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VARIATION OF RADON EMANATION IN WORKPLACES AS A FUNCTION OF ROOM PARAMETERS

(Variasi Emanasi Radon Di Tempat Kerja Sebagai Fungsi Parameter Bilik)

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Abstract

Modern life style requires people to spend most of their time indoors either in a house or in the workplace. Most modern buildings are made from soil based material which may consist of low concentration of naturally occurring radioactive materials (NORM). It is known that one of the daughters of natural uranium is ^{226}Ra which eventually produce radon (^{222}Rn) gas. Recently, more evidence has linked lung cancer to exposure to high levels of radon and also to cigarette-smoking. Consequently, this research was conducted to study the radon emanation rates in different workplaces. The radon emanations in 27 rooms with three different dimension (54 m^3, 210 m^3 and 351 m^3) and different building materials were determined for 96 hours using Sun Nuclear Radon Monitor. The radon emanations in the rooms studied were found to be in the range of 20.6 Bq m^{-3} $hour^{-1}$ to 134.3 Bq m^{-3} $hour^{-1}$.The increase in humidity was found to significantly increase the radon emanation rates in the building, whereas the increase in temperature will result the decrease of radon emanation rates. In addition, the findings shows that the radon emanation rates in building were higher during the night until early in the morning which is in agreement with the findings on humidity and temperature factors.

Keywords: Radon emanation, building materials, humidity, temperature

Abstrak

Kehidupan gaya moden memerlukan manusia untuk memperuntukkan masa mereka di dalam bangunan sama ada di rumah atau di tempat kerja. Kebanyakan bangunan moden diperbuat daripada bahan berasaskan tanah yang terdiri daripada kepekatan yang rendah unsur keradioaktifan tabiinya. Seperti mana yang diketahui bahawa salah satu daripada pereputan uranium semulajadi iaitu ^{226}Ra akan membebaskan gas radon (^{222}Rn). Terbaru, lebih banyak bukti mengaitkan kanser paru-paru dengan tahap radon yang tinggi dan juga asap rokok. Oleh yang demikian, kajian ini dijalankan untuk mengkaji kadar emanasi radon di empat kerja yang berbeza-beza. Emanasi radon di 27 bilik-bilik dengan tiga dimensi yang berbeza (54 m^3, 210 m^3, 351 m^3) dan bahan-bahan binaan yang berbeza telah ditentukan selama 96 jam dengan menggunakan peralatan Pemonitoran "Radon *Sun Nuclear"*. Emanasi radon dalam bilik-bilik kajian mendapati julat berada dalam lingkungan 20.6 Bq m^{-3} jam^{-1} hingga 134.3 Bq m^{-3} jam^{-1}. Pertambahan kelembapan didapati memberi pertambahan signifikasi pada kadar emanasi radon, manakala peningkatan suhu mempengaruhi penurunan kadar emanasi radon. Di samping itu, hasil penemuan menunjukkan kadar emanasi radon dalam bangunan adalah tinggi pada waktu malam hingga awal pagi di mana bersesuaian dengan penemuan faktor kelembapan dan suhu.

Kata kunci: Emanai radon, bahan binaan, kelembapan, suhu

Introduction

Natural radionuclides of ^{40}K, ^{238}U and ^{232}Th presented naturally in the earth's crust can be found in water, soil and rocks. Radon is an inert gas that is odourless and cannot be detected without the use of appropriate equipment. Radon, (^{222}Rn) is produced by disintegration of uranium. The human respiratory system has limited filtration system, which is unable to filter from inhaled radon gas. Radon intake will provide direct internal exposure to human. Radon is carcinogenic and one of the cause of lung cancer to human [1].

Radon easily enters the space in the building through cracks in pipelines and walls. However, building materials can also be a contributor in the radon content of building. Total radon produced depends on the concentration of uranium which is found in rock and soils. Housing development in Malaysia has increase rapidly, in line with government's objective to make Malaysia an advance country in the world. Growth in population and living standards also stimulate the increase in the number of building in Malaysia thus this also leads to greater demand for building materials. This has led to manufactures of building materials taking an initiative to use low cost, in large quantities and readily available raw material, such as the use of mixture of industrial wastes in building materials. In addition, consumers are more likely to choose the building material that have the elements of rocks and sand compared to wood based materials as they are far cheaper than wood [2].

