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# A Preliminary Indoor Gamma-ray Measurements in Some of the Buildings at Karadeniz Technical University (Trabzon, Turkey) Campus Area

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*Abstract*

Indoor gamma radiation dose rate and natural radionuclide concentrations ($^{238}$U, $^{232}$Th, and $^{40}$K) were measured inside former Geoscience Faculty Buildings of Karadeniz Technical University in Trabzon using a 512-channel portable gamma-ray spectrometer with a sodium iodide during the six-month period. Spectrometry data were collected on all floors for each building. The average radionuclide concentrations of $^{238}$U, $^{232}$Th, $^{40}$K and dose rate in the buildings were found to be about 4.07 ppm, 11.58 ppm, % 1.98 and 79.03 nGy/h for Dean Building, 4.81 ppm, 13.38 ppm, % 2.52 and 94.2 nGy/h for Geophysical Engineering Building, 4.03 ppm, 13.14 ppm, %2.59 and 89.99 nGy/h for Geology Engineering Building, 3.76 ppm, 14.15 ppm, %2.68 and 92.34 nGy/h for Geomatics Engineering Building, respectively. In addition to this, the radiation hazard parameters (absorbed dose in the air, radium equivalent activity, internal hazard index and annual effective dose equivalent) for indoor environment were calculated and then jointly interpreted in order to find out the whether a radiological hazard exists in these buildings. As a result from this study, there is no significant radiologic hazard for human in studied buildings.

*Keywords:* Gamma-ray spectrometer, Uranium, Thorium, Potassium, Indoor radiation level, Radiation hazard parameters.

## *1. Introduction*

Earth has a radioactivity since its existence. Radionuclides (radioactive elements) found in nature can be divided into three categories RAVISANKAR *et al.* (2012): The first one is called as primordial (terrestrial) radionuclides, which are naturally occurred in the Earth's crust since creation of the Earth. The second is cosmogenic radionuclides formed as a result of cosmic-rays from space includes energetic protons, electrons, gamma ray, and x-ray. And the last one is human produced radionuclides enhanced or formed due to human actions.

Natural radionuclides are the components of the Earth. These are widely spread in Earth's environment and exist in soil, sediment, water, building materials, plants and air. They are even found in the human body. There is nowhere on the Earth that one cannot find natural radioactivity. Radionuclides are unstable atoms that undergo spontaneous nuclear transformations and release excess energy in the form of ionizing radiation. The majority of human exposure to ionizing radiation occurs from natural sources (i.e. cosmic rays and terrestrial radiation) UNSCEAR (2000). Gamma rays as an electromagnetic ray often accompany the emission of alpha or beta particles from a nucleus. Gamma ray accounts for the majority of external human exposure to radiation from all source types due to its high penetration ability (ATSDR 1999; AL-SALEH 2007). Physical and chemical processes occurring following the radiation exposure involve successive changes at the molecular, cellular, tissue and whole body levels that may lead to a wide range of health effects varying from simple irritation, radiation-induced cancer, and hereditary disorders to immediate death (ATSDR 1999). Indoor exposure to gamma rays is often greater than outdoor exposure if earth materials are used as construction materials (HAZRATI *et al.* 2010).

All building materials such as concrete, brick, sand, aggregate, marble, granite, limestone, gypsum, etc., contain mainly natural radionuclides, including uranium ($^{238}$U) and Thorium ($^{232}$Th) and their decay products, and the radioactive potassium ($^{40}$K). The knowledge of the natural radioactivity of building materials is important for the determination of population exposure to radiations, as most of the residents spend about 80% of their time indoors. Building materials contribute to natural radiation exposure in two ways. First, by gamma radiation, from $^{40}$K, $^{238}$U, $^{232}$Th, and their decay products to an external whole body dose exposure and secondly by radon exhalation to an internal dose exposure due to deposition of radon decay products in the human respiratory tract (STOULOS *et al.* 2003).

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During the last decades, there has been an increasing interest in the study of radioactivity in various building materials, and in-situ determination of indoor and outdoor radiation levels and their main effects on living environment (KUMAR *et al.* 2003; AHMAD and MATIULLAH HUSSAIN 1988; AMRANI and TAHTAT 2001; BERETKA and MATHEW, 1985; CHONG and AHMAD 1982; MOLLAH *et al.* 1986; VIRESHKUMAR *et al.* 1999; ZAIDI *et al.* 1999; EL-ARABI 2005; EL-TAHAWY and HIGGY 1995; KHAN *et al.* 2002; MCAULAY and MORAN 1988; ALI *et al.* 1996; STOULOS *et al.* 2003; TUFAIL *et al.* 2007, BALCIOĞLU and APAYDIN 2013, ÇINAR *et al.* 2013).

Indoor gamma exposure measurements-related studies have mainly been carried out using Gamma-ray spectrometry and HPGe detector by various authors (CLOUVAS *et al.* 2001; BALDASSARRE and SPIZZICO 2002; CLOUVAS *et al.* 2004; XINWEI and XIAOLAN 2006; BRAHMANANDHAN *et al.* 2007; MAVI and AKKURT 2010; MEHRA *et al.* 2010; MEHDIZADEH *et al.* 2011; CEVIK *et al.* 2011; DAMLA *et al.* 2012; QUARTO *et al.* 2013). Soil-originated bricks and roof-tiles and their raw material in the Salihli-Turgutlu area were tested in situ for natural radiation levels using a gamma-ray spectrometer by UYANIK *et al.* (2013). DAMLA *et al.* (2011) measured the natural radioactivity of the bricks and roofing tiles in the seven region of the Turkey. CELIK *et al.* (2010) determined radioactivity levels in Ordu soil and building materials using gamma-ray spectrometry. As a result of this study, calculated all hazard parameters were found to be within the acceptable limits.

