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Radiation Protection Knowledge and Awareness of Naturally Occurring Radioactive Materials among Underground Goldmine Workers in Ghana

Theophilus Adjirackor[1*], Frederic Sam[4], Irene Opoku-Ntim[3], David Okoh Kpeglo[2], Prince K. Gyeye[1], Frank K. Quashie[3]

1. Nuclear Regulatory Authority, Radiation Applications, Department, Atomic Energy, Kwabenya, Accra, Ghana.
2. Radiation Protection Institute, Waste and Environmental Laboratory, Ghana Atomic Energy Commission, Accra, Ghana
3. National Nuclear Research Institute, Nuclear Track Detection Laboratory, Ghana Atomic Energy Commission, Accra, Ghana.
4. Department of Physics, University of Cape Coast, Cape Coast-Ghana.

Corresponding Author: theophilonov1@yahoo.com

ABSTRACT

The level of knowledge and awareness of naturally occurring radioactive materials and indoor radon among underground goldmine workers were measured using a well-structured closed ended five-point likert scale questionnaire using a one sample T test for the analysis. There was a significant relationship between the awareness and knowledge of NORM and radon gas among the underground workers apart from the awareness and knowledge of the increased risk of cancer due to exposure of radon for workers who smoke. The level of awareness and knowledge is positively correlated with the level of education of respondents and negatively correlated to the years of service and age of respondents, but the ANOVA table indicates a statistical significance between the demographic data and the awareness and knowledge of radon gas and NORM in their working environment with an adjusted R^2 of 46.1%.

Keywords: NORM, Indoor radon, correlation, awareness, knowledge.

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Introduction

Radon (chemical symbol, Rn) is a naturally occurring radioactive gaseous element that is emitted by radioactive material in the earth's crust (Appleton, 2013; Nemangwele, 2005). The most abundant isotope, 222Rn, is produced by the breakdown of uranium in the soil, rocks, and water. Radon is found naturally in certain geological formations such as Cave limestone where 238U occurs naturally. Radon has numerous different isotopes, but 220Rn, and 222Rn are the most common. 222Rn is the decay product of 226Ra. 222Rn and its parent, 226Ra, are part of the long decay chain of 238U. Since uranium is found everywhere in the earth's crust, 226Ra and 222Rn are present in almost all rocks, soil, and water.222Rn is the greatest source (69%) of absorbed dose due to natural radiation (Apraku, 2013). If the gas is inhaled into the lungs, its decay and more importantly the decay of the radon daughters that enter the lung can increase the chance of getting lung cancer (Keith et al., 2013; Nazaroff & Nero, 1988). In nature, mining involves the production of large quantities of waste, which may contaminate soils over a large area, thereby negatively impacting the environment and human health (Munyaradzi, Anna, & Makondelele, 2018). Mining is one of the major causes of elevation of NORMs concentrations on the earth's surface causing health risks to humans, especially when inhaled or ingested (Rowland, 1993). The most important NORMs in radiation protection are radionuclides from the Uranium-238 (238U) a Thorium-232 (232Th) decay series. Potassium-40 (40K), a non-series radionuclide, also contributes significantly to human exposure in the environment (Ziajahromi, Khanizadeh, & Nejadkoorki, 2015). Therefore, the knowledge Naturally Occurring Radioactive Materials and Radon gas among underground workers is essential for them to be aware of the radiological risk associated with their occupation.

Materials and Methods

Research Design and Statistics for data Analysis

The Primary aim of this research is to determine the awareness and knowledge of radon gas and naturally occurring radioactive materials among workers in the underground goldmine.

The research design that was employed in this study is descriptive research design. A descriptive design is a process of collecting data to answer questions concerning the status of the subjects in the study. It involves gathering of data that describes events and then organizes, tabulates, depicts, and describes the data. Descriptive studies portray the variables by answering who, what, and how questions (Babbie & Mouton, 2002; Cooper, Schindler, & Sun, 2006). The advantage of this design is that it is easy to understand as recommended by (Kothari, Kumar, & Uusitalo, 2005). Correlational design establishes a relationship between variables, and it was used to examine the data for differences, associations, and relationships to answer hypothesis.

Population under Study

The target population of the study comprises of all the underground workers. According to the underground mining manager there are about 500 local and foreign workers. The targeted population of hundred (50) is the unit for which information is required. The population for the study consists of the workers who spend the majority of their time underground, thus mostly supervisors, geologists, heavy-duty drivers, and workers in the blasting and Chemical office. The population is a composition of males and females of different ages and levels of education and experiences.

