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Research Article

Comparison of Public Indoor Internal Exposure from Radon-222 Inhalation in the Different Dwellings of 09 Regions of Madagascar

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Abstract

Radon is the radioactive gas naturally present in the environment produced by natural radioactive decay of uranium-238. It is uncolored and inodorous and present in outdoor air as well as in dwelling spaces. In nine (09) regions of Madagascar, radon study was carried out for indoor radon concentration measurement in 62 dwellings spread. The aim of this study is to compare the indoor internal exposure due to Radon inhalation. AphaGuard and SARAD equipment were used. The radon concentration and the annual effective dose vary respectively from (4.37 ± 1.74) $Bq.m^{-3}$ to (77.80 ± 4.51) $Bq.m^{-3}$ with average value of (31.04 ± 7.78) $Bq.m^{-3}$ and from (0.14 ± 0.05) $mSv.y^{-1}$ to (2.45 ± 0.14) $mSv.y^{-1}$ with average value of (0.98 ± 0.18) $mSv.y^{-1}$. The average value of Lung Cancer Case (LCC) per year and per million persons was found at 17.62. The average radon concentration is lower than the WHO, UNSCEAR 2000, and GSR Part N °3 Public limit value, however, its contribution to the total exposition to the population is significant. It has been found that all the obtained results during this works vary across regions. The Region of Vakinankaratra represents the highest effective average value of annual high effective dose and radon concentration due to high uranium potential of this region. Analanjirofo and Antsinanana regions represent the lowest annual effective dose and radon concentration due to the abundance of Th-232 concentration than Uranium in these regions.

Keywords

Radon, Environment, Radioactivity, Effective Dose, Public

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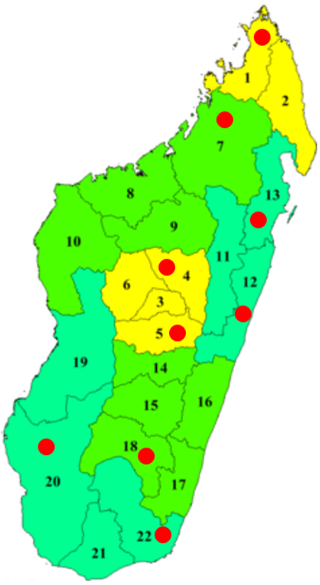
1. Introduction

Radioactivity is a natural phenomenon and natural sources of radiation are features of the environment [14]. The natural radioactivity from the earth's crust, in most rocks, in soil and in water [1] is the primary source of ionizing radiation exposure to humans and their environment. The elements responsible for natural radioactivity are mainly uranium-238, uranium-235 and thorium-232, as well as their descendants, which includes radon. This latter is a radioactive gas which is from the radium-226, radium-223 and radium-224 decays, themselves respective descendants of three father in the natural radioactive family [2]. Radon contributes on average for populations to about half of the exposures from all natural or man-made origin radiation sources, ionizing radiation can cause the health harmful effects including cancer and genetic disorder. Radon, in the form of gas present everywhere in the air inhalation, can also lead to this cancer type in some cases, so it should be detected by radon meter. Until now, no solution exists to manage radon, and this is why studies have been carried out to compare the internal public exposure due to indoor radon-222 inhalation in different dwellings of 09 regions of Madagascar, with some international references. The purpose of this work is to evaluate the radon activity concentration, to calculate the annual effective dose due to radon inhalation, and to determine the risk of lung cancer case (LCC).

2. Studies Areas

Madagascar is divided into 23 regions. These formerly second-tier administrative divisions became the first-level administrative divisions when the former six provinces were dissolved on 4 October 2009. Among these 24 regions, 09 regions were chosen to realize this indoor radon study of dwelling, because the radiation levels in these regions are among the highest compared with the others.

1) Vakinankaratra and Ihorombe Regions are rich in uranium,
2) Diana and Sofia Regions are rich in rare earths (bastnaesite, monazite, xenotime);
3) The Antsinanana, Atsimo Andrefana, Anosy and Analanjirofo Regions are rich in mineralized sands (ilmenite, rutile, zircon).
4) The Region of Analamanga where the levels of radioactivity are not high.



