

Al-Quds University  
Deanship of Graduate Studies  
Physics Master /P-hysics Department



Thesis Approval

Indoor Radon-222 Concentration Levels Measurement in Dwellings of  
Bethlehem Province, , Palestine

Prepared By : Khitam Muhammed Abed Shawawra

Registration No. : 20510224

Supervisor : Prof .Dr.Mohamd M. Abu Samreh

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The name and signatures of the examining committee members are as follows  
:

1- Head of Committee Prof. Dr. M. Abu-Samreh

Signature: .....

2- Internal Examiner Dr. Amin A. Leghrouz

Signature:.....

3- External Examiner Dr. Khaleel M. Dabayneh

Signature:..Kha.D

Jerusalem – Palestine

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## Abstract

The indoor radon concentration levels in different villages (about 11 village) in Bethlehem province have been investigated using CR-39 nuclear track detectors during Autumn and Winter seasons of the year 2007 and 2008. The study includes houses, schools, public dwellings in Bethlehem Province.

About 144 dosimeters were collected from 22 schools, 36 houses and 3 public places after a period about 6 months, then they are chemically etched in 6 molar NaOH solution at temperature of 70 °C for six hours, then the alpha tracks were counted by using optical microscope.

The radon concentration levels vary from 20 Bq/m<sup>3</sup> to 505 Bq/m<sup>3</sup> with average radon concentration 152 Bq/m<sup>3</sup>. The study had shown that radon levels in Bethlehem dwellings are within the international assigned standard levels in most 70% of the inspected areas. In almost 30% of the investigated dwellings, the radon levels exceeds the threshold assigned level (200 Bq/m<sup>3</sup>). The study showed that about 28.5% of the surveyed dwellings have radon concentration levels above 200 Bq/m<sup>3</sup>, 16.6% having radon levels between 150-200 Bq/m<sup>3</sup>, 41.7% between 100-150 Bq/m<sup>3</sup>, the rest of dwellings 13.2% have radon levels below 100 Bq/m<sup>3</sup>. Most of high levels were obtained in closed places, basements, and ground floors in

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## 1.1 Background Radiation

The term "radiation" is referred to the energy originated from a source and transmitted as particles (alpha, beta, protons and neutrons) or electromagnetic waves (EMWs) (gamma rays, light, radio waves, etc...) that can travel through material or space. Atoms and nuclides emit radiation as they attempt to decay into a more stable form either by naturally or artificially processes. Thus, sources of radiations, everywhere surrounding us, are either naturally or manmade.

Naturally occurring radiation (NOR) in the environment is known as background radiation. The main sources of natural radiation are the direct cosmic radiation that arrives at the earth's surface. This type of energy is created by energetically charged particles from outer space continuously hit the Earth's atmosphere and the secondary particles and photons they create, and the environmental (or the terrestrial) radiation that refers to radiation emitted from radioactive materials such as isotopes of uranium-238 ( $^{238}\text{U}$ ) in the Earth's rocks, soils, and minerals.

In addition to background radiation, people are exposed radiation generated by manmade (artificial) sources of radiation which include consumer products, medical sources, fallout from atmospheric atomic bomb tests, and industrial byproducts (NCRP, 1987). The medical or clinical devices include X-rays machines and ultrasound devices; while household or personal products include microwave ovens and cell phones industrial or commercial equipment such as telecommunication towers.

Fig. 1.1 is a pie chart showing the contribution size in percentage of each component of the background radiation doses received by the average Canadian (Canada: Living with radiation AECB,1995) or USA citizens (UNSCEAR, 2000)

