Effect of Extensive Use of Granite Countertops on the γ-Radiation Dose to Occupants of the New Buildings of King Abdulaziz University

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Abstract

Exposure dose due to γ-radiation was measured in the new buildings of King Abdulaziz University using an advanced car-borne monitoring system to evaluate the effect of the extensive use of granites on the exposure dose rate to occupants. The measurements were conducted inside and outside the new buildings. For comparison, measurements inside the old buildings of limited granite use were conducted. The results indicated that the average exposure dose rate in the corridors of granite countertops was 0.115 µSv/h compared to 0.093 µSv/h in corridors of marble floors in the old buildings. About 4.2% increase in the annual effective dose due granite use was estimated. A maximum excess fatal cancer risk to an individual working in the new buildings due to exposure to excess γ-radiation from granite countertops was estimated by $1.4x10^{-6}$. The obtained results are discussed in detail and some conclusions are drawn.

Keywords: Radiation protection; Dose assessment; Granite; Exposure to γ-radiation; Risk assessment.

1. Introduction

Researchers observed that igneous rocks of granitic composition usually enriched in uranium and thorium, compared to rocks of other composition (UNSCEAR, 2000). However, it is possible for any granite sample to contain varying concentrations of uranium and thorium that producing γ-emitting decay products. These radionuclides could pose potential health risk, especially if they occur in high concentrations (Elless et al., 1997) and used as constructing material. Granite slabs are examples of such constructing materials that containing uranium and thorium beside free silica, and have received a particular attention regarding their potential to emit γ-radiation. Granite countertops with elevated gamma exposure rates of about 1 µGy/hr result in potential γ-radiation doses that are significant fraction of a 1 mSv/y, a basic criterion for the general population (Bernhardt, et al., 2009). On the other hand, granites were early quarried by ancient societies and processed to produce commercial products such as ornaments, monuments and countertops. Granite countertops are widely used in building decoration, due to their durability and decorative appearance.

It is likely that the use of granite countertops in luxury buildings could increase variably the radiation dose above the normal natural background dose that comes from soil and other building materials. A potential health risk to occupants may occur due to the increase in external exposure to γ-radiation from the granite slabs.

Several studies have been achieved to assess the effect of granite use as building material on the radiation dose to occupants of such buildings. Some of these studies concluded that the investigated granites are safe to use as countertops (Darwish, et al., 2015; Chen et al., 2010; Myatt et al., 2010; Llope, 2011; Allen et al., 2013), whereas other studies concluded the opposite (Salas et al., 2006; Al-Saleh and Al Berzan, 2007) and, at most, just recommended some precautions. Owing to the vast range of radiation levels in granite rocks, radiation levels from different granites may reveal higher levels than expected, predominate the need to investigate the used granite depending upon a case-by-case basis.

To evaluate exposure to γ-radiation due to the use of granite countertops in buildings, the contribution from other interfering emissions should be considered. The other interfering emissions come from other sources as the underneath soil, concrete mix and other building materials. Granites are used widely as constructing material in the new buildings of King Abdulaziz University (KAU). Floors and walls (partially or entirely) of most corridors, and floors of office rooms are decorated with granites of different colors. Evaluation of potential increase in radiation doses to occupants of these buildings should be of significant interest.

The prospective of this work was to provide e radiological data to address the knowledge gap about the potential health risk associated with the use of the granite countertops in the KAU new buildings, and to answer the question addressed by the occupants whether granite countertops significantly increase exposure dose rate in the new buildings.

2. Experimental

2.1 Measurement protocol

A series of measurements were designed for characterizing the exposure to γ-radiation due to the use of granite countertops and the associated potential risk quantitatively, to meet the overarching question addressed by the occupants that whether granite countertops are significantly increasing the radiation exposure. The designed measurement protocol was as follows:

1. Conducting indoor and outdoor ground surveys to evaluate the exposure dose rate using the surveying system.
2. Estimating the effective dose rate to occupants, based on the measured dose rate values.
3. Assessment of potential risk to occupants due to radiation exposure dose.
4. The estimates of doses are compared to health-based limits for radiation safety proposed by authoritative organizations charged with protection of public health, as the International Commission on Radiological Protection (ICRP).

2.2 The used building materials

2.2.1 New buildings

In the new buildings, granite is extensively used as countertops in the floors and walls of most corridors, and in the floors of the office rooms (Fig. 1). Cement bricks were used in building the walls. Pink granite was used for wall decoration. White, pink and brown granites were used as countertops on the floors, where white granite was the most predominant, followed by the pink granite. Brown granite is minor. The three types of granites were quarried from adjacent local quarries located in Riyadh area, the central region of Saudi Arabia, and used as countertops (Fig 1).