Emanation of radon gas will occur, especially in enclosed spaces such as in rooms and buildings. Radon is one aspect that needs serious attention especially in the air quality index for most countries in the world. More individual prefer to spent their time indoors than to be outside of the building. It is therefore very important to determine the contribution of radon to the total dose received by occupants to assess acceptable risk [3].

Therefore, the main objectives in this study is to determine the level of radon emanation in different types of Malaysia's building at Universiti Kebangsaan Malaysia (UKM), the effective dose received by students and employees, the equivalent dose received by students and employees and to investigate the relationship between radon emanation with the factors of room parameters.

Materials and Methods

Research Workplace

This study was conducted to determine the effects of radon to the UKM students and employees, the selection of the study area includes buildings and buildings used by students and staff of the University.

Type of Building

Building and selected study areas were classified according to the age of the building (34 years), semi-long (16 years) and new building (2 years). There are 27 rooms with three different dimension (54 m^3, 210 m^3 and 351 m^3) and different building materials. The study area selected and the year of occupancy and age of the building is referred in Table 1.

Table 1 Study area selected and the year began of occupancy and age of the building

ID	Year of operation	Age (year)	Type of Workplace
ADM-B	1977	34	Administration Building
NSB	1995	16	Nuclear Science Building, Faculty of Science and Technology (FST)
EXT-B	2009	2	Extension Building, Faculty of Information Science and Technology (FTSM)

For each of the building studied, three types of rooms with different sizes were selected based on the following:

a) The small size of individual rooms (3 m x 6 m x 3 m)
b) The medium size such as tutorial rooms, meeting rooms, discussion rooms and operations room (7 m x 10 m x 3 m)
c) The large size such as lecture halls, laboratories, office space and seminar room (9nm x 13 m x 3m)

Three different rooms were selected for each type of area to make all the nine rooms. This makes all the nine rooms studied for each building selected. The total rooms studied are 27. Table 2, Table 3 and Table 4 show complete details of the Administration Building (ADM-B), Nuclear Science Building (NSB) and Extension Building (EXT-B).

Table 2. Information of study area for ADM-B Workplace, Administration Building

Workplace	Building	Size of studied room (m x m x m)	Rooms		Level	Ceiling	Wall	Floor
		3 x 6 x 3	ADM-B 1	Room 1, PHA	2	Asbestos	wall paper	carpet
			ADM-B 2	Room 2, PKK	2	Asbestos	cement,painted	tile
			ADM-B 3	Pantry Room	3	Asbestos	cement, painted	PVC
ADM-B	Administration Building	7 x 10 x 3	ADM-B 4	Meeting Room, Department of Bursary	3	Asbestos	cement,painted	carpet
			ADM-B 5	Meeting Room, PHA	2	Asbestos	wall paper	carpet
			ADM-B 6	Meeting Room, PKK	2	Asbestos	cement,painted	tile
		9 x 13 x 3	ADM-B 7	Office Room, Department of Bursary	3	Asbestos	cement, painted	PVC
			ADM-B 8	Office Room, PHA	2	Asbestos	wall paper	carpet
			ADM-B 9	Office Room, PKK	2	Asbestos	cement, painted	tile

*PHA = Office of International Relations *PKK= Office of Corporate Communications

Table 3. Information of study area for NSB Workplace, Nuclear Science Building

Workplace	Building	Size of studied room (m x m x m)	Rooms		Level	Ceiling	Wall	Floor
		3 x 6 x 3	NSB 1	Room 3	1	Asbestos	cement,painted	carpet
			NSB 2	Room 4	2	Asbestos	cement,painted	PVC
			NSB 3	Lab assistant Room	1	Asbestos	cement, painted	PVC
NSB	Nuclear Science Building	7 x 10 x 3	NSB 4	Meeting Room	1	Asbestos	wall paper	carpet
			NSB 5	Resource Room	1	Asbestos	cement,painted	PVC
			NSB 6	Tutorial Room	1	Asbestos	cement,painted	PVC
		9 x 13 x 3	NSB 7	Graduate Room	1	Asbestos	cement, painted	PVC
			NSB 8	Lecture Hall 1	1	Asbestos	cement, painted, wood panel, aluminium piece	PVC
			NSB 9	Electronic Lab	2	Asbestos	cement, painted	terrazo