The main aim of this work is to measure indoor concentration levels (indoor gamma exposure) of naturally occurred $^{40}$K, $^{238}$U and $^{232}$Th in former Geoscience Faculty Buildings of Karadeniz Technical University using the 512-channel (NaI) gamma-ray spectrometer. Moreover, using obtained data, it is mainly aimed to calculate radiological hazard parameters such as the absorbed gamma dose rate in the air at 1 m above the ground level, annual effective dose, radium equivalent activity, and internal hazard index. Also, radionuclide concentrations that could be measured inside of buildings are graphed in order to show variations on the natural radiation level. Apart from these, all the calculated parameters are compared with the worldwide acceptable values in order to assess the possible radiological risks for human health in the studied buildings.

## 2. *Materials and Method*

In order to obtain the radiometric data for this study, indoor gamma exposure measurements were carried out, using the 512-channel (NaI) portable gamma-ray spectrometer (GF Instrument) (Figure 1), in the former Geoscience Faculty Buildings (Geophysical Engineering, Geology Engineering, Geomatics Engineering Departments and Engineering Faculty Dean Building).

Gamma-ray spectrometer was delivered with a factory calibration set to high-volume standards. To create a new user calibration, the probe is placed at the middle of the calibration pad. Concentrations of the calibration pad corrected by the geometrical factor (i.e. multiplied by the geometrical factor value). Geometrical factor G = 1-h/r, where h is the height of the middle of the detector above the pad (the value is given in the description of the probes) and r is the diameter of the pad. The recommended time for recalibration is 3–5 years (For more detailed information see IAEA 2003) (GF INSTRUMENTS 2009). The total energy window of instrument was set from 100 keV to 3.00 MeV. One channel is equal to 5,877 keV. The 1.76 MeV $^{214}$Bi peaks of the $^{238}$U series were used for the equivalent uranium analysis (eU), whereas equivalent thorium (eTh) was determined from the 2.62 MeV $^{208}$Tl peak of the $^{232}$Th series. The concentration of radioactive potassium was determined directly from 1.46 MeV $^{40}$K (KALYONCUOĞLU 2014).

Indoor gamma exposure measurements were performed in each floor of the buildings during the six-month period from November to April. Time duration of each measurement is about 300 seconds per point.

*Figure 1.* The Gamma-ray spectrometer (NaI detector and control unit)

As a result of the measurements, Potassium (K, %), equivalent Thorium (eTh, ppm), equivalent Uranium (eU, ppm) and dose rate (D, nGy/h) values for each point were obtained.

Measured radionuclide concentrations were converted to the main activity unit (Bq/kg) using an appropriate conversion factor given in Table 1 in order to determine the radiation hazard parameters of each point. After the activity concentrations of radionuclides determined, hazard parameters such as adsorbed dose rate in air, radium equivalent activity, annual effective dose equivalent, and internal hazard index for points inside the building were calculated.

*Table 1*. Conversion factors from equivalent concentration (ppm, %) to activity (Bq/kg) (IAEA 1989)

| | | |
|---|---|---|
| % 1 K | 313 Bq/kg | $^{40}$K |
| eU (1ppm) | 12,35 Bq/kg | $^{238}$U or $^{226}$Ra |
| eTh (1ppm) | 4,06 Bq/kg | $^{232}$Th |

The calculations described below were performed to determine the radiological risk in addition to the measured natural radionuclide concentrations. Gamma dose rate in air, one meter above the ground, is used for the description of terrestrial radiation, and is usually expressed in nGy/h or pGy/h. The absorbed dose rate due to gamma radiation of naturally occurring radionuclide ($^{238}$U, $^{232}$Th, and $^{40}$K), were calculated on guidelines provided by (UNSCEAR 2000).

$$D(nGy/h) = 0.462A_U + 0.621A_{Th} + 0.0417A_K \quad (1)$$

Where 0.462, 0.621 and 0.0417 are the conversion factors for $^{238}$U, $^{232}$Th and $^{40}$K assuming that the contribution natural occurring radionuclide can be neglected as they contribute very little to total dose from environmental background.

To estimate annual effective doses, account must be taken of the conversion coefficient from absorbed dose in air to effective dose and the indoor occupancy factor. The average numerical values of those parameters vary with the age of the population and the climate at the location considered.

In the UNSCEAR 1993 Report, the Committee used 0.7 SvGy/y for the conversion coefficient from absorbed dose in air to effective dose received by adults and 0.8 for the indoor occupancy factor, i.e. the fraction of time spent indoors is 0.8. The annual effective dose is determined as follows: (UNSCEAR 1993).

$$AEDE\ (mSv/y) = D(nGy/h)x8760\ (h/y)x0.8x0.7(SvG/y) \quad (2)$$

To represent the activity levels of $^{238}$U, $^{232}$Th and $^{40}$K which take into account the radiological hazards associated with them, a common radiological index has been introduced. This index is called radium equivalent activity ($Ra_{eq}$) and is mathematically defined by (UNSCEAR 2000).

$$Ra_{eq}(Bq/kg) = A_U + 1.43A_{Th} + 0.077A_K \quad (3)$$

Where $A_U$, $A_{Th}$ and $A_K$ are the specific activities of Uranium, Thorium, and Potassium respectively. This equation is based on the estimation that 10 Bq/kg of $^{238}$U equal 7 Bq/kg of $^{232}$Th and 130 Bq/kg of $^{40}$K produced equal gamma dose. The maximum value of $Ra_{eq}$ must be less than 370 Bq/kg.

