

# Determination of Radon in Mine Dwellings of Gauteng Province of South Africa using AlphaGUARD Radon Professional Monitor

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## Abstract

Radon is ubiquitous in the environment and comparable in most of the places on earth, but in some localities its concentration varies by large amounts. This abnormally high amount is usually attributed to anthropogenic activities such as mining. Even with relatively efficient mining operations, high concentrations of radon are released into the air and water leaving a legacy of environmental contamination, which is a health threat to the community nearby. Because radon is a daughter of Uranium (<sup>238</sup>U), higher concentrations are usually found in the vicinity of uranium ore bodies. This uranium is the principal contaminant of concern within the gold mining areas of Gauteng Province in South Africa. In this study, indoor radon gas measurements were performed in mine dwellings from a gold mining area of Gauteng Province in South Africa using the AlphaGuard Radon Professional monitor. Radon measurements were also taken from a control area, geologically similar to the mining environment. The results showed that activity concentrations of indoor radon from mine dwellings in the area ranged between 1.0 to 472.0 Bq/m<sup>3</sup>, compared to 0.1 to 35.0 Bq/m<sup>3</sup> from the control area. The annual effective doses corresponding to the activity concentrations ranged between 0.03-11.89 mSv with a mean value of 3.01 mSv. This average value was higher compared to the results calculated from the control area. This average value of the annual effective dose of radon was also higher than that published for normal areas around the world signifying a potential health concern to the inhabitants of the area.

**Keywords:** Health risk; Indoor radon; Annual effective dose; Mining area; AlphaGUARD radon professional monitor

## Introduction

Mining is responsible for a series of environmental and human health disasters through the production of large volumes of waste into the environment. The global environment we live in contains small amounts of natural radio nuclides that are derived from primordial and cosmogenic sources. This is as a result of the material, from which the earth was formed, about 4.5 billion years ago [1]. It contained many unstable nuclides, which when they decay, continue to expose humankind to radioactivity. In most of the places on earth, levels of natural radioactivity are comparable, but in some localities it varies by large amounts [2]. This abnormally high amount is normally attributed to anthropogenic activities such as mining. Even with relatively efficient mining operations, high concentrations of natural radio nuclides are released into the air and water leaving a legacy of environmental contamination in nearby communities [3].

In Gauteng province, South Africa where mining takes place, gold is extracted from rocks leaving large amounts of the waste that usually contain long lived naturally occurring radioactive elements such as uranium (<sup>238</sup>U), potassium (40K) and thorium (<sup>232</sup>Th). <sup>238</sup>U decays into a number of daughter products that produce radioactive gas in the chain known as radon (<sup>222</sup>Rn) [4]. When radon is inhaled, it increases the risk of lung cancer through its short lived radioactive particles. Some radioactive particles emit alpha radiation inside the body, thereby causing potential damage to cells in the lung. Radon has been classified as a known human carcinogen and has been recognized as a significant health problem the world over [5]. It is reported to be the second leading cause of lung cancer after tobacco smoking [6]. The aim of study was therefore, to determine the indoor concentrations of radon in dwellings around the mine.

## The Study Area

The mining area is in the Gauteng province of South Africa, close to the town of Carletonville and is approximately 70 kilometres southwest of Johannesburg. It lies between 26°18' S - 26°26' S latitude and 27°23' E - 27°31' E longitude. Gold exploration in the area dates back to 1898 and mining started from 1945 to date. The area, approximately 86 km<sup>2</sup>, lies in the lower central part of the Wonderfonteinspruit Catchment Area (WCA), which is the world largest gold and uranium mining basin that covers an area of 1600 km<sup>2</sup> [7].

The mine dwellings are within the mining area, which has several shaft systems, rock dumps and mine tailings that have been accumulated throughout the operating history of the mine. In addition, the mine owns extraction and processing facilities, which beneficiate the gold bearing ore. The topography of the area is relatively flat and the vegetation is largely grassland. The climate is temperate, with temperatures averaging 24°C in summer and 13°C in winter. Annual rainfall is about 750 mm [8]. The study area has a worker population of around 14,000 [9]. There are also some informal settlements within the mining area. Moshawane Village, in the North West Province of South Africa, was chosen as the control area as it is geologically similar to the study area. It is situated close to Mafikeng, the provincial Capital City and lies between 25°47' S - 25°48' S latitude and 25°37' E - 25°38' E longitude.

