A Study on Radon Gas and Lung Cancer Incidence in Indoor Environment in Oman

Dr. K. H. Jonathan, Dr. P. Suvarna Raju

***Abstract*— Indoor air pollution is a growing health concern in the present urbanized world caused by increased use of radioactive materials. Many studies are being done to estimate and identify the sources of radioactive energy and its incidence in the indoor environment and subsequent implications on the human health. Radon is a color and odorless gas and enters indoor environments from ground surfaces and concentrates over time in absence of ventilation and the release from the soil varies on many ambient factors that changes temporally and spatially. The indoor concentrations of radon gas have serious effect on health and results in cancer among humans from the long-term exposure. The paper emphasizes to analyze the impact of radon gas in indoor and outdoor locations in Muscat region and compare the emissions with other GCC countries. Experiments are done at three stages using equipment by choosing some prominent building locations in Muscat region to estimate the indoor and outdoor levels of radon gas and consequently assess the implications. Gamma ray spectrometers are employed to detect the radiation from the chosen locations and the values recorded. The investigation reveals significant amounts of radon gas detected in comparison with other Arab countries in GCC but substantially less from developed countries. The study shows the concentration and presence of radon gas in indoor habitats relates to construction materials and the level of ventilation. The results indicate that radon gas concentrations during the study showed fluctuating intensities weekly with generous changes during each week.**

***Index Terms*— Air pollution, Indoor, Radioactive, Radon**

I. INTRODUCTION

Radioactive materials currently are being increasingly used in many different sectors of life, such as medicine, industry, agriculture, military, research, and scientific studies to explore new possibilities and applications. Despite the many benefits of this radioactive energy, they cause damage and pose a serious hazard to human life and the environment by the quality of radiological and nuclear accidents that occur as result of the improper use or human error.

The radioactive elements in nature exist in the crustal layers of earth, building materials, water and air adding to the overall radioactive emissions on earth. The levels of radioactive elements in the indoor environment especially radon occurrence is increasingly felt in most of the human dwellings. *Radon* is a cancer-causing radioactive gas and varies widely from place to place. Radon mostly appears with the decay chain of the radium and uranium series (^{222}Rn), and marginally with the thorium series (^{220}Rn). The element emanates naturally from the ground, and some building materials, all over the world, wherever traces of uranium or thorium can be found, and particularly in regions with soils containing granite or shale, which have a higher concentration of uranium. Radon seeps from the soil to the surface and the concentration of this gas in the air and can be found in some spring waters and hot springs. Epidemiological studies have shown a clear link between breathing high concentrations of radon and incidence of lung cancer. Thus, radon is considered a significant contaminant that affects indoor air quality worldwide [1]. There is a scope for studying the impact concentration of radon gas at different locations in the region that necessitates providing information on the prevalent emissions conditions of radon gas from different sources.

This paper explicitly discusses the impact of radon gas by analyzing the indoor and outdoor concentrations in some building locations in Oman and comparing the emission concentrations of the radon gas in Oman region with other GCC countries. This work also emphases on identifying the sources of radon gas in the environment and the incidence of lung cancers in Oman and GCC that would provide some appropriate recommendations and protection to aid indoor and outdoor inhabitants from the exposure of radon gas.

A. Source of radon gas in environment.

Radon is a chemical element with symbol Rn, radioactive, colorless, odorless, tasteless noble gas, occurring naturally as an indirect decay product of uranium or thorium. Its most stable isotope, ^{222}Rn, has a half-life of 3.8 days [1]. Radon is the only gas under normal conditions that has radioactive isotopes, and is considered a health hazard due to its radioactivity. Intense radioactivity has also hindered chemical studies of radon and only a few compounds are known. There are four basic sources of radon in buildings and probably the largest source in areas where uranium is prevalent in the soil. In general, the concentration of radon inside buildings depends on habitats, standard and type of dwellings and methods of ventilation. The extent of gas can be reduced by use of sealants on basement floors and walls and a sensible precaution in regions of high radon concentration [2], [3]. Radon gains entry through secondary routes such as from various building materials used like granite stone or phosphate rock containing high content of uranium or radium. Such areas, the indoor radon levels will be considerably higher for example, in Sweden, alum shale was often used in formulating concrete for home construction. This shale was relatively high in uranium and contributed significantly to radon levels in thousands of building. If reservoirs or other fresh water sources exist in areas where uranium is present in the rock or soil, radon will be present in the water body in

