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Measurements of radioactivity and dose assessments in some building materials in Bitlis, Turkey

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HIGHLIGHTS

- Highest radon concentration and effective radium content was determined in perlite.
- ELRC of the all samples show higher than the world average.
- The absorbed dose rate for all samples was below the permissible level.
- Ahlat-1, perlite and Brick-3 are not safe for use as building materials.

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ABSTRACT

In this study, samples of perlite, pumice and Ahlat stones (Ignimbrite) extracted from mines in Bitlis and samples of other building materials produced in facilities in Bitlis were collected and analyzed. Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in samples of building materials were measured using NaI detector (NaI(Tl)) with an efficiency of 24%. The radon measurements of building material samples were determined using CR-39 nuclear track detectors. ^{226}Ra, ^{232}Th and ^{40}K radioactivity concentrations ranged from (29.6 ± 5.9 to 228.2 ± 38.1 Bq/kg), (10.8 ± 5.4 to 95.5 ± 26.1 Bq/kg) and (249.3 ± 124.7 to 2580.1 ± 266.9 Bq/kg), respectively. Radon concentration, radium equivalent activities, absorbed dose rate, excess lifetime cancer risk and the values of hazard indices were calculated for the measured samples to assess the radiation hazards arising from using those materials in the construction of dwellings. Radon concentration ranged between 89.2 ± 12.0 Bq/m^3 and 1141.0 ± 225.0 Bq/m^3. It was determined that Ra_{eq} values of samples conformed to world standards except for perlite and single samples of brick and Ahlat stone. Calculated values of absorbed dose rate ranged from 81.3 ± 20.5 to 420.6 ± 42.8 nGy/h. ELCR values ranged from $(1.8 \pm 0.3) \times 10^{-3}$ to $(9.0 \pm 1.0) \times 10^{-3}$. All samples had ELCR values higher than the world average. The values of H_{in} and H_{ex} varied from 0.35 ± 0.11 to 1.78 ± 0.18 and from 0.37 ± 0.09 to 1.17 ± 0.13, respectively. The results were compared with standard radioactivity values determined by international organizations and with similar studies. There would be a radiation risk for people living in buildings made of perlite, Ahlat-1 and Brick-3.

1. Introduction

Natural radioactivity is widely spread in the earth's environment and it exists in various geological formation e.g. soils, rocks, plants, water, air and in building materials (Ramassay et al., 2004; Rati et al., 2010). All building materials contain various amounts of natural radioactive nuclides. Materials derived from rock and soil contains mainly natural radionuclides i.e. uranium (^{238}U), thorium (^{232}Th) and potassium (^{40}K). There are also several singly occurring radionuclides; the most important one is ^{40}K because it is a gamma-ray emitter in addition to beta decay sand therefore contributes significantly to the gamma radiation exposure. The members of the radioactive decay chains of ^{232}Th (14%), ^{235}U and ^{238}U (55.8%), along with ^{40}K (13.8%) are responsible for the main contributions to the dose from natural radiation (Bruzzi et al., 1997). In the uranium series, the decay chain segment starting from radium (^{226}Ra) is radiologically the most important and, therefore, reference is often made to radium instead of uranium.

Radon is a naturally occurring radioactive, colorless, odorless gas that is continuously released by natural sources, such as geological formations in soil and construction materials. Radon is considered a noble gas that occurs in several isotopic forms. Only two are found in significant concentrations in the human

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environment: Radon-222 and Radon-220. Radon-222 is a member of the radioactive decay chain of Uranium-238. Radon and its daughters are present in the atmosphere, especially at places where the ventilation is the lowest such as mines (Stranden et al., 1979). The radon concentration inside a room is dependent on the concentration of radium isotopes in the building materials and the porosity of the building materials. The emanation of gaseous radon from the ground is also of importance (Stranden et al., 1979).

Solid state nuclear track detectors (SSNTD) such as CR-39 detectors have widely been accepted and used for large-scale radon, radon dosimetry, neutron dosimetry, etc. (for example, Matiullah et al., 1988, 2005; Matiullah and Khan, 1988; Matiullah and Zaman, 2005).

The assessment of radiological risk related to inhalation of radon and radon progeny is based mainly on the integrated measurements of radon (Ramola and Choubey, 2003). The radiological impact caused by nuclides is due to radiation exposure of the body by the gamma rays and irradiation of the lung tissues from inhalation of radon and its progeny. Therefore, keeping in view the natural risk, it is necessary to know the dose limits of public exposure (Nain et al., 2006). Internal exposures due to the intake of naturally occurring short-lived daughter products of ^{222}Rn (^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po) in the indoor environment can pose a significant risk to human health (Maher et al., 1987).

Building materials contribute to environmental radioactivity in two ways. First, by gamma-radiation, mainly from ^{226}Ra, ^{232}Th, ^{40}K and their progenies to a whole body dose and in some cases by beta radiation to ask in dose, and second by radon exhalation to an internal dose exposure due to the deposition of radon decay products in the human respiratory tract (Faheem et al., 2008). Elevated dose rates indoors may arise from high activities of natural radionuclides in building materials.