# Sources of Background Radiation

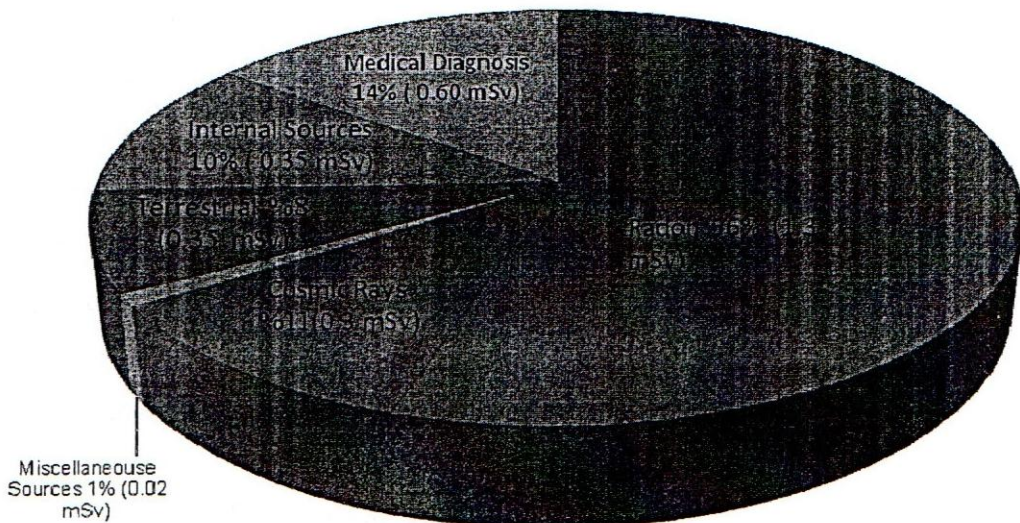


Fig. 1.1: Sources and average distribution of natural background radiation for the world population (UNSCEAR, 2000).

Radiation can be categorized into ionizing or non-ionizing, to denote the energy and danger of the radiation. On one hand, “ionizing” radiation is a term used to indicate a particle or wave with sufficient energy to ‘ionize’ a neutral atom or molecule, and leave them with either a positive or negative charge. Ionizing radiation, as part of our environment, can be short electromagnetic rays (i.e., X-rays and gamma rays) or particles (i.e., alpha and beta particles) originate from either natural (e.g. from the radioactive decay of natural radioactive substances such Uranium- 238 gas and( $^{238}\text{U}$ ) its decay products) or artificial source. On the other hand, the non-ionized radiations are particles or EMWs that have insufficient energy to ionize atoms or molecules, but they have enough energy to move or vibrate atoms. The long wave lengths electromagnetic (EM) spectra are classified as a non-ionized radiations ).

(<http://www.epa.gov/rpdweb00/sources/index.html> 20/11/2009) ..

Every day, humans come in contact with radiation in both their living and work environments and exposed to natural radiation arising from the earth as well as from outside the earth. People can be exposed externally (e.g., X-rays), or internally if a radioactive substance is inhaled or ingested or absorbed through intact skin. Natural radionuclides that can be inhaled and ingested include isotopes of uranium-238 ( $^{238}\text{U}$ )and its progeny, especially radon-222 ( $^{222}\text{Rn}$ ) and its progeny, thoron-220 ( $^{220}\text{Rn}$ ) and its progeny, potassium-40 ( $^{40}\text{K}$ ), rubidium-87 ( $^{87}\text{Rb}$ ), and carbon-14 ( $^{14}\text{C}$ ) (NCRP 1987).

Although people have little control over the amount of background radiation to which they are exposed, this exposure must be put into perspective (UNSCEAR, 2000). In this chapter, we shall discuss the concepts of radiations and radioactivity in a step of introducing radon decay modes and their effect on health.

([http://www.ornl.gov/sci/env\\_rpt/aser95/appa.htm](http://www.ornl.gov/sci/env_rpt/aser95/appa.htm)15/10/2009 )

In the following section, we shall discuss briefly radioactivity and the decay series from where radon and its progeny can be originated. Our focus will be concentrated on radon properties and address its health hazard on human bodies.

