***Original Research Article***

**Preliminary Assessment of Indoor Radon Concentration and the Associated Health Risk to the Dwellers Surrounding Minjingu Phosphate Mine**

**ABSTRACT**

Radon which is a radioactive gas and a decay product of uranium, pose a potential health risk to human. The aim of this study was to assess preliminary the indoor radon concentration at homes in the vicinity of Minjingu village and use results of measurements to estimate the annual effective dose received by the dwellers and the associated excess lifetime cancer risk. The measurements were conducted in selected 22 houses using Professional Radon gas Monitor, AlphaGUARD. Results indicated that the radon concentration ranged from 33±4 Bq/m3 to 1,080 ±57 Bq/m3 with the mean of 161±12 Bq/m3. The inhalation dose ranged from 0.8mSvy-1 to 27.2mSvy-1 with the average of 4.1mSvy-1. The excess lifetime cancer risk (ELCR) ranged from 0.3 to 10.5%, with the average of 1.6%. Since some of the observed readings in this study including the mean radon concentration are higher than the recommended levels of 300 Bqm-3, it is recommended to improve the ventilation system of the houses. Also, the long-term measurement of radon in this area is recommended in order to take into consideration the long-term variation of meteorological parameters such as temperature, relative humidity and pressure which are known to affect indoor radon levels.

**1. INTRODUCTION**

Radon is decay product of Uranium *ubiquitous* in rocks and soils with varying concentration [1,2]. These elements are naturally enriched in rocks of granites, igneous, metamorphic or sedimentary rocks and in monazite sands [3]. Therefore, the phosphate rock at Minjingu mine being a sedimentary rock is potential for Uranium contents [4]. 222Ra is a decay product of 226Ra which is commonly found in soils and rock containing uranium. This inert gas is considered to be radiation health hazard as it may increase a risk of cancer when inhaled by human [5,6,7,8,9,10,11]. The decay of radon produces respirable solid particles of 218Po and 214Po that attaches to the aerosol and dust particles present in the air [12]. The indoor radon is mainly caused by the local soil surrounding the building, the ground water used in the building, and the building materials [13]. For the reason of radon being the cancer cause, many countries in the world have specific national programs for measurement of radon in residential dwellings and offices and assess the associated public exposure[14]. When radon released from soil into the outdoors, it mixes with fresh air resulting in concentrations that is insignificant to be of concern to individuals. However, when radon enters inside a residential house or office; it can accumulate to a level significant for health concern. Entry of radon gas in houses and offices can be achieved through openings or cracks in foundation, walls and slabs, construction joints, pipes, window wells, or cavities inside walls. Ounce radon gas enters in a home or office it will accumulate to levels that can be of concern to the individual heath[15]. Exposure from radon gas is usually represented by the average concentration of radon gas per cubic metre of air an individual has been exposed over time, measured in the units of Becquerel per cubic metre (Bq/m3). The level of risk to individual depends on factors such as concentration of radon dilution effects caused by available ventilation mechanisms and duration of exposure. The health risk associated with long-term inhalation of indoor radon is an increased risk of developing lung cancer. Radon has the tendency to deposit onto lungs and when decay; they irradiate the lung [4]. The World Health Organization (WHO) has reported that, after cigarette smoking, radon is the second largest cause of lung cancer [16].

The concentration of indoor radon depend on various factors including: emanation rate, concentration of radium in soil, soil size, soil porosity and permeability, moisture content of the soil, atmospheric pressure and precipitation[15]. There are few studies in Tanzania conducted for indoor radon for example by Germana Mlay and Ismail Makundi at Manyoni district in Singida [17] where uranium deposits have been discovered. The results of this study have shown the mean concentration of 166±12 Bq/m3 and the highest value was 518±28 Bq/m3 which is above the WHO recommended value of 100 Bq/m3.

Elevated levels of uranium have been reported in phosphate rocks worldwide [18]. Therefore, elevated radon levels are suspected to be found in houses built in the vicinity of Minjingu Phosphate Mine, in Northern Tanzania. This study aim at assessing of indoor radon concentration at homes in the vicinity of Minjingu village and use the results of measurement to estimate the annual effective dose received by the dwellers and the associated excess cancer risk. Results of this study will help the regulatory body to enforce the required radiation protection measures to protect the public.

