources such as radioactive aerosols incorporated into the human organism is elucidated. The nature of atmospheric-air natural radioactivity as a result from a radioactive decay chain leading in the last reckoning to radionuclides is discussed. These radionuclides precipitate on various aerosols thus transforming them into β-radioactive aerosols. During the teaching experiment an aspiration method for extraction of β-aerosols is used. Subsequently, one estimates their activity and the corresponding volume β-radioactivity. The laboratory exercise enjoys a particular success. The students become aware of the physical foundations of radioactivity and of the processes during the irradiation. Besides they acquire a contemporary attitude to the problems of environment and radiation hygiene.

Key words: *radon, radioactive aerosols, volume β-radioactivity, teaching experiment*

INTRODUCTION:

Nowadays a particular interest in radon and its radiologic action relates to research in the 80s of the last century. It has been established that indoor air radon concentration, especially in first storey houses, often exceeds even the utmost permissible concentrations in uranium mines. The irradiation of the population of Earth is mainly due to radon isotope presenting with the longest half-life of 3,8 days $_{86}\mathbf{Rn}^{222}$ formed during α-decay of the most widely disseminated radium isotope $_{88}\mathbf{Ra}^{226}$ with half-life of $1{,}6.10^3$ years of the line of decay of uranium $_{92}\mathbf{U}^{238}$ with half-life of $4{,}5.10^9$ years.

Being an element of uranium-radium family, radon is worldwide disseminated. Some part of radon liberated in the earth crust diffuses through air pores, reaches the surface and enters the ground air (exhalation). It disseminates by diffusion and convection that depends on certain natural and climatic factors such as lay, temperature, rainfall, climatic season, etc. Radon exhalation velocity over the seas and oceans is by approximately 100 times smaller than that over the dry land.

On its part, during the radioactive decay of the gaseous $_{86}\mathbf{Rn}^{222}$ a chain of new radioactive products in a hard aggregate state is formed, namely polonium $_{84}\mathbf{Po}^{218}$ (α-decay mode), lead $_{82}\mathbf{Pb}^{214}$ (β-decay mode), bismuth $_{83}\mathbf{Bi}^{214}$ (β-decay mode), and polonium $_{84}\mathbf{Po}^{214}$ (α-decay mode) which are short-life decay products and with half-life for β-radionuclides below 30 min. When facing various aerosols in the atmosphere such as hard dust particles, smoke or mist droplets, these daughter radionuclides precipitate on their surface and transform them into radioactive aerosols. The activity of the latter is predominantly determined by the β-radionuclides bismuth $_{83}\mathbf{Bi}^{214}$ and lead $_{82}\mathbf{Pb}^{214}$. It is an interesting fact that radon itself being an inert gas does not form any aerosols. Numerous scientific investigations have proved that 98% of internal human irradiation results from inspiration of the daughter products of radon decay which persist and affect bronchial epithelium in the lungs as only 2% are caused by $_{86}\mathbf{Rn}^{222}$ itself.

According to the United Nations Scientific Committee on the Effects of Atomic Radiation (10), more than a half of the mean annual natural background irradiation of the population of 2,40 mSv is due to the atmospheric air and mainly to radon as in single regions it can even reach up to 10 mSv.

Radon and the products of its decay are the second important cause for lung cancer (1, 9) as in the USA only between 15,000 and 22,000 lethal cases are radon-related The risk for lung cancer increases by 8-16% for every 100 Bq/m^3 of increase of radon volume activity. The relationship between radon and tobacco smoking as the latter is a main pathogenetic factor in lung cancer (2). Along with more than 60 known cancerogens the tobacco smoke contains daughter products of radioactive radon decay (4). That is why passive tobacco smoking can cause lung cancer even in non-smokers and represents a greater danger than active smoking (8).

It is noteworthy that taking into consideration the risks related to radon and the products of its decay, in 2005, the World Health Organization (WHO) started an International Radon Project (IRP) designed to collect and analyze the information about radon policies, radon migration and prevention as well as radon risk communication (10).

AIM AND METHODS:

The aforementioned considerations allow the assumption that although radon is to a certain extent applied for medical purposes, e. g. in the so-called 'radon baths' radon itself together with the products of its decay represent an essential environmental factor and health risk. That is why it is necessary to include this topic into the syllabus of the students of medicine and of the public health inspectors as well.

