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MEASUREMENTS IN AFGHANISTAN USING AN ACTIVE RADON EXPOSURE METER AND ASSESSMENT OF RELATED ANNUAL EFFECTIVE DOSE

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Radon gas concentrations in eight basements, four living rooms and four caves from different locations in Kabul and Panjsher, Afghanistan, were measured by using eight active radon exposure meters recently developed by the Helmholtz Center in Munich, Germany. The two-phase measurements lasted from a week to a year. In the first phase of measurements which lasted one week, the mean activity concentrations ranged from 6 to 120 Bq/m^3 and 25 to 139 Bq/m^3 for the basements and caves, respectively. In the second phase of measurements which lasted one year, the mean activity concentrations ranged from 33 to 2064 Bq/m^3 and the corresponding effective annual doses calculated for the inhabitants were in the range between 0.6 and 33.4 mSv. As some of the values are rather high and exceed the recommended recommendations by IAEA and ICRP, based on the local conditions a number of simple recommendations has been proposed for the possible reduction of effective annual dose caused by radon in the measurement locations.

INTRODUCTION

Radon (i.e. ^{222}Rn) and its progeny is responsible for more than 50% of the natural radiation exposure in some areas of the world(1), and it is identified as the second cause of lung cancer after smoking(2). Being a decay product of ^{238}U, ^{222}Rn has a physical half-life of 3.8 days(3). Uranium is present in varying amounts in virtually all rocks and soils, it is the main source of indoor and outdoor radon exposure. However, drinking water from drilled wells, building materials, and industrial byproducts are also considered as potential radon sources(4). Emanating radon gas from the ground is transferred via cracks, wall and floor joints, chimneys, pipe openings, voids and similar routing paths(5). The concentration remains low if radon emanates to an open area, while it increases in enclosed spaces(6). General population is exposed to radon mostly in small enclosed buildings(7).

Radon level remains high in basements due to its vicinity to the ground(8) and in some cases improper ventilation. Besides the underlying rocks and soils, building materials, house type, ventilations system, construction style, crack insulation and the heating system are also the concentration enhancement factors(9).

One-third of Afghanistan is covered by mountains whereas only 12% of the land is arable(10). Caves excavated in the hills are used for housing, as either permanent residence or short-term shelters. As the caves were built in rocks, higher concentrations of indoor radon gas are expected.

Like many other infrastructures building inspection systems are also destroyed by decades of war in Afghanistan(11). Drought, unemployment and poverty forced inhabitants of rural areas to migrate to big cities like Kabul. As a consequence, an increasing number of illegal houses were built, often without appropriate ventilation and sewage system(12). To this date, no study has been performed to determine the radon concentration levels in residential buildings in Afghanistan. In this work the radon activity concentrations of radon gas from six sampling sites in Kabul and one site in Panjsher were measured using a flexible, portable prototype of a radon exposure meter developed by Helmholtz Center Munich (HMGU)(13).

MATERIALS AND METHODS

Measurement locations

The study was performed in two different phases from October 2014 to September 2016. In the first phase, three different sites were chosen for the measurements, out of which two were in Kabul Khair Khana area and one in Dasht-i-Rewāt of Panjsher province north of the country. The second phase covered four different sites in four geographical areas of Kabul. In the first phase, only basements and caves of a same level were measured, while in the second phase each sampling point consisted of an enclosed living room and a basement. The first phase included weeklong measurements, while the second phase was performed during four different measurement periods and seasons within 12 consecutive months; the seasonal values were averaged for annual concentration and dose assessment. The maps of the first and second phase of the measurements are shown in Figure 1a and b where the measurements sites are marked with red pins[14]. During the measurements period, the sites were regularly used by the inhabitants as living and working spaces.

Table 1 gives GPS coordinates and local names of measurement places, device IDs and their calibration factors used for each specific site.