Dr. K. H. Jonathan, Health, Safety and Environmental Management Department, International College of Engineering and Management, Muscat, Oman, + 968 9814 5830

Dr. P. Suvarna Raju, Health, Safety and Environmental Management Department, International College of Engineering and Management, Muscat, Oman, + 968 9294 8237

solute form. Consuming such infused water releases radon and its daughter products into the digestive systems and certain portion of radon gas gets released into the environment and reaches atmosphere through water discharge from bathing and washing etc. [4]. Radon gas also prevails in the indoor environment from gas powered stoves and room heaters.

Natural gas emerging from the ground may contain between 1 to 1500 pCi. Since radon in natural gas is separated from its solid parent source, it will decay during transfer and storage, so the amount present in the gas reaching our building may be much less than this [4]. Outdoor, radon quickly dilutes to very low concentrations and is generally not a problem. The average outdoor radon level varies between 5–15 Bq/m^3. However, indoors, radon concentrations are higher, with highest levels found in places like mines, caves, and water treatment facilities. In buildings, such as homes, schools, and offices, radon levels in the range of 10 Bq/m^3 to more than 10 000 Bq/m^3 have been found and the worldwide average indoor radon concentration has been estimated at 39 Bq/m^3 [5].

The primary source of radon in environment is ground (water, soil, and rock) and around 80% of radon gas [6], emanates outside from the central layers to the outer layers of the earth. Humidity, temperature and building materials likewise influence the radon exhalation from the sources [6]. Also, the presence of radium- 226 and uranium -238 in the different layers of the earth signifies the presence of radon gas in the soil and varies from location depending on the geological nature. In general, the rock in the earth's crust contains about 1 Bq/m^3 and about 0.7 Bq/m^3 in the soil [6]. Each disintegration of radium atom present in the soil or rock grains will give radon atom. The amount of the release of radon from soil depends on several factors, including permeability, soil moisture and studies have estimated that about 10% of the radon gas is generated at one meter off the surface of ground [7]. The oceans release approximately 1% of the concentration of radon into the outer area from the inner layers of the earth [6], since the sea water content of uranium and radium are much smaller than the soil and rock.

There are also other factors that affect the concentration of radon in buildings such as humidity and temperature while the latter plays an important role, because it is usually the temperature inside the buildings is higher than outside. This causes a slight difference in pressure leading to air suction from the soil beneath the building to the inside area of house, which in turn can raise the concentration of radon inside the house. Earlier reports have also supported that the concentration of radon in homes vary from season to season, from month to month and from day to day.

B. The risk of lung cancer in Arab league.

Radon gas exposure is considered the second major source of lung cancers in general population next to smoking [8] and risk factors of lung cancers alone increase by 8 % to 16% for every 100 Bq/m^3 increase in radon concentration [9]. United States Environmental Protection Agency (EPA) estimates that one in 15 homes in the U.S. has radon levels above the recommended guideline of 4 picocuries per liter (pCi/L) (148 Bq/m^3) [10]. Within GCC countries lung cancer was the most common cancer in males in Bahrain, Qatar and UAE and ranked 2nd, 3rd and 4th in Kuwait, Oman, and Saudi Arabia respectively [11].

II. METHODOLOGY

A. Experimental setup

The equipment that was used to collect the air from the atmosphere is high volume dust sample. The instrument consists of an air pump and fiber glass filter as shown in Figure 2. Gamma ray spectrometers HPGe was used to detect the radiation count from the sample. The energy calibration system and efficiency calibration, standard sources were measured.