To reflect the internal exposure, a widely used hazard index, called the internal hazard index ($H_{in}$), which is defined as following:

$$H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (4)$$

The value of the index must be less than the unity in order to keep the radiation hazard to be insignificant unity corresponds to the upper limit of radiation equivalent activity (370 Bq/kg).

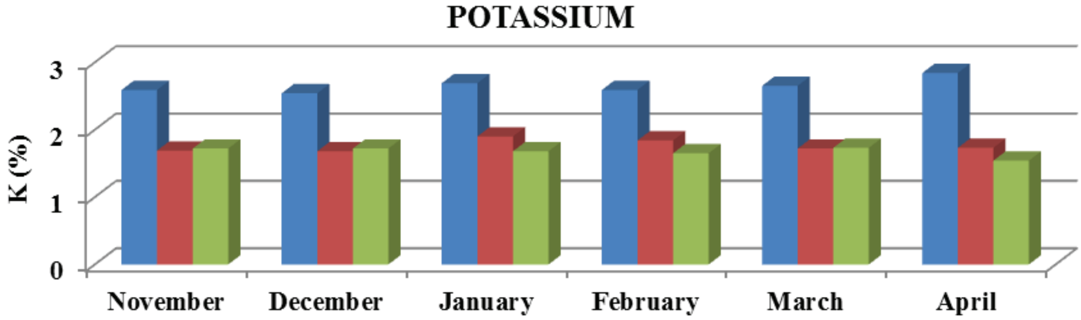
### *3. Result and Discussions*

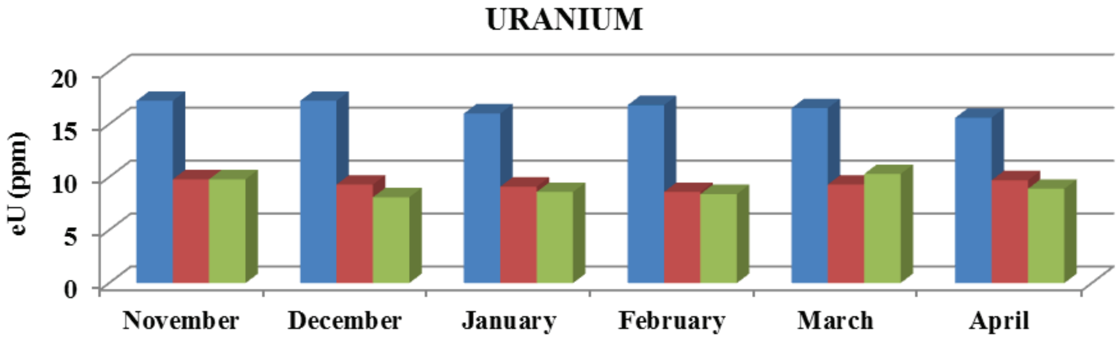
The indoor gamma exposure measurements were performed inside (including all floors) of buildings (Geophysical, Geology, and Geomatics Engineering Departments and Engineering Faculty's Dean Building) during six-month period using portable NaI (Tl) detector in order to determine total gamma dose rates and radionuclide concentrations. Table 2 shows the average values of the $^{238}$U, $^{232}$Th, $^{40}$K concentrations, measured (D) and calculated absorbed dose in air ($D_{absorbed}$), radium equivalent activity ($Ra_{eq}$), internal hazard index ($H_{in}$) and annual effective dose equivalent for indoor environment (AEDE) of buildings.

In general, these buildings are more than thirty years old. They were constructed with bricks, concrete (including sea-gravels as an aggregate) and sea-sands. Accordingly, relative contribution of different natural gamma emitters ($^{238}$U, $^{232}$Th and $^{40}$K) to the gamma dose rate varies from building to building due to the construction materials. Following figures (Figs 2, 3, 4 and 5) show semi-annual radionuclide and dose rate distributions for each building.

*Table 2:* Semi-annual average values for the radionuclide concentrations and the gamma radiation hazard indices for studied buildings (including each floors and entire building).