Sample and Sampling technique

A sample is a selection of the number of study units from a defined study population. A sample is, therefore, a small representation of a large population. Sampling is the process, procedure or technique of choosing a sub-group from a population to participate in the study (Ogula, 2005). The idea of sampling or determining a sample size is to obtain a part of the population from which a part of the entire population can be inferred. The sample size of 50 was obtained using a non-probability purposive sampling. The choice of the sampling technique was to target a particular group of workers who spends majority of their time underground.

Purposive sampling occurs when elements are selected for the sample by the judgment of the researcher. As the name implies, the researcher, adhering to the objectives of the study, selects respondents who can answer his research questions. He chooses his own respondents he wants to be included in his sample with a tangible reason or justification. The purposive sampling is used in impressionistic studies, in pilot and retesting procedures and when one wishes to gain a quick insight into a social phenomenon. The sample is selected on the basis that members conform to certain criteria. The researcher uses his judgment to select cases to answer certain research questions. The form of sampling is usually used when the main purpose is to select cases that are particularly informative.

Data collection instruments

Questionnaires are the commonly used methods when respondents can be reached and are willing to co-operate. The method can reach many subjects who are able to read and write independently. The study used a questionnaire made up of both closed-ended and open-ended questions.

Five- point Likert scale, ranging from strongly agree to strongly disagree was therefore used to measure the importance that the respondents attached to the variables since they are appropriate; abide by the principles of validity, reliability, and consideration.

The secondary source of data was collected from books, research reports and journals.

Test of Data Reliability

Reliability in statistics is the overall consistency of a measure. A measure is said to have a high reliability if it produces similar results under consistent conditions or the extent to which a measurement gives results that are very consistent. “It is the characteristic of a set of test scores that relates to the number of random errors from the measurement process that might be embedded in the scores. Scores that are highly reliable are accurate, reproducible, and consistent from one testing occasion to another. That is, if the testing process were repeated with a group of test takers, essentially the same results would be obtained.

Cronbach’s alpha is a measure of internal consistency, that is, how closely related a set of items are as a group. Cronbach’s alpha was used to measure the reliability of the instruments. According to Sekaran and Bougie (2016), the closer the reliability coefficient gets to 1.0, the better is the reliability. In general, reliability coefficient less than 0.60 are considered as poor, those in the range of 0.70 are acceptable and those above 0.80 are considered as good.

Test of Data Validity

Content validity is the degree to which an instrument has an appropriate sample of items for the construct being measured and is an important procedure in scale development. Content validity index (CVI) is the most widely used index in quantitative evaluation. For establishing content validity, the CVI was calculated by dividing the number of experts that arrived at an acceptable test grade 3 (quite relevant) or 4 (highly relevant), by the total number of assessments of the test. Using these assumptions, Lawshe developed a formula termed the content validity ratio: CVR = (ne-N/2) (N/2) where CVR content validity ratio, ne number of researchers indicating "essential", N total number of Researchers. This formula yields values which range from +1 to -1; positive values indicate that at least half the experts rated the item as essential. The mean CVR across items may be used as an indicator of overall test content validity and to calculate the content validity ratio we used the methodology described by Lawshe (1975) as citied by Ermis-Demirtas (2018) which indicates that all items should be analyzed by a group of experts, each expert having the possibility to describe the item as: 1= Irrelevant, 2=Important, but not essential and 3=Essential. The formula to calculate the ratio is: CVR = n-I/N, where n - number of experts who considered the item to be “Essential” or “Important, but not essential”; I - number of experts who considered the item “Irrelevant”; N - total number of experts; The logic behind the formula is that the more experts are in favor of one item as being important or essential, the more we can consider that item as being part of the construct. Thus, we can attain content validity of the construct. The formula gives a negative result when less than 50% of the experts rate the item as essential or important but not essential or a null result when 50% rate it as irrelevant. The CVI of >0.78 is considered valid.

To obtain content validity index for relevancy and clarity of each item (I-CVIs), the number of those judging the item as relevant or clear (rating 3 or 4) was divided by the number of content experts’ judgment on each item is made as follows: If the CVI>0.78 the item will be appropriate.

Table 1: The table added to the cover letter to guide experts for the scoring method.

Relevancy	**Clarity**
1 [not relevant]	1 [not clear]
2 [items need some revision]	2 [items need revision]
3 [relevant but need minor]	3 [clear but need minor revision]
4 [very relevant]	4 [very clear]

Administration of Research Instrument

The researchers personally administered questionnaires to the underground mining manager to distribute to the staff, of which questionnaire were collected by the researchers after respondents had returned them to the manager.

Method of Data Analysis

The researcher reviewed the appropriate statistical data analysis tools namely descriptive and test statistics before analyzing the data. Collected raw data was cleaned and edited for completeness and consistency. It was then systematically organized to confirm if it represents the target population and facilitate objective analysis at a later stage. The responses were also screened for correctness and accuracy and then they were assigned numerical values which represented various attributes being measured.