## Materials and Methods

### Radon-222 Measurement

Radon-222 gas activity in indoor air was measured by the Alpha Guard Professional Radon Monitor. This is a portable piece of equipment

designed for instantaneous and continuous measurement of radon gas activity [10]. Indoor radon-222 concentrations in air were measured over night from the 2 mine villages. Measurements were taken 1 m above ground from 6 houses (3 east villages and 3 west village) from the mine settlements as outlined by [11]. Similar radon-222 gas activity in air was also measured in 2 houses from the control area. The results were then used to estimate the annual effective dose due to inhalation of radon gas.

### The ALphaGuard Professional Radon Monitor

Radon-222 (<sup>222</sup>Rn) is a noble gas produced by the radioactive decay of <sup>226</sup>Ra. It is abundant in uranium-rich soils and rocks and can easily escape into the surrounding water or air [12]. The most common exposure route is through underlying soil gas into buildings. When <sup>222</sup>Rn decays, it produces a series of short-lived daughter radioisotopes [12]. Since it is chemically inert, most of the inhaled <sup>222</sup>Rn is rapidly exhaled, whereas its daughters may deposit in the airways of the lungs. Two of its daughters, <sup>218</sup>Po and <sup>214</sup>Po, emit alpha-particles [13]. When this happens in the lungs, the radiation can damage the cells lining the airways, potentially leading to cancer. Nuclear decay of radon products also releases energy in the form of beta particles and high energy photons, but the biological damage resulting from these emissions is regarded insignificant compared to the effects of alpha particles [13].

The ALphaGuard Professional Radon Monitor is a device that measures <sup>222</sup>Rn [10]. It uses the ionization principle for the measurement of radon in the environment. This detector works on the principle that as radiation passes through air or gas filled space, ionization of the molecules occurs. Figure 1 shows the schematic diagram of a Radon Monitor. This piece of equipment is designed for instantaneous or continuous measurement of radon (<sup>222</sup>Rn) gas activity. Air, water and soil exhalation measurements are performed using a large range of accessories and external probes. A Germany based company called Genitron Instruments GmbH supplied the instrument [10].

The device has an active volume of 0.56 dm<sup>3</sup> and the chamber case is held at a potential of +750 V (anode). By diffusion, the radon flows into the ionization chamber via a glass fiber filter that prevents radon daughters, from the surrounding air from entering the ionization chamber. The alpha particles produced by radon progeny are the ones that ionize the air in the ionization chamber. When a high voltage is applied between two areas of the air filled space, the positive ions will be attracted to the detector (the cathode) and free electrons to the positive side (the anode). These charges collected by the anode and cathode will then form a very small current along the wires as it flows to the detector [14]. By placing a very sensitive current measuring device between the wires of the cathode and anode, the small current signal is then measured and displayed. The more the radon that enters the chamber, the more current displayed by the instrument. Data EXPERT software then performs data analysis and storage [10].

### Annual effective dose from inhalation of radon

The annual effective dose (E<sub>inh</sub>) from the inhalation of indoor radon was calculated from the measurements. The calculation was determined using an expression suggested by UNSCEAR [15]:

$$E_{Rn} \text{ (mSv.y}^{-1}\text{)} = DCF_{Rn} F_{Rn} A_{Rn} T_{exp} \times 10^{-6} \quad (1)$$

Where;

$E_{Rn}$  = the annual effective dose of radon through inhalation,

$DCF_{Rn}$  = the dose conversion factor of radon via inhalation (assumed to be 9 nSv/Bqhm-3) [15],

$F_{Rn}$  = the indoor equilibrium factor between radon and its progeny (assumed to be 0.4) [15]),

$A_{Rn}$  = the radon activity concentration in Bqm-3, and

$T_{exp}$  = the exposure time to this concentration (assumed to be 7000 hours in one year) [15].