## 1.2 Radioactivity of Naturally Occurring Radioactive Materials

Radioactivity is a part of our earth- it has existed all along. The term "radioactivity" is generally referred to the spontaneous transformation of an unstable atomic nucleus to a new nucleus by the emission of a certain ionizing radiation such as alpha, beta and gamma radiations. This process is referred to as a transformation, a decay or a disintegrations of an atom. Elements that emit ionizing radiation are called radioactive; in some cases, one or more isotopes of an element are radioactive, and are called radioisotopes, or radionuclides. The naturally occurring radioactive materials include radioactive elements found in the environment. The long-lived radioactive elements of interest include uranium, thorium and any of their radioactive decay products, such as radium and radon.

The time that it takes for half the radionuclides to disintegrate or decay is called half-life. This differs for each radioelement, ranging from fractions of a second to billions of years. For example, the half-life of Iodine 131 is eight days, but for Uranium-238, which is present in varying amounts all over the world, it is 4.5 billion years. Potassium-40, the main source of radioactivity in our bodies, has a half-life of 1.42 billion year, where the half life of Radon 222 , Radon 220 and Radon 219 are 3.82 days ,55 second and 4 second respectively . The radioactive decay is expressed in units called becquerels. One becquerel equals one disintegration per second.

As a radionuclide decays, it becomes an isotope of another element. If this new isotope is also radioactive it decays further. Thus, there can develop a "decay series". The two most common naturally occurring radioactive materials decay series are the uranium-238 and the thorium-232 series. Fig. 1.2 lists the radioisotopes associated with the uranium-238 and thorium radioactive decay series, and also gives the chemical symbol for each element and

isotope. Our main interest is to explore the general properties of radon and its impact on health, and this will be discussed in a section next the following section .