1. **MATERIALS AND METHODS**
	1. **The Study Area**

The Minjingu Phosphate Mine is located in Minjingu Village, 106 km southwest of Arusha along the Arusha-Dodoma highway in Babati District, Manyara Region in the northern Tanzania. This mine is located at the latitude of 3o 41’ 52’’ South and the longitude of 35o51’ 43’’ East. The village land area is approximately 24,000 hectares and a population of about 11,000 people [19].

* 1. **Measurements of Radon in Indoor Environment**

There are many techniques available for measurements of indoor radon concentration [1, 20, 21]. This study considered the short-term measurement of radon concentration using AlphaGUARD professional radon monitor. The AlphaGUARD is a professional portable detector that determine continuously the concentration of radon and radon progeny in air [22]. It is a continuous active radon sampling sensor with an ionization chamber and uses an alpha spectroscopy to detect radon [23]. AlphaGUARD gives the option for the user to differentiate the measurements for radon and thoron, also to measure simultaneously the concentration of radon progeny as well as gamma dose rate [22]. This unit is designed for the long-term monitoring of radon gas concentration with a linear response from 2 to 2,000,000 Bq/m3 [23]. The AlphaGUARD was selected to measure the short-term radon concentration because of its availability and sensitivity. The measurement of radon concentration was conducted for two weeks in 22 selected dwellings in the vicinity of Minjingu village. The dwellings were randomly selected and the AlphaGUARD was placed inside each house for five hours to take the measurement. The measurement was conducted during daytime only because the night time was used to charge the AlphaGUARD. During the measurement time, the door and windows were closed. After five hours the detector (AlphaGUARD) was taken from the house and the readings were recorded for the average 222Rn concentration.



 Figure1. The front view of the AlphaGUARD

* 1. **Risk Estimation**

The average annual effective doses (in mSvy-1) for the residence of the studied houses were calculated according to the following formula [24]:

 $AED=C x F x T x D$ (1)

where C is the mean radon concentration in house (in Bq/m3), F is the equilibrium factor between radon and its decay products (taken equal to 0.4 according to the UNSCEAR [25], ICRP)[26]; T is the indoor occupancy (taken equal to 7000 hy−1), and D is the dose conversion factor for radon decay products assumed by ICRP and UNSCEAR which is 9 nSv per (h Bq m−3) [27,28].

The excess lifetime cancer risk (ELCR) was estimated using the following Equation:

 $ELCR=AED x DL x RF$ (2)

where AED is the annual effective dose, DL is the average duration of life estimated to 70 years, and RF is the fatal cancer risk per Sievert (5.5 10−2 Sv−1) [29] recommended by ICRP.

**3. RESULTS AND DISCUSSION**

The results of the indoor radon concentration measurements performed in the selected twenty two (22) houses in Minjingu village in the vicinity of Minjingu Phosphate Mine are presented in Table 1 and Figure 2. The presented values are the mean or average values collected during hours of radon measurements by AlphaGUARD. From these results, the minimum radon concentration was 33±4 Bq/m3 while the maximum concentration was 1,080 ±57 Bq/m3 with the overall mean concentration of 161±12 Bq/m3.

Table1. Indoor radon concentrations (Bq/m3) at each studied house

|  |  |
| --- | --- |
| House Number | Average Rn Concentration (Bq/m3) |
| DW1 | 115±9 |
| DW2 | 49±5 |
| DW3 | 88±9 |
| DW4 | 254±19 |
| DW5 | 46±4 |
| DW6 | 115±9 |
| DW7 | 41±4 |
| DW8 | 232±16 |
| DW9 | 35±3 |
| DW10 | 71±6 |
| DW11 | 36±4 |
| DW12 | 47±5 |
| DW13 | 33±4 |
| DW14 | 40±4 |
| DW15 | 49±5 |
| DW16 | 191±16 |
| DW17 | 1,080±57 |
| DW18 | 578±34 |
| DW19 | 142±15 |
| DW20 | 199±18 |
| DW21 | 73±9 |
| DW22 | 33±4 |