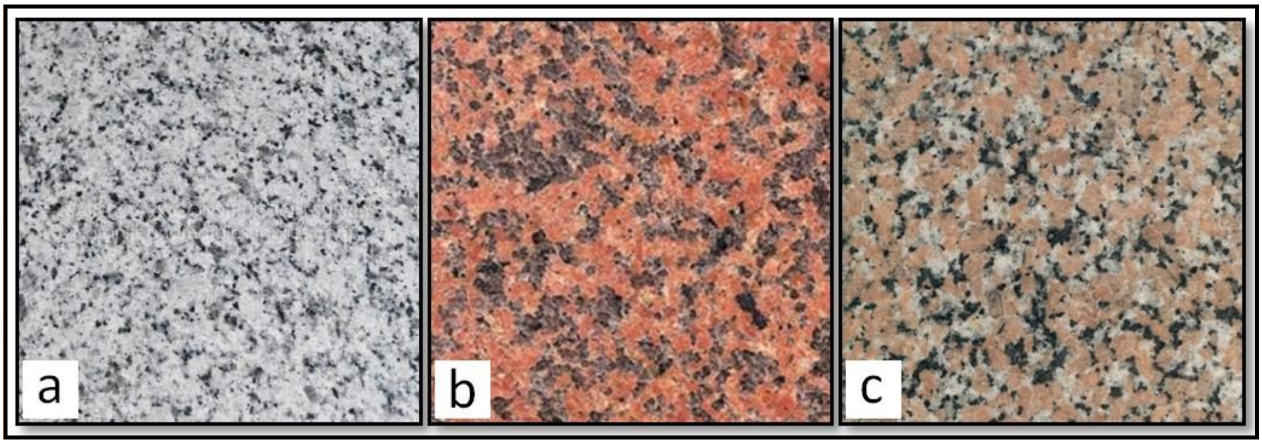

Figure 1. Granite countertops used in corridors and office rooms: a) White granite, b) Pink granite, c) Brown granite.

Unglazed pottery tiles (Fig. 2b) were used in some ground floor laboratories and their corridors, whereas floors of some other laboratories were covered with rubber sheets (Fig 2a). The floors of the open-air terraces were covered with prefabricated colored concrete tiles (Fig. 2c) and some brown granite.

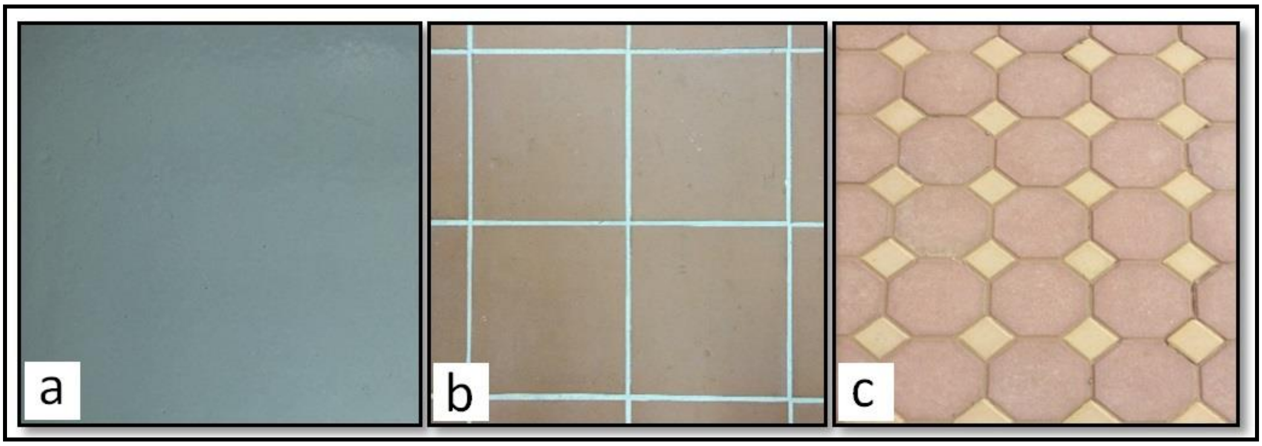

Figure 2. Other used building materials: a) Rubber sheet covering the concrete floor, b) Unglazed pottery tiles, c) Prefabricated colored concrete tiles.