The radioactivity levels of various building materials including bricks, cement, red clay bricks, marble and granite have been measured in different parts of the world (Stoulos et al., 2003; Turhan et al., 2007; Baykara et al., 2011; Shoeib and Thabayneh, 2014, etc.).

Pumice is a light-colored natural sponge-like material of volcanic origin composed of 60–75% SiO_2, 13–17% Al_2O_3, 1–3% Fe_2O_3, 1–2% CaO, 7–8% Na_2O–K_2O, low TiO_2 and SO_3 content in addition to be used in abrasives, cement, concrete, ceramic and glass industries (Turhan et al., 2007).

Perlite is also an amorphous volcanic glass that has a relatively high water content, typically formed by the hydration of obsidian. It occurs naturally and has the unusual property of greatly expanding when heated sufficiently. It is an industrial mineral and a commercial product useful for its light weight after processing.

Regional name of ignimbrites, Ahlat Stones are pyroclastic flow rocks, composed of volcanic glass, high amount of pumice and a small amount of lithic particles. Flow is under gravity and high temperature. It was stated that, by Ercan et al. (1990) and Aydar et al. (2003), about 100 km^3 volume of pyroclastic material were spreaded from Nemrut volcano; these pyroclastics are ignimbrites having various thicknesses, tuff, trachite, gray-black obsidians.

Assessment of radioactivity levels of materials used in the construction industry is important in order to detect whether people living in buildings are exposed to acceptable levels of radiation and to develop regulations and standards for management and utilization of these materials. For this purpose, building materials are generally measured regarding to ^{226}Ra, ^{232}Th and ^{40}K radionuclide concentrations, radon concentration and Ra equivalent activity values.

In this study the radioactivity and dose assessments in samples of perlite, pumice and Ahlat stone (Ignimbrite) extracted from mines in Bitlis (in the eastern Anatolia region of Turkey) and samples of other building materials produced in facilities in Bitlis were measured. ^{226}Ra, ^{232}Th and ^{40}K radioactivity concentrations, Ra equivalent activity values (Ra_{eq}), radon concentration (C_{Rn}), radon surface and mass exhalation rates (E_s and E_m), effective radium content (EC_{Ra}), external and internal hazard indices (H_{ex} and H_{in}), absorbed dose rates (D) and annual effective dose rates ($ADE_{in,\ out,\ tot}$), alpha and gamma level index (I_α, I_γ) and excess lifetime cancer risk (ELCR) of the above-mentioned materials were determined.

The results were compared with standard radioactivity values determined by international organizations and with similar studies.

2. Experimental methods

2.1. Sampling and sample preparation

Samples were taken from perlite, pumice, Ahlat stones (Ahlat-1, Ahlat-2, Ahlat-3 and Ahlat-4) and brick materials (Brick-1, Brick-2 and Brick-3). Samples Brick-1, Brick-2 and Brick-3 were $25 \times 20 \times 40$ cm. Brick samples were produced in a construction material facility in Bitlis. Bricks with a volume of 2 m^3 were prepared by using 1800 kg pumice, 260 kg cement and 130 L water. A small amount of perlite was also used to prepare the samples. However, perlite contents in each of the three kinds of samples were not exactly known. Perlite, pumice and Ahlat stones samples were obtained from mines in Bitlis, in the East Anatolian Region of Turkey (Fig. 1).

The samples described above were brought to the laboratory to measure natural radioactivity levels. They were dried in a drying stove at 105 °C for 24 h until all water in samples was evaporated. After the drying process, samples were pulverized and 90 μm powder pieces were obtained. Each sample was transferred to tared planchettes with 11.4 cm^2 active spaces without exceeding 5 mg/cm^2 specific weight. Distilled water was added to samples in the planchettes and then dried. Samples were adhered to planchettes by the drying process. By this way, samples were made ready for radionuclide concentration measurements.

2.2. Gamma-ray measurements

A gamma spectrometry system was used for measurements of radionuclide concentrations of the samples. Gamma-spectrometry was performed with a commercially available 2″ × 2″ NaI (Tl) well-type detector, in a 3.5 cm thick cylindrical lead shield.

Energy calibration was performed with ^{60}Co (1 μCi) and ^{226}Ra (10 μCi) point sources. The detector has an energy resolution of about 7.6% at 662 keV of ^{137}Cs. The photopeak at 1.460 MeV was used for the measurement of ^{40}K while those at 1.760 MeV peak from ^{214}Bi and 2.614 MeV from ^{208}Tl were used for the measurement of ^{226}Ra (^{238}U) and ^{232}Th, respectively. Background activities were obtained without samples for ^{238}U (^{214}Bi) energies at 609.3 keV were 0.0025 counts/s (Baykara et.al., 2007). The calibration efficiency of the detector was set at 24%. The count time for each sample was 3000 s. Each sample was counted three times and the average calculated. The specific activities (A_s) were calculated according to Eq. (1).

$$A_S(\mathrm{Bq/kg}) = \frac{C}{\epsilon \times P_\gamma \times M_S} \tag{1}$$

where C is the net gamma counting rate per second (the net gamma counting rate is obtained by subtracting the background counting rate from gamma counting rate per second), ε is the detectors efficiency of the specific γ -ray, P_γ is the absolute transition probability of γ-decay and M_s is the mass of the sample (kg)