Natural background radiation: sources, distribution and health impacts

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Abstract. Natural background radiation is a permanent component of the environment and represents the largest source of ionizing radiation exposure for the general population. It originates from cosmic rays, naturally occurring radioactive materials in the Earth's crust, radon gas, and radionuclides present within living organisms. Although radiation is often associated with harmful effects, natural radiation has been present since the formation of the Earth and constitutes an unavoidable part of everyday life. The level of exposure varies according to geographical location, altitude, geological composition, and environmental conditions. This review aims to present the main sources of natural background radiation, their distribution in the environment, and their potential effects on human health.

Keywords: natural background radiation, ionizing radiation, radon, cosmic radiation, terrestrial radiation, radionuclides.

Introduction. Radiation is the emission and propagation of energy in the form of waves or particles through space or matter. Among the different types of radiation, ionizing radiation has sufficient energy to remove electrons from atoms and molecules, leading to the formation of ions (Eisenbud & Gesell, 1997).

Natural sources of ionizing radiation have existed since the origin of the Earth and continue to contribute significantly to human radiation exposure. Natural background radiation is present in air, water, soil, food, and building materials, resulting in continuous exposure throughout human life (Shahbazi-Gahrouei et al., 2013; Pop et al., 2026).

According to scientific studies, natural radiation accounts for the majority of the annual radiation dose received by the world's population. Exposure levels vary depending on environmental and geographical factors, including altitude, geological formations, and local concentrations of naturally occurring radioactive elements (UNSCEAR, 2008).

Naturally occurring radionuclides can be classified into three main categories: primordial radionuclides, cosmogenic radionuclides, and radionuclides generated through natural radioactive decay series. Primordial radionuclides such as uranium-238, thorium-232, and potassium-40 have remained present since the formation of the Earth because of their long half-lives (Eisenbud & Gesell, 1997; Shahbazi-Gahrouei et al., 2013).

The study of natural background radiation is essential for understanding environmental radioactivity and assessing potential health risks. Knowledge of natural radiation levels provides the scientific basis for radiation protection standards and allows the distinction between natural and anthropogenic sources of radiation exposure (UNSCEAR, 2008; Autsavapromporn et al. 2024; Zlobina et al., 2022; Talapko et al., 2024; Adeola et al 2023; Nunes et al., 2023).

The objective of this review is to examine the principal sources of natural background radiation, discuss their distribution in different environments, and evaluate their significance for human health (Shahbazi-Gahrouei et al., 2013).

Sources of Natural Background Radiation. Natural background radiation originates from several sources that have been present since the formation of the Earth. These sources can be broadly classified into cosmic radiation, terrestrial radiation, radon and its decay products, and internal radiation from naturally occurring radionuclides within the human body. Together, they account for the majority of the radiation dose received by the general population worldwide (UNSCEAR, 2008; Shahbazi-Gahrouei et al., 2013).

Cosmic radiation. Cosmic radiation consists of high-energy particles originating from outer space, including the Sun, distant stars, and other astrophysical phenomena. When these particles enter the Earth's atmosphere, they interact with atmospheric gases and generate secondary particles such as neutrons, muons, and gamma rays, which contribute to human exposure at ground level (Eisenbud & Gesell, 1997; UNSCEAR, 2008).

The intensity of cosmic radiation varies according to altitude and latitude. At higher altitudes, the atmosphere provides less shielding against incoming cosmic particles, resulting in increased radiation levels. Consequently, individuals living in mountainous regions and airline crew members receive higher annual radiation doses than people living at sea level (UNSCEAR, 2008; ICRP, 2007).

Cosmic radiation contributes significantly to the average annual effective dose received by humans. Although exposure levels are generally low, they represent a continuous source of ionizing radiation and play an important role in environmental radioactivity studies (Shahbazi-Gahrouei et al., 2013).

Terrestrial radiation**.** Terrestrial radiation originates from naturally occurring radioactive materials present in rocks, soils, and sediments. The most important radionuclides contributing to terrestrial radiation are uranium-238 (238U), thorium-232 (232Th), and potassium-40 (40K), which have extremely long half-lives and remain detectable in the environment since the formation of the Earth (Eisenbud & Gesell, 1997; UNSCEAR, 2008).