2.2.2 Old buildings

In the old buildings, the floors of the laboratories are covered with either ceramic tiles or thin rubber sheets applied directly on the concrete floor. The floors of the corridors are decorated with Marble slabs. The floors of the office rooms are covered with ceramic tiles. Brown granite slabs were used only on the floors of the main entrances. The source of the old buildings granite is unknown, whereas the brown granite used in the new buildings was quarried from local quarry located in the Riyadh region (Fig. 3).

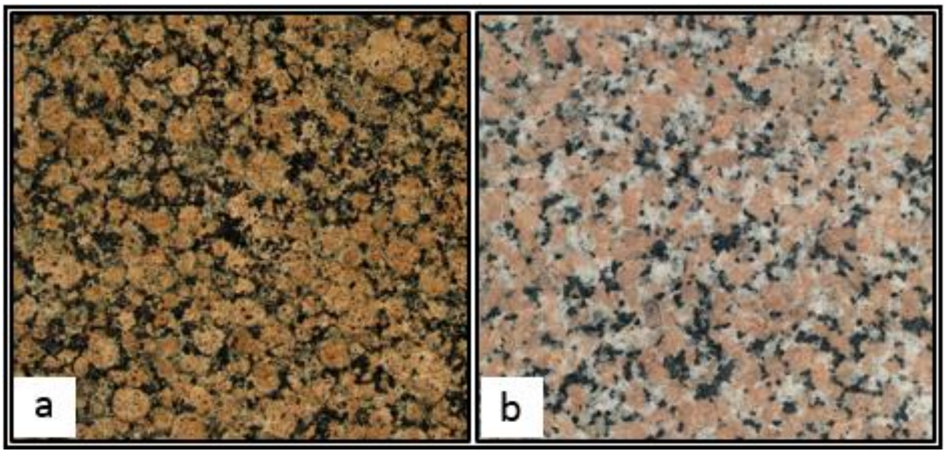

Figure 3. The used brown granite in; a) Old buildings, b) New buildings.

2.3. Equipment

An advanced car-borne movable radiation monitoring system (SPIR-IDENT MOBILE, from MIRION international, France) was used. It is ruggedized and friendly deployable equipment with the higher existing capability for both detection and identification of radiation sources. It has a 2-liter NaI (Tl) detector, which is very sensitive to radiation detection and dose rate measurements. It has a rugged detection case and wireless Tablet PC. The monitoring system has GPS and an immediate mapping capability for the surveyed area. The later function works only in open atmosphere due to the need of the GPS tracking system to connect with the satellite. Under this condition, the exposure dose rate values supposed to be due to terrestrial and cosmic γ-radiation which are reported simultaneously and separately. The movable monitoring system records the exposure dose rate within the car-track of 40 meters width during the car movement. Change in dose rate is due to the influence of lithologic changes within the car track when the car being 50 meters far of the nearest building. The altitude inside KAU campus range from 20 to 42 m because Jeddah city lies in the coastal plain of the Red Sea.

2.4 Quality assurance

For quality control purposes in exposure dose rate measurements, the used surveying system is factory-calibrated and programmed to be ready for direct exposure dose rate measurements.

2.5 Radiation dose measurements

The indoor and outdoor exposure dose rate due to γ-radiation was measured 1 meter above the ground using the car-borne monitoring system. The results were reported for each site as an average and range. The direct indoor measurement values supposed to be due to the terrestrial γ-radiation and radiation comes from the surrounding building materials. The remaining cosmic radiation supposed to be negligible due to wall shielding.

The outdoor measurement values supposed to be due to both terrestrial and cosmic radiation sources, thus, the observed variations in γ-radiation dose rate quantified in the different outdoor locations supposed to be related to variation in surface soil composition, whereas the observed indoor variations supposed to be mainly due to variation in the mix of the surrounding building materials. Cosmic radiation in such small areas is supposed to be uniform. The average outdoor dose value from cosmic rays is estimated by 0.038 μSv/h at Jeddah city that located in the coastal plain at altitude ranging from 10-55 m and lat. 27^o 45'. From the indoor and outdoor measurements and considering the UNSCEAR (2000) report for indoor time fraction (0.8), the annual effective dose for public due to indoor and outdoor exposure to natural γ-radiation was calculated. The exposure time to the measured concentration in the new buildings in hours (assumed to be equal to 8 hours/day and 22 working days/month and 10.5 months/year = 1848 h/y). However, the exposure time fraction to this concentration is estimated by 0.21 and the annual effective dose equals to the measured annual dose corrected the exposure time fraction.