Figure2. Radon concentrations (Bq/m3) at each dwelling

The measurements from seventeen (17) houses out of twenty two houses surveyed, indicated higher concentration values which were above the world average for the indoor radon. According to [30], the world average for indoor radon concentration is 40 Bq/m3. However, the overall mean radon concentration (161±12 Bq/m3) was within the reference range recommended by the International Commission on Radiological Protection (ICRP) and the World Health Organization (WHO) of 100-300 Bq/m3 for homes. The WHO recommended that the reference level should be set at 100 Bq/m3 but if this value cannot be achieved, then the level should not exceed 300 Bq/m3[31,32]. On the other hand, higher concentration levels above the WHO recommended range were observed in two houses (number DW17 and number DW18). In these houses, the radon concentration readings were 1,080±57 and 578±34 Bq/m3, respectively. Moreover, studies has shown that if the result of short-term measurements reveals values higher, such as 500 Bq/m3, it is a conclusive evidence for the reference limit to be exceeded [33]. The reason for the two houses having the higher levels of radon could be due to the house construction materials, poor ventilation, type of floor (non-cemented floor), and cracks present in the floor . The non-cemented floor and cracks may be the way for the radon emanation from the ground to enter in to the house through the floor-openings. Moreover, the two houses were constructed by mud walls which could be containing high 226Ra content which decays into 222Rn. Also, the houses were found to have poor ventilation, making it possible for radon to accumulate inside. The reason for the observed variation in indoor radon in the houses is that, indoor radon depend on both the building materials and the conditions of the ground. According to [34], two houses located very close to each other may give two different readings of radon concentration with significant different because radon emanation is not always uniform and may be varying locally within few meters due to cracks and porosity of the ground.

Moreover, the findings of this study was compared with the previous study done in Tanzania (Table 2) and also to the studies conducted in some of the European countries (Table 3).

 From Table 2, the overall mean radon concentration measure in this study (Minjingu Village) was less than that recorded in the villages of Muhalala, Mitoo, Mwanzi, Majengo and Kipondoda both in Manyoni district in Tanzania. On the other hand, this overall mean value was higher than the results obtained from the villages of Agondi and Mkwese also both in Manyoni district. Also, the results of this study indicated that, two houses recorded higher values (1,080±57 and 578±34 Bq/m3) than the maximum radon concentration value recorded in all of the above mentioned villages from Manyoni district which is 518±28 Bq/m3.

Table 2: Comparison between radon levels in Manyoni Uranium Deposit in Tanzania [17] and this study

|  |  |
| --- | --- |
| Villages | Mean Radon Concentration (Bq/m3) |
| Indoor | Outdoor |
| Agondi | 53±6 | 16±2 |
| Mkwese | 43±4 | 15±3 |
| Muhalala | 177±16 | 47±4 |
| Mitoo | 325±21 | 33±4 |
| Mwanzi | 287±17 | 32±4 |
| Majengo | 377±23 | 24±3 |
| KipondodaThis study | 169±13161±12 | 24±3- |

Also, the result obtained from this study was compared with the results of studies conducted in some of the European countries as indicated in Table 3. The overall mean radon concentration from this study (161Bq/m3) was higher than the overall means of the studies conducted in all of the European countries indicated in Table 3. The highest value of radon concentration in the European countries in the presented countries was observed in Czechoslovakia with the mean concentration of 140 Bq/m3 while the lowest concentration was observed in United Kingdom with the mean concentration of 20.5 Bq/m3.

Table3. Comparison of radon levels in dwellings of some European countries [35] and this study.

|  |  |  |  |
| --- | --- | --- | --- |
| Country | Average radon concentration (Bq/m3) | Percentage Radon conc. over 200 Bq/m3 | Percentage Radon conc. over 400 Bq/m3 |
| Belgium | 48 | 1.7 | 0.3 |
| Czechoslovakia | 140 | - | - |
| Denmark | 47 | 2.2 | < 0.4 |
| Finland | 123 | 12.3 | 3.6 |
| France | 85 | 7.1 | 2.3 |
| Germany | 50 | 1.5-2.5 | 0.5-1 |
| Greece | 52 | - | - |
| Hungary | 55 | - | - |
| Ireland | 60 | 3.8 | 1.6 |
| Italy | 75 | 4.8 | 1.0 |
| Netherlands | 29 | - | - |
| Norway | 60 | 5.0 | 1.6 |
| Portugal | 81 | 8.6 | 2.6 |
| Spain | 86 | - | 4 |
| Sweden | 108 | 14 | 4.8 |
| Switzerland | 70 | 5.0 | - |
| United KingdomThis study | 20.5161 | 0.59.1 | 0.29.1 |

The annual effective dose from the exposure to radon, the excess lifetime cancer risk (ELCR) due to exposure to radon and the percentage ELCR for an individual leaving in the surveyed houses were calculated using equations 1 and 2, respectively and the results as tabulated in Table 4. From this Table, the minimum annual effective dose was 0.8mSvy-1 while the maximum value was 27.2mSvy-1 with the average value of 4.1mSvy-1. For the case of the excess lifetime cancer risk (ELCR), the minimum was 3.202E-03 while the maximum was 1.048E-01with the average of 1.56E-02. The percentage ELCR ranged from 0.3% – 10.5% with the average of 1.6%.

