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Faculty of Graduate Studies

Indoor Exposure Assessment and Health Hazard of Radon in the Elementary Schools of Tulkarem Province, Palestine

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Dedication

To

My sweet family members:

My parents (Bassam & Aysha), brothers (Yousef, Mohammad, Omar, Hassan and Hossam), brothers' wives (Doaa, Hanan and Alaa) and my daughters

(Eila & Zeinah).

And especially to my soul mate…….. my wife

(Aminah)

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الإقــرار

انا الموقع ادناه مقدم الرسالة التي تحمل عنوان:

Indoor Exposure Assessment and Health Hazard of Radon in the Elementary Schools of Tulkarem Province, Palestine

تقييم التعرض والأثر الصحي لغاز الرادون في الهواء المغلق في المدارس الأساسية في محافظة طولكرم، فلسطين

أقر بأن ما اشتملت عليه هذه الرسالة إنما هو نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد، وأن 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:**
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List of Abbreviations

ARPD: Average Relative Percent Difference

Bq/m^3: Becquerel per cubic meter

CI: Confidence Interval

EPA: Environment Protection Agency

IARC: International Agency for Research on Cancer

ICRP: International Commission on Radiological Protection

IRB: Institutional Review Board

LEAR: Lifetime Excess Absolute Risk

MeV: Million electron Volts

MoE: Ministry of Education

mSv/y: MilliSievert per year

NaOH: Sodium Hydroxide

pCi/L: PicoCuries per Liter

SD: Standard Deviation

SE: Standard Error

SSNTDs: Solid-State Nuclear Track Detectors

UNRWA: United Nation Relief and Work Agency

UNSCEAR: United Nations Scientific Committee on the Effects of Atomic Radiation

U.S EPA: United States Environmental Protection Agency

WHO: World Health Organization

WL: Working Level

WLM: working Level per Month

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Indoor Exposure Assessment and Health Hazard of Radon in the Elementary Schools of Tulkarem Province, Palestine

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Abstract

Many public health agencies rank residential radon exposure as the second leading cause of lung cancer after cigarette smoking. Furthermore, it has been shown that the risk coefficient for lung cancer is higher for children than that for adults. Therefore, there is a special interest in radon measurement in kindergartens and elementary schools in different countries. This study aims to investigate the indoor radon levels in the elementary schools of Tulkarem province for the first time. As well as to set a baseline data for Tulkarem schools which would be of great help for "school's radon survey in the West Bank" in the near future. This study also aims to investigate the different parameters that may influence the indoor radon concentrations by different radon measurements methods such as active and passive methods.

Two hundred and thirty Solid-State Nuclear Track Detectors (SSNTDs) type CR-39 were distributed in the classrooms of twenty elementary schools located in Tulkarem province using stratified random sampling method of public, private and United Nations schools. About thirty of them were used for quality assurance purpose (10% duplicate detectors and 5% blank detectors). The CR-39 detectors were exposed in

the schools for three months during the school summer holiday from May 2012 to August 2012 and then collected and etched in Sodium Hydroxide (NaOH) 6.25 N solution at 75 °C for 6 h. The tracks were counted manually at the digital microscope. In parallel, twenty active measurements performed by RAD7 monitor (Durridge Company) were carried out in the same twenty classrooms for quality assurance and correlation analysis between the two types of measurements (passive and active).

The indoor radon levels results were generally low, ranging from 3.48 to 210.51 Bq/m^3 (Becquerel per cubic meter), with a mean radon concentration (mean±SE; standard error) of 40.42± 2.49 Bq/m^3. The average annual radon effective dose was assessed to be (mean±SE) 0.17 ± 0.01 mSv/y (milliSievert per year) while the excess lifetime lung cancer risk was approximately 0.09%. The research also focused on parameters affecting radon concentrations such as geographic location, the age of the building, school authority in relating to the building style and building material, and floor number of the classrooms. The study findings, as expected, showed that radon concentrations in ground floors were higher than in upper floors. The old-age school buildings showed significantly higher radon concentrations than new ones. The two measurements (CR-39 and RAD7) showed a highly significant correlation with (R^2) = 0.97.

Our results were below the action level provided by the United States Environmental Protection Agency of 148 Bq/m^3 which indicates no radiological health hazard. However, the relatively high concentrations in

some classrooms can be reduced by increasing the natural ventilation or classrooms supply with suction fans. The results obtained indicate that the indoor radon concentration was significantly affected by the floor level of the classroom and the school building age.

Chapter One

Introduction

1.1 Background

Radon has long been recognized as a cause of lung cancer, and in 1988, the International Agency for Research on Cancer (IARC) and the World Health Organization (WHO) (ICRP, 2010; WHO, 2009) classified radon as a human lung carcinogen. This classification was based on a review of evidence from experimental data on animals and from epidemiological studies of underground miners exposed to relatively high radon and radon progeny concentrations. Furthermore, indoor radon has been identified as an important public-health problem, estimated by the United States Environmental Protection Agency (U.S EPA) to cause about 21,000 American lung-cancer deaths per year (EPA, 2012). Moreover, numerous public health agencies rank residential radon exposure as the second leading cause of lung cancer after cigarette smoking (EPA, 2012; WHO, 2009).

On the other hand, it is well known that mankind exposure to radioactivity comes mainly from natural sources, being radon and its progeny breathed in the air responsible for more than 50% of the annual dose received from natural radiation (UNSCEAR, 2000). Radon (^{222}Rn) is a noble radioactive gas generated by disintegration of radium (^{226}Ra) which is present in soil, water and building materials (Appleton, 2007). The indoor radon level is strongly influenced not only by the radium in the underlying soil (or walls), but also by the life style and building use, that is to say by the natural or mechanical exchange of indoor air with outdoor air (Nazaroff and Nero, 1988).

Exposures to radon and its short-lived decay products at concentrations typically found indoors, deliver a dose to the sensitive cells of the lung corresponding to a dose of 1.3 milliSievert per year (mSv/y) out of the total effective dose (2.4 mSv/y) (UNSCEAR, 2000). However, due to the enhanced children sensitivity, The ICRP estimates that for groups of younger, the risk coefficient for lung cancer from inhaled radon daughters is about a factor of two (age $<$ 20 years) to four (age $<$ 10 years) higher than that for adults. (Malanca et al., 1998).

In Tulkarem province and in most of West Bank schools, information on concentration of radon is almost unavailable. There is therefore a need to study radon in Tulkarem province schools with the aim of measuring and documenting the actual level of concentration of radon in order to estimate the risk of radon exposure that the hosts of these schools might face. Dependently, the control measures can be taken to reduce the risk if necessary by simple mitigation ways. This study will provide preliminary data about indoor radon levels in Tulkarem province elementary schools for the first time as a baseline study for a wider future national survey in the whole West Bank schools.

1.2 Study justification and problem statement

Radon is a contaminant of indoor environments, including homes and schools. The elementary schools host young children who are considered as a very susceptible and vulnerable group compared to other age groups. It has been shown that the risk coefficient for lung cancer is higher for children than that for adults (Ismail, 2006). On the other hand, for most school's children and staff, the second largest contributor to their radon exposure is likely to be their school (as average time spent for a student is usually not less than 6 hours/day) after their homes (EPA, 1993). Moreover, most of the data related lung cancer to radiation exposure during childhood because children have small lung volumes and high breathing rates. Therefore, they are more sensitive to ionizing radiation than older ages (Abel-Ghany, 2008). Meanwhile, this study will estimate the indoor radon levels in the elementary schools of Tulkarem province area that is located in the central part of Palestine and in the extreme northwest of the West Bank, and nearly 15km east of the Mediterranean Sea. This area has the second highest prevalence rate of lung cancer compared with other districts in the West Bank (Diab, 2003). One of the hallmarks of epidemiological analyses is that health problems in a population can be better understood if the spatial frequency and distribution of the health problems are compared to spatial variations of the cause(s) of the health problems (George, 2009). Therefore, indoor radon evaluation in this area could further add to the explanations for this high cancer rate in this region.

It has been recognized that an increase in radon concentration of 100 Becquerel's per cubic meter (Bq/m^3) is associated with approximately a 16% increased chance of contracting lung cancer (Darby et Al., 2005). It's therefore, necessary to evaluate radon levels inside the elementary schools in general and in Tulkarem province in specific. Results of this study will be used to estimate the effective dose for the pupils and teachers from radon and it will provide an important database and information about the estimation of radiation hazard from indoor radon in Tulkarem province area.

1.3 Goal of the study

The goal of this study is to get a better understanding of indoor radon levels so that we can better inform and help protect the Palestinians from the risks of long term radon exposure.

1.4 Aim of the study

This study aims to carry out a survey of radon concentration in some selected elementary schools in Tulkarem province. This survey will help in:

1- Assess the safety of these buildings.

2- Take action to reduce the indoor radon levels in the schools (if necessary).

3- The measured level of radon can be considered in future studies as well as in constructing of schools in future.

On the basis of these results, a radon levels comparison can be sought with other parts of the West Bank and Gaza strip to draw a national contour map of radon concentration, in different regions.

1.5 Study objectives

1.5.1 General objective

To study if there is a radiological environmental hazard inside the selected elementary schools in Tulkarem province that could be associated with an increase in indoor radon exposure compared with the international workplace permissible exposure limits.

1.5.2 Specific objectives

1. To measure the average indoor radon concentration levels inside the selected elementary schools in Tulkarem province during a three-month period in the summer season.

2. To estimate the annual effective dose for the pupils and the teachers from the indoor radon exposure.

3. To compare the average indoor radon concentrations at different geographical sites in Tulkarem province.

4. To compare the average indoor radon concentrations between different floor levels inside the selected schools.

5. To compare the average indoor radon concentrations between new school buildings and old schools buildings.

6. To compare the average indoor radon concentrations between United Nation Relief and Work Agency (UNRWA) schools and governmental schools.

7. To estimate the lifetime excess lung cancer risk for the teachers from radon exposure.

8. To compare the average indoor radon concentration from active short term method (continuous radon monitor type RAD 7) and from passive long term method (radon dosimeter type CR-39).

1.6 Thesis overview

This thesis consists of six chapters. Chapter 2, "Conceptual framework", highlights different definitions and aspects of radon. Chapter 3 "Literature review", reviews the relevant literature. It includes a description of previous indoor radon studies that carried out in schools at the international and national levels. Also, provides a review of the International average and action levels of indoor radon concentration in the schools. Chapter 4, "Materials and methods", describes the study setting, population and sample. Also it describes the data collection and analysis. This includes the technical description of data collection methods and instruments used as well as the calculation of radon concentration, effective dose and lifetime risk.

Chapter 5, “Results”, presents the study results. While chapter 6, “Discussion”, evaluates our study findings and results. It also gathers information from all the results and presents future insights for further work and research. Finally, the study documents with other different annexes at the end of this thesis provide summaries related to this work which were essential parts of it including permissions to conduct the study.

1.7 Summary

While the harmful effects of indoor radon are generally accepted, information on indoor radon in the elementary schools of Tulkarem province is not readily available. There is therefore a need to study these schools with the aim of measuring and documenting the actual level of concentration of radon in schools in order to estimate the actual risk of radon exposure that the student and the staffs may face.

Chapter Two

Conceptual framework

2.1 Definition of radon

Radon is a naturally occurring colorless, odorless, tasteless radioactive gas that is formed from the normal radioactive decay of uranium. Uranium is present in small amounts in most rocks and soil. It slowly breaks down to other products such as radium, which breaks down to radon. Some of the radon moves to the soil surface and enters the air, while some remains below the soil surface and enters the groundwater (Bodansky et al., 1989). Uranium has been around since the earth was formed and has a very long half-life (4.5 billion years), which is the period of time it takes for one half of the initial quantity of radioactive atoms to radioactively decay (Niren, 1994).

Uranium, radium, and thus radon, will continue to exist indefinitely at about the same levels as they do now. Radon also undergoes radioactive decay. When radon decays, it divides into two parts (Papastefanou, 2008); one part is called radiation, and the second part is called a daughter. The daughter, like radon, is not stable; and it also divides into radiation and another daughter. Unlike radon, the daughters are metal and easily attach to dust and other particles in the air. The decay of daughters continuous until a stable, nonradioactive daughter is formed. The decay chain of radon involves the release of five energetic particles which are; three alpha particles (with energies of 5.49, 6.0 and 7.69 million electron volts) (MeV) and two beta particles with endpoints ranging from (0.69 to 3.26 MeV) (Hasan, 1996). Alpha particles are solids and can travel only a short distance. It cannot go through our skin but it can be breathed and deposited in the lung tissue. The energy deposition in lungs is extremely localized and may increase the risk of lung cancer (UNSCEAR, 2000).

2.2 Physical and chemical properties of radon

Radon is a mobile, chemically inert radioactive element, has a high melting point of -71^{o}C and a boiling point of -62.7^{o}C. Its atomic number of 86 makes it a noble element and therefore both non-reactive chemically and atomically mobile at normal temperatures, so it has greater ability to migrate freely through soil, air, etc. (Durrani and Ilic, 1997).

Radon has three important isotopes. These 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 action) belongs to, ^{235}U decay series. The decay chains for both ^{222}Rn and ^{220}Rn are given in figure 2.1. Scientifically, radon is known to be ^{222}Rn, the most abundant isotope of the element radon (Nazaroff and Nero, 1988; Hasan, 1996). In the literature, the term radon is often referred to ^{222}Rn. This term has been adopted in the present work. ^{219}Rn has a relatively low abundance in the earth's crust, i.e. only about 0.7%, and has the shortest half life of ~ 4 seconds. Because of its very short half-life, ^{219}Rn usually disappears soon after its production. ^{220}Rn is also not able to travel far (i.e. decays before reaching the earth's surface due to its-short half-life of 55.5 seconds), and can often be eliminated from the monitoring system by introducing filters or other delaying techniques. Therefore, the most important isotope of radon is

^{222}Rn. Its half-life is 3.82 days and can move substantial distances from its point of origin (Durrani and Ilic, 1997). That is why only ^{222}Rn is generally considered as a health hazard when estimating risk factors from exposure to radon.

2.3 Radon and its daughters

Radon is a noble gas with a lifetime relatively longer than the breathing time. And when breathed into the lung, it is mostly breathed out again except for a small amount which may be transferred to the blood or decay. The hazard from radon arises from the fact that, when radon decays in the air, its daughters are solids, and when they are inhaled they are deposited on the interior surfaces of the lung (Papastefanou, 2008).

Radon daughters, or radon decay products, or radon progeny are: Polonium 218 (^{218}Po, $t_{1/2}$=3.05 min; $t_{1/2}$: is the half life), Lead 214 (^{214}Pb, $t_{1/2}$=26.8 min.), Bismuth (^{214}Bi, $t_{1/2}$=19.7 min) and Polonium 214 (^{214}Po, $t_{1/2}=1.6\times10^{-4}$ s), as shown in figure 2.1 (Al-Mosa, 2007). Two of these, ^{218}Po and ^{214}Po, emit alpha particles which are the main source of radiation damage when they decay in the lung (Papastefanou, 2008).

