Journal of Radiation and Nuclear Applications
An International Journal

http://dx.doi.org/10.18576/jrna/100305

Radon Gas Riddlity in our Environment

Ahmed Saad Hussein[12*]

[1]Nuclear Security Program, Naif Arab University for Security Studies, Riyadh, KSA.
[2]Radiation Protection Department, Nuclear Power Plants Authority, Cairo, Egypt.

Received: 22 April. 2025, Revised: 15 June 2025, Accepted: 2 July 2025.

Published online: 1 Sep 2025.

Abstract: Radon is a radioactive gas that has no smell, color, or taste. Radon is produced from the natural radioactive decay of uranium, which is found in all rocks and soils. Radon can also be found in groundwater and natural gas. Radon escapes from the ground into the air, where it decays and produces further radioactive particles called radon progeny. Radon gas can get trapped inside homes and buildings and accumulate in the air. Radon moves up through the ground and can enter a building through cracks in foundations, floors, or walls. It can also be released from building materials and some groundwater. Radon levels are usually highest in basements or crawl spaces. About one-half of the effective doses from natural sources are estimated to be delivered by inhalation of the short-lived radon progeny. Radon progeny is well established as a causative agent of lung cancer and other types of cancers. Owing to this fact, radon is the most popular subject of studies on environmental radioactivity. Most radon-related cancer deaths occur among smokers. Despite the health problems caused by radon gas in a closed environment, it has many benefits that humanity can benefit from.
Radon's unique properties as a naturally radioactive gas have led to its use as a geophysical tracer for locating buried faults and geological structures, in exploring for uranium, and for predicting earthquakes. Radon has been used as a tracer in the study of the atmospheric transport process. There have been several other applications of radon in meteorology, water research, and medicine. This manuscript summarizes the health effects and the potential benefits of radon and its progeny.

Keywords: Radon, Effective Dose, Health Hazard, Geological Structure, Earthquake Prediction.

1 Introduction

In the literature, there are several reports dealing with radon in our environment [1-16]. The radiation dose from radon inhalation constitutes a major part of the total natural background dose received by man. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reports that nearly half of the dose received by man from natural sources is due to breathing radon and its progenies in the indoor environments, as shown in Figure 1[10].

Radon is the most important cause lo lung cancer after smoking and the leading cause of lung cancer among non-smokers.

Early studies on underground miners demonstrated an increased incidence of lung cancer in uranium miners exposed to very high concentrations of radon and its progeny. Epidemiological studies summarized in reports of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [13,14] and in publications of the International Commission on Radiological Protection (ICRP) [7-9] have shown a significant association between workers' exposure due to radon and lung cancer. These studies reflect the importance of protecting workers from exposure to radon. According to WHO, radon is estimated to cause between 3% to 14% of all lung cancers [17].

Depending on the average radon level indoors and smoking prevalence, long-term exposure can significantly increase the risks. The risk of lung cancer from radon is substantially greater for smokers: they are around 25 times more likely to develop lung cancer than non-smokers [17].

The International Agency for Research on Cancer (IARC) classified radon as a proven human carcinogen along with tobacco smoke, asbestos, diesel engine exhaust, and welding fumes [16].

*Corresponding author e-mail: aomar@nauss.edu.sa

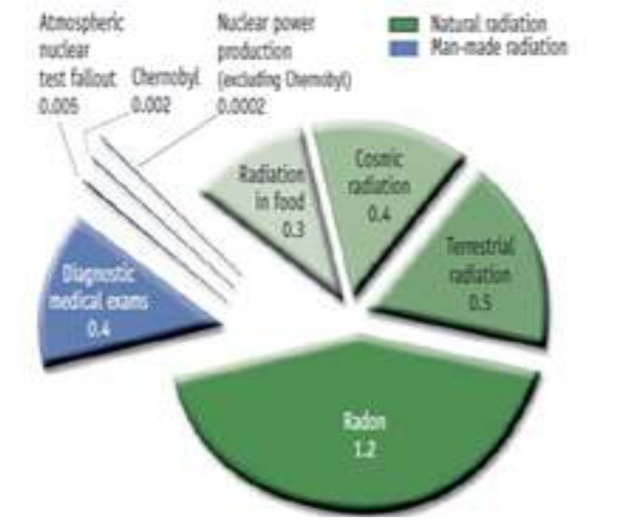

Fig. 1: Typical sources of public radiation exposure (in mSv per year) [10].