The concentration of these radionuclides varies considerably depending on local geological conditions. Regions rich in granitic rocks, phosphate deposits, or volcanic materials often exhibit elevated levels of natural radioactivity. As a result, radiation exposure may differ significantly between geographical locations (Aliyu & Ramli, 2015).

Building materials derived from natural rocks and minerals may also contain measurable concentrations of radionuclides. Materials such as granite, brick, and concrete can contribute to indoor radiation exposure, although their contribution is generally lower than that of radon in most residential environments (UNSCEAR, 2008; Shahbazi-Gahrouei et al., 2013).

Radon and its decay products. Radon is a naturally occurring radioactive noble gas produced during the decay of uranium-238 in the Earth's crust. The isotope radon-222 is particularly important because of its relatively long half-life and ability to migrate through soil and rock formations into the atmosphere and indoor environments (WHO, 2009; UNSCEAR, 2008).

Because radon is colorless, odorless, and tasteless, its presence cannot be detected without specialized instruments. It can enter buildings through cracks in foundations, construction joints, and other openings in contact with the soil. Poor ventilation may lead to the accumulation of radon indoors, increasing the radiation dose received by occupants (WHO, 2009).

Radon and its short-lived decay products are considered the largest contributors to natural radiation exposure for most populations. Numerous epidemiological studies have demonstrated a positive association between long-term radon exposure and the risk of lung cancer, making radon a major public health concern worldwide (Darby et al., 2005; WHO, 2009).

Internal radiation. Internal radiation results from naturally occurring radionuclides that are incorporated into the human body through food, water, and air. Among the most important naturally occurring radionuclides are potassium-40 (40K) and carbon-14 (14C), both of which are involved in normal biological processes (Eisenbud & Gesell, 1997).

Potassium-40 is naturally present in muscles and soft tissues because potassium is an essential element for cellular function. Similarly, carbon-14 becomes incorporated into living organisms through the carbon cycle and remains present throughout life. These radionuclides continuously irradiate internal tissues, contributing to the natural radiation dose received by humans (UNSCEAR, 2008).

Although internal radiation is unavoidable, the radiation doses associated with naturally occurring radionuclides in the body are generally low and fall within the range considered normal for human populations. Nevertheless, they represent an important component of total natural background radiation exposure (Shahbazi-Gahrouei et al., 2013).

Geographical Distribution of Natural Background Radiation. Natural background radiation is not uniformly distributed across the Earth's surface. Significant variations occur due to differences in geological formations, altitude, climate, and environmental characteristics. As a result, populations living in different regions may experience substantially different levels of radiation exposure (Aliyu & Ramli, 2015).

Several regions of the world are recognized as High Natural Background Radiation Areas (HNBRAs). Notable examples include Ramsar in Iran, Guarapari in Brazil, Kerala in India, and Yangjiang in China. In these areas, natural radiation levels may exceed the global average by several times because of elevated concentrations of naturally occurring radionuclides in local geological formations (Aliyu & Ramli, 2015).

The existence of High Natural Background Radiation Areas (HNBRAs) has attracted considerable scientific interest because these regions provide opportunities to investigate the long-term effects of chronic low-dose radiation exposure in human populations. Studies conducted in such areas have contributed significantly to radiation biology and radiological risk assessment (UNSCEAR, 2008; Aliyu & Ramli, 2015).

Variations in natural radiation levels are also influenced by altitude and building characteristics. For example, higher elevations are associated with increased cosmic radiation exposure, while indoor radon concentrations depend on construction materials, ventilation practices, and geological conditions beneath buildings (UNSCEAR, 2008; WHO, 2009).

Geographical Distribution of Natural Background Radiation. Natural background radiation is not uniformly distributed across the Earth's surface. According to UNSCEAR, the global average effective dose from natural sources is approximately 2.4 mSv/year, but this value can vary significantly depending on geological and environmental conditions (UNSCEAR, 2008). Variations are mainly caused by differences in the concentration of naturally occurring radionuclides in soil and rocks, as well as altitude and local climate conditions (Shahbazi-Gahrouei et al., 2013; Budae, 2026; Muntean, 2026).

High natural background radiation areas (HNBRA). Certain regions of the world are known as High Natural Background Radiation Areas (HNBRA), where the population is exposed to significantly higher levels of radiation than the global average. These areas have been extensively studied to understand long-term exposure effects on human populations (Aliyu & Ramli, 2015; UNSCEAR, 2008).

