An-Najah National University
Faculty of Graduate Studies

Measurement of Radon Exhalation from Building Materials Used in Nablus District, Palestine

By
Fathiya "Husam Al-din" Yousef Shoqwara

Supervisor
Prof. Ghassan Saffarini

Co-supervisor
Dr. Nidal Khaled Dwaikat

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This thesis was defended successfully on 12/8/2012 and approved by:

Defense Committee Members	Signature
Pro. Dr. Ghassan Saffarini (Supervisor).	.....
Dr. Nidal Khaled Dwaikat (Co-Supervisor).	.....
Dr. Kaleel Thabayneh (External Examiner).	.....
Dr. Musa El-Hasan (Internal Examiner)	.....

Dedication

To Prophet Mohammad who guided us to the way of light, faith, and knowledge… To my beloved parents who partied nights until I got to this place… To my dear husband (Qasem) for his encouragement, patience, and support… To my brothers and sisters … To my beloved child (Bara')…To all my friends, family, and those who are looking forward for more knowledge… with respect and love…

Acknowledgements

First of all great thanks to the glory of god for his steadfast love divine protection and guidance… I would like also to take this opportunity to express my gratitude to supervisors Prof. Ghassan Saffarini and Dr. Nidal Dwaikat for their advice, support and patience during this work... Thanks and appreciations are extended to the people who provided me their support all long my master study... Finally I would like also to express my sincere thanks to An-Najah National University providing all the required resources and support to finish my thesis, especially Physics, Chemistry, and Biotechnology Departments' Laboratory staff…

الإقرار

أنا الموقعة أدناه مقدمة الرسالة التي تحمل العنوان:

Measurement of Radon Exhalation from Building Materials Used In Nablus District, Palestine

اقر بأن ما اشتملت عليه هذه الرسالة إنما هو نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد، وان هذه الرسالة ككل، أو أي جزء منها لم يقدم من قبل لنيل أية درجة علمية أو بحث علمي أو بحثي لدى أية مؤسسة تعليمية أو بحثية أخرى.

Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

Student's name: …….....…… اسم الطالب:

Signature: ……..……..... التوقيع:

Date: …… التاريخ:

List of Abbreviations

EPA	Environmental Protection Agency
ATSDR	Agency for Toxic Substances and Disease Registry
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
NIST	National Institute of Standards and Technology
NCI	National cancer Institute
CDC	Center for Disease Control and Prevention
CCNR	Canadian Coalition for Nuclear Responsibility
WHO	World Health Organization
NTDs	Nuclear Track Detectors
ACDs	Activated Charcoal detectors
EICs	Electret Ion Chambers
EIDs	Electronic Integrating devices
CRMs	Continuous Radon Monitors
SSNTDs	Solid-State Nuclear Track Detectors
SD	Standard Deviation
NCRP	National Council on Radiation Protection and Measurements
G	Granite sample
M	Marble sample
C	Ceramic sample
P	Porcelain sample
Ce	Cement sample
S	Sand sample
B	Brick sample
Gr	Gravel sample
Co	Concrete sample
BS	Building Stone sample

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Abstract

Indoor radon has been recognized as one of the health hazards for mankind because long-term exposure to radon increases the risk of developing lung cancer. This study aims at assessing the contribution of building materials towards the total indoor radon exposure to the inhabitants of Nablus district. Radon exhalation rate have been carried out for common building materials used in construction in Nablus district from both national and international origins. The closed-can technique has been employed in this study using solid state nuclear track detectors (CR-39). After 100 days of exposure to radon, CR-39 detectors were etched chemically by (6.25 N) NaOH solution at 75^{o}C for 5 hours and then counted under an optical microscope. The measured track densities were related to radon exhalation rate, radon concentration, the effective radium content, and the annual effective dose for forty seven building material samples.

Results obtained from the current study show that radon exhalation rates from granite and marble have relatively high values as compared to other building material samples followed- in order- by cement, ceramic, concrete, building stones, and porcelain, while gypsum, sand, gravel and bricks contribute less to radon exhalation rate. The average radon

exhalation rate in the studied samples ranged from (55.37 ± 15.01) mBq/m^2h for gypsum samples to (589.54 ± 73.24) mBq/m^2h for granite samples, with a total average value of (268.56 ± 166.21) mBq/m^2h, the corresponding total average value of radon concentration and effective radium content are (148.49 ± 91.13) Bq/m^3 and (1.93 ± 1.20) Bq/Kg, respectively. On the basis of these values the annual effective dose for each sample was also determined and compared with the effective dose limit values recommended by the National Council on Radiation Protection and Measurements (from 1 to 5 mSv/y). In general, the annual effective doses from the investigated building materials are low and under the global value except for granite, marble and some cement samples with average values (8.12 ± 1.02), (6.06 ± 1.25), and (5.16 ± 0.84) mSv/y, respectively. Thus the studied materials are safe as construction materials especially with good ventilation rate, but special care must be taken when using granite, marble, and cement as building materials.

Chapter One

Introduction

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Introduction

1.1. General background:

During the last few decades researchers were concerned with the effect of natural radioactivity on human health. According to the U.S. Environmental Protection Agency (EPA), radon is a carcinogen and the second leading cause of lung cancer in the U.S. (EPA, 1999).

Radon (Rn) is a chemical element with atomic number 86. It is a radioactive, colorless noble gas. It is one of the densest substances that remain a gas under normal conditions (density = 9.73g/L). Radon is formed as part of the normal radioactive decay chain of uranium. Uranium has been around since the earth was formed and it's most common isotope ^{238}U (Natural abundance = 99.284%) has a very long half-life (4.5 billion years). Uranium, radium, and thus radon, will continue to occur for millions of years at about the same concentrations as they do now (ATSDR, 1990).

The hazards of Radon were first discovered in the thirties of the previous century during investigations into why half the uranium miners in the Ore Mountains in Czechoslovakia died of lung cancer (New Scientist, 1988). The damage of radon lies in that it decays quickly, giving off tiny radioactive alpha- particles .The α-particles travel less than 100 pm into lung tissue, but their high energy causes an intense local ionization, damaging the tissue with a subsequent risk for cancer development. β- and γ- radiation are also present from some of the decay products but this much lower energy content compared to α- radiation makes the effect relatively

marginal (Axelson O., 1995). Those radioactive particles when inhaled, can damage the cells that line the lung. And so, long-term exposure to radon can lead to lung cancer (NCI, 2004).

1.2. Literature Review:

1.2.1. International studies:

The first measurement on indoor radon concentration was made in Swedish dwellings in the 1950s (Hultqvist B., 1956). The levels found were in the range of 20 to 69 Bq/m^3. These observations seem not to have caused any concern from the health point of view. However, recent measurements of indoor radon in Swedish homes have revealed higher levels. The differences found between the earlier and the more recently measured concentrations may suggest a general increase in the levels over time (Axelson O., 1995).

Since that time many other measurements were made on indoor and outdoor radon all over the world. In 1992 a study was performed in Canada to determine radon exhalation rates from Canadian building materials. The study showed that radon exhalation rates of 11 typical Canadian building materials range from 0.1 to 22 nBq g^{-1} s^{-1}. This study concluded also that wood, glass, slate and marble have low exhalation rates while ceramic tiles, concrete, fiberglass, gravel and gypsum have mean rates which vary from 0.7 to 5.4 nBq g^{-1} s^{-1}, and that concrete is the strongest emanator among the materials studied (Zikovsky L., 1992).

In the United States the general findings from studies, along with extrapolations from radon-exposed underground miners, support the

conclusion that prolonged exposure to residential radon may contribute to a significant increase in lung cancer risk (William R. F., 2001). Based on a national residential radon survey completed in 1991, the average indoor radon level is about 1.3 picocuries per liter (pCi/L) in air in the United States. And the average outdoor level is about 0.4 pCi/L (EPA, 2006).

In 2005, a survey on radon emanation from soil was carried out in Turkey (Baykara O. et. al., 2005). The measured maximum values of the exhalation rate and radon concentration in the system were 400.7 (mBq/m^2 h) and 8.10 Bq/kg, respectively. In another study in 2006 it was found that radon exhalation rate in the water samples varied between 20.2 and 470.0 mBq/m^2 h (Baykara O., Dogru M., 2006).

In a neighboring country, Egypt, a study on ^{222}Rn exhalation rate from Egyptian building materials was performed in 2009 and found that the radon exhalation rate in the studied samples ranged from ($2.2 \times 10^4 \pm 7.2 \times 10^2$) $\mu Bq\ m^{-2}\ s^{-1}$, for granite sample, to $(3.4 \times 10^1 \pm 9.0 \times 10^0)$ $\mu Bq m^{-2}\ s^{-1}$, for portland cement with an average value $(1.8 \times 10^3 \pm 6.5 \times 10^1)$ $\mu Bq\ m^{-2}\ s^{-1}$ (Nabil M. H. et. al., 2009).

In Saudi Arabia, radon concentration in houses in Najran region was measured, the average concentration value measured in this study is 49 ± 14 Bq/m^3, which is higher than concentrations previously measured in Riyadh (Al-Awad S. H. M., 2008).

Other studies were performed all over the world for radon concentrations in water in Romania (Cosma C. et. al., 2008), in western north Carolina (USA) (David S. V. et. al., 2008),in Bangalore (Hunse T.

M. et. al., 2010), and in Idaho State (Bhushan G., Solomon L., 2010), other studies on Radon in soil in Pakistan (Munazza F., Matiullah, 2008) , and in building materials in Greece (Stoulos S. et. al., 2003), in Canada (Chen J. et. al., 2010), and also in Pakistan (Rafique M. et. al., 2011).

1.2.2. National studies:

In Palestine radon has been studied first in air at Hebron University where the indoor radon concentration was measured at the campus of the University and found that the average effective dose of radon there is equivalent to 1.49 mSv/y and that this dose is higher than the global value of 1.3 mSv/y (Hasan F. I., 1996). The second study was made on indoor radon concentration in four hospitals and two health centers in Nablus city. Results showed that the effective dose of radon was under the global value except at Al-Enjeli hospital with 2.29 mSv/y (Dwaikat N., 2001). Another study was performed in dwellings of old Nablus city where the Radon concentrations vary between (81.31 Bq/m^3) to (135.72 Bq/m^3) (Daragmeh A., 2001). A study performed in the dwellings of Gaza strip indicated that radon average concentration range from (13.36 Bq/m^3) up to (83.82 Bq/m^3) with a maximum value of 97.01 Bq/m^3 (Rasas M. F., 2005).

Recently, radon and radioactivity concentrations in building materials have been investigated (Dabayneh K. M., 2007). The average concentration levels of ^{222}Rn in building material samples were found in a study to range from 66 Bq/m^3 for limestone to 246 Bq/m^3 for granite samples (Dabayneh K. M., 2008), radon exhalation rate in granite samples was found in a study under publishing by Dabayneh K. M. to vary between 3.9 and 30.6 $Bqm^{-1}d^{-1}$, this study concluded that granite can be considered

to be one of the main sources of radionuclides and radon exhalation in the environment.

Finally, a study on radon concentration in drinking water supply of Nablus city was performed at An-Najah National University. This study had revealed that Radon concentration in wells and springs was below the U.S. environmental protection agency maximum contaminated level except for Badan well (Al Zabadi et al., 2012).

1.3. Study objectives:

The purpose of this study is to measure the Radon exhalation rates from building materials used in Nablus district in the west bank of Palestine. Our study will include samples of marble, granite, ceramic, porcelain, concrete, cement, sand, gravel, Bricks, gypsum, and building stones from different origins used in the mentioned area of study.

1.4. Study problem:

Concentration of Radon and the exhalation rate from building materials used in Nablus district was not previously investigated. Since all building materials contain various amounts of main natural radionuclides of the uranium (^{238}U) and thorium (^{232}Th) series, and since those radionuclides are sources of Radon gas (Nabil M. H., 2009) , then the knowledge of the natural radioactivity of building materials is important for the determination of population exposure to radiations. As most of the residents spend about 80% of their time indoors so their exposure to radiation from building materials become more significant especially if their homes had poor ventilation conditions. (Stoulos S. et al, 2003). For

the aforementioned reasons we intend to study the concentration of Radon and the exhalation rate from building materials in Nablus district in order to get some insight on its impact on the health of the Palestinian people residing in Nablus area.

1.5. Study overview:

In the next chapter the theory of radioactivity, nuclear stability, types of decay, units used in radiation studies and radiation effects on human body are presented. In chapter three Radon gas problem and its detection techniques is discussed. The experimental procedures are detailed in chapter four, and in the last chapter results are discussed and conclusions are obtained.

Chapter Two

Radioactivity and radioactive decay

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Radioactivity and radioactive decay

2.1. Radioactivity, discovery and history:

Radioactivity is the process of the spontaneous decay and transformation of unstable atomic nuclei accompanied with the emission of nuclear particles or electromagnetic radiation (Annunziata M. F., 2007).

Radioactivity was first discovered in 1896 by the French scientist Henri Becquerel, while working on phosphorescent materials. These materials glow in the dark after exposure to light, and he thought that the glow produced in cathode ray tubes by X-rays might be connected with phosphorescence. He wrapped a photographic plate in black paper and placed various phosphorescent salts on it. All results were negative until he used “uranium salts”. The result with these compounds was a deep blackening of the plate. These radiations were called Becquerel Rays. Radioactivity applications began only a few years after its discovery. Non-phosphorescent salts of uranium and metallic uranium also blackened the plate. Clearly there was a form of radiation that could pass through paper that was causing the plate to become black.

At first it seemed that the new radiation was similar to the recently discovered X-rays. Further research by Becquerel, Marie Curie, Pierre Curie, Ernest Rutherford and others discovered that radioactivity was significantly more complicated. Not long thereafter, during the beginning of the 20th century when Marie and Pierre Curie spearheaded the use of radium for the treatment of cancer (Curie P., 1967). We may consider their

work to be the first peaceful application of nuclear energy and the birth of modern nuclear medicine, upon which we now depend for the diagnosis and treatment of cancer and many other infirmities of the human body.

2.2. Nuclear Stability:

Nuclear stability means that nuclei are stable if they do not spontaneously emit any kind of radiation. It appears that neutron to proton (n/p) ratio is the dominant factor in nuclear stability. This ratio is close to 1 for atoms of elements with low atomic number and increases as the atomic number increases.

One of the simplest ways of predicting the nuclear stability is based on whether nucleus contains odd/even number of protons and neutrons. Most nuclides containing odd numbers of both protons and neutrons are the least stable and nuclides containing even numbers of both protons and neutrons are most stable, although some radioactive elements has even numbers for both protons and neutrons like ^{238}U and ^{232}Th.

A survey of the stable nuclei (Table 2.1) reveals that even-even nuclei are the ones most abundant in nature. This again lends support to the strong-pairing hypothesis, namely that pairing of nucleons leads to nuclear stability (Cohen B. L., 1971).

Table 2.1: Number of stable nuclei in nature

N	Z	*Number of Stable Nuclei*
Even	Even	156
Even	Odd	48
Odd	Even	50
Odd	Odd	5

Figure (2.1) shows that lighter elements have approximately equal numbers of protons and neutrons. However, the number of neutrons needed for stability increases more rapidly than the number of protons. As the number of neutrons in the nucleus increases, the ratio of neutrons to protons also increases to provide nuclear stability.