N°	Regions	Geographical position
1 and 7	Diana and Sofia	[-12.26820 ; 49.29349] and [-14.87995 ; 48.01131]
4	Analamanga	[-18.87644 ; 47.49818]
5	Vakinankaratra	[-19.86597 ; 47.04322]
12	Atsinanana	[-18.11270 ; 49.35744]
13	Analanjirofo	[-17.37874 ; 49.40872]
18	Ihorombe	[-22.40894 ; 46.11647]
20	Atsimo-Andrefana	[-23.28619 ; 43.67966]
22	Anôsy	[-24.97612 ; 46.97361]

Figure 1. *Indoor Radon concentration measurement in 9 Regions of Madagascar.*

3. Materials and Methods

3.1. Materials

For the measurement of Radon in dwelling spaces, two detectors (RTM 2100 SARAD and AlphaGUARD) were used (Figure 2).

The RTM 2100 SARAD Detector measures the radioactive gases concentration, in particular Radon-222 and Thoron-220 in air.

The AlphaGUARD [3] is an easy-to-use and highly efficient detector for measuring radon concentration in air, water and soil. It is a portable and chargeable device made of an aluminum alloy case on which has (seen from the front) a display screen and a warning light that comes on when switched on. This device makes it possible to continuously measure and record the radon-222 concentration. AlphaGUARD is equipped with an ionization chamber with a glass fiber filter at the inlet which allows radon-222 to pass through and retains aerosols present in the ambient air. The AlphaGUARD detector with its accessories is shown in figure 2, namely:

A charger is used to recharge the internal battery to ensure its permanent operation,

The AlphaGUARD is connected with a computer by a cable.

The transfer of recorded data from the AlphaGUARD to a computer is provided by the installation CD of the DataEXPERT software.

RTM 2100 SARAD AlphaGUARD with accessories

Figure 2. *Radon Detection Equipment.*

3.2. Methods

3.2.1. Radon Activity Concentration

Indoor radon concentrations measurements were done. All windows and doors in the dwellings are closed 12 hours before and during this measurement [4]. The average duration time was 24 hours. For a multi-storey dwelling, the radon-meter was placed at the ground floor as the lower the dwelling is, the greater the radon concentrations are. The Radon meter was placed at a distance between 1 and 2 meters from a door or window. Measurement was carried out at an altitude between 1 and 2 m from the ground.

3.2.2. Annual Effective Dose

The annual effective dose (HE) was calculated using equation (1) [5, 6] and [14]:

$$HE\ (mSv.\ y^{-1}) = C \times F \times T \times D \quad (1)$$

Where,

C is the radon activity concentration in Bq. m^{-3}, F is the indoor equilibrium factor (0.4), T is the annual time of the year (8760 h.y^{-1}), and D is the dose conversion factor, which is 9 x 10^{-6} mSv.m^3.Bq^{-1}.h^{-1}.

3.2.3. Lung Cancer Case (LCC)

The probability of lung cancer cases per year per million persons (LCC) caused by Radon-222 inhalation was given by equation (2): [7, 8]

$$(LCC) = HE \times (18 \times 10^{-6}\ /mSv.y^{-1}) \quad (2)$$

3.3. Results and Discussion

The placement of radon meter was carried out in 62 dwelling in the 09 Regions of Madagascar. AlphaGuard and SARAD detectors were used. The location of measurement point was provided by the GPS. The radon concentration and the annual dose received by the population during radon inhalation are shown in Table 1. The risk of lung cancer case is calculated using equation (2), the LCC values are shown in Figure 5. The annual effective dose values received by the inhabitants were compared with the regulatory limit value in radiation protection for the public in Madagascar [9, 16] and that of UNSCEAR 2000 [10] which is respectively 1 mSv.y^{-1} and 1.2 mSv.y^{-1} (Figure 3). The radon concentration results were compared with public limit values established by the WHO (100 Bq.m^{-3}) [11], UNSCEAR 2000 (46 Bq.m-3), and from GSR part N°3 (300 Bq.m^{-3}) [12, 15].

Table 1. Radon concentration and annual effective dose in the 09 regions of Madagascar.