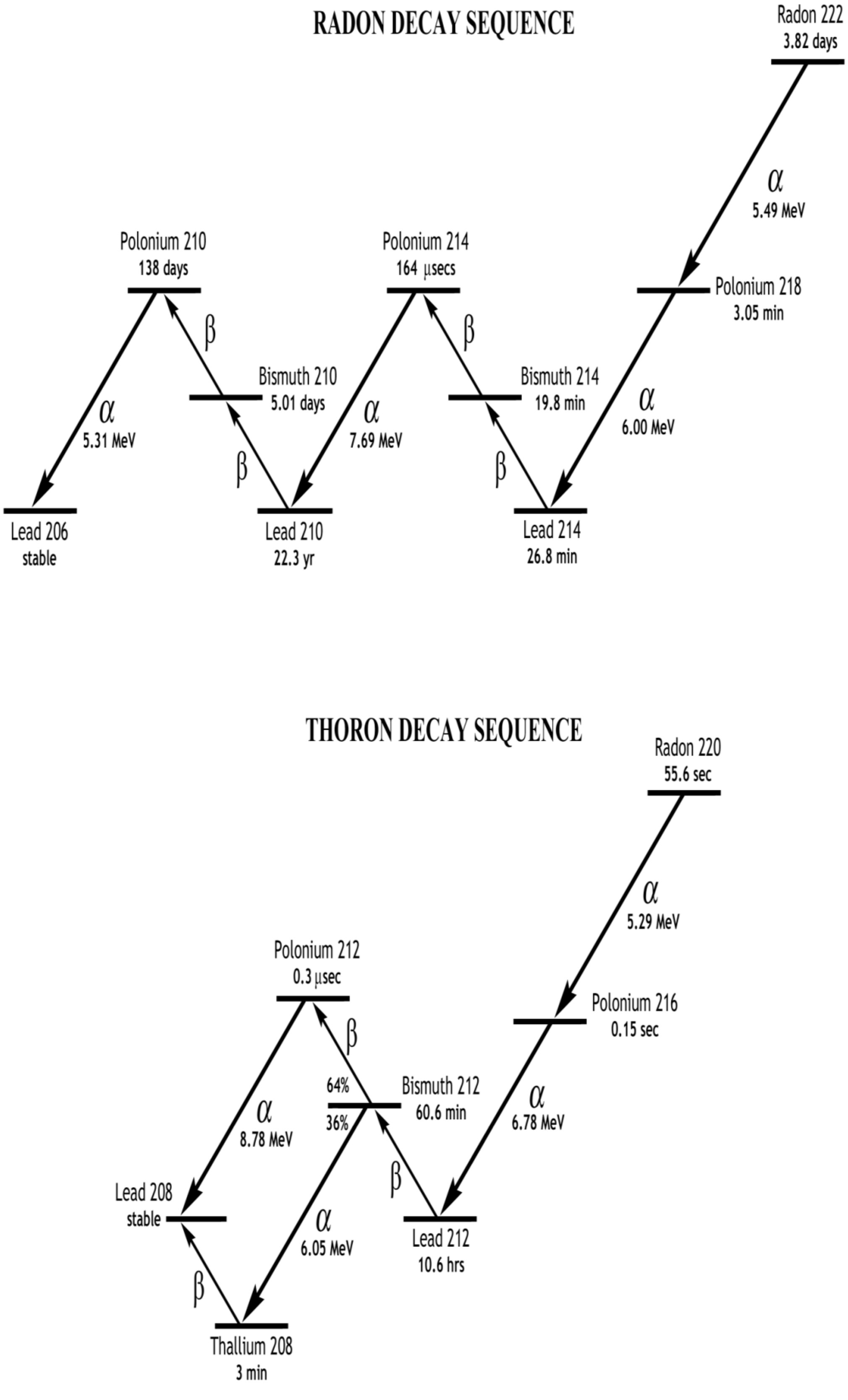

Figure (2.1): Radon-222, Radon-220 decay charts (Durridge Co., 2012).

2.4 Indoor radon sources

The primary sources of indoor radon are the soil adjacent to the building which contain amount of radium that is fixed in the soil grains. Buildings in general tend to have a slightly lower indoor air pressure compared to that in the ground. This is normally sufficient to draw soil gas from the ground into the building (Abd El-Zaher and Fahmi, 2008).

Radon gas can enter a building by many mechanisms but the most significant are diffusion and pressure driven flow from the ground beneath and immediately adjacent to the building, provided suitable entry routes are available. Entry routes for radon gas are usually cracks and holes in floors and walls, and gaps around service pipes and cables (Bodansky et al., 1989). In most dwellings with elevated indoor radon concentrations pressure-driven flow is recognized as the dominant mechanism of ingress (Ahmed and Haji, 2012).

Radon from domestic water and gas supplies and from building materials can contribute to the indoor radon concentration in a building, but in most cases the contribution is considered minor when compared with that from the soil gasses in the ground on which the building is constructed (George, 2009).

Building materials generally contribute fairly little to the total indoor radon concentration, except when the radium content in it is above the normal values. All building materials are derived from soil and rocks that contain trace amount of radioactive nuclides occurring in the earth's crust.

Many of the buildings materials such as bricks or concrete are sufficiently porous and emanate radon that enters into the indoor air. Materials which are not derived from the earth's crust, such as wood, tend to have a very low radium concentration (Al-Mosa, 2007).

Radon might enter into buildings via the water supply. With municipal water or surface reservoirs, most of the radon volatilizes to air or decays before the water reaches buildings, leaving only a small amount from decay of uranium and radium. Dissolved radon is easily released into the air when the water is used for showering, cleaning, and other everyday purposes in homes (Mehra1 et al., 2010).

The most important factors controlling radon migration and accumulation in buildings include 1) the transmission characteristics of the bedrock, including porosity and permeability; 2) the nature of the carrier fluids, including carbon dioxide gas, surface water, and groundwater; 3) weather; 4) soil characteristics, including permeability; 5) house construction characteristics, and 6) life style of house occupants (Appleton, 2007).

2.5 Radon and health risk

In many countries exposure to indoor radon gas represents the largest proportion of the radiation dose received by the general public (UNSCEAR, 2000). As mentioned before, Radon (^{222}Rn) decays to form very small solid radioactive particles, including (^{218}Po, ^{214}Po), that become attached to natural aerosol and dust particles. These may remain suspended in the air or settle on the surfaces. When these particles are inhaled, they irradiate the bronchial epithelial cells of the lung with alpha particles, and this may increase the risk of developing lung cancer. Apart from lung cancer, there is no epidemiological proof of radon causing any other type of cancer (Appleton, 2007). So, living in an elevated level of radon concentration for a long period of time means that the probability of inducing lung cancer increases (Abumurad and Al-Omari, 2008).

There is direct evidence from human studies of a link between exposure to radon and lung cancer. For this reason radon has been classified by the International Agency for Research on Cancer, a part of the WHO, as a Group 1 carcinogen. This places radon in the same group of carcinogens as asbestos and tobacco smoke as a cause of lung cancer (WHO, 2009). Radon is much more likely to cause lung cancer in people who smoke, or who have smoked in the past, than in lifelong non-smokers. However, it is the primary cause of lung cancer among people who have never smoked. The proportion of all lung cancers linked to radon is estimated to lie between 3% and 14%, depending on the average radon concentration in the country and on the method of calculation (ICRP, 2010; WHO, 2009; EPA, 1993).

Not everyone who breathes radon decay products will develop lung cancer. An individual's risk of getting lung cancer from radon depends mostly on three factors (Al-Mosa, 2007):

1- The level of radon.

2- The duration of exposure.

3- The individuals smoking habits.

The report of the International Commission on Radiological Protection (ICRP) publication 115 used the lifetime excess absolute risk (LEAR) to estimate the lifetime risk, which is associated to a chronic exposure scenario, expressed in number of death 10^{-4} per working level per month (WLM) (ICRP, 2010). The calculation of LEAR will be discussed in chapter four.

2.6 Radon concentration units

The concentration of radon in the air is measured in units of picocuries per liter (pCi/L) or Becquerel's per cubic meter (Bq/m^3). One Bq is corresponds to one decay per second. One pCi/L is equivalent to 37 Bq/m^3. The concentration of radon daughters is measured in units of working level (WL) which is a measure of the potential alpha particles energy per liter of air (Niren, 1994). Occupational exposure to radon daughters is expressed in working level months (WLM) and a working level month is equivalent to the exposure at an average concentration of 1 WL for 170 working hours (Wilkening, 1990). Measurement data are reported in either of the above units.

The Environment Protection Agency (EPA) recommends reducing the concentration of radon in the air within a school building to below EPA's radon action level of 4 pCi/L that is equivalent to 0.016 WL and 148 Bq /m^3 (EPA, 1993; Al-Mosa, 2007).

2.7 Radon measurement devices

The environmental radon concentration is a function of time and climatic conditions. To monitor radon, both active and passive techniques have been developed. Active methods are usually used for short-term measurements of radon. Passive methods are more suitable for the assessment of radon exposure over long time scales and can be used for large-scale surveys at a low cost. The terms active and passive are also used to designate radiation detectors which operate with and without power supply, respectively.

Table 2.1 contains the most popular radon measuring devices used by countries surveyed within the WHO International Radon Project (WHO, 2009).

Table (2.1): Radon gas measurement devices and their characteristics (WHO, 2009).

Detector Type (Abbreviation)	Passive/ Active	Typical Uncertainty* [%]	Typical Sampling Period	Cost
Alpha-track Detector (ATD)	Passive	10 - 25	1-12 months	Low
Activated Charcoal Detector (ACD)	Passive	10 - 30	2 - 7 days	Low
Electret Ion Chamber (EIC)	Passive	8 - 15	5 days - 1 year	Medium
Electronic Integrating Device (EID)	Active	~ 25	2 days - year(s)	Medium
Continuous Radon Monitor (CRM)	Active	~ 10	1 hour - year(s)	High

***Uncertainty expressed for optimal exposure durations and for exposures ~ 200 Bq/m^3.**

SSNTDs are low-cost, small-sized devices which are used for large-scale studies in which radon concentration in dwellings and workplaces as well as schools can very easily be measured (UNSCEAR, 2000).

2.7.1 Solid State Nuclear Track Detectors (SSNTDs)

The most widely used method for long radon monitoring periods is based on materials known as SSNTDs or etched-track detectors. The technique is simple to use and relatively inexpensive. Several detector materials have been developed. Operation of the SSNTDs is based on the fact that a heavy charged particle will cause extensive ionization of the material when it passes through a medium (Law et al., 2008). An alpha particle ionizes almost all molecules close to its path. This primary ionizing process triggers a series of new chemical processes that result in the creation of free chemical radicals and other chemical species which then created by etching process. This damaged zone is called a latent track (Nikezic and Yu, 2004).

The most popular member of the SSNTDs family is commercially known CR-39. It is made of polyallyl diglycol carbonate (PADC) with the chemical formula $C_{12}H_{18}O_7$ (also known as Tastrak) which was synthesized in 1978 (Al-Mosa, 2007). The working principle of this technique will be dealt with in chapter four.

2.7.2 Continuous Radon Monitor (CRM)

There are several types of continuous radon monitors in the market. Nearly all of these are designed to detect alpha radiation. Three types of alpha particle detectors are presently used in electronic radon monitors (Bodansky et al., 1989):

1. Scintillation cells or "Lucas cells"

2. Ion chambers

3. Solid state alpha detectors.

The Durridge RAD7 (figure 2.2) is one type of continuous radon monitors which uses a solid state alpha detector. The detector converts alpha radiation directly to an electric signal and has the possibility of determining electronically the energy of each particle, which allows the identification of the isotopes (^{218}Po, ^{214}Po) produced by radiation, so it is possible to instantaneously distinguish between old and new radon, radon from thoron, and signal from noise (Forkapić et al,2006).

With a continuous monitor, there is an ability to observe the variation of radon level during the period of the measurement. This can sometimes show big swings in radon concentration and may allow inferring the presence of processes influencing the level. For good data, it is important that there be sufficient counts to provide statistically precise readings (Durridge Co., 2012).

Figure (2.2): The Durridge RAD7 electronic continuous radon monitor with a HP printer mounted for immediate printing of results (Durridge Co., 2012).

2.8 Summary

This Chapter describes ^{222}Rn and its decay products found indoor including schools. Radon is an alpha emitter and can decay to its daughter after or before inhalation. After being inhaled ^{222}Rn decays to its four radionuclide daughters having half lives of less than 30 minutes, which causes ill health effects in the body. Radon decay product before being inhaled is removed from air not only by radioactive decay but also by ventilation, which is driven by airflow caused by pressure differences. There will be an increase in lung cancer in people who breathe in air with large concentrations of radon for a long period of time. The fractions of unattached radon daughters are considered to be an important parameter used to estimate the dose rate to human respiratory organs through inhalation of radon daughters. To monitor radon, both active (continuous radon monitors) and passive (SSNTDs) techniques have been developed.

Chapter Three

Literature Review

3.1 International average indoor radon concentration

The problem of health risks from radon in dwellings and workplaces has been of serious concern to international organizations and commissions such as ICRP, WHO, United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and other. The ICRP (1993) recommends that all the countries of the world should carryout radon survey to find radon prone areas (Nasir and Shah, 2012).

There is a large variability in indoor radon concentration levels between different countries, even between areas of the same country, because of differences in the geology of the subsoil, in the climatic parameters and in the building characteristics (Papaefthymiou, 2003). Also, Radon exposure patterns in large buildings such as schools, commercial buildings and multiunit residential structures may differ from exposure in detached houses due to differences in building structure, occupancy and heating, ventilation and air conditioning operation (WHO, 2009).

Radon concentrations in outdoor air are generally low (4-8 Bq/m^3), whereas radon in indoor air ranges from less that 20 Bq/m^3, to about 110000 Bq/m^3 with a population weighted world average of 39 Bq/m^3 (UNSCEAR, 2000; WHO, 2009). Country averages range from 9 Bq/m^3 in Egypt, 20 Bq/m^3 in the UK, 46 Bq/m^3 in the US, 108 Bq/m^3 in Sweden, and 140 Bq/m^3 in the Czech Republic (Appleton, 2007).

3.2 Comparison between various countries in the regulations and action levels of radon

The European Union (EU) accepts the recommended action levels included in the ICRP publication 65 which are between 500 and 1500 Bq/m^3 (Espinosa et al., 2009). The USA uses a reference level of 148 Bq/m^3 for dwellings and schools and a level of 400 Bq/m^3 for other workplaces (EPA, 1993). In the UK the Health and Safety Executive (HSE), has adopted a radon action level of 400 Bq/m^3 for workplaces. While the action level for workplaces in Hungary is 1000 Bq/m^3 (Espinosa G et al., 2009).

Israel uses a mandatory reference level of 150 Bq/m^3 for existing schools (Richter et al., 1997). There are no specific regulations or safe limit value in Palestine relating to indoor radon levels in either homes or workplaces. So that, in this thesis the reference level of EPA and Israel of 148 Bq/m^3 have been adapted.

3.3 Worldwide radon studies in the schools

Fifty-nine schools were surveyed in New York State in USA. Thirty-four of the schools were found to have one or more rooms with long-term radon levels exceeding EPA guidelines of 148 Bq/m^3 (Condon et al., 1995). Another large survey was occurred in Slovenia; 730 kindergartens with 65000 children and 890 schools with 280000 pupils, radon concentration was measured with alpha scintillation cells. In 46 kindergartens and 77 schools the national radon limit for dwellings of 400 Bq/m^3 was exceeded (Vaupotič , 2010).

One hundred and eight measurements of indoor radon concentrations were performed in 49 kindergartens and play-schools located in 26 towns of the Italian province of Parma. The method used was that involving Solid-State Nuclear Track Detectors (SSNTDs). The indoor radon levels resulted to be generally low, ranging from 10-108 Bq/m^3, with a mean±standard deviation (SD) activity concentration of 30±19 Bq/m^3. The mean annual radon effective dose equivalent was assessed to be 0.5mSv (Malanca et al., 1998). Also, Indoor radon concentrations were measured in 77 schools of the prefecture of Xanthi in northern Greece. The arithmetic mean radon concentration was 231 Bq/m^3 with a range between 45 and 958 Bq/m^3 (Clouvas et al., 2009).

While in Nigeria, about seventy CR-39 detectors were distributed in 35 schools of the Oke-Ogun area. The overall mean±standard deviation of radon concentration in the surveyed area was 45±27 Bq/m^3 (Obed et al., 2011).

3.4 Middle East radon studies in the schools

Indoor radon measurements were carried out in 30 elementary schools in Tunis, the capital city of Tunisia, during the winter months of December 2008 to early March 2009. Two classrooms, one each from ground floor and first floor were chosen from each school making a total of

60 classrooms. Nuclear track detectors types LR-115 (Kodalpha film type LR-115 is a nuclear track film produced by Kodak Company) were used for the measurements. The results show that the radon concentration levels are low in the range of 6–169 Bq/m^3 with a mean value of 26.9 Bq/m^3 (Labidi et al., 2010).

In another study in Egypt, one hundred CR-39 radon detectors were distributed in 10 classrooms in 5 levels chosen randomly in elementary school in Cairo. Where the mean±standard deviation of radon concentrations were found to be 57.6 ± 3.33, 48.5±3.10, 34.5 ± 1.71, 29.7 ± 1.33 and 25.3 ± 1.88 Bq/m^3 for first, second, third, fourth and fifth floors with good ventilation, respectively; and 78 ± 3.23, 66.9 ± 2.84, 40.3 ± 1.70, 34.4 ± 1.42 and 28.8 ± 1.75 Bq/m^3 for classes with poor ventilation respectively (Abel-Ghany, 2008).