Descriptive statistics methods are used in this study and analyzed using statistical package for social sciences (SPSS version 16.0). This is to enable data gathered to be presented into tables, graphs, and charts for quantitative explanations and analysis on knowledge and awareness of NORM and radon gas in the underground goldmine. One sample t-test and descriptive statistics was used for data analysis.

Descriptive Analysis Using Mean and One Sample T-Test

The one sample t-test was used to ascertain the relative significance of the variables. For a single sample test, the hypothesis was set as:

Ho: U= Uo

Ha: U >Uo

With Ho representing the null hypothesis, Ha representing the alternative hypothesis and Uo representing the hypothesized mean.

A statistical test of the mean was done to decide whether the population considered a particular variable is known to them or not. The mean ranking of each criterion was compiled to articulate the decisions that the

respondents expressed. For each variable, the null hypothesis was that this variable was not significant or not known them (Ho: U = Uo). The Uo is the critical rating above which the variable is considered known to the respondents.

Hypothesis for One sample T-test

H_0: The difference between the true mean and the comparison value/hypothesized mean is equal to zero. OR there is no difference between the hypothesized mean and the true mean.

H_1: The difference between the true mean and the comparison value/hypothesized mean is not equal to zero OR there is a difference between the hypothesized mean and the true mean.

Results and Discussion

This section presents and analysis results obtained from questionnaires administered to a sample of underground goldmine workers. Statistical tables and one sample t-test were presented followed by its discussion and analysis.

In all, fifty (50) questionnaires were distributed. Hence, the analysis is based on fifty (50) respondents.

Reliability Statistics

Table 2: Reliability Analysis

Cronbach's Alpha	N of Items
0.909	18

Cronbach's Alpha and Kaiser-Meyer-Olkin Measure (KMO) of Sampling Adequacy and Bartlett's Test of Sphericity was used to measure the reliability of the questionnaire as shown in Table 2. Cronbach's alpha is a measure of the internal consistency of a test or scale (Connelly, 2011). It is stated as a digit amid 0 and 1. A reliability coefficient of 0.7 or greater is considered acceptable (Taber, 2018). The Cronbach alpha of 0.909 shows that instrument used for the data collection is reliable.

Content Validity

To obtain content validity index for relevancy and clarity of each item (I-CVIs), the number of those judging the item as relevant or clear (rating 3 or 4) was divided by the number of content expert's judgment on each item is made as follows:

If the CVI>0.78 the item will be appropriate (Bertea & ZAIŢ, 2013). The number of experts that reviewed the questionnaire was 10 experienced researchers in the field of naturally occurring radioactive materials.

Table 3: Content Validity Index

Items	Relevant (Ratings 3 or 4)	Not Relevant (Rating 1or 2)	I-CVIs	Interpretation
1	9	1	0.9	Appropriate
2	8	2	0.8	Appropriate
3	9	1	0.9	Appropriate
4	9	1	0.9	Appropriate
5	7	3	0.7	Need for revision
6	8	2	0.8	Appropriate
7	7	3	0.7	Need for revision
8	9	1	0.9	Appropriate
9	9	1	0.9	Appropriate
10	10	0	1.0	Appropriate
11	7	3	0.7	Need for revision
12	9	1	0.9	Appropriate

13	10	0	1.0	Appropriate
14	8	2	0.8	Appropriate
15	9	1	0.9	Appropriate
16	10	0	1.0	Appropriate
17	9	1	0.9	Appropriate
18	10	0	1.0	Appropriate

If the CVI>0.78 the item will be appropriate, If the CVI ≤ 0.78 there is a need for revision, or the item is eliminated. The above table reveals the validity of the data.

Table 4: Descriptive Analysis Radiation Protection Awareness of Radon Gas & Naturally Occurring Radioactive Materials (NORM).

	N	Min-Max	Mean ± SD	Skewness	Kurtosis
Radon Gas & NORM Awareness	50	3.39-5.00	4.20±0.59	-0.015	-1.741
Valid N (listwise)	50				

Data Source: Field Survey 2022

The questionnaire administered to a sample of 50 underground goldmine workers sought to give them the opportunity to show by indicating on a five-point Likert scale radiation protection awareness of radon gas & naturally occurring radioactive materials. On the Likert scale, 1=Strongly Disagree, 2=Disagree, 3=Neutral, 4= Strongly Agree and 5=Strongly Agree.

