Soil radon detection using active scintillation cell

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\textbf{ABSTRACT}

The paper herein is intended to present the registration efficiency of 300A alpha-scintillation active cell and its application in the field of soil radon detection. In this work, a radon chamber based on a natural radon source has been constructed. This chamber allows calibration of the active scintillation cell under flow-through condition. Radon source has been designed, constructed, and the radon concentration output has been measured. It has been observed that a steady radon concentration can be obtained inside the chamber after a period longer than 30 days. The steady radon concentration inside the chamber is equal to 123.58 Bq/m\textsuperscript{3}. It is found that the registration efficiency and the sensitivity of the cell are equal to 0.69 and 1.243 CPM/pCi/l, respectively. After determining the calibration parameters of the cell, soil radon gas survey was carried out in the university city of Najran. It is found that the average radon activity concentration in the tested area is equal to 1332 ± 66 Bq/m\textsuperscript{3}. Results of sensitivity and efficiency evaluation, along with radon measurements, are addressed and thoroughly discussed.

\section{Introduction}

Radon is an inert and radioactive gas that can be emitted from rocks, soil, and building materials. It is clear that exposure of people to radon and its daughters can be one of the main causes of lung cancer. Measuring the concentration of radon in soil and at home is important for assessing health risks to people (Nisar et al., 2019). It is known that radium is present in soil, groundwater, natural gas, rocks, and various building materials (Saad et al., 2013). Many world organizations have reported risks related to radon emissions, according to the report published by World Health Organization (WHO) (2009); when the radon concentration level reaches 100 Bq/m\textsuperscript{3}, there is a high probability of increasing the risk of lung cancer. The radiation protection agency, Saudi Arabia (KSA) has adopted WHO action reference levels of 0.1 kBq/m\textsuperscript{3} (Abdulrahman & Aleissa, 2014). Moreover, after smoking, the exposure to radon is the second leading cause of lung cancer according to the US Environmental Protection Agency (US Environmental Protection Agency [EPA], 2007). Over the past decades, Environmental accidents caused by radon have been under study due to harmful effects on human health (Alonso et al., 2019; Hosoda et al., 2007). It is known that short-lived radioactive radon progeny decays by high-energy alpha particles; if the radon daughters deposit on the lung tissue, it will damage its cells. Also, in uranium mining, the concentration of radon atoms may be high to cause lung cancer (EPA, 2007).

Radon atoms are moving from soil and rocks to atmosphere by two methods, diffusion and convective flow (Etiophe & Martinelli, 2002; Kristiansson & Malmqvist, 1982; Shweikani et al., 1995; Sundal et al., 2008; Zmazek et al., 2006). The EPA report stated that, for most dwellings, the principal source of indoor radon gas concentration is the soil air which enters the dwellings through cracks and unsealed openings (EPA, 2007). It is known that the environmental parameters (atmospheric pressure, temperature, humidity, and geological structure and soil properties) affect the escape of radon from the soil to the atmosphere (De Jong et al., 1994; Swakon et al., 2005; Vaupotic et al., 2007). Also, radon diffusion length is responsible for radon diffusion through the pores in building materials and soil. At the same time, convection is caused by the pressure difference between the soil and air due to environmental parameters (heating and ventilation) (Narula et al., 2009 and Abu-Jarad & Al-Jarallah, 1986).

Determination of the specific activity concentration of radon in soil is useful, because radon concentration in soil may provide a basis for the prediction of the radon built in cretin areas or regions. A number of studies on the level of radon in Saudi Arabia have been completed but are still limited (Abu-Jarad & Al-Jarallah, 1986; Al-Ghamdi et al., 2011a, 2006, 2011b, 2014; Al-Jarallah et al., 2003; Alyami et al., 2010). The concentration of radon can be measured either by the detection of charged alpha particles or gamma rays emitted by radon and its progeny with short half-life time (El-Sammam et al., 2002). A scintillation cell lined with a layer of silver-activated zinc sulfide is often used for radon measurements. Measurements can be done in steady state or flow through (Eappen et al.,
This cell can be used for environmental application (radon gas in air and soil). In case of environmental air, radon sample from air is pumped inside the cell. The radon daughters have been filtered by using a filter. The activity concentration of radon has been evaluated using the efficiency parameter of the scintillation cell, theoretical factors resulting from the accumulation of radon progenies in sampling, and the delay time of counting. The principle of radon detection is based on the interaction of alpha particles with scintillation materials (ZnS), calculation of photons resulting from the interaction of the alpha particles produced by radon, and its progeny with the scintillator. Photomultiplier tube multiplicities the number of electron produce as a result of the interaction of photons with photoactive material (Eappen et al., 2008). Owing to the high detection efficiency and good sensitivity, alpha-scintillation cell is being adapted for measurements of radon (222Rn) concentration in the soil (Michael et al., 2014). Since the most significant source of radon is the subsoil, radon in soil must be measured. This work is contributing to the radon survey data in Najran, Saudi Arabia. The main aim of this study is to calibrate 300A active cell and determine the concentration of radon in the soil inside the university city of Najran, which is the main source of radon in nature, in order to classify the university city of Najran from radon risk perspective.