| | | U (ppm) | Th (ppm) | K (%) | D (nGy/h) | $D_{absorbed}$ (nGy/h) | $Ra_{(eq)}$ (Bq/kg) | $H_{in}$ | AEDE (mSv/y) |
|---|---|---|---|---|---|---|---|---|---|
| **Dean Building** | **Basement floor** | 5,58 | 16,55 | 2,65 | 108,01 | 109,8 | 229,05 | 0,804 | 0,53 |
| | **Ground floor** | 3,3 | 9,3 | 1,76 | 65,35 | 66,23 | 137,24 | 0,48 | 0,32 |
| | **First floor** | 3,33 | 8,9 | 1,54 | 63,75 | 64,47 | 133,92 | 0,47 | 0,31 |
| | **Entire Building** | 4,07 | 11,58 | 1,98 | 79,03 | 80,16 | 166,3 | 0,584 | 0,386 |
| **Geophysical Engineering** | **Basement floor** | 3,83 | 11,93 | 2,29 | 82,05 | 83,41 | 172,11 | 0,59 | 0,409 |
| | **Ground floor** | 5,35 | 14,1 | 2,49 | 98,75 | 99,94 | 208,26 | 0,741 | 0,490 |
| | **First floor** | 5,083 | 13,76 | 2,58 | 97,41 | 98,81 | 205,12 | 0,723 | 0,484 |
| | **Second floor** | 4,98 | 13,75 | 2,745 | 98,81 | 100,40 | 207,64 | 0,727 | 0,492 |
| | **Entire Building** | 4,81 | 13,38 | 2,52 | 94,2 | 95,64 | 198,28 | 0,695 | 0,468 |