In order to meet these requirements, a laboratory exercise entitled 'Radioactivity. Determination of volume activity of β-radioactive aerosols' was elaborated by the author and introduced into the teaching process (6, 7).

RESULTS:

Within the theoretical part of the exercise the students become familiar with the radioactivity as a process of spontaneous change of the mass, electrical charge or atomic nuclear energy accompanied by emission of α-particles, β-particles, and γ-rays. It is emphasized that radioactivity is inherent to unstable nuclei called radionuclides only. When the products of their decay are radioactive, too, a chain of radioactive conversions occurs that ends-up with a stable nucleus. There are natural (terrestrial and cosmogenic) and technogenic radionuclides illustrated by means of examples.

The main types of radioactive decay are presented. The α-decay is characterized by a spontaneous conversion of the nucleus and change of the electrical charge, atomic mass and nuclear energy. The β-decay consists in a spontaneous intranuclear conversion of a neutron and a proton and in a change of the electric charge and energy of the nucleus. Three types of β-decay are defined: 1. electron β-decay; 2. positron β-decay, and 3. electron capture (K-capture). A special attention is paid to the energy spectra of the particles liberated during the decay as well as to their penetrating capacity. It is noted that during the isomeric transition, the daughter nucleus passes from excited to ground state through γ-irradiation only. In the course of the discussion, proper examples illustrate every type and subtype of the radioactive decay.

The students become aware of the basic law of the radioactive decay and realize that radioactivity represents a statistical process. Within a large aggregate of radioactive nuclei, the number of the non-disintegrated nuclei diminishes exponentially with time. The constant magnitude of the radioactive decay is defined as the probability of nucleus decay per unit of time. The magnitudes of radioactive source activity and half-life are defined. The activity of a given radioactive source is directly proportional to the number of the radioactive nuclei in it and inversely proportional to their half-life. This activity decreases with time. The units of activity are defined in SI as becquerel, **Bq**. Here 1 **Bq** corresponds to the activity of a source in which one decay takes place in 1 **s**, activity per unit volume A_V (Bq/m^3), and activity per unit mass A_M (Bq/kg).

A particular attention is paid to the atmospheric air radioactivity and, predominantly, to radon and the products of its decay as an element of the uranium-radium family. It is outlined that radon is formed in the earth crust and permanently diffuses into the atmosphere and hydrosphere. The hygienic aspect of the problem is emphasized by the explanation that indoor radon concentration is by 4-6 times higher than outdoor one being considerably elevated in first storey houses. This is closely related with the higher health risk and the necessity of various preventive measures such as ventilation, etc

In the course of the discussion, the author outlines the presence of aerosols in the atmospheric air and their transformation into radioactive aerosols after radionuclide precipitation. The danger of irradiation by radioactive sources incorporated in the human body stresses. This is argued on the basis of the examples of the radioactive aerosols containing α- and β-radionuclides. On the one hand, this is related with the considerable volume of lung ventilation in the order of 10^4 $m^3/year$ and on the other hand - with the relatively high aerosol accumulation in the respiratory tract. The extent and main localization of this accumulation significantly depends on particle size and breathing depth (3, 5, 11). The important fact is outlined that, in this respect, tobacco smoking represents the factor considerably augmenting the health risk as it enhances the concentration of the small aerosols penetrating very deeply into the lungs, on the one hand, and increases inspiration depth, on the other hand.

The author further discusses the issues of the effect of the radionuclides incorporated into the organism, the primary processes of formation of extrinsic radicals, ions and excited molecules, of production of high-reactive radicals in the presence of oxygen as well as the secondary processes. Following the reaction of these primary products with the molecules in the living tissue such as lipids, nucleic acids and proteins, the obtained secondary products can become centeres of chain processes. In the last reckoning, damages of important biological molecules and cellular structures can develop into irradiation lesions presenting with their somatic and genetic effects.