Radon is a colorless, odorless, and tasteless gas produced by the radioactive decay of uranium and thorium. There are two main isotopes of radon in nature: – ^{222}Rn (T1/2=3.82d, here after caller radon) and its short-lived decay products: ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po, ^{210}Pb, 210Bi, ^{210}Po (uranium series), – ^{220}Rn (T1/2=55.6s, also called thoron) and its decay products: ^{216}Po, ^{212}Pb, ^{212}Bi, ^{212}Po, ^{208}Tl (thorium series) [10,11]. The radioactive decay chain of radon and thoron is shown in Figure 2 [18]. The danger of these two isotopes is incommensurable, and the main threat to humans is posed by the much longer-lived radon-222.

2 Radon in our environment:

2.1 Radon in air:

Radon concentrations indoors tend to differ among countries and even individual buildings because of differences in climate, construction techniques, types of ventilation provided, domestic habits, and, most importantly, geology.

After being released from bedrock material, radon passes through the soil, diluting in the air before entering buildings. Granites, migmatites, some clays, and tills are particularly rich in uranium and radium, which decay into radon. Radon exhaled from the ground beneath buildings is the main source of radon in indoor air.

Radon occurs in most indoor workplaces for the same reason as in dwellings. All types of workplaces may be affected: offices, workshops, mines, and tunnels. In underground workplaces, radon levels may be elevated due to the geological conditions or limited ventilation. The workplaces particularly affected are often associated with work in mines, tunnels, and basements. A large proportion of normal above-ground workplaces such as factories, shops, schools, museums, and offices may also have high concentrations of radon due to its presence in the ground, poor ventilation, or processing of raw materials [6].

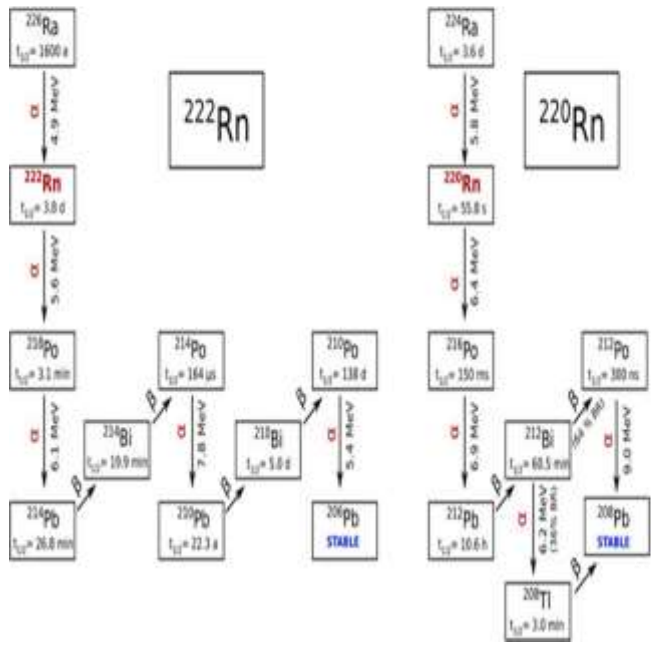

Fig. 2: Decay chains of ^{222}Rn (left) and ^{220}Rn (right) [18].

The radon content of outdoor air 1 meter above ground typically gives 4 to 15 Bq m^{-3}. The average indoor air concentration of radon varies from location to location, depending upon the uranium content and physical characteristics of the soil, moisture, winds, and building materials. In most countries, the average indoor radon concentration is a few tens of Bq m^{-3}; however, during the surveys, hundreds and even thousands could be found [10].

The International Commission on Radiological Protection (ICRP) therefore recommended action levels 200– 600 Bq m^{-3} for homes and 500-1500 Bq m^{-3} for workplaces, which correspond to annual doses of 3–10 mSv in either case [7].

According to ICRP publication 115, the upper value for radon reference levels at homes was lowered from 600 Bq m^{-3} to 300 Bq m^{-3} [9]. WHO considers that radon exposures should not be above 100 Bq m^{-3} [6,17]. IAEA has in its documents IAEA Basic Safety Standards,300 and 1000 Bq m^{-3}. The differential depends on the exposure type: residential or occupational [2-4].

The reference levels for the average indoor radon concentration in some countries are given in Table 1 [9].