| **Geology Engineering** | **Basement floor** | 3,55 | 10,5 | 2,31 | 76,96 | 78,28 | 160,68 | 0,55 | 0,384 |
| | **Ground floor** | 4,05 | 13,85 | 2,67 | 92,75 | 94,76 | 194,93 | 0,661 | 0,464 |
| | **First floor** | 4,12 | 13,41 | 2,675 | 92,083 | 93,99 | 193,32 | 0,659 | 0,461 |
| | **Second floor** | 3,88 | 13,73 | 2,68 | 91,71 | 93,68 | 192,40 | 0,649 | 0,459 |
| | **Third floor** | 4,58 | 14,23 | 2,65 | 96,46 | 98,33 | 203,27 | 0,701 | 0,482 |
| | **Entire Building** | 4,036 | 13,14 | 2,59 | 89,99 | 91,80 | 188,92 | 0,644 | 0,45 |
| **Geomatics Engineering** | **Basement floor** | 4,06 | 14,56 | 2,73 | 95,65 | 97,65 | 200,87 | 0,678 | 0,479 |
| | **Ground floor** | 3,91 | 13,83 | 2,6 | 91,28 | 93,13 | 191,62 | 0,648 | 0,456 |
| | **First floor** | 3,33 | 14,08 | 2,72 | 90,1 | 92,28 | 188,64 | 0,62 | 0,452 |
| | **Entire Building** | 3,76 | 14,15 | 2,68 | 92,34 | 94,35 | 193,71 | 0,648 | 0,462 |





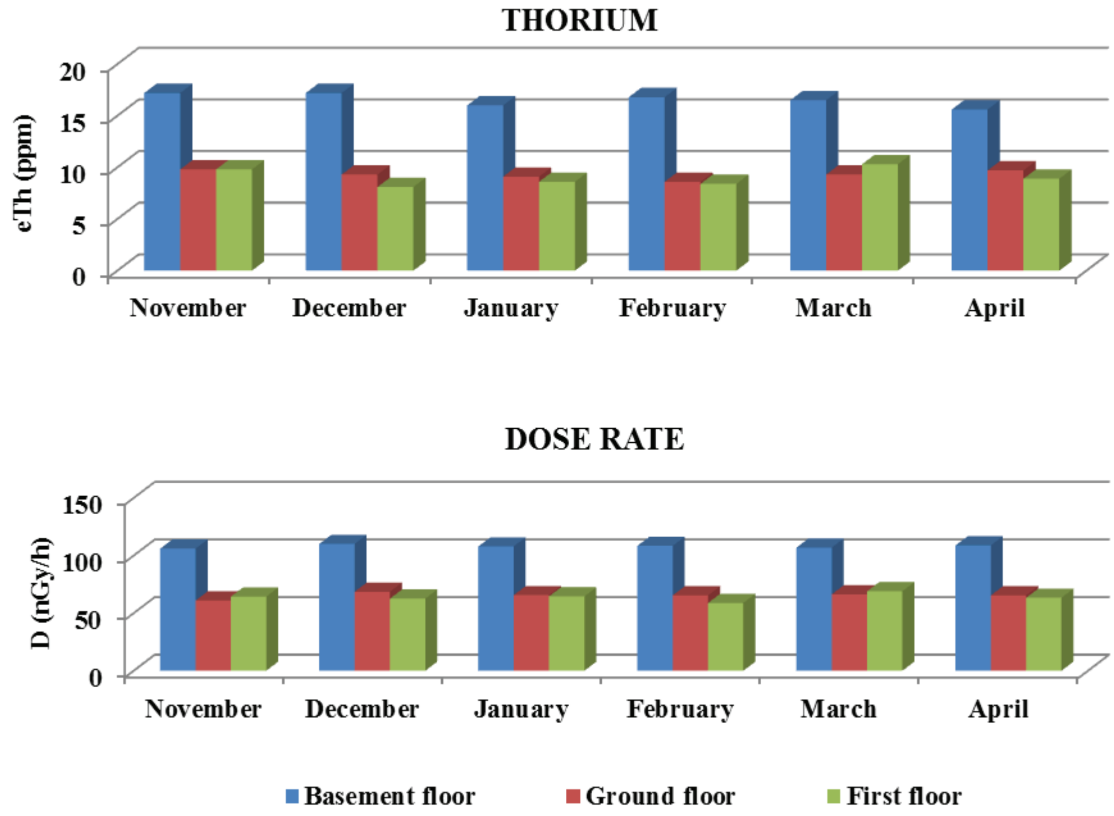
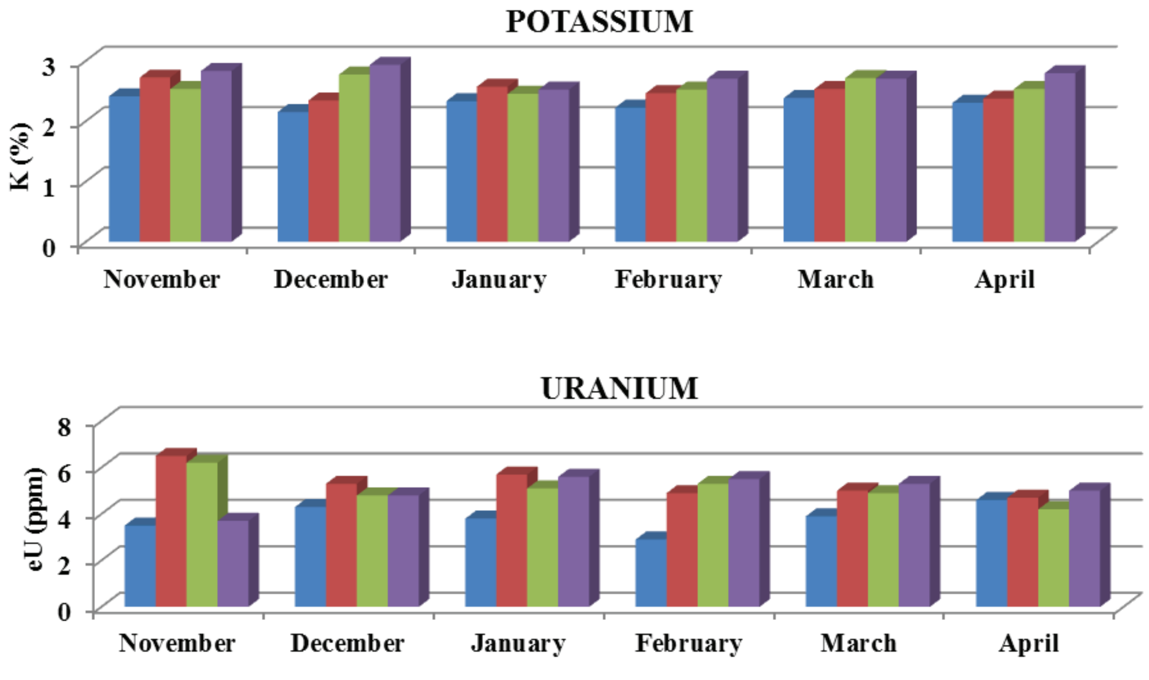