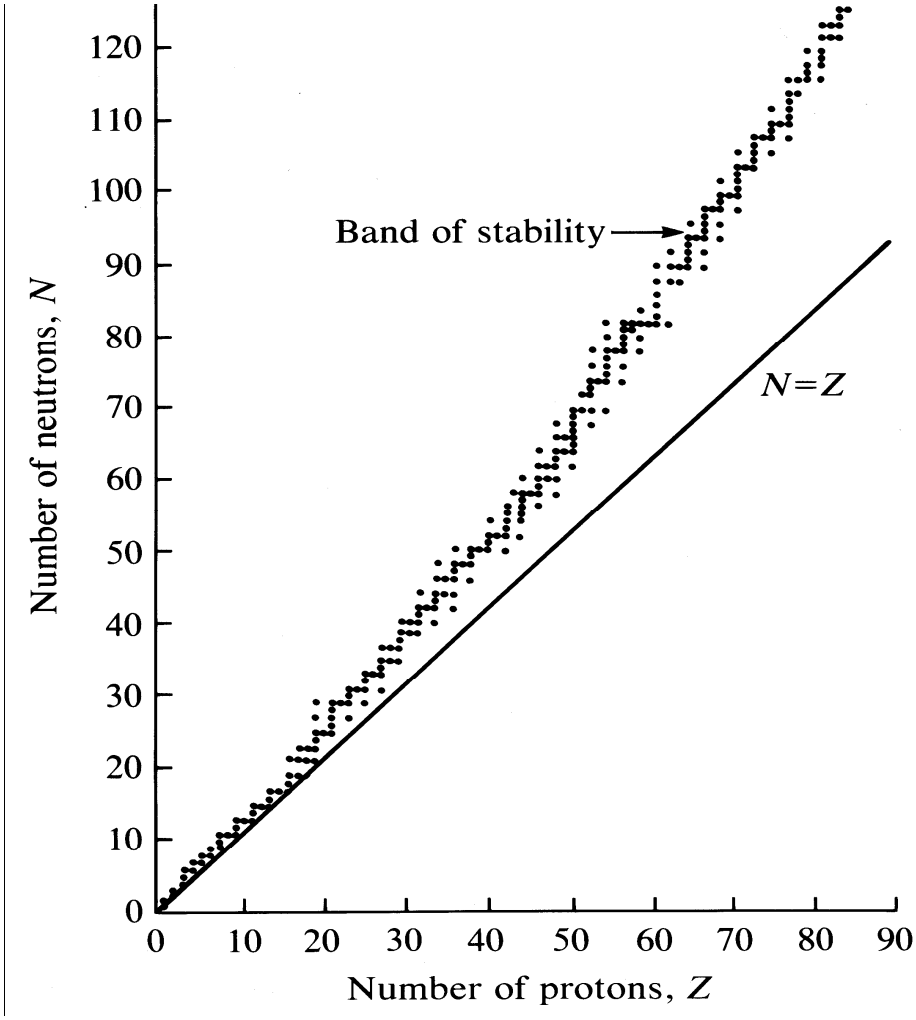

Figure 2.1: Plot of number of neutrons versus number of protons for the stable nuclides.

2.3. Radioactive decay:

Radioactive decay is the process in which an unstable atomic nucleus spontaneously loses energy by emitting ionizing particles and radiation. This decay, or loss of energy, results in an atom of one type, called the *parent nuclide* transforming to an atom of a different type, named the *daughter nuclide*. For example: a carbon-14 atom (the "parent") emits radiation and transforms to a nitrogen-14 atom (the "daughter"). This is a stochastic process on the atomic level, in that it is impossible to predict when a given atom will decay, but given a large number of similar atoms the decay rate, on average, is predictable.

2.3.1. The Radioactive Decay law:

Many years following the discovery of radioactivity it was noted that the decay rate of a pure radioactive substance decreases with time according to an exponential law. It took another period of time to realize that the decay is statistical in nature (Krane K. S., 1988) that it is impossible to predict when any given nucleus will disintegrate but we can predict the disintegration rate for the whole sample statistically.

It was found that if N radioactive nuclei are present at time t then the number dN decaying in time dt is proportional to N, and so

$$\lambda = -\frac{dN/dt}{N} \quad \text{..... (2.1)}$$

In which λ is a constant called the disintegration or decay constant. The right side of equation (2.1) is the probability per unit time for the decay of a nucleus. So this probability is constant, regardless of the age of the

nuclei. The negative sign in the above equation represents, as usual, the fact that the number of nuclei decreases as a result of decay.

Integrating equation (2.1) leads to the exponential law of radioactive decay:

$N(t) = N_0 e^{-\lambda t}$ ..... (2.2)

Where N_0 gives the original number of nuclei present at t = 0. As shown in figure (2.2).

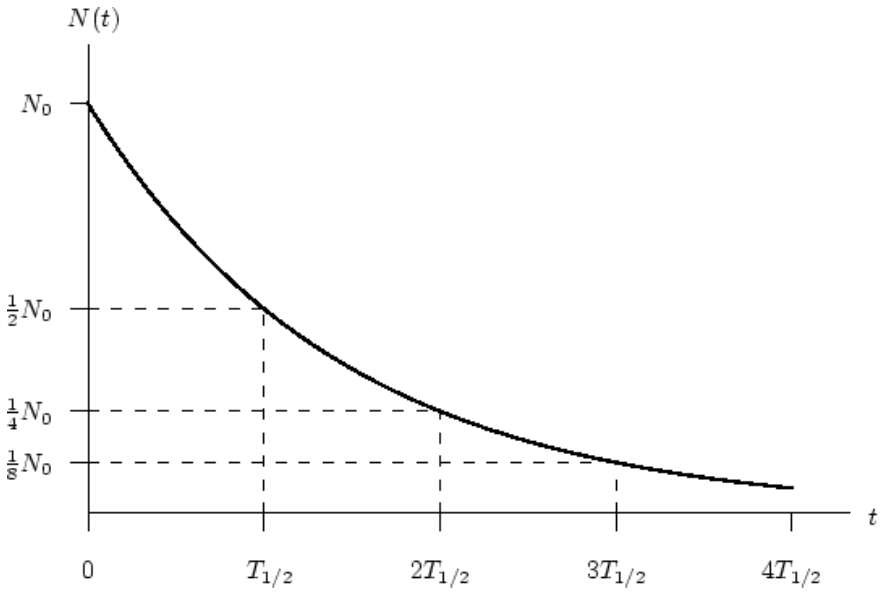

Figure 2.2: The exponential behavior of number of nuclei present in a sample N (t) versus time (t) for a radioactive material.

2.3.2. *Half- life* and *mean life time*:

The *half life* ($t_{1/2}$) is the time interval during which half of the nuclei in the sample decay. Putting $N=N_0/2$ in equation (2.2) gives:

$t_{1/2} = \frac{\ln 2}{\lambda}$ ..... (2.3)

If the decay constant (λ) is known or can be calculated, then the *half-life* ($t_{1/2}$) can be obtained and compared directly with measured values.

Another useful time scale for describing decays is the average or *mean life time* of a radioactive material (τ) which is defined as the average time that a nucleus is likely to survive before it decays, and it can be shown that it relates to the decay constant (λ) in the following way (Mittal V. K. et al., 2009):

$$\tau = \frac{1}{\lambda} \quad \text{..... (2.4)}$$

2.3.3. Activity:

The number of decays per unit time interval, i.e. the activity A, is defined by (Magill J. et al., 2005),

$$A = -\frac{dN}{dt} = \lambda N \quad \text{..... (2.5)}$$

Because it is difficult to count the remaining number of nuclei directly, we can use the following formula for equation (2.2)

$$A = A_0 e^{-\lambda t} \quad \text{..... (2.6)}$$

where A_0 is the initial activity at time t_0.

2.3.4. Radioactive equilibrium:

Radioactive equilibrium for a decay chain occurs when each radionuclide decays at the same rate it is produced. Understanding the equilibrium for a given decay series, helps scientists estimate the amount of radiation that will be present at various stages of the decay.

For example, as uranium-238 begins to decay to thorium-234, the amount of thorium and its activity increase. Eventually the rate of thorium decay equals its production its concentration then remains constant. As thorium decays to proactinium-234, the concentration of proactinium-234 and its activity rise until its production and decay rates are equal. When the production and decay rates of each radionuclide in the decay chain are equal, the chain has reached radioactive equilibrium. So equilibrium is the situation in which the ratio between the activities of the successive members of the decay series remains constant (Ehman W., Vance D., 1993; Krane K. S., 1988).

In the previous example if we call uranium the parent nuclide and thorium the daughter one, the decay rate of the parent nuclide according to equation(2.5) is,

$$dN_p/dt = - \lambda_p N_p \quad \ldots\ldots (2.7)$$

But the net decay rate of the formation of the daughter nuclide which is also radioactive is,

$$dN_d/dt = \lambda_p N_p - \lambda_d N_d \quad \ldots\ldots (2.8)$$

Now at equilibrium state the decay rate of the daughter nuclide must be zero, so equation (2.8) gives:

$$\lambda_p N_p = \lambda_d N_d \quad \ldots\ldots (2.9)$$

2.3. Types of decay:

As for types of radioactive radiation, it was found that an electric or magnetic field could split such emissions into three types of beams as

shown in figure (2.3). The rays were given the alphabetic names alpha "α", beta "β" and gamma "γ", still in use today. While alpha decay was seen only in heavier elements (atomic number 52 and greater), the other two types of decay were seen in all of the elements, so unstable nuclei can decay by one of three types (α, β or γ) each of which will be discussed briefly in this section.

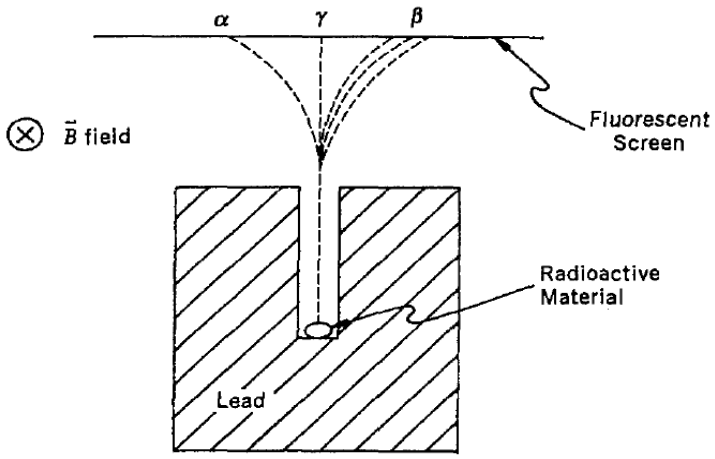

Figure 2.3: Separation of α, β and γ-rays in a magnetic field

2.3.1. α – decay:

In analyzing the nature of the decay products, it was obvious from the direction of electromagnetic forces that alpha rays carried a positive charge (see figure 2.3). From the magnitude of deflection, it was clear that alpha particles are much more massive than other decay particles, because most of them arrived close to the same spot on the screen; they indicated that the α-particles in the beam were essentially mono-energetic, with typical velocities of about 0.1 c. Furthermore, the range of a-particles was found to be relatively short. Passing alpha particles through a very thin glass window and trapping them in a discharge tube allowed researchers to

study the emission spectrum of the resulting gas, and ultimately prove that alpha particles are Helium nuclei (Das A. , Ferbel T., 2003), (Patel Sb., 1991).

The reason alpha decay occurs is because the nucleus has too malny protons which cause excessive repulsion. In an attempt to reduce the repulsion, a Helium nucleus is formed and then emitted. The way it works is that the Helium nuclei are in constant collision with the walls of the nucleus and because of its energy and mass; there exists a nonzero probability of transmission. That is, an alpha particle (Helium nucleus) will tunnel out of the nucleus; this process is represented as follows:

$$^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.9)$$

where X and Y are known as “parent” and “daughter” nuclei respectively. An important example on this type of decay is the decay of Radium-226 into Radon-222 as shown in the following equation:

$$^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.10)$$

The high mass and charge of the alpha particle, relative to other forms of nuclear radiation, give it greater ionization power but a poorer ability to penetrate matter. In air, alpha particles may travel only a few centimeters. This short range of travel varies depending on the initial energy of the particle. For example, a 5.5 MeV alpha particle, such as that emitted in equation (2.10) previously described, has a range of approximately 4 cm in dry air at standard temperature and pressure (Annunziata M. F., 2007) as illustrated in figure (2.4) below:

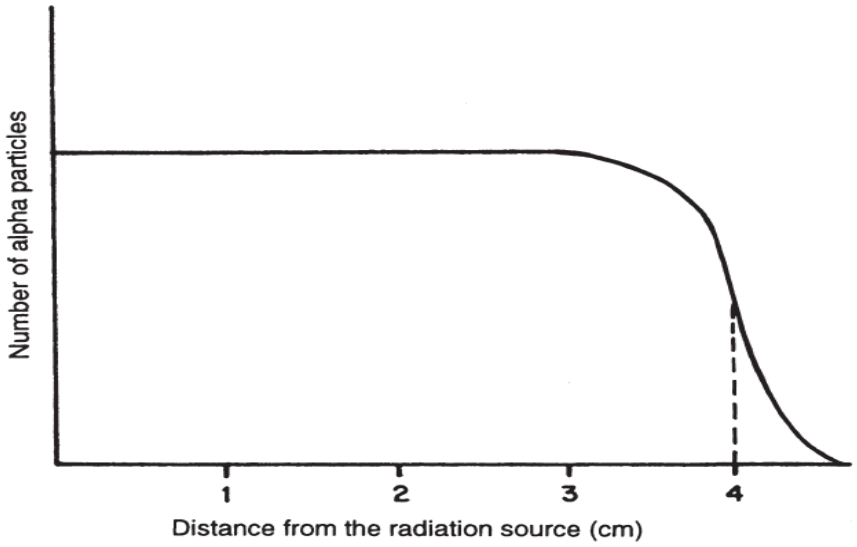

Figure 2.4: Range of 5.5 MeV α-particle in air

2.3.2. β⁻ decay :

In contrast to α- particles, the most common forms of β-particles were found to bend in an opposite direction, (as shown in figure 2.3), indicating that β-radiation consisted of negatively charged particles. These particles were observed to be well dispersed along the screen, which meant that, unlike the α-particles, the β-particles had a continuous spectrum of velocities, which were as high as 0.99 c (Das A. , Ferbel T., 2003). Other measurements revealed that β-particles had longer ranges and were less ionizing than α-particles.