Table 4. Information of study area for EXT-B Workplace, Extension Building

Workplace	Building	Size of studied room (m x m x m)		Rooms	Level	Ceiling	Wall	Floor
		3 x 6 x 3	EXT-B 1	Technician Room Graduate Lab	2	Asbestos	cement,painted	tile
			EXT-B 2	Assistant Information System Officer Room	2	Asbestos	cement,painted	tile
			EXT -B 3	Information System Officer Room	2	Asbestos	cement, painted	tile
EXT-B	Extension	7 x 10 x 3	EXT -B 4	PC Recovery Workshop	1	Asbestos	cement,painted	tile
	Building		EXT -B 5	Machine Control Workshop	1	Asbestos	cement,painted	tile
			EXT -B 6	Meeting Room,	2	Asbestos	cement,painted	carpet
		9 x 13 x 3	EXT -B 7	Network Lab	1	Asbestos	cement, painted	tile
			EXT -B 8	Graduate Lab	2	Asbestos	cement,painted	tile
			EXT -B 9	Office Room	2	Asbestos	cement, painted	tile

Research Equipment

This study was conducted using radon monitor equipment by “Sun Nuclear” for model 1028 and 1029. This equipment was used to measure radon emanation in study area and the readings obtained in unit Bqm^{-3}. Continuous readings were obtained for a period of time required to meet the purpose and needs of the research. Continuously readings were taken for 96 hours which is equivalent to 4 days.

Method of Monitoring

Radon monitor was placed in the selected study area. The characteristics of the study area were identified according to the height of the study area from ground level, the estimated area of research, building materials used for walls, ceilings and floors of the study area. The sizes of area studied for each building were ensured to be similar. Figure 1 shows the measurement geometry of the recommended for radon emanation studied in an enclosed space.

The radon monitor was placed in appropriate place that suit the actual conditions on site so that it will not interfere with the working space. In addition, to avoidance of interruption during the process of monitoring. A continuous reading is taken over 96 hours and readings were taken of an interval of one hour. The readings were classified into a set of 24 hours and the unit in Bqm^{-3}. The monitoring data obtained from the area studied calculate the concentration of radon and its risks to employees in the area studied. Determination of the risk to be used to the students and employees was done by calculating the effective dose and the equivalent dose received by students and employees.

