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Radiological evaluation of the use of clay brick and pumice brick as a structural building material

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HIGHLIGHTS

- Radiological comparison of the use of clay and pumice bricks was made.
- The radioactivity in clay and pumice bricks was determined using a gamma-ray spectrometry.
- Radon exhalation rates from brick samples was firstly measured using a radon monitor system.
- The radiation protection index and alpha index were estimated for each brick sample.
- Externally absorbed indoor gamma dose rate and annual effective dose were estimated.

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ABSTRACT

In this study, clay brick (CBRICK) and pumice brick (PBRICK) samples used as structural material in the construction of dwellings, schools, workplaces and factories in Turkey were compared with each other from a radiological viewpoint. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K naturally occurring in CBRICK and PBRICK samples collected from different regions of Turkey were determined by using a gamma-ray spectrometer with a high purity germanium detector (HPGe). The average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in CBRICK and PBRICK samples were found as 35.4 ± 3.3, 37.5 ± 2.4 and 593.7 ± 42.7 Bq kg^{-1} and 81.9 ± 2.5, 65.8 ± 6.0 and 1066.0 ± 46.6 Bq kg^{-1}, respectively. The radon surface exhalation rate (EX_S) and radon mass exhalation rate (EX_M) of CBRICK and PBRICK samples were measured by using an active radon gas analyzer with an accumulation container. The average value of EX_S and EX_M of CBRICK and PBRICK samples found as 45.9 ± 2.9 mBq m^{-2} h^{-1} and 3.7 ± 2.9 mBq kg^{-1} h^{-1} and 100.9 ± 4.7 mBq m^{-2} h^{-1} and 9.9 ± 0.5 mBq kg^{-1} h^{-1}, respectively. Radiological parameters related to external and internal exposure to members of the public such as the radiation protection index, alpha index, and indoor absorbed gamma radiation dose rate and the corresponding annual effective dose from external exposure, annual effective dose from inhalation of radon, and the lifetime cancer risk were estimated for CBRICK and PBRICK samples. The results were compared with each other and with the international recommended limits or criteria. The results reveal that the average values measured and estimated for CBRICK samples are approximately two times lower than those measured and estimated for PBRICK samples. Thus, from the radiological viewpoint, clay brick is preferable to pumice brick as a structural material in the building sector.

1. Introduction

Human beings are exposed to different types of natural ionizing radiation (alpha, beta and gamma) released from natural radioactive sources throughout their lives. This exposure of individuals may vary according to living standards, region and the geographical conditions in which they live. The majority of the ionizing radiation members of the public are exposed to stems from natural radiation. Approximately 85% of the average annual effective radiation dose of 2.8 mSv is due to natural radiation sources (UNSCEAR, 2008). Natural radiation sources are composed of cosmogenic radionuclides formed by the interaction of cosmic particles in the atmosphere and primordial radionuclides in the earth's crust. Building materials originating in the earth's crust, such as clay, pumice, marble, granite, ceramic tile, cement, concrete, gypsum

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and, limestone, contain primordial radionuclides of the uranium (^{238}U), and thorium (^{232}Th) decay series and radioactive potassium (^{40}K). Individuals can be exposed to ionizing radiation emitted from the radionuclides in building materials via two different routes. The first route is to externally expose the whole body to gamma rays emitted from ^{226}Ra, ^{232}Th, and their decay products and ^{40}K. The second route is internal exposure of the human respiratory tract through alpha and beta rays from inhalation of the radioactive radon gas (^{222}Rn, a daughter product of ^{226}Ra in the ^{238}U series) and its short-lived secondary decay products (Abbady, 2006; Turhan, 2009). Therefore, knowledge of the level of natural radioactivity in building materials is important to assess the possible radiological hazards to human health and to develop standards and guidelines for the use and management of these materials (Turhan, 2009).