Beta decay occurs in nuclei that have too many neutrons or too few neutrons for stability. A remains the same while Z either increases by 1 or decreases by 1 by converting a neutron into a proton or a proton into a neutron, this process can be performed by three possible ways each of which will be discussed briefly in this section;

2.3.2.1. Negatron decay (β^--decay):

A nucleus with an over abundance of neutrons (i.e., with a value of N/Z greater than that for stable nuclei) can transform to a more stable nucleus by emitting an electron. This kind of process is known as β^--*decay* or Negatron decay, and the transformation can be denoted by

$$^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + e^- + \bar{\upsilon}_e \quad \text{..... (2.11)}$$

Where ($\bar{\upsilon}_e$) is the anti particle of the Neutrino (υ_e) which is a particle that experiments showed that it was needed for the conservation of angular momentum in the previous decay (Serway R. A., 2004).

From electric-charge conservation, it follows that the proton number of the daughter nucleus in such decays increases by one unit. However, the nucleon number remains unchanged as shown in equation (2.11).

An example of this reaction is:

$$^{137}_{55}Cs \rightarrow {}^{137}_{56}Ba + e^- + \bar{\upsilon}_e \quad \text{..... (2.12)}$$

2.3.2.2. Positron decay (β^+-decay):

A proton-rich nucleus (i.e., with a value of N/Z smaller than that for stable nuclei) emits a positron, positrons are antiparticles of electrons, and have the same properties as electrons but positive electric charge (Das A. , Ferbel T., 2003), and thereby reduces the nuclear charge by one unit. However, the nucleon number remains unchanged also. This kind of process is known as "β^+ -*decay*" or "Positron decay", In this case, the transformation can be represented by:

$$^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + e^{+} + \upsilon_e \quad \text{(2.13)}$$

An example of this process is:

$$^{22}_{11}Na \rightarrow {}^{22}_{10}Ne + e^{+} + \upsilon_e \quad \text{(2.14)}$$

2.3.2.3. Electron Capture:

Electron capture is a process in which a proton-rich nuclide absorbs an inner atomic electron changing a nuclear proton to a neutron and simultaneously emits a neutrino. This process is referred to as electron capture, and can be represented as:

$$p + e^{-} \longrightarrow n + \upsilon_e \quad \text{(2.15)}$$

Various photon emissions follow, in order to allow the energy of the atom to fall to the ground state of the new nuclide, so one or more X-rays are usually emitted (Friedlander G. et al., 1981)

An example of this process is:

$$^{26}_{13}Al + e^{-} \rightarrow {}^{26}_{12}Mg + \upsilon_e \quad \text{(2.16)}$$

2.3.3. γ - decay:

Gamma radiation is electromagnetic radiation that is emitted by an unstable nucleus of an atom during radioactive decay. A nucleus in an unstable state may fall to a more stable state by the emission of energy as gamma radiation. Unlike α-decay or β-decay, neither the mass number A nor the atomic number Z changes during γ decay. γ-decay follows either α-decay or β-decay. For example, if a radioactive parent nucleus decays by β decay to an excited state of the daughter nucleus, the daughter nucleus then

decays to its ground state by γ emission. Because this kind of de-excitation is electromagnetic, we expect lifetimes for such processes to be very small (about 10^{-16} sec). A few γ emitters have very long lifetimes, of the order of hours. Nuclear energy states that have such long lifetimes are called metastable states. (Serway R. A., 2004; Krane K. S., 1988; Ralph E. L.,1972).

2.4. Natural Decay Chains:

In nature, there are three main decay chains, the naturally occurring radioactive parents have atomic numbers mostly between Z = 81 and Z = 92, and are characterized by substantial neutron excess (Das A., Ferbel T., 2003). Nevertheless, the presence of a large number of protons in these nuclei leads to strong Coulomb repulsion and instability. Such nuclei can decay by successive emissions of α, β or γ, until the nucleus reaches the N-Z stability band (Figure: 2.1).

The three natural decay series are headed by Uranium-238, Thorium-232, and Uranium-235, and because an α-particle has four nucleons, the alternate decays will define a radioactive nuclear series with atomic mass numbers that differ by four nucleon units. So the decay chains are known as (4n+2), (4n) and (4n+3) for ^{238}U, ^{232}Th and ^{235}U respectively, where n is an integer (Ralph E. L., 1972).

The radionuclides of the uranium-238, thorium-232, and uranium-235 decay series are shown in Figures 2.5, 2.6, and 2.7, along with the major mode of radioactive decay for each (Baum et al., 2002).

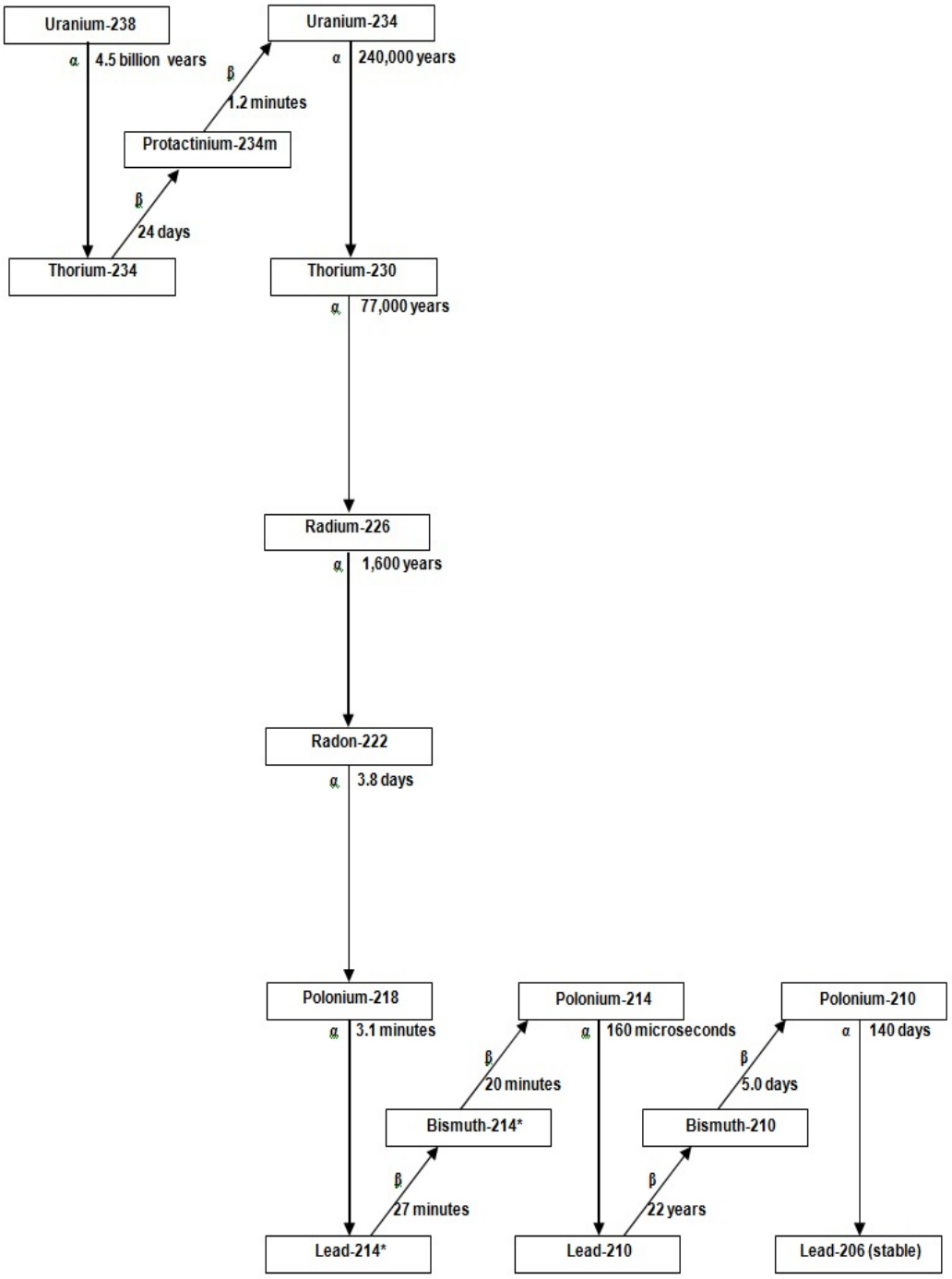

Figure 2.5: Natural Decay Series for Uranium-238

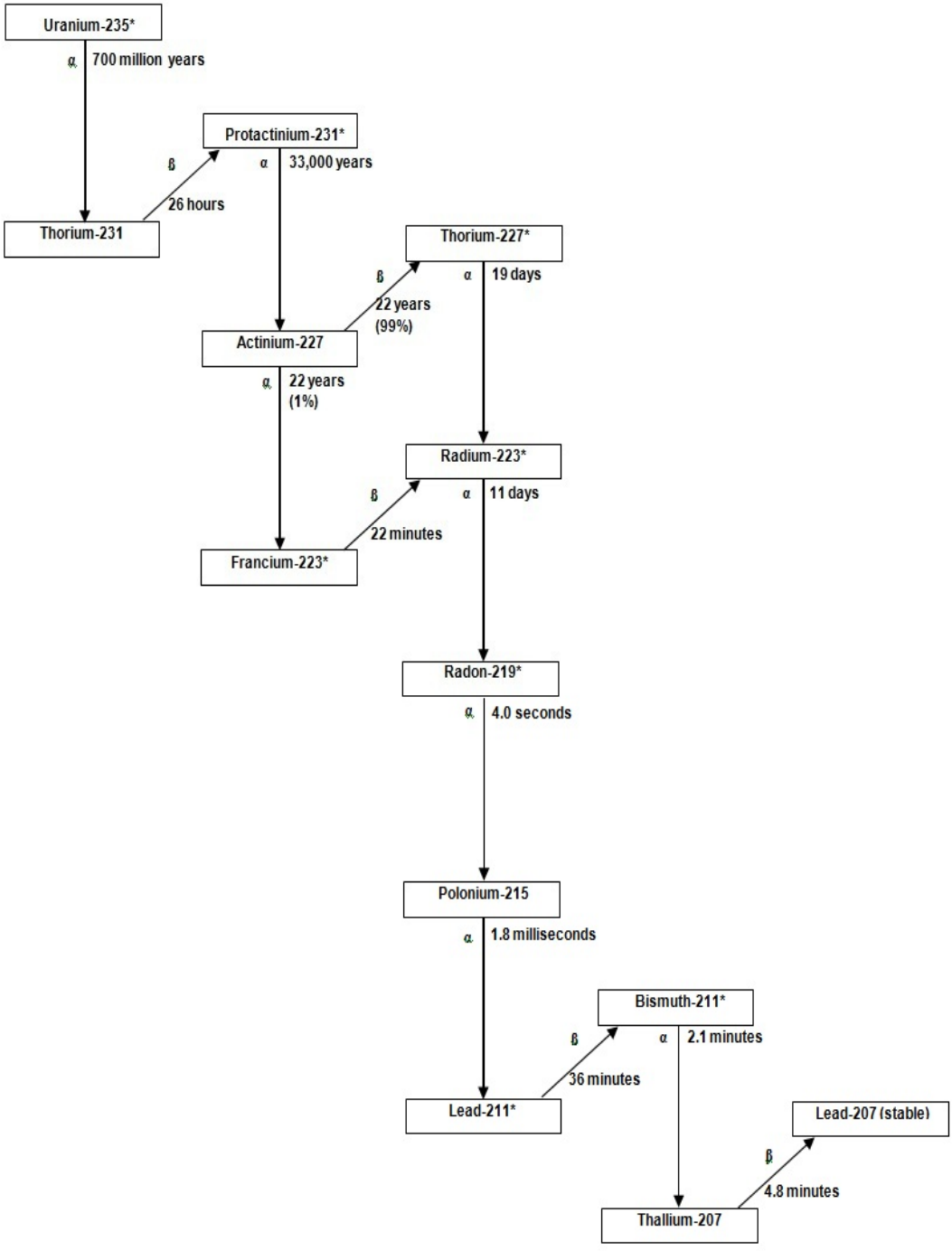

Figure 2.6: Natural Decay Series for Uranium-235

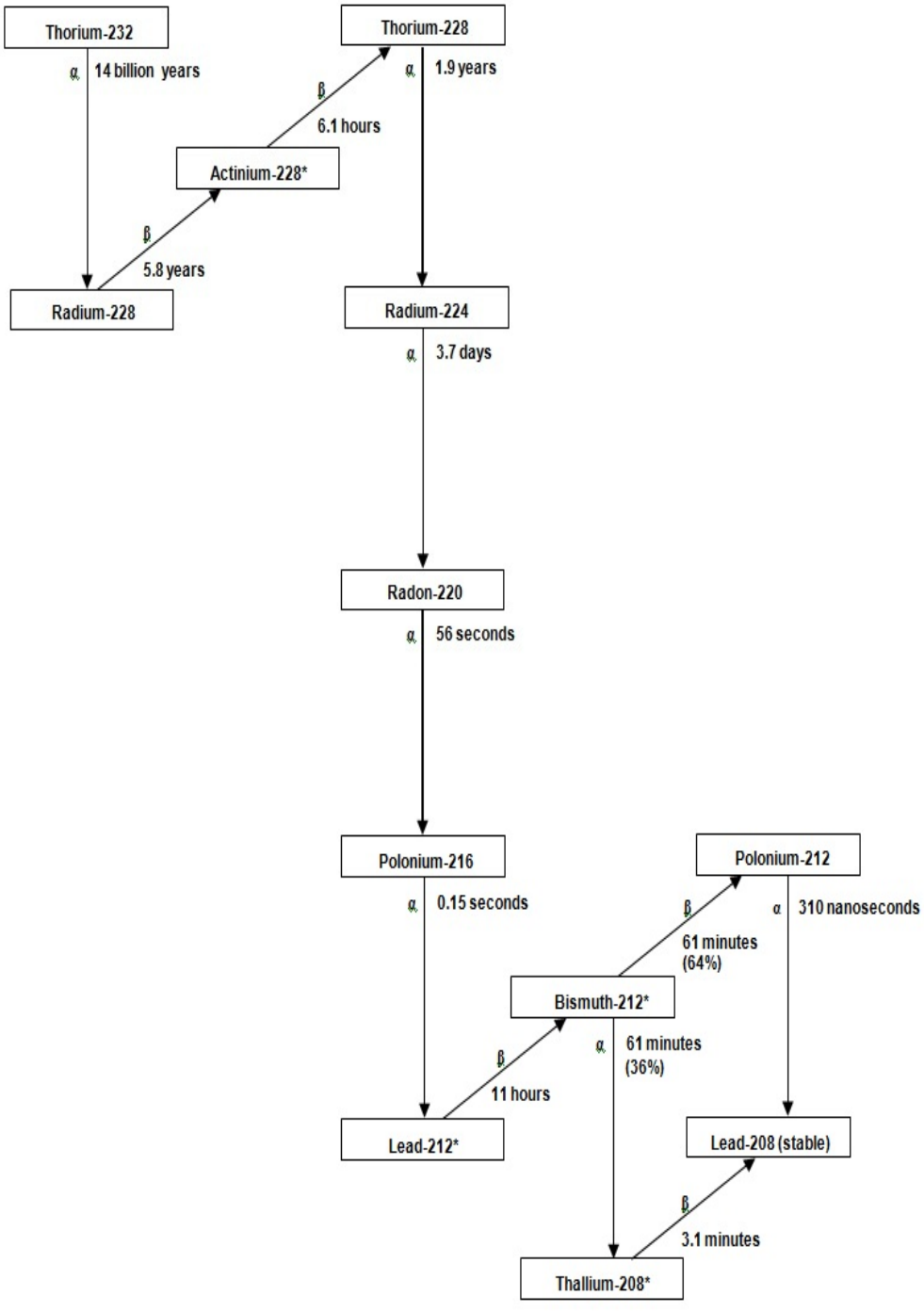

Figure 2.7: Natural Decay Series for Thorium-232

2.5. Effects of radiation on human body:

As our research is concerned with Radon radiation from building materials and since the population exposure to radiations is the major interest in this research, it was important to understand how this radiation can interact with human body and causes damage on the living cells.