The minimum and maximum value of 3.39 and 5.0 on the five-point likert scale shows that some of the underground goldmine workers were neutral or not that sure whiles others strongly agreed of the awareness and knowledge of NORM, radon gas and its associated risk in their working environment. The mean response of 4.2 shows that on average the underground goldmine workers agreed that they are aware and knowledgeable of NORM, radon gas and its associated risk. A negative skewness in the distribution shows that the number of underground workers that are aware and knowledgeable of NORM, radon gas and its associated risk are more than number or average number of workers who were not aware and a leptokurtic distribution of the responses also shows that majority of responses from the workers are closer or clustered around mean response (4.2) which indicates a strong agreement of the awareness and knowledge of NORM, radon gas and its associated risk in their working environment.

Radiation Protection Awareness of Radon Gas & Naturally Occurring Radioactive Materials (NORM) using Mean and One Sample T-Test.

The one sample t-test was used to ascertain the relative significance of the variables. For a single sample test, the hypothesis was set as:

Ho: U= Uo

Ha: U >Uo

With Ho representing the null hypothesis, Ha representing the alternative hypothesis and Uo representing the hypothesized mean. The mean ranking of each criterion was compiled to articulate the decisions that the respondents expressed. For each variable, the null hypothesis was that this variable was not significant (Ho: U=Uo). The Uo is the critical rating above which the variable is considered as the workers are aware and knowledgeable of NORM, radon gas and its associated risk in their working environment.

for the purposes of this analysis the higher ratings of 4 and 5 were chosen for the rating scale as strongly agree and agree respectively while hypothesized mean (Uo) was set at 3.5, with 5% as the significance level.

Analysis of One Sample T-Test

The one sample t-test for the variables had t-values (the strength of the test) to be positive. This indicates the mean was above the acceptable mean of 3.5. Thus, the underground miners are aware and have enough knowledge of NORM, radon gas and its associated risk in their working environment.

In terms of statistical significance to attest if there is enough statistical evidence that the underground workers are aware and have knowledge of NORM, radon gas and its associated risk in their working environment, 10 out of the 18 variables were found to be statistically significant at the 5% level of significance.

Table 5: Response A

Variables	Test Value = 3.5				
	Mean	t	df	Sig. (2-tailed) P-value	Mean Difference
Radon is a naturally occurring radioactive gas that has no colour, smell or taste.	4.64	3.953	49	.002	1.143

Data Source: Field Survey 2022

The analysis from table 5 indicates that there is statistical significance at the 5% level of significance (P<0.5) that the underground goldmine workers are aware and know that Radon is a naturally occurring radioactive gas that has no colour, smell or taste. Thus, there is enough statistical evidence to conclude that underground goldmine workers have knowledge and are aware of these characteristics of radon.

Table 6: Response B

Variables	Test Value = 3.5				
	Mean	t	df	Sig. (2-tailed)	Mean Difference
Radon can be harmful to your health and causes lung cancer	4.79	8.310	49	.000	1.286

Data Source: Field Survey 2022

The analysis from table 6 indicates that there is statistical significance at the 5% level of significance (P<0.5) that Radon can be harmful to their health, and it can also cause lung cancer. Thus, there is enough statistical evidence to conclude that underground goldmine workers have knowledge and are aware of this risk of radon. Since radon is a gas, it has a high possibility of attaching itself to the lungs as compared to other organs in the body. Epidemiological studies have revealed a strong correlation between lung cancer and exposure to radon (Yoon, Lee, Joo, & Kang, 2016). It was identified as a human lung carcinogen in 1986 by the World Health Organization – WHO.

Table 7: Response C

Variables	Test Value = 3.5				
	Mean	t	df	Sig. (2-tailed)	Mean Difference
Radon exposure can cause other cancers besides lung cancer.	4.50	4.377	49	.001	1.000

Data Source: Field Survey 2022

The analysis from table 7 indicates that there is statistical significance at the 5% level of significance (P<0.5) that Radon exposure can cause other cancers besides lung cancer. Thus, there is enough statistical evidence to conclude that underground goldmine workers have knowledge and are aware of this risk of radon. Since radon can be found in water there is a possibility of it causing stomach related cancers apart from lung cancer. The inhaled radon passes from lungs into the blood and body tissues and may irradiate different soft tissue causing cancers such as lung cancer, kidney cancer and prostatic cancer. Radon has also been linked with melanoma and some childhood cancers. There is also a positive association between coronary heart disease and radon exposures where an elevated risk of mortality from coronary heart disease was observed among miners with accumulative radon exposure exceeding 1000 Working Level Month (WLM) (Bajwa & Virk, 1997; Hussein, 2008).