 Table4. Annual effective dose and risk

|  |  |  |
| --- | --- | --- |
| House No. | Annual Effective Dose (mSvy-1)  | RiskELCR ELCR (%) |
| DW1 | 2.9 | 1.116E-02 | 1.12 |
| DW2 | 1.2 | 4.754E-03 | 0.48 |
| DW3 | 2.2 | 8.538E-03 | 0.85 |
| DW4 | 6.4 | 2.464E-02 | 2.46 |
| DW5 | 1.2 | 4.463E-03 | 0.45 |
| DW6 | 2.9 | 1.116E-02 | 1.12 |
| DW7 | 1.0 | 3.978E-03 | 0.40 |
| DW8 | 5.8 | 2.251E-02 | 2.25 |
| DW9 | 0.9 | 3.396E-03 | 0.34 |
| DW10 | 1.8 | 6.888E-03 | 0.69 |
| DW11 | 0.9 | 3.493E-03 | 0.35 |
| DW12 | 1.2 | 4.560E-03 | 0.46 |
| DW13 | 0.8 | 3.202E-03 | 0.32 |
| DW14 | 1.0 | 3.881E-03 | 0.39 |
| DW15 | 1.2 | 4.754E-03 | 0.48 |
| DW16 | 4.8 | 1.853E-02 | 1.85 |
| DW17 | 27.2 | 1.048E-01 | 10.48 |
| DW18 | 14.6 | 5.608E-02 | 5.61 |
| DW19 | 3.6 | 1.378E-02 | 1.38 |
| DW20 | 5.0 | 1.931E-02 | 1.93 |
| DW21 | 1.8 | 7.082E-03 | 0.71 |
| DW22 | 0.8 | 3.202E-03 | 0.32 |

For the case of effective dose calculated at each house, the values of the doses from twenty (20) houses together with the overall mean were both below the ICRP reference level of 10mSvy-1[26]. However, two houses (DW17 and DW18) recorded higher values of doses which were above this reference level. These readings from the two houses were 27.2mSvy-1 and 14.6mSvy-1, respectively.

The results of the excess lifetime cancer risk (ELCR) estimated in seven houses indicated higher values than that of the action level recommended by the U.S. Environmental Protection Agency (EPA). According to U.S. EPA, the action level is 1.3% which is due to radon exposure of 148 Bq/m3 [36]. Also, the overall mean for the ELCR was higher than this U.S.EPA action limit. Although fifteen houses had the ELCR values below the action level, that does not eliminate the possibility of lung cancer risk. It has been suggested that there is no safe radon level for residential radon since even the radon concentration below the action level of 100 Bq/m3 have found to produce lung cancer [37, 38]

**4. CONCLUSION**

The indoor radon concentration measurements were conducted in twenty two selected houses in the vicinity of Minjingu Phosphate Mine in Minjingu Village. The overall average concentration of radon was found to be within the recommended range of 100-300 Bq/m3. However, two houses recorded higher radon concentration values above the recommended limit. Also, the annual effective dose and the excess lifetime cancer risk were estimated. The doses were below the ICRP dose limit with an exception of two houses. However, other recorded values of concentration despite being below the limit, it does not eliminate the possibility of producing lung cancer. Although the study was conducted for short-term, the dose and its associated risk were estimated to give roughly or preliminary estimates of the risk which may be associated with the radon present in the buildings. Therefore, the long-term measurement of indoor radon in this studied area is highly recommended in order to take into account long-term and seasonal variations.

**COMPETING INTERESTS DISCLAIMER:**

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

**5. REFERENCES**

1 International Atomic Energy Agency, *Design and Conduct of Indoor Radon Surveys*. in Safety Reports Series, no. 98. Vienna, Austria: International Atomic Energy Agency, 2019.

2 M. Janik, P. Bossew, Md. M. Hasan, and G. Cinelli, “Indoor Radon Research in the Asia-Pacific Region,” *Atmosphere*, vol. 14, no. 6, 2023, doi: 10.3390/atmos14060948.

3 International Atomic Energy Agency, *The environmental behavior of radium*. in Tecnical Reports Series, no. 478. Vienna, 2014.