Table 1: The reference levels for the annual indoor radon activity concentration (C_{Rn}) in the world [9].

Country	C_{Rn} (Bq m^{-3})	Country	C_{Rn} (Bq m^{-3})
Australia	200	Romania	200-400
Canada	200	Russian Federation	100-200
China	200	Slovenia	200-400
Denmark	200	Turkey	400
France	300	UK	200
Germany	300	USA	150
India	150	EU	300
Ireland	200	ICRP	300
Norway	200	WHO	100

2.2 Radon in building materials:

Most building materials produce an insignificant amount of radon naturally. At the same time, some specific materials can act as significant sources of radon exposure. Such materials tend to have a combination of high levels of Radium-226 (which decays into radon) and high porosity, which allows the radon gas to escape. These include lightweight concrete with alum shale, phosphogypsum, and Italian tuff. Use of material from old uranium tailings (by-products of uranium mining) as filling under the buildings can also contribute to significant concentrations of radon indoors [1,21].

Requesting tested materials is a good first step. Porous materials tend to have more radon in them, so watch for those. Finally, improving ventilation, installing mitigation systems, and incorporating fans, piping, and radon fan cover boxes can minimize radon exposure.

The International Commission for Radiological Protection has suggested that areas where 1% or more of the buildings have indoor radon concentration higher than 10 times of national average should be considered as "radon prone" areas. Therefore, it is desirable not only to measure the radon but also to find out the sources of radon, especially in houses. Radiation exposure due to natural radionuclides in building materials, as well as radon concentration in closed spaces, was recognized as a significant risk for the general population only in the early 1970s of the 20th century [7].

Radon exhalation from building materials depends not only on the radium concentration, but also on factors such as the fraction of radon produced that is released from the material's grain to its interstitial space, also known as the emanation power of the fraction, the porosity of the material, and the surface preparation and building material covering. Knowledge of ionizing radiation levels in buildings, related to radionuclide content in building material samples, is clearly of fundamental importance in the assessment of population exposure, as most of the residents spend about 80% of their time indoors [10].

2.3 Radon in water:

Radon can dissolve and accumulate in groundwater sources, such as water pumps or drilled wells in uranium-rich geological areas. Radon in water can be released into the air during water use, such as showering or laundry. Radon levels may be high in workplaces in water treatment facilities or spa facilities using natural water [19]. Ingestion of radon in water is also thought to pose a direct health risk. Radon in drinking water could potentially produce adverse health effects in addition to lung cancer. According to the Swedish Food Agency states that radon activity concentration in water must not exceed 100 Bq $l^{-1,}$ and water that contains more than 1000 Bq l^{-1} should not be used for drinking or cooking [20].

3 Radon measurement techniques:

There are several techniques that have been used for radon measurements. These techniques include scintillation cells, ionization chambers, solid state nuclear track detectors (SSNTDs), solid state surface barrier detectors, thermoluminescent dosimeters, electret ion chambers, and the electrostatic precipitation technique. For developing countries wishing to undertake national survey programs to monitor environmental radon levels, the most appropriate techniques are those making use of SSNTDs (CR-39 and LR-115) because they are versatile, simple in handling and processing, low-cost cost and insensitive to beta and gamma radiation. Also, these detectors incorporate the effects of seasonal and diurnal fluctuation of radon concentrations due to physical and geological factors, as well as meteorological conditions [3, 21].

4 Radon mitigation measures:

Strategies to prevent and reduce indoor radon exposure to as low as reasonably achievable (ALARA) may include:

• Established national reference levels for radon in indoor air and drinking water.

• Recommendations for residents to mitigate radon concentrations in existing homes exceeding the national reference levels.

• Mechanical ventilation and/or a radon membrane over the entire base area of the building in combination with a passive or active radon sump system.

It is necessary to establish building codes, public awareness, and undertake mitigation measures to reduce indoor radon exposure below the national reference level in existing houses. Well-tested, durable, and cost-efficient mitigation methods exist to prevent radon from entering new buildings and to reduce radon in existing buildings [6].