A gamma-ray spectroscopy system consists of a detector and high voltage power supply for the detector, pre-amplifier, amplifier, analog-to-digital converter, multi-channel analyzer, and an output device as shown in Figure 1. The sample is presented to the detector and a pre-amplifier is attached directly to the detector to amplify the signal. The signal is shaped by the spectroscopy amplifier and then converted from an analog to a digital signal by the analog-to-digital converter. The results are stored in digital form multi-channel analyzer. Spectrum results and calculations are visually plotted on personal computer.

Calibration is performed by using the peaks of a known source, such as caesium-137 or cobalt-60. Because the channel number is proportional to energy, the channel scale can then be converted to an energy scale. If the size of the detector crystal is known, one can also perform an intensity calibration, so that not only the energies but also the intensities of an unknown source or the amount of a certain isotope in the source can be determined.

Because some radioactivity is present everywhere like background radiation, the spectrum should be analyzed when no source is present. The background radiation must then be subtracted from the actual measurement.

B. Experimental procedure

The procedure is performed in three sections, dust collection, energy calibration system and measurement.

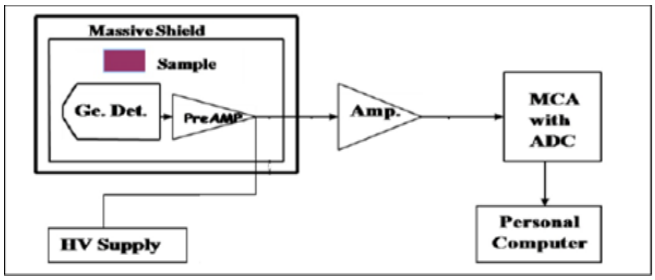

Fig 1: The experimental setup

Fig 2: The equipment of experimental setup (a) filter (b) air pump and (c) HPGe detector

C. Dust collection

Prior to dust collection the mass of the fiber glass filter was measured to determine the weight of dust sample. Then the air pump was run for 2 hours to collect one air dust sample from

indoor location. From the air pump the flow rate was recorded and the volume of the air passing through the filter was obtained. Later, the mass of the filter was measured again to measure the mass of the dust.

D. Dust collection

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E. Energy calibration system

The standard sources of radionuclides with defined energies were used to calibrate the germanium detector system. These sources were ^{241}Am, ^{57}Co, ^{137}Cs and ^{60}Co.

F. Measurement

The background radiation was measured for 1 hour by using the gamma ray spectrometer. Then the filter was placed in top of the detector and the sample was performed for the same time and then corrected for the background. The experiment was repeated in the outdoor location once a week for over 5 weeks.

III. RESULTS AND DISCUSSION

A. The measurement of radon gas in indoor and outdoor locations.

For each sample the mass of dust was measured and the flow rate was also recorded for each sample. The volume of a sample collected from air was calculated from the flow rate and the time of flow as;

$$Volume = Flow\,rate \times Time$$

After measuring the sample activity for 1 hour and each data was corrected for the background. Then the spectrum was plotted for each sample as shown in Figure 3. From the software programme, the nuclides that are found in the dust, activity of each nuclide, its energy and the branching ratio of each nuclide were collected for each sample (appendix 2), were determined.

In the indoor sample, the nuclides identified were ^{212}Bi, ^{212}Pb, ^{214}Bi and ^{214}Pb. ^{212}Bi and ^{212}Pb are $^{2\ 20}$Rn daughters; while ^{214}Bi and ^{214}Pb are ^{222}Rn daughters.