Radioactive materials produce ionizing radiation, which has sufficient energy to strip away electrons from atoms or to break some chemical bonds. Any living tissue in the human body can be damaged by ionizing radiation in a unique manner. The body attempts to repair the damage, but sometimes the damage is of a nature that cannot be repaired or it is too severe or widespread to be repaired. Also mistakes made in the natural repair process can lead to cancerous cells. The most common forms of ionizing radiation are alpha and beta particles, or gamma and X-rays (UNSCEAR, 2008).

The most abundant substance in cells is water. Because of its abundance, it is the water molecule that absorbs the major fraction of all incident radiation. High energy absorption can cause the molecular bonds within the water molecule to break, creating H^+ and OH^- ions within the cell. Usually these ions have low energy and quickly recombine to form water; but, at higher energies "hydrogen peroxide" will form through a series of reactions which can be summarized as follows (Eisenbud M., Gesell T., 1997):

$$3(H_2O) + \text{energy} \longrightarrow 3\,H^+ + 3OH^- \longrightarrow H_2O_2 + 2\,H_20$$

The substance H_2O_2 is common hydrogen peroxide, a highly reactive oxidizing compound. It is this highly reactive compound which can attack other molecules such as DNA and other important molecules which regulate and control vital cellular functions. Although the cell is able to repair most molecular damage, excessive molecular damage can lead to cellular death or mutation (Reshetnyak S. A., 1996; Leroy C., Rancoita P. G., 2004).

An example of an α-particle emitter is the ^{238}U nuclide, which together with its decay products contributes to the natural radioactivity background. The ^{222}Rn gas, which is the scope of this research can be assimilated by man and is responsible for about 40% of the natural radioactivity average exposure of human beings (ATSDR, 1990).

2.6. Radiation Units:

2.6.1. Units for measuring radioactivity:

As we mentioned in section 2.3, radioactivity or the strength of radioactive source is measured in units of Becquerel (Bq), Where 1 Bq equals 1 event of radiation emission per second. An old and still popular unit of measuring radioactivity is the curie (Ci) where 1 Ci = 3.7×10^{10} Bq. Obviously, One curie is a large amount of radioactivity, commonly used subunits (i.e. μCi, nCi, and pCi).

2.6.2. Units for measuring radiation energy:

The energy of ionizing radiation is measured in electronvolts (eV). One electronvolt is an extremely small amount of energy. Commonly used multiple units are kiloelectronvolt (keV) and megaelectronvolt (MeV).

Another popular unit of radiation energy is the “Joule” where 1 Joule equals 1.6 x 10^{-19} eV.

2.6.3. Units for measuring radiation exposure:

Alpha, beta and gamma-ray exposure is often expressed in units of Roentgen (R), which refers to the amount of ionization present in the air. One roentgen of gamma- or x-ray exposure produces approximately 1 rad (0.01 gray) tissue dose (see next section for definitions of gray (Gy) and rad units of dose), the SI unit for radiation exposure is Coulomb/Kg, where Roentgen was last defined by the US National Institute of Standards and Technology (NIST) as exactly equals 2.58x10^{-4} C/Kg of air (UNSCEAR, 2000).

2.6.4. Units for measuring radiation dose:

When ionizing radiation interacts with the human body, it gives its energy to the body tissues. The amount of energy absorbed per unit weight of the organ or tissue is called absorbed dose and is expressed in units of gray (Gy). One gray dose is equivalent to one joule radiation energy absorbed per kilogram of organ or tissue weight. Rad is the old and still used unit of absorbed dose. One gray is equivalent to 100 rads.

Equal doses of all types of ionizing radiation are not equally harmful. Alpha particles produce greater harm than do beta particles, gamma rays and x rays for a given absorbed dose. To account for this difference, radiation dose is expressed as equivalent dose in units of sievert (Sv). The dose in Sv is equal to "absorbed dose" multiplied by a "radiation weighting

factor" (W_R - see Table 2.2 below) (Ehman W.,1993; Ralph E. L. et al,1972).

Equivalent dose is often referred to simply as "dose" in everyday use of radiation terminology. The old unit of dose equivalent was “rem”.

Table 2.2: Recommended Radiation Weighting Factors

Type and energy range	**Radiation weighting factor, W_R**
Gamma rays and x rays	1
Beta particles	1
Neutrons, energy	
< 10 keV	5
> 10 keV to 100 keV	10
> 100 keV to 2 MeV	20
> 2 MeV to 20 MeV	10
> 20 MeV	5
Alpha particles	20

2.6.5. Units for measuring the Effective dose:

Effective dose is a measure of dose in which the type of radiation and the sensitivity of tissues and organs to that radiation is taken into account. The probability of a harmful effect from radiation exposure depends on what part or parts of the body are exposed. Some organs are more sensitive to radiation than others. A tissue weighting factor (w_T) is used to take this into account (see table 2.3) (Ehman W.,1993). When an equivalent dose to an organ is multiplied by the (w_T) for that organ, the

result is the effective dose to that organ: Effective dose = sum of [organ doses x tissue weighting factor].

Table 2.3: Tissue Weighting Factors (W_T) for some Tissues and Organs.

Tissue or Organ	Tissue Weighting Factor (W_T)
Gonads (testes or ovaries)	0.20
Colon	0.12
Lung	0.12
Stomach	0.12
Breast	0.05
Liver	0.05
Skin	0.01
Bone surfaces	0.01

Table 2.4 below shows radiation SI units and the corresponding non-SI units, their symbols, and the conversion factors between all the above units.

Table 2.4: Radiation Units and Conversion Factors

Quantity	SI unit	Non-SI unit	Conversion factor
Radioactivity	Becquerel "Bq"	curie "Ci"	1 Ci = 3.7 x 10^{10} Bq
Absorbed dose	Gray "Gy"	Rad	1 rad = 0.01 Gy
"Dose" (Equivalent dose)	Sievert "Sv"	Rem	1 rem = 0.01 Sv
Exposure	Roentgen "R"	C/kg	1 R = 2.58x10^{-4}C/Kg

Chapter Three

Radon as an Environmental Problem

Chapter Three

Radon as an Environmental Problem

3.1. Radon gas properties and sources:

Radon is a gaseous element discovered by German physicist Friedrich Ernst Dorn in 1900. Radon is a colorless, odorless, tasteless inert gas. The atomic radius is 1.34 angstroms and it is the heaviest known gas (density= 9.73g/L), (about eight times denser than air). Because it is a single atom gas (not a molecule) it easily penetrates many common materials like paper, leather, low density plastic, most paints, and building materials like gypsum board, concrete block, mortar, wood paneling, and most insulations. Radon has a heavily neutron-rich nucleus that makes it a radioactive element (CDC, 2010). It is an alpha emitter that decays with a half-life of 3.8 days.

Radon gas is by far the most important source of ionizing radiation among those that are of natural origin (WHO, 2009). The most important isotope, in terms of environmental effects is (^{222}Rn) which is formed from the α-decay of radium (^{226}Ra), which is a decay product of Uranium (^{238}U). Uranium and radium occur naturally in soils and rocks. Soil gas infiltration became recognized as the most important source of indoor radon. Other sources, including building materials and well water were given the same importance after studies were performed.

3.2. Radon isotopes and daughters:

Radon occurs in several isotopic forms, it has 33 isotopes whose half-lives are known with mass numbers from 195 to 229, none are stable. The most known isotopes are:

(1) ^{222}Rn called Radon, (belongs to ^{238}U decay series).

(2) ^{220}Rn (called Thoron, belongs to ^{232}Th decay series).

(3) ^{219}Rn (called Actinon, belongs to, ^{235}U decay series). (see figures 2.5 through 2.7 for the decay chains of ^{238}U, ^{232}Th, ^{235}U) .

As shown in table 3.1 ^{222}Rn has 3.82 days half-life, whereas ^{220}Rn (55.6 s) and ^{219}Rn (3.96 s) have much shorter half-lives. Because of such short half-lives, their emanation from building materials, as well as, its infiltration from the ground and further migration is restricted to a few centimeters only (Guo Q. et al, 1992). This is why ^{220}Rn and ^{219}Rn are given less importance in environmental studies.

Table 3.1: Radon isotopes, their chemical symbols and half-lives

No.	Radon isotope name	Chemical symbol	Decay series it belongs to	Half – life
1-	Radon	^{222}Rn	^{238}U	3.82 d
2-	Thoron	^{220}Rn	^{232}Th	55.6 s
3-	Actinon	^{219}Rn	^{235}U	3.96 s

The chart below (Figure 3.1) lists all of the decay products of radon gas (^{222}Rn) in their order of appearance. They are called the "radon progeny" (formerly "radon daughters"). Each radioactive element on the list gives off alpha, beta and sometimes gamma radiation too, thereby

transforming itself into the next element on the list. It is the short-lived daughters of radon (^{218}Po and ^{214}Po), which arise through decay of radon, that actually deposit on the bronchial airways and deliver the carcinogenic dose as they give high energy alpha particles (with energies 6.00MeV and 7.69 MeV, respectively). The total energy deposition in the lungs from the decay products is about 500 times greater than that derived from ^{222}Rn itself (Eisenbud M., Gessel T., 1997).

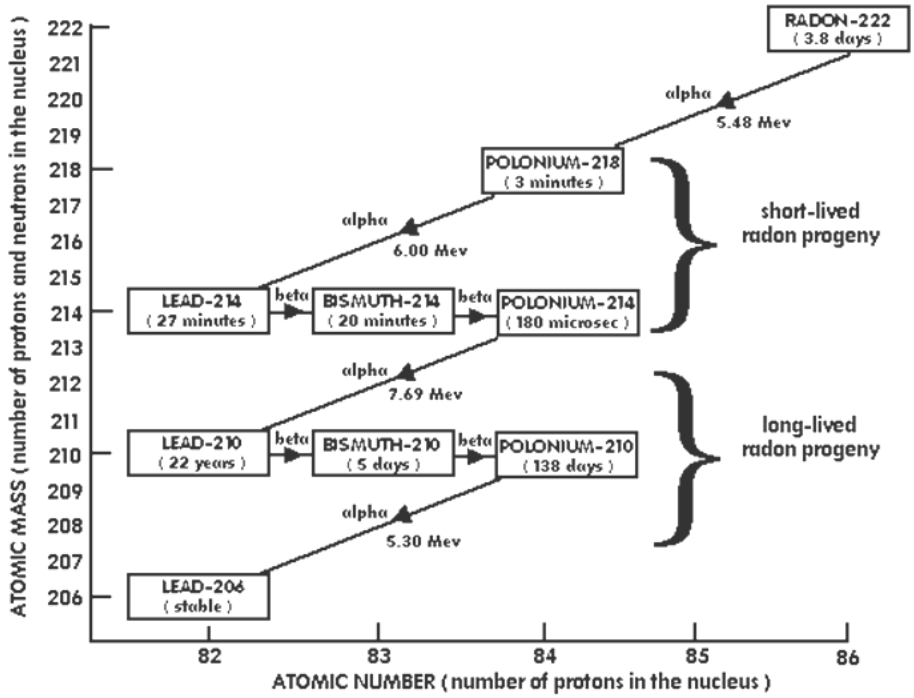

Figure 3.1: Decay products of Radon gas, their half-lives and alpha particle energies (CCNR, 1998).

3.3. Health effects of radon:

Recent studies of people exposed to radon have confirmed that radon in homes represents a serious health hazard. The main health risk associated with long-term, elevated exposure to radon is an increased risk

of developing lung cancer, which depends on the radon concentration and the length of exposure (WHO, 2009).

Health effects of radon, most notably lung cancer, have been investigated for several decades. Initially, investigations focused on underground miners exposed to high concentrations of radon in their occupational environment. However, in the early 1980s, several surveys of radon concentrations in homes and other buildings were carried out, and the results of these surveys, together with risk estimates based on the studies of mine workers, provided indirect evidence that radon may be an important cause of lung cancer in the general population. Radon is now recognized as the second most important cause of lung cancer after smoking in the general population (EPA, 1999).

When radon gas is inhaled, densely ionizing alpha particles emitted by deposited decay products of radon can interact with biological tissue in the lungs leading to DNA damage. Cancer is generally thought to require the occurrence of at least proliferation of intermediate cells that have sustained degree of DNA damage which can greatly increase the pool of cells available for the development of cancer. Since even a single alpha particle can cause major genetic damage to a cell, it is possible that radon-related DNA damage can occur at any level of exposure (UNSCEAR, 2008). Therefore, it is unlikely that there is a threshold concentration below which radon does not have the potential to cause lung cancer.

Other than lung cancer, when an individual spends time in an atmosphere that contains radon and its decay products, the part of the body that receives a high dose of ionizing radiation is the bronchial epithelium,

although the extra thoracic airways and the skin may also receive appreciable doses. In addition, other organs, including the kidney and the bone marrow, may receive low doses (Kendall GM et al, 2002). If an individual drinks water in which radon is dissolved, the stomach will also be exposed.

However, a recent case study evaluating the incidence of leukemia, lymphoma, and multiple myeloma in Czech uranium miners (Rericha V., 2006) found a positive association between radon exposure and leukemia, including chronic lymphocytic leukemia. A case-control study of stomach cancer in an area where there were high concentrations of natural uranium and other radionuclides in drinking water gave no indication of an increased risk (Auvinen A., 2005).

3.4. Methods to reduce radon concentration indoors:

There are several methods to reduce radon concentration; one is by removing the source of radon if it was possible like the waste of uranium mines that are close to residential areas, or sealing cracks and other openings in the foundation which limits the flow of radon into homes, thereby making other radon reduction techniques more effective and cost-efficient. Also, good ventilation system is recommended for controlling radon daughters to below the exposure limits by using a fan to blow air outdoors or simply through the ventilation of buildings through windows (EPA, 2010).

To avoid high concentration of radon gas in buildings that will be built in the future we advise according to this study not to use building

materials that release large amounts of this radioactive gas and to avoid the construction of buildings in areas with high radioactive concentrations.

3.5. Measuring radon concentration techniques:

Radon measurements are often discussed in terms of either a short-term or long-term test (Quindos LS et al., 1991). A short-term test for radon, using an activated charcoal detector or another type of detector such as an electret ion chamber, can provide a first indication of the mean long-term radon concentration in a home. However, diurnal and seasonal radon variations should be taken into account when performing short-term radon measurements. Since high radon concentrations commonly occur during periods when homes are “closed up” (i.e. windows closed), a short-term measurement performed during this period, or season, can overestimate the yearly mean radon concentration. Alternatively, a short-term radon measurement performed during a period when the house has increased ventilation (e.g. windows open) can substantially underestimate the mean annual radon concentration. Therefore, in order to assess the annual average radon concentration within a home, devices that provide a long-term integrated radon measurement are preferred. However, it should be noted that even yearly radon concentrations in the same home can vary (Zhang Z., 2007).