4 C. Szilas, “The Tanzanian Minjingu Phosphate Rock,” p. 187, 2002.

5 United States Enviromental Protection Agency, “EPA Assessment of Risks from Radon in Homes,” 2003.

6 S. Yang, J. Goyette Pernot, C. Hager Jörin, H. Niculita-Hirzel, V. Perret, and D. Licina, “Radon Investigation in 650 Energy Efficient Dwellings in Western Switzerland: Impact of Energy Renovation and Building Characteristics,” *Atmosphere*, vol. 10, no. 12, Art. no. 12, Dec. 2019, doi: 10.3390/atmos10120777.

7 C. Su *et al.*, “Approaches to Estimating Indoor Exposure to Radon—A Systematic Review,” *Atmosphere*, vol. 16, no. 3, 2025, doi: 10.3390/atmos16030286.

8 S. Darby *et al.*, “Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies,” *BMJ*, vol. 330, no. 7485, p. 223, Jan. 2005, doi: 10.1136/bmj.38308.477650.63.

9 UNSCEAR 2006, “United Nations Scientific Committee on the Effects of Atomic Radiation Report to the General Assembly with Scientific Annexes: Effect of Ionizing Radiation. United Nations: New York, NY, USA, 2006.,” United Nations : Scientific Committee on the Effects of Atomic Radiation. Accessed: Aug. 30, 2023. [Online]. Available: //www.unscear.org/unscear/en/publications/2006\_2.html

10 M. Tirmarche *et al.*, “ICRP Publication 115. Lung cancer risk from radon and progeny and statement on radon,” *Ann ICRP*, vol. 40, no. 1, pp. 1–64, Feb. 2010, doi: 10.1016/j.icrp.2011.08.011.

11 J.-F. Lecomte *et al.*, “ICRP Publication 126: Radiological Protection against Radon Exposure,” *Ann ICRP*, vol. 43, no. 3, pp. 5–73, Sep. 2014, doi: 10.1177/0146645314542212.

12 P. M. Moshupya, S. C. Mohuba, T. A. Abiye, and I. Korir, “Evaluation of Indoor Radon Activity Concentrations and Controls in Dwellings Surrounding the Gold Mine Tailings in Gauteng Province of South Africa,” *International Journal of Environmental Research and Public Health*, vol. 20, no. 21, Art. no. 21, Jan. 2023, doi: 10.3390/ijerph20217010.

13 J. Elío *et al.*, “The first version of the Pan-European Indoor Radon Map,” *Nat. Hazards Earth Syst. Sci.*, vol. 19, no. 11, pp. 2451–2464, Nov. 2019, doi: 10.5194/nhess-19-2451-2019.

14 International Atomic Energy Agency and Internationales Arbeitsamt, Eds., *Radiation protection against radon in workplaces other than mines*. in Safety reports series, no. 33. Vienna: International Atomic Energy Agency, 2003.

15 International Atomic Energy Agency, *Design and Conduct of Indoor Radon Surveys*. in Safety Reports Series, no. 98. Vienna, Austria: International Atomic Energy Agency, 2019.

16 World Health Organization, Ed., *WHO handbook on indoor radon: a public health perspective*. Geneva, Switzerland: World Health Organization, 2009.

17 Mlay and Makundi, “Assessment of indoor radon-222 concentration in the vicinity of Manyoni uranium deposit, Singida,” *TSJ*, 2018, [Online]. Available: https://www.researchgate.net/publication/325382008\_Assessment\_of\_indoor\_radon-222

18 R. R. Diwa, J. D. Ramirez, and N. H. Haneklaus, “Uranium supply potential from imported phosphate rocks for the Philippine nuclear power program,” *The Extractive Industries and Society*, vol. 15, p. 101303, Sep. 2023, doi: 10.1016/j.exis.2023.101303.

19 N. Mohammed and L. Nkuba, “Concentration Levels and the Associated Health Risks of Elements in Food Crops Grown in the Neighbourhood of Minjingu Phosphate Mine, Tanzania,” *Chemical Science International Journal*, vol. 18, pp. 1–9, Jan. 2017, doi: 10.9734/CSJI/2017/31476.

20 A. El-Taher, “An Overview of Instrumentation for Measuring Radon in Environmental Studies,” *J. Rad. Nucl. Appl*, vol. 3, no. 3, pp. 135–141, Sep. 2018, doi: 10.18576/jrna/030302.

21 Canada and Health Canada, *Guide for radon measurements in residential dwellings (homes)*. Ottawa: Health Canada, 2008.