2.6 Risk assessment due to γ-radiation

Although a great uncertainty is found in the literature in applying risk estimates, the fatal cancer risk for the public due to γ-radiation was assessed in this work based on the average annual effective dose to individual and the risk factor 0.05 per Sv, according to ICRP Publication (ICRP, 1990). The average annual effective dose was calculated based on the exposure dose rate and the annual time fraction of exposure to this rate. If 10% of the business time inside the new buildings proposed to be spent in corridors, then the indoor occupancy time fraction (0.8) of occupants of the new buildings will be spent as follows: 0.21 inside the new building (0.021 in the corridor, 0.189 in the office), 0.59 in other traditional buildings (homes, restaurants, markets, etc.). The extra effective dose is related to the difference in the exposure dose rate between traditional buildings (old buildings) and the new buildings of extensive use of granite countertops for decoration corrected to the occupancy time fraction of exposure to the extra dose.

3. Results and discussion

3.1 Exposure dose rate due to γ-radiation

3.1.1 Dose rate outside buildings (background dose rate)

Radiometric surveying, in open air inside KAU campus, has been conducted using the car-borne monitoring system to estimate the exposure dose rate due to terrestrial background γ-radiation. The background radiation levels are shown in Fig. 4.

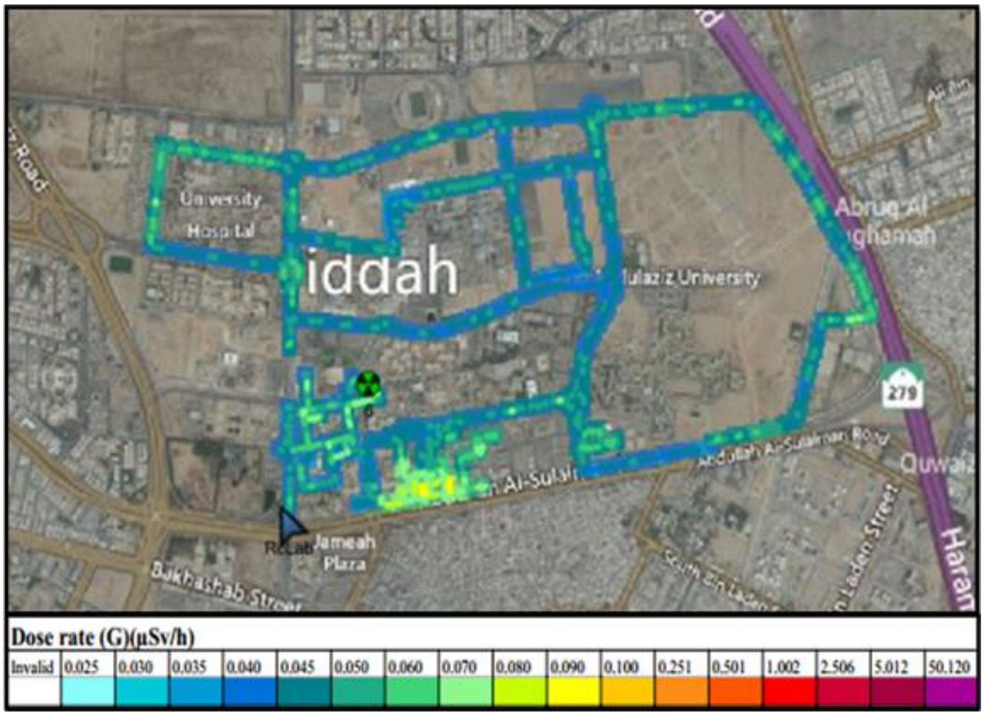

Figure 4. A map of radiometric ground surveys in open air inside KAU campus using the immediate mapping capability of the monitoring system.

Fig. 4 shows the exposure dose rate within the car track. From the colored map-key, it is clear that the background dose rate is almost uniform ranging roughly from 0.04 to 0.05 μSv/h. No extreme maximum values were observed in sites 50 meters away of the nearest building, indicating almost uniform radiation level. Higher radiation level was observed near the entrances of old buildings due to the brown granite countertops (Fig. 4). This uniform background radiation level may be attributed to the uniform lithology of the surface soil.

3.1.2 Dose rate inside buildings

a) New Buildings

Direct indoor surveys, one meter above the floors of corridors, office rooms and laboratories of the new buildings were conducted for exposure dose rate measurements due to indoor γ-radiation, with emphasis on the corridors and rooms of granite countertops. Some attention was given to the corridors and rooms that are not decorated with granite countertops.

The surveying system was loaded on a trolley and manually pushed inside the building with no connection with satellites and hence the system could not map the surveying track. The measurements were conducted in the different levels of the buildings and the results were recorded manually and given in Table 1.