Table 8: Response D

Variables	Test Value = 3.5				
	Mean	t	df	Sig. (2-tailed)	Mean Difference
Smoking can make radon exposure more harmful to your health.	4.07	1.772	49	.100	.571

Data Source: Field Survey 2022

A mean of 4.07 from table 8 indicates that the workers are aware and have knowledge that Smoking can make radon exposure more harmful to their health but the statistical insignificance (P>0.05) at the 5% level of significance indicates that there is not enough statistical evidence that the workers are aware of the increased risk of cancer with smokers.

Table 9: Response E

Variables	Test Value = 3.5				
	Mean	t	df	Sig. (2-tailed)	Mean Difference
Uranium is everywhere (soils, building materials, etc.) and Uranium decays eventually to radium the parent of radon and is very soluble.	3.71	.504	49	.622	.214

Data Source: Field Survey 2022

A mean of 3.71 from the table 9 indicates that the workers are aware and have knowledge that Uranium is everywhere (soils, building materials, etc.) and Uranium decays eventually to radium the parent of radon and is very soluble but the statistical insignificance (P>0.05) at the 5% level of significance indicates that there is not enough statistical evidence that the workers are aware of where uranium is present as well as its decay chain and its solubility.

Table 10: Response F

Variables	Test Value = 3.5				
	Mean	t	df	Sig. (2-tailed)	Mean Difference
Radon is also everywhere, and the major source of radon is the soil, but ground water, natural gas, and building materials also contribute.	4.00	1.803	49	.095	.500

Data Source: Field Survey 2022

A mean of 4.00 from table 10 indicates that the workers are aware and knowledgeable that radon is also everywhere and the major source of radon is the soil, but ground water, natural gas, and building materials also contribute to radon exposure but the statistical insignificance (P>0.05) at the 5% level of significance indicates that there is not enough statistical evidence that the workers are aware of the major sources of radon.

Table 11: Response G

Variables	Test Value = 3.5				
	Mean	t	df	Sig. (2-tailed)	Mean Difference
The half-life of radon is only 3.8 days. The daughter products Polonium, bismuth, and lead (among others) are produced by radon decay and its health risk are the daughters finding itself in the lung causing lung cancer.	4.29	2.956	49	.011	.786

Data Source: Field Survey 2022

The analysis from table 11 indicates that there is statistical significance at the 5% level of significance (P<0.5) that the half-life of radon is 3.8 days. The daughter products Polonium, bismuth, and lead (among others) are produced by radon decay and its health risk are the daughters finding itself in the lung causing lung cancer. Thus, there is enough statistical evidence to conclude that underground goldmine workers have knowledge and are aware of this risk of the daughters of radon. Radon, after being exhaled, migrates along ventilation currents while it generates the solid decay products: ^{218}Po, ^{214}Pb, ^{214}Bi e ^{214}Po (Cousins et al., 2011). These radionuclides attach to the aerosol particles in the air, forming what is termed attached radon progeny. The fraction of radon progeny that does not attach to the aerosol particle in the air is termed the unattached state. In both cases, concentrations of these radon decay products increase rapidly with residence time of the air in the mine. If inhaled, both attached and unattached radon progenies may be deposited in the lung, especially in the upper respiratory tract, and irradiate the lung tissue as they decay. The entry of radioactive aerosol into the respiratory tract depends on their size; larger particles stop in the nasal cavity, while smaller aerosols reach the lungs (Planinic, Faj, Radolić, Šmit, & Faj, 1999).

Table 12: Response H

Variables	Test Value = 3.5				
	Mean	t	df	Sig. (2-tailed)	Mean Difference
All rocks contain some uranium: average values between 1 and 3 parts per million (ppm). Some types of rocks have higher than average uranium contents (light-coloured volcanic rocks, granites, dark shales, sedimentary rocks that contain phosphate, and metamorphic rocks derived from these rocks)	3.93	1.935	49	.075	.429

Data Source: Field Survey 2022

A mean of 3.93 from table 12 indicates that the workers are aware that all rocks contain some uranium: average values between 1 and 3 parts per million (ppm). Some types of rocks have higher content than others but the statistical insignificance (P>0.05) at the 5% level of significance indicates that there is not enough statistical evidence that the workers are aware of the ppm and different types of rocks that contains different amount of uranium, or some type of rocks contain higher uranium content than others.

Table 13: Response I

Variables	Mean	t	df	Sig. (2-tailed)	Mean Difference
Radon moves more rapidly through permeable soils, such as coarse sand and gravel, than through impermeable soils, such as clays.	4.29	3.562	49	.003	.786

Data Source: Field Survey 2022

The analysis from table 13 indicates that there is statistical significance at the 5% level of significance (P<0.5) that radon moves more rapidly through permeable soils, such as coarse sand and gravel, than through impermeable soils, such as clays. Thus, there is enough statistical evidence to conclude that underground goldmine workers have knowledge and are aware of this characteristic of radon since it's a gas in nature.