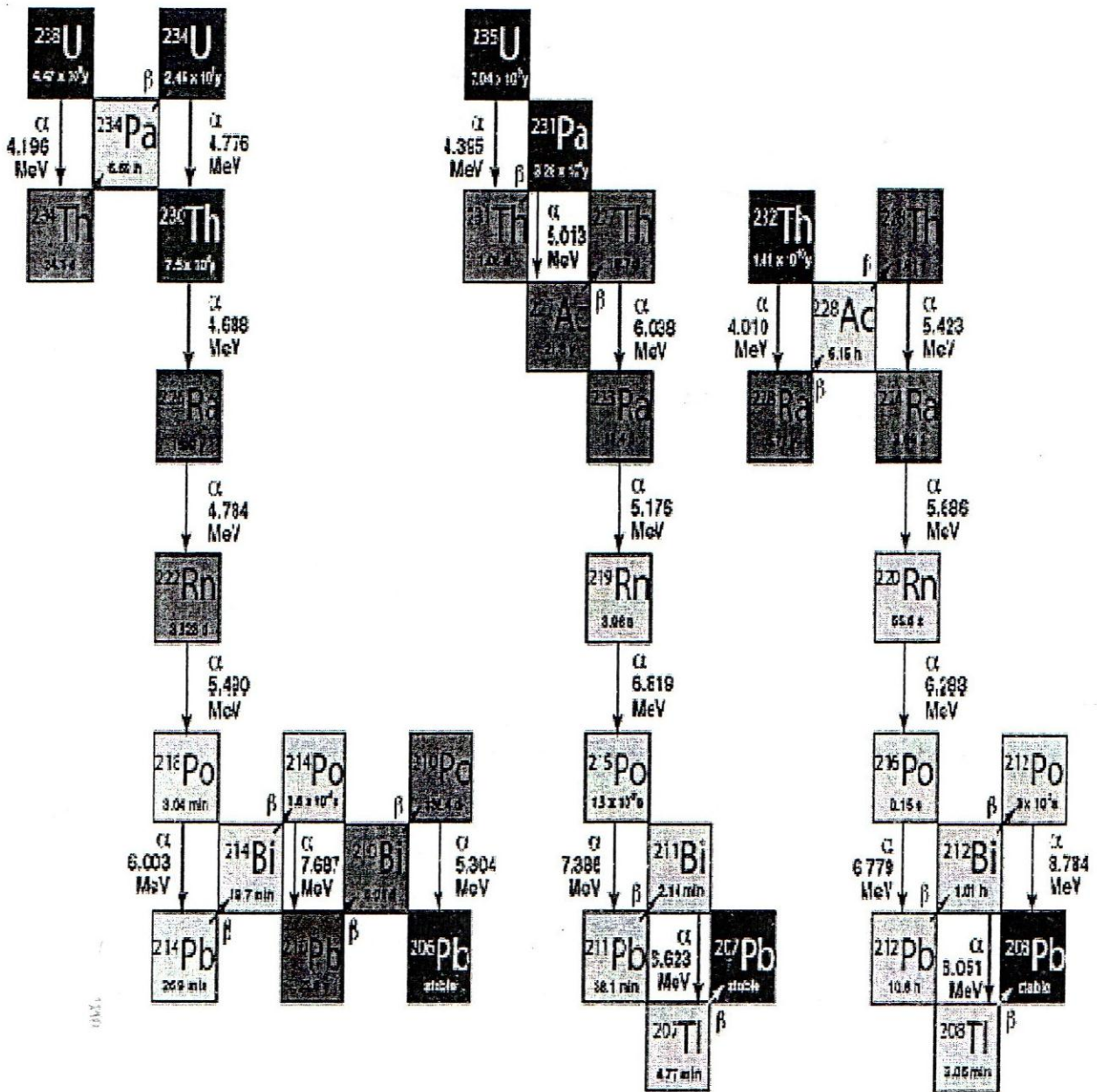


Fig. 1.2: U-238 , U-235 and Th -231 decay series

[http://www.gemoc.mq.edu.au/Participants/Research/ADosseto/decay\\_chains.gif](http://www.gemoc.mq.edu.au/Participants/Research/ADosseto/decay_chains.gif)

### 1.3 Radiation Units and Measurements

There are also several units used to quantify radiation. The Becquerel (Bq) is an activity unit which is defined as the activity of a source produced when one disintegration per second (1Bq=disin/sec) occurs from a radioactive source.

The most useful unit for health effects is the dose equivalent, which takes into account the differing abilities of the types of radiation to interact with biological systems. The absorbed dose describes the amount of energy deposited per kilogram of exposure time, measured in the gray (1Gy= 1J/kg) and in rads (1 Gy=100 rads).

An individual may receive an "internal" exposure to a radioactive substance, by inhaling radioactive gas or particles suspended in the air, or by ingesting radioactive dust. The material may remain in the body for some time after the intake, giving a dose. The life-time dose that will be received from an internal exposure is the "committed dose," also expressed in sieverts. The biological damage produced on a given organism is called the dose equivalent, measured in sieverts (Sv), the sievert (Sv) is also the unit of Effective Dose of radiation, and accounts for the total effect of different types of radiation on different parts of the body,. As Sv is a very large unit, the millisievert (mSv) as well as the microsievert ( $\mu$ Sv), are more common in usages..

The ICRP defines the effective dose as the sum of all tissue equivalent doses multiplied by the appropriate tissue weighting factors associated with each respective tissue. Most occupational doses are in the millisievert range, or  $\mu$ Sv. The World Health Organization (WHO) recommendation is to express the dose on a yearly basis, as millisieverts per year or mSv/year. The worldwide annual exposed dose limit to general public must not exceed 1 mSv ( ICRP 77, 1997; IEA, 115, 1996). The recommended radiation dose limits are shown in Table (1.1).

There is an average internal dose of about 1.0 mSv from the inhalation of radon progeny; but the dose varies greatly with the geological composition of the environment. Another source of internal radiation is from a radio-active isotope of potassium: muscle tissue contains potassium, of which 0.0118 % is potassium-40, a natural gamma and beta ray emitter which contributes about 0.35 mSv per year.