Also, indoor radon measurements were carried out during summer season inside different kindergartens in three main regions (Erbil, Duhok and Sullimaniye) in Iraqi Kurdistan. The mean±standard deviation of radon concentration was 96.815±26.94 Bq/m^3 (Ismail, 2006).

In Jordan, a neighboring country to Palestine, a study was performed to measure the indoor radon concentration levels for 74 kindergartens in Amman. Using CR-39 detectors, they found that the radon concentrations inside the classrooms of these schools range from 40.7 to 193.5 Bq/m ^{3} with an average of 76.8 Bq/m^3. They also found that the average value was twice that of Amman's dwellings (mostly residential houses) (Kullab et al., 1997).

3.5 General radon studies in Palestine

In 1996, the first study of radon in Palestine had been conducted to measure indoor radon concentrations at the campus of Hebron University. Fifty- four radon detectors were mounted in the four university buildings. The average radon concentration in the four buildings was found to be 29.8 Bq/m^3 with an average effective dose equivalent of 1.49 mSv/y (Hasan, 1996). Another indoor radon measurement in Southern part of West Bank, at Yatta city in Hebron district, was conducted during the summer season of year 2000. The overall mean±standard deviation of radon concentrations in the monitored zones were found to be 111 ± 63 Bq/m^3 and the average effective doses in dwellings of Yatta city is estimated to be 5.6 mSv/y (Abu-Samreh, 2005). While in Dura city, the radon concentration levels were found to vary from 21.9 to 134.0 Bq/m^3, with annual effective dose equivalent from 0.38 to 2.30 mSv/y (Dabayneh and Awawdeh, 2007).

Also, a study reported the seasonal variations of indoor radon levels in dwellings located in the Ramallah province and East Jerusalem suburbs, the study found that the radon concentration levels in summer varied from 43 to 192 Bq/m^3 for buildings in the Ramallah province and from 30 to 655 Bq/m^3 for East Jerusalem suburbs. In winter, the radon concentration levels are found to vary from 38 to 375 Bq/m^3 in the Ramallah buildings and from

35 to 984 Bq/m^3 in East Jerusalem suburbs. (Ismail and Abu-Samreh, 2008).

Indoor radon level was monitored also throughout Gaza Strip. Five hundred CR-39 dosimeters were distributed over six locations in the middle region of Gaza Strip. The results suggested that Radon concentrations ranged from 13 to 84 Bq/m^3 and the average Radon concentrations was 38 Bq/m^3 with standard deviation of 11.23 (Rasas et al., 2005).

In Nablus city, however, the total average of indoor radon concentration in the homes in the old city was found to be 98.8 Bq/m^3 (Daragmeh, 2001). Another study of indoor radon was made in four hospitals and two health centers in Nablus city also. It showed that the averages of indoor radon were within the global mean of 39 Bq/m^3 except for AL- Ethad and AL- Enjeli hospitals were higher than the global mean (Dwaikat, 2001).

Recently, two studies performed in Nablus city one of them studied radon in drinking water supplies and the other studied radon in building materials. The first study had revealed that radon concentration in wells and spring was below the U.S.EPA maximum contaminated level, except for Badan well (Al Zabadi et al., 2012).

The second study showed that the radon exhalation rate from building material that are usually used in Palestine was low and under the global value except for granite, marble and some cement samples

(Shoqwara, 2012). However, building materials were also studied in previous work. The maximum radon concentration was found in granite (Dabayneh, 2008). Furthermore, the radon exhalation rate in granite samples used in Palestinian buildings were recently measured and ranged between 3.9 and 30.6 $Bqm^{-1}day^{-1}$ (Dabayneh, 2013).

3.6 Radon studies in the Palestinian schools

In Palestine, just a few schools tested for radon mainly a study performed in four governmental girls' schools in Tarqumia town that is located in the North Western part of Hebron city. The radon dosimeters type TASTRAK (CR-39) had been stayed for 70 days between february 2006 and April 2006. The results showed that the radon concentration were varied from 12 to 232.5 Bq/m^3 with an average of 34.1 Bq/m^3 and the annual effective dose were varied from 0.62 to 12.0 mSv/y with an average of 1.76 mSv/y, respectively (Dabayneh, 2006).

In Jerusalem, ambient radon levels exceeding 10,000 Bq/m^3 has been detected and measured in a basement shelter workroom of a multilevel public elementary school. The measurements were taken after diagnosis of certain cancers (breast and multiple myeloma) in two workers who spent their workdays in basement rooms (Richter et al., 1997).

3.7 Summary

Several countries have conducted national programs of indoor radon concentration measurements in schools. This chapter summarized some previous studies of indoor radon that carried out in different schools at international and national level. It focused also on the regulations and the action levels of indoor radon.

Chapter Four

Methodology

4.1 Introduction

Two different methods to measure the indoor radon concentration in the elementary schools in Tulkarem province had been used. The first measurement technique was by means of integrative passive radon sampling while the second method was by means of continuous active radon sampling. The first method is considered passive, and requires no electrical power as in the case of the continuous radon monitor. The passive integrative radon detector used in this work, uses technique that give the average radon concentration during the measurement period. The second device is a continuous radon monitor, which can be used to make multiple readings over a given period.

The choice of these techniques was based on the time over which an instrument can be devoted to measurements at a single location, the kind of the information required and the desired accuracy with which measurements can be related to an estimate of the risk. The two techniques differ considerably and were used to complete different tasks in measuring the factors that affect radon concentrations and to get reliable data.

The passive SSNTD is constructed in such a way that a thin piece of plastic or film is mounted on the inside of the chamber (plastic cup). The chamber allows for radon to diffuse into the detector via a filtered covered opening. The purpose of the filter is to keep dust and radon decay products out.

4.2 Study area and characteristics

Tulkarem province is located in the central part of Palestine and in the extreme northwest of the West Bank, and nearly 15km east of the Mediterranean Sea with an area of 246 km^2 (PCBS, 2011). It is bounded by Jenin and Nablus province in the north, east and south and by the 1948 cease-fire line in the west as shown in figure 4.1. The district of Tulkarem lies between 40 to 500 m above sea level and is entirely within a fertile zone (ARI, 1995). The population density in the Tulkarem district is about 682 person/km^2. The population of the Tulkarem province is estimated to be 168,973 people in the middle of 2011 (PCBS, 2011) including the two refugee camps (Tulkarem and Nur Shams), representing about 7% of the total West Bank population.

The climate of Tulkarem province is subtropical, with rainfall limited to the winter. The average temperature in the winter ranges from 8 to 16 °C, while the average temperature in the summer ranges from 17 to 30 °C. The average temperature is 27 °C in August, while February's average temperature doesn’t fall below 13.5 °C. Humidity is moderate in summer, estimated about 40-70%, though it rises in winter to be between 70-85%.Tulkarem receives in excess of 550 millimeters of rain yearly, which is a dispersed and intermittent characteristic of the Mediterranean Basin (HWE, 2008).

The district is mainly covered by sedimentary carbonate rocks such as limestone, dolomite, marl and chalk (HWE, 2008).

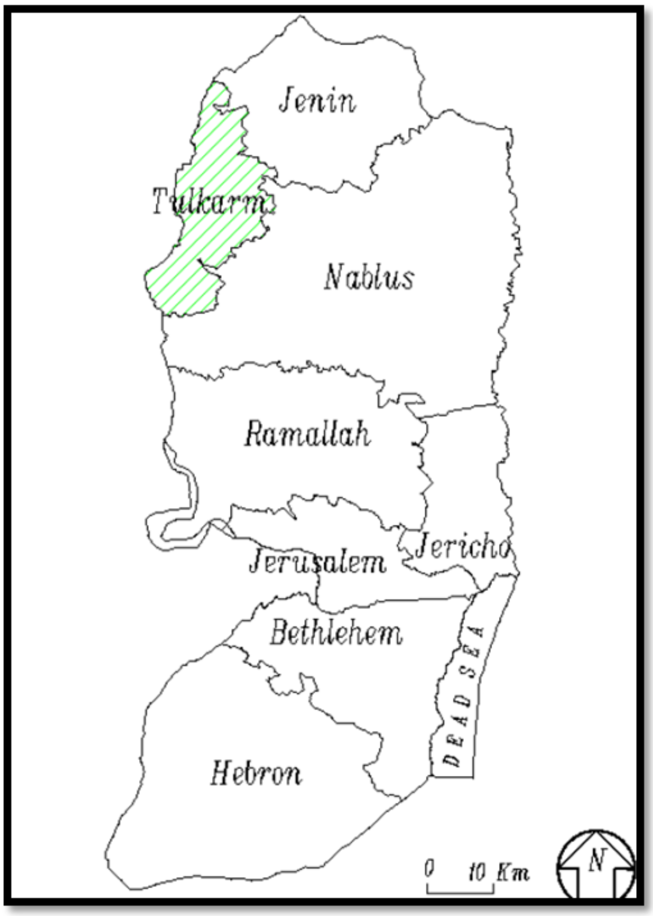

Figure (4.1): Tulkarem province location map

4.3 Study targets

The study targets were the host of the Palestinian elementary schools that located in Tulkarem province area. According to the Palestinian Central Bureau of Statistics (PCBS, 2011), there are 88 elementary schools in Tulkarem: 75 governmental schools host 35045 pupils, 6 UNRWA schools host 3850 pupils and 7 Private schools host 685 pupils . Overall, the schools host 39580 children whose age ranged from 6-16 years and about 1940 teachers, where they stay for at least six hours/day and five days a week. Table 4.1 below shows the Tulkarem elementary schools and table 4.2 shows the students of these schools (both tables by location and supervising authority).

Table (4.1): Number of elementary schools in Tulkarem province by location and supervising authority (PCBS, 2011).

Location	Government	UNRWA	Private	Total
Tulkarem city	19	0	2	21
Villages	56	0	5	61
Refugee camps	0	6	0	6
Total	75	6	7	88

Table (4.2): Number of students in the elementary schools in Tulkarem province by location and supervising authority (PCBS, 2011).

Location	Government	UNRWA	Private	Total
Tulkarem city	7422	0	305	7727
Villages	27623	0	380	28003
Refugee camps	0	3850	0	3850
Total	35045	3850	685	39580

4.4 Sample size and settings

The study was conducted at elementary schools in Tulkarem province area which consists of Tulkarem city, two refugee camps and about 42 villages distributed around the city (PCBS, 2011). A stratified random sampling technique was used to select a sample from the all 88 elementary schools in Tulkarem province. The directorate of Education in Tulkarem province classification and distribution of schools was used in the selection process as they are the most accurate. We have selected for the study 20 schools from all the elementary schools of Tulkarem province (n=88). This was done as follows; (A) schools were stratified by location into three subgroups (city schools, village’s schools and refugee’s camps schools), (B) depending on the number of schools in each stratum and by authority, a proportional random samples were taken from each stratum. The proportional sampling was nearly one school to be selected per 5-7 schools. However, because the UNRWA schools are little and have a special building characterization and international standards design differed from both the governmental and private schools, all of these schools were selected (n=6). In order to compare the radon concentration between UNRWA and government schools. While physical characteristics of a building (ventilation, painting and building materials) can play an important role in the radon levels throughout the building. The study selected schools stratified by authorities, locations are shown in table 4.3. Annex (G) contains a map of the selected schools in Tulkarem province.

Table (4.3): The study selected schools stratified by authorities, locations.

Location	Government schools	UNRWA schools	Private	Total
Tulkarem city	3	0	1	4
Villages	10	0	0	10
Refugee camps	0	6	0	6
Total	13	6	1	**20**

4.5 Ethical and administrative considerations

The research project was approved by the Institutional Review Board (IRB) (Annex C) and the scientific research committee of the Public Health Department as well as the faculty of graduate studies scientific research board at An-Najah National University. A permission to conduct the study in the elementary schools was obtained from the Palestinian Ministry of Education (MoE) (Annex D and Annex E) for the governmental schools and private school and from UNRWA Education Office for UNRWA schools. We explained to the Head-Master and teachers about the importance of the study and they were asked to take care, protect and keep safe the study instruments from the employee and pupils.

4.6 Data collection

In this study, radon was monitored in schools. Therefore, it is interesting to find out a correlation between short-term measurements and long-term measurements for quality assurance and quality control purposes which reflect a better average radon concentration of our measurements. Also, to determine if the short term method can be reliable indicator of average indoor radon concentration and can be used as substitute of long term method in future works. For that, two technical methods were used, passive long term method (doesn’t need electrical supply) by CR-39 detectors and active short term method (need electrical supply to operate) by RAD7 detector.

4.6.1 Short-term measurements by active system

A calibrated portable continuous radon monitor type RAD7 (Durridge Company, USA) was used in this study, the same monitor was recently used in previous work (Al Zabadi et al., 2012). The measuring gas gets in diffusion mode via a large surface glass filter into an ionization chamber. Only the gaseous ^{222}Rn may pass, while the radon progeny products are prevented to enter the ionization chamber. At the same time the filter protects the interior of the chamber from contamination of aerosol particles. This radon measuring system can be operated either on battery or online electrical circuitry.

The system also registers air temperature, parametric pressure and relative humidity. A personal computer (PC) Software support named (CAPTURE) allows a graphic presentation and calculation of the average concentration in the measured period. The measurements were carried out in a total of 20 classrooms from 5 schools out of the 20 selected elementary schools. The five schools were chosen from the main 20 schools sample on the basis that they were easy to be accessed while handling the instrument every day during the measurement period.

For all runs, the RAD7 was put on a table in the center of the classroom as shown in figure 4.3. This classroom was closed one day before the start of measurement and was kept close during the run period.

Figure (4.2): Measurement apparatus RAD7

The radon concentration was measured in 1-hr cycles for an average time of 48 hrs in each classroom in parallel of the measurements period with the CR-39 dosimeters which lasted three months. The average radon concentration was calculated by the system in RAD7. And every cycle (hour) the printer printed out the outputs (Annex B contains run # 1 printer output). Down is just an example of a sample output:

0103 97.2 ± 40.0 b Sniff

SUN 03-JUN-12 11:47

26.4`C RH: 6.00% B: 7.03V

Where 0103 are the run (01) and cycle (03) numbers, 97.2 is the measured radon concentration, 40.0 is the statistical uncertainty, b indicates the units (in this case Bq/m^3), and Sniff shows that, for this reading, only the Po-218 decays are being counted (after three hours, the mode changes automatically to normal). The second line is clearly the date and time, while the third shows the temperature and humidity inside the measurement chamber, and the battery voltage.

To bring the humidity in the instrument down we purged the instrument in each run. Also the active desiccant and the inlet filter place were checked in each run.

4.6.2 Long-term measurements by passive radon dosimeter

As mentioned in chapter two, CR-39 detector is the most popular member of the SSNTDs family. It was selected because of its good sensitivity, stability against various environmental factors, and high degree of optical clarity (Ahn and Lee, 2005).

Large sheet of CR-39 were supplied by Intercast Co, Parma-Italy (http://www.df.unibo.it/macro/intercast). The sheet was of 1.0 mm in thickness and there was a mark on front better surface to avoid the possibility of tracks on the back surface by correctly handled and positioned the detectors.

4.6.2.1 Dosimeters preparation

The CR-39 sheet was cut into square shapes sized 1.5 × 1.5 cm by a special hand cutter and a serial number was engraved on each detector in Arabic numerals for ease of identification. Then the detector was inserted flat into the bottom of a conical plastic cup held in place by a small piece of blu-tac to reduce any error that might be caused by its movement. The mouth of the pot was completely covered with a single layer of cling film that was held by an elastic band. This film was used as a permeable membrane to discriminate short-lived thoron by delaying the entry of gases into the chamber, limits access of moisture, and blocks the entry of radon progeny and dust present in the ambient air (Hasan, 1996; Dwaikat, 2001; Obed et al., 2011).

This means that the radon concentration inside the detector chamber quickly approaches that outside. It can be shown that the long-term average radon concentration inside the detector chamber is the same as that outside, despite any variations in the outside concentration (Ahn and Lee, 2005). The radon dosimeter developed in this study is shown in figure 4.4.

On the bottom of the dosimeter (from outside) some instructions were written, to protect the dosimeter and to keep it close.

