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RADON IN HUMAN ENVIRONMENT AND CARCINOMA – PART 1

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Abstract: The article describes basic theories of small doses of ionizing radiation's impact on an organism and the current views on mechanisms of cancer emergence influenced by radiation. The risk estimation of lung carcinoma caused by inhalation of radon present in human environment was provided.

Key words: radon, ionizing radiation, lung carcinoma.

Historical overview

123 years ago (in 1879), Harting and Hesse published observations on the increase in lung carcinoma among miners of the Schneeberg mine in Germany [1]. A couple of decades later (1913), the same observations were made in Czech mines [2]. In 1924, the increase in radioactivity was detected and it was suggested that the ionizing radiation is responsible for the increased number of lung carcinoma among the miners [3]. More profound understanding of etiological role of radon and its decay products in the development of lung carcinoma took place as late as in the 60s of the 20^{th} century, when in the USA large mining cohorts in uranium mines underwent systematic observations [4]. A more detailed analysis of exposing mining staff was carried out in the extensive literature in 80s and 90s of the 20^{th} century [5–9].

In the 70s of the previous century, more intensive concentration of radon in apartments than in ambient air was determined. It was not, however, presumed that the air in apartments possesses as high concentration as to pose danger to health. In numerous countries, the programmes of an indoor radon audit were initiated due to the activation of alarm systems during the routine control conducted by a power plant's employee in the USA in 1984. It turned out that the excess of permissible standards of pollution was caused by the presence of radon progeny on the employee's clothes. High concentration of radon was detected in his house [10].

Exposure of population to natural and artificial sources of ionizing radiation

Ionizing radiation, which human organism is exposed to, originates from natural and artificial sources of radiation. Natural sources of radiation include: cosmic ray and elements present in the earth's crust and human body. Annual effective dose provided to Polish population from cosmic ray and natural isotopes present in the earth's crust constitutes 2.43 mSv, including:

- cosmic Ray – 0.39 mSv;
- natural isotopes present in human body – 0.279 mSv;
- gamma radiation from the earth's crust – 0.46 mSv;
- thoron – 0.1 mSv;
- radon – 1.2 mSv;
- *natural in total 2.433 mSv – 73,8%*;
- medical diagnosis – 0.85 mSv;
- nuclear accidents – 0.006 mSv;
- other – 0.008 mSv;
- *artificial in total 0.864 mSv – 26.2%.*

A statistical inhabitant of Poland is exposed to 3.3 mSv of the total amount from the aforementioned sources annually [11].

The largest contribution to the effective dose is obtained through radon inhalation. Radon concentration may sometimes disclose high values and often there are houses where the effective dose exceeds 10 mSv annually and exceptionally these values may be even higher [12–14]. In the general balance of the total average effective dose received by the world's population, the whole population is given the greatest part of the dose from radon and this exposure is very often treated separately, as the concentration of radon and its progeny reveals considerable geographic diversity. Moreover, it is possible to decrease the dose from radon in houses, however, it is troublesome and expensive. Minimizing exposure form other natural sources is very difficult and sometimes practically impossible.

Radon concentration in the indoor air in the temperate zone is higher than in the outdoor ambient air. In tropical areas, where houses are well ventilated, the differences in radon concentration between indoor and outdoor air are minor and generally the exposure to radon is of less importance than in the temperate zone. The most significant exposure to radiation caused by radon comes from inhalation of its short-living progeny present in the indoor air. The inhaled radon progeny accumulate in respiratory tracts [15]. The α particles emitted by radon progeny cause a considerable radiation of epithelial cells covering trachea and bronchi. The accuracy of the estimated effective dose received by bronchial epithelial cells is constantly improved [16, 17].

Radon in soil and water as sources of radon in buildings

Radon in soil

The amount of radon in soil air reaches from 5 000 Bq m^{-3} to 700 000 Bq m^{-3} [18]. The soil, ground and rocks present in the ground, generally constitute the main sources of radon in the indoor air. The convective transfer of radon from soil to the inside of buildings depends on the sub-pressure existing in the building. Soil gas containing radon enters the building through cracks, fissures in the foundations' structure and concrete elements that constitute the basements' floor [19]. The permeability of particular types of soil in relation to the air (together with radon) may greatly vary. The differences may reach even 7 orders of magnitude. The permeability in wet clay amounts to 10^{-15} m^2 and in coarse gravel 10^{-7} m^2 [20]. The soil permeability that is equal or higher than 10^{-9} m^2 is considered high and in such conditions, the convective transfer gains profound significance [21]. Toth et.al. noticed that in areas with greatly diversified geological surface there may appear considerable differences in radon concentration within the area of one village and even neighboring houses [22]. The volume of radon transfer in soil depends additionally on the soil type and meteorological conditions [23].