Table 1.1: Radiation dose limits

Affected Group	Annual Effective dose (mSv)	Five Years Cummulative Dose Limit (mSv)	Refrence
Occupationally Exposed Workers	20	100	Health Canada, 1993
Incidentally Exposed Workers and Members of the Public	1	5	Eckerman et.al,1996

They are classified as NORM Workers working in an occupational exposure environment, and their average annual effective dose must not exceed 20 mSv (Eckerman et.al,1996). They are considered as members of the public who work in an occupational exposure environment and, as such, the annual effective dose limit for these workers is 1 mSv.

These release limits are based on the dose arising from all the radiation exposure pathways arising from the release, and are based on a maximum annual dose limit of 0.3 mSv as recommended by ICRP (ICRP 77, 1997).

Radon concentration in air is measured by the number of transformations per second in a cubic metre of air (Bq/m<sup>3</sup>).

### 1.4 Radon Basic Properties

Amongst the uranium decay series products, radon is an important source of natural radiation, it is estimated that 50-55% (see Fig. 1.1) of the average annual dose from natural background radiation is contributed by <sup>222</sup>Rn alone ( UNSCEAR, 2000). Radon is an odourless, colourless and tasteless radioactive gas produced naturally by the decay of radium isotopes in both the uranium and thorium radioactive decay series in the earth's crust (see Fig. 1.2). It exists all over the world, although its production and, consequently, its concentration are not uniform. It is the heaviest noble gas with density ~9.9 kg/m<sup>3</sup> which is about ten times heavier than of the air (Forkapic et al., 2006), and it has the highest boiling point 211.3 Kelvin, melting point 202 Kelvin and critical temperature of all noble gases 377 Kelvin (<http://www.webelements.com/radon/30/9/2010>)

highest boiling point 211.3 Kelvin, melting point 202 Kelvin and critical temperature of all noble gases 377 Kelvin (<http://www.webelements.com/radon/30/9/2010>)

Radon is a noble gas and has three natural isotopes  $^{219}\text{Rn}$ ,  $^{220}\text{Rn}$ , and  $^{222}\text{Rn}$ , which occur in the  $^{235}\text{U}$ ,  $^{232}\text{Th}$  and  $^{238}\text{U}$  series respectively. Because of the low activity of  $^{235}\text{U}$  (0.07%) and the short half life of  $^{219}\text{Rn}$  ( $t_{1/2} = 3.96$  s), this isotope is not significant for human exposure.  $^{220}\text{Rn}$  also has a short half life ( $t_{1/2} = 55$  s), therefore this isotope is not significant for human exposure except where the concentration of  $^{232}\text{Th}$  is high. Obviously,  $^{222}\text{Rn}$  isotope ( $t_{1/2} = 3.824$  days) is the most significant contributor of human exposure to natural sources (UNSCEAR 1993).

Because radon is a gas, it can easily move through small spaces in soils and other materials, allowing it to enter the air we breathe, both outdoors and inside buildings. In the outdoors, radon mixes with large volumes of fresh air and is diluted to low concentrations. Being a rare gas, it usually migrates freely through faults and fragmented soils, and may accumulate in caves or water. However, if radon enters an enclosed or poorly ventilated space in a building, it can accumulate to levels that can pose a risk to health. Its concentration varies greatly with season and atmospheric conditions (Health Canada, 2008).

#### **1.4.1 Radon Guidelines**

Radon released from soil beneath a building gives rise to an average indoor background concentration of about  $50 \text{ Bq/m}^3$ , but much higher values are possible in some areas. Radon concentration varies wildly from place to place. In the open air, it ranges from 1 to  $100 \text{ Bq/m}^3$ , even less ( $0.1 \text{ Bq/m}^3$ ) above the ocean. In caves or aerated mines, or ill-aerated houses, its concentration climbs to  $20\text{--}2,000 \text{ Bq/m}^3$ . Radon concentration can be much higher in mining contexts. Outdoor radon levels are usually very low. The average outdoor radon level varies between 5 and  $15 \text{ Bq/m}^3$  (Sperrin et al., 2001).