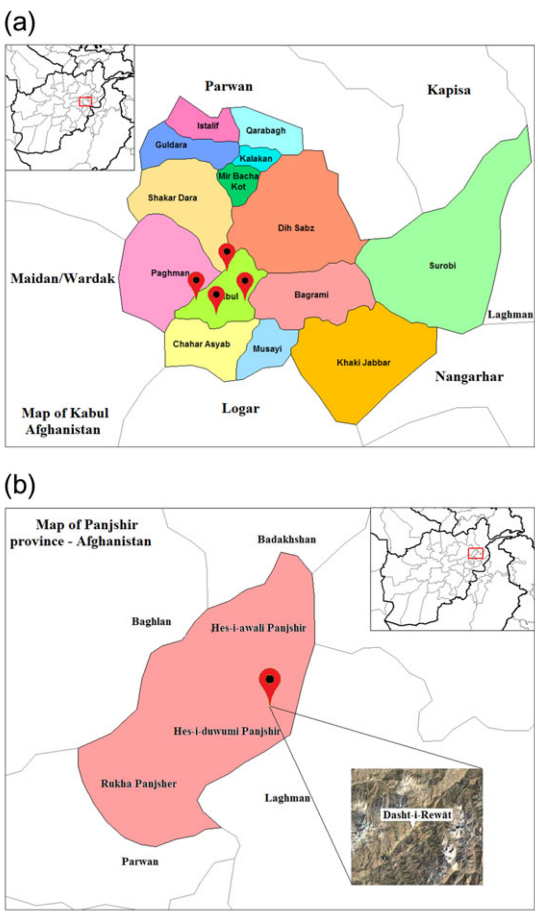

Figure 1. (**a**) Shows a map of Kabul and its districts and (**b**) shows the map of Panjshir and its district map; sampling sites are marked with red pins.

The reason for choosing these locations as sampling sites was their geographical and constructional material diversity as well as accessibility and availability.

Experimental conditions

Measurement devices

Eight recently developed radon exposure meters[15] with different calibration factors were utilized for the measurements. The devices include two silicon sensors inside the measurement chamber which has several holes covered by a filter. As the radon gas enters the chamber, the alpha particles emitted by radon progeny are recorded[16]. The portable robust device has a typical sensitivity of about 3 cph at 100 Bq/m^3, a mass of 150 g and a small size (11 cm × 6 cm × 3 cm) which makes it easy to carry it to any remote location; a fresh battery can last up to six months. The sensitivity together with the prevailing radon concentration and measurement time determines the number of recorded counts and, thus, the statistical uncertainty associated with the measurements. Radon concentrations were recorded every 10 min. Before measuring, the device needs to be reset with the help of software and a connector. After the reset, the devices were placed on the floor close to a wall for practical reasons, to avoid interference by persons and possible physical damage to the device (assuming constant indoor distribution of the noble gas radon, an assumption which is usually made for inhabited rooms). The measurement duration differed depending on location. As the devices have no manual on/off switches, they keep on recording unless the battery is removed. Thus, following the measurement a laptop was taken to the sampling site for on-site transfer of data from the device. Raw data were then converted into an excel file for evaluation. More details on the devices used are given in Refs.[13, 15–18].

Device calibration

The devices employed in this work have been calibrated following the recent ISO standard for radon measurements[19]. As radon source, pitchblende was employed. A gamma-spectrometric analysis of a 538 mg rock resulted in a specific ^{226}Ra activity of 23.0 ± 0.4 Bq/g. As secondary calibration standard a Saphymo AlphaGuard was used. The calibration is traceable since it was calibrated at the PTB (German metrology agency). During the calibration process all the devices (exposimeter and AlphaGuard) as well as the radon source were placed in a hermetically sealable steel vessel. Radon concentration would be stable only after about 23 days, if a completely tight vessel with a semi-permeable source is used. Note that in a less airtight calibration chamber, equilibrium between emanation of the source and loss through leakage will be reached in a shorter time[20]. After equilibrium has been reached the setup was left undisturbed for several

Table 1. Specification of the sampling sites and the devices used for the measurements.