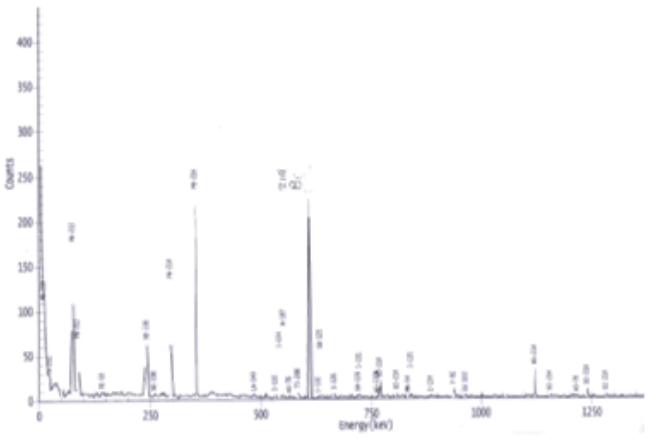

Fig 3: The spectrum of indoor sample

Time (Day)	^{212}Bi A (Bq/m^3)	^{212}Pb A (Bq/m^3)	^{214}Bi A (Bq/m^3)	^{214}Pb A (Bq/m^3)
09-Nov	0.60±0.20	0.84±0.07	8.78±0.29	6.25±2.52
16-Nov	0.14±0.03	0.07±0.01	0.74±0.01	0.58±0.01
23-Nov	0.03±0.01	0.03±0.01	0.34±0.01	0.20±0.01
30-Nov	0.14±0.03	0.41±0.02	4.51±0.16	2.96±0.10
07-Dec	0.02±0.01	0.54±0.09	0.34±0.01	5.07±0.76
Average	0.18±0.06	0.38±0.04	2.94±0.09	3.01±0.68

Table 1: shows the activity concentration of each identified nuclide in indoor environment

From the data in Table 1, the activity of each nuclide versus the time was plotted and shown in "Fig." 4.

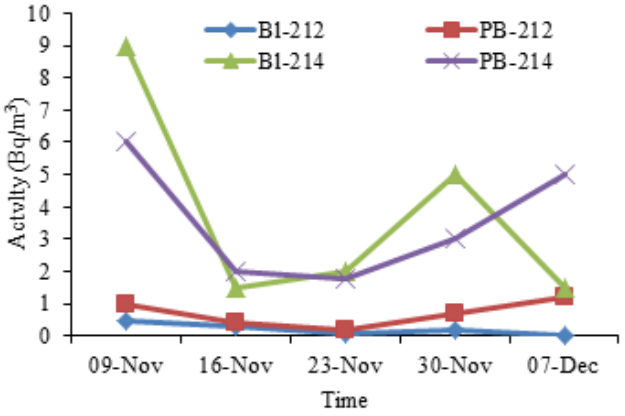

Fig 4: showing the activity of nuclide with time

From the above graph, it is evident that the nuclides concentration fluctuates weekly. The ^{214}Pb has the highest average concentration with (3.01 ± 0.68) Bq/m^3. The ^{214}Bi has an average concentration of (2.94 ± 0.09) Bq/m^3. The ^{212}Pb has an average concentration of (0.38 ± 0.04) Bq/m^3. The ^{212}Bi is the less one on concentration and its average concentration is (0.18 ± 0.06).

Nuclide	A (Bq/m^3)	λ (s^{-1})	N (m^{-3})	E (MeV)	NE (MeV m^{-3})
BI-212	0.18± 0.06	1.91E-04	(9.53± 2.88) E+02	7.8	(0.74±0.23) E+04
PB-212	0.38± 0.04	1.81E-05	(2.09± 0.22) E+04	7.8	(1.61±0.17) E+05
BI-214	2.94± 0.09	5.81E-04	(5.06± 0.17) E+03	7.69	(3.89±0.13) E+04
PB-214	3.01± 0.68	4.31E-04	(6.99± 1.58) E+03	7.69	(0.54±0.12) E+05

Table 2: PAEC of identified nuclide

PAEC is the sum of the potential alpha particle energy of all the short-lived radon or thoron daughters in a unit volume of air during their decay to Pb and Pb, respectively.

$$PAEC = \Sigma\, N\, E \quad (1)$$

$$N = A/\lambda \quad (2)$$

$$\lambda = ln^2/T_{1/2} \quad (3)$$

The potential alpha energy concentration (PAEC) was calculated by the number of daughter atoms of each type per unit volume of air multiplying these numbers by the potential alpha particle energy associated with each type of atom and then sum by using equation (1). The number of atom of radionuclide associated with an activity A was calculated by using equation (2) and the λ is the constant decay which is calculated by using equation (3). The data collected is shown in Table 2. From Table 2, the PAEC was calculated as $(2.62 \pm 0.17) \times 10^5$ MeV/m^3 from the sum of the last column.