5 Harmful Effects of Radon:

Until the late 1970s, radon and its progenies were regarded as radiation health hazards only encountered in the mining and milling of uranium. This dramatically changed because of widespread indoor measurements of radon in parts of the world [7,10,15]. Attention to the problem of radon exposure and the associated health risks has thus been growing around the world [15,17]. Nowadays, radon and its progeny, known to be carcinogenic in high radon concentration places, if it is poorly ventilated and if the radon input from its sources is high, such as mines, caves, cellars, ancient tombs, and energy-conserved airtight houses. The inhaled radon and its progenies pass from the lungs into the blood and body tissues and may indicate many types of soft tissue cancers, such as lung cancer, kidney cancer, and prostatic cancer [15]. Some radon may be dissolved in body fats, and its daughter products transferred to the bone marrow. The accumulated dose in older people can be high and may give rise to leukemia. Radon has also been linked with melanoma and some childhood cancers [22]. There is a positive association between coronary heart disease and radon exposures, where an elevated risk of mortality from coronary heart disease was observed among miners with cumulative radon exposure exceeding 1000 Working Level Month (WLM) [23]. Radon daughters ^{218}Po and ^{214}Po could be regarded as potential carcinogenic agents for the induction of skin cancer [24]. It is also noticed that the combination of inhalation of radon gas and smoking increases the risk of lung cancer [15,26-28].

The principal health effect in breathing air containing ^{222}Rn is due to its daughters ^{218}Po, ^{214}Pb, and ^{214}Bi (^{214}Po). Their contribution to the radiation dose to the lung is 2- 3 orders of magnitude greater than that of ^{222}Rn [25].

Ingested radon dissolved in drinking water is a health risk because it may cause stomach cancer. The risk caused by drinking water containing dissolved radon is extremely much lower than inhaling radon [17].

The health threat from radon can be addressed by identifying geographic areas that could produce elevated levels of indoor radon, developing strategies to reduce exposure, conducting research on effective remedial measures to be taken in buildings, and providing educational programs for health officials and the public [4,17,21].

To the contrary, Reports exist on various epidemiological studies demonstrating a negative correlation of lung cancer risk with radon in dwellings, which shows that exposure to low-level ionizing alpha radiation has resulted in positive health effects [29-32]. Also, it was reported that there was no association between residential radon and the risk of childhood acute myeloid leukemia AML [30].

Recognizing the importance of radon as a public health issue, large-scale national and international radon programs were initiated worldwide, such as the International Radon Project (IRP) by the WHO on public health aspects of radon exposure. This project enjoys high priority with the WHO´s Department of Public Health and Environment. The key elements of the IRP include [17] :

1. Estimation of the global burden of disease (GBD) associated with exposure to radon, based on the establishment of a global radon database

2. Provision of guidance on methods for radon measurements and mitigation

3. Developing evidence-based public health guidance for Member States to formulate policy and advocacy strategy, including the establishment of radon action levels

6 Development of approaches for radon risk communication.

Recently, Bruneaux, Serena's study supports that higher radon concentrations are associated with higher mortality from neurodegenerative diseases, including Alzheimer’s disease, Parkinson’s disease, and Multiple Sclerosis. Additionally, radon is correlated with higher mortality rates from nervous system cancer and cerebrovascular diseases [32,33]. Also, Taylor et al. conclude that everyday home radon exposure may be impacting youths’ mental health and support the need for better public policy surrounding indoor radon mitigation efforts, and public awareness of the potential harm of home radon. Based on the results of this study, they recommend that the broader public make efforts to reduce indoor radon concentrations when possible, and/or limit the amount of time spent in dwellings for which radon concentrations cannot be readily reduced to promote neurocognitive health [34].

7 Radon benefits in our environment:

There is more and more information accumulating on the beneficial effects of radon at cell biological level, known as radon therapy. Radon measurements can be used to solve radiation safety problems at nuclear and industrial facilities. In addition to that, radon is very important for many applications in earth sciences. It can be used as a geological tool in mineral exploration, earthquake and volcanic activity prediction, and the search for geothermal energy sources. Radon can also be used in atmospheric studies.

7.1 Radon as medicine (radon SPAS and radon therapy):

In radon treatment, radioactive radon is applied to people for medicinal purposes. Patients are exposed to a high concentration of radon for a short period to alleviate pain for several months, and so to reduce their use of painkillers for a certain period. Radon therapies are mainly used for rheumatic diseases.