*Figure 2*. Distribution of $^{40}$K, $^{238}$U, $^{232}$Th and dose rate for Engineering Faculty's Dean building.



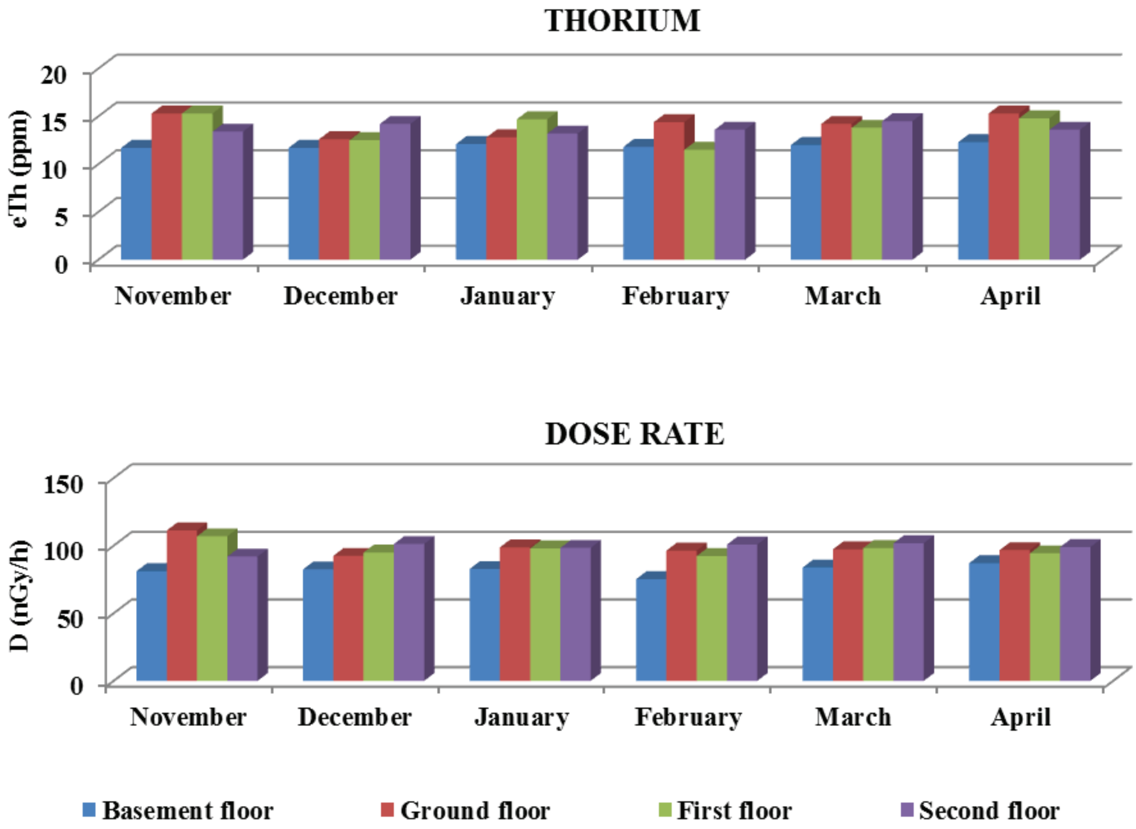
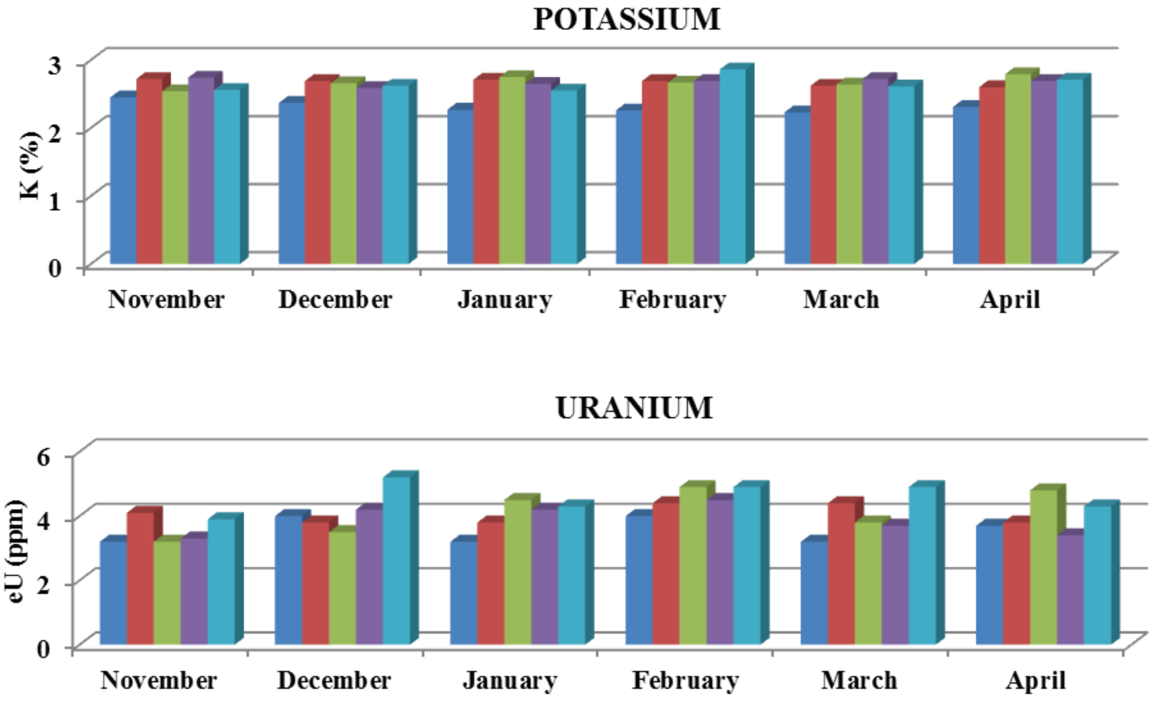