Region	Numbers of radon measurement	Radon Concentration [Bq.m^{-3}]			Annual effective Dose [mSv.y^{-1}]			LCC × 10^{-6}
		Min	Max	Average	Min	Max	Average	
Sofia et Diana	6	56 ±17	78 ±15	67 ±16	1.77 ±0.54	2.46 ±0.47	2.11 ±0.50	37.98
Atsimo Andrefana	12	4 ±0.10	63 ±11.80	22.25 ±8.59	0.13 ±0.00	1.99 ±0.37	0.70 ±0.27	12.04
Atsinanana	4	5 ±0.50	14 ±6.00	9.5 ±3.14	0.16 ±0.02	0.44 ±0.19	0.30 ±0.10	5.40
Analanjirofo	7	1.20 ±0.07	8.10 ±3.10	4.37 ±1.74	0.04 ±0.00	0.26 ±0.10	0.14 ±0.05	2.52
Ihorombe	5	1.6 ±0.09	32 ±5.23	12.04 ±2.24	0.05 ±0.00	1.01 ±0.16	0.38 ±0.07	6.84
Anosy	6	13 ±0.89	70 ±13.00	36.17 ±6.12	0.41 ±0.03	2.21 ±0.41	1.14 ±0.19	20.52
Vakinakaratra	9	10 ±1.00	295.63 ±10.63	77.80 ±4.51	0.32 ±0.03	9.32 ±0.34	2.45 ±0.14	44.10
Analamanga	13	8.1 ±0.50	44 ±2.00	19.18 ±3.90	0.26 ±0.02	1.9 ±0.37	0.61 ±0.12	10.98
Average	62			31.04 ±5.78			0.98 ±0.18	17.62
Min				4.37 ±1.74			0.14 ±0.05	5.40
Max				77.80 ±4.51			2.45 ±0.14	44.10

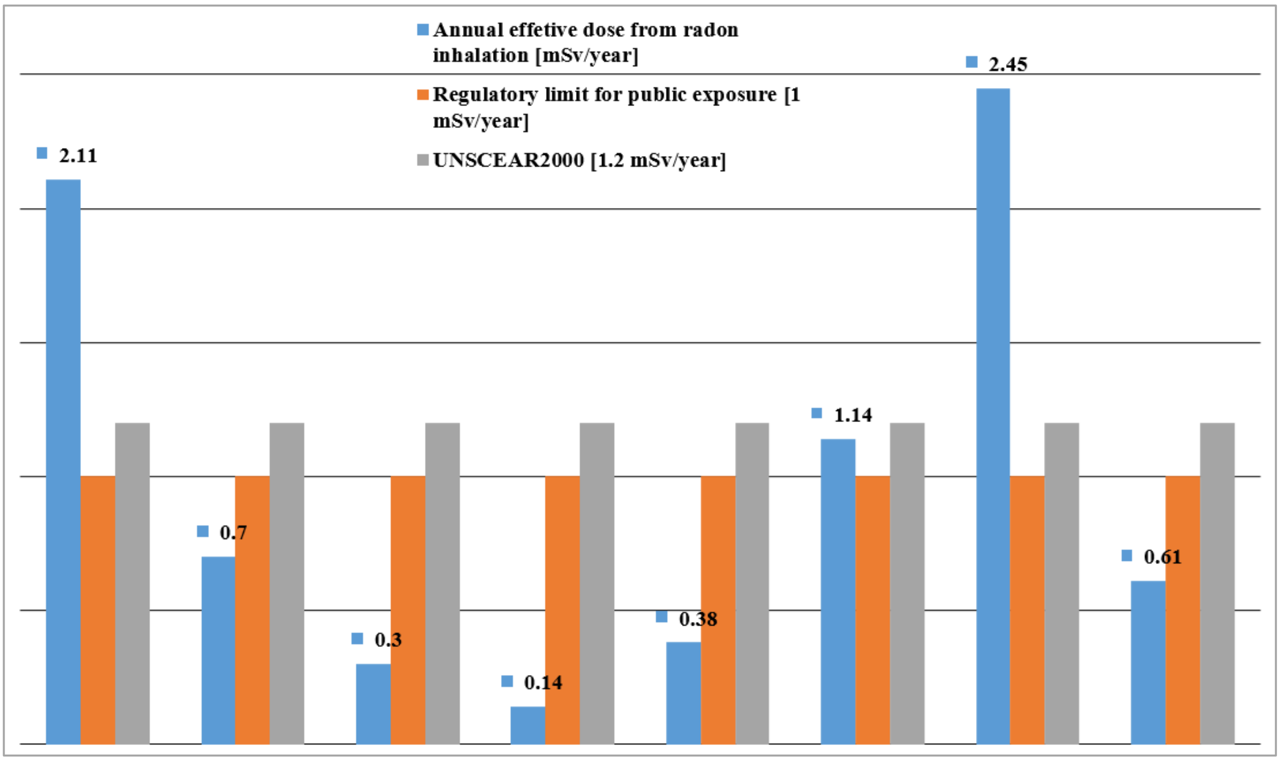


Figure 3. Annual effective dose efficace due to radon inhalation in the 9 regions of Madagascar.