Table 14: Response J

Variables	Test Value = 3.5				
	Mean	t	df	Sig. (2-tailed)	Mean Difference
The factors affecting radon movement are the amount of water present in the pore space (the soil moisture content), the percentage of pore space in the soil (the porosity), the soil permeability and the "interconnectedness" of the pore spaces determines the soil's ability to transmit water and air.	4.28	6.816	49	.000	.72

Data Source: Field Survey 2022

The analysis from table 14 indicates that there is statistical significance at the 5% level of significance (P<0.5) that the factors affecting radon movement are the amount of water present in the pore space (the soil moisture content), the percentage of pore space in the soil (the porosity), the soil permeability and the "interconnectedness" of the pore spaces determines the soil's ability to transmit water and air. Thus, there is enough statistical evidence to conclude that underground goldmine workers have knowledge and are aware of some of the factors that contribute to exposure of radon gas.

Table 15: Response K

Variables	Test Value = 3.5				
	Mean	t	df	Sig. (2-tailed)	Mean Difference
Long-lived radioactive elements such as uranium, thorium, and potassium and any of their decay products, such as radium and radon are examples of NORM an acronym for Naturally Occurring Radioactive Material. These elements have always been present in the Earth's crust and atmosphere.	4.12	4.128	49	.000	.88

Data Source: Field Survey 2022

The analysis from table 15 indicates that there is statistical significance at the 5% level of significance (P<0.5) that the long-lived radioactive elements such as uranium, thorium, and potassium and any of their decay products, such as radium and radon are examples of NORM an acronym for Naturally Occurring Radioactive Material and these elements have always been present in the Earth's crust and atmosphere. Thus, there is enough statistical evidence to conclude that underground goldmine workers have knowledge and aware that naturally occurring radioactive materials are present in the earth crust and the atmosphere which contributes to the effective dose of radiation to every individual and the environment.

Table 16: Response L

Variables	Test Value = 3.5				
	Mean	t	df	Sig. (2-tailed)	Mean Difference
NORM potentially includes all radioactive elements found in the environment. However, the term is used more specifically for all naturally occurring radioactive materials where human activities have increased the potential for exposure compared with the unaltered situation.	4.20	6.326	49	.000	.80

Data Source: Field Survey 2022

The analysis from table 16 indicates that there is statistical significance at the 5% level of significance (P<0.5) that NORM potentially includes all radioactive elements found in the environment. However, the term is used more specifically for all naturally occurring radioactive materials where human activities have increased the potential for exposure compared with unaltered situations. Thus, there is enough statistical evidence to conclude that underground goldmine workers have knowledge and are aware that NORMS is everywhere, but an elevated situation occurs when the environment is altered like mining of minerals.

Table 17: Response M

Variables	Test Value = 3.5				
	Mean	t	df	Sig. (2-tailed)	Mean Difference
NORM issue relates to radon exposure in homes, particularly those built on granitic ground. Occupational health issues include the exposure of flight crew to higher levels of cosmic radiation, the exposure of tour guides to radon in caves, exposure of miners to radon underground, and exposure of workers in the oil & gas and mineral sands industries to elevated radiation levels in the materials they handle	4.12	5.167	49	.000	.620

Data Source: Field Survey 2022

The analysis from table 17 indicates that there is statistical significance at the 5% level of significance (P<0.5) that NORM issue relates to radon exposure in homes, particularly those built on granitic ground. Occupational health issues include the exposure of flight crew to higher levels of cosmic radiation, the exposure of tour guides to radon

in caves, exposure of miners to radon underground, and exposure of workers in the oil & gas and mineral sands industries to elevated radiation levels in the materials they handle. Thus, there is enough statistical evidence to conclude that underground goldmine workers have knowledge and aware that NORMS are generated from man-made practices and cosmic radiations.

Table 18: Response N

Variables	Test Value = 3.5				
	Mean	t	df	Sig. (2-tailed)	Mean Difference
Radium-226 is one of the decay products of uranium-238, which is widespread in most rocks and soils. When this radium decays it produces radon-222, an inert gas with a half-life of almost 4 days.	4.10	5.378	49	.000	.600

Data Source: Field Survey 2022

The analysis from table 18 indicates that there is statistical significance at the 5% level of significance (P<0.5) that radium-226 is one of the decay products of uranium-238, which is widespread in most rocks and soils. When this radium decays it produces radon-222, an inert gas with a half-life of almost 4 days. Thus, there is enough statistical evidence to conclude that underground goldmine workers have knowledge and are aware of radium decay product and the half lives of their products.

Table 19: Response O

Variables	Mean	t	df	Sig. (2-tailed)	Mean Difference
Radium-224 is a decay product of thorium, and it decays to radon-220, also known as thoron, with a 54-second half-life.	4.10	4.786	49	.000	.600

Data Source: Field Survey 2022

The analysis from table 19 indicates that there is statistical significance at the 5% level of significance (P<0.5) that radium-224 is a decay product of thorium, and it decays to radon-220, also known as thoron, with a 54-second half-life. Thus, there is enough statistical evidence to conclude that underground goldmine workers have knowledge and are aware of the thorium decay product and the half lives of their products.

Table 20: Response P

Variables	Test Value = 3.5				
	Mean	t	df	Sig. (2-tailed)	Mean Difference
Radon is short-lived, alpha decays to several daughter products which are solid and very short-lived, there is a high probability of its decay when breathed in, or when radon daughter products in dust are breathed in.	3.94	3.923	49	.000	.440

Data Source: Field Survey 2022

The analysis from table 20 indicates that there is statistical significance at the 5% level of significance (P<0.5) that radon is short-lived, alpha decays to several daughter products which are solid and very short-lived, there is a high probability of its decay when breathed in, or when radon daughter products in dust are breathed in. Thus, there is enough statistical evidence to conclude that underground goldmine workers have knowledge and are aware there is a high probability of radon inhalation through dust.

Table 21: Response Q

Variables	Test Value = 3.5				
	Mean	t	df	Sig. (2-tailed)	Mean Difference
This alpha particle produced in the lung is hazardous. This radon comes from the ground, with exposure affected by factors such as local geography, building construction and mining.	4.20	4.141	49	.000	.700

Data Source: Field Survey 2022

The analysis from table 21 indicates that there is statistical significance at the 5% level of significance (P<0.5) that alpha particle from radon inhaled into the lung are hazardous and this radon comes from the ground, with exposure affected by factors such as local geography, building construction and mining. Thus, there is enough statistical evidence to conclude that underground goldmine workers have knowledge and aware radon produces alpha particles that are hazardous to the lungs of human.

Table 22: Response R

Variables	Mean	t	df	Sig. (2-tailed)	Mean Difference
NORM has the potential to cause human health effects. It is important that these adverse health effects are evaluated using the basic principles of toxicology, including the magnitude and type of exposure, as well as threshold and dose response and that is why the ICRP and the WHO, IAEA has recommended reference levels for Radon gas in Homes/Building works as 300Bqm^{-3} and workplaces/Mines as 1000Bqm^{-3}. Above which there is a need of remediation	4.38	8.579	49	.000	.880

Data Source: Field Survey 2022

Finally, the analysis from table 22 indicates that there is statistical significance at the 5% level of significance (P<0.5) that NORM have the potential to cause human health effects. It is important that these adverse health effects are evaluated using the basic principles of toxicology, including the magnitude and type of exposure, as well as threshold and dose response and that is why the ICRP and the WHO, IAEA has recommended reference levels for Radon gas in Homes/Building works as 300Bqm^{-3} and workplaces/Mines as 1000Bqm^{-3}. Above which there is a need for remediation. Thus, there is enough statistical evidence to conclude that underground goldmine workers have knowledge and are aware of the limit set by international bodies for the radiation protection of the members of the public and occupationally exposed workers.

Demographic Analysis of Questionnaire

Table 23 : Questionnaire Correlation matrix

Demographic variables		Level of Education	Years of Service	Age of the Respondents	Radon Gas & NORM Awareness
Level of Education	Pearson Correlation	1	0.533**	0.579**	0.034
	Sig. (2-tailed)		0.000	0.000	0.817
Years of Service	Pearson Correlation	0.533**	1	0.857**	-0.301
	Sig. (2-tailed)	0.000		0.000	0.34
Age of the Respondents	Pearson Correlation	0.579**	0.857**	1	-0.468**
	Sig. (2-tailed)	0.000	0.000		0.001
Radon Gas & NORM Awareness	Pearson Correlation	0.034	-0.301*	-0.468	1
	Sig. (2-tailed)	0.817	0.034	0.001	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Data Source: Field Survey 2022

Table 24: Questionnaire Age of respondents * Years of Service

Age of respondents (Years)	Years of service						
20-30	7	0	0	0	0	0	7
	14.0%	0.0%	0.0%	0.0%	0.0%	0.0%	14.0%
31-40	0	7	11	3	0	0	21
	0.0%	14.0%	22.0%	6.0%	0.0%	0.0%	42.0%
41-50	0	0	0	0	6	0	6
	0.0%	0.0%	0.0%	0.0%	12.0%	0.0%	12%
51 and above	0	0	0	8	0	8	16
	0.0%	0.0%	0.0%	16.0%	0.0%	16.0%	32.0%
	7	7	11	11	6	8	50
	14.0%	14.0%	14%	22.0%	12.0%	16.0%	100%

Data Source: Field Survey 2022

The correlation matrix in table 23 shows a positive correlation with NORM, radon gas and its associated risk with the level of education among the respondents. This explains that workers with higher education are aware and knowledgeable of the risk as compared to those with lower level of education, but the relationship was weak and insignificant at the 5% level of significance (P< 0.5).

It was also observed in table 23 that the years of service and age of the respondents was negatively correlated with the awareness and knowledge on NORMS, radon gas and its associated health risk in their working environment. This explains that the younger employee is more knowledgeable and aware of the risk as compared to the elderly employees. This observation was justified by a crosstabulation between the years of service and age of respondents in table 24. Thus, if the number of respondents who are considered to be young ranges from 20-40 years, then 56% representing 28 out of 50 respondents were young employees who responded to the questionnaire or the older employees have the tendency of opposing change and due to advancement in age, they might have failing memories, and the relationship was statistically significant at the 5% level of significance (P<0.05).

Also, with respect to the years of service which negatively correlated with the knowledge and awareness in table 23 shows that those who have worked in underground mine for lesser years have more knowledge and are aware of the risk as compared to those for longer years. This reason could not be justified by the crosstabulation in table 24 since equal number of respondents who have fewer years of experience are equal to the number of respondents who had higher number of years of experience (25 respondents each) considering 1-10 years as less experience and 15-21years and above as high experience. It also reflects that knowledge and awareness of NORMS; radon gas and its associated risk is not influenced by the years of service of a worker or influenced by experience and this relationship was statistically significant at the 5% level of significance (P<0.5).

Table 25: Crosstabulation of Gender of the respondents* Employment Statues

Gender	Employment Statues			
	Full Time	Contract	Expatriate	Total
Male	32	6	2	40
	64.0%	12.0%	4.0%	80.0%
Female	7	2	1	10
	14.0%	4.0%	2.0%	20.0%
Total	39	8	3	50
	78.0%	16.0	6.0%	100%

Data Source: Field Survey 2022

The cross tabulation of gender and employment status in table 25 also shows that 80% of the respondents are males of which 32 were full time, 6 contract workers and 2 expatriates and 20% were females of which 14 are full time, 4 contract workers and 2 expatriates. In terms of employment status 78% were full time,16% contract workers and 6% expatriates. This shows that male workers dominate female workers as well as full time workers also dominates contract and expatriates, but the number of expatriates recorded the lowest in terms of employment status of the goldmine company.

Table 26: Questionnaire Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.718[a]	0.516	0.461	7.86210

a. Predictors: (Constant), Years of Service, Gender of the Respondents, Employment Status, Level of Education, Age of the Respondents

Data Source: Field Survey 2022

The Adjusted R^2 of 0.461in table 26 shows that 46.1% of the knowledge and awareness of the risk of NORM and radon gas among the underground goldmine workers were dependent on the demographic variables (Level of education, years of service, age, and employment status) and the rest of the 53.9% may be due to other factors that were not considered in the study. However, a correlation of R = 0.718 shows that those who have worked with the mine for longer years, older employees, status of employees, gender of employees and those with higher education have a positive influence of the knowledge and awareness of NORM and radon gas. Thus, there is a positive relationship between the demographic data and knowledge and awareness of NORM and radon among the workers.

Table 27: Questionnaire ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig
Regression	2897.766	5	579.553	9.376	0.000[b]
1 Residual	2719.754	44	61.813		
Total	5617.520	49			

a. Dependent Variable: Radon Gas & NORM Awareness

b. Predictors: (Constant), Years of Service, Gender of the Respondents, Employment Status, Level of Education, Age of the Respondents

Data Source: Field Survey 2022

The statistical significance of the ($P < 0.05$) in the analysis of variance in table 27 shows that there is enough statistical evidence to conclude that all the demographic variables have some level of influence of the awareness and knowledge of NORM, radon gas and its associated health risk among workers in the underground mine.

Conclusion

In terms of statistical significance to attest if there is enough statistical evidence that the underground workers are aware and have knowledge of NORM, radon gas and its associated risk in their working environment, 10 out of the 18 variables were found to be statistically significant at the 5% level of significance. There is not enough statistical evidence that the underground goldmine workers are aware or have enough knowledge that Smoking can make radon exposure more harmful to their health. It was also realized that they did not have enough knowledge on the sources of radon and materials that could produce radon gas but there was enough knowledge among the workers that radon emanates from the uranium decay series and the parent of radon (radium) are found in rocks and they are soluble in water.

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