Table 1. Radiometric survey data on various sites scattered in the different levels of the new buildings.

Site	Specification		Level	Exposure dose rate, µSv/h	
	Floor	Wall		Range	Average
Corridors	Granite	Granite up to 125 cm height	0*	0.106 - 0.133	0.119
			1	0.109 - 0.143	0.130
			2	0.096 - 0.126	0.111
			3	0.097 - 0.126	0.112
			4	0.088 - 0.127	0.109
	Unglazed pottery	Unglazed pottery up to 125 cm height	0	0.086 – 0.121	0.107
Corridor-intersections	Granite	Entirely granite	0	0.099 - 0.171	0.160
			1	0.123- 0.163	0.155
			2	0.101 - 0.145	0.128
			3	0.105 - 0.141	0.124
			4	0.107 - 0.141	0.127
Office rooms	Granite	Concrete	1	0.111 - 0.127	0.121
			2	0.091- 0.120	0.103
			3	0.084 - 0.106	0.093
			4	0.086 - 0.106	0.093
Laboratories	Pottery	Concrete	0	0.081 - 0.098	0.091
			2	0.086 - 0.105	0.091
			4	0.082 - 0.106	0.089
Laboratories	Rubber sheet	Concrete	0	0.063 - 0.083	0.069

* 0 level = ground level

The data in Table 1 showed that the exposure dose rate in granite corridors ranging from 0.088 to 0.143 µSv/h, with an average value of 0.115 µSv/h. The dose rate in the corridors of unglazed pottery tiles was slightly lower or almost the same, ranging from 0.086 to 0.121 µSv/h, with an average value of 0.107 µSv/h. The average dose rate at corridor intersections showed the highest levels ranging from 0.099 to 0.171 µSv/h, with an average value of 0.139 µSv/h, where floors and walls are entirely covered with granite slabs. Measurements in the office rooms of granitic floors showed an exposure dose rate ranging from 0.084 to 0.127 µSv/h with an average value of 0.103 µSv/h. The dose rate measurements inside the laboratories of floors covered with unglazed pottery tiles and laboratories of rubber sheet floors were 0.082 to 0.106 and 0.063 to 0.083 µSv/h, with average values of 0.091 and 0.069 µSv/h, respectively.

Based on the average values, it is clear that the exposure dose rate inside the new buildings follows the sequence: corridors intersections (floor and entire walls are of granite countertops) > corridors (granite countertop on floors and 125 cm height on walls) > office rooms (floors of granite countertops) ≈ laboratories (floors of unglazed pottery tiles) > laboratories (floors of rubber sheets).

The average exposure dose rate on the corridor intersection sites is almost double the average value reported in the rooms that do not contain any granites or unglazed pottery tiles. It is also clear that the exposure dose rate correlates with the extent of granite use, where the higher values are in the sites of the extensive granite slabs. Surveys showed dose rate on floors of unglazed pottery tiles comparable to that on the granite floors but higher than that on the concrete mix of lowest radiation emission due to the high content of sand (silica) in the mix.

Comparing the exposure dose rate in sites of the same characteristics but lie in the different levels, including the ground level, the variation was insignificant. This may be related to the quench of the soil background radiation by the armed concrete layer underneath the buildings. This spatial variation in exposure dose rate inside the buildings seemed to be due to geologic differences in the surrounding building materials. This variation is in agreement with the relative average abundance of the primordial radionuclides in common lithologic units in the used materials (Rogers & Adams, 1969), where granites and clays that derived from igneous rocks, have the higher radiation emission.

Surveys on floors of open wide yards and on floors of some open air corridors lie among the new buildings were conducted, where the monitoring system was connected to the satellite for mapping (Fig. 5). The walls are decorated with pink granite slabs and the floors are decorated with brown granite slabs and colored concrete tiles.