*Figure 3*. Distribution of $^{40}$K, $^{238}$U, $^{232}$Th and dose rate for Geophysical Engineering building.



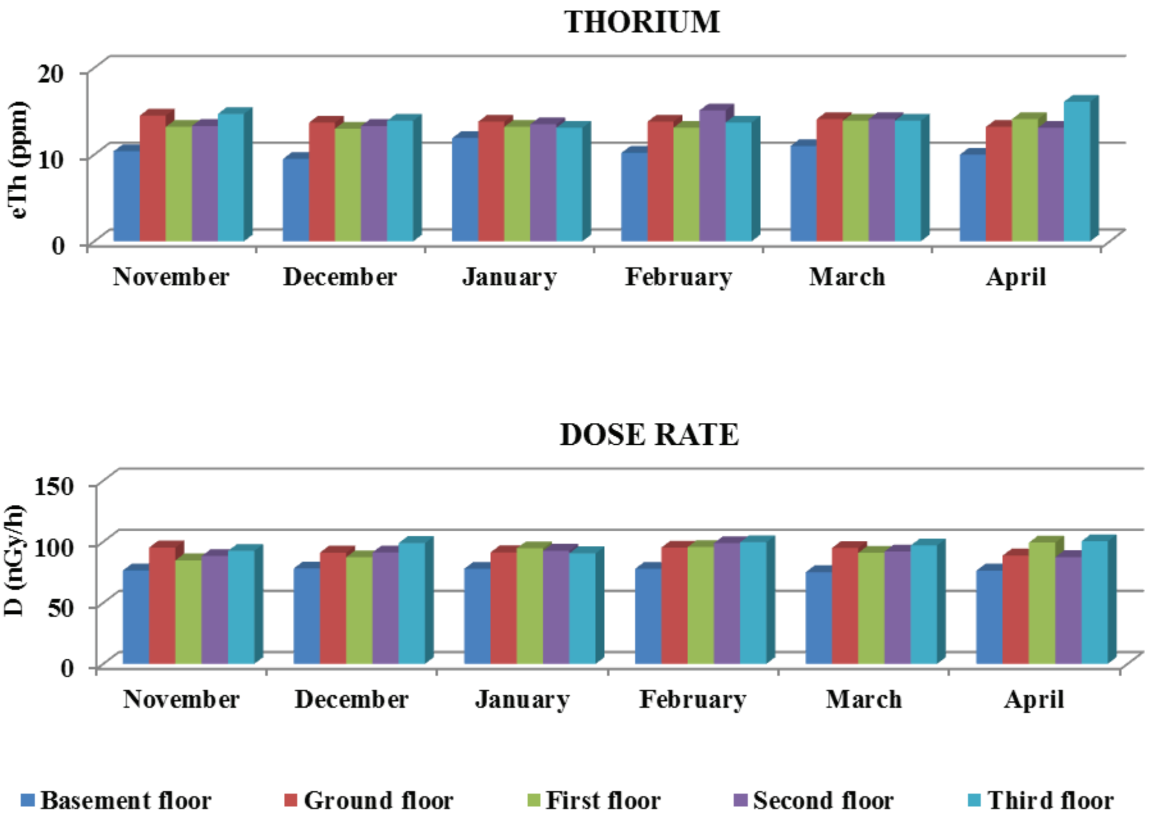
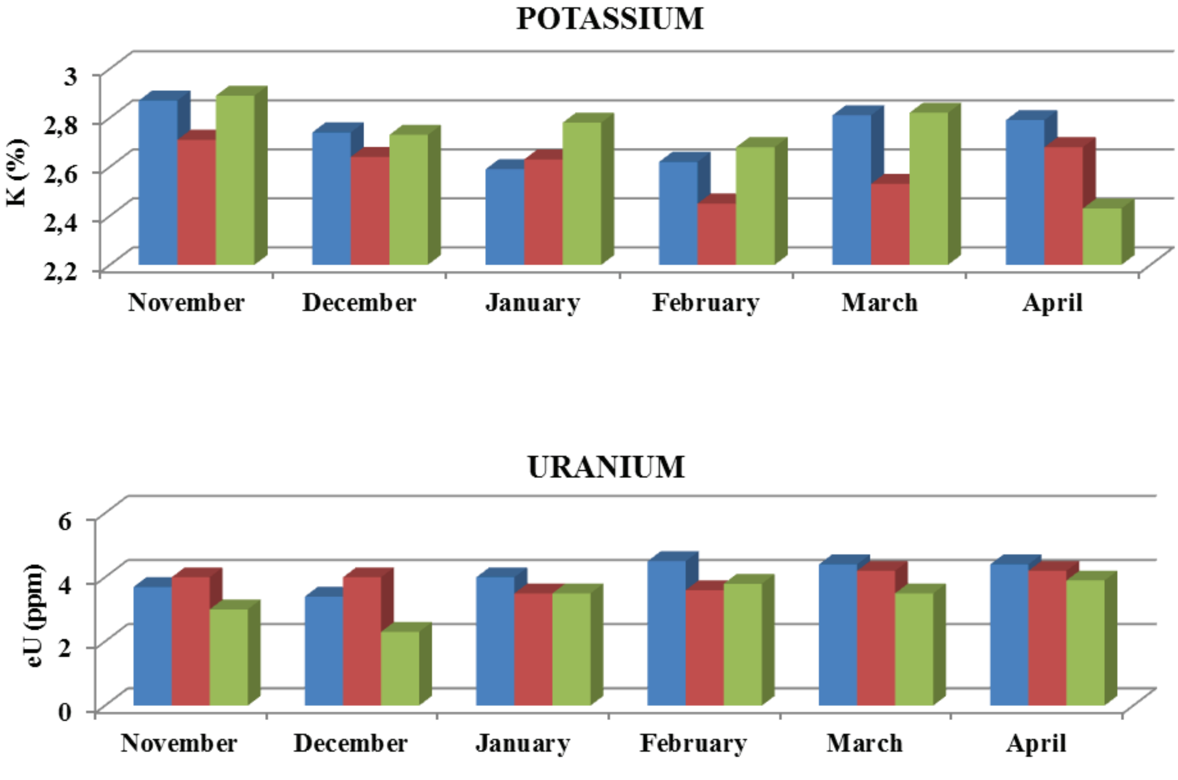


*Figure 4*. Distribution of $^{40}$K, $^{238}$U, $^{232}$Th and dose rate for Geology Engineering building.