Date	Device ID	GPS coordinates	Local name	Type of the space	Construction type and age
Fall 2014	V 309	N 34.584421° E 69.155582°	Sher Pacha basement	House	House constructed 2014; concrete, bricks
	V 317	N 34.584435° E 69.155361°	Agha basement	House	Constructed 1970; Adobe bricks, covered with cement rendering
	V 326	N 34.589251° E 69.156174^0	Karim 1 basement	House	Constructed 2012; concrete, bricks
	V 331	N 34.589265° E 69.156030^0	Karim 2 basement	House	"
	V 309	N 35.284841° E 69.495710°	Haji Dost	Cave	Cave excavated in 2013; solid rocks
	V 317	N 35.284063° E 69.495731°	Gen Azumdin	Cave	"
	V 326	N 35.284252° E 69.495701°	Qurban	Cave	"
	V 331	N 35.284294° E 69.495705°	Maazudin	Cave	"
Fall 2015–Fall 2016	V 309	N 34.504987° E 69.098102°	Mirza room	House	Constructed after 2010; concrete, bricks, ceramic tiles
	V 311	N 34.541523° E 69.047857°	Abobaker basement	House	Constructed in 1980s; adobe, cement rendering (?)
	V 315	N 34.522385° E 69.119731°	AAEHC basement	House	Constructed in 1950s; concrete
	V 317	N 34.510362^0 E 69.242040°	Samay basement	House	Constructed in 2008 on temporary basis; puddle clay, rocks, cement rendering
	V 321	N 34.541523° E 69.047857°	Abobaker room	House	(see above)
	V 326	N 34.504987° E 69.098102°	Mirza basement	House	(see above)
	V 330	N 34.522385° E 69.119731°	AAEHC hall	House	(see above)
	V 331	N 34.510362° E 69.242040°	Samay room	House	(see above)

days. The calibration factor and its standard deviation were then, for each device, derived from the hourly count rates and the measured radon concentration. Theoretically, the calibration factors of the devices depend on casing size, and environmental conditions such as temperature and air pressure (altitude). For the casing size used here, Monte Carlo simulations (results not shown) showed that the calibration factor differed by less than a few percent, for the altitude and temperature where the calibration was performed (Munich, Germany; around 500 m asl; 20°C), when compared to altitude and temperature where the measurements were performed (Kabul, around 1800 m asl; Panjsher province, around 2300 m asl; down to –2.9°C)[17]. Thus, no corrections were applied.

Measurement conditions

In the first phase of measurements launched in October 2014 none of the sites had electrical ventilation, but the house basements had at least one entrance and one glass window, while the caves only had one entrance. The second measurement phase was launched in fall (10–17 October 2015). Follow up measurements were performed in winter (20–27 January 2016), spring (20 and 27 May 2016), and summer (1–7 September 2016). During the measurement in spring the device V 317 failed, and was substituted by V 331 for Samay home and basement for the spring and summer measurements. In none of the buildings appropriate electrical ventilation systems were installed in the above-ground rooms, but all of them had an entrance, some had one or two windows as well. The devices were placed in the same GPS coordinates on different floor levels.

For the sampling locations in Kabul an annual temperature graph of Kabul city is shown in Figure 2. The city is influenced by the local steppe climate; the average annual temperature and precipitation are 11.4°C and 362 mm, respectively, with the highest temperature in July (23.2°C) and the lowest in January (−2.9°C). The driest month June has an average of 1 mm rainfall, while March as the wettest month has an average of 88 mm rainfall.

RESULTS AND DICUSSION

As the incident recording time was set to 10 min, the data were summed up for six consecutive data points for an hourly interval count rate. The activity concentration was obtained from the count rate by multiplication with the calibration factors given in Ref.[21]. Uncertainties were calculated for the total integrated counts only. Due to low count rates, time resolved, e.g. hourly based, uncertainties are not meaningful. Due limited access the devices could neither be tested nor calibrated at the measurement sites prior to the sampling campaign. The effective dose was calculated using the following equation recommended by ICRP[22].

$$H_{Rn} = A_{Rn} * F * t_{exp} * AR * d_{Rn} \quad (1)$$

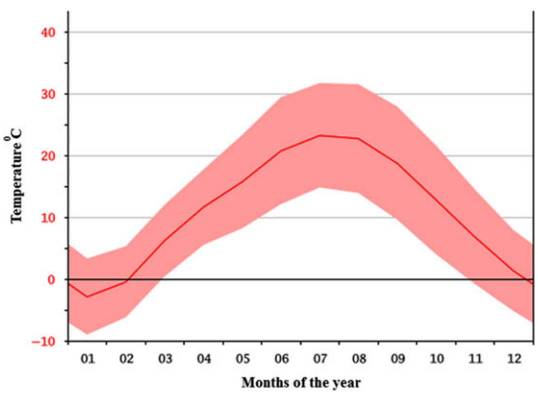

Figure 2. Average annual temperatures in Kabul city[18].