2. Methods

2.1. Study area

Najran is a city that lies in southwestern Saudi Arabia. It contains three geographical areas. The mountainous area in the west and the north is distinguished by granite rocks, which are considered as the main source of radon in nature. The flat area is located in the middle of Najran. The sandy area, which lies in the east, is a part of the Empty Quarter. Najran city is one of the most cities containing granite rocks so measuring the radon in the soil is indispensable to predict the level of radon in buildings. Soil radon gas concentration was measured in the university city of Najran. The soil samples have been measured on a total area of 18,000 km². In this project, radon concentration in 70 samples was measured. In order to survey all the geological sites in the university city of Najran, samples were taken from different places covering the area under study.

2.2. Calibration process

AB-5 Radiation monitor and scintillation active cell (300A) have been used for calibration. Not only for the high price of radioactive sources but also for the need of many import procedures, the calibration process has been done by the local radon calibration system. The local calibration system is operated by a radon source consisting of the raw granite ore, since granite is the main rocks in Najran. According to the literature, granite contains a considerable amount of natural radioactive material (Al-Azmi, 2009; Sutej. et al., 1988). In this work, the alternative and temporary natural radon source that contains 10 kg of granite from Najran city was used after grinding into powder form. Also, polyethylene membrane was used as a filter to prevent 220Rn &219Rn radon isotopes from diffusing into the active volume of the radon detector (Sutej, et al., 1988). For calibration, the granite ore was stored after being ground in a metallic cylindrical barrel for 3 months to obtain the highest concentration of radon and reach the secular equilibrium between radon and its daughters. The granite ore was placed in polyethylene bags to prevent dust births from entering the detector during calibration, as shown in Figure 1. Also, inside the metallic cylindrical barrel, the raw material was placed in a PVC cylinder containing holes covered with filter paper. The radon source has two openings with its cover in the high face of the source, with a diameter of 15 cm and 5 cm, respectively, to handle samples and other instruments. The radon source has two gas tight valves to control the flow of radon gas through the system.

Experimental determination of sensitivity and efficiency was performed by irradiation of 300A Cell in a radon calibration system; as depicted in Figure 2, the local radon calibration system consists of (AB-5) radon monitor (AB-5), flowmeter to measure the flow of radioactive radon gas inside the system, and radon source. Before the calibration process, the average activity of radon inside the radon source has been determined by stander cell with AB6 radon monitor. An active standard Lucas cell (610A) attached with radon monitor (AB6) was used to evaluate the activity level of radon during the experiment. Figure 3 shows the accumulation of radon within the source. Figure 3 depicts that radon accumulates at a rapid rate in the first 8 days and then decreases the accumulation rate. The radon concentration reaches a fixed amount after approximately 26 days. Figure 3 clears the growth of radon gas activity with time inside the source. It is clear that the average value of radon gas is 123.58 Bq/m³ (Abdalla, 2019a). During nine intervals, the average cell efficiency and sensitivity were calculated. Using Equations (1)and 2), the registration efficiency of the cell has been determined for radon gas concentration measurements. Table 1 depicts the values of the sensitivity and the calculated registration efficiency. It is found that the registration efficiency and the sensitivity of the cell are equal to 0.69 and 1.243 CPM/pCi/l, respectively. There is a considerable agreement between the calibration results and the published data for 610A radon cell (Abdalla. et al., 2019b):
\[ C_{\text{Rn}} (\text{PCi/l}) = \frac{\text{CPM} - \text{BG}}{G}, \]  

