Measurement of Indoor Radon Concentration at Malaysia Nuclear Agency (Malaysia Nuclear) and Radionuclide Monitoring Station, Cameron Highlands, Pahang, Malaysia

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1. Introduction

Radon is naturally occurring radioactive noble (NORM) gas which is a colorless and odorless radioactive. It is produced by the small amount of decaying uranium that occur naturally from soils, rocks and groundwater (Vaupotic 2010; Alofabi et. al 2015). It can enter the human body through the inhalation and ingestion processes. The highly ionizing alpha particles emitted during decaying process of the radon gas interact the biological tissue in the lung leading to damage of DNA (Baradan 2014). Long-term of exposure to high levels of radon can cause the lung cancer and considered as a second leading cause of lung cancer among the non-smokers (ICRP 2014). The U.S. Environmental Proctection Agency (USEPA) reported about 21 000 lung cancer deaths per year caused by radon (WHO 2009).

In Malaysia, the research of radon and progenies were still new in Malaysia compared to another country. The regulations and guidelines of radon are only regulated in the mineral industry only but not in the buildings, especially the old buildings and residences (AELB 2010). Other developed countries such as the United States of America (USA) and Japan, they have a radon safety certification, which will be given to a previously inhabited building and demonstrated that the building is safely to occupied (USEPA 2001). Radon can enter the home and building through cracks, sink and other holes in the foundation and traps it in the building (WAG 2001).

So, this paper aims to measure radon concentration during working hours in the building at Malaysia Nuclear Agency (Malaysia Nuclear) and Radionuclide Monitoring Station at Cameron Highlands and investigate the factors influencing radon readings. The results of effective and equivalent dose exposed to the workers also discussed.

2. Methods and Materials

Malaysia Nuclear had been chosen as the location of sampling for the radon measurement, which focused on two buildings, MN11 and MN15 respectively. While at Cameron Highlands, Radionuclide Monitoring Station's building renamed as RN42 was chosen as a location for sampling of radon measurement. DOSEman Pro is used to measure the activity of radon concentration in the study areas. It has been conducted for three weeks to record the activity of radon concentration on weekdays and weekends for 9 hours, starting from 8am to 5pm. After that, it was taken and connected to the computer to collect the results.

Table I: Details of Building

Building	Year	Materials	Usage
MN11	1996	Cement	Graphic unit
MN15	1989	Red bricks	Office
RN42	1989	Red bricks	Meeting room

3. Result and Discussions

3.1 Measurement of Radon Concentration

The results show the measurement of radon concentration has been conducted three weeks on weekdays and weekends after analyzing the data in Table II.

Table II: Range of radon concentration

Building	Radon concentration, Bq/m^3	
	Weekdays	Weekends
MN11	2.2-151.1	190.7-301.1
MN15	44.8-262.2	303.0-396.3
RN42	20.7-48.5	19.3-34.4

The range of radon concentration in MN15 is higher than MN11 and RN42 on both weekend and weekdays respectively. This might be attributed with a few factors such as airflow system and age of building construction (Gillmore et. al 2005; Groves-Kirby et. al 2009; UNSCEAR 2009; Al-Khateeb et. al 2017). The airflow system used at Malaysia Nuclear was fan and an air conditioner. These fan and air conditioner mixed with the air and remove the airborne inside the room to the outside. Besides, the building material also affected the radon concentration in this study (Gillmore et. al 2005; Groves-Kirby et. al 2009; UNSCEAR 2009; Khateeb et. al 2017). MN15 was built in 1989 using red bricks and painted it, while MN11 was constructed in 1996 from cement and painted. The table shows the red bricks have high reading compared to the cement according to WHO (2001), Haquin (2008) and Ahmed et. Al (2010).

The difference of the range of radon concentration between Malaysia Nuclear's buildings and RN42 was particularly significant during the weekend due to the temperature, geographical location and daily activity inside the room (Gillmore et. al 2005; Groves-Kirby et. al 2009; UNSCEAR 2009; Khateeb et. al 2017) . RN42 is located in hill area and have lower temperature, while both MN11 and MN15 buildings are located on the edge of Bangi area and have high temperature compared to Cameron Highlands.

Table III: Average of radon concentration

Building	Radon concentration, Bq/m^3	
	Weekdays	Weekends
MN11	35.7	254.9
MN15	115.4	341.1
RN42	34.7	24.2

It clearly shows the different measurement of radon concentration in all study areas during weekdays and weekends in Table III. The mean of radon concentration in MN11 is 35.7 Bq/m^3 on weekdays and 254.9 Bq/m^3 at the weekends. While the average of radon concentration in MN15 on both weekdays and weekends are 115.4 Bq/m^3 and 341.1 Bq/m^3 respectively. Meanwhile, the average radon concentration in RN42 is the lowest compared to MN11 and MN15 on weekdays and weekends which are 34.7 Bq/m^3 and 24.2 Bq/m^3 respectively. The readings of radon concentration on weekends of RN42 is maintained at low reading because the room was used by the guests who visited the station and it does not have the air conditioner in the room. So the door at this room was opened to ensure a good ventilation.

In this study, the readings of radon activity obtained were higher than previous researchers who stated that the range of radon activity at five locations Malaysia is 11.1 Bq/m^3 to 56.98 Bq/m^3 and does not exceed USEPA's action level of 148 Bq/m^3. This study representing the different types of settlement such as the city, housing complex, traditional residential area at five different locations; Ampang, Selangor; Kampung Gajah,Perak; Lumut, Perak; Shah Alam, Selangor (Saat et al. 2007). Overall, the average of radon activity on the weekends is higher than weekdays. However, both readings are still low compared with 400 Bq/m^3 referring to the standards by the National Radiological Protection Board (NRPB), United Kingdom and the Economic European Community (EEC) (Ravikumar et al., 2013). On the other hand, present results show the low level of radon compared to ICRP standard values which is 1500 Bq/m^3 (ICRP 2013).

2.2 Annual Effective and Equivalent Dose

The annual effective dose is calculated on weekdays only for MN11 and MN15, while for RN42, it involved both of the weekdays and weekends because they work 24 hours per day. According to the Table IV, the highest annual effective dose and annual equivalent dose is MN15, followed by MN11 and RN42. From the results, the doses are still below the standard by ICRP for workers is 10 mSv and 20 mSv (Jing 2005; ICRP 2007; ICRP 2014).

Table IV: Annual effective dose and annual equivalent dose

Building	Annual Effective dose, mSv/year	Annual Equivalent dose, mSv/year
MN11	0.096 ± 0.038	0.231 ± 0.091
MN15	0.311 ± 0.098	0.747 ± 0.236
RN42	0.093 ± 0.022	0.224 ± 0.052

4. Conclusions

All the objectives of this study successfully studied. MN15 has the highest readings of radon activity on both weekdays and weekends, followed by MN11 and RN42. All study areas shown the different measurement of radon concentration due to several factors such as ventilation, weather and type of building materials. The annual effective dose and annual equivalent dose were calculated to be in the range of 0.093-0.311 mSv and 0.224-0.747 mSv. These values are still low and below the action levels recommended by ICRP which are 10 mSv and 20 mSv.

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