The most popular radon measuring devices (Table 3.2) used by countries surveyed within the WHO International Radon Project (WHO, 2007) were passive nuclear-track detectors (NTDs), electret ion chambers (EICs), and activated charcoal detectors (ACDs). Active devices in use by many countries included electronic integrating devices (EIDs) and

continuous radon monitors (CRMs). Passive devices do not require electrical power or a pump to work in the sampling setting, whereas active devices require electricity and include the ability to chart the concentration and fluctuations of radon gas during the measurement period. For homes, NTDs are a popular choice to obtain a long-term radon measurement and are often deployed for a one-year period, while EICs are often used for short to intermediate measurement periods. The use of CRMs has become more prevalent as the price of these detectors has slowly declined (WHO, 2009).

Table 3.2: Radon gas measurement devices and their characteristics.

Detector Type	Passive/ Active	Typical Sampling period	Cost
Nuclear-Track Detector (NTD)	Passive	1 – 4 months	Low
Activated Charcoal detector (ACD)	Passive	2 - 7 days	Low
Electret Ion Chamber (EIC)	Passive	5 days - 1 year	Medium
Electronic Integrating devices (EID)	Active	2 days	Medium
Continuous Radon Monitor (CRM)	Active	1 hour	High

3.6. Solid state nuclear track detectors:

In this research we are concerned with the Nuclear-Track Detector (NTD) type. An NTD is a small piece of specially produced plastic which is generally a polyallyl diglycol carbonate ($C_{12}H_{18}O_7$) commercially known as (CR-39), cellulose nitrate (LR-115), or polycarbonate material.

Radon concentrations in samples will be measured in this study using passive integral solid-state nuclear track detectors (SSNTD) commercially known as (CR-39). This is a clear 1cm x 1 cm stable plastic

sensitive to the tracks of alpha particles, which is the most widely used and accurate detector for radon measurements (Sofija C. et. al., 2004).

Nuclear-track detectors are generally deployed for an exposure period ranging from 1 month to 1 year. Alpha-track detectors are insensitive to humidity, temperature, and background beta and gamma radiation. Cross-sensitivity to thoron can be avoided by using a diffusion chamber with a large diffusion resistance to gas entering the chamber.

3.6.1. Tracks formation:

When alpha particles are generated by radon or radon decay products in proximity to the detecting material, they can strike the detecting material, producing microscopic areas of damage inside the plastic in the form of broken molecular chains and free radicals called alpha tracks (Frenje JA et al, 2002). The size and shape of these tracks provide information about the mass, charge, energy, and direction of motion of the particles. Therefore, CR-39 detectors can semi qualitatively be used to distinguish the types and energies of individual particles (Nikezic D., 2004).

3.6.2. Chemical etching:

Chemical etching of the plastic detector material enlarges the size of the alpha tracks, making them observable by light microscopy so that they can be counted either manually or by an automated counting device. The number of tracks per unit surface area, after subtracting background counts, is directly proportional to the integrated radon concentration. A conversion

factor obtained by controlled exposures at a calibration facility allows conversion from track density to radon concentration.

Chemical etching conditions differ from one type of detector to another in terms of type of the chemical solution, its concentration, etching duration, and temperature. Usually Potassium Hydroxide (KOH) or Sodium Hydroxide (NaOH) solutions are used in chemical etching process with various concentrations at a temperature that varies from (40-100)^{0}C (Durrani S., Ilic R.,1997).

Chapter Four

Experimental work

Chapter Four

Experimental work

This study started in October 2011, ended in March 2012, and included the following main stages:

1. Samples' Collection.
2. Samples' preparation.
3. Preparation of dosimeters.
4. Collecting detectors and chemical etching.
5. Detectors scanning, counting tracks and calculation.

Before we start in the details of the experimental work through these stages we have to introduce the area of study through the next section.

4.1. Introducing the area of study:

In this study, we present our data concerning measurement of the radon exhalation rate from building material samples collected from Nablus district in the West Bank in Palestine using close vessel technique. The location of this district is shown in Figure 4.1. Houses in this district are mainly constructed from soil, bricks, cement, sand, granite and marble. This district is located in the northern part of the West Bank of Palestine.

4.1.1. Geography:

Nablus lies in a strategic position at a junction in the shade of two mountains: Ebal (940m height) to the North and Gerizim (881m height) to the South. The city stands at an elevation of around 550 meters

(1,800 ft) above sea level, in a narrow valley between the two mentioned mountains.

Nablus (Figure 4.1) is located 110 kilometers west of Amman, capital of Jordan, 63 kilometers north of Jerusalem, the capital of Palestine, and 42 kilometers east of the Mediterranean, lies on the latitude 14^{o}-32^{o} to the north of the Equator, and the longitude 15^{o}-35^{o} to the east of Greenwich (Nablus.ps, 2008).

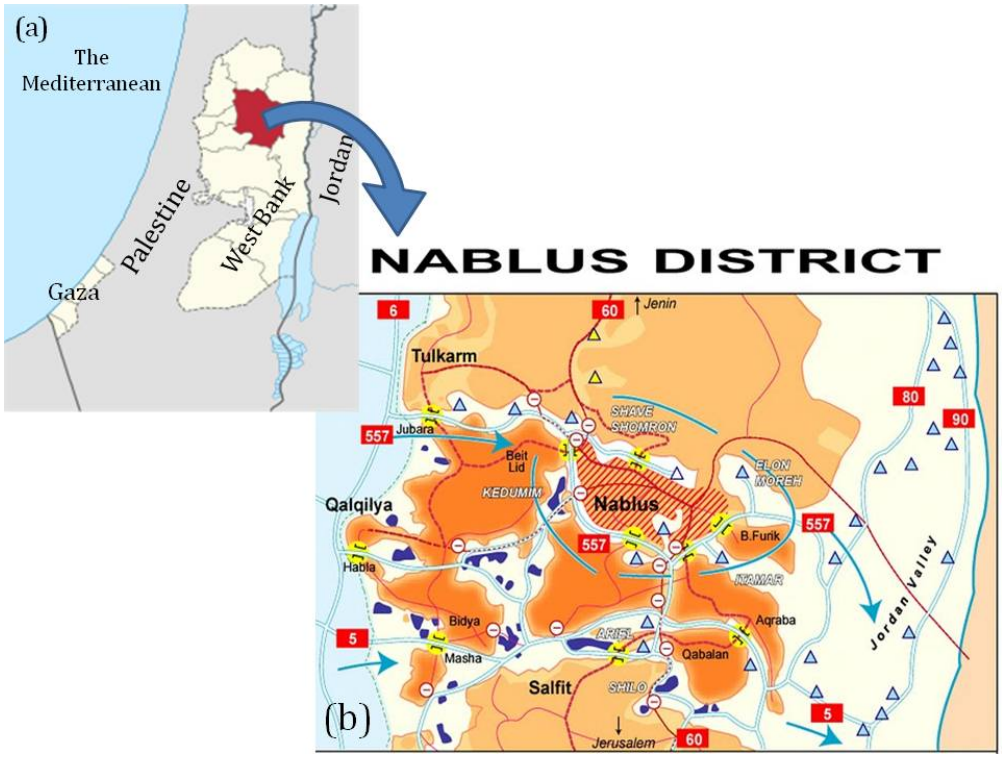

Figure 4.1: (a) Palestine map, (b) The study region (Flickr.com, 2011).

4.1.2. Climate:

The relatively temperate Mediterranean climate brings hot, dry summers and cool, rainy winters to Nablus. Spring arrives around March–April and the hottest months in Nablus are July and August with the

average high being 29.4 °C. The coldest month is January with temperatures usually at 7.2 °C. Rain generally falls between October and March, so the period during which this study was performed was in the cold months including December, January and February (Nablus.ps, 2008).

4.2. Experimental work Stages:

4.2.1. Samples' Collection:

Different samples of building materials from different origins used in building in Nablus district, Palestine were collected randomly from different organizations, quarries and commercial companies all around the area of study during October and November.

Samples included five types of granite and marble each, seven of ceramic, four from each of porcelain, sand, bricks, gravel, cement, and building stones, three from concrete and gypsum each, with a total of forty seven samples those materials were from American, Chinese, Italian, French, Spanish, Turkish, Arabian, and Palestinian's origins.

4.2.2. Samples' preparation:

After collecting samples, the solid ones were crushed and milled to a fine powder with a uniform particle size, while the powder samples were used in their natural form. The respective net weights of the samples ready for measurement were recorded. Samples were then identified and given a number and an identifying symbol, and then dried in an oven at about 100 °C for two hours to evaporate all moisture content. At this time the samples were ready for examination, a list of numbers, symbols, the country of

origin for each sample and informations about some of them are shown in table 4.1.

4.2.3. Preparation of "Dosimeters":

The close vessel technique was used in this study "can technique" or we call them "Dosimeters".

Dosimeters are plastic cylindrical vessels of volume (2.945 X 10^{-3}) m^3 with cross sectional area of (0.01227 m^2) as shown in figure 4.2. The building material samples were put at the bottom of these vessels. The ratio of volumes of the containers and samples was more than 10, which reduces the probability of back diffusion (Hafez. A.F et al, 2001). The dosimeters were completely sealed for about 27 days to allow the ^{238}U to reach equilibrium with its progeny. This step was necessary to ensure that the radon gas and its daughters are confined within the sample.

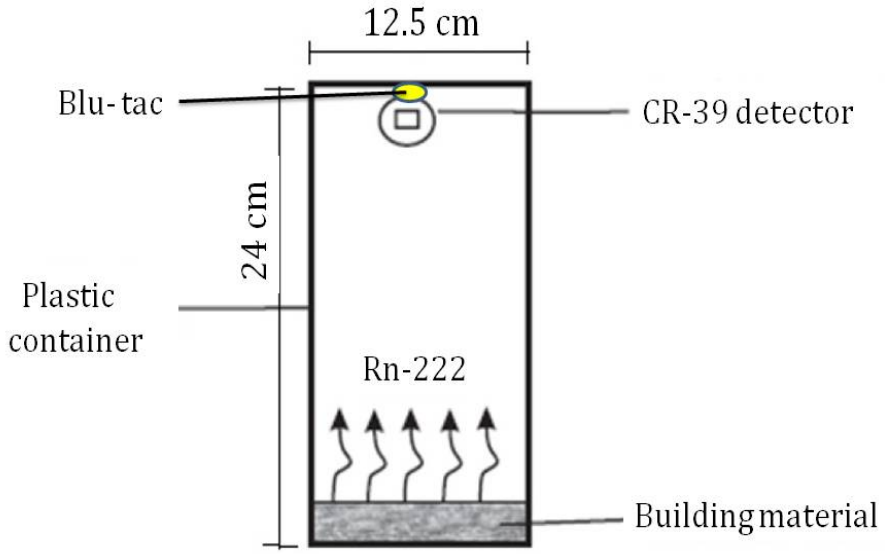

Figure 4.2: Experimental set up for the measurement of radon exhalation rate.

Table 4.1: List of numbers, codes and the country of origin for samples studied in this research.

Sample No.	Sample code	Type	Country of Origin /Info.	Sample No.	Sample code	Type	Country of Origin/Info.	Sample No.	Sample code	Type	Country of Origin/Info.
1	G1	Granite	America	**17**	C7	Ceramic	Japan	**33**	B4	Brick	Insulation Brick
2	G2	Granite	China	**18**	P1	Porcelain	China	**34**	Gr1	Gravel	Nablus/ Jamma'en
3	G3	Granite	Italy	**19**	P2	Porcelain	Spain	**35**	Gr2	Gravel	Nablus/ Al-Kassarat
4	G4	Granite	Saudi Arabia	**20**	P3	Porcelain	China	**36**	Gr3	Gravel	Nablus/ Al-Badan
5	G5	Granite	Spain	**21**	P4	Porcelain	Italy	**37**	Gr4	Gravel	Hebron
6	M1	Marble	Turkey	**22**	Ce1	Cement	Turkey	**38**	Gy1	Gypsum	Israel
7	M2	Marble	Palestine/ Hebron	**23**	Ce2	Cement	Jordan	**39**	Gy2	Gypsum	Saudi Arabia
8	M3	Marble	Turkey	**24**	Ce3	Cement	Israel	**40**	Gy3	Gypsum	Egypt
9	M4	Marble	China	**25**	Ce4	Cement	France	**41**	Co1	Concrete	250 gauge
10	M5	Marble	Spain	**26**	S1	Sand	Israel/ Haifa	**42**	Co2	Concrete	300 gauge
11	C1	Ceramic	Turkey	**27**	S2	Sand	Nablus/ Jamma'en	**43**	Co3	Concrete	400 gauge
12	C2	Ceramic	China	**28**	S3	Sand	Israel/ Ashdood	**44**	BS1	Building Stone	Nablus/ Jamma'en
13	C3	Ceramic	Spain	**29**	S4	Sand	Nablus/ Badan	**45**	BS2	Building Stone	Nablus/Beit Dajan
14	C4	Ceramic	Italy	**30**	B1	Brick	Normal Brick	**46**	BS3	Building Stone	Palestine/ Beir Zeit
15	C5	Ceramic	China	**31**	B2	Brick	Wall Brick	**47**	BS4	Building Stone	Nablus/ Aseera
16	C6	Ceramic	Spain	**32**	B3	Brick	Roof Brick				

Square pieces (1cm X 1cm) of solid-state nuclear track detectors (SSNTDs) commercially known as (CR-39) manufactured in Italy, were then fixed at the inside cover of the vessels using Blu-tac paste at a distance of about (22.5 cm) from the surface area of the samples so as to count only the contribution of ^{222}Rn and to evade the role of thoron from the surface of sample (Durrani S., Ilic R, 1997; Rehman, Matiullah, 2006). In this experimental system, the distance between the sample surface and detector was about 22.5 cm, which suggests the thoron concentration around the detector decreases to less than 10%, compared with that around the sample surface (Eappean K. P. et al, 2008). Even if we assume the radon and thoron exhalation rate are the same, the effects of thoron on the detector readings can be neglected.

In order to determine the background distribution due to naturally occurring radionuclides in the environment around the detector, an empty container was installed in the same manner as the samples. After measurement and subtraction of the background, the activity concentrations were calculated.

Cans were hermitically sealed and stored in the months from November 2011 through February 2012 for about 100 days.

The detectors received variable level of radon exposure (i.e. starting from zero ^{222}Rn concentration level to equilibrium concentration level). Consequently, effective exposure time needs to be determined. The effective exposure time was calculated using the following relation (Walley El-Dine N. et al, 2001):

$$T_{eff} = t + \tau(e^{-\lambda t} - 1) \quad \text{.....(4.1)}$$

Where τ is the mean life of radon (5.5 days), t is the total exposure time and λ is ^{222}Rn decay constant. This type of correction is needed only for a closed system (Durrani S., Ilic R, 1997).