Where H_{Rn} is the annual effective dose in Sv, A_{Rn} is the activity concentration in Bq/m^3, F is the dimensionless equilibrium factor of ^{222}Rn daughter decay chain (Note: because it was not possible to measure F, the standard value of 0.4 recommended for typical indoor environments was assumed[23]). t_{exp} is the annual time period of indoor stay in hours (assumed here to be 4380 h; note that due to cultural difference in working and living regimes, the typical indoor stay for all the locations including working and living spaces in caves and basements investigated here was assumed to reach 12 h per day). AR is the typical breath factor proposed by ICRP for a reference worker as 1.2 m^3/h[24] and d_{Rn} is the inhalation dose factor for radon (7.7×10^{-9} Sv/Bq) The results of the mean measured activity and dose values for different locations of the first phase of the measurements are shown in Table 2.

The Sher Pacha, Karim 1 and Karim 2 basements have relatively good ventilation by having one entrance and two windows whereas Agha basement has just one entrance from the corridor and no air exchange with open air. All of the caves had more air exchange possibility during the day as a fact of human activity and in the night only mountain breeze could cause minor air exchange. The limited ventilation condition led to rather high radon levels. Keeping in mind the average activity concentration level as 300 Bq/m^3 corresponding to an annual effective dose of 10 mSv recommended by the ICRP and the IAEA on the assumption of an annual occupancy of 7 000 h and an equilibrium factor of 0.4 for ^{222}Rn[25, 26], one can conclude that all measurement sites above have a lower concentration than the recommended level, and thus do not pose considerable risk of lung cancer originated from higher concentrations of radon.

The seasonal averages of the activity concentrations and annual effective doses for different locations of the second phase are shown in Table 3, where relatively higher values are marked as bold.

As it can be seen in Table 4, except for the AAEHC basement all other locations show an annual

Table 2. Mean measured activity and dose values for different locations of the first phase of the measurements.

Location/local name	Average activity (Bq/m^3)	Uncertainty (Bq/m^3)	Annual effective dose (mSv/a)	Uncertainty (mSv/a)
Sher Pacha basement	6	±1	0.1	±0.02
Agha basement	120	±10	1.9	±0.16
Karim 1 basement	36	±4	0.6	±0.06
Karim 2 basement	34	±4	0.5	±0.06
Haji Dost	26	±6	0.4	±0.09
Gen Azumdin	133	±16	2.1	±0.25
Qurban	140	±15	2.2	±0.23
Maazudin	35	±6	0.5	±0.09

Table 3. Seasonal averages of the activity concentrations and annual effective doses of the second phase.