Rather early, the stimulation of DNA repair was observed upon radon exposure. Similar DNA repair was indicated in lymphocytes of people living in increased radon concentration, and the adaptive response reaction was provoked under a 10 mSv “priming” dose [21,35]. The spas containing radon have been used with success for hundreds of years for special illnesses, mainly in the pain therapy of chronic rheumatic illnesses. Radon spas are widespread in the USA, Japan, and Europe (Greece, Germany, Austria, the Czech Republic, Hungary, Romania, Slovenia, Russia, etc). Clinical experience has shown that the long-lasting pain of the patients was considerably reduced with fewer analgesic pharmaceuticals. The presence of radon in spas, accordingly, cannot be considered as risky to health; just the opposite, more and more information accumulates on its positive health effects, completing the other beneficial factors present in health spas [35-39]. The Environmental Protection Agency states that there is no safe level of radon and that any exposure poses some risk of cancer. Others support the positive or neutral effects of low-dose radiation.

The question is whether or how much the radon impacts or damages the tissue [38]. So that any radon spa treatments should be given by a medical practitioner [4]. It was reported that the application of radon inhalation therapy to patients with 4 types of cancer: colon, uterine, lung, and liver cancer. The radon treatments were given to improve the efficacy of chemotherapy and were potent in all 4 cases [40].

Radon therapy is one of the types of balneotherapy based on radon radiation for therapeutic, prophylactic, and rehabilitation purposes. A significant number of authors report a positive effect of radon baths on the condition of patients with osteochondrosis [41].

Radon has been used for radon therapy for pain reduction in external genital endometriosis. Further research is crucial to establish its efficacy and safety. The prospect of pain reduction, improved quality of life, and reduced reliance on conventional treatments makes radon therapy a compelling area of investigation [42-43]

7.2 Radon and radiation safety in nuclear and industrial facilities:

In recent years, problems of radiation and nuclear safety have been multiplied rapidly due to the release of natural alpha-radioactivity from waste material produced by power plants, the chemical and metallurgical industry. Therefore, the measurements of radon concentration, as well as radon progenies in air, soil, and water, have been of great concern for radiological safety [2,4,6,15,17].

7.3 Radon and mineral exploration:

Over the years, a large number of techniques and methods have been developed to measure radon concentration in the "soil gas' and groundwater in selected areas of interest. These measurements can yield a lot of information regarding the subsurface geological features and the presence of mineral and oil/gas reserves [21].

7.4 Radon and earthquake prediction:

Real-time radon monitoring is an extensively studied area to give premonitory signs before earthquakes. The strain change that occurred on the Earth's surface during an earthquake is expected to enhance the radon concentration in soil gas and groundwater. In addition to continuous radon monitoring in groundwater, other geochemical parameters such as electrical conductivity and water temperature should be measured [44-48].

7.5 Radon and volcanic surveillance:

Radon has been recognized for a long time as a detectable component of fluids associated with volcanoes (fumaroles, ground waters, or soil gases). It was reported that radon measurements should be supplemented by measurements of other physical or chemical parameters. Under such circumstances, knowledge of the geochemistry of volcanoes could rapidly increase in the immediate future [49-50].

7.6 Radon and geothermal energy prediction:

A geothermal source may be defined as the natural heat of the earth trapped close enough to the earth's surface to be extracted economically. Normally, geothermal sources are associated with volcanic regions. Hot water springs and vapor emanations may suggest prospecting for geothermal energy sources. The observation of exceptionally high radon levels may indicate the possible existence of geothermal energy sources lying deep underneath the Earth's surface. The method of using radon signal for locating geothermal energy sources has met some success in countries such as New Zealand, Mexico, and the USA [57-60].

7.7 Radon applications to atmospheric studies:

The keen interest in environmental radon monitoring can be attributed to its attractive characteristics as a tracer of atmospheric processes. Radon is primarily of terrestrial origin, and its predominant sink is by radioactive decay. Since it is a noble gas, it does not react chemically with other species. Furthermore, since radon is relatively insoluble in water and does not attach to aerosols, it is not highly susceptible to dry or wet atmospheric removal processes. The half-life of radon (3.8 days) is comparable to the lifetimes of short-lived atmospheric pollutants (e.g., NOx, SO2, CO, O3) and the atmospheric residence time of water and aerosols. This timescale is also comparable to many important aspects of atmospheric dynamics, making radon a useful tracer at local, regional, or global scales.