4.2.4. Collecting detectors and chemical etching:

After the mentioned period, forty seven detectors were taken out of the dosimeters. The detectors were then chemically etched in 6.25 N-solution of Sodium Hydroxide (NaOH) at a temperature of 75^0C for five hours (Nabil M. H., 2009).

The etching process was performed at chemistry Laboratories at An-Najah National University Using the setup shown in Figure 4.3 below.

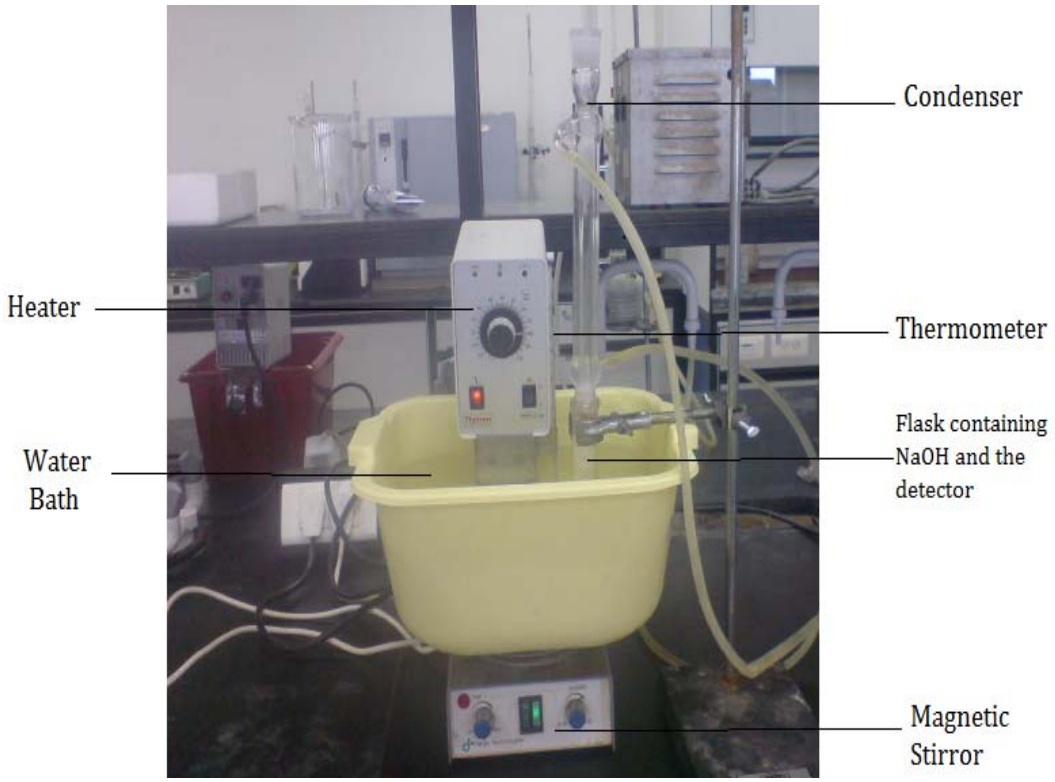

Figure 4.3: Etching process experimental set up.

During the etching process, the solution has to be stirred constantly by using the magnetic stirrer shown in the figure to avoid the accumulation of the solution. In addition, the function of the condenser is to keep the concentration of the NaOH solution constant, and the function of the thermometer is to make sure that the temperature is constant during the whole period of the etching process.

After five hours detectors were washed by running and distilled water and then dried to remove any remaining amount of the etchant from the surface of the detectors. By now alpha tracks formed on the detectors were ready for scanning and counting.

4.2.5. Detectors scanning, counting tracks and calculations:

A digital optical microscope with 400 times magnification was used to count the number of tracks per field of view; about thirteen fields of view were scanned randomly for each detector. Tracks of alpha particles emitted by radon in a CR-39 detector scanned by the microscope are shown in figure 4.4. The area of the field of view was calculated by the digital microscope and found to be equal about ($5.3x10^{-3}$ cm^2); the average number of tracks per field of view was used to count the track density per cm^2.

The calculated track density was converted into radon concentrations in Bq/m^3 using the calibration factor (k) obtained by the manufacturer, where every track per cm^2 per day on the CR-39 detectors corresponds to an exposure of 12.3 Bq/m^3 for the activity of radon gas and its daughters.

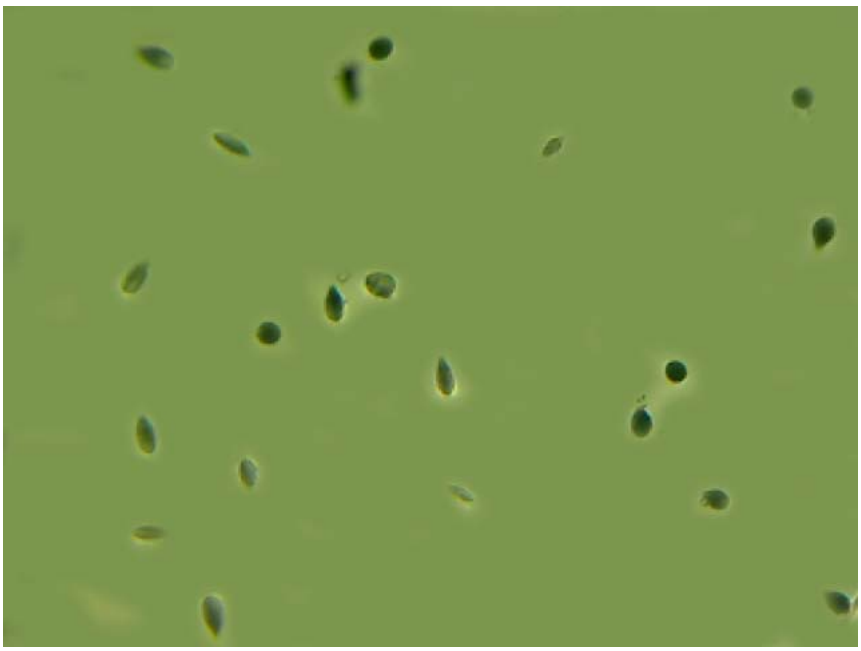

Figure 4.4: Tracks of alpha particles emitted by radon in a CR-39 detector. One viewing field from the microscope has the area of about 0.53 mm^2

From the measured average track densities (after background subtraction), the radon exhalation rate was calculated via the relation (Sroor A. et al, 2001):

$$E = \frac{\rho}{\eta A}\left[\frac{\lambda V}{Teff}\right] \quad \text{..... (4.2)}$$

where; E: is radon exhalation rate (Bq m^{-2} h^{-1})

ρ : is the track density (tracks / cm^2)

η : is the detector sensitivity (tracks cm^{-2} h^{-1} / Bq m^{-3})

λ : is the decay constant (= 7.56 x 10^{-3} h^{-1})

V: is the void volume of the container (cm^3)

A: is the area of the sample (cm^2)

T_{eff}: is the effective exposure time defined by equation 4.1 (h).

While radon concentrations were calculated using the measured average track densities according to the following relation (Baykara O., Dogru M., 2006):

$$C_{Rn}=k\frac{\rho}{Teff} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.3)$$

Where; C_{Rn}: is the radon concentration (Bq/m^3)

k : is the calibration factor (Bq m^{-3}/ tracks cm^{-2} h^{-1}

ρ : is the track density (tracks / cm^2)

T_{eff}: is the effective exposure time defined by equation 4.1 (h).

The effective radium content (in Bq/Kg) [was] found from the following relation (Baykara O. et al, 2005):

$$C_{Ra} = \frac{\rho V}{\eta M Teff} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.4)$$

Where; C_{Ra} : is the effective radium content (Bq/Kg)

M : is the mass of the sample (Kg).

And the other symbols carry the same meaning as in equation (4.2)

The annual effective dose equivalent was calculated from radon concentrations. UNSCEAR, in its 2000 report (UNSCEAR, 2000) noted the difference in radon doses and recommended a radon effective dose conversion factor of 9 nSv per (Bq h m^{-3}). Assuming 7000 hours per year indoor (an indoor occupancy factor of 80%) and an equilibrium factor of 0.4 (Chen J., 2005), using the mentioned UNSCEAR recommendation, the

effective dose for one year radon exposure is calculated using the relation (Guo Q., Cheng J, 2005):

$$Dose = \epsilon\, f_{Rn}\, T\, C_{Rn} \quad \ldots\ldots (4.5)$$

Where, f_{Rn}: is the conversion factor = 9 nSv / (Bq h m^{-3}).

T : is the time spent indoors per year = 7000 hours

ϵ: is the equilibrium factor (= 0.4)

C_{Rn}: is the radon concentration.

Substituting the previous parameters in equation 4.5 we can evaluate the annual effective dose simply according to the following relation:

$$Dose\ (mSv/y) = 0.0252 \times C_{Rn} \quad \ldots\ldots (4.6)$$

Chapter Five

Results, Discussion and conclusions

Chapter Five

Results, Discussion and conclusions

Results and discussion for radon concentrations, radon exhalation rates, the effective radium content and the annual effective dose for building material samples used in Nablus city are given in the first section of this chapter, and conclusions are made in the following section.

5.1 Results and discussion:

Equations 4.2 through 4.5, respectively, were used for calculating radon exhalation rates, radon concentrations, the effective radium content and the annual effective dose from building material samples used in this study which include marble, granite, ceramic, porcelain, concrete, cement, sand, gravel, bricks, gypsum, and building stones samples.

Radon concentration, radon exhalation rate, the effective radium content, and the annual effective dose of all samples collected from Nablus area are summarized in Tables 5.1 through 5.12. A comparing histogram for the average radon concentrations and average exhalation rates from different building material types is shown in Figure 5.1. The correlation between the effective radium content and each of radon concentration and exhalation rates from building material samples are represented in Figures 5.2 and 5.3, respectively.

Table 5.1: Radon exhalation rate, radon concentration, effective radium content and the annual effective dose from granite samples.

sample No.	sample name	E (mBq/m^2 h)	C_{Rn} (Bq/m^3)	C_{Ra} (Bq/Kg)	Dose (mSv/y)
1	G1	949.46	516.73	7.43	13.02
2	G2	429.41	235.20	3.12	5.93
3	G3	703.97	383.09	4.89	9.65
4	G4	138.92	76.62	0.84	1.93
5	G5	725.97	399.13	4.85	10.06
	Ave.	589.54	322.16	4.23	8.12
	SD	73.24	40.61	0.37	1.02

E: exhalation rate, C_{Rn}: radon concentration, C_{Ra}: radium content, Dose: annual effective dose, Ave: Average, SD: Standard deviation.

As can be noted from the data listed in table 5.1, radon exhalation rate from granite samples ranged from 138.92 mBq/m^2 h for G4 sample which is from Saudi Arabian origin (see table 4.1 for the country of origin for each sample), to 949.46 mBq/m^2 h for the American granite sample (G1) with an average value of (589.54 ± 73.24) mBq/m^2 h, and the corresponding radon concentration, effective radium content and the annual effective dose average values, respectively, were (322.16 ± 40.61) Bq/m^3, (4.23 ± 0.37) Bq/Kg, and (8.12 ± 1.02) mSv/y. In comparison with other building material samples one can see (table 5.12) that granite have the highest radon concentration of all other materials. Consequent upon this, the annual effective dose from granite samples is higher than the NCRP (National Council on Radiation Protection and Measurements) maximum value of 5 mSv/y (NCRP, 2004). Thus, it can be concluded that some

granite samples are not safe to be used as building materials which is usually used in the kitchens of Palestinian homes. This may be due to high radium content in granite samples and low level in the other samples (Morawska L., 1989; Durrani S., Ilic R., 1997). Therefore, granite can be a significant source of radon in houses, when used in tiling large enclosed areas.

Table 5.2: Radon exhalation rate, radon concentration, effective radium content and the annual effective dose from marble samples.

sample No.	sample code	E (mBq/m^2 h)	C_{Rn} (Bq/m^3)	C_{Ra} (Bq/Kg)	Dose (mSv/y)
6	M1	395.28	215.60	2.78	5.43
7	M2	277.82	151.46	2.13	3.82
8	M3	378.40	206.69	2.63	5.21
9	M4	496.09	272.62	3.60	6.87
10	M5	646.35	356.37	3.90	8.98
	Ave.	438.79	240.55	3.01	6.06
	SD	89.38	49.60	0.61	1.25

Radon exhalation rate from marble samples (table 5.2) ranged from a minimum value of 277.82 mBq/m^2 h for a local origin sample (M2) manufactured at Hebron city, to 646.35 mBq/m^2 h for the Spanish sample (M5) with an average value of (438.79 ± 89.38) mBq/m^2 h. The corresponding radon concentration, effective radium content and the annual effective dose average values for marble samples, respectively, were (240.55 ± 49.60) Bq/m^3, (3.01 ± 0.61) Bq/Kg, and (6.06 ± 1.25) mSv/y. Comparing with other building materials one can see that marble samples have the highest radon concentration after granite samples. Also the annual effective dose from marble samples is slightly higher than the NCRP

maximum value of 5 mSv/y, so it can be concluded that marble samples are not safe and that they also have a radon problem except for the Hebron marble.

However, keeping in mind that radon concentrations were measured by the closed can technique which means that the air at the whole exposure time was confined within the container, thus, with good ventilation conditions in buildings one is exposed to lower doses.

Radon exhalation rate from ceramic and porcelain samples (tables 5.3 and 5.4) ranged from a minimum value of 160.26 mBq/m^2 h for the Japanese ceramic sample (C7), and 187.31 mBq/m^2 h for Chinese porcelain (P1), to a maximum value of 707.25 mBq/m^2 h for the Spanish ceramic (C3), and 313.3 mBq/m^2 h for Italian porcelain (P4), with an average value of (347.42 ± 79.95) mBq/m^2 h and (246.14 ± 59.29) mBq/m^2 h for ceramic and porcelain respectively. The corresponding radon concentration, effective radium content and the annual effective dose average values for ceramic and porcelain samples, respectively, were (193.71 ± 45.10) and (135.86 ± 32.67) Bq/m^3, (2.59 ± 0.57) and (1.79 ± 0.44) Bq/Kg, and (4.88 ± 1.14) and (3.42 ± 0.82) mSv/y. In comparison it can be seen that ceramic samples have a slightly higher radon concentrations than porcelain and lower than both granite and marble samples. Also the corresponding average annual effective doses from both of ceramic and porcelain are lower than the NCRP maximum value except for the Spanish ceramic sample. In general it can be concluded that both of ceramic and porcelain are safe to be used as building materials.