Season	Location	Average activity concentration (Bq/m^3)	Annual effective dose (mSv/a)
Fall 2015 (10–17 October)	Mirza room	36.2 ± 0.1	0.6 ± 0.001
	Abobaker basement	40.3 ± **0.1**	0.7 ± **0.001**
	AAEHC basement	**2087.3** ± **16.8**	**33.8** ± **0.18**
	Samay basement	43.5 ± **0.1**	0.7 ± **0.001**
	Abobaker room	33.2 ± **0.2**	0.6 ± **0.18**
	Mirza basement	136.1 ± 0.4	2.2 ± 0.004
	AAEHC hall	28.8 ± 0.1	0.5 ± 0.001
	Samay room	38.6 ± **0.1**	0.6 ± **0.001**
Winter 2016 (20–27 January)	Mirza room	31.9 ± **0.1**	0.5 ± **0.002**
	Abobaker basement	127.9 ± **0.1**	2.0 ± **0.003**
	AAEHC basement	**1959.9** ± **16.2**	**31.8** ± **0.27**
	Samay basement	86.3 ± **0.1**	1.4 ± **0.003**
	Abobaker room	68.3 ± **0.1**	1.1 ± **0.002**
	Mirza basement	325.4 ± **0.3**	5.3 ± **0.006**
	AAEHC hall	32.3 ± **0.1**	0.5 ± **0.001**
	Samay room	77.4 ± **0.1**	1.3 ± **0.003**
Spring 2016 (20–27 May)	Mirza room	35.7 ± **0.2**	0.6 ± **0.004**
	Abobaker basement	41.2 ± **0.2**	0.7 ± **0.003**
	AAEHC basement	**2006.7** ± **15.9**	**32.5** ± **0.26**
	Samay basement	46.8 ± **0.1**	0.8 ± **0.002**
	Abobaker room	27.9 ± **0.1**	0.5 ± **0.002**
	Mirza basement	125.2 ± **0.3**	2.0 ± **0.006**
	AAEHC hall	42.5 ± **0.1**	0.7 ± **0.001**
	Samay room	52.6 ± **0.1**	0.9 ± **0.002**
Summer 2016 (1–7 September)	Mirza room	30.0 ± **0.1**	0.5 ± **0.002**
	Abobaker basement	38.5 ± **0.1**	0.6 ± **0.002**
	AAEHC basement	**2204.1** ± **16.5**	**35.7** ± **0.27**
	Samay basement	38.6 ± **0.1**	0.6 ± **0.001**
	Abobaker room	29.5 ± **0.1**	0.5 ± **0.002**
	Mirza basement	136.0 ± **0.3**	2.2 ± **0.006**
	AAEHC hall	31.0 ± **0.1**	0.5 ± **0.001**
	Samay room	37.9 ± **0.1**	0.6 ± **0.002**

Table 4. Annual averages of the activity concentration and the effective dose for different locations of the second phase measurements.

	Local name	Average activity concentration (Bq/m^3)	Uncertainty (Bq/m^3)	Average annual dose (mSv/a)	Uncertainty (mSv/a)
Average annual dose (October 2015–September 2016)	AAEHC basement	2064	±38	33	±0.62
	AAEHC hall	34	±2	0.5	±0.03
	Mirza basement	181	±6	2.9	±0.1
	Mirza room	33	±3	0.5	±0.04
	Abobaker basement	62	±3	1.0	±0.04
	Abobaker room	40	±3	0.6	±0.05
	Samay basement	54	±2	0.8	±0.03
	Samay room	52	±2	0.8	±0.03

effective dose well below the level of 300 Bq/m^3 proposed by IAEA. As far as ventilation is concerned the AAEHC basement has poor ventilation and the only entrance of the basements is opened and closed about two to six times a day, which does not allow for sufficient air circulation and exchange and makes it a highly radon concentrated environment. The opening frequency of this basement decreases with decreasing temperature and as expected, the radon level should increase. The contrasting observation of decreasing concentration in winter is readily explained by the use of a wood-fired stove for heating. The burning fire causes additional air circulation through the chimney allowing also radon to escape. This space is mainly used by the cleaning staff. The AAEHC hall has no electrical ventilation system but is equipped with an air ventilator fan which has an air exchanger pipe placed outside the window. It has one entrance and two small windows which are opened from three to five times a day, and this space is mostly used as working office. The Abobaker basement has one entrance and a window, the entrance is opened two to four times a day and the window remains blocked almost all the time. This space is used as sleeping and living room. The Abobaker room is a living room having two big windows and one entrance. The Mirza basement and room have an entrance and a window, the basement window is smaller than that of the living room but both basement and room are used as living rooms. Samay basement has one entrance while the living room has two entrances and two windows, one entrance is opened to the corridor and another to the balcony, and it is used as regular living room, while the basement is used as kitchen and baking space on regular basis. In all cases except the Samay basement the ventilation situation gets poor as the temperature drops. Keeping the annual indoor occupancy hours as 4380 (12 h/d) and comparing these values to those for the countries in the neighborhood, one concludes that except the AAEHC basements, all other locations should not be considered as high risk areas of radon originating lung cancer. The reason that the IAEA recommendation and standards were chosen for comparisons in this section is that they cover a wider range of area in their studies than ICRP which is mostly focused on Europe. A daily based radon concentration distribution for the fall season measurements of AAEHC basement is given in Figure 3.