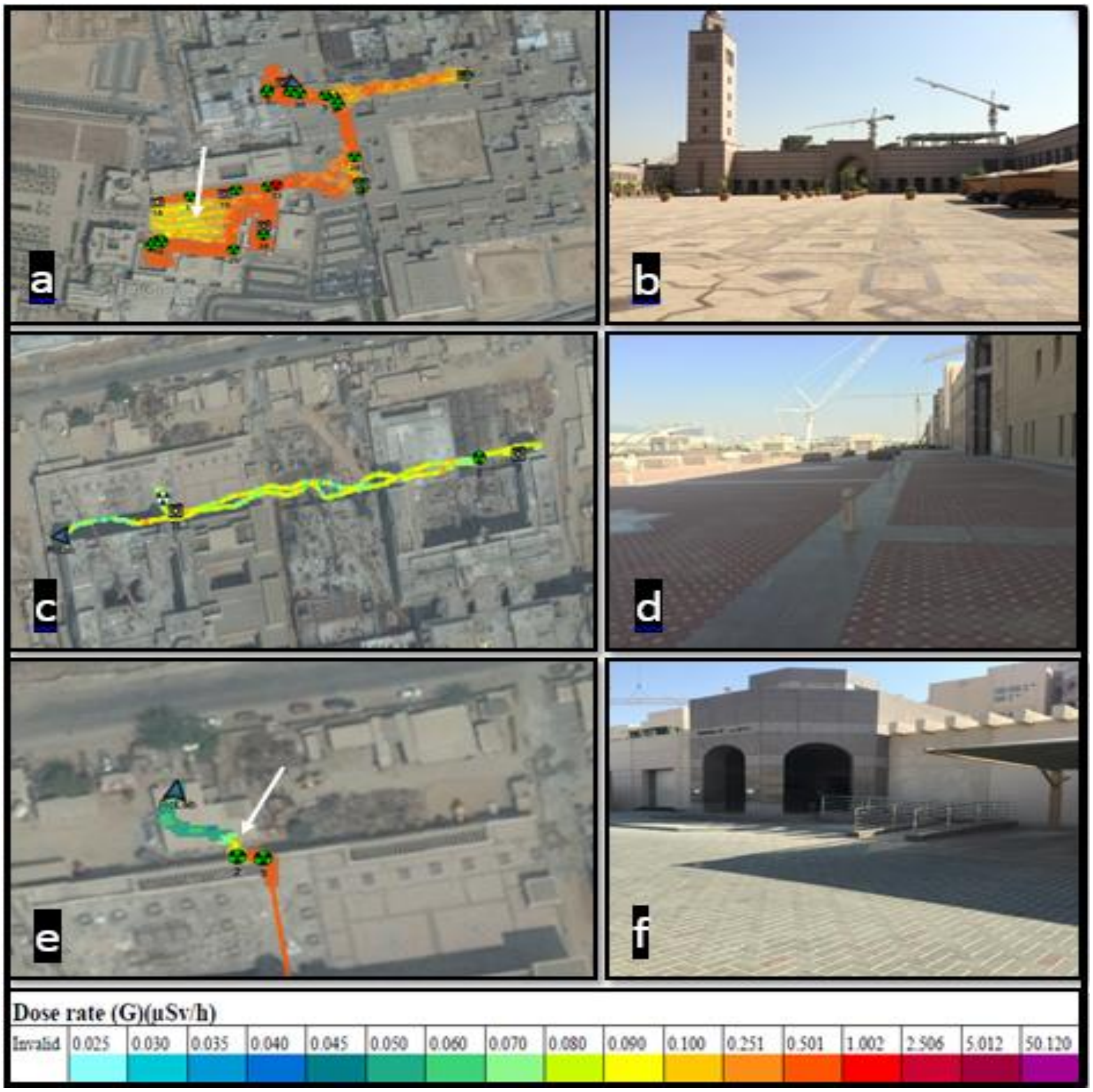

Figure 5. A composite map showing the exposure dose rate among the new buildings.

Fig. 5a shows the track of the monitoring system on open-air yards and corridor segments among the new buildings. The white arrow in Fig. 5a indicates the wide yard in Fig. 5b. It is clear that higher dose rate in the narrow corridors and the outer parts of the wide yard (0.10 to 0.25 µSv/h) due to the close granite walls and granite floors to the system track. At the middle area of the yard, the dose rate was lower (0.09 to 0.10 µSv/h), where the floor is decorated with both granite slabs and mostly pre-fabricated concrete tiles. The granitic walls are farer, indicated the effect of granite countertops on raising the exposure dose rate.

Fig. 5c shows the track of the system on the open-air wide terrace of the first level. This terrace extended to include the front side of three contiguous new buildings, where a wall is in one side and open air in the other sides (Fig. 5d). The floor of the terrace is decorated with colored prefabricated concrete tiles and minor brown granite slabs. The wall is decorated with granite slabs and prefabricated concrete tiles, where the granite is also a minor fraction. From Fig. 5c, the exposure rate was found to be ranging from 0.06 to 0.09 µSv/h. This data reflected the effect of using granite countertops on raising the exposure dose rate, which is in agreement with the monitoring data inside the buildings.