The radon concentration was calculated by using the concentration of ^{214}Pb which decays from ^{218}Po with branching ration of 100% and ^{218}Po was produced from Rn-222 with branching ratio of 100%, so by using the number of atoms of 214 Pb and half-life of radon, the average radon concentration of indoor samples was calculated as (21.14±0.01) Bq/m^3.

In outdoor sample, the spectrum was plotted as shown in Figure 4, has one identified nuclide which was ^{214}Pb with concentration of (0.12 ± 0.03) Bq/m^3. The concentration of the ^{214}Pb outdoor is less than ^{214}Pb in the indoor sample. The PAEC was calculated as $(2.14 \pm 0.54) \times 10^3$ MeV/m^3. The average radon concentration of outdoor samples was calculated as (0.84± 0.21) Bq/m^3.

In the Arab countries, the radon concentration varied in range of 2-50 Bq/m^3. So, based on the radon concentration assessed in Al Seeb location, is compliant with the range of the concentration in the Arab countries. Through the experiment its signifies that the concentration of radon gas in the first floor is significantly more than the succeeding floors of buildings due to the nearness to the ground/earth surface. This indicates that people living on the first floor are considerably more exposed to radon gas.

B. Emission of radon gas in Oman and other countries.

Radon gas prevalence across different countries in the world reveal that the concentrations are widespread. In North and Central America, the US and Canada have the concentration of radon generally range between 30-184 Bq/m^3.

Mexico, the concentration varied across locations with the average maximum recorded concentration was 1740 Bq/m^3 (SMC, 2012). Australia and New Zealand has average radon concentration level generally in the range of 7-25 Bq/m^3 while the maximum value was recorded as 420 Bq/m^3 [5].

In Brazil and Ecuador, the average radon concentration varies in the range of 50-100 Bq/m^3 and the maximum value of radon level was recorded in Brazil with value of 346 Bq/m^3 [5].

In Asia, radon concentration level varies from 10-200 Bq/m^3 in different countries. The radon concentration in Russia, Iran, India, and South Korea are in the range of 40-100 Bq/m^3. In Japan and Thailand, the radon concentration varies between 7- 25 Bq/m^3. In Oman, the ^{222}Rn was calculated as (21.14 ± 0.01) Bq/m^3 for indoor sample and (0.84 ± 0.21) Bq/m^3 for outdoor sample. The radon concentration in Al Seeb follows within the range of radon concentration detected in Arab countries which is 2-50 Bq/m^3.

C. The risk rating of lung cancer between Oman and GCC as result of radon gas.

The estimated attributable portion of lung cancer cases in Oman is reported from various activities, for example; active smoking, radon, occupational carcinogen, and outdoor air pollution. The lung cancer cases reported through active smoking is around 60 percent while from the exposure to radon gas is nearly 23% and occupational exposures to carcinogens in workplaces account for approximately 15 percent. Almost 2% of lung cancer cases are result of outdoor air pollution. Because of the interactions between exposures from various portions, the combined attributable risk for lung cancer can exceed 100 percent. Lung cancer incidences are highly reported and are caused from occupational exposures of asbestos, uranium, and coke which is major fuel in the manufacture of iron, blast furnace and foundries.

There is positive relationship between asbestos exposure and smoking to the increasing development of lung cancer risk around the world. Environmental exposures also can increase the risk of lung cancer death through asbestos. Research studies reveal that among nonsmoking workers exposed to asbestos are five times more likely to develop lung cancers than nonsmokers not exposed to asbestos. Apparently, the combined case of smoking and exposure to asbestos can significantly increase the risk of lung cancer beyond 60%. Hence, the radon exposure is estimated to be the second leading cause of lung cancer after smoking that is leading to around 231 lung cancer deaths each year in Oman.