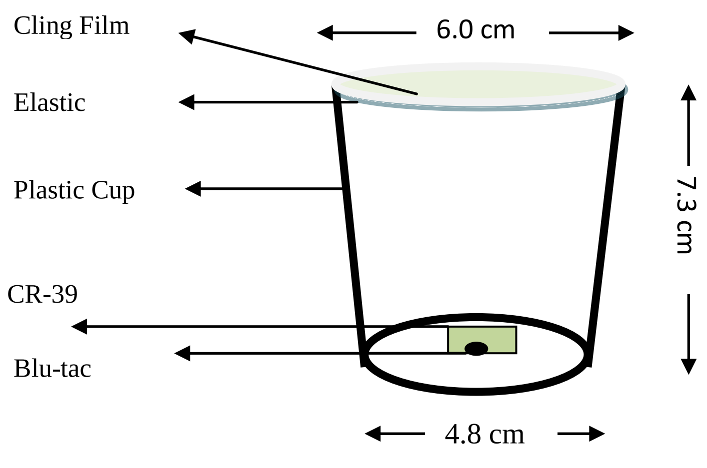

Figure (4.3): Schematic diagram of the radon dosimeter**.**

4.6.2.2 Dosimeters distribution

Two hundred and thirty dosimeters were prepared and distributed in the selected schools at the frequently occupied classrooms. About 10 classrooms from all floor levels were randomly selected in each school. The dosimeters were hanged on the wall at least 1.5 m above the floor and at least 10 cm from any objects. About thirty three dosimeters were used for quality assurance purposes to ensure that measurement results are reliable. They were left in place for long period of time three months (91 days) from May to August 2012 during the summer school holidays, in demi-close conditions; At least 60 days under close conditions during the summer holiday, and the rest 30 days under normal operating conditions of schools (the schools were some time opened for Al Tawjehi exams and for the summer camps). These demi-close conditions may be the same conditions of normal operation in winter season as windows and doors are kept close for children's safety and conservation of heating energy. Because all monitored schools didn’t had heating systems or heating supplies.

The dosimeter serial number and the classroom name and location were written on the external side of each dosimeter and in a notebook. Information about every school was recorded in the notebook, as shown in (annex F).

4.6.2.3 Dosimeters collection

After three months of exposure, 207 dosimeters were collected back at the end of August 2012 before the new schools year started. 10% of the dosimeters were lost. And three detectors were damaged during etching process. Table 4.6 represents the number and the date of the distributed and the collected dosimeters in each school.

Table (4.4): Dosimeters distribution and collection in the elementary schools of Tulkarem province.

School No.	School name	Distributions		Collection		Lost	Damage	Measured
		Date	Number of detectors	Date	Number of detectors			
1	Al Isra' Ideal Girls	27/5/2012	9	26/8/2012	9	0	0	9
2	Mahmoud Hamshary Basic Girls	27/5/2012	11	26/8/2012	8	3	0	8
3	Helmi Hannon Basic Boys	27/5/2012	10	26/8/2012	4	6	0	4
4	Hasan Al Qaisy Basic	27/5/2012	10	26/8/2012	10	0	0	10
5	Tulkarem Basic Girls No.1	29/5/2012	10	28/8/2012	9	1	0	9
6	Tulkarem Basic Girls No.2	29/5/2012	5	28/8/2012	5	0	0	5
7	Tulkarem Basic Boys No.1	29/5/2012	10	28/8/2012	10	0	0	10
8	Tulkarem Basic Boys No.2	29/5/2012	11	28/8/2012	10	1	0	10
9	Nur shams Basic Boys	28/5/2012	13	27/8/2012	9	4	0	9
10	Nur shams Basic Girls	28/5/2012	13	27/8/2012	12	1	0	12
11	Shuwaika Basic Girls	30/5/2012	11	29/8/2012	10	1	0	10
12	Zieta Basic Girls	30/5/2012	11	29/8/2012	11	0	0	11
13	Illar Basic Boys	30/5/2012	13	29/8/2012	13	0	0	13
14	Baqa- Al Sharqiah Basic Boys	30/5/2012	14	29/8/2012	13	1	2	11
15	Irtah Basic Girls	27/5/2012	9	26/8/2012	9	0	0	9
16	Kufor sur elementary	31/5/2012	11	30/8/2012	11	0	0	11
17	Shofah Basic Girls	31/5/2012	12	30/8/2012	10	2	0	8
18	Beit Leed Basic Boys	31/5/2012	10	30/8/2012	9	1	0	9
19	Anabta Basic Boys	31/5/2012	12	30/8/2012	11	1	0	11
20	Bala' High Basic Girls	31/5/2012	13	30/8/2012	12	1	0	12
Blank			12		12	0	1	11
Total			230		207	23	3	204

4.6.2.4 Detectors etching

The CR-39 detectors were detached from the dosimeters and were chemically etched in 6.25 N solution of sodium hydroxide (NaOH; serial No. 2355535200067, Frutarom company, Israel) at a temperature of 75 $^{\circ}$C for 6 hours in a constant temperature water bath to enlarge the latent tracks produced by alpha particles from the decay of radon.

In the etching process the magnetic stirrer was used to avoid the accumulation of the solution. Also, the condenser was used to keep the concentration of NaOH solution constant as well as the thermometer to keep the temperature under control. This process performed at the chemistry laboratories at An-Najah National University using the setup shown in figure 4.5.

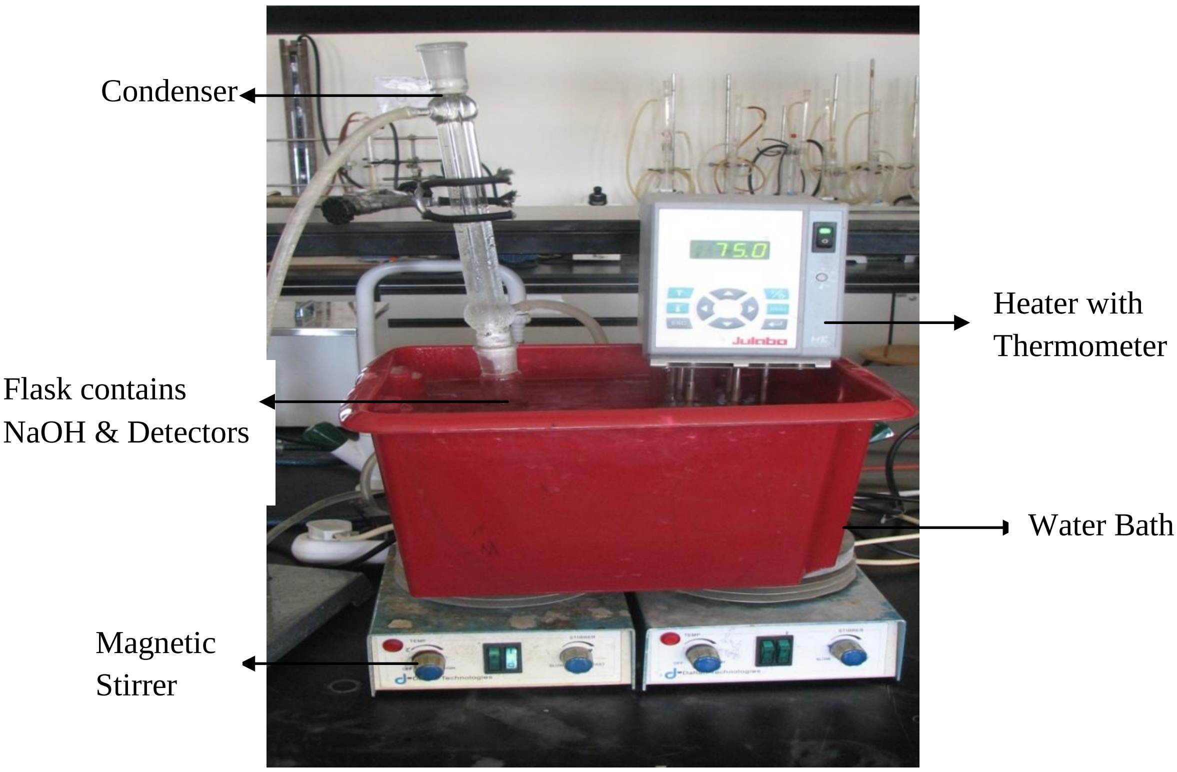

Figure (4.4): Etching process experimental set up.

The detectors were etched in groups of fifteen detectors. Once each group of detectors is etched, the detectors were removed from the holder and washed for 30 minutes with running cold water, then with distilled water and finally with a 50% water/alcohol solution. After a few minutes of drying in air, the detectors were carefully isolated from the dust inside a clean cup with cover for track counting.

4.6.2.5 Detectors scanning

For measuring radon concentration that is dependent on the track density, a digital optical microscope with built-in camera (Optika company, Italy) at biology laboratories at An-Najah National University (see figure. 4.6) was used with 400 times magnification power. Since the field of view is a circle, the size of the field of view is its area. For that, the microscope fixed at the lowest powered. Then the diameter of the field of view was found, using a transparent ruler and micrometer. The diameter measurement divided by 2 to get the radius. After that the formula for the area of a circle, Area = πr^2 was used. Finally the area of the field of view at our magnification 400 x found to be (53.1×10^{-4} cm^2).

The counting microscope is ready now for counting α-tracks. During the scanning process, the sample must be carried carefully from its corner and it should not be touched by bare hands.

Figure (4.5): Tracks counting system.

In counting process of the tracks care must be taken to distinguish between the α- tracks and dust particles; α- tracks appear as black holes with different volumes and shapes (Dwaikat, 2001). The average diameter of the tracks left on the surface of the plastic will depend on the incident mean energy of the particles as well as how the CR-39 is processed (Mosier-Boss et al., 2009). The shape of the track depends on the angle of incidence of the α- particles as shown in figure 4.7; circle faces of the tracks result from vertical incidence while elliptical tracks that have entered the CR-39 detector in an oblique angle (Mosier-Boss et al., 2009; Dwaikat, 2001).

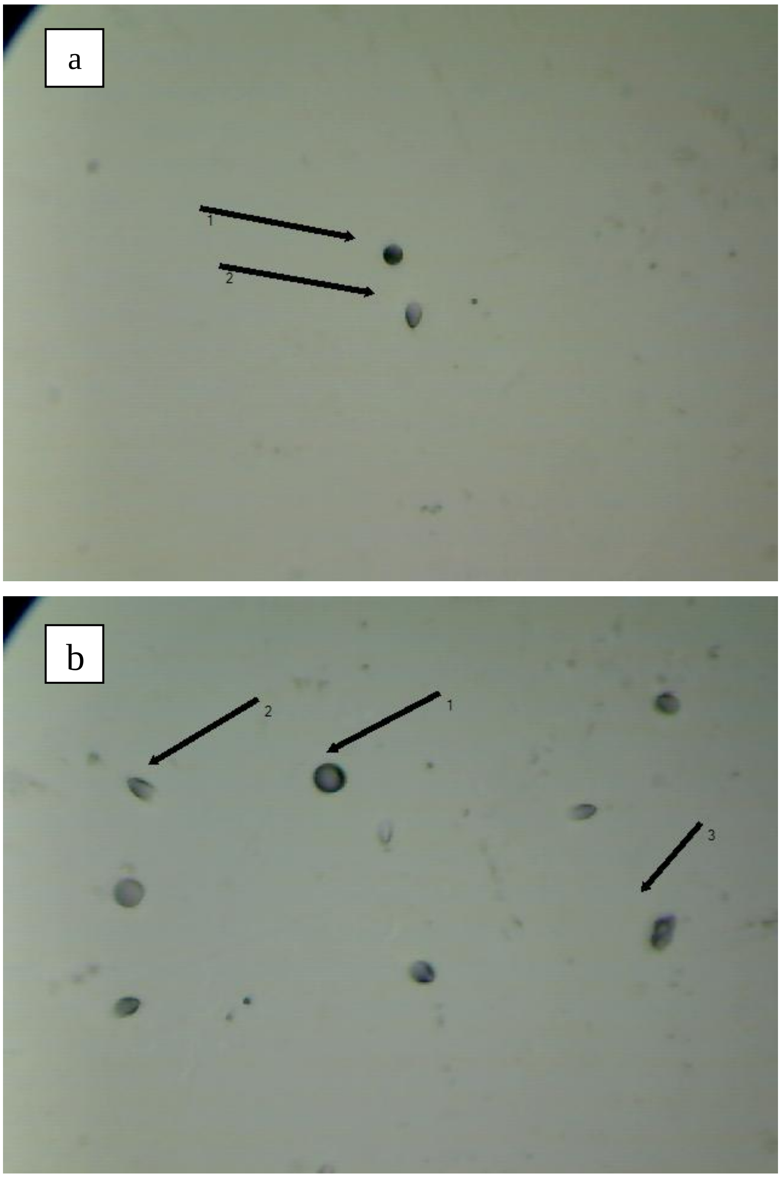

Figure (4.6): Images of alpha tracks in two field views of CR-39 detector. In (a) and (b) images ; Number 1 represents a circle face of the track results from vertical incidence of alpha particle while in number 2 an elliptical track that has entered the CR-39 detector in an oblique angle. But number 3 of image (b) shows a dirt particle.

To produce an unbiased and accurate estimate we reject the field of view that contains overlap tracks.

15 fields of view were counted and the numbers of the tracks were registered in a table (annex A), and the average number of the tracks of each detector was calculated as follow:

$$\text{Average number of the tracks} = \frac{\text{Total number of tracks counted in all fields of view}}{\text{Number of fields of View}} \quad (4.1)$$

The average number of the tracks was used to calculate the Tracks density (Track/cm^2) as follow:

$$\text{Tracks density} = \frac{\text{Average number of the tracks}}{\text{area of one field of view}} \quad (4.2)$$

The error in the present study measurements as well as the Track density was the standard error of the mean and calculated as:

$$\text{Error} = \frac{\sigma_{n-1}}{\sqrt{n}} \quad (4.3)$$

Where σ_{n-1}: is the standard deviation and n: is the number of fields of view.

4.7 Measurement of radon concentration in unit of Bq/m^3

The calculated track densities (T_D) after background subtraction (see section 4.11.2) were converted into radon concentrations (C_{Rn}) in Bq /m^3 using the calibration factor (F) supplied 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 of radon concentration, divided by the exposure time (Δt) in day (91 days for all detectors). That is: (Obed et al., 2011).

$$C_{Rn} = F \times \frac{T_D}{\Delta t} \quad (4.4)$$

4.8 Estimation of the effective dose

It is a common practice in radon surveys to convert the radon concentration to dose, and in case of schools to calculate the annual effective dose for the students and the teachers. Together, the selected schools host about 8140 students and 455 teachers. It was found that ^{222}Rn and its short-lived decay products account for around 1.3 mSv /y out of the total effective dose (2.4 mSv/y) from the natural sources (UNSCEAR, 2000). The problem is that the mean radon concentration takes also into account the radon concentration when the school is closed. For this, the estimated effective doses may be a little overestimated as the classrooms are closed during nights, weekends and holidays. (Clouvas et al., 2011; Clouvas et al., 2009).

The effective dose in mSv/y at any location depends upon the occupancy factor. The occupancy factor for the students and the teachers of Tulkarem elementary school was calculated using the following equation:

$$30 \text{ h /wk} \times 37 \text{ wk /yr} = 1110 \text{ h /yr} \qquad (4.5)$$

So the school occupancy factor (H) = 1110h / 8760h = 13%.

The expected annual effective doses received by the students and the teachers of the surveyed area were calculated using equation 4.6, the UNSCEAR model (2000, 2009) (Nasir and Shah, 2012).

$$E = C_{Rn} \times H \times F \times D \times T \qquad (4.6)$$

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

H: is the occupancy factor (0.13)

F: is the equilibrium factor (0.4)

T: is hours in a year (8760)

D: is the dose conversion factor (9×10^{-6} m Sv/h per Bq/ m^3).

4.9 Estimation of the lung cancer risk

In order to estimate the lifetime risk associated to a chronic exposure to indoor radon we calculated the radon exposure in WLM per year for the teacher by the following equitation (ICRP, 2010):

1 Bq/$m^3$of radon during 1 year = 1.26×10^{-3} WLM per year at work (4.7)

Assuming 2000 hours per year at work (While the occupancy factor is approximately 1110h/year in Tulkarem schools, the 2000 h/year indoor occupancy can be applied at the case of schools), and an equilibrium factor of 0.4. Also assuming that the teachers start their work at the age of 23 years and retire at the age of 60 years then the WLM per life are given below: (Dwaikat, 2001).