Your risk of lung cancer increases substantially with exposure to higher radon levels. Lung cancer risk rises 16% per 2.7 pCi/L increase in radon exposure. (World Health Organization, 2009) Studies show that radon is the primary cause of lung cancer among people who have never smoked. However, the absolute numbers of radon-induced lung cancers are much larger in people who smoke, or who have smoked in the past, due to a strong combined effect of smoking and radon.

The World Health Organization organized several conferences and symposiums to discuss the radon health hazards and some radon concentration levels have been adopted

(ICRP, 2007; WHO, 2007; WHO, 2009). (ICRP) has suggested an action level for  $^{222}\text{Rn}$  gas between 200 and 400  $\text{Bq m}^{-3}$  and has proposed a conversion of 5 mSv/WLM for risk assessment from workplace exposure to radon progeny (ICRP, 1993; ICRP,1994; Gonzalez, 1993). Action levels for  $^{222}\text{Rn}$  that vary from 150 to 600  $\text{Bq m}^{-3}$  have been recommended by IAEA (EPA, 1988), ICRP), and USA intervention radon action levels(EPA, 1988). The  $^{222}\text{Rn}$  level of 150  $\text{Bq m}^{-3}$  has been adopted in USA and some European countries as a reference to radon action levels for the general public before recommendation of mitigation takes place (ICRP, 1993; ICRP,1994; Gonzalez, 1993).

The recommended indoor action level for the general public is ranged between 200 and 600  $\text{Bq/m}^3$  (ICRP, 1994). The radon level of 150  $\text{Bq/m}^3$  has been adopted in USA as a reference point to  $^{222}\text{Rn}$  concentrations level before mitigation takes place. The current Canadian guideline for radon in indoor air for dwellings is 200  $\text{Bq/m}^3$ . This was recently reduced from 800  $\text{Bq/m}^3$ (Canadian Guidelines, 1997).

In 2007, Health Canada announced a revised guideline for indoor radon levels The new guideline, is 200  $\text{Bq/m}^3$ , lowered from the previous guideline of 800  $\text{Bq/m}^3$ . The United States Environmental Protection Agency encourages that action be taken at concentrations as low as 74  $\text{Bq/m}^3$  (2 pCi/L) (EPA, 1992) and the European Union recommends action be taken when concentrations reach 400  $\text{Bq/m}^3$  (11 pCi/L) for old houses and 200  $\text{Bq/m}^3$  (5 pCi/L) for new ones (UNSCEAR, 2000). According to ICRP the radon concentration levels from 50  $\text{Bq/m}^3$  to 150  $\text{Bq/m}^3$  are acceptable values ( ICRP,2000). On 8 July 2010 the UK's Health Protection Agency issued new advice setting a "Target Level" of 100  $\text{Bq m}^{-3}$  whilst retaining an "Action Level" of 200  $\text{Bq m}^{-3}$ . In 2009, the World Health Organization set a new recommended radon reference level of 2.7 pCi/L (100  $\text{Bq m}^{-3}$ ) for residential structures. Most countries have adopted an indoor radon concentration of 200–400  $\text{Bq/m}^3$  as a reference level above which mitigation measures should be taken.

In the UNSCEAR 2000 Report, the worldwide average annual effective dose from ionizing radiation from natural sources is estimated to be 2.4 mSv/y, of which about 1.3mSv/y is due to radon exposure (UNSCEAR ,2000).

#### **1.4.2 The Health Effects of Radon**

In the open air, the amount of radon gas is very small and does not pose a health risk. However, in some confined spaces like basements and underground mines, radon can accumulate to relatively high levels and become a health hazard. Exposure to high levels of

- Place Elevation: low radon levels are found in high floors; while underground and ground floors in general have higher radon levels.
- Painting: Some high values are obtained in places having well painted and well ventilations, so that the high value is explained on the basis of raw material used and to the soil structure.
- Cracks: Some high values are attributed to the cracks in walls and the unfinished rooms and places.
- Soil structure: Soil around dwellings sometimes plays a major role in the radon levels especially when the soil is rich with radioactive materials as uranium.