The system started a mission from outside to enter a new building via the main entrance (Fig. 5f). The position of this entrance is shown by white arrow in Fig. 5e. When the system entered the building, connection with the satellite was lost after 10 meters movement inside the building through the main corridor. Fig. 5e shows this mapped short track. This track shows three segments of different colors (different radiation levels). The first segment (greenish blue segment) is outside the building and showing a background dose rate ranging roughly from 0.04 to 0.05 µSv/h. The middle segment (yellow segment shown by the white arrow in the figure) is on the beginning of the entrance, where the system became near to the granite walls and the granite floor. The exposure dose rate at this point increased, ranging from 0.08 to 0.09 µSv/h. The last segment (orange) represents the first 10 meters inside the building before system disconnection with the satellite and losing the mapping function. In this section, the floor and the walls are decorated with granite slabs, where the radiation level at this area showed orange color. This color represents a dose rate ranging from 0.1 to 0.25 µSv/h indicating the significant effect of granite countertops on raising the exposure dose rate.

b- Old buildings

Meaningful estimate of the effect of the extensive use of granite as countertops in the new buildings could be made by examining the exposure dose rate inside the old buildings for comparison.

The dose rate measurements were conducted inside the old buildings and the results are given in Table 2.

Table 2. Radiometric surveys on various sites scattered inside the old buildings.

Site	Specifications		Level	Exposure dose rate, µSv/h	
	Floor	Wall		Range	Average
Main entrance	Brown granite	Concrete	0*	0.121 - 0.223	0.190
Corridors	Marble	Concrete	0	0.089 - 0.096	0.093
			1	0.065 - 0.094	0.077
Office rooms	Ceramic	Concrete	0	0.086 - 0.110	0.090
			1	0.090- 0.099	0.092
Laboratories	Rubber sheet	Concrete	0	0.065 - 0.085	0.071

* 0 level = ground level

The data in Table 2 show that the exposure dose rate on the brown granite slabs of the main entrance ranging from 0.121 to 0.223 µSv/h, with an average value of 0.190 µSv/h. Corridors of Marble floors and laboratories of floors covered with rubber sheets showed the lowest exposure dose rate values. These values are ranging from 0.065 to 0.096 µSv/h, with an average value of 0.085 µSv/h for the former, and ranging from 0.065 to 0.085 µSv/h, with an average value of 0.071 µSv/h for the later. The dose rate in the office rooms of ceramic floors range from 0.086 to 0.116 µSv/h, with an average value of 0.094 µSv/h. The minimum values inside the building were found on the Marble and concrete floors and the maximum values were found on the granite floors of the main entrances. However the exposure dose rate inside the old buildings also follows the sequence: Main entrances of granitic floors > rooms of ceramic floors > rooms of concrete floors ≈ Marble corridors. The average exposure dose rate in the main entrance sites is about 2.2 times higher than that in the office rooms or the Marable corridors due to granite countertops.
To simplify the comparison look, the data in Tables 1 and 2 are summarized in Table 3.

Table 3. Comparison between the indoor exposure dose rate due to γ-radiation in new and old buildings.

Site	Exposure dose rate, µSv/h					Remarks
	New building			Old building		
	Average	Range		Average	Range	
Main entrances	0.139	0.099 – 0.171		0.190	0.121 – 0.223	26.8% lower
Corridors	0.115	0.088 - 0.143		0.085	0.065 - 0.096	35.3% higher
Office rooms	0.103	0.082 - 0.127		0.091	0.086 - 0.110	13.0% higher
Laboratories	0.069	0.063 - 0.083		0.071	0.065 - 0.085	No change
Outdoors	0.040	0.035 - 0.055		0.040	0.035 - 0.055	No change

Except the main entrances, Table 3 showed significant increase in exposure dose rate in the new buildings due to the use of the granite countertops. About 35% increase in the exposure dose rate in the corridors of the new buildings, compared to that of the old buildings, owing to the use of granite countertops in decorating floors and walls. Only about 13% increase, in the exposure dose rate in the office rooms, due to the only use of the granite slabs for floors decoration instead of ceramic tiles in the old buildings. Exposure dose rate in the laboratories is lower and almost the same in both types of buildings due to the absence of granite countertops and ceramic tiles. It is also clear that the average outdoor exposure rate was the lowest

(0.04 µSv/h in average and ranging from 0.035 to 0.055 µSv/h). The average dose rate, due to γ-radiation inside the common buildings, is 2 times of magnitude higher than that outside due to the contribution of the building materials.