WLM/life = WLM/year $\times$ 37 (working year per life) (4.8)

The estimate of lifetime risk used in the ICRP Publication 115 (ICRP, 2010) was the lifetime excess absolute risk (LEAR) associated to a chronic exposure scenario, expressed in number of death 10^{-4} per WLM. The ICRP concluded that a LEAR of 5×10^{-4} per WLM, should now be used as the nominal probability coefficient for radon and radon progeny induced lung cancer, replacing the ICRP Publication 65 value of $2.8x10^{-4}$ per WLM (ICRP, 2010).

$$LEAR = WLM/life \times 5 * 10^{-4} \quad (4.9)$$

4.10 Quality assurance

The EPA guidance (EPA, 1998) for quality assurance has been adopted to make sure that the results of the present study are reliable, accurate and precise. Quality assurance includes activities consist of using duplicate and blank measurement. Duplicate measurements to evaluate precision and blank measurements help to evaluate accuracy. About thirty three detectors were used for these purposes.

4.10.1 Duplicate measurements

The purpose of duplicate measurements is to assess how well two side by side measurements with the same type of detector agree with each other (precision). Each detector measures the same indoor air environment and, therefore, they should give similar test results.

In this study 21 pairs of detectors were distributed in different classrooms, one of them were lost. Thus, approximately one pair duplicated detectors in each school as shown in table 4.7. As recommended by EPA duplicate measurements should be representing 10% of all the detectors deployed (Condon et al., 1995). The pairs were kept together during and after the measurement (pairs stored and shipped back in the same box).

Table (4.5): The collected duplicate detectors.

School name	Sample No.	
	D1	**D2**
Anabta Basic Boys	201	212
Beit Leed Basic Boys	176	200
Shuwaika Basic Girls	108	109
Zieta Basic Girls	124	132
	125	139
Baqa- Al Sharqiah Basic Boys	154	155
Illar Basic Boys	143	144
Irtah Basic Girls	11	17
Kufor sur elementary	177	186
Shofah Basic Girls	188	198
Helmi Hannon Basic Boys	36	37
Mahmoud Hamshary Basic Girls	20	30
Al Isra' Ideal Girls	1	6
Nur shams Basic Boys	81	82
	77	78
Nur shams Basic Girls	97	98
	91	92
Tulkarem Basic Boys No.1	101	105
Tulkarem Basic Boys No.2	69	70
Tulkarem Basic Girls No.1	65	67

To analyze the duplicates measurement the average relative percent difference (ARPD) for each duplicate pair that exceeds 148 Bq/m^3 (4.0 pCi/L) was calculated. A relative percent difference (RPD) is a measure of precision (RPD; difference divided by the mean) (EPA, 1998). If the ARPD for all duplicate pairs exceeds 25%, then the quality of the measurements is questionable (EPA, 1998; EPA, 1993).

If the average of the pair was less than 148 Bq/m^3, then the difference in readings should be less than 18.5 Bq/m^3 (0.5 pCi/L) (Condon et al, 1995).

4.10.2 Blank Measurements

Blank measurements are unexposed control detectors made to determine the background contamination leaked into the detectors during shipment or storage or from detector material itself. The number of blank measurements should be equal to 5% of all testing locations. Field blanks (blanks deployed at the testing location) are not required. However, allocating 3% field blanks and 2% office/laboratory blanks is recommended (EPA, 1998).

For this purpose, 12 detectors were used. About 5 of them stored in a closed bottle (one detector was damaged during the etching process) and the other 7 detectors used with each shipments or trip to the schools to assess the transit exposure. If any of the blank measurements is equal to or greater than 37 Bq/m^3 (1.0 pCi/L), then the accuracy is questionable (EPA, 1998). But in the present study the maximum result of background radiation was 6.79 Bq/m^3. And the average number of track was 0.13 (track per field of view) which is subtracted from the average number of tracks for each detector to eliminate the effective background radiation from radon concentration measurements.

4.11 Data analysis

The data collected in this study were analyzed using an Excel spreadsheet. Excel is used to calculate radon concentration, to estimate the effective dose of both students and teachers and the lifetime risk for the teachers**.** The data analysis is also based on the different parameters that may affect indoor radon concentration levels mainly: geographic location, school building age, floor level and school authorities as well as their building style. The statistical t-test (unpaired t-test, two-tailed) was used to investigate if the mean radon concentrations of these study parameters are significantly different from each other. *P*-value less than 0.05 was always considered significant. Correlation analysis was also used between short-term measurements (RAD7) and long term measurements (CR-39). The results of this study are presented in Chapter 5 using tables and figures**.**

4.12 Summary

Two hundred and thirty SSNTDs type CR-39 were distributed in the classrooms of twenty elementary schools located in Tulkarem province using stratified random sampling method of public, private and United Nations schools. About thirty of them were used for quality assurance purpose (10% duplicate detectors and 5% blank detectors). The CR-39 detectors were exposed in the schools for three months during the school summer holyday from May 2012 to August 2012 and then collected and etched in Sodium hydroxide 6.25 N solution at 75 $^{\circ}$C for 6 h. The tracks were counted manually at the digital microscope. In parallel, twenty active measurements performed by RAD7 monitor (Durridge Company) were carried out in the same twenty classrooms for quality assurance and correlation analysis between the two types of measurements (passive and active).

Chapter Five

Results

5.1 Introduction

A passive diffusion radon dosimeter containing CR-39 solid state nuclear track detectors (SSNTDs) and an active continuous radon monitor type RAD7 were used in this survey to measure indoor radon concentration in the elementary schools of Tulkarem for the first time. Two hundred and thirty CR-39 dosimeters were randomly distributed in 20 elementary schools in different classroom locations in Tulkarem province. After 91 days they were collected. 23 (10%) of them were lost, three detectors were damaged and eleven detectors used for blank purpose. The rest one hundred and ninety three detectors were analyzed and radon concentrations were measured as shown in (Annex A).

The results of this chapter divided in two sections: The first section is the results of CR-39 detectors which tabulated from table 5.1to table 5.20.

The second section represents the results of 20 indoor radon concentration measurements in five schools by continuous radon monitor type RAD7. This is tabulated in table 5.27and table 5.28.

5.2 Indoor radon concentration in the 20 elementary schools of Tulkarem province by using CR-39

Results from CR-39 measurements in the 20 elementary schools are presented in 20 tables (from table 5.1 to table 5.20). Each table contains the results of indoor radon concentration, effective dose and LEAR for the tested classrooms in one school. Also contains information’s about the dosimeters sample No., school name, school authority, school geographic location, school building age, classroom name and floor level.

The numbers in the classroom name column indicate the grade of the classroom, i.e. (1A) represent A first grade, (2C) represent C second grade, etc.

The abbreviation (GF) in the floor level column indicates the ground floor, (F1) the first floor and (F2) the second floor.

The error in the following tables is the standard error of the mean as we mentioned in the previous chapter.

The indoor radon concentration, effective dose and LEAR in Tulkarem city schools are presented in four tables (from table 5.1 to table 5.4).

Table (5.1): Indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of school No.1.

School Name: Al Isra' Ideal Girls, Geographic Location: Tulkarem City, Authority: Private.

Detector Type: CR-39, Building Age: 13 Years, Serial No.:1, School Classification No.: 41.

Serial No.	Dosimeter Sample No.	Classroom Name	Floor Level	Radon Concentration	±	Error	Avg Concentration	±	Error	Effective Dose (mSv/y)	Avg Effective Dose	±	Error	WLM per Year	WLM per Life	Lifetime Risk*10^{-4}	Avg Lifetime Risk*10^{-4}	±	Error *10^{-4}
1	1D	1D	GF	35.72	±	8.56	24.03	±	4.69	0.15	0.10	±	0.02	0.05	1.67	8.33	5.60	±	1.09
2	2	9A	F1	17.05	±	5.09				0.07				0.02	0.80	3.98			
3	3	8A	F1	8.57	±	4.21				0.04				0.01	0.40	2.00			
4	4	5A	F1	6.87	±	3.33				0.03				0.01	0.32	1.60			
5	5	2A	GF	18.75	±	6.51				0.08				0.02	0.87	4.37			
6	6D	1D	GF	32.33	±	8.89				0.13				0.04	1.51	7.54			
7	7	1C	GF	18.75	±	5.48				0.08				0.02	0.87	4.37			
8	8	1B	GF	27.24	±	7.93				0.11				0.03	1.27	6.35			
9	9	1A	GF	50.99	±	6.51				0.21				0.06	2.38	11.89			

Table (5.2): Indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of school No.2.

School Name: Mah. Hamshary Basic Girls, Geographic Location: Tulkarem City, Authority: Government.
Detector Type: CR-39, Building Age: 58 Years, Serial No.: 2, School Classification No.: 42.

Serial No.	Dosimeter Sample No.	Classroom Name	Floor Level	Radon Concentration	±	Error	Avg Concentration	±	Error	Effective Dose (mSv/y)	Avg Eff. Dose	±	Error	WLM per Year	WLM per Life	Lifetime Risk $*10^{-4}$	Avg Lifetime Risk$*10^{-4}$	±	Error $*10^{-4}$
1	20D	4A	GF	23.84	±	5.81	34.02	±	7.60	0.10	0.14	±	0.03	0.03	1.11	5.56	7.93	±	1.77
2	21	5B	F1	20.45	±	5.25				0.08				0.03	0.95	4.77			
3	23	7C	GF	39.12	±	10.73				0.16				0.05	1.82	9.12			
4	24	7B	GF	15.36	±	5.81				0.06				0.02	0.72	3.58			
5	25	7A	GF	17.05	±	5.66				0.07				0.02	0.80	3.98			
6	26	8A	GF	50.99	±	7.80				0.21				0.06	2.38	11.89			
7	29	5C	GF	78.15	±	12.96				0.32				0.10	3.64	18.22			
8	30D	4A	GF	27.24	±	5.09				0.11				0.03	1.27	6.35			

Table (5.3): Indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of school No.3.

School Name: Helmi Hannon Basic Boys, Geographic Location: Tulkarem City, Authority: Government.
Detector Type: CR-39, Building Age: 9 Years, Serial No.: 3, School Classification No.: 43.

Serial No.	Dosimeter Sample No.	Classroom Name	Floor Level	Radon Concentration	±	Error	Avg Concentration	±	Error	Effective Dose (mSv/y)	Avg Eff. Dose	±	Error	WLM per Year	WLM per Life	Lifetime Risk $*10^{-4}$	Avg Lifetime Risk $*10^{-4}$	±	Error $*10^{-4}$
1	36D	9A	GF	59.48	±	9.90	52.27	±	15.06	0.24	0.21	±	0.06	0.07	2.77	13.86	12.18	±	3.51
2	37D	9A	GF	91.72	±	10.68				0.38				0.12	4.28	21.38			
3	38	10C	GF	32.33	±	5.98				0.13				0.04	1.51	7.54			
4	39	10B	GF	25.54	±	6.02				0.10				0.03	1.19	5.95			

Table (5.4): Indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of school No.4.

School Name: Hasan Al Qaisy Basic, Geographic Location: Tulkarem City, Authority: Government.

Detector Type: CR-39, Building Age: 11 Years, Serial No.: 4, School Classification No.: 44.

Serial No.	Dosimeter Sample No.	Classroom Name	Floor Level	Radon Concentration	±	Error	Avg Concentration	±	Error	Effective Dose (mSv/y)	Avg Eff. Dose	±	Error	WLM per Year	WLM per Life	Lifetime Risk $*10^{-4}$	Avg Lifetime Risk$*10^{-4}$	±	Error $*10^{-4}$
1	41	4B	F1	54.39	±	10.08	54.73	±	15.23	0.22	0.22	±	0.06	0.07	2.54	12.68	12.76	±	3.55
2	42	3A	F1	18.75	±	5.48				0.08				0.02	0.87	4.37			
3	43	3B	F1	50.99	±	12.39				0.21				0.06	2.38	11.89			
4	44	2B	F1	37.42	±	7.78				0.15				0.05	1.74	8.72			
5	45	2A	F1	30.63	±	5.91				0.13				0.04	1.43	7.14			
6	46	4A	F1	28.93	±	6.79				0.12				0.04	1.35	6.74			
7	47	5A	GF	61.18	±	12.14				0.25				0.08	2.85	14.26			
8	48	1B	GF	44.21	±	6.51				0.18				0.06	2.06	10.30			
9	49	10A	GF	34.02	±	5.48				0.14				0.04	1.59	7.93			
10	50	1A	GF	186.75	±	11.62				0.77				0.24	8.71	43.53			

Table 5.5 to 5.10 summarizes the results of indoor radon concentration, effective dose and LEAR in Tulkarem camps schools.

Table (5.5): Indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of school No.5.

School Name: Tulkarem Basic Girls No.1, Geographic Location: Tulkarem Camps, Authority: UNRWA.
Detector Type: CR-39, Building Age: 10 Years, Serial No.: 5, School Classification No.: 51 .

Serial No.	Dosimeter Sample No.	Classroom Name	Floor Level	Radon Concentration	±	Error	Avg Concentration	±	Error	Effective Dose (mSv/y)	Avg Eff. Dose	±	Error	WLM per Year	WLM per Life	Lifetime Risk *10^{-4}	Avg Lifetime Risk *10^{-4}	±	Error *10^{-4}
1	59	8A	F1	40.81	±	7.23	43.08	±	8.11	0.17	0.18	±	0.03	0.05	1.90	9.51	10.04	±	1.89
2	61	5B	F1	15.36	±	3.90				0.06				0.02	0.72	3.58			
3	62	9A	GF	23.84	±	5.81				0.10				0.03	1.11	5.56			
4	63	9C	GF	30.63	±	4.06				0.13				0.04	1.43	7.14			
5	64	9B	GF	22.15	±	7.03				0.09				0.03	1.03	5.16			
6	65D	7A	GF	74.75	±	9.45				0.31				0.09	3.48	17.42			
7	66	7B	GF	52.69	±	11.16				0.22				0.07	2.46	12.28			
8	67D	7A	GF	86.63	±	9.58				0.36				0.11	4.04	20.19			
9	68	7C	GF	40.81	±	8.41				0.17				0.05	1.90	9.51			

Table (5.6): Indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of school No.6.

School Name: Tulkarem Basic Girls No.2, Geographic Location: Tulkarem Camps, Authority: UNRWA.
Detector Type: CR-39, Building Age: 10 Years, Serial No.: 6, School Classification No.: 52.

Serial No.	Dosimeter Sample No.	Classroom Name	Floor Level	Radon Concentration	±	Error	Avg Concentration	±	Error	Effective Dose (mSv/y)	Avg Eff. Dose	±	Error	WLM per Year	WLM per Life	Lifetime Risk *10^{-4}	Avg Lifetime Risk *10^{-4}	±	Error *10^{-4}
1	54	1B	F2	6.87	±	4.16	7.21	±	0.63	0.03	0.03	±	0.00	0.01	0.32	1.60	1.68	±	0.15
2	55	2B	F2	8.57	±	3.39				0.04				0.01	0.40	2.00			
3	56	2A	F2	5.18	±	3.21				0.02				0.01	0.24	1.21			
4	57	4A	F2	6.87	±	3.33				0.03				0.01	0.32	1.60			
5	58	3C	F2	8.57	±	3.39				0.04				0.01	0.40	2.00			

Table (5.7): Indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of school No.7.

School Name: Tulkarem Basic Boys No.1, Geographic Location: Tulkarem Camps, Authority: UNRWA.

Detector Type: CR-39, Building Age: 4 Years, Serial No.: 7, School Classification No.: 53.