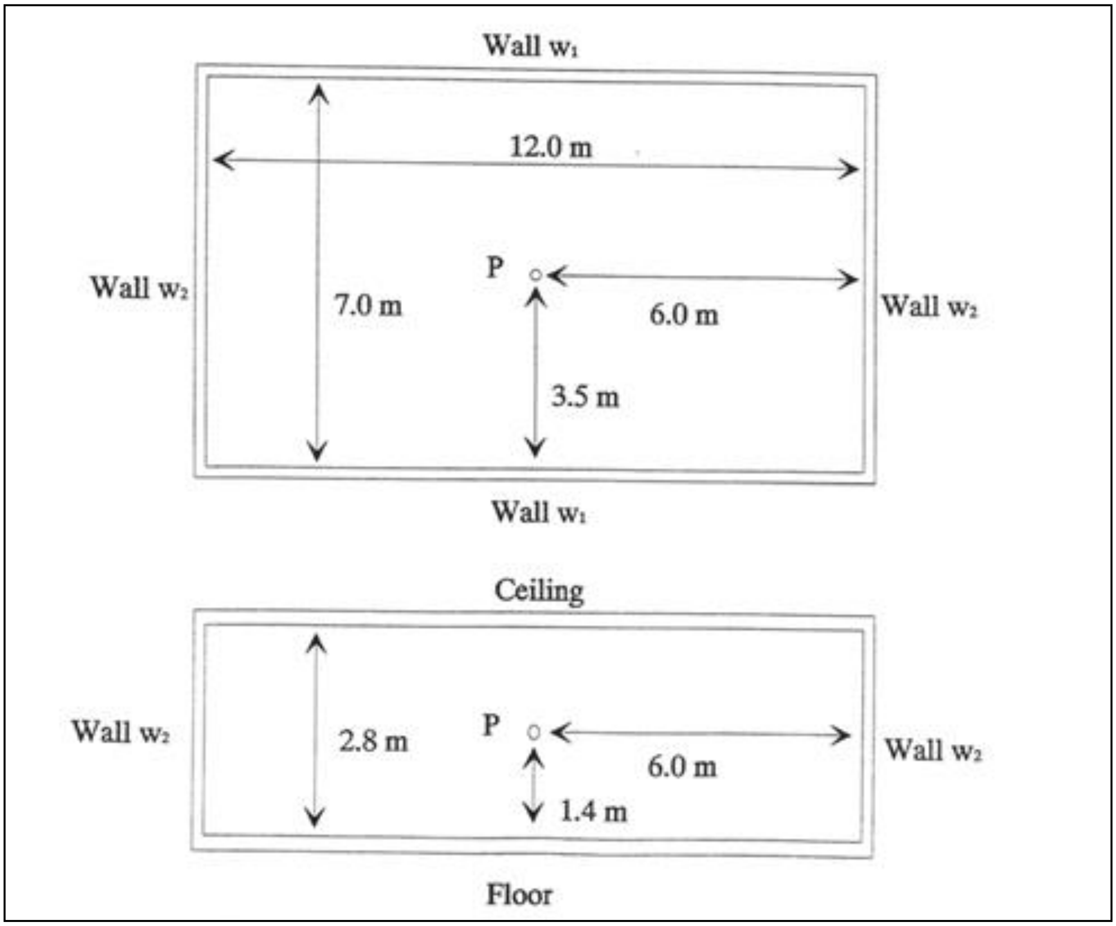

Figure 1. Geometry of the proposed for dose measurement in the building according to Finnish Centre For Radiation and Nuclear Safety, Finland Recommendation (STUK-B-STO 32, 1995).

Results and Discussion

Results and information from this study was compared with the previous studies and in accordance to the parameter studied. The results obtained were used to determine whether the concentration of radon in building around UKM, Bangi is below or above the International Recommended level.

Concentration of radon content in the study area

The radon emanation for each area studied was measured using a radon monitor that was left for 96 hours at the workplace. The reading of radon emanation ($Bqm^{-3}h^{-1}$) was obtained, recorded and classified according to study area. The value was calculated by subtracting the average reading of first three readings since they were considered unstable [1]. The average reading at each workplace were classified into a set of 24 hours, which the average concentration of radon readings taken accordingly in the time range of 0-24 hours, 25-48 hours, 49-72 hours and 73-96 hours with a standard deviation calculated for each interval of 24 hours. The average radon emanation was determined using the following equation.

$$\text{Average Reading} = \frac{\text{Total reading 96 hours (Bqm}^{-3}\text{)} - \text{3 first reading on each set of 24 hours measurement (Bqm}^{-3}\text{)}}{\text{93 hours}}$$

Workplace ADM-B, Administration Building (1977)

Nine workplaces selected in this 34 years old building that cover the Office of International Relation (PHA), Office of Corporate Communications (PKK) and Department of Bursary. Table 5 shows average reading of radon emanation for the nine selected workplaces in this building.

Table 5. Average concentration of radon in selected area in Workplace ADM-B, Administration Building

Workplace	Level	Average Readings $Bqm^{-3}h^{-1}$
Room1, PHA	2	34.6 ± 7.5
Room 2, PKK	2	36.5 ± 5.8
Pantry Room, Department of Bursary	3	24.5 ± 5.0
Meeting Room, Department of Bursary	3	33.5 ± 4.7
Meeting Room, PHA	2	41.0 ± 5.0
Meeting Room, PKK	2	34.1 ± 7.0
Office Room, Department of Bursary	3	30.7 ± 5.1
Office Room, PHA	2	39.7 ± 7.2
Office Room, PKK	2	36.0 ± 6.0

Workplace NSB, Nuclear Science Building (1995)

For 16 years old building, the radon emanation readings were recorded in the nine areas used by students and employees of the university. Table 6 below indicates average reading of radon emanation for 9 areas in Nuclear Science Building.