Conversely, the exposure dose rate was higher (average value equals 0.19 µSv/h) at the main entrances of the old buildings of old brown granite floors compared to that (0.139 µSv/h in average) of the new buildings, despite of the more extensive use of granite (floors and entire walls) as countertops. The exposure dose rate was in average about 36.7% higher in the entrances of the old buildings, where the brown granite showed the higher radiation emission than that used in the new buildings (Table 3).

3.2 Annual effective dose due to γ-radiation and the associated risk

Based on the obtained results in Table 3, the average annual exposure dose values due to γ-radiation emitted from building materials are calculated and given in Table 4. The average annual exposure dose value was 0.771 mSv/y inside the old buildings of almost no granites. The obtained values in the office rooms of granite floors and corridors of extensive granite use in the new buildings were 0.902 and 1.0 mSv/y, respectively, resulted in extra dose to occupants due to granite estimated by 0.131 and 0.236 mSv/y, respectively (Table 4). These average γ-radiation dose rate values exceeded the annual exposure dose interval of 0.3-0.6 mSv reported by UNSCEAR (2000) for worldwide typical normal range of annual effective dose value due to terrestrial γ-radiation.

Table 4. Average annual effective dose and estimated risk to occupants due to γ-radiation.

Radiation source	Occupancy time fraction	Indoor occupancy time subfractions	Average exposure rate, mSv/y		Estimated risk
			annual	Annual effective	
Outdoor	0.2		0.35	0.070	3.50×10^{-6}
Indoor	0.8	0.59 (exposure to normal dose)	0.771	0.617	30.8×10^{-6}
Office (granite)		0.189 office time (exposure to normal + extra doses)	0.131ǂ	0.025	1.20×10^{-6}
Corridor (granite)		0.021 corridor time (exposure to normal + extra doses)	0.236†	0.005	0.20×10^{-6}
Total	1.0		--	0.717	35.7×10^{-6}

ǂ Extra dose due to granite countertops in office rooms (the difference between the dose rate in the offices of the old and new buildings).

† Extra dose, due to granites, in the corridors (the difference between the dose rate in the corridors of the old and new buildings).

The outdoor exposure dose rate due to terrestrial γ-radiation ranging from 0.30 to 0.48 mSv/y with an average value of 0.35 mSv/y. This average is about 24% lower than the global average (0.46 mSv/y) in normal background areas. The average value in the old buildings (resemble most residential homes of Jeddah city) is about 1.7 times higher than the global average value. Based on the average indoor exposure dose rate (0.771 mSv/y), significant dose fraction is related to the building materials. The average annual effective dose (outdoor and indoor) were calculated to individuals living in Jeddah city (not working in the new buildings of KAU) and the data are included in Table 4. These values were 0.07 and 0.62 mSv/y, respectively, with 0.69 mSv as a total annual effective dose value. An extra effective dose value is added to the occupants of the new buildings due to granite countertops estimated by 0.03 mSv/y. In other words, only 4.2% increase in the annual effective dose to the occupants of the new building due to the emitted γ-radiation from the granite countertops. This is related to the lower occupancy time fraction (0.21) inside the new buildings.

The fatal cancer risk, to an individual living in Jeddah city has been estimated (Table 4). The average value was about 34.3 $x10^{-6}$. This value was about 35.7 $x10^{-6}$ for occupants of the new buildings. These values means that per 29,000 individuals living permanently in Jeddah city a cancer case, due to exposure to natural γ-radiation, may occur along their lifetime and for the occupants of KAU new building, a cancer case may occur per 28,000 individuals. However, the contribution of countertops to the annual dose due to exposure to γ-radiation is very low or negligible due to insignificant higher annual effective dose to occupants.

4. Conclusions and recommendations

Based on the obtained data and health risks related to exposure of occupants to γ-radiation, the following conclusions could be drawn and some recommendations could be submitted:

- A normal background dose rate due to γ-radiation was observed inside the KAU campus. No extreme maximum values were detected indicating almost uniform normal radiation level due to uniform lithology of the surface soil.
- The use of granite countertops in corridors of the new buildings resulted in about 14% increase in the exposure dose rate due to γ-radiation.
- This dose rate inside the new buildings follows the sequence: corridors of granite countertops > corridors of unglazed pottery > office rooms of granite floors ≈ laboratories of floors of unglazed pottery tiles > laboratories of floors of rubber sheets.
- Only 4.2% increase in the annual effective dose to the occupants of the new KAU building due to the emitted γ-radiation from the granite countertops, which is not too high to cause alarm.
- A negligible increasing potential risk due to exposure to γ-radiation, indicating no need for controlling actions due to the use of these granites as building materials.
- It is recommended that the brown granite of the old buildings should be used under specific circumstances or excluded from utilization as safe building material.

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