Serial No.	Dosimeter Sample No.	Classroom Name	Floor Level	Radon Concentration ± Error	Avg Concentration ± Error	Effective Dose (mSv/y)	Avg Eff. Dose ± Error	WLM per Year	WLM per Life	Lifetime Risk $*10^{-4}$	Avg Lifetime Risk $*10^{-4}$ ± Error $*10^{-4}$
1	101D	6C	F1	18.75 ± 5.48	55.41 ± 14.01	0.08	0.23 ± 0.06	0.02	0.87	4.37	12.92 ± 3.27
2	105D	6C	F1	27.24 ± 7.53		0.11		0.03	1.27	6.35	
3	114	6B	F1	84.93 ± 13.11		0.35		0.11	3.96	19.80	
4	115	8C	F1	25.54 ± 7.40		0.10		0.03	1.19	5.95	
5	116	6A	F1	32.33 ± 7.78		0.13		0.04	1.51	7.54	
6	118	8B	F1	67.96 ± 9.36		0.28		0.09	3.17	15.84	
7	120	8A	F1	59.48 ± 10.50		0.24		0.07	2.77	13.86	
8	126	7C	F1	17.05 ± 6.67		0.07		0.02	0.80	3.98	
9	129	9A	GF	163.00 ± 20.01		0.67		0.21	7.60	37.99	
10	130	9B	F1	57.78 ± 9.87		0.24		0.07	2.69	13.47	

Table (5.8): Indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of school No.8.

School Name: Tulkarem Basic Boys No.2, Geographic Location: Tulkarem Camps, Authority: UNRWA.

Detector Type: CR-39, Building Age: 56 Years, Serial No.: 8, School Classification No.: 54.

Serial No.	Dosimeter Sample No.	Classroom Name	Floor Level	Radon Concentration ± Error	Avg Concentration ± Error	Effective Dose (mSv/y)	Avg Eff. Dose ± Error	WLM per Year	WLM per Life	Lifetime Risk $*10^{-4}$	Avg Lifetime Risk $*10^{-4}$ ± Error $*10^{-4}$
1	69D	4B	F1	13.66 ± 4.06	35.72 ± 10.10	0.06	0.15 ± 0.04	0.02	0.64	3.18	8.33 ± 2.35
2	70D	4B	F1	11.96 ± 4.16		0.05		0.02	0.56	2.79	
3	71	3C	F1	20.45 ± 6.32		0.08		0.03	0.95	4.77	
4	72	3B	F1	42.51 ± 10.88		0.17		0.05	1.98	9.91	
5	73	3A	F1	5.18 ± 4.06		0.02		0.01	0.24	1.21	
6	75	2B	F1	10.27 ± 4.88		0.04		0.01	0.48	2.39	
7	117	1C	GF	112.09 ± 8.91		0.46		0.14	5.23	26.13	
8	119	1B	GF	44.21 ± 10.79		0.18		0.06	2.06	10.30	
9	127	1A	GF	52.69 ± 9.36		0.22		0.07	2.46	12.28	
10	128	2A	F1	44.21 ± 9.58		0.18		0.06	2.06	10.30	

Table (5.9): Indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of school No.9.

School Name: Nur shams Basic Boys, Geographic Location: Tulkarem Camps, Authority: UNRWA.

Detector Type: CR-39, Building Age: 8 Years, Serial No.: 9, School Classification No.: 55.

Serial No.	Dosimeter Sample No.	Classroom Name	Floor Level	Radon Concentration	±	Error	Avg Concentration	±	Error	Effective Dose (mSv/y)	Avg Eff. Dose	±	Error	WLM per Year	WLM per Life	Lifetime Risk $*10^{-4}$	Avg Lifetime Risk $*10^{-4}$	±	Error $*10^{-4}$
1	52	5B	F1	10.27	±	4.21				0.04				0.01	0.48	2.39			
2	53	5C	F1	11.96	±	3.33				0.05				0.02	0.56	2.79			
3	77D	4C	F1	6.87	±	3.33				0.03				0.01	0.32	1.60			
4	78D	4C	F1	8.57	±	4.21				0.04				0.01	0.40	2.00			
5	80	2C	GF	50.99	±	11.62	27.43	±	6.56	0.21	0.11	±	0.03	0.06	2.38	11.89	6.39	±	1.53
6	81D	2B	GF	28.93	±	7.23				0.12				0.04	1.35	6.74			
7	82D	2B	GF	35.72	±	10.79				0.15				0.05	1.67	8.33			
8	83	1A	GF	32.33	±	7.37				0.13				0.04	1.51	7.54			
9	85	1C	GF	61.18	±	11.88				0.25				0.08	2.85	14.26			

Table (5.10): Indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of school No.10.

School Name: Nur shams Basic Girls, Geographic Location: Tulkarem Camps, Authority: UNRWA.

Detector Type: CR-39, Building Age: 12 Years, Serial No.: 10, School Classification No.: 56.

Serial No.	Dosimeter Sample No.	Classroom Name	Floor Level	Radon Concentration	±	Error	Avg Concentration	±	Error	Effective Dose (mSv/y)	Avg Eff. Dose	±	Error	WLM per Year	WLM per Life	Lifetime Risk $*10^{-4}$	Avg Lifetime Risk $*10^{-4}$	±	Error $*10^{-4}$
1	86	4B	F1	30.63	±	6.88	28.93	±	2.92	0.13	0.12	±	0.01	0.04	1.43	7.14	6.74	±	0.68
2	88	4A	F1	32.33	±	5.44				0.13				0.04	1.51	7.54			
3	89	3C	F1	34.02	±	8.91				0.14				0.04	1.59	7.93			
4	90	3B	F1	44.21	±	6.97				0.18				0.06	2.06	10.30			
5	91D	3A	GF	32.33	±	10.77				0.13				0.04	1.51	7.54			
6	92D	3A	GF	40.81	±	3.90				0.17				0.05	1.90	9.51			
7	93	2C	GF	8.57	±	4.21				0.04				0.01	0.40	2.00			
8	95	2B	GF	30.63	±	5.91				0.13				0.04	1.43	7.14			
9	96	2A	GF	22.15	±	6.08				0.09				0.03	1.03	5.16			
10	97D	1C	GF	20.45	±	6.32				0.08				0.03	0.95	4.77			
11	98D	1C	GF	34.02	±	9.58				0.14				0.04	1.59	7.93			
12	100	1A	GF	17.05	±	7.11				0.07				0.02	0.80	3.98			

The results of indoor radon concentration, effective dose and LEAR in Al Shaarawiah villages schools are given in tables 5.11 to 5.14.

Table (5.11): Indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of school No.11.

School Name: Shuwaika Basic Girls, Geographic Location: Al Shaarawiah villages, Authority: Government.

Detector Type: CR-39, Building Age: 12 Years, Serial No.: 11, School Classification No.: 21.

Serial No.	Dosimeter Sample No.	Classroom Name	Floor Level	Radon Concentration	±	Error	Avg Concentration	±	Error	Effective Dose (mSv/y)	Avg Eff. Dose	±	Error	WLM per Year	WLM per Life	Lifetime Risk $*10^{-4}$	Avg Lifetime Risk $*10^{-4}$	±	Error $*10^{-4}$
1	102	3C	F1	37.42	±	5.44	49.47	±	5.58	0.15	0.20	±	0.02	0.05	1.74	8.72	11.53	±	1.30
2	103	3B	F1	28.93	±	10.96				0.12				0.04	1.35	6.74			
3	106	4B	F1	52.69	±	9.03				0.22				0.07	2.46	12.28			
4	107	2B	F1	44.21	±	7.40				0.18				0.06	2.06	10.30			
5	108D	2A	F1	40.81	±	9.12				0.17				0.05	1.90	9.51			
6	109D	2A	F1	52.69	±	8.31				0.22				0.07	2.46	12.28			
7	110	1B	GF	71.36	±	10.68				0.29				0.09	3.33	16.63			
8	111	2C	GF	86.63	±	10.50				0.36				0.11	4.04	20.19			
9	112	1C	GF	34.02	±	6.97				0.14				0.04	1.59	7.93			
10	113	1A	GF	45.90	±	12.54				0.19				0.06	2.14	10.70			

Table (5.12): Indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of school No.12.

School Name: Zieta Basic Girls, Geographic Location: Al Shaarawiah villages, Authority: Government.

Detector Type: CR-39, Building Age: 56 Years, Serial No.: 12, School Classification No.: 22.

Serial No.	Dosimeter Sample No.	Classroom Name	Floor Level	Radon Concentration	±	Error	Avg Concentration	±	Error	Effective Dose (mSv/y)	Avg Eff. Dose	±	Error	WLM per Year	WLM per Life	Lifetime Risk $*10^{-4}$	Avg Lifetime Risk $*10^{-4}$	±	Error $*10^{-4}$
1	124D	2B	GF	139.24	±	15.47	71.98	±	17.07	0.57	0.30	±	0.07	0.18	6.49	32.46	16.78	±	3.98
2	125D	1A	GF	54.39	±	14.79				0.22				0.07	2.54	12.68			
3	131	3B	GF	20.45	±	6.32				0.08				0.03	0.95	4.77			
4	132D	2B	GF	161.30	±	19.06				0.66				0.20	7.52	37.60			
5	133	6A	GF	168.09	±	17.29				0.69				0.21	7.84	39.18			
6	134	5A	GF	22.15	±	6.57				0.09				0.03	1.03	5.16			
7	135	4A	GF	23.84	±	5.81				0.10				0.03	1.11	5.56			
8	136	3A	GF	69.66	±	19.38				0.29				0.09	3.25	16.24			
9	137	2A	GF	35.72	±	8.19				0.15				0.05	1.67	8.33			
10	138	1B	GF	56.09	±	10.14				0.23				0.07	2.61	13.07			
11	139D	1A	GF	40.81	±	5.81				0.17				0.05	1.90	9.51			

Table (5.13): Indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of school No.13.

School Name: Illar Basic Boys, Geographic Location: Al Shaarawiah villages, Authority: Government.

Detector Type: CR-39, Building Age: 62 Years, Serial No.: 13, School Classification No.: 23.

Serial No.	Dosimeter Sample No.	Classroom Name	Floor Level	Radon Concentration	±	Error	Avg Concentration	±	Error	Effective Dose (mSv/y)	Avg Eff. Dose	±	Error	WLM per Year	WLM per Life	Lifetime Risk *10^{-4}	Avg Lifetime Risk*10^{-4}	±	Error *10^{-4}
1	140	6B	GF	98.51	±	14.48	38.59	±	8.29	0.40	0.16	±	0.03	0.12	4.59	22.96	9.00	±	1.93
2	141	1A	GF	67.96	±	8.31				0.28				0.09	3.17	15.84			
3	142	2A	GF	93.42	±	16.52				0.38				0.12	4.36	21.78			
4	143D	2B	GF	23.84	±	8.04				0.10				0.03	1.11	5.56			
5	144D	2B	GF	40.81	±	7.64				0.17				0.05	1.90	9.51			
6	145	4A	GF	11.96	±	4.16				0.05				0.02	0.56	2.79			
7	146	6A	GF	10.27	±	3.39				0.04				0.01	0.48	2.39			
8	147	5B	GF	27.24	±	5.66				0.11				0.03	1.27	6.35			
9	148	4B	GF	22.15	±	6.57				0.09				0.03	1.03	5.16			
10	149	5A	GF	11.96	±	4.84				0.05				0.02	0.56	2.79			
11	150	3A	F1	18.75	±	4.21				0.08				0.02	0.87	4.37			
12	151	1B	GF	40.81	±	8.41				0.17				0.05	1.90	9.51			
13	152	3B	F1	34.02	±	5.48				0.14				0.04	1.59	7.93			

Table (5.14): Indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of school No.14.

School Name: Baqa Al Sh. Basic Boys, Geographic Location: Al Shaarawiah villages, Authority: Government.

Detector Type: CR-39, Building Age: 70 Years, Serial No.: 14, School Classification No.: 24.

Serial No.	Dosimeter Sample No.	Classroom Name	Floor Level	Radon Concentration	±	Error	Avg Concentration	±	Error	Effective Dose (mSv/y)	Avg Eff. Dose	±	Error	WLM per Year	WLM per Life	Lifetime Risk $*10^{-4}$	Avg Lifetime Risk $*10^{-4}$	±	Error $*10^{-4}$
1	154D	3B	F1	20.45	±	4.63				0.08				0.03	0.95	4.77			
2	155D	3B	F1	34.02	±	7.40				0.14				0.04	1.59	7.93			
3	156	3A	F1	23.84	±	9.12				0.10				0.03	1.11	5.56			
4	157	4A	F1	32.33	±	6.48				0.13				0.04	1.51	7.54			
5	158	2A	F1	37.42	±	8.53				0.15				0.05	1.74	8.72			
6	161	1B	F1	47.60	±	10.54	37.26	±	3.57	0.20	0.15	±	0.01	0.06	2.22	11.10	8.69	±	0.83
7	162	1A	F1	37.42	±	6.94				0.15				0.05	1.74	8.72			
8	163	6B	GF	42.51	±	9.03				0.17				0.05	1.98	9.91			
9	164	6A	GF	32.33	±	8.53				0.13				0.04	1.51	7.54			
10	166	5B	GF	37.42	±	6.94				0.15				0.05	1.74	8.72			
11	167	5A	GF	64.57	±	9.18				0.26				0.08	3.01	15.05			

For Al Kafriat villages schools the indoor radon concentration, effective dose and LEAR are presented in tables 5.15, 5.16 and 5.17.

Table (5.15): Indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of school No.15.

School Name: Irtah Basic Girls, Geographic Location: Al Kafriat villages, Authority: Government.

Detector Type: CR-39, Building Age: 7 Years, Serial No.: 15, School Classification No.: 31.

Serial No.	Dosimeter Sample No.	Classroom Name	Floor Level	Radon Concentration	±	Error	Avg Concentration	±	Error	Effective Dose (mSv/y)	Avg Eff. Dose	±	Error	WLM per Year	WLM per Life	Lifetime Risk *10^{-4}	Avg Lifetime Risk *10^{-4}	±	Error *10^{-4}
1	11D	3A	F1	28.93	±	7.64				0.12				0.04	1.35	6.74			
2	12	4B	F2	8.57	±	4.21				0.04				0.01	0.40	2.00			
3	13	4A	F2	6.87	±	5.44				0.03				0.01	0.32	1.60			
4	14	5A	F2	8.57	±	4.21				0.04				0.01	0.40	2.00			
5	15	6A	F2	23.84	±	8.41	18.75	±	3.35	0.10	0.08	±	0.01	0.03	1.11	5.56	4.37	±	0.78
6	16	3B	F1	34.02	±	7.80				0.14				0.04	1.59	7.93			
7	17D	3A	F1	27.24	±	5.09				0.11				0.03	1.27	6.35			
8	18	2A	F1	15.36	±	6.79				0.06				0.02	0.72	3.58			
9	19	1A	GF	15.36	±	6.79				0.06				0.02	0.72	3.58			

Table (5.16): Indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of school No.16.

School Name: Kufor sur elementary, Geographic Location: Al Kafriat villages, Authority: Government.

Detector Type: CR-39, Building Age: 52 Years, Serial No.: 16, School Classification No.: 32.

Serial No.	Dosimeter Sample No.	Classroom Name	Floor Level	Radon Concentration	±	Error	Avg Concentration	±	Error	Effective Dose (mSv/y)	Avg Eff. Dose	±	Error	WLM per Year	WLM per Life	Lifetime Risk $*10^{-4}$	Avg Lifetime Risk $*10^{-4}$	±	Error $*10^{-4}$
1	169	8A	F2	18.75	±	7.80				0.08				0.02	0.87	4.37			
2	177D	2A	GF	193.54	±	17.99				0.79				0.24	9.02	45.11			
3	178	9A	F2	39.12	±	8.11				0.16				0.05	1.82	9.12			
4	180	4A	F1	32.33	±	11.86				0.13				0.04	1.51	7.54			
5	181	7A	F2	73.06	±	13.38				0.30				0.09	3.41	17.03			
6	182	5A	F1	20.45	±	8.04	80.00	±	21.59	0.08	0.33	±	0.09	0.03	0.95	4.77	18.65	±	5.03
7	183	1A	F1	34.02	±	7.40				0.14				0.04	1.59	7.93			
8	184	6A	F1	28.93	±	6.79				0.12				0.04	1.35	6.74			
9	185	3A	GF	76.45	±	16.64				0.31				0.10	3.56	17.82			
10	186D	2A	GF	210.51	±	20.30				0.86				0.27	9.81	49.07			
11	187	1B	GF	152.81	±	16.07				0.63				0.19	7.12	35.62			

Table (5.17): Indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of school No.17.

School Name: Shofah Basic Girls, Geographic Location: Al Kafriat villages, Authority: Government.