Table 6. Average concentration of radon in selected area in Workplace NSB, Nuclear Science Building

Workplace	Level	Average Reading $Bqm^{-3}h^{-1}$
Room 3	1	33.6 ± 4.8
Room 4	2	26.1 ± 3.0
Lab Assistant Room	1	46.9 ± 8.5
Meeting Room	1	51.7 ± 14.4
Resource Room	1	30.6 ± 3.5
Tutorial Room 1	1	32.4 ± 2.8
Graduate Room	1	37.5 ± 2.9
Lecture Hall 1	1	36.8 ± 8.6
Electronic Lab	2	20.6 ± 1.4

Workplace EXT-B, Extension Building, FTSM (1995)

Nine of the area studied in the 2 years old building also includes areas that are often used by students and staff. Table 7 shows average reading of radon emanation for 9 areas in Extension Building, FTSM.

Table 7. Average concentration of radon in selected area in Workplace EXT-B, Extension Building, FTSM

Workplace	Level	Average Reading Bq m^{-3}
Technician Room Graduate Lab	2	134.3 ± 14.9
Assistant Information System Officer Room	2	46.0 ± 10.1
Information System Officer Room	2	78.7 ± 15.3
PC Recovery Workshop	1	30.7 ± 4.2
Machine Control Workshop	1	67.2 ± 26.4
Meeting Room	2	96.2 ± 8.5
Network Lab	1	97.2 ± 15.1
Graduate Lab	2	110.1 ± 2.8
Office Room	2	78.6 ± 29.6

The result showed that the building built two years ago recorded an average value of radon emanation higher than other buildings constructed 34 and 16 years ago. The range of radon emanation readings in building built 34 years (Administration Building), 16 years (Nuclear Science Building) and 2 years (Extension Building) recorded readings of 24.5 ± 5.0 Bq m^{-3} to 41.0 ± 5.0 Bq m^{-3}, 20.6 ± 1.4 Bq m^{-3} to 51.7 ± 14.4 Bq m^{-3} and 30.7 ± 4.2 Bq m^{-3} to134.3 ± 14.9 Bq m^{-3} respectively. Note the trends for older buildings (34 years and 16 years) showed that the lower floors revealed higher emanation of radon but not observed in newer building (2 years). This is due to the building materials and type of soils used in the older building. The older buildings were using the red bricks and other building materials that contained high NORM. It was also affected by the working practice such as factors of open-close doors, ventilation and air conditioner system applied by the workers.

Malaysia has not to set the value of radon emanation in the building, but follow International Recommended level used in this study. Among the recommendation from the U.S. Environmental Protection Agency (USEPA), which suggested the Action Level of 148 Bq m^{-3} [1], Health Protection Agency (HPA) recommends 100 Bq m^{-3} up to 200 Bq m^{-3} [2], International Commission on Radiological Protection (ICRP) recommends 300 Bq m^{-3} until 1000 Bq m^{-3} [4]. The Action Level value used in this study is according to the ICRP recommendations. Based on the results, radon emanation is still low when compared to the ICRP recommended limit.

Radon emanation

Variation of radon emanations workplaces studied has shown that The Extension Building, FTSM recorded the highest value compared to Administration Building and Nuclear Science Building. This is due to influence radon emanations in the building. Results showed radon emanation in the building was also contributed by the soil and rock in the building surrounding. The factors mentioned earlier is related to the room parameters such as types of building construction materials used for example rocks, sand, cement, tile, PVC and terrazzo. Other influences include, level of building, atmospheric layer stability, temperature and humidity.