The characteristics of radon make it a reliable indicator of the extent of air mass contact with land. This is more accurate information than can be derived from back trajectories alone. Furthermore, the simulation of radon transport is currently one of the best tools for the evaluation of transport schemes in regional and global models. Due to its short half-life, the vertical distribution of radon in the atmosphere shows great sensitivity to sub-grid scale processes. It has also been demonstrated that trace gas emissions originating from large land areas can be estimated using radon as a marker for emissions from soil. With the automated detectors, changes in radon concentration can be measured to high precision and temporal resolution a either permanent stations or on-board ships [61-63].

8 Conclusion and recommendations:

In recent years, radon monitoring and indoor radon concentration levels have been of scientific and technological interest due to their health hazards, not only to underground miners but also to people in dwellings and workplaces with high radon levels, and their multiple applications, as a useful tool in studies in hydrology, geology, oceanography, and earthquake prediction. In addition to that, radon measurements can be used to solve radiation safety problems at nuclear and industrial facilities. It has proved to be a good friend and a powerful enemy at the same time, or it is both a hazard and some help.

I recommend:

• Carry out a national program for estimating radon levels and effective doses to people in the indoor environments in the country, and regroup all efforts dealing with it and turn to a collective work.

• Use the educational programs to inform health officials and the public about the health threat from radon and about associated risk factors, such as smoking.

• Apply the Geographical Information System (GIS) technology in the analysis of radon data and the creation of an indoor radon map of the country.

• Promote scientific research dealing with radon applications in earth sciences and radiation safety at nuclear and industrial facilities.

References

[1] IAEA. International Atomic Energy Agency, Protection against exposure due to radon indoors and gamma radiation from construction materials – methods of prevention and mitigation, IAEA-TECDOC-1951, 2021.

[2] IAEA. International Atomic Energy Agency, Design and conduct of indoor radon surveys, Safety Reports Series No.98, 2019.

[3] IAEA. International Atomic Energy Agency, National and regional surveys of radon concentration in dwellings, Review of methodology and measurements techniques, AQ; 33:1-13,2013.

[4] IAEA Safety Reports Series No.33, Radiation Protection against Radon in Workplaces other than Mines, 2003.

[5] EPA. Environmental Protection Agency, Overview EPA’s state indoor radon grants: 2019 Activities, Wexford, 2020.

[6] WHO. World Health Organization, Handbook on indoor radon: a public health perspective, Geneva, Switzerland, 2009.

[7] Alshahri, F., El-Taher, A., Elzain., AEA., 2019 Measurement of radon exhalation rate and annual effective dose from marine sediments, Ras Tanura, Saudi Arabia, using CR-39 detectors.Romanian Journal of physics 64 (811), 1-12.

[8] Althoyaib, SS., El-Taher, A.., The measurement of radon and radium concentrations in well water from Al-Jawaa, Saudi Arabia. J Radioanal Nucl Chem 304, 547-552. 2015.

[9] Alharbi, WR., Abbady, AGE., El-Taher, A., Radon concentrations measurement for groundwater using active detecting method. Am. Sci. Res. J. Eng. Tech. Sci 14, 1-11. 2015.

[10] UNSCEAR. United Nations Scientific Committee on the Effects of Atomic Radiation, New York, United Nations, 2000.

[11] UNSCEAR. United Nations Scientific Committee on the Effects of Atomic Radiation, New York, United Nations,2006.

[12] UNSCEAR. United Nations Scientific Committee on the Effects of Atomic Radiation, New York, United Nations, 2019.

[13] UNSCEAR. United Nations Scientific Committee on the Effects of Atomic Radiation, New York, United Nations, 2020.

[14] UNSCEAR. United Nations Scientific Committee on the Effects of Atomic Radiation, New York, United Nations, 2022.

[15] NAS. The National Academy of Science, Biological effects of ionizing radiation, the health effects of exposure to indoor radon, BEIR VI, 1999.

[16] IARC, The International Agency for Research on Cancer, https://www.iarc.who.int/news-events/lung-cancer-awareness-month-2024.

[17] WHO. World Health Organization, Radon, https://www.who.int/news-room/fact-sheets/detail/radon-and-health/

[18] Bruenner S., Cichon D., Eurin G., Gomez P., Jorg F., Undagoitia T., Singer H., and Rupp N., Radon daughter removal from PTFE surfaces and application in liquid xenon detectors, Eur. Phys. J.C.,2021,81:343.

[19] IAEA. International Atomic Energy Agency, what is radon, and how are we exposed to it? https://www.iaea.org/newscenter/news/what-is-radon-and-how-are-we-exposed-to-it.