Radon in water

Radon dissolves quite well in water. In the temperature of 15°C, the molar fraction of radon solubility in water amounts to 2.3×10^{-4}, which constitutes 10 times greater solubility than oxygen [24]. If water is collected from drilled water wells in geological formations containing increased ^{226}Ra levels, then the emerging radon (due to radon decay) dissolved in water may sometimes be transmitted to houses in considerable amounts [25]. In general, however, the amount of radon in water used in a household is at the level of about 10 000 Bq m^{-3} [26]. The amount of radon in water in north-east Poland depends on the well's type and reaches from 1 100 Bq m^{-3} to 28 000 Bq m^{-3} [27]. It is estimated that while using water at home (shower, washing, cooking), a minor fraction of radon contained in water is passed to the indoor air, because from 10 000 Bq m^{-3} concentration included in water, the amount that is passed to the air increases the concentration at home of only 1 Bq m^{-3} [28].

Methods of registering radon concentration

Radon and its progeny registration, similarly to other radioactive elements, is based on registering particles and gamma photons emitted during the decay of those isotopes [29]. When radon atom decays, it emits α particle and Po-218 atom emerges from it. Polonium undergoes further decay and emits the next α particle and transforms into Pb-214 atom. After the two α decays, there are two β decays due to which Bi-214 and Po-214 are created. The β radiation emission is accompanied by gamma radiation. Radon measurements may concerns only to radon present in the air or radon is measured jointly with its progeny. Most frequently, radon measurements are carried out due to radiological protection or geophysical surveys, mainly with regards to geology. More frequently used techniques are:

1. techniques utilizing radon absorption on coal activated in combination with radon radioactivity measurements by liquid scintillator counter;
2. scintillator counters utilizing scintillation in solids (NaJ, ZnS crystals);
3. synthetic materials (SSNTD – solid state nuclear track detectors) registering tracks caused by alpha radiation (particle track registration);
4. ionization chambers;
5. electrets;
6. thermoluminescence methods;
7. semiconductor detectors.

Radon present in houses can be registered by short-term or long-term measurements. Due to a short-term measurement, lasting a couple of minutes or several hours, a quick reading is obtained. These kind of measurements are sometimes useful also for commercial purposes (e.g. house purchase deal). However, in the majority of research connected with radiological protection, it is mostly about obtaining average values in longer periods, i.e. during a couple of months or a year and sometimes even a couple of years. In short-term measurements, dosimeter's exposure to radon lasts from several minutes (ionization chambers) to more than hundred hours. Radon concentration measured by short-term methods may sometimes vary significantly from the value of the average annual concentration. The measurements in which dosimeter's exposure to radon lasts longer than a month are called long-term. Taking into consideration the accuracy of an average measurement for multiannual assessment of human exposure, the readings carried out after annual exposure are mostly recommended.

In radon concentration measurements carried out in field research, very often the scintillation methods are used, which register radon in the air by the so-called Lucas chamber [30]. There are many types of this chamber, which have different construction details. Most frequently, such a chamber is made of a cylindrical glass vessel that is covered inside with scintillator material. As a result of α particles emitted by radon with scintillator (ZnS), the flares emerge in places where the particles hit the scintillator. Light photons produced in this way generate electron emission on registering photocathode. After correspondingly large enhancement of the stream of electrons by a photomultiplier they are then registered as current pulse.

Another measurement technique of radon quantity allowing to carry out reading in field conditions is the utilization of ionization chambers [29]. Recently manufactured chambers have the ability to conduct initial analysis of radon concentration in field conditions and after returning to the laboratory, to carry out detailed reading of the conducted measurements [31]. While carrying out measurements by ionizing chamber, radon contained in the measured air is entered into an ionization chamber (by pumping together with the air in which the measurement is to be conducted). After entering the chamber, by emitting alpha radiation, radon ionizes the interior of the chamber. The quantity of this ionization can be determined by measuring the ionizing current, which is measured after applying voltage to electrodes placed in the ionization chamber. This technique enables an immediate reading, which provides the possibility of determining instantaneous concentration of radon in the examined place.

In order to carry out short-term exposure, activated carbon is most frequently used. Radon present in the surrounding air will be absorbed on the carbon present in the container. After opening such a container in the room, in which we aim to carry out radon concentration measurements, the following processes take place: radon atoms diffusion from the surrounding air to the container and radon absorption on the carbon surface. After finishing the exposure, the container is closed and carried to laboratory. The amount of radon absorbed on carbon is most often measured with liquid scintillation methods by registering α or γ radiations emitted by radon progeny [32,33].

Relatively widely, the radon progeny concentration measurement is carried out by gamma radiation registration. Sodium iodine scintillation crystal [5] or semiconductor detectors [34] are most frequently used to register gamma radiation [34].

Liquid scintillators are used to register alpha or beta radiations. Liquid scintillators are made of organic solvents, usually xylene or toluene, in which PPO and POPOP scintillator substances are dissolved. Radon adsorbed during exposition on carbon, after entering to contact liquid scintillator, gradually passes to the solvent. The process of total radon desorption from carbon lasts several hours. Radon atoms dissolved in a scintillator, by emitting α radiation, evoke in it scintillations. These scintillations, similarly as in case of a crystal scintillator, are registered by a photosensitive electrode of a photomultiplier and the produced electrons are enhanced to the value of current pulse, which can be registered by the electronic circuit [33,35].