(1)

where \( C_{\text{Rn}} \) is the radon concentration, \( \text{CPM} \) is the average of the 12-min count converted to counts per minute (cpm), \( \text{BG} \) is the average background count based on a 5-min count converted to a count per minute. \( G \) is the sensitivity.

\[ G = (\varepsilon \times K \times V), \]  

(2)

where \( G \) is counting efficiency, \( \varepsilon \) is the conversion of dpm to pCi (2.22), \( K \) is the approximate number of alpha emitters (2), \( V \) is the volume of gas sample in liters (0.272).
2.3. Qualitative estimation of radon in soil

The active scintillation cell is used for radon concentration measurements for a long time (Papastefanou, 2002). The active cell used in this work has a volume of approximately 272 ml (Pylon Electronics Inc, 2009). Figure 4 depicts the system used to investigate the specific activity of radon level concentration in the pore soil with the help of a manual pump. At each site, a hole was drilled to a depth of 65 cm. Air samples were withdrawn using an evacuated scintillation cell. The depth of the hole has been adjusted to be as close as possible to the surface of the earth. A qualitative estimate of radon in soil was obtained by using Equation (1) (Pylon Electronics Inc, 2009). To collect samples from the soil, the following steps have been used:

(a) With AB-5 turned off, remove the protective cap from the PMT tube housing.
(b) Connect the ABA to the AB-5 by screwing the assembly onto the PMT housing.
(c) Insert and fasten a 300A cell in the ABA.
(d) Connect the tube from the vacuum gauge on the Pylon model 154 vacuum soil probe to one connector on the 300A cell.
(e) Connect the vacuum pump to the other connection on the 300A cell.
(f) Turn the AB-5 on. Set it to continue mode and 1-min intervals.
(g) With an appropriate boring tool, drill a hole that is approximately 2.5 cm in diameter to a depth of approximately 65 cm.
(h) Insert a small amount of cotton into the probe inlet to filter any loss material from the hole. The cotton should be inspected before each use for clogging.
(i) Gently insert the probe into the hole, see Figure 4. More details about the qualitative estimation of radon in soil can be seen in (Pylon Electronics Inc, 2009) manual soil radon probe instruction sheet.

3. Results and discussion

3.1. Soil radon level

After calibration, 300A active scintillation cell was used in local radon concentration survey inside the university city of Najran, Saudi Arabia. The level of radon gas concentration in the soil in the university city of Najran has been determined, at a depth of 65 cm below the ground by using a metal pipe probe and vacuum gauge (Neznal et al., 1996). The experimental results will be important to evaluate the radon potential due to naturally radioactive isotopes existing in the earth’s crust. Samples of soil air have been collected by a pylon soil probe, as shown in Figure 4. The activity of the radon in the soil has been investigated in situ using the AB-5 radon monitor. The background of the system has been determined before each sampling. In the present work, the activity of radon level in 70 samples, at University city of Najran, Saudi Arabia (KSA), was investigated using alpha-scintillation cell (300A). After each sample is measured, the cell is purified using nitrogen gas. Nitrogen gas flows within the cell for 5 min. The radiation background of the cell is measured before each measurement process. Table 2 depicts the results of soil radon levels. Table 2 depicts typical levels of the specific activity of radon concentration as investigated by using an active scintillation cell. One can summarize the results of this survey in the following points, the average value of radon concentration in the soil is 1332 ± 66 Bq/m² (with minimum value 115 ± 6 Bq/m² and maximum value 3372 ± 168 Bq/m²). Among the 70 samples, the highest detected values of the concentration of radon in the soil have been detected in two of the samples (11,090 & 9576 Bq/m²), as shown in Figure 5. The measurement was repeated at the same location of the sample and no high values were obtained for radon concentration, which confirms the low
Table 2. Soil radon gas concentration for 70 samples in the university city of Najran.