The radon concentration in the 09 regions of Madagascar varies from (4.37 ±1.74) Bq.m^{-3} to (77.80 ±4.51) Bq.m^{-3} with an average value of (31.04 ± 5.78) Bq.m^{-3} (Table 1). The annual effective dose varies from (0.14 ± 0.05) mSv.y^{-1} to (2.45 ±0.14) mSv.y^{-1} with an average value of (0.98 ±0.18) mSv.y^{-1} (Table 1). The average radon concentration value is lower than the WHO, OMNIS, and IAEA GSR Part N °3 limit values for the public. The average value of the annual effective dose due to inhalation of Radon is almost equivalent to the regulatory limit values in radiation protection for the public in Madagascar and that of UNSCEAR 2000. The case of lung cancer varies from 5.40 to 44.10 per year per million persons with an average value of 17.62 per year per million persons which is less than the range limit of [170-230] per year per million persons recommended by the ICRP [13], This means that the probability that a lung cancer occurred for the population living in these nine regions is 18/1000 000. The Vakinankaratra region has the highest cancer risk due to high levels of radon (44.10 cases of lung cancer in 1 million inhabitants).

It has been shown that the Region of vakinankaratra has a high average radon concentration (77.80 ± 4.51 $Bq.m^{-3}$) and higher annual effective dose (2.45 ± 0.14 $mSv.y^{-1}$) when compared to other regions, this is due to the preponderance of uranium in this region for instance, the presence of Vatovory uranium legacy site operated by the CEA in 1965. The indoor radon concentration measurement in this location is situated at 140 m from this legacy site (Figure 4). The dose rate measurement at 1 m above the ground on this site is 21 $\mu Sv.h^{-1}$.

The regions of Analanjirofo and Antsinanana represent annual average effective doses of 0.14 ± 0.05 $mSv.y^{-1}$ and 0.30 ± 0.10 $mSv.y^{-1}$, respectively. These two values are not high, when compared to Vakinankaratra region because these regions are very rich in mineralized sands, the Thorium concentration is higher than uranium (the concentration of Thorium is more abundant than the uranium). Thereby, these two regions are not uranium zones. In the regions of Sofia and Diana that are rich in rare earth, the annual average effective dose is 2.11 ± 0.50 $mSv.y^{-1}$. The rare earths concentration in these regions is are more abundant than that of mineralized sand of Antsinanana and Analanjirofo regions.

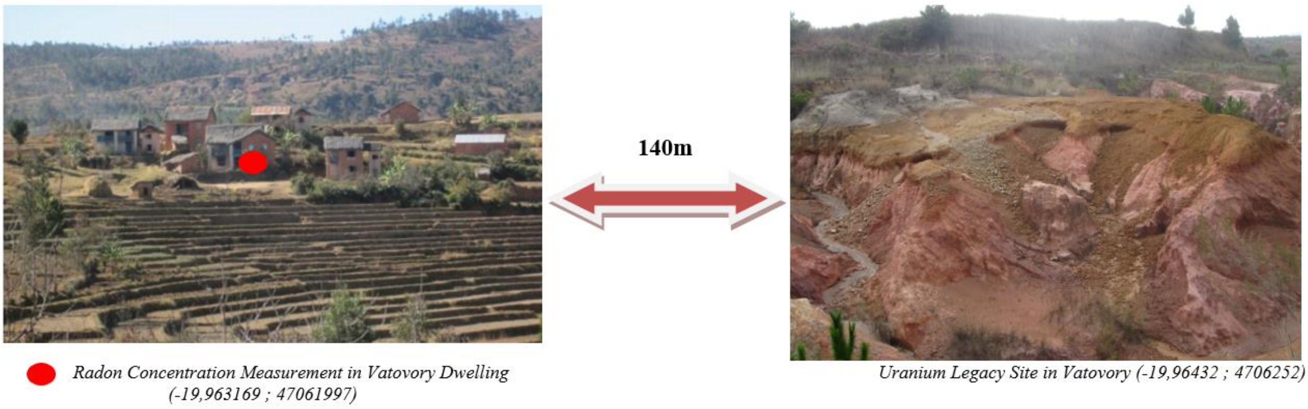


Figure 4. *Distance between indoor radon Concentration in Vatovory and Uranium Legacy Site in Vatovory in the region of Vakinankaratra.*