Since the 90s, it has become popular to use a certain type of electrets (EPERM – Electret Passive Environmental Radon Monitoring) for a long-term measurements of radon radioactivity. Electrets constitute the materials made of specially dissected dielectrics, which for a long period of time stay electrified, when they are not exposed to ionizing radiation or other extreme physical conditions. Dielectric material constituting an electret generates a strong electric field. This field attracts charges of opposite signs, produced in the process of ionization invoked by passing the α particle through dielectric volume. The magnitude of a neutralized charge in an electret is proportional to the number of α particles that came to it. The measurement of the charge loss magnitude for particular time of exposure helps determine radon concentration in the measured surrounding [36].

Special foils from synthetic materials (solid state nuclear track detectors) are used for long-term measurements [37]. On these foils, alpha particles leave traits of tracks, which constitute very small ditches or areas with changeable physiochemical properties, which after special chemical treatments can be displayed and counted under a microscope. This is the way of determining their volume per unit of special registering foil area. The density of traits on the examined foil determined in this way is proportional to exposure's magnitude of this foil in the place of measurement (exposure is the multiplication of radon concentration and the time of exposure). The simultaneously conducted calibration exposures of other parts of the foil (from the same factory series) in a radon chamber, allow to compare the number of tracks produced on them due to the exposure. The comparison of tacks' density on measurement and calibration foils enables to count the obtained tracks' density on measurement foils and average radon concentration existing in the examined time in a particular room [38].

Thermoluminescent detectors are also used in long-term measurements of radon concentration. The rule for registration of ionizing radiation in these detectors is based on the phenomenon taking place in detector's crystal as a result of the interaction between ionizing radiation with the network of the detector's crystals. It involves transporting certain number of electrons from valence strand to conductivity strand. The result of such an impact is immobilization, for a long period of time, of part of expelled electrons in the place of crystal network defects and the production of holes in the valence strand. The measurement of the quantity of the absorbed ionizing radiation includes heating the crystal, which leads to recombination of the elements with the holes. This recombination causes the light in the visible range. The intensity of this light is proportional to the magnitude of the exposure of thermoluminescent detectors' crystal on ionizing radiation at the place of concentration's measurement [39].

Variability in time of radon concentration in the air

The indoor radon concentration does not constitute a constant value and may relatively quickly change, but these changes may also appear slowly [40]. Instantaneous concentration of radon in houses is the dynamically changing resultant of the processes of radon inflow to the inside of the house and its elimination from the house's inside to the outside with ventilating air. Temporary concentration changes, which may be observed within several hours or days, are mostly caused by a change in meteorological conditions [41]. The slow changes of radon concentration in houses are linked with slow changes of weather and seasons [42]. The fluctuations of radon concentration that quickly take place, one after another, are the result of the fast changing values of atmospheric pressure connected with the weather. In not fully air-tight buildings, pressure variations caused by winds may greatly influence the sub-pressure's magnitude inside the building. The winds may thus change the size of radon's stream flowed from the ground together with soil air [43]. Moreover, the quantity of air interchange between the inside of the building and the surrounding depends on wind speed and together with it, the speed of escaping radon from the building into the surrounding [44]. Such an effect was observed in buildings situated on the ground with high concentration of radon in soil gas and considerable permeability of the substrate [45].

The existing seasonal fluctuations of radon concentration are connected with seasons of the year [42,46,47]. They are to be noticed in buildings in which air exchange is made through natural ventilation. If the temperatures inside and outside the house are similar, as in summer, the chimney effect existing in ventilation system provides a minor flow of air between the building and the surrounding. In cooler seasons of the year, when temperature variations amount to between ten and twenty degrees Celsius or more, the sub-pressure developed in the building may cause, on the one hand, pumping into the building a considerable amount of radon from the substrate [48]. On the other hand, the pressure difference developed in this way increases the convective flow of air in the building [49]. If the main source of radon in the apartment are building materials, then the convective air flow increases building's ventilation and by this decreases radon concentration. In summer, when the windows are open, the convective air flow in a building may be invoked by wind and cause a considerable exchange of the air. In winter, on the other hand, when the ground around the building freezes, the radon transport from soil is practically cut and due to this radon concentration in soil is increasing. However, the ground under the building is not frozen and through it radon is transported to the building in greater amount than in summer [50]. As can be concluded from the above review, such factors as: building airtightness, type of ventilation, habits of ventilating the apartment and the seasons of the year, mainly condition the level of radon concentration inside the building. The concentration outside the building, in the ambient air, usually fluctuates between 5-15 Bq m^{-3} [40,51]. Hayashi et al. [52], Hatanaka et al. [53] noticed the increase in radon concentration in the air on seismic hazard zones before the incoming earthquake.

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