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Natural radioactivity and radiological hazards of some building materials of Aden, Yemen

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ABSTRACT

Common building materials collected from Aden, Yemen were analyzed for the natural radioactivity of ^{226}Ra, ^{232}Th and ^{40}K using gamma-ray spectroscopy. The average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the studied building materials range from 20.78 to 68.6, from 15.48 to 95.08 and from 116.7 to 2636.68 Bq kg^{-1}, respectively. The measured activity concentrations for these radionuclides were compared with chemical data obtained by XRF analysis and with the reported data of other countries and compared also with the worldwide average activities. The radium equivalent activities of the studied samples that range from 69 to 369.3 Bq kg^{-1} are below the internationally accepted values (370 Bq kg^{-1}), except those of Hapach hard rock (407.6 Bq kg^{-1}). The external and internal hazard indices that range from 0.2 to 1.1 and from 0.3 to 1.3, respectively, of all analyzed building materials are less than unity, except those of Hapach hard rock ($H_{ex} = 1.1$ and $H_{in} = 1.3$) and hard rock of Crater ($H_{in} = 1.2$). The mean values of indoor absorbed dose rate for all building materials range from 30.7 to 199.8 nGy h^{-1} except those for cement, macadam, hard rock of Habaylin and hard rock of Abyan which are higher than the world population-weighted average of 59 nGy h^{-1} and the total annual effective dose values of building materials that range from 0.15 to 0.98 mSv y^{-1} are lower than 1 mSv y^{-1} except for the samples of Hapach hard rock (0.98 mSv y^{-1}) which have the closed value (the limit of accepted value (1 mSv y^{-1}) reported in the UNSCEAR (2000)). The study shows that the measured radioactivity for building materials does not pose as significant source of radiation hazard and is safe for use in the construction of dwellings, while when using Hapach hard rock and hard rock of Crater for construction, their natural radioactivity level should be monitored.

1. Introduction

The human population is always exposed to ionizing radiation due to background radiation. Besides man-made radiation, the main source of background radiation is natural radioactivity. Terrestrial radiation arises from radioisotopes whose half-lives are comparable to the age of the earth and from the decay products of those long-lived isotopes. These radionuclides of ^{226}Ra, ^{232}Th and ^{40}K can be found almost in all types of rocks, sand, cement and gypsum from which building materials are produced. As natural radiation is the largest contributor to the external dose of the human body, it is important to assess the gamma radiation dose from natural sources (UNSCEAR, 1988). Buildings are very important in human life as most of the lifetime is spent (about 80%) at home and/or office. The main source of indoor gamma radiation is building materials besides terrestrial and cosmic radiations. Measuring the radioactivity of building materials will enable us to assess any possible radiological hazard to human health (Mavi and Akkurt, 2010).

All building raw materials and products derived from rock and soil contain various amounts of mainly natural radionuclides of the uranium (^{238}U) and thorium (^{232}Th) series and the radioactive isotope of potassium (^{40}K). In the ^{238}U series, the decay chain segment starting from radium (^{226}Ra) has radiologically the most important effects and, therefore, reference is often made to ^{226}Ra instead of ^{238}U. These radionuclides are sources of the external and the internal radiation exposures for dwellings. The external exposure is caused by direct gamma radiation while the inhalation of radioactive inert gases is radon (^{222}Rn, a daughter product of ^{226}Ra) and thoron (^{220}Rn, a daughter product of ^{224}Ra), and their short-lived secondary products lead to the internal exposure of the respiratory tract to alpha particles. The specific activities of ^{226}Ra, ^{232}Th and ^{40}K in the building raw materials and products mainly depend on geological and geographical conditions as well as geochemical characteristics of those materials (UNSCEAR, 1993).

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The main objective of the present work is to determine the activity concentration of natural radionuclides in fifty three samples of building materials that are used commonly in Aden of south Yemen using gamma ray spectrometry. To assess the potential radiological hazards associated with the usage of building materials by computing the radium equivalent activity, the external and internal hazard indices, the indoor absorbed dose rate and the annual effective dose are calculated. The results obtained in the present study are compared with the recommended values and results from other countries.

2. Experimental method

2.1. Sampling and sample preparation

Fifty three samples of cement, cement block, red bricks, sand, macadam, hard rocks and pumice (used to make lightweight building materials such as concrete and concrete block and for plastering the buildings made of bricks) that are commonly used as building materials in Aden City were randomly collected from local supplies, quarries and construction sites to study their radionuclide concentration. Samples with large grain size were crushed and milled to a fine powder with a particle size less than 1 mm, except for cement and sand samples. Each sample was dried at 110 °C for 24 h to ensure that any significant moisture was removed from the samples (Mavi and Akkurt, 2010).

Typically, 250 cm^3 of each sample was placed in plastic containers at dimensions of 55 mm in diameter and 75 mm in height. The samples were weighed and stored for a minimum period of one month to allow daughter products to come into radioactive equilibrium with their parents ^{226}Ra and ^{232}Th.

2.2. Detector calibration

Each sample was measured with a gamma-ray spectrometer consisting of a NaI(Tl) setup and multichannel analyzer 8192 channel, with the following specification: resolution full width maximum half (FWMH) at 661.6 keV ^{137}Cs (i.e., it is about 40 keV) and about 60 keV for the photopeak of ^{60}Co at 1332 keV. The detector is shielded in a chamber of two layers starting with stainless steel (10 mm thick) and lead (30 mm thick). This shield serves to reduce different background radioactivities.