22 Bertin Technologies, “AlphaGUARD User Manual.” Accessed: Mar. 18, 2025. [Online]. Available: https://www.laurussystems.com/wp-content/uploads/USER-MANUAL-ALPHAGUARD-2019.pdf

23 Campbell Scientific, “Interfacing the AphaGUARD Radon Monitor with Campbell Scientific’s CR1000 Datalogger.” Accessed: Mar. 18, 2025. [Online]. Available: https://s.campbellsci.com/documents/us/technical-papers/alphaguard.pdf

24 D. Spasi ́c and L. Gulan, “High Indoor Radon Case Study: Influence of Meteorological Parameters and Indication of Radon Prone Area,” p. 13, 2022, doi: https://doi.org/10.3390/atmos1312212.

25 UNSCEAR, “Sources and effects of ionizing radiation: United Nations Scientific Committee on the Effects of Atomic Radiation: UNSCEAR 2000 report to the General Assembly, with scientific annexes,” New York, Volume I, 2000.

26 ICRP, International Commission on Radiological Protection, “Summary of ICRP Recommendations on Radon.” 2018.

27 UNSCEAR, United Nations Scientific Committee on the Effects of Atomic Radiation, “Sources, Effects and Risks of Ionizing Radiation,” New York, UNSCEAR 2019 Report to the General Assembly, with Scientific Annexes, 2020.

28 Pervin, S.: Yeasmin,S.; Khandaker, M.U.; and Begum, A., “Radon Concentrations in Indoor and Outdoor Environments of Atomic Energy Centre Dhaka, Bangladesh, and Concomitant Health Hazards,” 2022.

29 Loffredo, F.; Savino, F.; Amato, R.; Irollo, A.; Gargiulo, F.; Sabatino, G.; Serra, M.; Quarto, M., “Indoor Radon Concentration and Risk Assessment in 27 Districts of a Public Healthcare Company in Naples, South Italy,” 2021, doi: https://doi.org/10.3390/life11030178.

30 United Nations, Ed., *Sources and effects of ionizing radiation: United Nations Scientific Committee on the Effects of Atomic Radiation: UNSCEAR 2000 report to the General Assembly, with scientific annexes*. New York: United Nations, 2000.

31 J.D. Harrison and J.W. Marsh, “ICRP recommendations on radon.” Accessed: Apr. 12, 2023. [Online]. Available: https://journals.sagepub.com/doi/epub/10.1177/0146645320931974

32 M. Birk *et al.*, “Impact of Indoor Radon Exposure on Lung Cancer Incidence in Slovenia,” *Cancers*, vol. 16, no. 8, Art. no. 8, Jan. 2024, doi: 10.3390/cancers16081445.

33 K. V. Mphaga, T. P. Mbonane, W. Utembe, and P. C. Rathebe, “Short-Term vs. Long-Term: A Critical Review of Indoor Radon Measurement Techniques,” *Sensors*, vol. 24, no. 14, 2024, doi: 10.3390/s24144575.

34 O. Axelson, “Occupational and environmental exposures to radon: cancer risks,” *Annu Rev Public Health*, vol. 12, pp. 235–255, 1991, doi: 10.1146/annurev.pu.12.050191.001315.

35 WHO and Europe, “Radon,” in *Air Quality Guidelines - Second Edition*, Copenhagen, Denmark, 2001. [Online]. Available: https://www.euro.who.int/\_\_data/assets/pdf\_file/0005/123089/AQG2ndEd\_8\_3Radon.pdf

36 A. Azhdarpoor et al, “Assessment of excess lifetime cancer risk and risk of lung cancer due to exposure to radon in a middle eastern city in Iran.” Accessed: Mar. 26, 2025. [Online]. Available: https://mednexus.org/doi/epdf/10.1016/j.radmp.2021.07.002

37 A. Ruano-Ravina, K. T. Kelsey, A. Fernández-Villar, and J. M. Barros-Dios, “Action levels for indoor radon: different risks for the same lung carcinogen?,” *European Respiratory Journal*, vol. 50, no. 5, Nov. 2017, doi: 10.1183/13993003.01609-2017.

38 L. De Maria *et al.*, “Indoor Radon Concentration Levels in Healthcare Settings: The Results of an Environmental Monitoring in a Large Italian University Hospital,” *International Journal of Environmental Research and Public Health*, vol. 20, no. 6, 2023, doi: 10.3390/ijerph20064685.