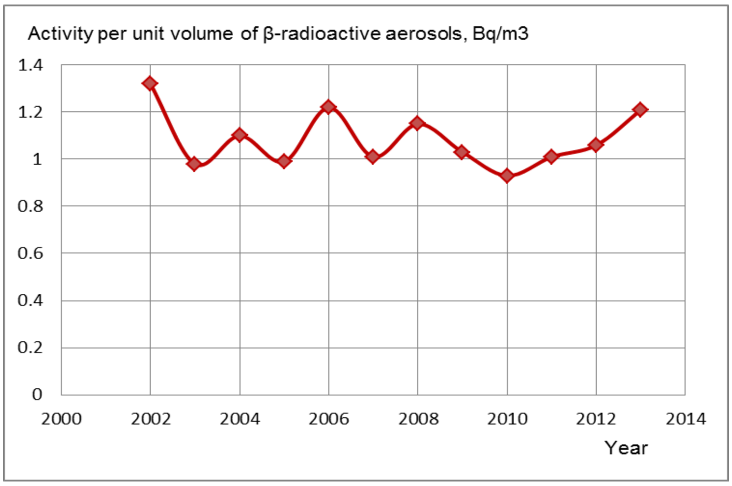

Figure 1. Activity per unit volume of β-aerosols

As a consequence of the relatively low concentration of air radioactive aerosols, their activity can’t be immediately measured. Thus for the purposes of the teaching process the author has elaborated an experimental set-up based on the aspiration method. By using an aspiration device of a known capacity (m^3/s), a certain volume of air is passed through a suitable micro-filter and then the magnitude of β-irradiation beam density is estimated by means of dosimeter-radiometer. By reading filter surface, β-activity of this beam is calculated. Volume β-activity is calculated by reading the air volume from which the examined β-radioactive aerosols are extracted, i. e. the air volume passed through the micro-filter during the time of sample taking. Some average results from teaching experiments for year’s period 2002—2013 are illustrated in Figure 1.

CONCLUSION AND DISCUSSION:

The introduction of this laboratory exercise proves to be particularly suitable and timely. The students are really interested in the physical and biophysical foundations of radioactivity and in the action of the ionizing radiations. They enlarge their knowledge of the radiation hygiene and ecology and convince themselves in the close relationship between a risk factor such as radon and the products of its decay, on the one hand, and the unhealthy life-style such as tobacco smoking, on the other hand, concerning the enormous increase of the health risk in case of combined action of these harmful factors. Last but not least, it is noteworthy that the students are encouraged to receive a respectful and up-to-dated attitude to the problems of radioactivity, ionizing radiations, and radiation safety.

REFERENCES:

1. Alberg AJ, Samuel JM, Epidemiology of lung cancer, *Chest*, **132** (S3), 29S—55S, 2007.
2. Biesalski, HK et al., European Consensus Statement on Lung Cancer: risk factors and prevention. Lung Cancer Panel, *CA Cancer J Clin*, **48** (3): 167–176, 1998.
3. Ferron GA, Aerosol properties and lung deposition, *Eur. Respir. J*, **7**: 1392—1394, 1994.
4. Hecht, S., Tobacco carcinogens, their biomarkers and tobacco-induced cancer. *Nature Reviews. Cancer*, **3** (10): 733–744, 2003.
5. Isaacs KK, JA Rosati, TB Martonen, Mechanisms of particle deposition, in *Aerosols Handbook: Measurement, Dosimetry and Health Effects*, eds. Ruzer, LS and Harley NH, 1st ed., CRC Press, 2004.
6. Krustev S. M., Radioactivity. Determination of the activity per unit volume of β-radioactive aerosols. (in Bulgarian), in *Biophysics workbook*, Physics and Biophysics department, Prof. Paraskev Stoyanov Medical University of Varna, Varna, 2001.
7. Krustev S. M., Radioactivity. Determination of the activity per unit volume of β-radioactive aerosols., in *Biophysics workbook*, Physics and Biophysics department, Prof. Paraskev Stoyanov Medical University of Varna, Varna, 2008.
8. Schick, S, Glantz S, Philip Morris toxicological experiments with fresh sidestream smoke: more toxic than mainstream smoke. *Tobacco Control* , **14** (6): 396–404, 2005.
9. Schmid K., Kuwert T, Drexler H). Radon in Indoor Spaces: An Underestimated Risk Factor for Lung Cancer in Environmental Medicine. *Dtsch Arztebl Int* , **107** (11): 181–186, 2010.
10. Sources and effects of ionizing radiation, UNSCEAR 2008, United Nations Scientific Committee on the Effects of Atomic Radiation, United Nations, New York, 2011.
11. Vincent, JH, Aerosol Science for Industrial Hygienists, Elsevier Science, New York, 1995.