The spectrometer was calibrated for efficiency and energy using multi-nuclide standard solution (QCY 48) PTB (Germany) (a mixed source containing ^{241}Am, ^{57}Co, ^{60}Co, ^{85}Sr, ^{88}Y, ^{109}Cd, ^{137}Cs, ^{139}Ce and ^{203}Hg).

^{226}Ra activity of the samples was determined via its daughters (^{214}Pb and ^{214}Bi) through the intensity of the 351.93 keV, for ^{214}Pb and 609.31; 1120 and 1764.49 keV, for ^{214}Bi gamma-line. ^{232}Th activity of the sample was determined from the daughters (^{228}Ac), (^{212}Pb) and (^{208}Tl) through the intensity of 911.2 keV gamma-line for (^{228}Ac), (^{212}Pb) emissions at 238.63 keV and (^{208}Tl) emission at 2614 keV gamma-line. ^{40}K activity was determined from the 1460.7 keV emission gamma-line. The samples were counted for 12–24 h depending on the concentration of the radionuclides.

The activity concentrations for the natural radionuclides in the measured samples were computed using the following relation (IAEA, 1989).

$$A_{EI} = NP/t_c \times I_\gamma\left(E_\gamma\right) \times \varepsilon\left(E_\gamma\right) \times M\left(\mathrm{Bq\ \ kg}^{-1}\right) \tag{1}$$

where NP is the number of counts in a given peak area corrected for background peaks of a peak at energy E, $\varepsilon(E_\gamma)$ is the detection efficiency at energy E, t is the counting lifetime, $I_\gamma(E_\gamma)$ is the number of gamma rays per disintegration of this nuclide at energy E, and M is the mass in kg of the measured sample.

2.3. Calculation of the radiological parameters

Because the radiation exposure to the population can be increased appreciably by the use of building materials containing natural radioactivity, therefore it is very important to assess the radiological risks of building materials. The most widely used radiation hazard index is called the radium equivalent activity (Ra_{eq}). The radium equivalent activity is a weighted sum of activities of the ^{226}Ra. ^{232}Th and ^{40}K radionuclides based on the assumption that 370 Bq kg^{-1} of ^{226}Ra, 259 Bq kg^{-1} of ^{232}Th and 4810 Bq kg^{-1} of ^{40}K produce the same gamma ray dose rate (Krisiuk et al., 1971). Radium equivalent activity can be calculated from the following relation suggested by Beretka and Mathew (1985).

$$Ra_{eq} = A_{Ra} + (A_{Th} \times 1.43) + (A_K \times 0.077) \tag{2}$$

where A_{Ra} is the activity concentration of ^{226}Ra in Bq kg^{-1}, A_{Th} is the activity concentration of ^{232}Th in Bq kg^{-1} and A_K is the activity concentration of ^{40}K in Bq kg^{-1}.

For limiting the radiation dose from building materials to 1.5 mGr y^{-1} Krieger (1981) proposed the following conservative model based on infinitely thick walls without windows and doors to serve as a criterion for calculating the external hazard index (H_{ex}). This criterion considers only the external exposure due to the emitted gamma-ray and corresponds to a maximum Ra_{eq} of 370 Bq kg^{-1} for the materials. The value of this index must be less than unity for the radiation hazard to be negligible.

$$H_{ex} = A_{Ra}/370 + A_{Th}/259 + A_K/4810 \leq 1 \tag{3}$$

where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively. The calculated average external hazard index was found to be less than unity.

Internal exposure arises from the intake of terrestrial radionuclides by inhalation and ingestion. Doses by inhalation result from the presence in air of dust particles containing radionuclides of the ^{238}U and ^{232}Th decay chains. The dominant components of inhalation exposure are the short-lived decay products of radon (^{222}Rn). In addition to the external hazard, radon and its short-lived products are also hazardous to the respiratory organs. To assess the internal exposure to ^{222}Ra gas and its daughter products the internal hazard index has been defined by Beretka and Mathew (1985) as:

$$H_{in} = A_{Ra}/185 + A_{Th}/259 + A_K/4810 \leq 1 \tag{4}$$

where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively. For the safe use of a material in the construction of dwelling, H_{in} should be less than unity.

The total air absorbed dose rate (nGy h^{-1}) due to the mean activity concentrations of ^{238}U, ^{232}Th and ^{40}K (Bq kg^{-1}) can be calculated using the formula of Beck et al. (1972) and UNSCEAR (1988).

$$D = 0.462\ A_{Ra} + 0.604\ A_{Th} + 0.042\ A_K \tag{5}$$

where: A_{Ra}, A_{Th} and A_K are the mean activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively, in Bq kg^{-1}.

Beck et al. (1972) derived this equation for calculating the absorbed dose rate in air at a height of 1.0 m above the ground from measured radionuclide concentrations in environmental materials.

In addition, the annual effective dose rate indoors (E) (measured in μSv y^{-1}) was calculated assuming a value of 0.7 Sv/Gy for the conversion factor from absorbed dose in air to annual effective dose received by adults and a 0.8 factor for the indoor occupancy (UNSCEAR (2000)). The formula used is:

$$E\left(\mu\mathrm{Sv\ \ y}^{-1}\right) = D\left(\mathrm{nGy\ \ h}^{-1}\right) \times 24\ \ \mathrm{h} \times 365.25\ \ \mathrm{d} \times 0.8 \times 0.7\ \ \mathrm{Sv/G\ \ y} \times 10^{-6} \tag{6}$$