[20] Nordic Radiation and Nuclear Safety Series, Radon dose conversion coefficients and their use in the Nordic Countries, No. 3, 2023.

[21] Durani S.A. and. Illic, R., Radon Measurements by Etched Track Detectors, World Scientific, Singapore (1997).

[22] Henshaw D.L., Eatough J.P. and Richardson L.B., Radon as a causative factor induction of myeloid leukemia and other cancers, Lancet, 1990, Vol 335, pp. 1008.

[23] Leenhouts H.P. and Brugmans M.J.P. Calculation of lung cancer incidence in the Netherlands and Sweden

caused by smoking and radon: risk implication for radon. Radiat, Environ. Biophys.,2001, Vol 40, pp.11.

[24] Eatough J.P. Alpha particle dosimetry for the basal layer of the skin and the radon progeny 218Po and 214P, Phys Med.Biol., 1997, Vol 42, pp.1899.

[25] Ruzer, L. and Sextro, R., Measurement of radon decay products in air by alpha and beta spectroscopy.Radiat. Prot. Dosim., 1997, Vol.72, pp.43.

[26] Liu Y., Xu Y., Xu W., He Z., Fu C., and Du F. Radon and lung cancer: Current status and prospects, Critical Reviews in Oncology, Vol 198, 2024.

[27] Chen J. A population-level study on smoking and radon-induced adenocarcinoma and small-cell carcinoma among males and females in Canada, Radiation Medicine and Protection, 2024.5,170-177.

[28] Heinzl F., Schnelzer M., and Scholz-Kreisel P. Lung cancer mortality attributable to residential radon in Germany, Radiation and Environmental Biophysics,2024.

[29] Averbeck D., Testard I., and Boucher D. “Changing views on ionizing radiation-induced cellular effects.” Int. J. Low Radiat., Vol. 2006, 3, pp.117–134.

[30] Steinbuch M., Weinberg C., Buckley J., Robinson L., and Sandler D. Indoor residential radon exposure and risk of acute myeloid leukaemia. Br. J. Cancer, Vol. 1999,81, pp. 900.

[31] Kyn Kang J., Seo S.and Jin Y.W. Health effects of radon exposure, Yonsei Med J,2019, 60(7), pp597-603.

[32] Reddy A.,Conde C.,Peterson C. and Nugent K. Residential radon exposure and cancer, Oncology Reviews,2022, Vol.16, pp.558.

[33] Serena B. The link between radon exposure and neurodegenerative disease risk factors, Honor Theses, Eastern Kentucky University ,2024.

[34] Taylor B., Pulliaam H.,Smith O.,Rice,D.,Johnson H.,Coutant A.,Glesinger R. and Wilson T. Effects of chronic home radon exposure on cognitive behavioral and mental health in developing children and adolescents, Frontiers in Psychology,2024.

[35] URAET S. Bello J. Simon , A.S. Aliyu , A. Abdulqadir., The Use of Nuclear Energy to Solve Nigeria's Energy Crisis and Help the Country Achieve its SDGs. J. Rad. Nucl. Appl. 9 (1), 77- 82. 2024.

[36] Wael M Badawy, Andrey Yu Dmitriev, Hussein El Samman, Atef El-Taher, Maksim G Blokhin, Yasser S Rammah, Hashem A Madkour, Safwat Salama, Sergey Yu Budnitskiy., Elemental composition and metal pollution in Egyptian Red Sea mangrove sediments: characterization and origin. Marine Pollution Bulletin 198, 115830. 2024.

[37] Massoud, E., El-Taher, A., Najam, LA., Elsaman, R., Ecological impacts of Assuit fertiliser factory in Upper Egypt: Environmental implications and spatial distribution of natural radionuclides. International Journal of Environmental Analytical Chemistry 103 (5), 1039-1052. 2023.

[38] Oraby, AH., Saleh, GM., Hassan, EM., Eldabour, SE., El Tohamy, AM., Kamar, MS., El Feky, MG ., El Taher, A., Natural radioactivity and radioelement potentiality of mylonite rocks in Nugrus Area, Southeastern Desert, Egypt. Radiochemistry 64 (5), 645-655. 2022.

[39] American Nuclear Society: Radon Spas.

[40] Kojima S.,Cuttler J., Longuchi K.,Yorozu, K.,Horii T.,Shimura, N.,Koga H. and Murata, A. Radon therapy is very promising as primary or adjuvant treatment for different types: 4 Case Reports, Dose RResponse: AnInternational Journal,2019.