| Sample number | Radon concentration Bq/m³ | Sample number | Radon concentration Bq/m³ | Sample number | Radon concentration Bq/m³ | Sample number | Radon concentration Bq/m³ |
|---------------|---------------------------|---------------|---------------------------|---------------|---------------------------|---------------|---------------------------|
| 1             | 285 ± 14                  | 15            | 551 ± 27                  | 29            | 1425 ± 71                 | 43            | 318.3 ± 15                |
| 2             | 1014 ± 50                 | 16            | 396 ± 20                  | 30            | 1425 ± 71                 | 44            | 906.9 ± 45                |
| 3             | 740.3 ± 37                | 17            | 1225 ± 61                 | 31            | 732.9 ± 36                | 45            | 910.6 ± 45                |
| 4             | 721.8 ± 36                | 18            | 1370 ± 68                 | 32            | 684.8 ± 34                | 46            | 1451 ± 72                 |
| 5             | 11,090 ± 554              | 19            | 9576 ± 478                | 33            | 1555 ± 77                 | 47            | 1547 ± 77                 |
| 6             | 1003 ± 50                 | 20            | 114.7 ± 5                 | 34            | 1669 ± 83                 | 48            | 1895 ± 92                 |
| 7             | 503.4 ± 25                | 21            | 892.1 ± 44                | 35            | 1718 ± 85                 | 49            | 1177 ± 58                 |
| 8             | 1099 ± 54                 | 22            | 1473 ± 73                 | 36            | 1299 ± 64                 | 50            | 1329 ± 66                 |
| 9             | 721.8 ± 36                | 23            | 1395 ± 69                 | 37            | 1229 ± 61                 | 51            | 1470 ± 73                 |
| 10            | 229.5 ± 11                | 24            | 1518 ± 75                 | 38            | 1144 ± 57                 | 52            | 1181 ± 59                 |
| 11            | 129.6 ± 6                 | 25            | 1085 ± 54                 | 39            | 1085 ± 54                 | 53            | 1099 ± 54                 |
| 12            | 155.5 ± 7.7               | 26            | 1314 ± 17                 | 40            | 910.6 ± 45                | 54            | 684.8 ± 34                |
| 13            | 1340 ± 67                 | 27            | 1059 ± 52                 | 41            | 329.4 ± 16                | 55            | 1059 ± 52                 |
| 14            | 381.3 ± 19                | 28            | 1036 ± 52                 | 42            | 507.1 ± 25                | 56            | 921.7 ± 46                |

Figure 5. Soil radon gas concentration for 70 samples in the university city of Najran.

Concentration of radon in the university city of Najran. Considerable agreement between the average radon concentration measured in this work (1332 Bq/m³) within the average radon concentration (1439 Bq/m³) measured in other places in Saudi Arabia has been noticed (Al-Ghamdi, 2014); the registered significant differences in the concentration of soil radon gas in the investigated region can be attributed to meteorological and geological factors.

To estimate the radon risk in Najran University city, the following expression has been used to investigate the potential of the soil due to radon gas (RP) (National Council on Radiation Protection and Measurements, 2009).

\[ RP = \frac{(C_{Rn} - 1)}{(-\log K - 10)} \]  

Knowing that \( C_{Rn} \) is the radon concentration level in the soil (kBq/m³), and the constant of the soil permeability is \( K \) (m²), in the study, the soil permeability is \( 2.4 \times 10^{-11} \) m². In these calculations, the concentration values of less than 1 kBq/m³ were excluded. According to the latest studies on radon concentration to assess the risk of radon concentration in buildings, the soil radon potential can be classified into the following ranges:

- RP < 10 for low danger,
- 10 ≤ RP < 35 for medium danger,
- And, RP ≥ 35 for high danger and it is dimension-less (Neznal & Neznal, 2005).

Figure 6 depicts the radon potential (RP) of the studied sites in university city of Najran. Based on modern ways of danger assessment of radon, the majority of the measured samples show low radon risk (RI), for which the radon potential RP <10. It can be said that the buildings inside the university city of Najran are safe from the dangers of radon while maintaining good ventilation for buildings and material stores. To assess the level of radon inside the houses in Najran city, radon concentration will be measured in some housing in the city. Because the Najran city geology has not been well described and there are many granite rocks, this work illustrates the need to
4. Conclusion

The specific activities of 222Rn were tested by using alpha-particle scintillation cells in 70 different soil samples. It can be seen from the result that the average soil radon concentration is $1332 \pm 66$ Bq/m$^3$. The results of this study showed that the degree of radon risk is low (RI), where the radon potential RP <10. In addition, given these experimental results, this study shows that measured soil samples were within recommended safety limits and did not constitute an important source of radiation risk.

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