The factors discussed in this study are in agreement with the factors discussed in other studies performed in Hebron (Dabayneh, 2007).

### **5.3 Conclusion and Recommendations**

The study had shown that radon levels in Bethlehem dwellings are within the international assigned standard levels in most 70% of the inspected areas. In almost 30% of the investigated dwellings, the radon levels exceeds the threshold assigned level (200 Bq/m<sup>3</sup>) Based on the obtained results, the following recommendations are addressed to the inhabitants and to the law makers in the investigated sectors.

#### **5.3.1 Immediate Recommended Actions**

Remedial measures should be undertaken in a dwelling whenever the average annual radon concentration exceeds 200 Bq/m<sup>3</sup> in the normal occupancy area. The higher the radon concentration, the sooner remedial measures should be undertaken. This might include improve ventilations or any other action necessary.

#### **5.3.2 Long-Term Recommended Actions**

##### **5.3.2.1 General Recommendations**

The following recommendation might be a matter of interest for homeowners as well as law makers to keep radon levels as low we can to ensure safe homes to live in.

For dwellings owners where a relatively high levels are reported, they should improve ventilations of their houses (dwellings) and try to finish constructing their places.

Inhabitants should avoid closed doors and windows for a long time in order not to allow radon concentration to be higher than the international levels. This is because radon entered dwelling will stay as long as the dwelling is closed.

The cracks in the underground floors and walls should be fixed and walls should be painted. As these cracks allow radon gas to diffuse into the place and trapped in closed places under bad ventilations conditions.

The construction raw materials should be tested against radon materials. Many studies showed a relation between some building materials and radon levels like some kinds of granite (Dabayneh ,2008), so such type of materials should be avoided.

For Places below the ground, a radioactive test should made to test the presence of radioactive materials.

For public places such as schools, hospitals, and universities, places of high radon levels should be re-examined and mitigation measures should be implemented.

Radon safety should be considered when new houses are built, particularly in high radon areas. The construction of new dwellings should employ techniques that will minimize radon entry and will facilitate post-construction radon removal. In Europe and the United States of America, the inclusion of protective measures in new buildings has become a routine measure. In some countries it has become a mandatory procedure. Passive systems of mitigation have been shown to be capable of reducing indoor radon levels by up to 50%. Accordingly, for law makers, a new law to force people to examine their places before building construction and to ensure radon safety should be extracted from Palestinian Legitimate Council and should be implemented by local authorities.

### **5.3.2.2 General tips to reduce indoor radon pollution in your home**

Because there is some risk at any level, homeowners may want to reduce their exposure to radon, regardless of levels tested. Some of the steps you can take to reduce radon levels in your home include (<http://www.hc-sc.gc.ca/ewh-semt/air/in/poll/out-ext/index-eng.php>) :

Increase the mechanical ventilation to keep air pollutants at low levels, via a heat recovery ventilator (HRV), to allow an exchange of air.

Improve the ventilation of the house by installing a positive pressurization or ventilation system. Ensure adequate ventilation, especially in rooms with excess water vapor-like bathrooms

Seal floors and walls. Seal all cracks and openings in foundation walls and floors, and around pipes and drains. Ensure leaks and cracks in walls, floors, roofs and basements are fixed.

- 1- Paint basement floors and foundation walls with two coats of paint and a sealant.
- 2- Avoid the passage of radon from the basement into living rooms. Ventilate the basement sub-flooring by installing a small pump to draw the radon from below the concrete slab to the outside before it can enter your home.
- 3- Renovate existing basement floors, particularly earth floors.
- 4- Don't permit smoking in your home.
- 5- Immediately clean any mould found growing in your home.
- 6- Keep your home clean: dust and vacuum regularly.
- 7- Do not store paints, solvents or varnishes inside your home.