Clay and pumice brick are commonly used for wall masonry and/or internal partition walls in construction projects in Turkey because of their aesthetic appearance and their performance characteristics, which include high compressive strength, good durability, superior fire and weather resistance, and good heat and sound insulation. Clay brick, which is made from clay mud, kaoline and other raw materials, is produced in diverse classes, types and sizes as fired and non-fired brick. Pumice brick is made from pumice, which is a very porous form of vitrified volcanic rock, sand, cement and aggregate. Pumice brick is increasingly used as a masonry wall unit in Turkey because of its relatively low thermal conductivity. Several studies have recently been performed on the natural radioactivity, physical, chemical and mechanical properties, and production costs of clay and pumice brick samples used in the construction of dwellings, schools and workplaces (Tufail et al., 2007; Al-Hadhrami and Ahmad, 2009; Asghar et al., 2010; Rafique et al., 2011; Damla et al., 2011; Viruthagiri and Ponnarasi, 2011; Ravisankar et al., 2011; Galván-Ruiz and Zaleta-González, 2013; Uyanık et al., 2013; Abass and Karim, 2014; Elhusna and Gunawan, 2014; Léopold et al., 2014; Laaroussi et al., 2014; Turhan et al., 2014; Sutcu, 2015; Kovács et al., 2017). Righi and Bruzzi (2006) surveyed the radon specific exhalation rate, emanation fraction and natural radioactivity of forty-two building materials commonly used in Italian dwellings using the accumulation method, and gamma-ray spectrometer and assessed the radiological hazards caused from use of these building materials. They found that the hazard indexes estimated for several of the materials exceeded the European Commission limit values. Abbady (2006) reported the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in limestone, sand, marble, clay brick, red brick, gypsum, Portland cement and white cement collected from Upper Egypt used in building manufacturing and the radioactive heat production values of these materials. Tufail et al. (2007) and Asghar et al. (2010) reported the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in clay bricks used as building materials in Pakistan and the radiological hazards of the bricks. They reported that the values of the hazard indices estimated for brick samples were below their limit values. Rafique et al. (2011) measured the radon exhalation rate from soil, sand, bricks, and sedimentary samples collected from Azad Kashmir (Pakistan) using nuclear track detector (CR-39). Ravisankar et al. (2011) reported the natural radioactivity mainly due to ^{226}Ra, ^{232}Th and ^{40}K and their daughter products in the clay brick samples used in India and the radiological hazard assessment the use of the clay brick samples. They found that the brick samples may be safely used as construction materials and do not pose significant radiation hazards. Abass and Karim (2014) determined the alpha particles concentrations in clay bricks samples used in Iraq using nuclear track detector (CR-39). Bavernegin et al. (2012) determined the radionuclide contents and the radon exhalation rates from building materials (marble, granite, brick, gypsum, travertine, mosaic and concrete) used in Iran using the radon gas analyzer and gamma-ray spectrometer system. They indicated that the use of these building materials in construction of Ramsar dwellings is considered to be safe for human habitation. Kovács et al. (2017) reported the mass radon exhalation characteristics of the heat-treated manganese clay and the activity concentrations of major naturally occurring radionuclides ^{40}K, ^{226}Ra and ^{232}Th. In Turkey, Damla et al. (2011) studied the distribution of natural radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in brick and roofing tile samples commonly used as building materials in Turkey using gamma spectrometry and assessed the radiation hazard for people living in dwellings made of the materials studied. They pointed out that the brick and roofing tile samples do not pose any significant source of radiation hazard and are safe to be used as building materials. Uyanık et al. (2013) measured the activity concentrations of ^{40}K, ^{238}U and ^{232}Th and air-absorbed radiation rates of soil, raw material heaps, and brick and roof-tile stacks and waste brick heaps collected from the Salihli-Turgutlu area of the western Turkey and assessed radiological risks. They reported that the annual dose rate and radium-equivalent activity values of the brick and roof-tiles were below the level of criteria.

The main purpose of this study is to improve consumer awareness of the fact that in the preference of structural materials, the radioactivity contained in the material is also important, as well as the physical, mechanical and chemical properties and cost of the material. To this end, firstly the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in 26 CBRICK and 26 PBRICK samples collected from manufacturers and building material suppliers in Turkey were determined using a gamma-ray spectrometer with a high purity germanium detector (HPGe). Secondly, the ^{222}Rn surface and mass exhalation rates from CBRICK and PBRICK samples were measured using a continuous active radon monitoring system with an accumulation container. Thirdly, all known radiological parameters for external and internal exposure were estimated for each CBRICK and PBRICK sample to assess the radiological hazards associated with usage of CBRICK and PBRICK samples as structural building materials in Turkey. The estimated values of radiological parameters (radiation protection index, alpha index, indoor absorbed gamma dose rate and the corresponding external annual effective dose from external exposure, internal annual effective dose from inhalation of radon, and excess lifetime cancer risk) were compared with each other and with the international recommended limits or criteria.

These radiological parameters should be used only as screening tools for ready-to-use building materials. Any actual decision on restricting the use of a material should be based on a separate dose assessment. Turkey applies a strict criterion based on a dose in the range 0.3–1 mSv y^{-1} for structural building materials.

2. Materials and method

2.1. Collection and preparation of samples

A total of fifty-two CBRICK and PBRICK samples used as structural building materials in Turkey were collected from manufacturers and building material suppliers. The CBRICK and PBRICK samples brought to the Sample Preparation Laboratory were properly catalogued, marked and coded taking into account the business concerns of the brick manufacturers. Each sample was then crushed into small pieces by a crusher, powdered with the aid of grinding and passed through a sieve in order to obtain a sample with geometry similar to that of the standard calibration source. Each powdered sample was subjected to a drying process in a temperature-controlled furnace at 110 °C for 24 h to remove moisture. The sample was transferred to a 1 L plastic Marinelli container and weighted to determine its net mass. Each sample container was tightly sealed with a lid and then wrapped around the lid with a teflon tape to ensure radon-tight. They were then kept in a laboratory for at least one month to ensure secular equilibrium between ^{226}Ra and its short-lived decay products.

2.2. Determination of activity concentrations in samples

The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in each brick