## Results and Discussion

Measurements of activity concentrations of Indoor radon taken over night for a period of 24 hours from selected mine dwellings and from the control area are recorded in Table 1. The table also shows calculated values for the corresponding annual effective dose to which members of the public are exposed to. According to [16], the international limit of indoor radon is 200 Bq/m<sup>3</sup>. The results in Table 1 indicate that the average activity concentration of indoor radon from the mining area is 119.6 Bq/m<sup>3</sup>, a value much higher than 19.7 Bq/m<sup>3</sup> from the control area. This is because <sup>238</sup>U, grandparent of Radon-222, has a high activity concentration in the area. Although the average value from the mine dwellings was lower than the international limit, some values were higher in some dwellings. The activity concentrations of indoor radon from the mining area ranged from 1.0 to 472.0 Bq/m<sup>3</sup>, compared to 0.1 to 35.0 Bq/m<sup>3</sup> from the control area. The annual effective doses from inhalation of radon corresponding to the activity concentrations were calculated using Equation 1 and the results are also indicated in Table 1. The annual effective dose ranged from 0.03-11.89 mSv with a mean value of 3.01 mSv. These dose values were higher than the results estimated from the control area which ranged from 0.00-0.88 mSv with an average of 0.5 mSv. The results were also significantly higher than those published for normal areas around the world. According to [15], the average annual effective dose from inhalation of radon and its decay products is 1.26 mSv.

A simple statistical analysis of the measurements was carried out between the mining and the control areas to check if there were any statistical differences between the two areas. The results in Table 2 show that there were significant differences in radon concentrations between the mining area and the control area.

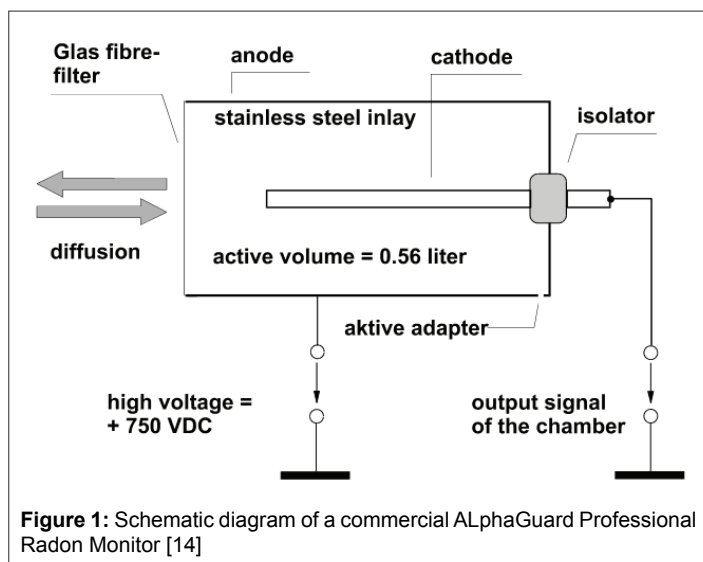
Results from indoor radon measurements taken from the mining area and from the control area also showed that levels reach their maximum in the early morning and their minimum at noon. This is illustrated in Figure 2, where fluctuations in indoor radon activity concentrations were

**Table 1:** Activity concentrations of Indoor radon and the corresponding annual effective dose from Inhalation measured from selected mine dwellings and control area