Room Parameters

From the results obtained, this study has found that new building built two years ago (Extension Building) recorded higher average value of radon emanation than old building (34 years and 16 years). There is a connection between radon emanations with building age. Hence, the age of the building will be one of the room parameter that influences radon emanation. ANOVA statistical test was performed to determined differences in radon emanation for each building built in 34, 16 and 2 years ago. There were two different hypotheses whether there are significant differences between the samples. The two hypotheses presented as Null Hypothesis (H_0) and alternative hypothesis (H_1). Null hypothesis (H_0) states that the concentration of radon in the building is not dependent on the age of the building while the alternative hypothesis (H_1) stated that the radon concentration in building is dependent on the age of building.

ANOVA test gives results of F value and F_{crit}. If value of $F > F_{crit}$, Null hypothesis (H_0) will be rejected and if value of $F_{crit} > F$, Null hypothesis (H_0) will be accepted.

	Administration Building	Nuclear Science Building	Extension Building, FTSM
1	34.6	33.6	134.3
2	36.5	26.1	46.0
3	24.5	46.9	78.7
4	33.5	51.7	30.7
5	41.0	30.6	67.2
6	34.1	32.4	96.2
7	30.7	37.5	97.2
8	39.7	36.8	110.1
9	36.0	20.6	78.6
N	9	9	9
X	34.511	35.133	82.111
S	4.888	9.647	31.872
X_{ave}	50.585		

source	df	SS	MS	F	F crit	P-value
treatments	2	13419.176	6709.588	17.77	3.40	0.00
error	24	9062.278	377.595			
total	26	22481.454				

The statistical results gave value of F= 17.77 and the F_{crt}= 3.40 with a value of P= 0.00. If $F > F_{crit}$, Null hypothesis (H_0) is rejected and the alternative hypothesis (H_1) is accepted which stated that the radon emanation in the building depends on age of building. These results were in agreement with the previous studies [6], which indicated that the age of building in a contribution factor to radon concentration in building. The age of the building shows positive results since room parameter can give variation of radon emanation in the work places.

Diurnal variation of radon emanation

As in the previous studies, the emanation of radon has shown certain pattern. The radon concentration was found high at night and early morning and low during the daytime [3; 6; 7; 8; 9]. Figure 2 describe the pattern of radon production for 24 hours over three consecutive days in ADM-B, NSB, EXT-B.

Figure 2 shows that high radon concentration started at night until early in the morning and began in the early morning; radon concentration began to decrease until it reached the night time and often that it continues to increase. As in the previous studies, this was done to the stability of the atmospheric surface layer. [6]

At night until early morning, the earth's surface is in a stable condition in which the surface layer and the atmosphere have nearly the same temperature and the radon tends to accumulate near the earth's surface. In the daytime, as the temperature rises during the day it create the difference between temperature of surface to the temperature of the atmosphere. There is a heat transfer process and this process makes the atmospheric surface layer becomes unstable and produces convection. This forces radon gas upward and spread away from the surface. Then in the evening, the surface temperature began to decrease and the opposite occur for radon. This stabilizes the atmospheric conditions and radon again gathered close to the earth's surface. [3, 6]