Table 5.3: Radon exhalation rate, radon concentration, effective radium content and the annual effective dose from ceramic samples.

sample No.	sample code	E (mBq/m^2 h)	C_{Rn} (Bq/m^3)	C_{Ra} (Bq/Kg)	Dose (mSv/y)
11	C1	363.42	204.91	2.56	5.16
12	C2	330.54	183.53	2.40	4.62
13	C3	707.25	395.57	5.44	9.97
14	C4	345.75	190.66	2.65	4.80
15	C5	304.18	171.06	2.21	4.31
16	C6	220.57	121.16	1.71	3.05
17	C7	160.26	89.09	1.17	2.25
	Ave.	347.42	193.71	2.59	4.88
	SD	79.95	45.10	0.57	1.14

Table 5.4: Radon exhalation rate, radon concentration, effective radium content and the annual effective dose from porcelain samples.

sample No.	sample code	E (mBq/m^2 h)	C_{Rn} (Bq/m^3)	C_{Ra} (Bq/Kg)	Dose (mSv/y)
18	P1	187.31	103.35	1.36	2.60
19	P2	206.33	114.04	1.49	2.87
20	P3	277.63	153.24	2.03	3.86
21	P4	313.30	172.84	2.28	4.36
	Ave.	246.14	135.86	1.79	3.42
	SD	59.29	32.67	0.44	0.82

Cement as a building material is a fine-grained compound that turns into a solid when mixed with water. Cement is used to bind mixtures of materials into a composite solid. From table 5.5 one can see that the radon exhalation rate from cement samples ranged from 250.89 mBq/m^2h for the Jordanian cement (Ce2), to 497.30 mBq/m^2h for the Israeli cement (Ce3) with an average value of (363.38 ± 58.77) mBq/m^2 h. The corresponding radon concentration, effective radium content and the annual effective dose average values for cement samples, respectively, were (204.91 ± 33.45)

Bq/m^3, (2.61 ± 0.49) Bq/Kg, and (5.16 ± 0.84) mSv/y. It is obvious that cement sample have medium radon concentration between marble and ceramic. The corresponding annual effective doses from cement are lower or at the boundary of the NCRP maximum value except for the Israeli cement with a high annual effective dose value of 7.1 mSv/y, so more attention is required in choosing the type of cement that must be used in building in Nablus district.

Table 5.5: Radon exhalation rate, radon concentration, effective radium content and the annual effective dose from cement samples.

sample No.	sample code	E (mBq/m^2 h)	C_{Rn} (Bq/m^3)	C_{Ra} (Bq/Kg)	Dose (mSv/y)
22	Ce1	353.28	199.57	2.56	5.03
23	Ce2	250.89	140.76	1.81	3.55
24	Ce3	497.30	281.53	3.35	7.09
25	Ce4	352.06	197.78	2.72	4.98
	Ave.	363.38	204.91	2.61	5.16
	SD	58.77	33.45	0.49	0.84

Brick is a block, or a single unit of a material used in masonry construction, usually stacked together using various kinds of mortar to hold the bricks together and make a permanent structure. Bricks are usually made up from Silica (sand), mud (soil), gravel, water and cement to bind the mixtures together, so we will discuss the results obtained for brick, sand and gravel together. Radon exhalation rate from sand, brick, and gravel samples respectively (tables 5.6 through 5.8) have average values of (80.62 ± 21.8) mBq/m^2 h, (112.92 ± 26.58) mBq/m^2 h and (126.05 ± 31.53) mBq/m^2 h. The corresponding radon concentration average values for them, respectively, are (44.99 ± 12.15), (62.36 ± 14.77), and (69.49 ± 17.00) Bq/m^3, the annual effective dose average values are

(1.13 ± 0.31), (1.57 ± 0.37), and (1.75 ± 0.43) mSv/y, while the effective radium content average values are (0.48 ± 0.13), (0.86 ± 0.22), and (0.91 ± 0.23) Bq/Kg. From the measured values it is clear that radon concentrations and exhalation rates from brick, sand and gravel samples are very low, also the corresponding average annual effective doses from all of them are much lower than the NCRP maximum value and at the boundary of the recommended minimum value (of 1 mSv/y), so it can be concluded that each of brick, sand and gravel used in Nablus district from all origins do not pose a radiation danger when used as building materials.

Table 5.6: Radon exhalation rate, radon concentration, effective radium content and the annual effective dose from sand samples.

sample No.	sample code	E (mBq/m^2 h)	C_{Rn} (Bq/m^3)	C_{Ra} (Bq/Kg)	Dose (mSv/y)
26	S1	121.46	67.71	0.73	1.71
27	S2	38.21	21.38	0.22	0.54
28	S3	76.72	42.76	0.48	1.08
29	S4	86.08	48.11	0.49	1.21
	Ave.	80.62	44.99	0.48	1.13
	SD	21.80	12.15	0.13	0.31

Table 5.7: Radon exhalation rate, radon concentration, effective radium content and the annual effective dose from brick samples.

sample No.	sample code	E (mBq/m^2 h)	C_{Rn} (Bq/m^3)	C_{Ra} (Bq/Kg)	Dose (mSv/y)
30	B1	133.09	73.06	1.06	1.84
31	B2	116.70	64.15	0.84	1.62
32	B3	127.50	71.27	0.97	1.80
33	B4	74.37	40.98	0.56	1.03
	Ave.	112.92	62.36	0.86	1.57
	SD	26.58	14.77	0.22	0.37

Table 5.8: Radon exhalation rate, radon concentration, effective radium content and the annual effective dose from gravel samples.

sample No.	sample code	E (mBq/m^2 h)	C_{Rn} (Bq/m^3)	C_{Ra} (Bq/Kg)	Dose (mSv/y)
34	Gr1	132.89	73.06	0.92	1.84
35	Gr2	80.65	44.55	0.61	1.12
36	Gr3	214.48	117.60	1.63	2.96
37	Gr4	76.18	42.76	0.48	1.08
	Ave.	126.05	69.49	0.91	1.75
	SD	31.53	17.00	0.23	0.43

Gypsum is a soft powder used after mixing it with water as a finish for walls and ceilings or as a decorative material with different shapes and colors. Results obtained for radon concentration and exhalation rates for gypsum (table 5.9) are the lowest values compared with all other building materials with radon exhalation rate average value of (55.37 ± 15.01) mBq/m^2 h, radon concentration of about (31.48 ± 8.59) Bq/m^3 , and a corresponding effective radium content and annual effective dose average values around (0.37 ± 0.09) Bq/Kg and (0.79 ± 0.22) mSv/y, respectively. However, it is worth mentioning that the Israeli gypsum sample (Gy1) recorded the highest value of radon concentration and the samples manufactured at Saudi Arabia (Gy2) and Egypt (Gy3) recorded lower values but all values were in the low and safe limit on radon content.

Table 5.9: Radon exhalation rate, radon concentration, effective radium content and the annual effective dose from gypsum samples.

sample No.	sample code	E (mBq/m^2 h)	C_{Rn} (Bq/m^3)	C_{Ra} (Bq/Kg)	Dose (mSv/y)
38	Gy1	84.75	48.11	0.58	1.21
39	Gy2	28.30	16.04	0.20	0.40
40	Gy3	53.07	30.29	0.34	0.76
	Ave.	55.37	31.48	0.37	0.79
	SD	15.01	8.59	0.09	0.22

Concrete is a mixture of cement, sand and gravel. Cement is the glue of concrete. According to different ratios of concrete ingredients, manufacturers make different types of concrete in order to make samples with different strengths for example the 250 gauge concrete can handle a pressure of 250 Newton/mm^2. Increasing the ratio of cement and gravel makes the concrete stronger. Our results indicate that the 400 gauge concrete (Co3) recorded the highest value of radon exhalation rate of 356.59 mBq/m^2 h (table 5.10), while the 250 gauge sample (Co1) has a minimum value of 291.86 mBq/m^2 h, with an average value of (325.38 ± 32.43) mBq/m^2 h. The corresponding radon concentration, effective radium content and the annual effective dose average values for concrete samples, respectively, were (179.37 ± 16.94) Bq/m^3, (2.46 ± 0.26) Bq/Kg, and (4.52 ± 0.43) mSv/y. In comparison it can be seen that concrete samples have radon concentration value close to cement samples. This is to be expected as the main ingredient of concrete is cement. The annual effective dose from concrete is lower than the NCRP maximum value, so it can be concluded that concrete samples are safe as a building material.

Table 5.10: Radon exhalation rate, radon concentration, effective radium content and the annual effective dose from concrete samples.

sample No.	sample code	E (mBq/m^2 h)	C_{Rn} (Bq/m^3)	C_{Ra} (Bq/Kg)	Dose (mSv/y)
41	Co1	291.86	162.15	2.17	4.09
42	Co2	327.68	179.97	2.55	4.54
43	Co3	356.59	196.00	2.67	4.94
	Ave.	325.38	179.37	2.46	4.52
	SD	32.43	16.94	0.26	0.43

Building stones are stones that are used in Nablus district to cover the buildings from outside after finishing the construction which increases their durability. Stone-pits are spread all over the west bank, the most used building stones in Nablus district are from Jamma'en, Beit Dajan, Beir Zeit and Aseera regions. The building stone sample collected from Beir Zeit region (BS3) recorded the lowest radon exhalation rate with a value of 163.81 mBq/m^2h (table 5.11), while that collected from Jamma'en region (BS1) recorded the highest exhalation rate with a value of 413.13 mBq/m^2h, with a corresponding annual effective dose value of 5.70 mSv/y which slightly exceeds the NCRP maximum value. But on the average, excluding the Jamma'en sample, all other building stone samples recorded an acceptable radon exhalation rate with an average value of (268.59 ± 54.27) mBq/m^2h. Radon concentration, effective radium content and annual effective dose average values were (147.00 ± 29.90) Bq/m^3, (1.95 ± 0.37) Bq/Kg and (3.70 ± 0.75) mSv/y, respectively.

Table 5.11: Radon exhalation rate, radon concentration, effective radium content and the annual effective dose from building stones samples.

sample No.	sample code	E (mBq/m^2 h)	C_{Rn} (Bq/m^3)	C_{Ra} (Bq/Kg)	Dose (mSv/y)
44	BS1	413.13	226.29	2.91	5.70
45	BS2	305.73	167.49	2.29	4.22
46	BS3	163.81	89.09	1.27	2.25
47	BS4	191.67	105.13	1.34	2.65
	Ave.	268.59	147.00	1.95	3.70
	SD	54.27	29.90	0.37	0.75

The histogram in figure 5.1 and the data listed in table 5.12 clearly show that granite and marble are the most radon radiants followed by cement, ceramic and concrete while gypsum, sand, gravel and bricks have low radon and radium contents.

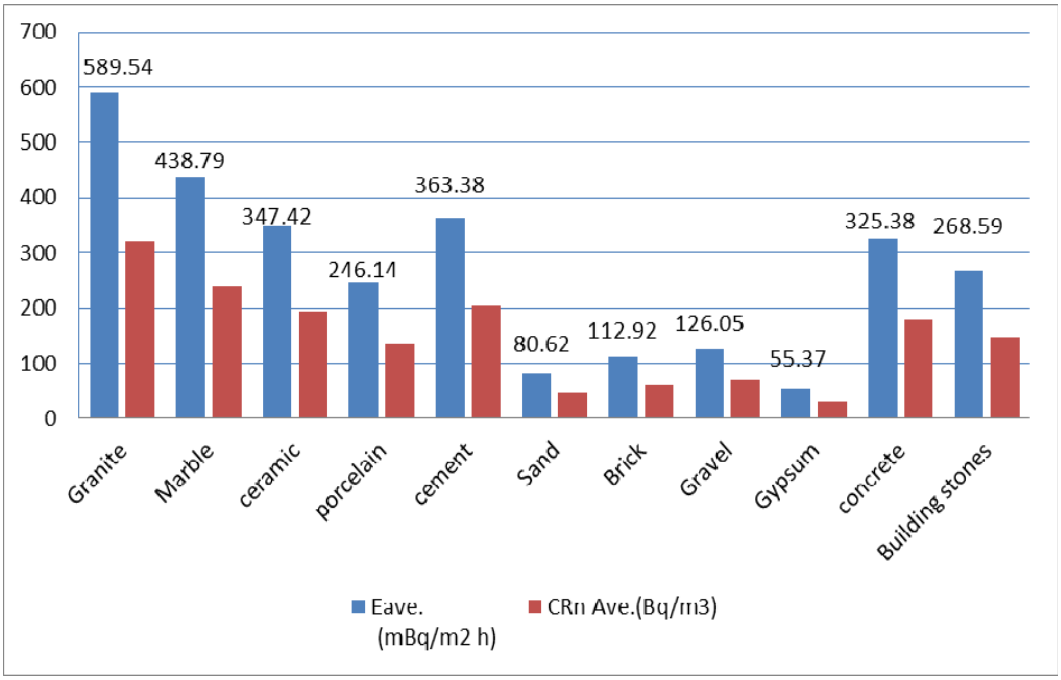

Figure 5.1: Comparing histogram for the average radon concentrations ($C_{Rn\ Ave.}$) and exhalation rates ($E_{Ave.}$) from building materials used in Nablus district.

Table 5.13 summarizes clearly the safety condition for each of the studied samples basing on the NCRP limit values. This table can be considered as a reference for the public to see which kind or origin for building materials is preferably to be used as a construction material from the health point of view.

Table 5.12: Summary of results of the average radon exhalation rate, radon concentration, effective radium content and the annual effective dose from building materials used in Nablus district.

Sample Type	$E_{ave.}$ ± SD (mBq/m^2 h)	$C_{Rn\ Ave.}$ ± SD (Bq/m^3)	$C_{Ra\ Ave,}$ ± SD (Bq/Kg)	$Dose_{Ave.}$ ± SD (mSv/y)
Granite	589.54 ± 73.24	322.16 ± 40.61	4.23 ± 0.37	8.12 ± 1.02
Marble	438.79 ± 89.38	240.55 ± 49.60	3.01 ± 0.61	6.06 ± 1.25
Ceramic	347.42 ± 79.95	193.71 ± 45.10	2.59 ± 0.57	4.88 ± 1.14
Porcelain	246.14 ± 59.29	135.86 ± 32.67	1.79 ± 0.44	3.42 ± 0.82
Cement	363.38 ± 58.77	204.91 ± 33.45	2.61 ± 0.49	5.16 ± 0.84
Sand	80.62 ± 21.80	44.99 ± 12.15	0.48 ± 0.13	1.13 ± 0.31
Brick	112.92 ± 26.58	62.36 ± 14.77	0.86 ± 0.22	1.57 ± 0.37
Gravel	126.05 ± 31.53	69.49 ± 17.00	0.91 ± 0.23	1.75 ± 0.43
Gypsum	55.37 ± 15.01	31.48 ± 8.59	0.37 ± 0.09	0.79 ± 0.22
Concrete	325.38 ± 32.43	179.37 ± 16.94	2.46 ± 0.26	4.52 ± 0.43
Building stone	268.59 ± 54.27	147.00 ± 29.90	1.95 ± 0.37	3.70 ± 0.75
Average	268.56 ± 166.21	148.35 ± 91.13	1.93 ± 1.20	3.74 ± 2.30

Figures 5.2 and 5.3 show good correlation between both radon exhalation rate and radon concentration with the effective radium content from building material samples with a correlated coefficient R^2=0.996 which means that our results give reliable data.