[41] Polshchakova, T, Gushcha, S., Bevz,L. and Plakida A. The use of radon baths in the rehabilitation of patients with osteochondrosis, Eur .Rev. Med. Pharmacol Sci., 2022,26(17), pp.6107-6109.

[42] Nuriddinovna A.F. Exploring radon therapy for pain relief in external genital endometriosis, Journal of Modern educational Achievements, 2024, Vol.8.

[43] Ataeva F.N., Juraeva A. and Ramizhanova N.F. The use of radon baths in the rehabilitation of patients with external genital endometriosis after surgical treatment, American Journal of Medicine and Medical sciences, ,2023,13(3), pp.207-209.

[44] Kamislioglu M. and Kulahci F. Chaotic behavior of soil radon gas and applications, Acta Geophysica, Vol.64,2016, pp.1563-1592.

[45] Tsuchiya M.,Nagahama H.,Muto J., Hirano,M. and Yasouka Y. detection of atmospheric radon concentration anomalies and their potential for earthquak prediction using Random Forest analysis, Scientifi Reports,14,2024.

[46] Pathak J.S. Variation in radon concentration as an earthquake precursor, Journal of Multiciliary Studies, Vol.II , 2024.

[47] Pratama T.O., Sunarno, Wijatna ,A.B. and Haryono,E. Grindulu fault cloud radon date for earthquake magnitude prediction using machine learning, International Journal of Artificial Intelligence, Vol.13,No.4,2024, pp.4572-4582.

[48] Gumus A.S. Investigation of the relationship between the decline in well waters radon anomalies and earthquake magnitude, Journal of Radio analytical and Nuclear Chemistry, 333,2024, pp.2307-2320.

[49] Voltattorni N., Giammanco S.,Galli G.,Gasparini A and Neri M. Indoor radon monitoring and associated diffuse radon emissions in the Fanks of Mt.Etna(Italy), Atmosphere ,15,2024.

[50] Cigolini C.,Laiolo M.,Coppola D. and Trovato C. Radon surveys and monitoring active volcanoes: Learning from Vesuvius, Stromboli,La Soufriere Villarrica, Geological Society London Special Publicatios,451(1),2016.

[51] Sun J.,Liu K.,He Q.,Yu T. and Deng Y. Erratum to thermal infrared remote sensing and soil gas radon for detecting blind geothermal areas, Geothermics,106,2022.

[52] Nurohman H., Nugrah E.D. and Iskandarsyah

,T.y. Investigation on radon levels in soil and water associated with Mount Tampomas geothermal activity in Indonesia, Radiation Medicine and Protection,5,2024, pp.248-253.

[53] Baskaran M. Applications of radon in atmospheric studies, Chapter in book: Radon: a tracer for geological, geophysical and geochemical studies, Springer Geochemistry,2016.

[54] Sultani M.A.,Bulko M.,Holy K, Mullerova M., Masarik J.,Tonhauzerv P. and Helej M. The use of radon as a tracer for air quality assessment: a case study in Bratislava, Slovakia, Journal of Radioanalytical and Nuclear Chemistry,333,2024, pp.2515-2527.

[55] El-Taher and Al-Turki, A., Radon activity measurements in irrigation water from Qassim Province by RAD7. Journal of environmental biology 37 (6), 1299. 2016.

[56] Tatedac Y. and IwaocK, High 210 Po atmospheric deposition flux in the subtropical coastal area of Japan, J.Env.Rad., Vol.99,2008, pp.98-108.

[57] Elsaman,R., Seleem, EMM., Salman, SA., Ella, EMAE., El-Taher, A.., Evaluation of natural radioactivity levels and associated radiological risk in soil from Siwa Oasis, Egypt. Radiochemistry 64 (3), 409-415. 2022.

[58] El-Taher, AM., Abojassim, AA., Najam, LA., Mraity, H., Assessment of annual effective dose for different age groups based on radon concentrations in the groundwater of Qassim, Saudi Arabia. Iranian Journal of Medical Physics 17 (1), 15-20. 2020.

[59] Abojassim, AA., Mohammed, H., Najam, LA., El-Taher, A., Uranium isotopes concentrations in surface water samples for Al-Manathera and Al-Heerra regions of An-Najaf, Iraq Environmental earth sciences 78 (5), 132. 2019.