### 5.3.3 Concluding Remark

While no level of radon gas is completely safe, as with most things in life we must balance the benefits and costs to find our own "acceptable" levels. We walk outside and work in the sun, exposing ourselves to ultraviolet radiation and increasing our risk of developing skin cancer. We drive in automobiles almost every day even though greater than 1 in 86 deaths is a result of automobile accidents. People smoke, eat poorly, and engage in dangerous behaviors on a daily basis. To some degree, radon gas is another daily risk that we all must take. However, you choose what you eat, whether or not you smoke, and how and when you drive. You have no choice but to breathe the air in your home. A simple and inexpensive radon test can give you the information you need to make an informed decision about what level of radon gas exposure is acceptable to you in your home.

### 5.4 Further Studies

In Palestine, a few investigation had been performed in some parts in and still other sectors do not investigated. Accordingly, this study can be extended to include other places and locations in this province and other places in the West Bank. Thus,

- The study areas in Bethlehem cover only (20% ) of the province so further studies will helpful to have a full picture of the radon levels in the province is recommended.
- It has been shown in some studies that the risk for having lung cancer is higher for children than that for adults (Kullab ,1997), hence more studies on radon levels in schools and kindergartens, hospitals, and universities are of great importance.

- Most studies in Palestine interested in indoor air radon concentration, so this study might be extended to include outdoor radon concentration levels and radon levels in water resources, soil, and construction materials.
- Radon map of Palestine. Other studies in other areas and province will be helpful in exploring radon levels in Palestine .

## الملخص

ختام محمد عبد شواورة

قياس مستويات تركيز غاز الرادون في بنايات مأهولة في محافظة بيت لحم

تناولت هذه الدراسة دراسة تركيز غاز الرادون في 11 قرية مبعثرة في محافظة بيت لحم خلال فصلي الخريف والشتاء من عام 2007 باستخدام كواشف الحالة الصلبة للمسارات النووية (SSNTDs) والمعروف تجاريا باسم (CR-39). لقد تم جمع 180 كاشفا معظمها من بلدتي العبيدية والشواورة، وبعد انقضاء فترة التعرض وهي 6 اشهر، تم جمع الكواشف فقط من 36 منزلا ، 22 مدرسة، وتمت معالجتها في جامعة القدس من خلال وضعها داخل محلول هيدروكسيد الصوديوم الذي تركيزه 6 مولار و على درجة حرارة 70 درجة مئوية حيث تم اظهار المسارات الناتجة من سقوط جسيمات ألفا المنبعثة من غاز الرادون على مادة الكاشف ثم عدت هذه المسارات باستخدام مجهر ضوئي بتكبير 10 X للحصول على تراكيز غاز الرادون .

تراوحت تراكيز غاز الرادون في المحافظة ما بين 20 بيكرل ام<sup>3</sup> و 505 بيكرل ام<sup>3</sup> و بمعدل 152 بيكرل ام<sup>3</sup>. اظهرت الدراسة ان معدل تركيز غاز الرادون في معظم الأماكن التي تمت دراستها ضمن المستويات المقبولة ( أقل من 200 بيكرل ام<sup>3</sup> ) حيث أن 28.5% من النتائج تزيد عن 200 بيكرل/م<sup>3</sup>، 16.6% من النتائج ما بين 150-200 بيكرل/م<sup>3</sup>، 41.7% من النتائج ما بين 100-150 بيكرل/م<sup>3</sup>، و فقط 13.2% من النتائج أقل من 100 بيكرل /م<sup>3</sup>. ومعظم القراءات العالية التي تم الحصول عليها لتراكيز غاز الرادون تتعلق بالاماكن المغلقة، والطوابق الأرضية. ووجد أن هناك علاقة بين تركيز غاز الرادون ونسبة التهوية لان معظم مستويات التركيز المرتفعة والتي زادت عن 200 بيكرل ام<sup>3</sup> كانت في اماكن مغلقة وذات معدلات تهوية منخفضة . كما بينت الدراسة إن تركيز غاز الرادون في الطوابق المنخفضة (الأرضية و تحت الأرضية ) أعلى منها في الطوابق العلوية .