Among the most well-known HNBRA are Ramsar (Iran), Kerala (India), Guarapari (Brazil), and Yangjiang (China). In these regions, the annual effective dose can vary from a few mSv/year up to tens or even hundreds of mSv/year in localized hotspots, depending on the geological composition of the soil and building materials (Restier-Verlet et al., 2025).

Ramsar (Iran). Ramsar is considered one of the highest natural radiation background areas in the world. Elevated radiation levels in this region are mainly caused by radium-rich hot springs, which bring uranium decay products to the surface. These materials contribute to both external gamma radiation and high indoor radon concentrations (Restier-Verlet et al., 2025).

Some local hotspots in Ramsar show very high dose rates compared to global averages, making this area an important case study for understanding long-term exposure to naturally elevated radiation levels (UNSCEAR, 2008).

Kerala (India). The coastal region of Kerala is another well-known HNBRA, where high radiation levels are primarily associated with monazite-rich sands containing thorium-232. These heavy mineral deposits are unevenly distributed along the coastline, leading to significant spatial variation in exposure levels among the population (Shahbazi-Gahrouei et al., 2013).

Studies indicate that although radiation levels are elevated compared to global averages, large-scale epidemiological investigations have not consistently demonstrated a statistically significant increase in radiation-related health effects in exposed populations. This makes such regions important natural laboratories for radiobiological research and radiation risk assessment (Aliyu & Ramli, 2015).

Guarapari (Brazil). Guarapari, located in the state of Espírito Santo in Brazil, is another classical example of a high natural radiation area. The elevated radiation levels are mainly due to monazite sands found in beaches and coastal sediments. These sands contain thorium and uranium, which contribute to both external gamma exposure and internal exposure through environmental pathways (UNSCEAR, 2008).

Radiation levels in some parts of Guarapari are significantly higher than the global average due to the presence of monazite-rich beach sands, although exposure varies depending on location and human activity patterns (UNSCEAR, 2008; Aliyu & Ramli, 2015).

Yangjiang (China). Yangjiang, located in China, is also recognized as a region with elevated natural background radiation. The primary source of radiation in this area is the local soil composition, which contains enhanced concentrations of uranium, thorium, and potassium-40. This results in a higher external gamma dose rate compared to global background levels (UNSCEAR, 2008).

Yangjiang has been included in long-term epidemiological studies investigating possible health effects associated with chronic low-dose radiation exposure (Aliyu & Ramli, 2015).

Factors influencing regional variation. The variation in natural background radiation across different regions is influenced by several key factors. Geological composition plays the most important role, particularly the presence of uranium and thorium-bearing minerals. In addition, altitude influences cosmic radiation exposure, with higher elevations receiving greater doses due to reduced atmospheric shielding (ICRP, 2007).

Human activities, such as the use of local materials in construction, can also increase indoor radiation exposure, particularly through radon accumulation in enclosed spaces. Therefore, both natural and environmental factors contribute to the observed geographical differences in radiation levels worldwide (UNSCEAR, 2008; WHO, 2009).

Biological Effects and Health Impacts of Natural Background Radiation. The interaction between ionizing radiation and biological systems is primarily based on the deposition of energy in tissues, which can lead to ionization of atoms and molecules. According to ICRP, this process may result in direct DNA damage or indirect damage through the formation of reactive oxygen species, potentially leading to cellular dysfunction or mutations (ICRP, 2007).

Mechanisms of radiation interaction with biological tissue. Ionizing radiation can affect biological tissues through two main mechanisms: direct ionization of DNA molecules and indirect effects mediated by water radiolysis. The latter process generates free radicals that can damage cellular structures, including proteins and nucleic acids. Although living organisms possess efficient DNA repair mechanisms, unrepaired or misrepaired damage may contribute to long-term biological effects (UNSCEAR, 2008).

The severity of biological effects depends on radiation dose, dose rate, and the type of radiation involved. Low doses of natural background radiation typically induce minimal immediate biological effects, while higher doses or chronic exposure may increase the probability of stochastic effects such as cancer (ICRP, 2007; UNSCEAR, 2008).

Health effects of chronic low-dose exposure. Natural background radiation is generally considered a form of low-dose chronic exposure. According to UNSCEAR, the average global exposure from natural sources is not sufficient to produce deterministic health effects; however, stochastic effects, particularly cancer risk, remain a theoretical concern (UNSCEAR, 2008).