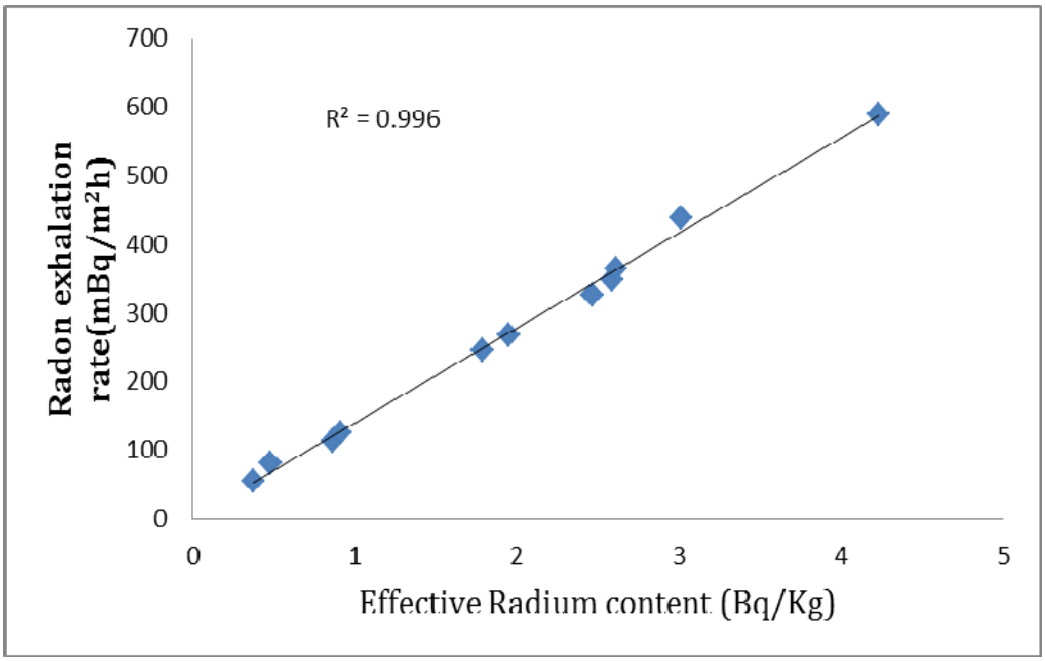

Figure 5.2: Correlation between radon exhalation rate from building material samples and the effective radium content.

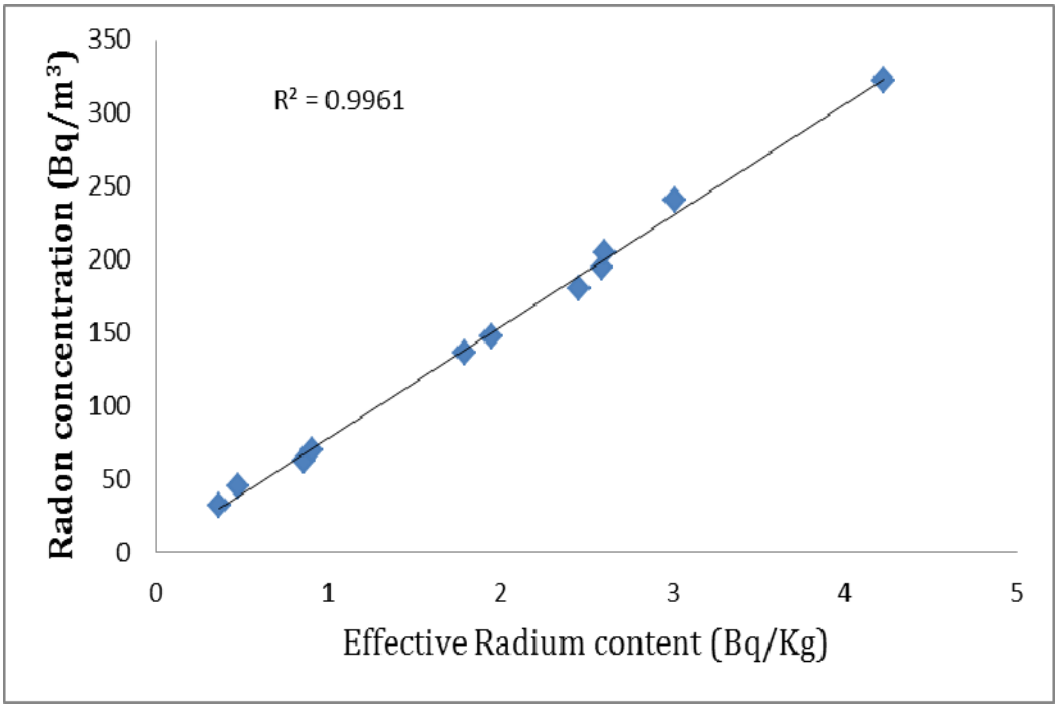

Figure 5.3: Correlation between radon concentration for building material samples and the effective radium content.

Table 5.13: Safety conditions for building material samples according to the NCRP limit values.

Sample No.	Sample code	Country of Origin/Info.	safety for use	Sample No.	Sample code	Country of Origin/Info.	safety for use	Sample No.	Sample code	safety for use	Country of Origin/Info.
1	G1	America	X	**17**	C7	Japan	√	**33**	B4	√	Insulation Brick
2	G2	China	X	**18**	P1	China	√	**34**	Gr1	√	Nablus/ Jamma'en
3	G3	Italy	X	**19**	P2	Spain	√	**35**	Gr2	√	Nablus/ Al-Kassarat
4	G4	Saudi Arabia	√	**20**	P3	China	√	**36**	Gr3	√	Nablus/ Al-Badan
5	G5	Spain	X	**21**	P4	Italy	√	**37**	Gr4	√	Hebron
6	M1	Turkey	X	**22**	Ce1	Turkey	X	**38**	Gy1	√	Israel
7	M2	Palestine/ Hebron	√	**23**	Ce2	Jordan	√	**39**	Gy2	√	Saudi Arabia
8	M3	Turkey	X	**24**	Ce3	Israel	X	**40**	Gy3	√	Egypt
9	M4	China	X	**25**	Ce4	France	√	**41**	Co1	√	250 gauge
10	M5	Spain	X	**26**	S1	Israel/ Haifa	√	**42**	Co2	√	300 gauge
11	C1	Turkey	X	**27**	S2	Nablus/ Jamma'en	√	**43**	Co3	√	400 gauge
12	C2	China	√	**28**	S3	Israel/ Ashdood	√	**44**	BS1	X	Nablus/ Jamma'en
13	C3	Spain	X	**29**	S4	Nablus/ Badan	√	**45**	BS2	√	Nablus/Beit Dajan
14	C4	Italy	√	**30**	B1	Normal Brick	√	**46**	BS3	√	Palestine/ Beir Zeit
15	C5	China	√	**31**	B2	Wall Brick	√	**47**	BS4	√	Nablus/ Aseera
16	C6	Spain	√	**32**	B3	Roof Brick	√				

Types of samples: G: granite, M: marble, C: ceramic, P: porcelain, Ce: cement, S: sand, B: brick, Gr: gravel, Gy: gypsum, Co: concrete, BS: building stone.
√: indicates that the sample is safe (Dose is smaller than 5 mSv/y), X: indicates that the sample is not safe (Dose is greater than 5 mSv/y).

A lot of data have been published regarding radon exhalation rates in open literature. The results of the current study have been compared with the already published data (Table 5.14). The radon exhalation rate from granite samples was also seen to have a maximum value in Hebron with a value of 146 mBq/m^2h, and also in Canada with a larger value than the current obtained average value with 1750 mBq/m^2h. Another study made by Al-Jaralla et al in saudi Arabia found closer radon exhalation rate value of 700 mBq/m^2h. However; while our study showed higher exhalation rate from marble than ceramic samples a study in Egypt showed that ceramic has a slightly higher rate with values of 224 mBq/m^2h and 189 mBq/m^2h for ceramic and marble, respectively. We can glimpse the convergence in the results obtained for other building materials like sand, gravel, and bricks from table 5.14.

Table 5.14: Comparison of present data of building materials' radon exhalation rate with the values reported for different countries of the world.

Building material	Country	E_{Rn} (mBq/m^{2}h)	Reference
Granite	Saudi Arabia	700	Al- Jarallah et al, 2001
	Canada	1750	Chen J. et al , 2010
	Greece	1240 ± 119	Stoulos S., 2003
	Palestine/Hebron	146	Dabayneh K.M., 2008
	Palestine/Nablus	589.54 ± 73.24	Current study
Marble	Egypt	189	Maged A. F. et al, 2005
		333 to 1250	Walley El-Dine N.,2001
	Palestine/Hebron	127	Dabayneh K.M., 2008
	Palestine/Nablus	438.79 ± 89.38	Current study
Ceramic	Egypt	224	Maged A. F. et al, 2005
	Palestine/Hebron	75	Dabayneh K.M., 2008
	Palestine/Nablus	347.42	Current study
Sand	Pakistan	366 ± 8 to 649 ± 8	Rafique M. et al , 2011
		261	Rahman et al., 2007
	Palestine/Hebron	48	Dabayneh K.M., 2008
	Palestine/Nablus	80.62 ± 21.80	Current study
Gravel	Pakistan	168 ± 17 to 322 ± 11	Rafique M. et al , 2011
	Palestine/Hebron	143	Dabayneh K.M., 2008
	Palestine/Nablus	126.05 ± 31.53	Current study
Bricks	Pakistan	184 ± 14 to 231 ± 14	Rafique M. et al , 2011
		292	Rahman et al., 2007
	India	112.4	Kumar et al., 2004
	Greece	210 ± 18	Stoulos S., 2003
	Palestine/Hebron	90	Dabayneh K.M., 2008
	Palestine/Nablus	112.92 ± 26.58	Current study

5.2 Conclusions and future work:

Using the closed can technique and the solid state nuclear track detectors (CR-39), radon exhalation rate from building material samples used in Nablus district was found with the aim to assess the contribution of individual material (e.g., granite, marble, ceramic, cement, concrete, sand, gravel, and bricks) to the total indoor radon exposure of the inhabitants of Nablus district.

The corresponding radon concentration, effective radium content and the annual effective dose were determined and compared with the effective dose limit values recommended by the National Council on Radiation Protection and Measurements (from 1 to 5 mSv/y). Results obtained from the current study show that the radon exhalation rates from granite and marble have relatively high values as compared to other building material samples followed by cement, ceramic and concrete while gypsum, sand, gravel and bricks contribute less to the indoor radon. The radon exhalation rate in the studied samples ranged from (589.54 ± 73.24) mBq/m^2h for granite samples to (55.37 ± 15.01) for gypsum samples with an average value of (268.56 ± 166.21) mBq/m^2h.

In general, the radon exhalation rate from the investigated building materials is low and under the global value except for granite, marble and some cement samples and thus except for the excluded, the studied materials are safe as construction materials.

It is possible in the future to establish a database for all materials available in the Palestinian market using the proposed simple passive method and to increase the awareness of the citizens on what kinds of building materials are more safely to be used and those that must been restricted according to this study and the forthcoming studies. Although restricting the use of certain building materials might have significant economical, environmental and social consequences at a local or national level. Such consequences, together with the existing national levels of radioactivity in building materials, should be assessed and considered when establishing binding regulations.

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جامعة النجاح الوطنية
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قياس انبعاث غاز الرادون من مواد البناء المستخدمة في محافظة نابلس، فلسطين

إعداد
فتحية "حسام الدين" يوسف شقوارة

إشراف
أ. د. غسان سفاريني
د. نضال خالد دويكات

قدمت هذه الأطروحة استكمالاً لمتطلبات درجة الماجستير في الفيزياء بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس، فلسطين
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الملخص

أصبح غاز الرادون يعتبر كواحد من أهم المخاطر التي تهدد صحة الإنسان بعد أن لوحظ أنّ التعرض لغاز الرادون يزيد على المدى الطويل من خطر الإصابة بسرطان الرئة. تهدف الدراسة إلى تقييم مساهمة مواد البناء في زيادة تعرض السكان في محافظة نابلس لغاز الرادون داخل المباني. في هذه الدراسة تم قياس معدل انبعاث الرادون من بعض مواد البناء المتعارف على استخدامها في محافظة نابلس من مصادر محلية وعالمية. وذلك باستخدام كواشف الحالة الصلبة للمسارات النووية المعروفة تجاريا باسم (CR-39) وباستخدام تقنية "الأوعية المغلقة", بعد تعرض الكواشف لغاز الرادون المنبعث من العينات لمدة 100 يوم , تم تظهيرها كيميائيا باستخدام محلول هيدروكسيد الصوديوم بتركيز (6.25 M) ودرجة حرارة 75^0C لمدة 5 ساعات ثم تم حساب متوسط عدد المسارات في وحدة المساحة باستخدام مجهر ضوئي والتي استخدمت لحساب كل من معدل انبعاث غاز الرادون وتركيزه ومحتوى الراديوم الفعال والجرعة المكافئة السنوية الناتجة عن كل من عينات مواد البناء المستخدمة.

تشير النتائج التي تم الحصول عليها من الدراسة الحالية إلى أن معدل انبعاث غاز الرادون من عينات الجرانيت والرخام ذات قيم مرتفعة نسبيا بالمقارنة مع غيرها من مواد البناء يليها – على الترتيب– كل من الاسمنت والسيراميك والخرسانة وحجر البناء، بينما وجدت مساهمة أقل لكل من عينات الجبس والرمل والحصى والطوب في تركيز غاز الرادون داخل المباني. تراوحت قيم معدلات انبعاث الرادون من العينات المستخدمة في الدراسة من

(55.37±15.01mBq/m^{2}h)لعينات الجبس الى (589.54 ± 73.24 mBq/m^{2}h) لعينات الجرانيت بمتوسط حسابي كلي يساوي (268.56±166.21mBq/m^{2}h) , والمتوسط الحسابي لكل من تركيز الرادون ومحتوى الراديوم الفعال تساوي في المتوسط (148.49 ± 91.13 Bq/m^3) و (1.93 ± 1.20 Bq/Kg) على الترتيب ، وعلى أساس هذه القيم تم أيضا تحديد الجرعة السنوية الفعالة لكل عينة ومقارنتها مع حدود الجرعة الفعالة الموصى بها من قبل المجلس الوطني للقياسات والحماية من الإشعاع (NCRP) (من 1 إلى 5 mSv/y)، بشكل عام وجد أن الجرعات المكافئة الناتجة عن عينات مواد البناء المستخدمة منخفضة إلى ما دون الحدود العليا للقيم العالمية باستثناء تلك الناتجة عن الرخام والجرانيت وبعض من عينات الاسمنت والتي أخذت القيم المتوسطة التالية على الترتيب (8.12 ± 1.02 mSv/y) و (6.06 ± 1.25 mSv/y) و(5.16 ± 0.84mSv/y) ، بناء على ذلك يمكن الاستنتاج أن العينات التي تمت دراستها آمنة للاستخدام كمواد للبناء خاصة مع وجود أنظمة تهوية جيدة داخل المباني، ولكن يجب توخي الحذر عند استخدام كل من الجرانيت والرخام والاسمنت كمواد للبناء.