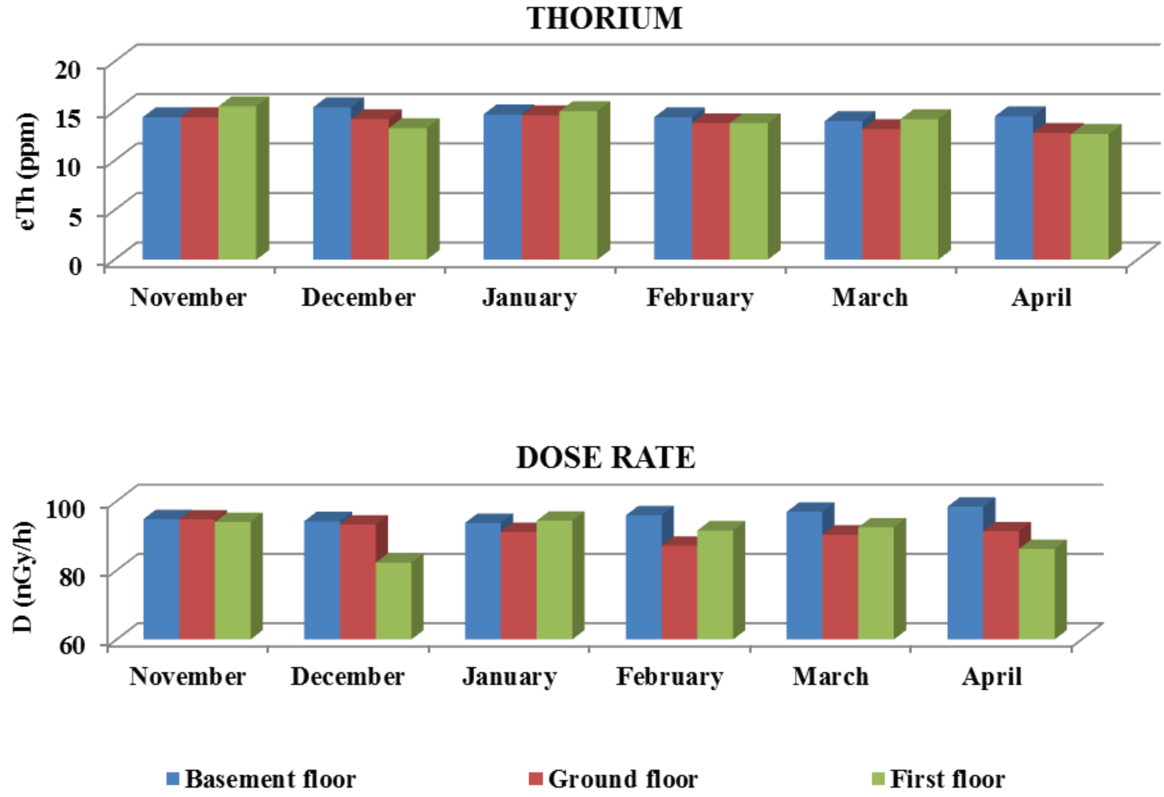


*Figure 5.* Distribution of $^{40}$K, $^{238}$U, $^{232}$Th and dose rate for Geomatics Engineering building.

While higher U concentration (5.9 ppm) was observed in Geophysical Engineering building, the lowest one (2.3 ppm) was in Geomatics building. Lower and higher Th values were measured in Dean Building about 8.1 ppm, and 17.2 ppm, respectively. Higher K value (% 2.93) was measured in Geophysical Engineering building and lowest (% 1.54) was in Dean building. These higher concentration values are originated from different building materials such as sea sand and gravel used for building construction in the past. MAVI and AKKURT (2010) determined radionuclide concentrations ($^{226}$Ra, $^{232}$Th and $^{40}$K) of some building materials such as brick clay, gravel, cement and gypsum. These researchers found that all samples have higher Potassium activity concentration, and brick clay samples have also highest Potassium activity concentration. Furthermore, sea-sands have more Silicon and mafic mineral contents, and they showed high radioactivity value depending mostly on their acidic properties. DAMLA *et al.* (2012) carried out chemical analyses on sand, cement, gas concrete, tile and brick samples using energy dispersive X-ray fluorescence (EDXRF) spectrometer. These researchers found that Silicon dioxide ($SiO_2$) content of sand, cement and bricks samples were to be % 64.6, % 34.7 and % 57.88, respectively. Thus, it could be said that the building materials have higher Silicon content show greater radioactivity values.

On the other hand, the soils which surround the foundation of these buildings are volcanic origin. Leakage of radionuclides from the soil via to micro-cracks exist in buildings increases the measured indoor radiaton level. Furthermore, the concentrations of radionuclides in the air depend on their emanation rate from the soil, meteorological and geographical factors, and on the height above the ground surface. Even though the ventilation rate is higher in summer the higher exhalation rate of radon and thoron (daughter elements of Uranium decay) results in higher contribution to indoor gamma dose rate. The high moisture content in atmosphere, on walls and floor acts as a shield to indoor gamma radiation, which results in lower dose rate in winter (SIVAKUMAR *et al.* 2002). In this study, measurements were carried out in winter and spring, and lower indoor gamma dose rate was observed in winter, and highest one was in spring.

In UNSCEAR (2000), it is reported that median values of $^{238}$U, $^{232}$Th, $^{40}$K activities of 35 Bq/kg, 30 Bq/kg, and 400 Bq/kg, respectively. The world population-weighted average for the indoor gamma dose rate is 89 nGy/h. The mean values of both radionuclide concentration and dose rate for each building are slightly higher than the values given by UNSCEAR (2000).

The radiological hazard parameters calculated for each building are all well below the acceptable limit. The highest absorbed dose rate in air was observed in Geophysical Engineering department, this may be attributed to the higher concentration of uranium and thorium in building materials, and the lowest in Engineering Faculty's Dean Building 112.23 and 59.69 nGy/h, respectively. The results of this study show that the average values of $Ra_{eq}$ obtained for the all buildings are less than recommended value (370 Bq/kg) by UNSCEAR (2000), and this value does not pose a radiological hazard for people who working in these buildings. The mean annual effective dose equivalent for the indoor environment is approximately 1.5 mSv/y ICRP (1993). Our results for the average annual effective dose in all buildings are compatible with the range of worldwide acceptable value. Obtained mean value for each building is less than the acceptable value (≤1). The internal hazard index is less than 1, which means that it is safe for working people in this area.

## *4. Conclusion*

Gamma ray spectrometry method was used to determine the natural radioactivity concentration of $^{40}K$, $^{232}Th$, $^{238}U$ and dose rate values and evaluate the natural radiation level inside the buildings. Radionuclide activity concentrations and dose rates in the buildings are higher than the median values given in the literature. The absorbed dose rates in the air, radium equivalent activities, the internal hazard indices and the annual effective dose rates were calculated from the activity concentrations, and they were compared to the corresponding world median values. All these hazard parameters are found to be lower than recommended value by UNSCEAR. It is concluded that indoor radionuclide level of studied buildings are not dangerous for human health.

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