The difference in concentration between the basements and rooms/hall is shown in Figure 4.

The figure clearly shows a concentration difference in concentration between living rooms/halls and basements especially in the case of AAEHC hall and basement.

As one can also see from the figure, the AAEHC basements have higher annual effective dose (33.43) than the proposed level by ICRP, IAEA and EURATOM. The reasons for this fact are existing ventilation conditions as well as used construction

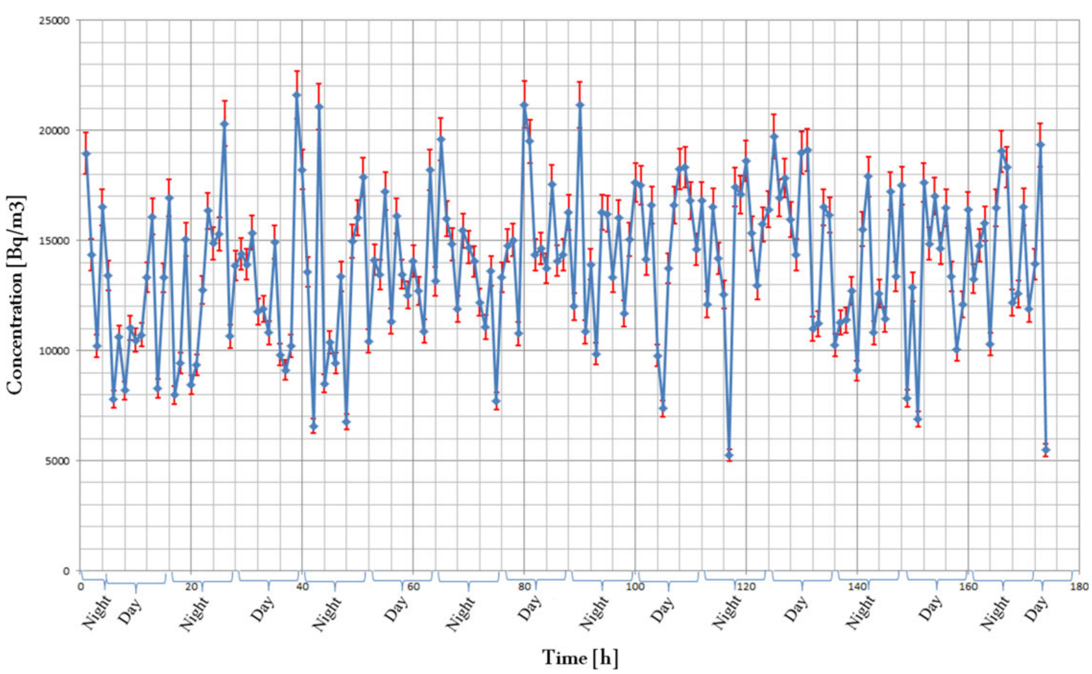

Figure 3. Shows hourly measurement of the fall season at AAEHC basement with the determined hours for day and night.

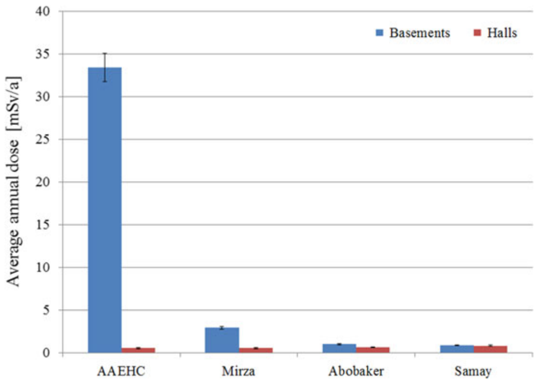

Figure 4. Comparison of estimated annual dose between basements and living rooms/hall.