Detector Type: CR-39, Building Age: 50 Years, Serial No.: 17, School Classification No.: 33.

Serial No.	Dosimeter Sample No.	Classroom Name	Floor Level	Radon Concentration	±	Error	Avg Concentration	±	Error	Effective Dose (mSv/y)	Avg Eff. Dose	±	Error	WLM per Year	WLM per Life	Lifetime Risk $*10^{-4}$	Avg Lifetime Risk $*10^{-4}$	±	Error $*10^{-4}$
1	188D	2A	GF	86.63	±	8.19	51.33	±	7.61	0.36	0.21	±	0.03	0.11	4.04	20.19	11.97	±	1.77
2	189	1B	GF	50.99	±	8.19				0.21				0.06	2.38	11.89			
3	191	9A	F1	28.93	±	6.32				0.12				0.04	1.35	6.74			
4	193	7A	F1	25.54	±	6.97				0.10				0.03	1.19	5.95			
5	194	6A	F1	39.12	±	9.83				0.16				0.05	1.82	9.12			
6	195	3A	GF	52.69	±	11.16				0.22				0.07	2.46	12.28			
7	196	4A	GF	39.12	±	7.31				0.16				0.05	1.82	9.12			
8	197	5A	GF	49.30	±	6.79				0.20				0.06	2.30	11.49			
9	198D	2A	GF	100.21	±	7.23				0.41				0.13	4.67	23.36			
10	199	1A	GF	40.81	±	6.32				0.17				0.05	1.90	9.51			

The indoor radon concentration, effective dose and LEAR in Wad El Shaeer Villages schools are presented in three tables (from table 5.18 to 5.20).

Table (5.18): Indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of school No.18.

School Name: Beit Leed Basic Boys, Geographic Location: Wad El Shaeer Villages, Authority: Government.

Detector Type: CR-39, Building Age: 70 Years, Serial No.: 18, School Classification No.: 11.

Serial No.	Dosimeter Sample No.	Classroom Name	Floor Level	Radon Concentration	±	Error	Avg Concentration	±	Error	Effective Dose (mSv/y)	Avg Eff. Dose	±	Error	WLM per Year	WLM per Life	Lifetime Risk $*10^{-4}$	Avg Lifetime Risk $*10^{-4}$	±	Error $*10^{-4}$
1	168	3A	GF	39.12	±	7.31				0.16				0.05	1.82	9.12			
2	170	4B	GF	25.54	±	5.48				0.10				0.03	1.19	5.95			
3	172	6B	GF	20.45	±	8.77				0.08				0.03	0.95	4.77			
4	173	7A	GF	22.15	±	6.57				0.09				0.03	1.03	5.16			
5	174	5B	GF	35.72	±	9.25	22.52	±	3.51	0.15	0.09	±	0.01	0.05	1.67	8.33	5.25	±	0.82
6	175	5A	GF	20.45	±	8.41				0.08				0.03	0.95	4.77			
7	176D	4A	GF	15.36	±	5.25				0.06				0.02	0.72	3.58			
8	179	4C	GF	3.48	±	3.01				0.01				0.00	0.16	0.81			
9	200D	4A	GF	20.45	±	5.81				0.08				0.03	0.95	4.77			

Table (5.19): Indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of school No.19.

School Name: Anabta Basic Boys, Geographic Location: Wad El Shaeer Villages, Authority: Government.

Detector Type: CR-39, Building Age: 79 Years, Serial No.: 19, School Classification No.: 12.

Serial No.	Dosimeter Sample No.	Classroom Name	Floor Level	Radon Concentration	±	Error	Avg Concentration	±	Error	Effective Dose (mSv/y)	Avg Eff. Dose	±	Error	WLM per Year	WLM per Life	Lifetime Risk $*10^{-4}$	Avg Lifetime Risk $*10^{-4}$	±	Error $*10^{-4}$
1	201D	7A	GF	32.33	±	5.98				0.13				0.04	1.51	7.54			
2	202	7B	GF	39.12	±	7.31				0.16				0.05	1.82	9.12			
3	203	5A	GF	27.24	±	3.68				0.11				0.03	1.27	6.35			
4	204	5B	GF	32.33	±	7.78				0.13				0.04	1.51	7.54			
5	205	6A	GF	45.90	±	4.63				0.19				0.06	2.14	10.70			
6	206	6B	GF	30.63	±	4.76	32.33	±	2.39	0.13	0.13	±	0.01	0.04	1.43	7.14	7.54	±	0.56
7	207	8A	GF	28.93	±	7.23				0.12				0.04	1.35	6.74			
8	208	8B	GF	20.45	±	4.63				0.08				0.03	0.95	4.77			
9	209	7C	GF	44.21	±	5.48				0.18				0.06	2.06	10.30			
10	211	4B	GF	23.84	±	4.63				0.10				0.03	1.11	5.56			
11	212	7A	GF	30.63	±	6.41				0.13				0.04	1.43	7.14			

Table (5.20): Indoor radon concentrations, doses and lifetime risks of radon induced lung cancer of school No.20.

School Name: Bala'a High Basic Girls, Geographic Location: Wad El Shaeer Villages, Authority: Government.

Detector Type: CR-39, Building Age: 13 Years, Serial No.: 20, School Classification No.: 11.

Serial No.	Dosimeter Sample No.	Classroom Name	Floor Level	Radon Concentration	±	Error	Avg Concentration	±	Error	Effective Dose (mSv/y)	Avg Eff. Dose	±	Error	WLM per Year	WLM per Life	Lifetime Risk $*10^{-4}$	Avg Lifetime Risk $*10^{-4}$	±	Error $*10^{-4}$
1	213	5A	F1	20.45	±	4.63	25.68	±	4.26	0.08	0.11	±	0.02	0.03	0.95	4.77	5.99	±	0.99
2	214	5B	F1	15.36	±	4.63				0.06				0.02	0.72	3.58			
3	215	5C	F1	8.57	±	3.39				0.04				0.01	0.40	2.00			
4	216	5D	F1	34.02	±	4.88				0.14				0.04	1.59	7.93			
5	217	8A	F1	10.27	±	3.39				0.04				0.01	0.48	2.39			
6	218	8B	F1	18.75	±	5.48				0.08				0.02	0.87	4.37			
7	219	8C	F1	30.63	±	10.14				0.13				0.04	1.43	7.14			
8	220	7C	F1	10.27	±	4.21				0.04				0.01	0.48	2.39			
9	221	7B	F1	32.33	±	7.37				0.13				0.04	1.51	7.54			
10	222	7A	F1	54.39	±	11.77				0.22				0.07	2.54	12.68			
11	223	6B	F2	47.60	±	7.86				0.20				0.06	2.22	11.10			
12	225D	6A	F2	25.54	±	6.51				0.10				0.03	1.19	5.95			

Table (5.21): Summary analysis of the average radon concentration, average effective dose and average life time risk over different classifications.

Classification	No. of Dosimeters	Radon Concentration Bq/m^3	Effective Dose (mSv/y)	Lifetime Risk *10^{-4}
Tulkarem Province	193	40.42 ± 2.49	0.17 ± 0.01	9.42 ± 0.58
Tulkarem City	31	40.16 ± 6.02	0.16 ± 0.02	9.36 ± 1.40
Tulkarem Camps	55	35.07 ± 3.91	0.14 ± 0.02	8.18 ± 0.91
Al Shaarawih V.	45	48.84 ± 5.30	0.20 ± 0.02	11.39 ± 1.24
Al Kafriaat V.	30	52.07 ± 9.34	0.21 ± 0.04	12.14 ± 2.18
Wad Al Shaeer V.	32	27.08 ± 2.11	0.11 ± 0.01	6.31 ± 0.49
Government	129	43.84 ± 3.28	0.18 ± 0.01	10.22 ± 0.76
UNRWA	55	35.07 ± 3.91	0.14 ± 0.02	8.18 ± 0.91
Private	9	24.03 ± 4.69	0.10 ± 0.02	5.60 ± 1.09
Ground Floor	107	50.20 ± 4.01	0.21 ± 0.02	11.70 ± 0.93
First Floor	72	29.73 ± 1.88	0.12 ± 0.01	6.93 ± 0.44
Second Floor	14	20.57 ± 5.37	0.08 ± 0.02	4.79 ± 1.25
New Building	99	35.52 ± 2.85	0.15 ± 0.01	8.28 ± 0.67
Old Building	94	45.58 ± 4.08	0.19 ± 0.02	10.62 ± 0.95

5.2.1 Average radon concentration in Tulkarem province

The indoor radon concentration in Tulkarem province elementary schools was varied from 3.48 to 210.51 with mean of 40.42 ± 2.49 Bq/m^3 as shown in tables 5.21, 5.22.

Table (5.22): The minimum, mean, standard deviation, standard error of the mean and the maximum values of radon concentrations in Tulkarem Province.

Min	Max	mean	SD	SE
3.48	210.51	40.42	34.58	2.49

The general observation in figure 5.1 is that 85% of the detectors have radon concentration less than 60 Bq/m^3. On the other hand, about 4% of the detectors have concentration above 150 Bq/m^3.

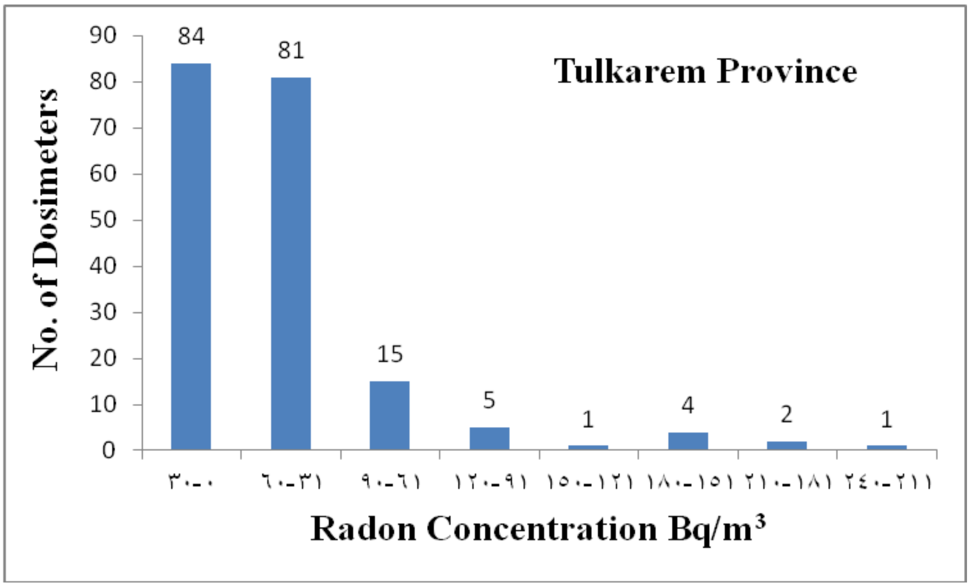

Figure (5.1): Radon concentration distribution in Tulkarem province area.

The effective dose due to indoor radon that the students and the teachers of the elementary schools of Tulkarem province exposed to was found to be 0.17 ± 0.01 mSv/y (See table 5.21).

The LEAR which estimates the lifetime risk factor for radon induced lung cancer for teachers in Tulkarem province elementary schools was worked out to be about (9.42± 0.58) $\times 10^{-4}$. (Table 5.21)

5.2.2 Average radon concentration and geographic location dependence

In this survey, the area of Tulkarem province was divided into five regions in order to evaluate the effects of geographic location in indoor radon concentration and for the purpose of statistical evaluation we considered the administrative divisions of Tulkarem municipality; Tulkarem city in the west region of the province, Tulkarem camps in the middle, Al Shaarawih Villages in the north region, Al Kafriaat Villages in the south and Wad Al Shaeer Villages in the east region as shown in Figure 5.2.

The average radon concentrations for each region of the five regions respectively are: 40.16 Bq/m^3, 35.07 Bq/m^3, 48.84 Bq/m^3, 52.07 Bq/m^3 and 27.08 Bq/m^3, and the minimum concentrations were 6.87 Bq/m^3, 5.18 Bq/m^3, 10.27 Bq/m^3, 6.87 Bq/m^3 and 3.48 Bq/m^3, also the maximum concentrations were: 186.75 Bq/m^3, 163.00 Bq/m^3, 168.09 Bq/m^3, 210.51 Bq/m^3 and 54.39 Bq/m^3 (as shown in Table 5.23).

The corresponding effective dose and lifetime risk of radon induced lung cancer respectively was found to be 0.16 ± 0.02 mSv/y and (9.36 ± 1.40) $\times$ 10^{-4} in Tulkarem city, 0.14 ± 0.02 mSv/y and (8.18 ± 0.91) $\times$ 10^{-4} in Tulkarem camps, 0.20 ± 0.02 mSv/y and (11.39 ± 1.24) $\times$ 10^{-4} in Al Shaarawih Villages, 0.21 ± 0.04 mSv/y and (12.14 ± 2.18) $\times$ 10^{-4} in Al Kafriaat Villages and 0.11 ± 0.01 mSv/y and (6.31± 0.49) $\times$ 10^{-4} in Wad Al Shaeer Villages (as shown in Table 5.21).

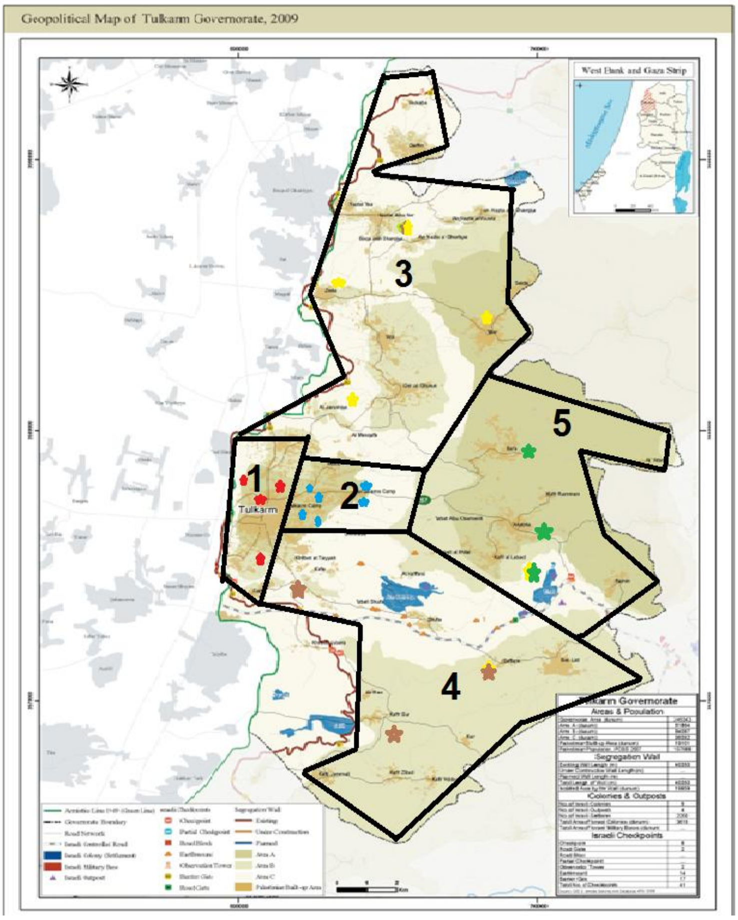

Figure (5.2): The surveyed schools in the five regions shown in Tulkarem province map.

Key for Figure 5.2:

Region # 1= Tulkarem city

Region # 2= Tulkarem camps

Region # 3= Al Shaarawih Villages

Region # 4= Al Kafriaat Villages

Region # 5= Wad Al Shaeer Villages

Table (5.23): The minimum, mean, standard deviation, standard error of the mean and the maximum values of radon concentrations in the five regions.

Region	Min	Max	Mean	SD	SE
City	6.87	186.75	40.16	33.54	6.02
Camps	5.18	163.00	35.07	28.99	3.91
Al Shaarawih Villages	10.27	168.09	48.84	35.58	5.30
Al Kafriaat Villages	6.87	210.51	52.07	51.14	9.34
Wad Al Shaeer Villages	3.48	54.39	27.08	11.94	2.11

Figure 5.3 shows radon concentration distribution in Tulkarem city (region1). It can be seen that 87 % of the detectors have concentration less than 60 Bq/m^3. And just one detector out of 31 detectors has concentration exceed the permissible level of 150 Bq/m^3.