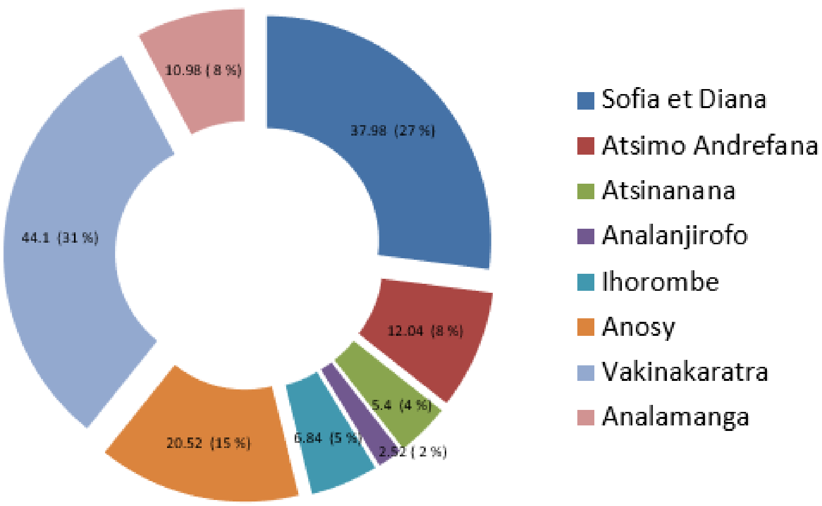


Figure 5. *Lung Cacer Case per year per million person in the 09 regions of Madagascar (LCC).*

3.4. Conclusions

Indoor Radon concentration measurements were carried out in the 62 dwelling of the 09 regions of Madagascar. AlphaGuard and SARAD were used to measure the radon concentration. This latter was used to convert to annual effective dose. International standards were used for the results comparison. The lung cancer case was calculated to assess the cancer risk probability in these 09 regions. It was concluded that the average radon concentration in the 09 regions of Madagascar was under the WHO, OMNIS, and

IAEA GSR Part N°.3 limit values for the public. The annual average effective dose value was almost equivalent to the regulatory limit values in radiation protection for the public in Madagascar and that of UNSCEAR 2000. The case of lung cancer was estimated at 22 per year per million persons. It was observed that the Vakinankaratra region represented the highest annual effective dose, and the highest lung cancer case due to the abundance of very high U-238 concentration (uranium legacy site at Vatovory). The Regions of Analanjirofo and Antsinanana received the lower annual effective dose due to the higher Th-232 concentration than uranium in the mineral sands for these areas. The rare earths concentration in the regions of Sofia and Diana is higher than that of mineralized sand of the regions of Antsinanana and Analanjirofo, this means that the annual effective dose obtained from the rare earths is higher than the mineralized sands.

Abbreviations

CEA	Commissariat à l'Energie Atomique
GPS	Global Positioning System
GSR	General Safety Requirements
IAEA	International Atomic Energy Agency
ICPR	International Commission on Radiological Protection
INSTN	Institut National des Sciences et Techniques Nucléaires
LCC	Lung Cancer Case
OMNIS	Office des Mines Nationales et des Industries Stratégiques
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
WHO	World Health Organization

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Author Contributions

Tiana Harimalala Randriamora: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Resources, Software, Visualization, Writing – original draft, Writing – review & editing

Hary Andrianarimanana Razafindramiandra: Conceptualization, Data curation, Formal Analysis, Investigation, Software, Visualization, Writing – original draft

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Joseph Lucien Radaorolala Zafimanjato: Conceptualization, Project administration, Resources, Supervision, Validation, Visualization

Tahiry Razakarimanana: Investigation, Resources, Software, Visualization

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Conflicts of Interest

The authors declare no conflicts of interest.

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