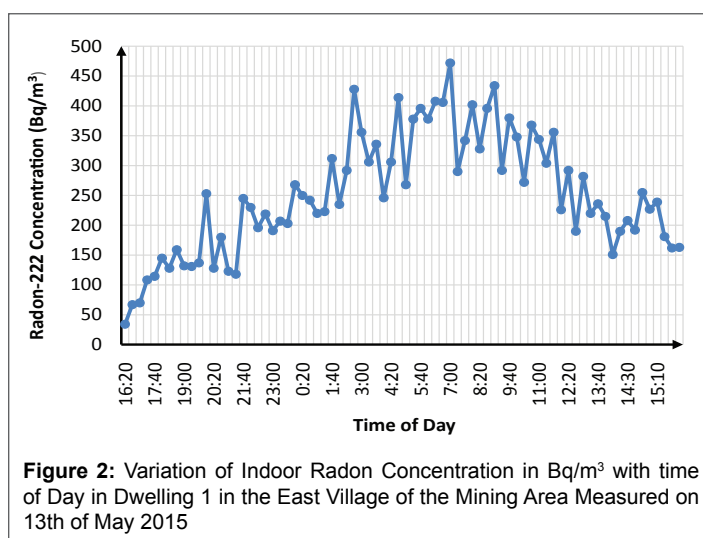
Location	Source	Parameter	Indoor radon activity concentrations (Bq/m <sup>3</sup> )	Average annual effective dose (mSv)
Control area	Dwelling 1	Range Average	2.5-22.5 12.1	0.06-0.57 0.30
	Dwelling 2	Range Average	0.1-35.0 27.3	0.00-0.88 0.69
Overall control area		Range Average	0.1- 35.0 19.7	0.00-0.88 0.50
Mining area	West Village Dwelling 1	Range Average	23.1-194.0 77.6	0.58-4.89 1.96
	West Village Dwelling 2	Range Average	3.3-177.9 56.6	0.08-4.48 1.43
	West Village Dwelling 3	Range Average	24.7-345.8 120.3	0.62-8.71 3.03
	East Village Dwelling 1	Range Average	34.2-472.0 256.5	0.86-11.89 6.46
	East Village Dwelling 2	Range Average	1.0-91.5 28.5	0.03-2.31 0.72
	East Village Dwelling 3	Range Average	12.0-386.4 178.2	0.3-9.74 4.49
Overall mining area		Range Average	1.0-472.0 119.5	0.03-11.89 3.01

**Table 2:** Statistical Analysis on the measurements from the mining area and the control area

	Control Area	Mining Area
Mean	19.7	119.6
Standard Error	7.6	34.7
Median	19.7	99.0
Standard Deviation	10.7	85.1
Sample Variance	115.5	7241.7
Kurtosis	N/A	-0.2
Skewness	N/A	0.8
Minimum	12.1	28.5
Maximum	27.3	256.5
Sum	39.4	717.7
Observations	2	6
Hypothesized Mean Difference	0	
df	5	
t Stat	-2.81	
P(T<=t) one-tail	0.02	
t Critical one-tail	2.02	
P(T<=t) two-tail	0.04	
t Critical two-tail	2.57	



**Figure 1:** Schematic diagram of a commercial ALphaGuard Professional Radon Monitor [14]



**Figure 2:** Variation of Indoor Radon Concentration in Bq/m<sup>3</sup> with time of Day in Dwelling 1 in the East Village of the Mining Area Measured on 13th of May 2015

recorded from one of the mine dwellings (East Village Dwelling 1). This was also supported by [4], which stated that radon concentrations in the air vary daily and seasonally. Maximal concentrations occur in late summer, and minimal levels in winter. The availability of radon inside dwellings also depends on (i) the concentration of radon in the soil (ii) the rate of extraction of soil gas and (iii) the pressure difference needed to extract it, among other factors [4]. Inside dwellings, low rates of air exchange can result in a build-up of radon and its decay products to levels much higher than those typically observed outdoors.

## Conclusions

The study has shown that activity concentrations of indoor radon from the mine dwellings ranged from 1.0 to 472.0 Bq/m<sup>3</sup>, compared to a range of 0.1 to 35.0 Bq/m<sup>3</sup> from the control area. The annual effective doses corresponding to the activity concentrations ranged from 0.03-11.89 mSv with a mean value of 3.01 mSv. This average value was higher compared to the results calculated from the control area and values published for normal areas around the world. According to [15], the average annual effective dose from Inhalation of radon and its decay products is 1.26 mSv. This mean value from the mining area is of radiological concern to the community living in this mining area.

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