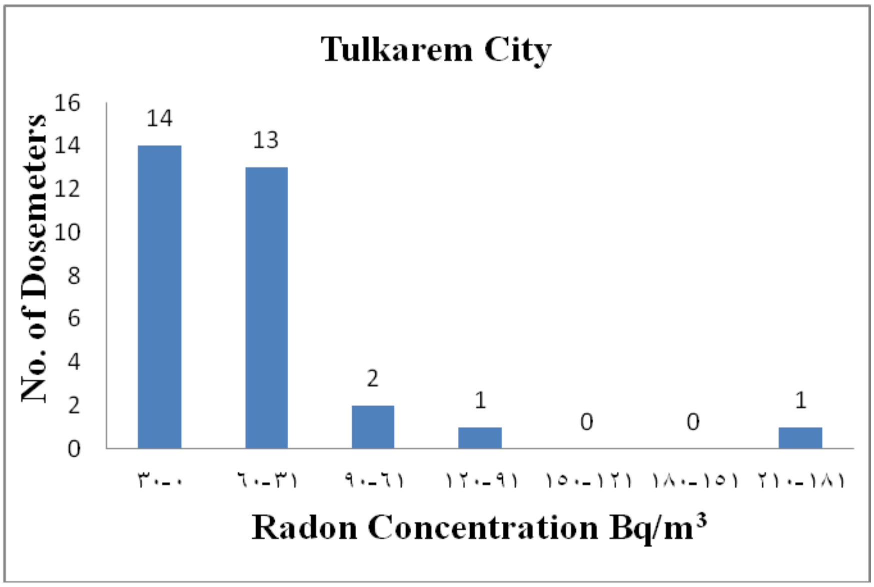

Figure (5.3): Radon concentration distribution in Tulkarem City.

While figure 5.4 shows the concentration levels for Tulkarem camps (region 2). Nearly 87 % of the detectors have concentration less than 60 Bq/m^3. This is exactly the same percentage of region 1.

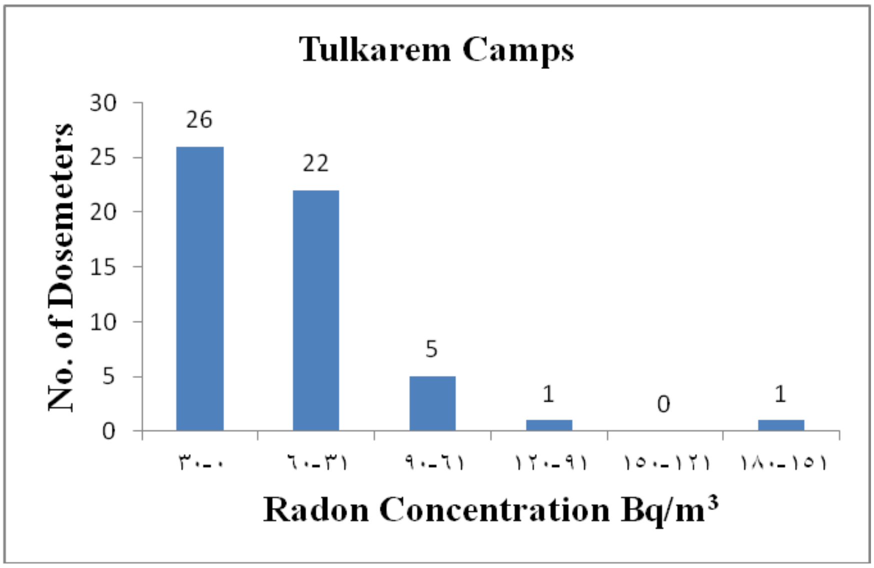

Figure (5.4): Radon concentration distribution in Tulkarem Camps.

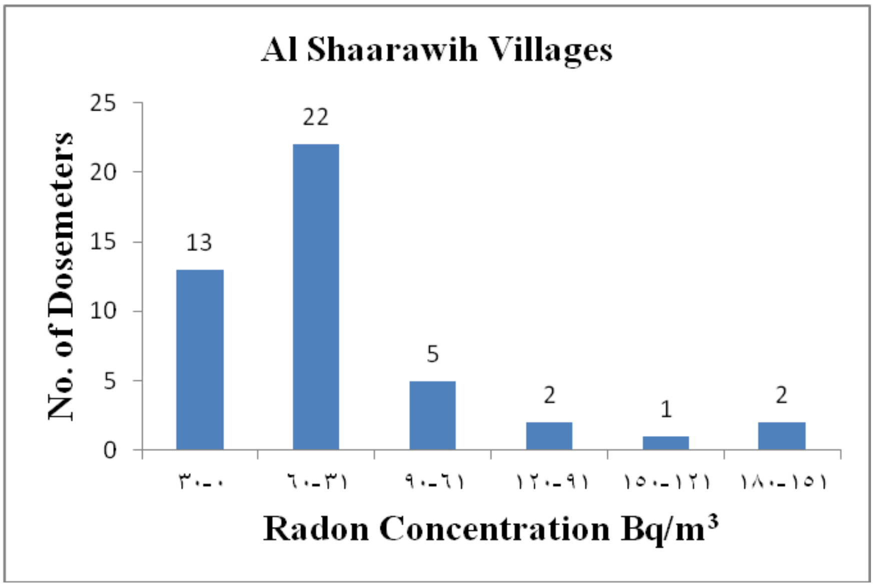

Figure (5.5): Radon concentration distribution in Al Shaarawih Villages.

Figure 5.5 represents the concentration level in Al Shaarawih Villages (region 3). It can be seen that 49 % of the detectors have concentration interval between 30 Bq/m^3 and 60 Bq/m^3. And In figure 5.6 the concentration level of Al Kafriaat Villages (region 4) is presented. It shows that 10% of the detectors have concentration more than 150 Bq/m^3.

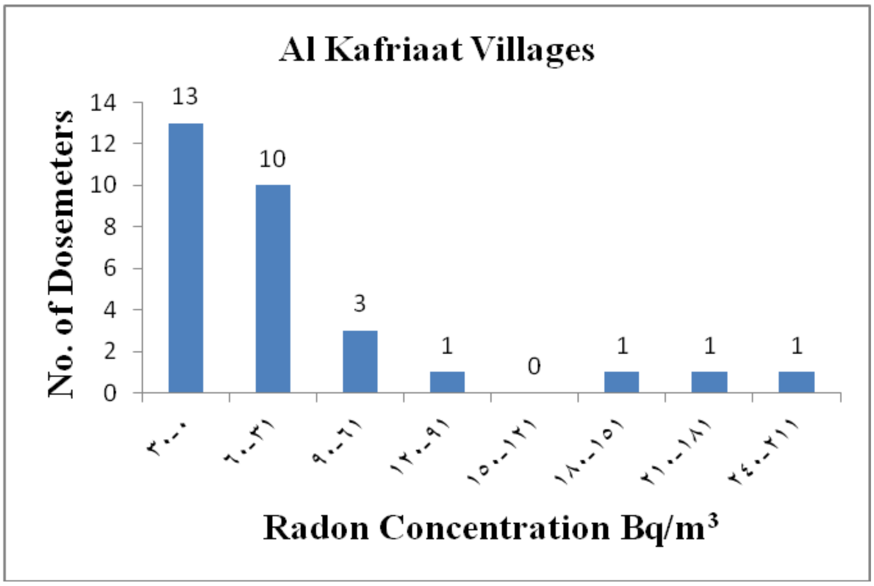

Figure (5.6): Radon concentration distribution in Al Kafriaat Villages.

Figure 5.7 below shows the concentration levels in Wad Al Shaeer Villages (region 5). All of the detectors have concentration less than 60 Bq/m^3.

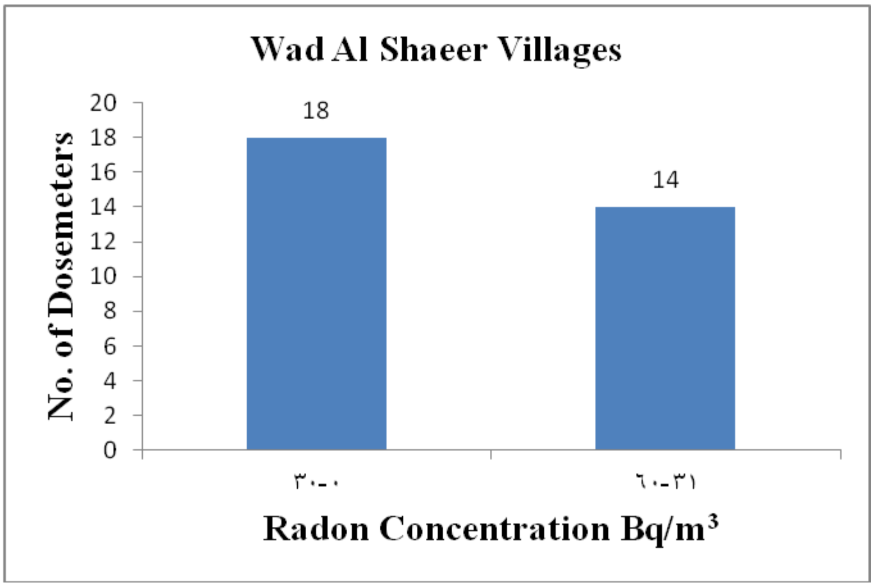

Figure (5.7): Radon concentration distribution in Wad Al Shaeer Villages.

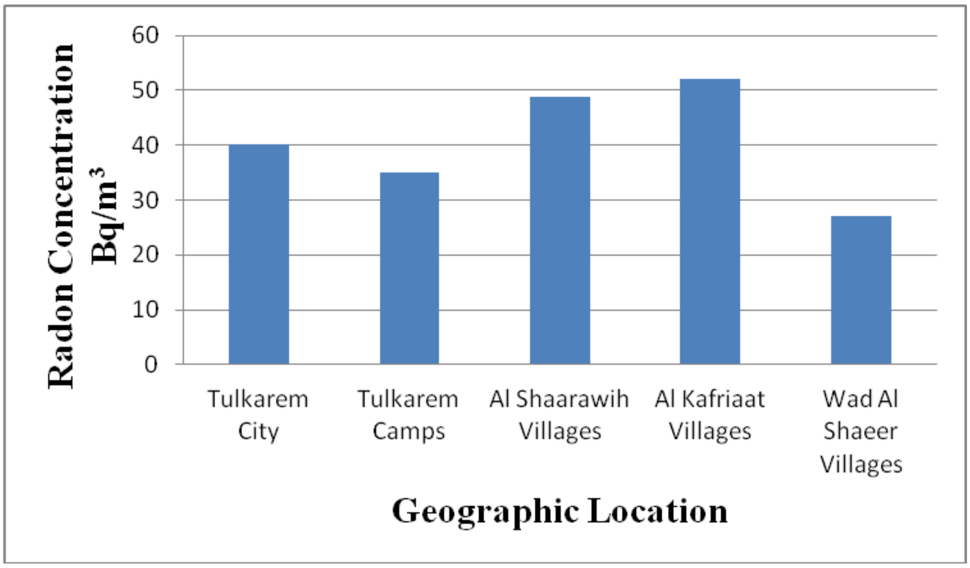

Figure (5.8): The average indoor radon distribution due to geographic location**.**

A statistical T-test was used to investigate if regions in figure 5.8 are significantly different from each other. The groups are considered different if the 95% confidence interval of their average overlap, i.e. T-test with p <

0.05 is considered different. If the results of pairs of regions are compared and the T-test value is calculated then:

For the five regions, region 1 was compared with regions 2, 3, 4 and 5.

Region 1 with region 2: p= 0.482

Region 1 with region 3: p= 0. 283

Region 1 with region 4: p= 0.289

Region 1 with region 5: p= 0.048

From the previous T-test results none of them were significantly different from each other except region 1 with region 5 which represent Tulkarem city with Wad Al Shaeer villages respectively.

For region 2 with regions 1, 3, 4 and 5 we get:

Region 2 with region 1: p= 0.482

Region 2 with region 3: p= 0.04

Region 2 with region 4: p= 0.101

Region 2 with region 5: p= 0.076

The T-test results show that region 2 with region 3 is significantly different, while there was no statistically significant difference when region 2 was compared with region 1, 4 and region 5.

For region 3 with regions 1, 2, 4 and 5 we get:

Region 3 with region 1: p= 0. 283

Region 3 with region 2: p= 0.04

Region 3 with region 4: p= 0.765

Region 3 with region 5: p= 0.000

From the above results we can notice that region 3 was highly significant with region 2 and region 5, where when compared with others was not significantly different.

For region 4 with regions 1, 2, 3 and 5 we get:

Region 4 with region 1: p= 0.289

Region 4 with region 2: p= 0.101

Region 4 with region 3: p= 0.765

Region 4 with region 5: p= 0.014

Region 4 is highly significantly different with region 5, whereas not significantly different with region 1, 3 and region 4.For region 5 with regions 1, 2, 3 and 4 we get:

Region 5 with region 1: p= 0.048

Region 5 with region 2: p= 0.076

Region 5 with region 3: p= 0.0003

Region 5 with region 4: p= 0.014

Region 5 is highly significant with region 1, 3 and region 4, whereas it different but not significant with region 2.

5.2.3 Average radon concentration and school authority dependence

The elementary schools of Tulkarem province authorized by government or UNRWA or private schools. However they have different building style; building material, number of windows in each classroom, painting, maintenance of cracks in the buildings, etc. Also some of them have international building standard as UNRWA schools. This may affects indoor radon concentration level.

As seen in table 5.24 the average radon concentration in government, UNRWA and private schools were 43.84 Bq/m^3, 35.07 Bq/m^3, and 24.03 Bq/m^3 respectively. And the minimum concentrations were 3.48 Bq/m^3, 5.18 Bq/m^3, and 6.87 Bq/m^3 respectively. Also the maximum concentrations were 210.51 Bq/m^3, 163.00 Bq/m^3 and 50.99 Bq/m^3 respectively.

Table (5.24): The minimum, mean, standard deviation, standard error of the mean and the maximum values of radon concentrations in different schools authorities.

Authority	Min	Max	Mean	SD	SE
Government	3.48	210.51	43.84	37.21	3.28
UNRWA	5.18	163.00	35.07	28.99	3.91
Private	6.87	50.99	24.03	14.06	4.69

Figure 5.9 shows radon concentration distribution in governmental schools. It can be seen that nearly 84% of the detectors have concentration less than 60 Bq/m^3. On the other hand 87% of the detectors had radon levels of less than 60 Bq/m^3 in UNRWA schools as seen in figure 5.10.

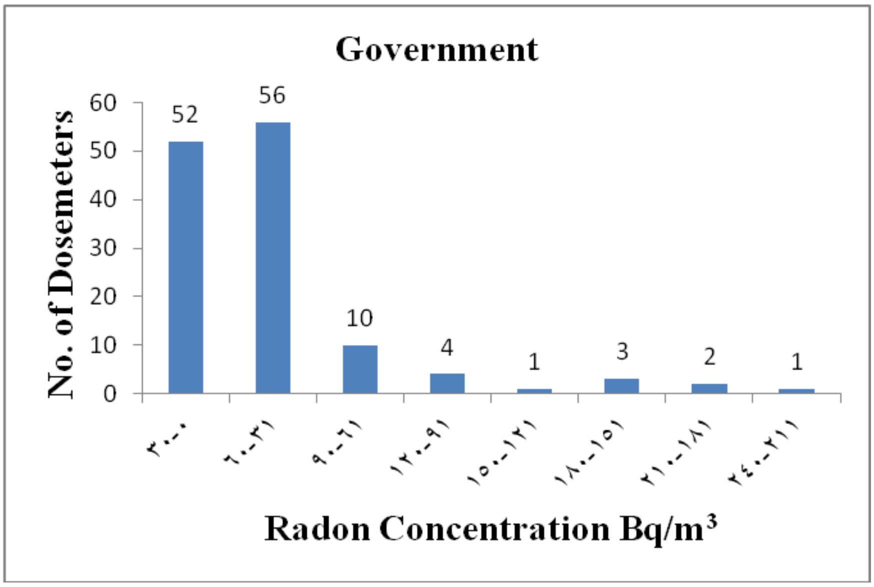

Figure (5.9): