KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

COLLEGE OF SCIENCE
FACULTY OF PHYSICAL SCIENCES
DEPARTMENT OF PHYSICS

TITLE:

MEASUREMENT OF RADON GAS LEVEL IN ASHANTI REGION AND DESIGN OF A RADON VULNERABILITY MAP FOR GHANA

A REPORT SUBMITTED TO THE DEPARTMENT OF PHYSICS IN PARTIAL FULFILMENT FOR THE AWARD OF MSc. PHYSICS DEGREE

Submitted by:
Lawrence George Badoe
(PG. 76388-04)

SUPERVISOR:
Prof. Aba Bentil Andam

February, 2007

DECLARATION

This thesis entitled "measurement of radon gas level in Ashanti region and design of a radon vulnerability map for Ghana" has been carefully conducted and apart from references made to other writers all other information, results and deductions are from experiments conducted by me .

………………………………… ………………………………

Lawrence George Badoe Prof. Aba Andam

(Student) (Supervisor)

………………………………………..

(Head of Department)

ACKNOWLEDGEMENT

I wish to express my sincere thanks to the almighty God for seeing me through another level of my education

My greatest appreciation also goes to my supervisor, Prof. Aba Bentil Andam for her immense contribution and advice

I also want to thank my parents, brothers and sister, uncles, aunties and all other family members who in diverse ways have helped to make this level a possibility

Special thanks go to my grand mum, who pays for every trip made to school, I really am grateful.

Finally my appreciation to all technicians, lecturers and post-graduate students of the Physics Department.

DEDICATION

For all the love and well wishes, am indebted to you greatly.

This work is dedicated to my father

MR. KOJO BADOE

ABSTRACT

This thesis work was conducted to ascertain the variation of radon gas levels with passing years in the Lake Bosomtwi area and base on the obtained results a radon vulnerability map drawn for Ghana. Samples were collected in four villages around the lake and analyzed in the nuclear physics laboratory of the physics department of the Kwame Nkrumah University of Science and Technology. The results obtained were compared with results from previous years and it came out clear that year 2006 had the lowest average radon gas level of 99.95 $pCiL^{-1}$ or 3.70 $KBqm^{-3}$, with year 2001 having the highest of 167.2 $pCiL^{-1}$ or 6.19 $KBqm^{-3}$. Overall the average radon gas level between the years 2001 to 2006 for the Lake Bosomtwi area was 130.94 $pCiL^{-1}$ and this value according to the United States' Environmental Protection Agency is within the range of 0.1WL – 1WL (20-200 $pCiL^{-1}$) which means that exposures in this range are considered greatly above average for residential structures. A vulnerability map of Ghana shows that research work have been conducted in the following regions Western, Central, Greater Accra and Ashanti and other regions like Eastern, Volta and the Northern parts of Ghana have experience little or no research.

TABLE OF CONTENT

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

TABLE OF FIGURES

TITLE:

MEASUREMENT OF RADON GAS LEVEL IN ASHANTI REGION AND DESIGN OF A RADON VULNERABILITY MAP FOR GHANA

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MISSION

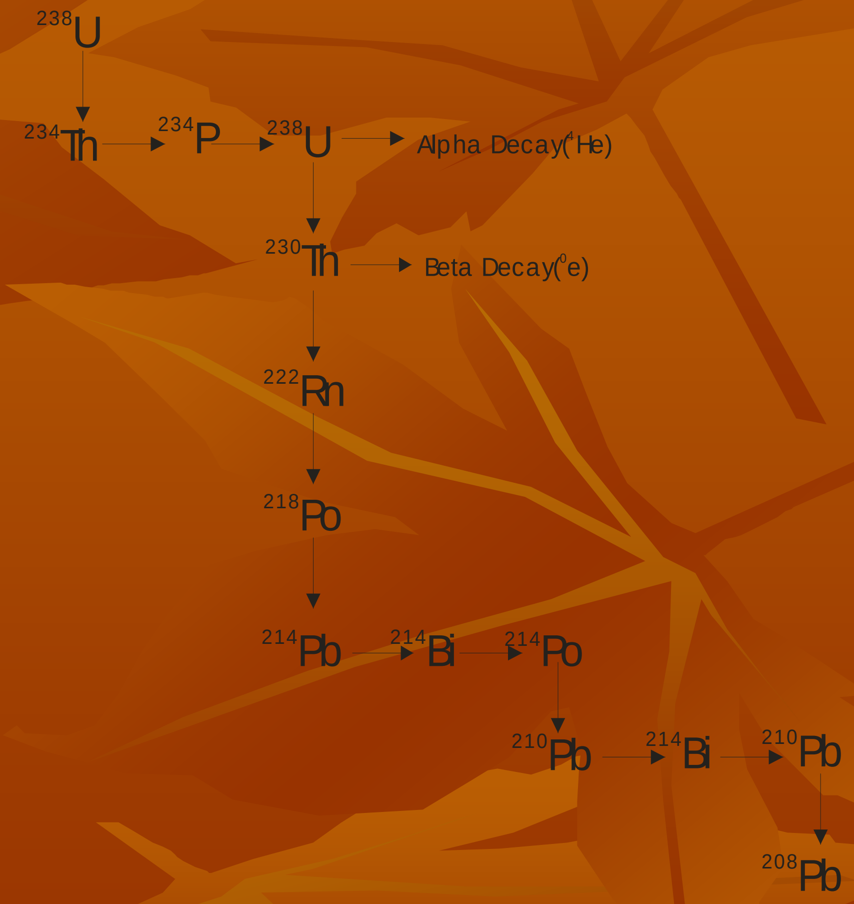
- Calculation of average radon concentration around the Lake Bosomtwi area from the year 2001 to the year 2006
- Study variation of radon concentration with passing years
- Base on the above variation, validate results obtain years ago
- Design a Radon vulnerability map for Ghana

CONTENT

- INTRODUCTION/FACTS ABOUT RADON
- METHODOLOGY
- RESULTS & OBSERVATION FROM RESULTS
- DISCUSSION & DEDUCTION
- CONCLUSION

FACTS ABOUT RADON

- Radon is a radioactive gas found in nature.
- It has no colour, odour or taste and is chemically inert.
- Its source is uranium
- Radon levels are expressed as the concentration of radon in units of picocuries per liter of air (pCi/liter),
- SI units as Becquerel per cubic meter (Bq/m3),
- or radon daughters are expressed in working levels (WL).



^{232}U decay series - the source of ^{222}Rn (radon)

FACTS ABOUT RADON (Cont'.)

- **EPA RECOMMENDATIONS**
- **How quickly should action be taken?**

  The EPA believes that radon levels should be permanently reduced as much as possible. Based on current available information, the EPA believes that levels in most homes can be reduced to about 4 pCi/liter
- **If results are about about 200 pCi/liter or higher:**

  Exposure in the range are among the highest observed in homes.
- **If results are about 20 to 200 pCi/liter:**

  Exposures in the range are considered greatly above average for residential structures.
- **If results are about about 4 pCi/liter to about 20 pCi/liter:**

  Exposures in this range are considered above average for residential structures.
- **If results are about 0.02 WL or lower, *or* about 4 pCi/liter or lower:**
- Exposure in this range are considered average or slightly above average for residential structures. Although exposures in this range do present some risk of lung cancer, reduction of levels this low may be difficult, and sometimes impossible, to achieve.
- NOTE: The higher the radon level in a home, the faster action should be taken to reduce exposure.
- 1pCi = 37KBq/m^{-3}

METHODOLOGY

- To begin a station was first selected; the station had enough space around it for profiling.
- Ten (10) profiles were made on each location; these profiles were about 2m apart and in reference to the selected station.
- Five (10) holes were made on every profile and soil samples weighing about 100g were collected from depths of 10cm.
- the soil samples were bagged and labeled.

METHODOLOGY (Cont'.)

- SAMPLE PREPARATION
- Each soil sample picked up from the field was dissolved in about 100cc of water and the resulting mixture was shaken thoroughly to enable the water to absorb the radon gas trap by the soil sample. The mixture was then allowed to settle for about 2 weeks so that all the various gaseous composition of the soil will be fully trapped in the water.

METHODOLOGY (Cont'.)

- Samples were degas using the Radon Degassing Unit 200 (RDU-200)
- Radon detector analyzer (RDA-200) was the instrument used in the radiation counting. The alpha emitting properties of the short-lived Radon daughters were used to determine the radioactivity counting ability of the RDA-200. Each cell was put in turn into the RDA-200 after filling with radon gas.

RESULTS & OBSERVATION FROM RESULTS

- Evaluate radon concentration level at Lake Bosomtwi in 2006
- Compare results from 2003 and 2006
- Compare averages from 2001 to 2006 and determine the total average

RESULTS & OBSERVATION FROM RESULTS (Cont'.)

AREA	RADON CONCENTRATION $pCiL^{-1}$.		
	MINIMUM	MAXIMUM	AVERAGE
ADWAFO	31.90	135.57	74.43
KUSUASO	39.83	143.54	82.94
DUASI	95.69	191.39	146.73
TEPASO	55.82	143.54	95.70

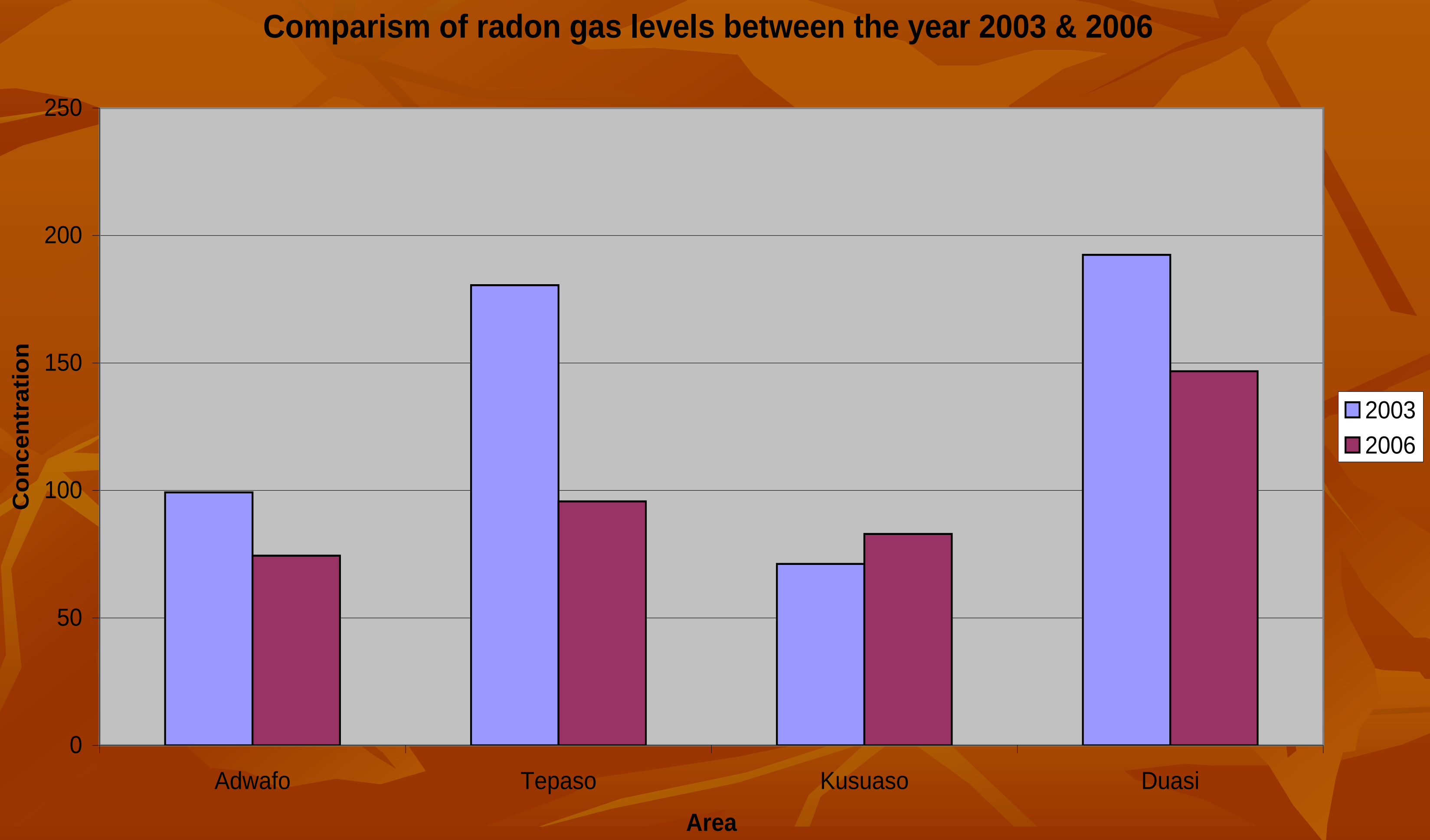
Overall

Minimum Value 31.90 pCiL-1.

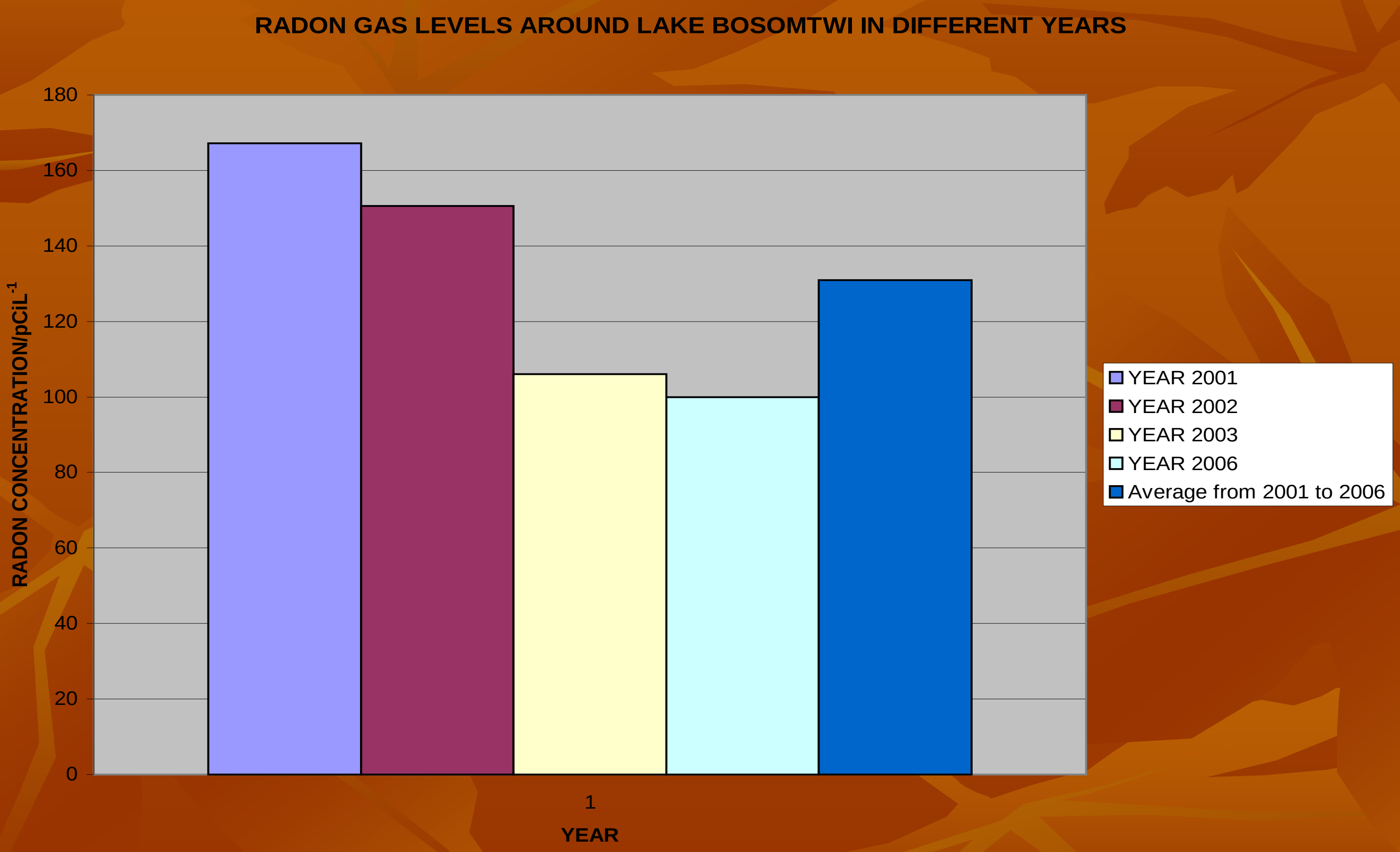
Maximum Value 191.39 pCiL-1.

Average Value 99.95 pCiL-1. Or 3.70 KBqm-3.

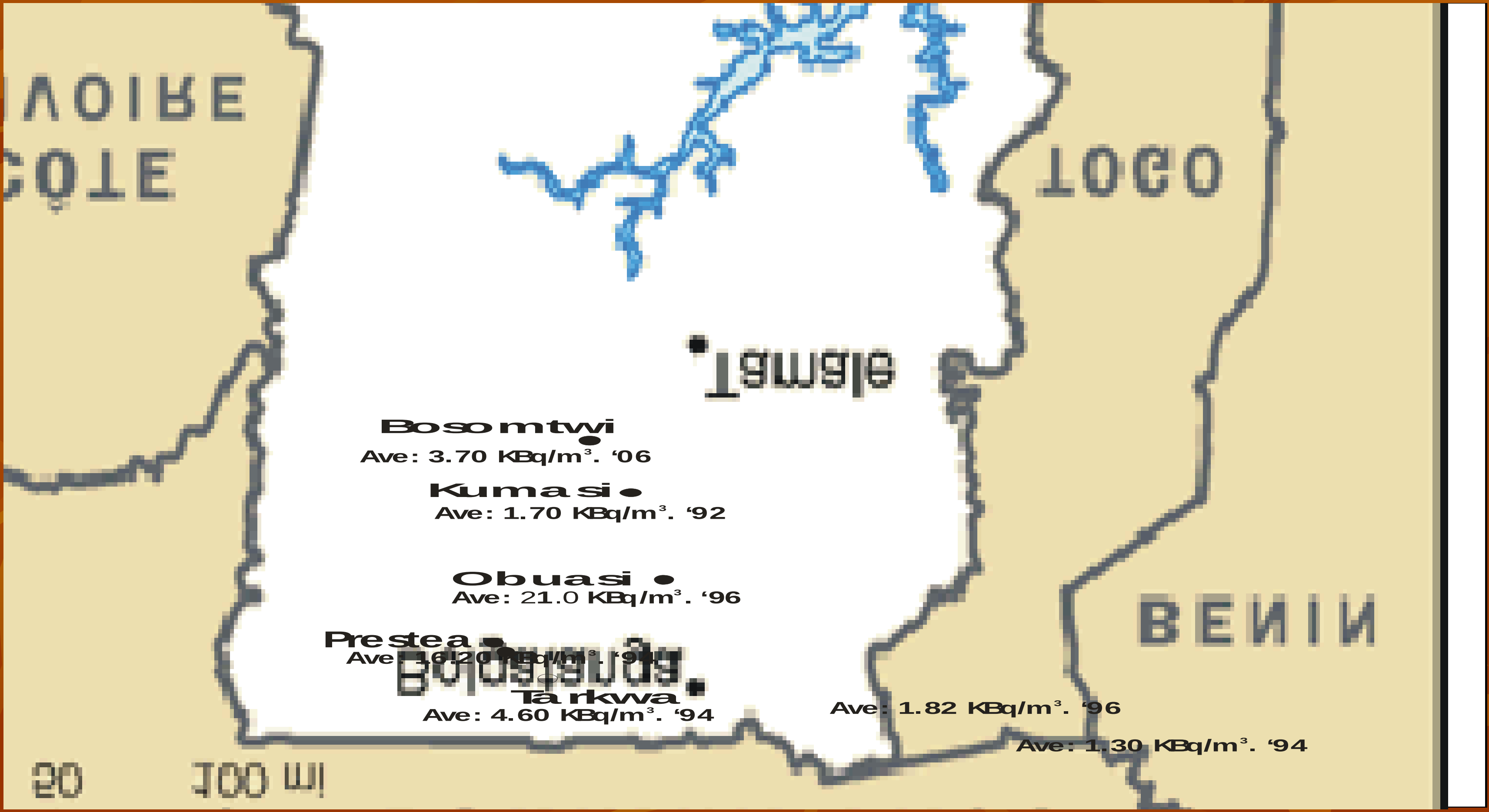
RESULTS & OBSERVATION FROM RESULTS (Cont'.)



RESULTS & OBSERVATION FROM RESULTS (Cont'.)



DISCUSSION & DEDUCTION



VULNERABILITY MAP OF RADON GAS LEVELS IN GHANA

CONCLUSION

- The average radon gas level in the Lake Bosomtwi area for the 2006 is 99.95pCiL-1 and this result was obtained from four (4) Villages.
- Average radon gas level between the periods 2001 to 2006 is 130.94pCiL-1.
- Variation in radon gas levels with passing years is insignificant.
- Currently Obuasi has the highest Radon gas level of 567.57pCiL or 21KBq/m^{-3}
- A vulnerability map of Ghana shows that research work have been conducted in the following regions Western, Brong Ahafo, Central, Greater Accra and Ashanti and other regions like Eastern, Volta and the Northern parts of Ghana have experience little or no research

APPENDIX

Radon Degassing Unit-200 with a cell and a glass tube containing sample

THANK YOU

CHAPTER ONE

1.0 INTRODUCTION

1.1 GENERAL INTRODUCTION

The potential hazard of radiation exposures to radon gas and its daughter products from natural background has been highlighted in the world of scientific press and has become a matter of concern and a source of confusion to the public. Home owners are besieged with devices to measure radon levels, and may not know what to do about the results they get. The Environmental Protection Agency (EPA) has issued guidelines, as has the National Council on Radiation Protection and Measurement (NCRP), the International Commission on Radiation Protection (ICRP) and other groups concerned with radiation protection matters. The guidelines and recommended actions are in general agreement, although they differ in detail. A matter of concern is that the media have chosen the lowest level of the guideline, which the public translates into the upper limit of "safe dose". It is not surprising that there is widespread confusion regarding the nature and severity of the problem, the risk magnitude, the steps that should be taken to cope with different circumstances, and the costs associated with different actions. The material distributed in the Radon Update is intended to provide information needed to help understand these issues and to provide a compilation of the relevant facts for those individuals interested in the potential health effects of environmental radon. [1]Many articles have been published in the scientific literature dealing with the issue of human risk from radon exposures, and many of these appear in publications by the National Academy of Sciences (NAS), NCRP, EPA , Department of Energy (DOE), as well as in the radiation related journals, primarily the Health Physics Journal, and its Newsletter, and Radiation Research.

1.2 STATEMENT OF OBJECTIVE

The overall performance goal for this Project

i. **This survey was carried out to ascertain radon gas emanation levels with time in the Ashanti region**. The survey will be conducted all over Ghana with time, but this project was to take note of some areas in the Ashanti region with possible hazardous radon emanation levels.

ii. **To put together results obtained for compilation as a national database and come out with a radon vulnerability map of surveyed areas**. It is very worrying to know that Ghana has no information on its radon emanation levels, which means there are people living in areas with high radon levels without any knowledge.

iii. **To educate the average Ghanaian on the hazardous effect of radon gas, and how to handle such hazards, through organized forums and symposiums.** One of the key ways to mitigate the effect of radon is through education. The general public, once educated will have some knowledge on radon and simple ways of avoiding over exposure.

iv. **As a collaborative research, this Project has brought together Ghanaian scientists from various institutions to work on a theme of national interest.** The results of this project have brought up other areas of concern and hopefully other Ghanaian scientists will research into those areas.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 HYPOTHESIS OF RADON

Radon is a radioactive gas found in nature. It has no colour, odour or taste and is chemically inert. Its source is from uranium. As the uranium molecule decays to form stable lead, a process taking many, many years, it changes from one radioactive element to another in a sequence known as the Uranium Decay Cycle. Partway through this cycle, the element radium becomes radon which as a gas moves up through the soil to atmosphere. Uranium is found in most soils and in granite.(2)

Radon, Rn-222 (T 1/2= 3.82 days), is a daughter product of radium, Ra-226, which in turn is derived from the longer-lived antecedent, U-238. Thoron, Rn-220 (T 1/2 = 56 seconds) is a daughter of thorium, Th-232, which is present in larger amount in the earth's crust than radon. Because of thoron's short half-life, it is essentially all gone before it leaves the ground, and is of no significant radiobiologic consequence. These radionuclide series are present in slowly decreasing amounts in the environment (geologic time scale), due to radioactive decay of their parents, which has been known and understood since the end of the 20^{th} century.

Widely varying radon levels exist in different regions related to geological circumstances. New concern regarding radon exposures is traceable to the discovery that there are more houses with high radon levels than previously realized and to the use of a new method of expressing and summing doses from partial body exposures, such as the lung dose from radon daughters. This method of expressing dose was promulgated by the ICRP and the

NCRP based on defined weighting factors which make it possible to sum partial body doses and thereby estimate a total body dose which would have a quantifiable risk. This quantity is defined as the Effective Dose (ED) . Thus, the previously estimated partial body environmental radon dose to the tracheobronchial epithelium (TBE) (2500 mrem/year.) was not included in whole body dose calculations because that exposure was limited to a small fraction of the body.

The new method of calculation multiplies the 2500 mrem/year. dose to the TBE by a weighting factor (WF) which allows the dose to the TBE to be included in the ED from environmental radiation exposure Different WFs have been proposed, including 0.12 (EPA), 0.08 (NCRP) and (NAS-NRC BEIR V), and 0.06 (ICRP). These WFs raise the radon contribution to the whole body from 0 mrem to 300, 200, and 150 mrem respectively. NCRP quotes an uncertainty of +/- 50% in these numbers. Based on these estimates, radon in equilibrium with its daughters delivers 2 times more dose than previously accepted as the total dose received from all sources of natural background exposure (approx. 100 mrem/year on the average in the United States). Thus, it is not surprising that adoption of the effective dose notion by many radiation protection groups (including the NCRP and the EPA in the United States), has led to increased concern regarding the potential health effects of radon. It should be noted that lung cancer risk coefficients from radon are not increased. There are no new cases of lung cancer that led to the increased dose estimate. In fact, the new estimates of radiation dose imply a lower risk coefficient. That is, when the same numbers of lung cancer cases that occur are attributed to the higher doses (ED), the risk per unit exposure is decreased. (3)

2.1.1 Units of measurement for Radon levels

Almost all measurements of radon levels in the home or outdoors are expressed as the concentration of radon in units of picocuries per liter of air (pCi/liter), or in SI units as Becquerel per cubic meter (Bq/m^3), or radon daughters are expressed in working levels (WL). A working level month (WLM) is defined as 170 hrs (2l.25 working days/month x 8 hrs/day) in a work place at one WL. Thus, a 12 hour a day exposure in the home at one WL, corresponds to approx. 26 working level months per year i.e. 2.1 X the occupational exposure, assuming equal radon levels at home and in the work place. Exposure rate is typically given in working level months per year (WLM/year).

The WL unit was developed for use in radon occupational exposure assessment since often there was incomplete information on the degree of equilibrium with daughter products. It is the dose delivered in one liter of air that results in the emission of 1.3×10^5 MeV of potential alpha energy. The amount of time spent in the mine or in the home determines the number of WLM associated with a particular exposure level, but because most people spend more time at home than at work, the WLM could be higher than from a comparable mine radon daughter concentration. Typical outdoor levels in the U.S.A. are given by NCRP # 78 as 0.2 pCi/liter.

The correspondence between WLs and radon concentration in air in pCi/liter depends on the extent to which radon daughters (which impart dose to the tracheobronchial epithelium dose, "TBE") are in equilibrium with the parent radon. At complete equilibrium, one pCi/liter results in an exposure equal to 0.01 working levels. The assumption is generally made that inside buildings the radon decay product/radon equilibrium is 50%. Thus, inside buildings, 1 pCi/liter = 0.005 WL, or 1 WL= 200 pCi/liter. (Note: Consideration must also be given to radionuclide attachment and distribution.). (4)

2.2 MEDICAL EFFECT OF RADON INHALATION

Natural sources contribute significant quantities of radiation toward the total radiation exposure that humans receive. The majority of this natural radiation is harmless to humans in the ambient environment. However, radon, a large component of the natural radiation that humans are exposed to (greater than sixty percent), can pose a threat to the public health when radon gas accumulates in poorly ventilated residential and occupational settings.

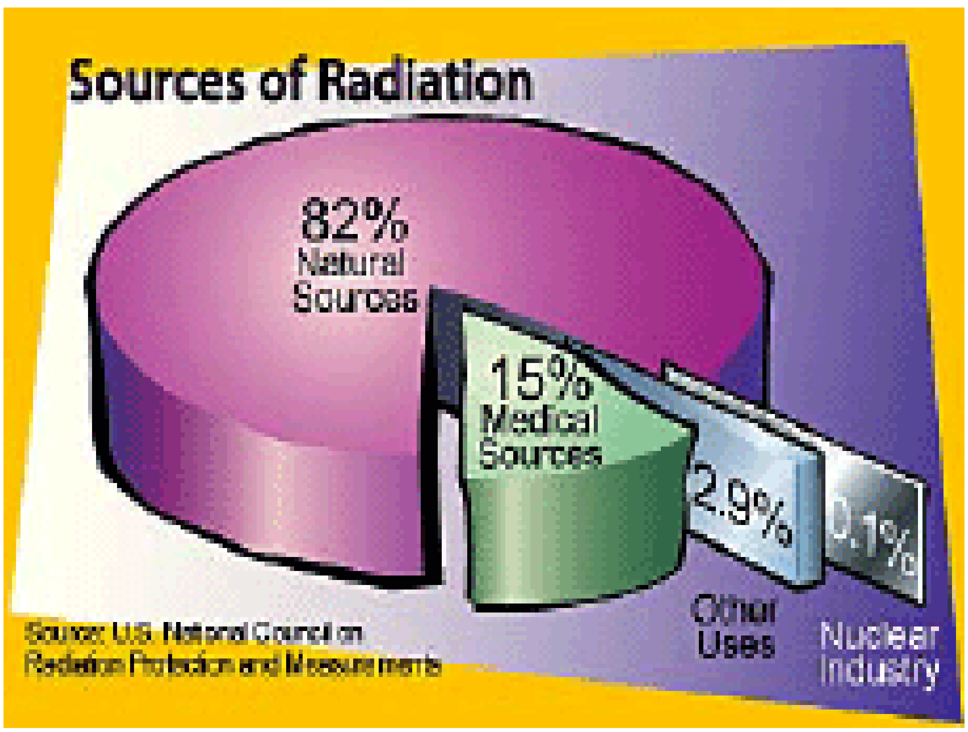


Figure 1. Sources of Radiation

According to the Office of the Surgeon General: "Indoor radon gas is a serious health problem in our nation that can be addressed by individual action. Unless people become aware of the danger radon poses, they will not act. Millions of homes are estimated to have elevated radon levels. Fortunately, the solution to this problem is straight-forward. Like the hazards from smoking, the health risks of radon can be reduced." (5)

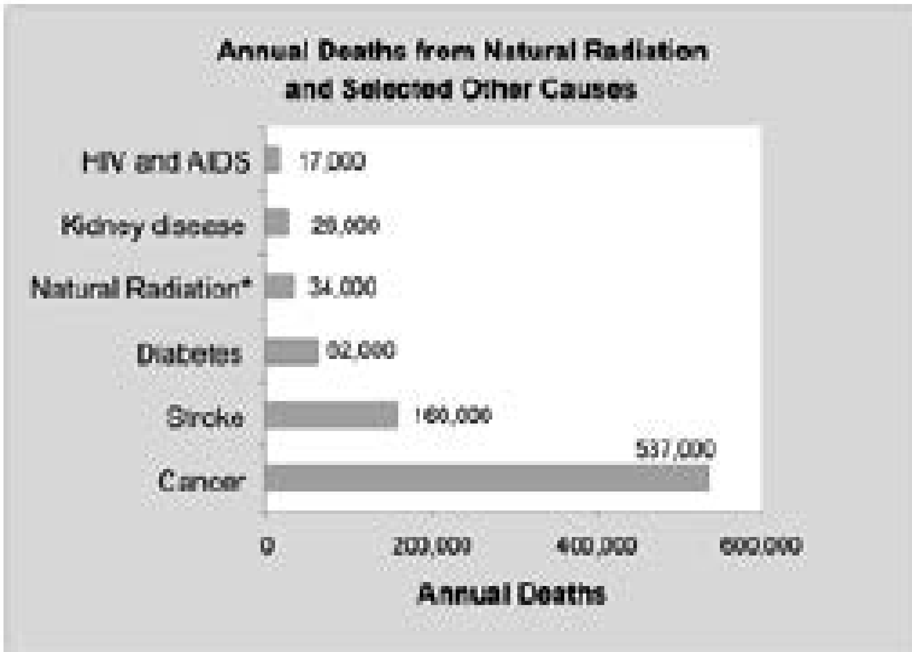


Figure 2. Annual Deaths from natural radiation and selected other causes

Radon accounts for more than half of the total average annual exposure to radiation, about 200 of 360 millirem per year. Radon, although not always publicized as a tremendous public health concern (in the way that drunk driving is), ranks highly among other preventable causes of death, including drunk driving, drowning, and fires. Additionally, the death risk to the average person from radon gas at home is 1,000 times higher than the risk from any other carcinogen or toxin regulated by the EPA. For these reasons, research must be conducted to evaluate certain subgroups that have elevated risks and technology must be developed and implemented in order to limit exposure to dangerous levels of radon and its harmful progeny.

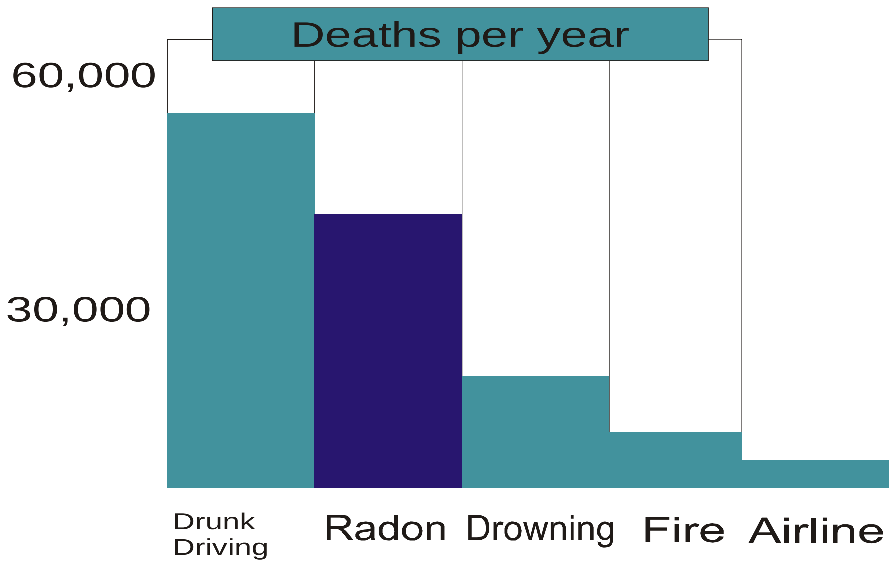


Figure 3. Radon is estimated to cause thousand of cancer deaths in the US each year

The most recent National Academy of Science (NAS) report on radon, The Health Effects of Exposure to Radon estimated that about 14 percent of the 164,100 lung cancer deaths in the United States each year are attributable to exposure to radon - correlating to approximately 15,000 to 22,000 lung cancer deaths each year. 160 of these deaths have been attributed to radon dissolution exposure in ingested water, and 700 deaths from exposure in outdoor air (mostly exposure from mines). The majority of the radon caused deaths occur from inhalation of radon and radon progeny. The average number of years of life expectancy lost per death from lung cancer is about fifteen. In a second NAS report published in 1999 on radon in drinking water, the NAS estimated that about 89 percent of the fatal cancers caused by radon in drinking water were due to lung cancer from inhalation of radon released to indoor air, and about 11 percent were due to stomach cancer from consuming water containing radon. (6)

Certain characteristics of the residence and environmental factors will play a role in determining the indoor radon concentrations. The highest radon levels are typically found in the lowest level of the house. If well water is the major source of radon, upper floors can be affected more than lower floors because of dissolution of radon from the water. Radon levels are elevated in colder climates (winter) rather than in more mild temperatures (summer and spring).

The risk of lung cancer associated with lifetime inhalation of radon in air at a concentration of 1 Bq m^{-3} (37.027pCi/liter) was estimated on the basis of studies of underground miners. The values were based on risk projections from three follow-up studies. These three reports used data from 4 to 11 cohorts of underground miners in seven countries and developed risk projections of 1.0×10^{-4}, 1.2×10^{-4}, and 1.3×10^{-4} per unit concentration in air (1 Bq m^{-3}), respectively. The three values were for a mixed population of smokers and nonsmokers. The risk of lung cancer (discussed in two reports of the National Research Council and one of the National Institutes of Health) posed by lifetime exposure to radon (222Rn) in water at 1 Bq m^{-3} was calculated to be 1.3×10^{-8}.

As already stated, an increase in the number of radiation particles that pass through the human body correlates to an increase in the chance of developing cancer. Therefore, the risk to people is proportional to the length of exposure and the radon concentration in air (linear, no-threshold hypothesis). However, the radon risk begins to level off for extremely high concentrations, like for miners, because more lung cells are killed off by the radiation rather than becoming cancerous and some radiation is wasted on the already killed cells (the "inverse exposure-rate effect"). But at lower concentrations, like in residences, every emitted particle will have an impact. (7)

2.2.1 Who is at Risk?

This is a list of occupations that have the potential for high 222Rn progeny exposure:

- Mine workers, including uranium, hard rock, and vanadium
- Workers remediating radioactive contaminated sites, including uranium mill sites and mill tailings
- Workers at underground nuclear waste repositories
- Radon mitigation contractors and testers
- Employees of natural caves
- Phosphate fertilizer plant workers
- Oil refinery workers
- Utility tunnel workers
- Subway tunnel workers
- Construction excavators
- Power plant workers, including geothermal power and coal
- Employees of radon health mines
- Employees of radon balneotherapy spas (waterborne 222Rn source)
- Water plant operators (waterborne 222Rn source)
- Fish hatchery attendants (waterborne 222Rn source)
- Employees who come in contact with technologically enhanced sources of naturally occurring radioactive materials
- Incidental exposure in almost any occupation from local geologic 222Rn sources(8)

2.2.2 Geographic and Residential Risks

The amount of radon emanating from the earth and concentrating inside homes varies considerably by region and locality, and is greatly affected by the residential structure as well as soil and atmospheric conditions. Nearly every state in the United States has dwellings with measured radon levels above acceptable limits. The EPA estimates that 6% of American homes (approximately 6 million) have concentrations of radon above 4 pCi/L. Areas of the country that are likely to have homes with elevated radon levels are those with significant deposits of granite, uranium, shale, and phosphate, which are all high in radium content and, therefore, potential sources of radon gas. However, due to the many determinants of indoor radon levels, local geology alone is an inadequate predictor of risk. The only way to determine indoor radon concentration is by testing. Other factors that predispose homes to elevated levels of radon include soil porosity, foundation type, location, building materials used, entry points for soil gas, building ventilation rates, and source of water supply. Further research is being conducted on ways to predict which homes are most likely to have significant levels of radon. (9)

2.2.3 Risk for Smokers

Apart from the results of very limited in-vitro and animal experiments, the only source of evidence on the combined effect of the 2 carcinogens (cigarette smoke and radon) was the National Academy of Science (NAS) data collected from 6 of miner studies. Analysis of that data indicated a synergistic effect of the two exposures acting together, which was characterized as sub multiplicative (i.e., less than the anticipated effect if the joint effect were the product of the risks from the two agents individually, but more than if the joint effect were the sum of the individual risks). The risk of lung cancer from radon exposure is estimated to be approximately 10 -15 times greater for persons who smoke cigarettes in comparison with those who have never smoked. According to the NAS Committee on the Biological Effects of Ionizing Radiation, a breakdown of the contribution of smoking and radon exposure to lung cancer deaths in the United States illustrates that of every 100 persons who died of lung cancer, approximately 93 were current or former smokers, whereas 7 had never smoked. However, it is important to remember that the lung cancer incidence among non-smokers is much lower than among smokers. Radon in homes causes 11% of lung cancer deaths among ever-smokers, but 23% among never-smokers. Therefore, increasing the radon levels presents a much higher relative risk to non-smokers. For example, increasing the radon concentration from 1.5 pCi/L to 4 pCi/L, the cancer risk for a non-smoker increases 100%, but only 42% for a smoker. Although there is no sure explanation for the synergistic effect of radon exposure and smoking, the predominant hypothesis is that smokers have a higher potential retention of deposited radon progeny due to increased mucus production and iterations in mucociliary clearance. (10)

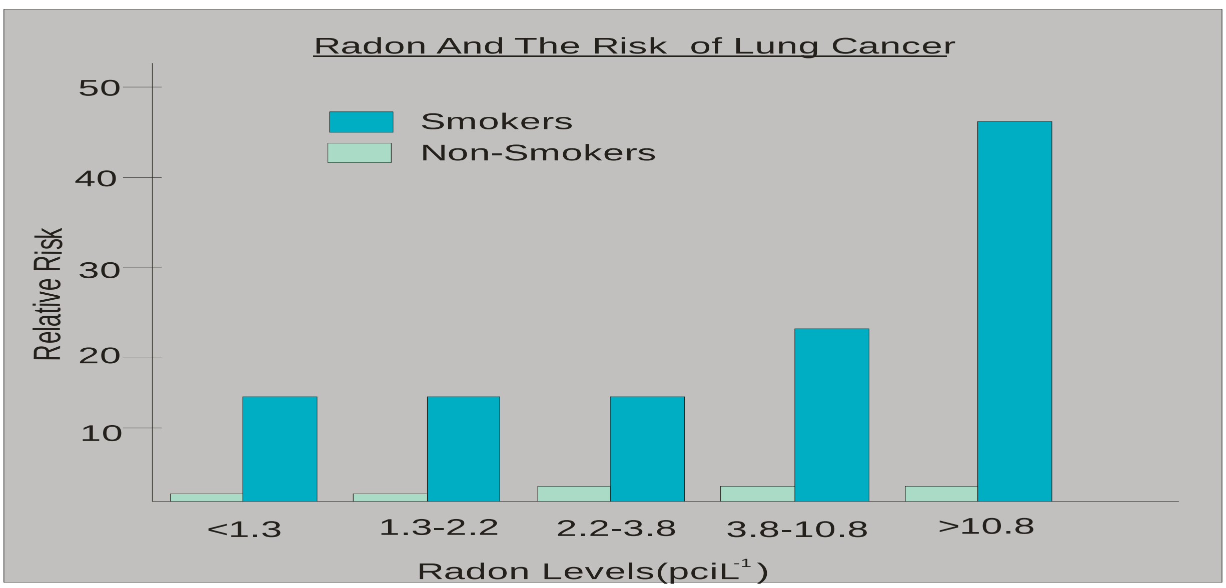


Figure 4. Radon and the Risk of Lung Cancer Between Smokers and Non-smokers

2.2.4 Risk for Women and Men

The effect of radon exposure on lung cancer risk in women might be different from that in men because of differing lung dosimetry or other factors related to gender (the risk model was developed using epidemiological studies in male miners). Women have displayed lower rates of lung cancer incidence than males, even after stratifying the analysis to control for smoking history. In 1999, the National Academy of Sciences calculated the lifetime risks of exposure to Radon-222 at home for each Becquerel/m3 (0.007 pCi/L) in air:

Lung cancer risks from exposure to Radon-222 at 1 Bq/m3		
	Ever-Smokers	**Never-Smokers**
Men	3.1 x 10-4	0.59 x 10-4
Women	2.0 x 10-4	0.40 x 10-4
Population	1.6 x 10-4	

2.2.5 Risk for Children and Elderly

Data on the effects of radiation in children is rather limited, however, several studies have showed that children are more susceptible to radon exposure than adults. Children have different lung architecture and breathing patterns, resulting in a somewhat larger dose of radiation to the respiratory tract. Children also have longer latency periods in which to develop cancer. Hofmann reported that the radon dose was strongly dependent on age, with a maximum value reached at about the age of 6 years. Despite these findings, no conclusive data exists on whether children are at greater risk than adults from radon. Because of the latency time for cancer to develop and the cumulative nature of radon risk through time, there is very little possibility that someone could get lung cancer from radon before age 35, although exposures before that age contribute to the risk at later ages. The relative risk from domestic radon exposure is also higher for children because they spend more time at home and/or the basement. On average, children spend 70% more time in the house than adults. Studies regarding the rates of translocation in a person show that there exists an exponential increase in the number of translocation with an increase in age. Characterized by the formula:2.8 + 0.0025 x (age)2

It has been hypothesized that decreased efficiency in DNA repair mechanisms is a function of age. Therefore, as a person gets older, their DNA becomes more unstable and abnormalities persist through the cell cycling process because of a lack of repair capabilities. For this reason, alpha particle exposure at later life stages can have greater potential for causing genomic changes. However, individuals of this age are probably too old to die of the associated tumor progression (cancer endpoints take many years [usually >15] to manifest themselves). (11)

2.3 RADON MEASUREMENT TECHNIQUES

Radon measurements are performed for different application. These go from mineral prospecting to geothermal studies and volcanic eruption and earthquake prediction, including in between, tectonics and hydrogeology studies.

The first choice is to determine whether to measure radon itself or its daughter products. In both cases, alpha and gamma radioactivity are the detectable phenomenon. The measurement can be continuous or discrete or by carrying out grab sampling. It can be active, which involves the pumping of soil gas into or through a detecting instrument, or passive when the radon concentration is measured in situ under natural conditions

2.3.1 Radon concentration measurement in the ground

Radon concentration measurement in situ always requires having detectors put in place and left there for a sufficient amount time. Depending on the depth needed, the bore hole is sheathed or not. Additionally, the detector is placed in a container that allows radon to enter it but prevents the detector from damage, a simple cardboard cup or a more sophisticated vessel can be used. The container also determines the volume of detection and hence large enough containers ensures maximum detection efficiency. Since alpha particles from radon have a range of 4.2 cm in the air, a free space of this order in front of the detector will be convenient.

In principle the measurement of radon concentration in the soil is simple. However some consideration must be given to the 'thoron problem'. The two isotopes of radon generally occur together. When a radon detector is place in the ground, both radon isotopes should theoretically be detected unless some sort of discriminating mechanism can be applied. There are two ways to solve the problem: the first is to prevent the thoron from entering the detection device by taking advantage of the difference between its half-life (55s) and that of radon (3.82day), the diffusion barrier can be as simple as a certain length of air. It has been shown that traveling 30cm in the air by diffusion is enough for thoron to be reduced down to 95% of its initial amount. The second is a decipher between thoron and radon response once both isotopes have entered the device. A set-ups consisting of a 30 to 35 cm long narrow pipe instead of a mere inverted cup, the upper end of the pipe will hold the detector. This type of arrangement offers the most rugged way to dispose off the thoron problem. Other diffusion barriers are made of thin membranes of different materials. The use of such membranes allows to work with smaller set-up and also to ensure a moisture free atmosphere within the volume of detection.

The various detectors one can use in a bore hole for radon concentration measurement are essentially solid state nuclear track detectors, daughter's collectors (such as the alpha cards, electrets detector and thermo luminescent phosphors) and solid state electronic detectors such as photodiodes and gas absorbers which behaves like active charcoal. (12)

2.3.2 Solid state nuclear track detectors

Basically, solid state nuclear track detectors work as follows: "The passage of heavily ionizing particles, such as alphas, through most insulating solids creates narrow path of intense damage on an atomic scale. These damage trials may be enlarged, up to be seen under an optical microscope, by chemical treatment that rapidly and preferentially removes the damage material. It is less rapidly removes the surrounding on damaged matrix in such a manner as to enlarge the etched tracks that mark and characterized the site of the originally damage region. Some SSNTDs are sensitive to alpha particles but totally insensitive to beta and gamma rays. They also are unaffected by humidity, low temperature, moderate heating and light. They of course do not require energy to operate. After irradiation, SSNTDs are processed and the determination of the number of particles that have impinged the detector can be performed by various means. The most common is the counting of the tracts under an optical microscope but many techniques have been devised. Two of them are more popular. The first one is the spark counting technique initially proposed by Cross and Tommasino. It provides reliable and fast counting up to 5000 tracks/cm2. The second technique is the use of an image analyzer. The tracks are counted automatically and their number stored in the unit for further data analysis. It offers the advantage to allow the counting of thick detectors. (13)

2.3.3 Electrets detector

One of the most recent techniques for radon measurements and monitoring is the electrets radon monitor. An electrets is a piece of dielectric material that exhibits an almost permanent electrical charge if not otherwise perturb, this charge produces a strong electric field which is able to collect ions of opposite signs and the total charge of the electrets decreases. The electrets radon monitor is basically made of steel can on the lower top of which the electrets dosimeter is fixed. At the bottom is a small inlet allows the radon gas to enter the assembly through a filter. Decaying away, radon produces ionizing particles that intend produce ions within the inner volume. These ions are collected and the total charge of electrets changes. After some time the surface potential of the electrets is measured by the shutter method using a battery operated, lightweight piece of equipment. This method is nondestructive and the electrets can be measured several times without having their charge value altered. After proper calibration, the electrets dosimeter can deliver a dose response curve. The electrets dosimeter offers several advantages, an example is its ability to store information over relatively long period, it is independent of the humidity in its environment and easy to take readings if it is well calibrated. But its response curve does not cover efficiently the very low or very high doses and also it is sensitive to gamma radiation background which in some case may induce significant error or even preclude their use. (14)

2.3.4Activated charcoal

Radon on activated charcoal (ROAC) is a radon measure technique based on the absorption of the gas on charcoal and then on the measurement of the gamma activity of tracked daughters 214Pb and 214Bi. Essentially the absorption of radon is achieved using a plastic can containing a few grams of activated charcoal. The plastic can is placed into the ground, lid open and left in place for 4 to 12 days. It is then retrieved and the lid closed and brought to the lab where the gamma activity is determined by means of a NaI counter. The thoron problem is solved in principle by taking advantage of the decay curves of both daughter products. Normally after 3 to 5 days all the thoron contained in cup should have disappeared and the count rate should represent radon only. Using some 400 grams of charcoal, Megumi and Mamuro determined the ratio between thoron and radon emanation from a soil. On the contrary using its grounds of product Hambleton-Jones and Smit found their charcoal cartridges were unable to absorb sufficient amount of thoron and they concluded that ROAC setup could be used with impunity in high thorium environment.(15)

2.4 RADON RESEARCH WORKS CONDUCTED IN GHANA

2.4.1 Indoor Radon measurement in traditional constructed house in Ghana.

From the targeted sample of 50 houses only 26 houses agreed to take part in the survey. For the first sampling period from March to June the minimum radon concentration measured was $10Bq/m^3$ and the maximum was 580 Bq/m^3. For this period, 10 houses were found to have radon concentrations that exceeded the remedial action level of $150Bq/m^3$ set by the Environmental Protection Agency (EPA) of the United State of America. Of these houses four exceeded the immediate action level of $400Bq/m^3$. the mean radon concentration for all the houses monitored was $193Bq/m^3$ with the standard error of mean $35Bq/m^3$.

For the total period of the nine months survey, 75% of the detectors were collected. Of these 28% exceeded the action level of $150Bq/m^3$ with 5% exceeding the immediate action level of $400Bq/m^3$. The median value for the radon concentration is $69Bq/m^3$. (17)

2.4.2 Monitoring of natural background radiation in some Ghanaian homes.

The average radon concentration for the modern sand Crete building was found to be 2 Bq/m^3. This is at the threshold of detection for the seven months exposure period. The mean for the nine single unit houses was 3Bq/m^3 which was the same for the one storey buildings. The fourth storey' of the block of flats had an average value of 1.0 Bq/m^3, this shows the thinning out of radon concentration with height above ground level.

For the traditionally constructed houses, the mean radon concentration was 121 Bq/m^3 with a standard error of the mean being 15 Bq/m^3 for all the measurements during the nine months exposure period. The test house monitored continuously for a year period had a mean value of 28 Bq/m^3.

During the period from March to June nine houses exceeded the remedial action limit of 150 Bq/m^3 with three of these exceeding the immediate level of 400 Bq/m^3 set by the Environmental Protection Agency (EPA) of the United State of America. The mean for this period was 171 Bq/m^3 with error of 34 Bq/m^3. The radon concentration range from below 5 Bq/m^3 to 580 Bq/m^3. (18)

2.4.3 The contribution of Radon to population dose from natural radiation in Ghana.

Indoor radon dose in Kumasi and Neighboring areas, Ashanti Region, Ghana. Exposure time was 90 days.

Location	**Radon Dose (mSv)**
1. A staff bungalow, UST Kumasi	2.4 error 0.2

2. Student hall of resident UST 2.4 error 0.3

3. The Shell oil company Premises, Kumasi

    a. Managers office(air-conditioned) 4.3 error 0.4

    b. General office (no air-conditioner 2.8 error 0.3

    c. Workshop (no air-conditioner) 2.5 error 0.3

4. Premises of Ashanti Goldfields Corporation, Obuasi

    a. A staff member's house 2.2 error 0.2

    b. An office at the Ore Temperature Plant 3.6 error 0.3

    c. An office at a mining shaft 4.5 error 0.5

5. Ayeduase (Adobe house)

    a. House 1 4.4 error 0.4

    b. House 2 3.9 error 0.4

    c. House 3 4.1 error 0.4

In-situ measurement, Cape Coast, Central Region

Location	**Radon Dose(mSv)**
1. Cape Coast Town	
a. House 1 (Adobe House)	6.5
b. House 2	4.3

2. UCC Campus

    a. Student Hall of Resident(old site) 4.8

    b. Science Laboratory (New site) 2.4

3. Biriwa (Adobe House)

    a. House 1 4.7

    b. House 2 4.9

4. Abandzi (Adobe House)

    a. House 1 4.0

    b. House 2 4.9

5. Apewosika (Adobe House)

    a. House 1 4.9

    b. House 2 6.0

In-situ measurement, Kumasi, Ashanti Region

Location	**Radon Concentration (KBq/ m^3)**
1. Premises of Ashanti Goldfields, Obuasi	21 error 1.4
2. Ayeduase	
a. House 1	1.73 error 1.3

b. House 2 — 1.10 error 0.8

3. Student hall UST — 2.20 error 1.6

4. A staff's Bungalow — 1.26 error 1.0

The result for indoor radon measurement shows a maximum radon dose of 6.5mSv in Cape Coast town with an average of 3.3mSv in the Ashanti Region and 4.7mSv in the Central Region. The result represents the contribution of radon gas to the overall population dose to natural ionizing radiation in Ghana. Subsoil emanation is a key parameter in influencing the indoor radon concentration in an environment. (19)

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2.4.4 Radon Measurement in Deep Mines in Ghana.

We report measurement of radon gas concentration in two deep gold mines in Ghana viz Tarkwa Goldfields and Prestea Goldfields. Radon concentration measured underground at Tarkwa were in the range 56 Bq/ m^3 to 268 Bq/ m^3. Corresponding values for Prestea were 43 Bq/ m^3 to 878 Bq/ m^3

These results represent the first published data on underground radon concentration in deep gold mines in Ghana. Measurement of the radon gas was done by means of the solid state nuclear track technique, with CR – 39 plastic recording medium for the alpha particles from radon decay.

The study is part of a nation wide radon monitoring program. (20)

2.5 OTHER RESEARCH WORKS ON RADON

2.5.1 Indoor and outdoor radon survey in Slovenia etched track detectors

Method

Two passive time-integrating dosimeters for radon monitoring in air was developed. The first dosimeter, which is used for the long term measurements, is a diffusion chamber equipped with CR-39 detector. The dosimeter is a plastic cup (volume of 0.25dm^3), close by a membrane made of fiberglass filter paper. Filter stops airborne particles, slows down diffusion to the cup and allows easy diffusion of radon inside the cup. The collection of moisture on the detector surface is reduced by its thermal insulation from the cup walls. The detectors were buried in the ground so they could be exposed to radon radiation for 3 weeks after which etching was done on the detectors.

The Etching System

Two systems for chemical and electrochemical etching were setup. The chemical etching of CR-39 detector is carried out in 6.25 N NaOH at 70^{o}C for 5hours. The stainless steel rack and size of a thermal bath enables etching of about 50 detector foils simultaneously. Recently a procedure for revealing the track which involves combined chemical etching and electrochemical etching is introduced. The chemical etching is carried out in 6 N KOH at 40^{o}C for 3 hours. The system used for the electrochemical consist of a high voltage and signal generator and the etching cell. This cell enable simultaneous etching of 8 detector foils and is therefore not good for large series.

The Reading System

For the evaluation of large quantities of detector foils a fully automatic system was set up. It consisted of an optical microscope equipped with a video CCD camera and a computer controlled microscope stage. The stage has a working area of 100 mm x 100 mm which enables simultaneous processing of 9 to 25 electrochemically and chemically etched detector foils, respectively. The signal from the camera is led to the video digitizer card connected with a PC compatible computer with a 16 MHz 80386 processor, 80387 coprocessor, 8 Mbytes of dynamic RAM and 80 Mbyte hard disk. A special program which enables automatic scanning of large area of the detector foil and counting of tracks was developed. A typical processing time for a single electrochemically etched detector foil is about 2 minutes. (16)

2.5.2 Radon in ground water of the lower Susquehanna and the Potomac River basins in the united state

Abstract

Ground-water samples collected from 267 wells were analyzed for radon as part of a water-quality reconnaissance of subunits of the Lower Susquehanna and Potomac River Basins conducted by the United States Geological Survey (USGS) as part of the National Water-Quality Assessment (NAWQA) program. Radon is a product of the radioactive decay of uranium. Airborne radon has been cited by the Surgeon General of the United States as the second-leading cause of lung cancer and the United States Environmental Protection Agency (USEPA) has identified ground-water supplies as possible contributing sources of indoor

radon. Eighty percent of ground-water samples collected for this study were found to contain radon at activities greater than 300 pCi/L (Pico curies per liter), the USEPA's proposed Maximum Contaminant Level for radon in drinking water, and 31 percent of samples contained radon at activities greater than 1,000 pCi/L. The 10 subunits where samples were collected were grouped into three classes - median ground-water radon activity less than 300 pCi/L, between 300 pCi/L and 1,000 pCi/L, and greater than 1,000 pCi/L. Subunits underlain by igneous and metamorphic rocks of the Piedmont Physiographic Province typically have the highest median ground-water radon activities (greater than 1,000 pCi/L); although there is a large variation in radon activities within most of the subunits. Lower median radon activities (between 300 pCi/L and 1,000 pCi/L) were found in ground water in subunits underlain by limestone and dolomite. Of three subunits underlain by sandstone and shale, one fell into each of the three radon-activity classes. The large variability within these subunits may be attributed to the fact that the uranium content of sandstone and shale is related to the uranium content of the sediments from which they formed.

What was done

This investigation is part of the National Water-Quality Assessment (NAWQA) of water resources in 60 major river basins throughout the United States (Gilliom and others, 1995). During 1993-95, NAWQA projects in the Lower Susquehanna and Potomac River Basins conducted studies to determine the effects of land use on shallow ground-water quality. Water samples collected from wells in the study areas were analyzed for both man-made substances and naturally occurring substances, such as radon. The spatial distribution and density of sampling sites are not sufficient for a detailed study of radon. However, general conclusions about the regional distribution of radon in ground water can be made on the basis of these reconnaissance studies.

The study area includes the District of Columbia and parts of Maryland, Pennsylvania, Virginia, and West Virginia. Ground-water-quality assessments were conducted in subunits in the two basins that were defined on the basis of the geology (type of bedrock) and the physiographic province (an area of similar elevation, topography, and physical features). The three general types of bedrock in this area are (1) limestone and dolomite, (2) sandstone and shale, and (3) igneous or metamorphic rocks, such as granite, schist, and quartzite. The physiographic provinces studied include the Piedmont and the Ridge and Valley.

Division of the study area on the basis of bedrock type and the physiographic provinces and sections resulted in seven areas where radon in ground water was studied. Three of these areas were further subdivided on the basis of river drainage basin. Within these 10 subunits, 267 ground-water samples were collected from wells and analyzed for dissolved radon. Because sampling was conducted independently in each basin, the subunits generally do not cross the basin divide. The Piedmont and Appalachian Mountain limestone subunits include those areas in both basins because both contained too little area in the Potomac River Basin to be studied separately. The areas of igneous and metamorphic bedrock are termed "crystalline" in the names of the subunits. The Piedmont sandstone and shale subunit, which also contains abundant diabase, is commonly called the "Triassic Lowlands." The Western Piedmont crystalline subunit was sampled as a part of the Piedmont subunit as defined in the Potomac NAWQA study design (Blomquist and others, in press); however, this subunit was considered separately for the radon study. The study design did not allow for sampling in every physiographic province or subunit.

The wells selected for sampling had to meet certain location and construction criteria and have similar characteristics, including type, depth, and age. All wells sampled were constructed as open boreholes, drilled and completed with casing typically set a few feet into the bedrock. Wells were to have a maximum depth of 200 feet and a maximum age of 20 years. A few of the wells sampled exceeded the age and depth criteria.

Results

The ground-water samples were analyzed at the USGS National Water-Quality Laboratory in Arvada, Colo. The results were analyzed to determine general patterns in the concentration of radon among the 10 subunits. The amount of radon in ground water from each subunit is highly variable, so the subunits were classified on the basis of the median concentration for the subunit. The median is the concentration at which half of the samples have a lower concentration and half have a higher concentration. On the basis of graphical and statistical analyses, 300 pCi/L and 1,000 pCi/L were chosen as boundary values for grouping subunits by their median radon concentrations. The use of 300 pCi/L as a limit for the lowest grouping also may be significant because it is the proposed MCL for radon in drinking water.

Ground-water radon concentrations are highly variable, even within individual subunits. Concentrations of radon from 9 of the 10 subunits range from less than 300 pCi/L to greater than 1,000 pCi/L. The central tendency of radon concentrations in the subunit, represented by the median concentration, is useful to draw general conclusions about the occurrence of radon in ground water in that subunit but should not be used to predict concentrations at specific sites.

The subunits with median concentrations of radon greater than 1,000 pCi/L are the Piedmont crystalline subunits (not including the Western Piedmont subunit) and the Piedmont sandstone and shale subunit. The highest median concentration of all the areas sampled was 3,100 pCi/L and the highest concentration from a single sample was 38,000 pCi/L which are both in the Piedmont crystalline subunit of the Lower Susquehanna River Basin.

The group of subunits with median radon concentrations between 300 and 1,000 pCi/L includes all the subunits underlain by limestone bedrock and the Appalachian Mountain sandstone and shale subunit in the Lower Susquehanna River Basin. The limestone subunits generally have less variability in the range of radon concentrations, even though relatively large numbers of samples were collected in these subunits. The Appalachian Mountain limestone subunit has the least amount of variability of all the subunits and also is the only subunit that did not have any samples with radon concentrations greater than 1,000 pCi/L.

The subunits with median concentrations of less than 300 pCi/L include the Western Piedmont crystalline subunit and the Appalachian Mountain sandstone and shale subunit in the Potomac River Basin. The sandstone and shale subunit has the lowest median concentration of all 10 subunits (about 80 pCi/L); however, the maximum concentration detected in the subunit was 2,500 pCi/L. This again shows a high degree of variability within these physiographic and bedrock type subunits.

Of the 267 ground-water samples collected, 80 percent contained radon concentrations above the proposed MCL (300 pCi/L), 31 percent were above 1,000 pCi/L, and less than 1 percent were above 10,000 pCi/L. (8)

What does all of this information on radon mean to homeowners

Although radon concentrations in ground water of the Lower Susquehanna and Potomac River Basins are more likely to be higher in certain areas relative to others, the only way to be certain of the radon concentration in the water supplied by any given well is to have the water tested. Although differences in median radon concentration between subunits are apparent, there is a high degree of local variability within each subunit. This makes prediction of radon concentration at an individual well very difficult and imprecise. The USEPA and the Surgeon General of the United States recommend that all homes below the third floor be tested for airborne radon that may be entering the home through the basement (U.S. Environmental Protection Agency and Centers for Disease Control, 1992). In homes where high indoor radon levels are measured and where water is supplied by a privately owned well, the USEPA further recommends that the well water be tested as a potential contributing source of the airborne radon. For every 10,000 pCi/L of radon in water about 1 pCi/L of radon is released to the air, in addition to any airborne radon that may enter a home through the basement. If a large percentage of the radon in your house is from your water, the USEPA recommends that you consider installing a water treatment system to remove radon. Both homes and water supplies can be treated to reduce radon levels (U.S. Environmental Protection Agency, 1992). (8)

1. Principles of Selecting Sampling Sites

The inhalation of radon (2 22 Rn) and its progeny in the nation-wide radon survey, clearly showed that dwellings is one of the most important sources of natural radiation exposure to the public. According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), about half of the annual effective dose received by human beings living in radiation normal background areas of the world is contributed from the inhalation of ^{222}Rn and its progeny. This was carried out by all the institutions that belong to the Chinese National Environmental Radioactivity Monitoring Network (CNERMN), located in provinces, municipal region or city all over the country. Sampling sites were selected by local investigators based on principles of representative in the feature of both geographical, architecture characteristics and living custom, as well as the population factor in each area. The number of sampling sites were determined by the ability and resources of local institution, however, a minimum number, not less than 1 site per half million population, was requested by LIH for statistical concern.

There are great changes in China with the country-wide development both in economy and in the lifestyle in recent years, such as living situation, dwelling construction, composition change of building materials and the use of air condition. As a consequence, the exposure from natural radiation to the general population is supposed to be growing, especially the exposure concerning indoor radon levels. A nation-wide investigation on public exposure due to natural radiation, especially on the increase of the exposure is in the planning stages and a more proactive measure will be put in place to reduce the effect. Normally two indoor samplings in different measurement points, which at least one in bedroom, were chosen at each site. Usually, the sampling points were at a height of 1.5 m above floor and with distances larger than 0.5 m from walls. It is necessary and important to know the accurate radon

2. Sampling and Measurement Methods

Levels in the early years of the radon research when compared with exposures from today shows a steady increase in the concentration of the gas. In the period from 1984–1990, a nation-wide environmental radon survey was carried out under the coordination of the Laboratory of Industrial Hygiene, Ministry of Health (LIH), it was the largest of such research ever conducted within the period but still no general conclusion was given out for some reasons until now. One of the reasons, for example, was that grab sampling was taken as the main method throughout the radon survey. Even though the radon survey introduced by this paper was not enough both in the number of dwellings and in the duration in some areas, as a preparative work of the investigation planning, all the results reported by local individuals, who participated in the radon project during 1984–1990 were reviewed and summarized, and it is still a valuable reference.

(1) Grab Sampling and Measurement

For the limited measurement condition at that time, most of the institutions in local province took a grab sampling during the survey, but not integrating measurement that applied for environmental evaluation at the present time. There were three kinds of grab sampling and measurement methods were made use of for radon and its progeny measurements during the nation-wide survey. (21)

2.6 GUIDELINES FOR MITIGATING HIGH LEVELS OF RADON IN THE HOME

Currently there are no U.S. statutory limits covering naturally occurring radioactive materials such as radon and its progeny. However, both the NCRP and EPA have published guidelines for acceptable levels of radon in the home. The NCRP recommends that in single family homes remedial action be taken to reduce radon levels if the average annual exposure exceeds 2 WLM/year (equal to 8 pCi/liter assuming radon daughters are in 50% equilibrium with Rn-222).

EPA recommendations are based on average airborne radon levels in the home, and they recommend a graded scale of actions. Their recommendations suggest action at a lower dose (factor of 2) than NCRP, but otherwise there is no major difference. The recently passed radon act 51(55) poses a long term goal of remediation to outdoor levels of 0.2 - 0.7 pCi/liter, which would require many billions of dollars to accomplish. The urgency of recommended actions depends on the average radon levels in the living areas of individual homes, and not simply on the highest level in an uninhabited portion of the house. The amount of time spent in the home and where one spends most of that time needs to be considered when making decisions on corrective actions. If high levels are found in high occupancy areas, remedial action should be considered and advice obtained from experts. Radiation control officials at the state or local level can suggest additional kinds of measurements, as well as recommend remedial actions, if indicated.

The EPA estimates approx. 22,000 lung cancer deaths per year may be related to radon exposure in the USA. Over a period of 70 years, with 75% of persons day spent in the home, they calculate that an indoor level of 4 pCi/L, with a 50% equilibrium between radon and its daughters would result in 54 WLM cumulative exposure. Assuming 0.25 WLM/yr and 240 million people results in 60 million affected people for a working level month (WLM), then it can be assumed that 360 deaths per million WLM from lung cancer (age-averaged rate for the US population), and computed to be 21,600 deaths due to lung cancer due to radon per year. The ICRP gives a range of 8,600-25,900 to these estimates.

Much controversy surrounds the true magnitude of health risks from radon, and the appropriate actions to be taken at different measured levels in the home or workplace. The issue boils down to understanding the magnitude of the health and economic risks, the costs and benefits of different responses. The ICRP recommends that "proposed interventions should ...be sufficiently (beneficial) to justify the harm and the costs, including social costs, of the intervention. The form, scale and duration of the intervention should be chosen so that the net benefit of the reduction of dose, i.e. the benefit of the reduction in radiation detriment, less the detriment associated with the intervention, should be maximized."

The issue comes down to cost and benefit. The EPA has estimated the cost per life saved (by averting a predicted lung cancer from radon) for various action levels that might be chosen. The numbers range from 1.1 million dollars at 2.0 pCi/L to 0.7 million at 4 pCi/L and 0.4 million at the NCR level of 8 pCi/L. The cost per life saved from other non radiological risks can reach the 0.4 million figure. (22)

2.7 EPA RECOMMENDATIONS

How quickly should action be taken?

In considering whether and how quickly to take action based on test results, the following guidelines may prove useful. The EPA believes that radon levels should try to be permanently reduced as much as possible. Based on currently available information, the EPA believes that levels in most homes can be reduced to about 0.02 WL (4 pCi/liter)

If results are about 1.0 WL *or* higher or about 200 pCi/liter or higher:

Exposure in the range are among the highest observed in homes. Residents should undertake action to reduce levels as far below 1.0 WL (200 pCi/liter) as possible. It is recommended that action should be taken within several weeks. If this is not possible, consultation with appropriate state or local health or radiation protection officials can determine if temporary relocation is appropriate until the levels can be reduced.

If results are about 0.1 to about 1 WL *or* about 20 to 200 pCi/liter:

Exposures in the range are considered greatly above average for residential structures. Action should be undertaken to reduce levels as far below 0.1 WL (20 pCi/liter) as possible within several months.

If results are about 0.02 to about 0.1 WL *or* about 4 pCi/liter to about 20 pCi/liter:

Exposures in this range are considered above average for residential structures. Action should be undertaken to lower levels to about 0.02 WL (4 pCi/liter) or below within a few years, sooner if levels are at the upper end of this range.

If results are about 0.02 WL or lower, *or* about 4 pCi/liter or lower:

Exposure in this range are considered average or slightly above average for residential structures. Although exposures in this range do present some risk of lung cancer, reduction of levels this low may be difficult, and sometimes impossible, to achieve.

NOTE: There is increasing urgency for action at higher concentrations of radon. The higher the radon level in a home, the faster action should be taken to reduce exposure. (23)

2.8 RADON GAS HAZARD: GHANA IN PERSPECTIVE

Radon gas exists, and whether human beings believe it or not, its effect on life in general and human life in particular will continue. The United State of America and other developed countries have identified the health risk this gas poses to humans and are developing mitigating measures to keep most of their citizens alive; unfortunately this story is different on our side of the world. Radon is only known to a few physicists, chemist and other areas of study but not all of these fields even see the need for such a detailed research into this radon problem. Radon is harmful at higher levels and since most lung cancers are initiated by radon exposures there is the need to know how vulnerable someone is. Ghana has no record of its radon emanation levels; it also doesn't have any information on radon concentration level of indoor dwellings, no vulnerability map of the gas concentration in water and soil. For all the reasons stated above, this project is a must.

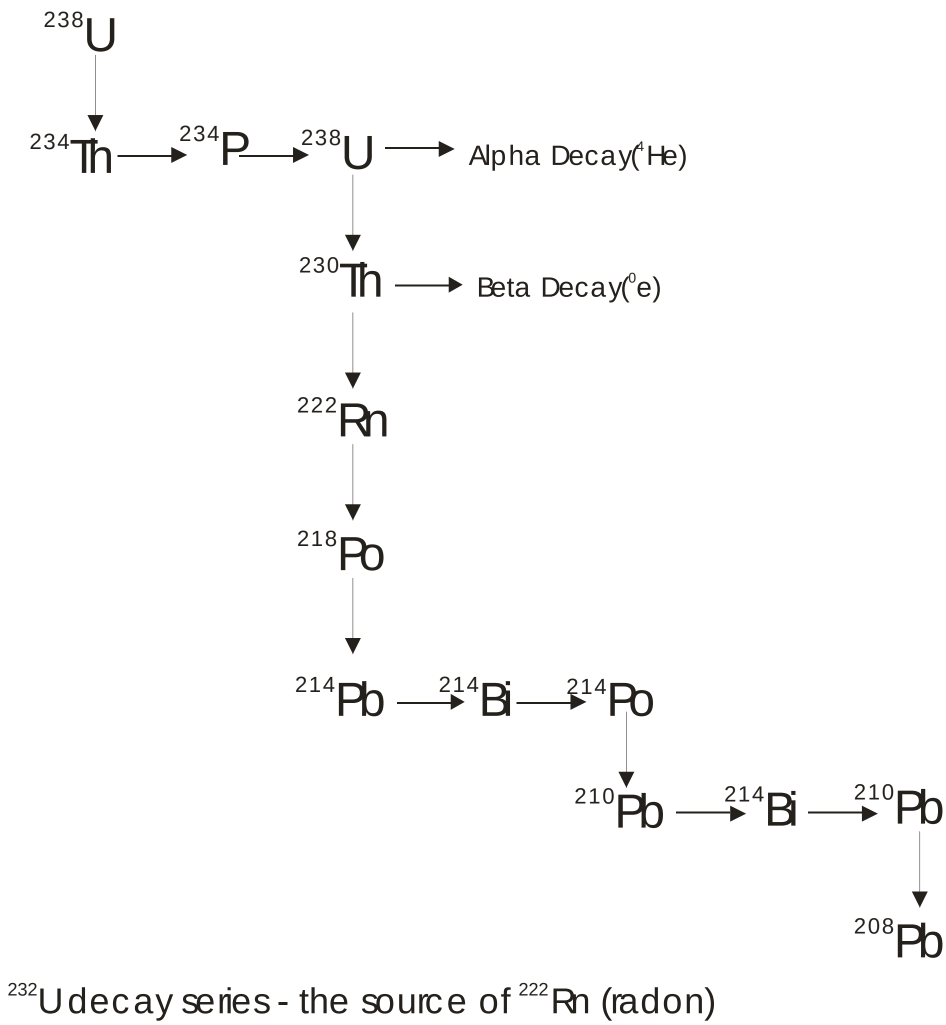

Figure 5. Uranium decay series-the source of radon – 222 (24)

<u>CHAPTER THREE</u>

3.0 METHODOLOGY

3.1 DESIGN

Area to be surveyed – Selected Villages around Lake Bosomtwi

Reasons for the choice

The Lake Bosomtwi community is one of the most interesting research areas in Ghana due to the geological nature of the area. Radon surveys already conducted shows very interesting developments and hence the need for an in-depth study so that further extrapolation will be made to cover the whole Ghana.

Sampling Area

Sampling area will be around the Lake and some communities close to the Lake. An area further away from the community will be surveyed to serve as a buffer.

Sampling method

Profiles will be set-up and these profiles will be 2m apart, soil samples will be collected at depths of 10cm and about 50 to 100 grams of soil quantity will be collected and sent to the Laboratory for analysis

Conclusions to be made

Results obtained will be compared with previous results obtained from previous surveys around the Lake areas, after which the following conclusions will be made

- The average radon gas level at Lake Bosomtwi for the year 2006.
- Are there variations in radon gas levels from the soil between the years 2001 to 2006?
- The average radon gas level from 2001 to 2006.
- Design a radon vulnerability map for Ghana

3.2 SAMPLING

Even though the samples were in groups and belong to the same community care was taken so that soil samples collected can clearly be identified as to which particular spot it was picked from.

To begin a station was first selected; the station had enough space around it for profiling. Ten (10) profiles were made on each location; these profiles were about 2m apart and in reference to the selected station. Five (5) holes were made on every profile and soil samples weighing about 100g were collected from depths of 10cm. the soil samples were bagged and labeled.

The under listed Materials and Equipment were used in the sample collection

- A hollow stainless steel tube of about 2.5inches in diameter and 3 feet long for cutting through the soil.
- A steel rod to prevent distortion of the stainless steel holder
- A wooden rod to cushion the stainless steel against the hammer impact
- Opaque polythene bags for holding the soil sample
- Sledge-hammer

3.3 PROCEDURE

SAMPLE PREPARATION

Each soil sample picked up from the field was dissolved in about 100cc of water and the resulting mixture was shaking thoroughly to enable the water to absorb the radon gas trapped by the soil sample. The mixture was then allowed to settle for about 2 weeks so that all the various gaseous composition of the soil will be fully dissolve in the water.

PROCEDURE TO OBTAIN RESULTS

- The RDU-200 carrying case was opened and the knurled screw unfastened on the bubbler tube slide. This allowed the bubbler tube to be moved sideways to an extend of its slide.
- The heavy rubber tubing from the vacuum pump provided with the RDU-200 was connected to the pump input port on the console.
- RDX-012 was connected to the scintillator cell connector on the RDU-200 making sure to push so hard so that it was fit into place.
- The vacuum valve was opened to make sure that the flash valves were closed.
- The cell was evacuated using the pump provided to a gauge reading between 20 to 30 inches of mercury. The valve was then closed
- The bubbler tube was then filled with solution
- With the flow regulator knob in the fully closed position the flow valve was opened.
- Slide suction at the top of the bubble was provided by slightly opening and closing the regulator.
- Checking of the gauge on the vacuum pressure was regular.

- The flow regulator knob was slowly opened to position where it could take 3 minutes to reduce the vacuum gauge to zero. This time interval ensured the complete degassing of the Radon gas.

Overall, about 400 samples were collected from 4 different villages around the lake and this was done within the period of 14th to 17th January, 2006.

3.4 RADIATION COUNTS

Radon detector analyzer (RDA-200) was the instrument used in the radiation counting. The alpha emitting properties of the short-lived Radon daughters were used to determine the radioactivity counting ability of the RDA-200. Each cell was put in turn into the photomultiplier tube chamber of the RDA-200 after filling with radon gas. Sixty seconds was allowed before counting to allow any light that may have been seen by the PMT to dissipate. The power toggle was set to INT and Ra/Am switch set to the Ra and time (MIN) knob set to two minutes. After the sixty seconds the sample button was pressed to start the two minutes count. The display button count was recorded after the buzzer signaled with its sound. The process was then repeated for all other samples to obtain results.

CHAPTER FOUR

4.0 RESULTS, DISCUSSION AND CONCLUSION

4.1 RESULTS

These results were obtained from the evaluation of the following

- Calculation of average radon concentration around the Lake Bosomtwi area from the year 2001 to the year 2006
- Study variation of radon concentration with passing years

2001

In the year 2001, Radon research conducted at the Lake Bosomtwi area was more of Geophysics research even though it still made use of the changing concentration of radon gas emanation from the soil

DEPTH/cm	**RADON CONCENTRATION/pCil^{-1}.**		
	MINIMUM	MAXIMUM	AVERAGE
10	92.4	187.7	167.2
20	102.1	220.1	195.5

Overall

Minimum Value 92.4 pCil^{-1}.

Maximum Value 220.1 pCil^{-1}

Average Value 167.2 pCil^{-1} or 6.19 KBq/m^3. (29)

2002

Research work in 2002 was mainly to find out how radon emanation from the soil is affected by depth, for this reason soil samples were collected from different depths and analyzed using the Radon Degassing Unit-200 (RDU-200) and the Radon Detector Analyzer-200 (RDA-200) for degassing and analysis. Samples were collected in a village named Abonu. Below is a summary of 2002 results converted to $pCil^{-1}$.

DEPTH/cm	**RADON CONCENTRATION/$pCil^{-1}$.**		
	MINIMUM	MAXIMUM	AVERAGE
10	104.7	240.9	150.59
20	106.5	250.1	201.3
30	140.8	250.2	195.8
40	135.0	294.5	204.1
50	190.2	298.9	203.2

Overall

Minimum Value 104.7 $pCil^{-1}$.

Maximum Value 298.9 $pCil^{-1}$

Average Value 150.59 $pCil^{-1}$ or 5.572 KBq/m^3. (30)

2003

In 2003 the sample area was widened to help monitor accurately the emanation of radon to help predict the possible occurrence of an earthquake. Samples were collected from 6 different areas namely Adwafo Town, Tepaso Village, Mmorontuo Village, Ataa Junction, Tumiabu Atonbisi Village and Duasi Village.

AREA	**RADON CONCENTRATION pCiL^{-1}.**		
	MINIMUM	MAXIMUM	AVERAGE
DUASI	36.22	335.14	192.43
TEPASO	11.35	295.14	180.54
TUMIABU ATONBISI	11.89	75.41	58.28
ADWAFO	10.33	132.12	99.25
MMORONTUO	3.91	67.25	54.45
KUSUASO	19.56	87.37	71.19

Overall

Minimum Value 3.91 pCiL^{-1}.

Maximum Value 335.14 pCiL^{-1}.

Average Value 106.02pCiL^{-1}. Or 3.92 KBqm^{-3}. (31)

2006

AREA	RADON CONCENTRATION $pCiL^{-1}$.		
	MINIMUM	MAXIMUM	AVERAGE
ADWAFO	31.90	135.57	74.43
KUSUASO	39.83	143.54	82.94
DUASI	95.69	191.39	146.73
TEPASO	55.82	143.54	95.70

Overall

Minimum Value 31.90 $pCiL^{-1}$.

Maximum Value 191.39 $pCiL^{-1}$.

Average Value 99.95 $pCiL^{-1}$. Or 3.70 $KBqm^{-3}$.

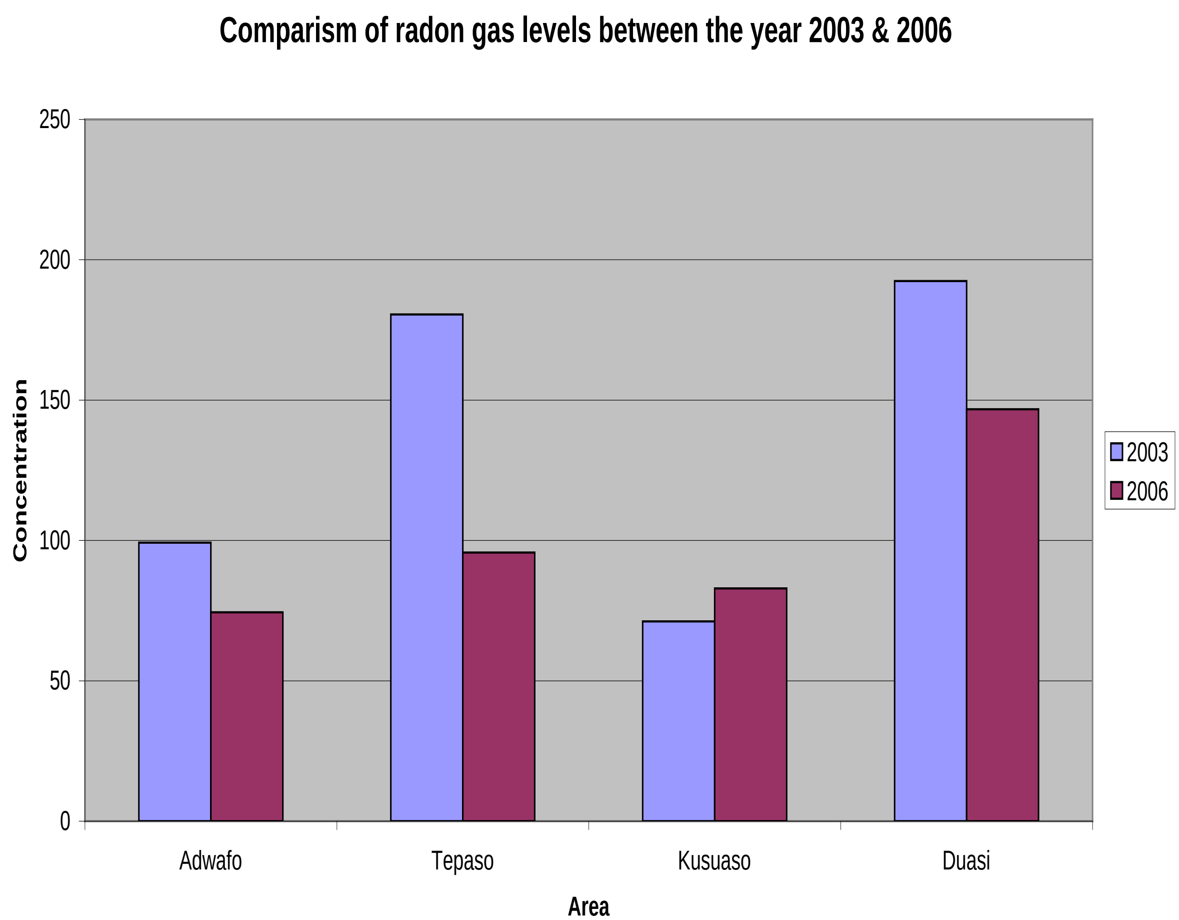

Figure 7: Comparison of Radon gas level between years 2003 & 2006 at Lake Bosomtwi

Based on the similarities between results from 2003 and 2006 it can clearly be seen that radon gas levels have little or no change with passing years if geological and climate condition remain virtually the same. Areas like the Greater Accra, Central, Western and Ashanti regions have not experienced any significant change in climatic and geological condition and for this reason results obtained way back in the 90's could still be valid and hence their application in the development of the vulnerability map.

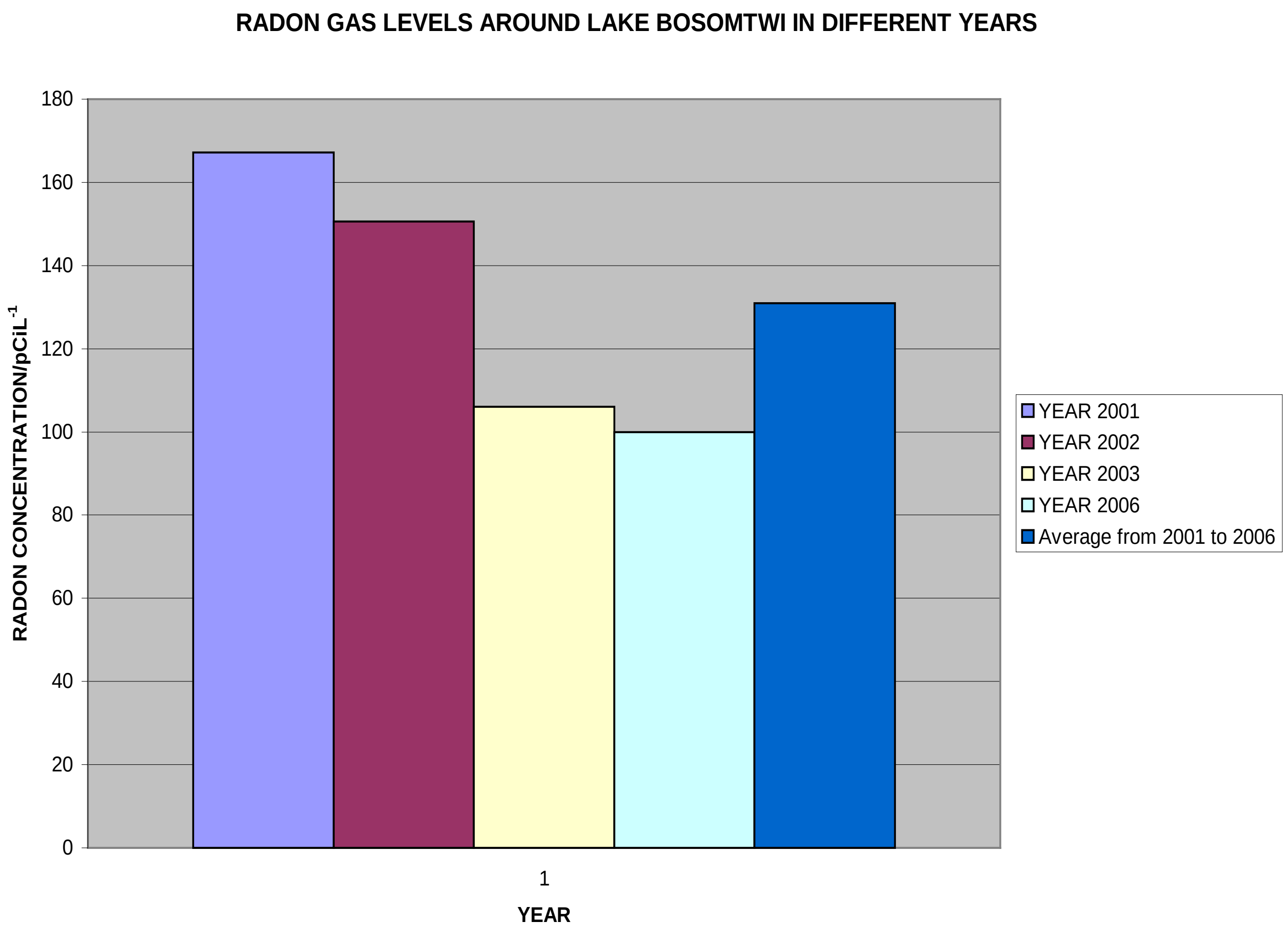

Figure 8: VARIATION IN RADON CONCENTRATION WITH PASSING YEARS

In comparing results, variation in variables may be used to plot a chart. The results obtained for this year's survey were compared with results from previous years and a plot of radon concentration levels verses years was made. Year 2001 had the tallest bar standing slightly above 160 $pCiL^{-1}$ with 2002 being within the 140 $pCiL^{-1}$ - 150 $pCiL^{-1}$ range. These values are very high compared to other years and it's quite reasonable because different villages around the lake have different radon concentration and since these results were from single villages the possibility of high concentration levels exist.

2003 and 2006 had an increase in accuracy because different villages were selected around the circumference of the lake so these results gave a more accurate value for radon gas level. 2003 had a concentration a little above 100 $pCiL^{-1}$ and 2006 had a concentration slightly below 100 $pCiL^{-1}$.

An overall average which is an average of all the results obtained within 2001 to 2006 was calculated and a value above the 120 $pCiL^{-1}$ mark on the plot was obtained.

4.1.3 RADON VULNERABILITY MAP OF GHANA

Below is a vulnerability map of radon gas concentrations in different parts of Ghana. This map was developed based on both previous and current research works. The map shows areas in Ghana where some research work have been conducted; it can be observed that regions such as Western, Central, Greater Accra and Ashanti have experienced more research work than regions like Eastern, Volta and the Northern parts of Ghana. With the increasing awareness in radon, every part of Ghana may undergo some form of sampling soon then a national average radon concentration can be developed. The map apart from showing areas which have undergone some research, it also gives the estimated radon gas concentration and the year in which the research was conducted. These values are dependable because the variation in radon gas concentration with passing years is not very great at lake Bosomtwi and hence it can be assumed that these values obtained else where will share similar properties.

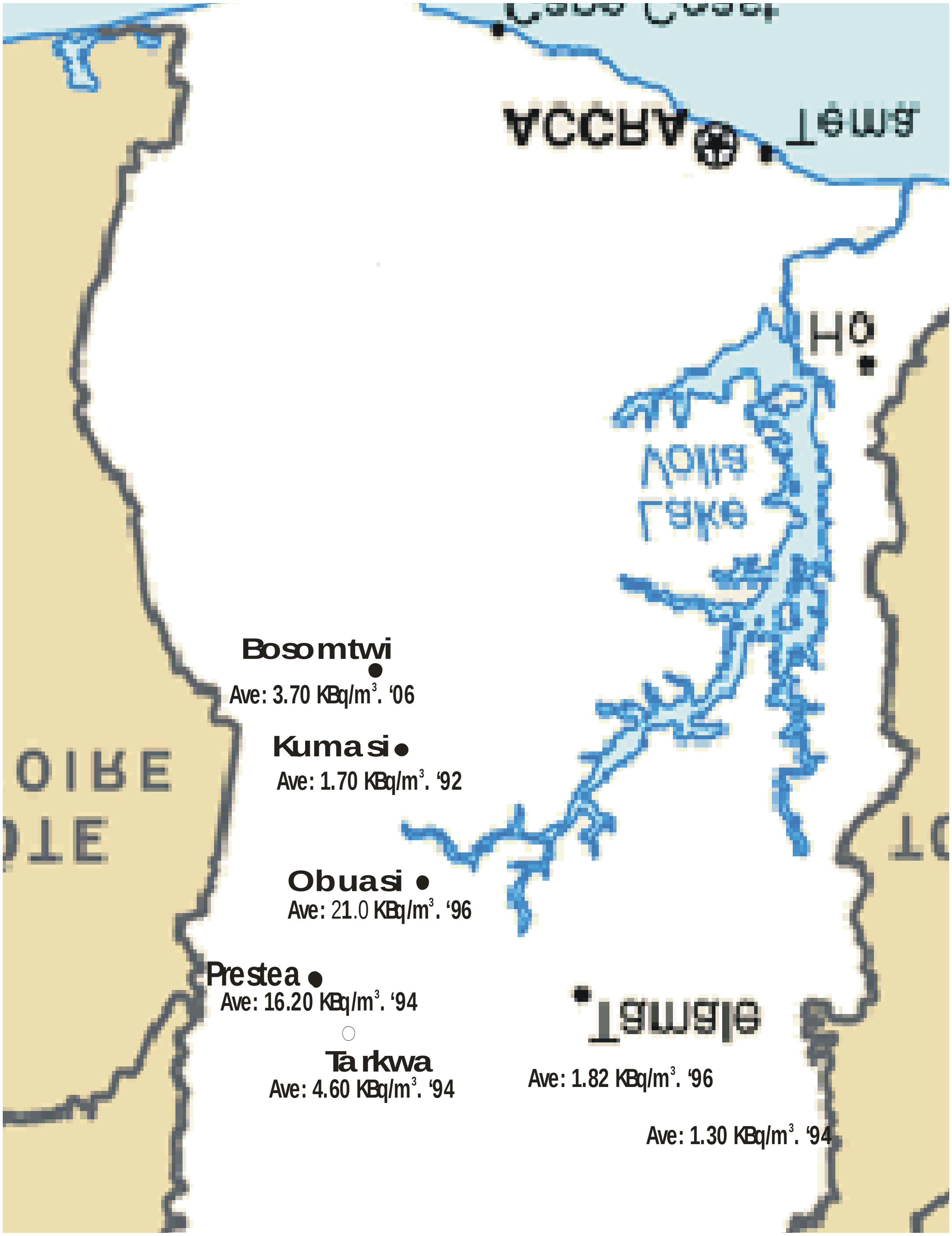

Figure 8: VULNERABILITY MAP OF RADON GAS LEVELS IN GHANA

4.2 DISCUSSION

4.2.1 Comprehensive Radon Analysis from Lake Bosomtwi

Radon analysis at Lake Bosomtwi has been an ongoing activity for quite sometime now. Results obtained even though hasn't been at alarming level further research into radon levels always brings out very interesting results. These results are interesting because it gives a clearer picture of how human and climatic activities are affecting the Eco-System.

Over the years radon gas levels from the results obtained have been fluctuating with minimum and maximum values changing and this fluctuation may be attributed to various reasons such as

- Change in climatic condition
- Inhabitation/Settlement
- Human Activities (Farming, Building, Development, etc)

2001

The results obtained in the 2001 radon research conducted at Lake Bosomtwi was a comparison of soil depth to radon concentration. An average calculated for the 10cm and 20cm depth where the sample was collected gave a minimum value of 92.40 at 10cm and a maximum of 220.10 $pCiL^{-1}$ at 20cm. Overall an average of 167.20 $pCiL^{-1}$ was tabulated for the 10cm depth 195.5 $pCiL^{-1}$ for the 20cm, but for the sake of this experiment, only the average for the 10cm will be considered.

2002

Research work in 2002 was an improvement of the results obtained in 2001; the expected result was to ascertain the effect of soil depth on radon gas emanation. The results obtained showed a minimum of 104.7pCiL^{-1} at 10cm and a maximum of 298.90pCiL^{-1} at 50cm. the results proofed that depth really had an effect on radon emanation. In this work also only the average for 10cm was considered.

2003

2003 saw a different turn in the radon research. Samples were collected in six (6) different villages around the lake and the results showed that Duasi Village had the maximum value both for the sample count and the average, with Mmorontuo Village having the minimum for the sample count and the average. A minimum value of 3.91pCiL^{-1} and a maximum of 35.14pCiL^{-1} were recorded with an overall average of 106.02pCiL^{-1}.

2006

A confirmation analysis was done on the results obtained in 2003, so four (4) of the six (6) villages which recorded high values in 2003 were sampled again. Of all the villages, a minimum value of 31.90pCiL^{-1} was recorded by Adwafo village and Duasi got the maximum value of 191.39pCiL^{-1}. Overall calculated average was 99.9pCiL^{-1}.

SUMMARY

Overall, 2001 had the highest average radon gas level of 167.20 $pCiL^{-1}$, with 2006 recording the lowest average of 99.95$pCiL^{-1}$. The averages for 2001 and 2002 were from single villages so do not give a true reflection of radon gas level in the Lake Bosomtwi area compared to that of 2003 and 2006 because those averages were from samples collected all around the lake. The results also show a downward trend from 2001. In the period 2001 to 2006 the average radon gas level at the Lake Bosomtwi area is 130.94$pCiL^{-1}$, this value according to the United States' Environmental Protection Agency is within the range of (20-200) $pCiL^{-1}$.

4.3 CONCLUSION

In conclusion this research work was a success. A lot more findings and research tactics were developed after which the following conclusion were made,

- The average radon gas level in the Lake Bosomtwi area for the 2006 is 99.95$pCiL^{-1}$ and this result was obtained from four (4) Villages.
- Average radon gas level between the periods 2001 to 2006 is 130.94$pCiL^{-1}$.
- Variation in radon gas levels show a slight reduction from the results in 2003
- A vulnerability map of Ghana shows that research work have been conducted in the following regions Western, Central, Greater Accra and Ashanti and other regions like Eastern, Volta and the Northern parts of Ghana have experienced little or no research.

APPENDIX I

CALCULATION OF RESULTS

These are the calculations which yielded the results above. Samples collected were counted till the counts were taken. The time difference in minutes between sample collection and counting and correction factor were determined. The delay constant and corrected count were also calculated

Example 1

Sample from station 1

Cell number 1

Cell background count	1.00
Two minutes sample count	4.40
Sample count per minute	2.20
Net count per minute (CPM)	1.20
Collection time	10am (17/01/06)
Analysis time	10am (02/02/06)
Time up to middle of count	10minutes
Total time delay (Δt)	14days x 24hours x 60minutes + 10min
	= 40330min
total decay factor (DF)	$e^{-\lambda \Delta t}$
	= 0.079
λ	Decay constant of radon
	= 0.0001258 per minute

corrected net count per minute $= \frac{CPM}{DF}$

$= \frac{1.20}{0.079}$

= 15.19 cpm

Calculation of Cell Efficiency

The cell efficiency was calculated to convert counts per minute into activity unit of Pico Curie per liter since the method was standardized. This was done by filling the cells with radon from the pylon radon source under count per minute.

Examples 2

Cell number	1
Cell Background count	1
Net count per minute	254.73

Cell efficiency = $\frac{cpm \times sc \times c}{3 \times 60 \times DA \times A} = \frac{254.73 \times 1.0010 \times 1.00094}{3 \times 60 \times 2.66 \times 0.79}$ = 0.55cpm/dpm

Calculation of Activity of Radon Gas

Activity = $\frac{15.19}{0.55 \times 60}$ dpm = 0.46dps

But 1 dps = 1 Bq

Activity = 0.46 Bq

Volume of cell = Volume of gas = $1.3 \times 10^{-4} m^3$

Activity = $\frac{0.46Bq}{1.3 \times 10^{-4} \text{m}^3} = 3.54 \times 10^3 Bqm^{-3}$

Also 37Bqm^{-3} = 1 pCiL^{-1}.

Hence $3.54\times10^{3}\,Bqm^{-3} = \dfrac{3.54\times10^{3}\,Bqm^{-3}\times1\,pCiL^{-1}}{37\,Bqm^{-3}}$

$= 95.70\ pCiL^{-1}$

SC: Sequential correction for activity greater than ten(10) Successive samples = 1.00

C: Correction factor for radon decay during counting = 1.0094

DA: Dispensing Activity = 2.66 Bq

A: Correction factor for radon decay from the time of collection to start of counting =0.97

3: Number of alpha emitters

60: To convert decay per second(dps) to decay per minute(dpm)

APPENDIX II

TABLE OF RESULTS

STATION NUMBER	Profile Number	Background Count	Net Count per Minute	Radon Conc/pCiL^{-1}
1	1	1	4.4	95.70
	2	1.2	4.2	71.77
	3	1.4	4.2	55.82
	4	1.4	3.6	31.90
	5	1.2	5.8	135.57
2	1	1.4	3.8	39.87
	2	1.4	4.6	71.77
	3	1	5.6	143.54
	4	1.4	5.2	95.70
	5	1.2	4.8	63.80
3	1	1.6	6.6	135.57
	2	1.4	7.4	183.42
	3	1	5.2	127.60
	4	1.2	4.8	95.69
	5	0.8	6.4	191.39
4	1	1.4	4.2	55.82

	2	1.6	4.8	63.80
	3	1.2	4.6	87.72
	4	1	5.2	127.60
	5	1.4	6.4	143.54

APPENDIX III

SETUP IN PICTURES

Figure 9. Radon Degassing Unit-200 with a cell and a glass tube containing sample

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