The main risk of radon gas exposure is leading to lung cancers as described from data shown in table 3. Which compelled the food and water laboratories center of the Ministry of Regional Municipalities and Water resources for assessing the risk of gas concentration rate of radon in human dwellings. On an average an individual spends around 7000 hours/year indoor and resides outdoors around 1760 hours/year. From the data obtained through the national center for statistics & information from ministry of economy, on the human population in the nine cities of Oman, there are 11,94,209 inhabitants residing until 2010.

City	Al'seeb	Nizwa	Salalah	Sohar	Sur	Musandam	Thumrait	Ibri	Ibra
Population	302992	84528	172570	140006	111711	31423	121087	116416	113476
Radon concentration rate (Bq/m^3)	21	22	29	39	25	8	30	14	25
Cancer cases	7	5	26	32	5	1	29	8	10

Table 3: Estimate of annual cases of lung cancer in the cities from radon gas.

The overall concentration of radon gas rate in homes across the nine cities on the average is approximately 22 Bq /m^3 which reveals that the incidence of lung cancer each year because of potential radon is 123 cases. Table 3. shows the estimated incidence of cancer in different cities by population and the concentration of radon in homes. The analysis of Table 3. reveals clear relationship between radon concentration and the type of floor housing depending on the type of construction materials and the type of ventilation used. It is usually expected that the radon concentration in the ground floor is higher than the upper floors because of the differential weight properties of radon gas to air. Persons residing in the ground floor are more affected than people residing in upper floors due to the proximity to the ground surface and thereby the high risk of lung cancers.

IV. CONCLUSION

Gamma ray spectroscopy measurement concentration of samples collected from air in Al Seeb area of Muscat for 5-week period detected the following nuclides 214 Pb, 214 Bi, 212 Pb and 212 Bi in the sample. The 222 Rn was calculated as (21.14±0.01) Bq/m^3 for indoor sample and (0.84± 0.21) Bq/m^3 for outdoor sample. The radon concentration in Al Seeb follows within the range of radon concentration detected in Arab countries which is 2-50 Bq/m^3. The PAEC was also calculated for indoor and outdoor as $(2.62 \pm 0.17) \times 10^5$ MeV/m^3 and $(2.14 \pm 0.54) \times 10^3$ MeV/m^3. Radon is the second most important cause of lung cancer after smoking. The proportion of lung cancers attributable to radon is estimated to range from 3 to 14% of all lung cancers in a country [11].

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Dr. K H Jonathan is a senior lecturer working in health, safety, and environmental management department in International college of engineering and management (ICEM), Sultanate of Oman. He has doctorate in Environmental Sciences from Andhra University and published several research papers in peer reviewed journals nationally and internationally. He has extensive field work experience on Eastern Ghats and mangrove forests of east coast of India. Worked with different esteemed national and international organizations (WORLD BANK, SERP, WWE) and holds memberships with professional bodies such as IOSH, NEBOSH – UK. He is also approved trainer for international accredited health and safety courses. Also, certified reviewer for international journal of engineering research and technology (IJERT).

Dr. P. Suvarna Raju is a lecturer working in health, safety, and environmental management department in International college of engineering and management (ICEM), Sultanate of Oman. He has doctorate in Environmental Sciences from Andhra University and published several research papers in peer reviewed journals nationally and internationally. Formally worked as scientist MS Swaminathan Research Foundation (MSSRF). He has completed NEBOSH-UK certificate in HSW. He has diversified experience in mangrove forests and coastal biodiversity, mangrove consultant for UNEP, UNDP, WORLD BANK funded projects. Former associate professor in Chirala Engineering College. Also, professional member of Indian society of technical education (ISTE) and holds memberships with professional bodies. He is also certified reviewer for international journal of engineering research and technology (IJERT.