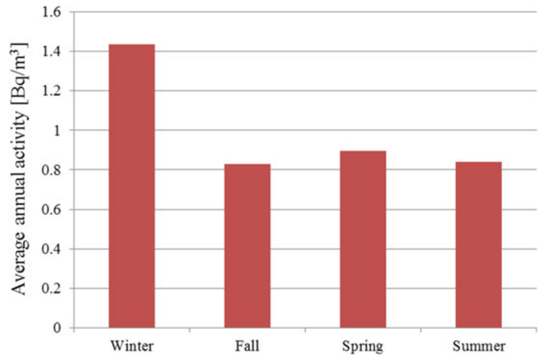

Figure 5. Relative mean seasonal dependence for all locations in four seasons.

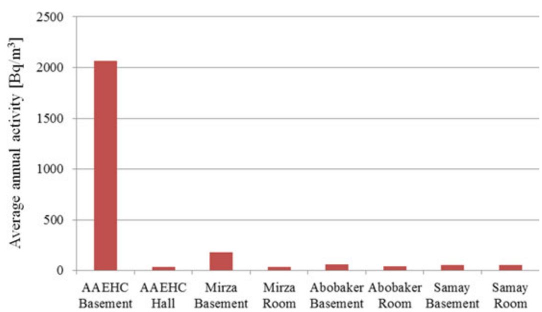

Figure 6. Mean annual effective dose for each site.

materials. Both basements are equipped with very poor ventilation systems. Additionally, due to working and weather conditions the doors and windows are not regularly opened for aeration, especially when ambient temperatures are very high or low. The building materials are mainly cement, ceramic and gypsum, which are considered well-known sources of radon. The adjacency of the basement to the ground also counts for the enhancement of radon concentration. The results of this study show that ventilation and adjacency to the ground play a crucial role in enhancement of radon concentration. Furthermore, buildings made of concrete show somewhat higher radon concentrations than other buildings. Due to a lack of appropriate heating, ventilation and air exchange, the seasonal weather change is an intensifying factor concerning radon activity enhancement. This could be observed from an increase of radon activity during the cold season, when doors and windows were constantly kept closed. The only seasonal measurement which does not follow the temperature path is that in the AAEHC basement. The reason for that is mentioned in the interpretation of Table 4 above. The relative mean seasonal dependence for all locations in four seasons is shown in Figure 5.

As seen in Figure 5 the seasonality plays an important role in the enhancement of the radon concentration.

In an overall look at mean annual concentration of each measurement site, one can conclude that the basement with its poor air exchange possibility has higher concentration. The mean annual effective dose for each site is shown in Figure 6.

As seen in the figure, the AAEHC and Mirza basements show higher radon concentration than the other locations. This may be either due to the fact that the ventilation is bad or that the concrete buildings have a higher potential to enhance radon concentration.

CONCLUSIONS

To the best of our knowledge, this is the first study providing systematic data on indoor radon concentrations for Afghanistan. We note, however, that the number of measurement locations was too small for a representative radiological country-wide evaluation, due to the difficult political, economical and societal situation in this country. Nevertheless, a number of conclusions can be drawn.

Beside a high radon concentration, the occupancy time is an important parameter that governs high effective doses. As the residents of all of the measurement sites including offices and caves used these spaces on average for about 12 h including weekends, they are all considered as normal residents or members of the public with a slight workload. Therefore any dose exceeding the level proposed by IAEA for members of the public will need further action for minimizing the radon dose[26].

Having said that, it is recommended:

- In order to give radon more chance to escape specially in cold seasons, equip new and old buildings with proper warming systems.

- Open and close doors and windows as often as possible, to increase natural ventilation and minimize radon concentrations[27].
- For places like AAEHC basement this recommendation needs to be fulfilled as quickly as possible.
- Further radon measurements in Afghanistan at different climatic conditions and various building materials are recommended.
- Due to its building material and style, priority should be given to old hospitals, offices, kindergartens, military barracks, cinemas, halls, schools and university buildings which are built in Soviet times with relatively enhanced use of concrete and their ventilation systems being semi or fully out of order.

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