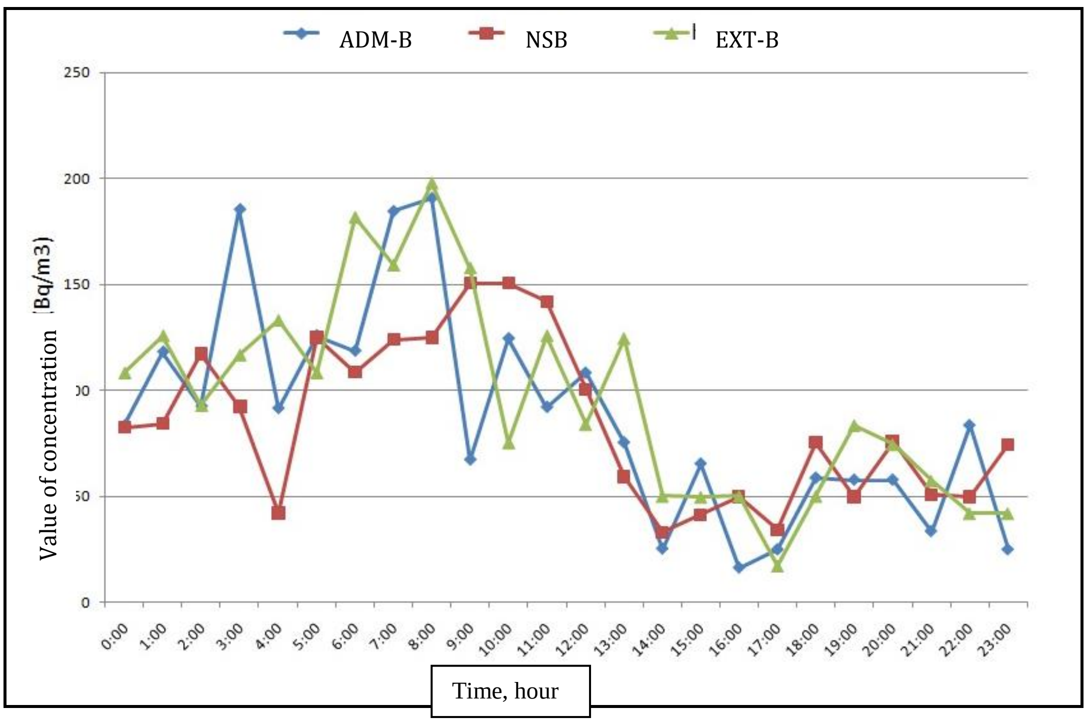

Figure 2. The diurnal variation of radon emanation in ADM-B, NSB and EXT-B

Radon in indoor air may be diluted by increased ventilation of the indoor spaces with outdoor air. This method can be done in terms of energy loss, particularly in working time. Energy loss can happen while opening and closing the doors frequently. Besides that, switching on the air conditioner in the workplace during the day may affect the radon gas decreasing as well as the indoor air is entered the air conditioner system in and out.

Temperature and Humidity

Temperature and humidity is also a part of room parameters that affect the level of radon emanation in building. The level of radon concentration with humidity factor has a positive correlation that is with the increment of humidity, the level of radon concentration also increase. Meanwhile, for temperature there is a negative correlation with radon concentration. The rise in temperature in the building will reduce the level of radon concentration. [6, 7].

This study was found to be in agreement with the previous studies that stated that the level of radon concentration in the building will increase with the increase in humidity but radon concentration will decrease when temperature is increase. Figure 3.0 shows the distribution of radon concentration with temperature and Figure 4.0 shows the distribution of radon concentration with humidity at Electronic Lab in the Nuclear Science Building. The influence of temperature and humidity as a function of room parameters can be one of the factor that influence radon emanation.

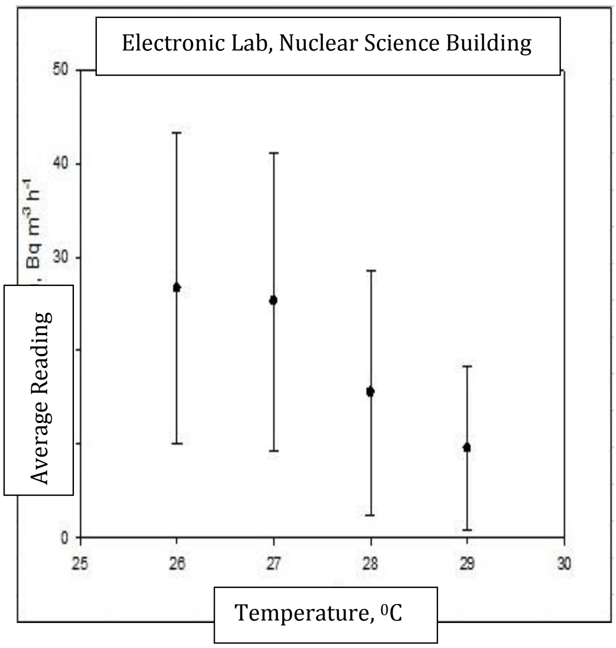

Figure 3. Pattern of radon concentration with temperature

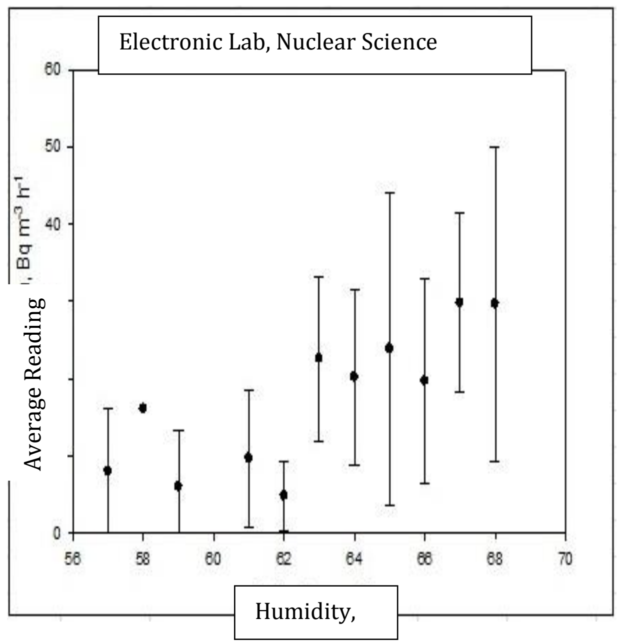

Figure 4. Pattern of radon concentration with humidity

Effective Dose

Effective dose, also called exposure dose is the total dose of radon exposure received by occupants in a year. By using the average value of radon concentration ($Bqm^{-3}h^{-1}$), annual effective dose for workers in the study area will be determined using the formula below [8].

$$D = C_{Rn} \text{ x } F \text{ x } O \text{ x } T \text{ x } D \text{ (unit = mSv)}$$

where;

C_{Rn}	average of radon concentration	Bq m^{-3}
F	equivalent factor	0.4
O	occupancy factor	0.25 (8h/24h x 100%)
D	exchange unit	9 nSv (Bq h $m^{-3})^{-1}$
T	time	8760 hour (365d x 24h)

From the results calculated, the range of effective dose for the Administration Building (34 years), Nuclear Science Building (16 years) and Extension Building (2 years) was 0.19 mSv – 0.32 mSv, 0.16 mSv – 0.41 mSv and 0.24 mSv – 1.06 mSv.

Equivalent Dose

Equivalent dose is the dose received by occupants on the type of radiation produced by radon and also with the organ and tissue involvement. It using weighting factors for alpha particle and weighting factors for lung tissue [4].

$$E = D \times wR \times WT \qquad (\text{unit} = \text{mSv y}^{-1})$$

where:

D	annual exposure dose,	mSv
wR	weighting factors for alpha particle	20
WT	weighting factors for lung tissue	0.12

From the results calculated, the range of equivalent dose for the Administration Building (34 years), Nuclear Science Building (16 years) and Extension Building (2 years) was 0.46 mSv y^{-1} – 0.77mSv y^{-1}, 0.38 mSv y^{-1} – 0.98 mSv y^{-1} and 0.58 mSv y^{-1} – 2.54 mSv y^{-1}.

Conclusion

Variation of radon emanation in workplaces was successfully studied. The radon emanations in the rooms studied were found to be in the range of 20.6 $Bqm^{-3}h^{-1}$ to 134.3 $Bqm^{-3}h^{-1}$. Several factors were found to influence the quantity radon emanation such as; room parameters that are the type and source of construction materials use, atmospheric layer stability, temperature and humidity. The radon emanation also indicated a pattern where it was higher at night and early morning but lower during daytime. The measured radon emanation values were lower than 300 Bqm^{-3}. This is a limit of radon emanation in workplace as suggested by ICRP 103. The calculated annual effective dose values and annual equivalent dose values were calculated to be in the range of 0.16 mSv to 1.06 mSv and 0.38 mSv y^{-1} to 2.54 mSv y^{-1} were still below the action levels recommended by ICRP which were 20 mSv and 10 mSv.

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