Epidemiological studies suggest that the relationship between low-dose radiation exposure and cancer risk is consistent with the linear no-threshold (LNT) model, which assumes that any increase in radiation dose, no matter how small, carries a proportional increase in risk. However, this model remains subject to scientific debate, especially at very low exposure levels typical of natural background radiation (ICRP, 2007).

Radon exposure and lung cancer risk. Among all natural radiation sources, radon exposure represents the most significant health risk. Radon gas and its short-lived decay products emit alpha particles, which can cause substantial localized damage to lung tissue when inhaled. Long-term exposure to elevated radon concentrations has been strongly associated with an increased risk of lung cancer in both occupational and residential settings (WHO, 2009).

Large pooled epidemiological studies have confirmed a statistically significant relationship between indoor radon exposure and lung cancer risk, with risk increasing proportionally with cumulative exposure. This has led international health organizations to classify radon as a major public health hazard (WHO, 2009; UNSCEAR, 2008).

Effects observed in high natural background radiation areas. Populations living in high natural background radiation areas (HNBRA), such as Ramsar (Iran), Kerala (India), Guarapari (Brazil), and Yangjiang (China), have been studied extensively to evaluate potential long-term health effects. These studies have generally not shown clear evidence of increased cancer incidence or genetic abnormalities compared to control populations, although interpretations remain complex due to confounding environmental and socioeconomic factors (Aliyu & Ramli, 2015).

The absence of clearly observable adverse health effects in these regions has contributed to ongoing scientific discussions regarding the validity of risk models at low doses. Some researchers suggest the possibility of adaptive biological responses, while others emphasize the limitations of epidemiological sensitivity at low exposure levels (UNSCEAR, 2008).

Radiation protection considerations. Although natural background radiation cannot be eliminated, understanding its biological effects is essential for radiation protection frameworks. International guidelines focus primarily on reducing avoidable exposure, particularly from radon accumulation in indoor environments. Building design, ventilation improvements, and monitoring programs are commonly recommended strategies for minimizing exposure (WHO, 2009; ICRP, 2007).

Overall, natural background radiation represents a continuous but generally low-level exposure that forms part of the baseline environmental conditions under which human biology has evolved (UNSCEAR, 2008).

Conclusions. Natural background radiation represents a ubiquitous and persistent component of the Earth's environment, constituting the dominant source of ionizing radiation exposure for the general population. This review highlights that such radiation originates from multiple natural sources, including cosmic radiation, terrestrial radionuclides, radon and its decay products, and internally incorporated radionuclides, all of which contribute to a continuous, lifelong exposure.

The spatial distribution of natural background radiation is highly heterogeneous and is primarily governed by geological composition, altitude, and environmental conditions. Regions characterized by elevated concentrations of naturally occurring radionuclides, such as high natural background radiation areas, demonstrate that exposure levels can significantly exceed global averages. These environments provide valuable natural laboratories for investigating the long-term biological effects of chronic low-dose radiation exposure, although current epidemiological evidence does not consistently demonstrate clear adverse health outcomes in resident populations.

From a biological perspective, ionizing radiation interacts with living tissues through direct and indirect mechanisms, potentially leading to molecular damage, particularly at the level of DNA. While natural background radiation typically occurs at low dose rates insufficient to induce deterministic effects, the potential for stochastic effects, especially carcinogenesis, remains a subject of ongoing scientific investigation. Among all sources, radon exposure represents the most significant health concern, with strong epidemiological evidence supporting its role in increasing lung cancer risk.

Despite the long-standing presence of natural radiation throughout evolutionary history, uncertainties persist regarding the health implications of chronic low-dose exposure, particularly in relation to the validity of current radiological risk models. Consequently, continued research integrating epidemiological, radiobiological, and environmental data is essential for refining risk assessment frameworks. At the same time, practical radiation protection strategies should focus on mitigating avoidable exposures, especially in indoor environments where radon accumulation can be effectively controlled.

In conclusion, natural background radiation should be regarded not only as an unavoidable environmental factor but also as a critical reference baseline for understanding radiation exposure and its potential health impacts. A comprehensive understanding of its sources, variability, and biological effects remains fundamental for both scientific advancement and the development of evidence-based public health policies.

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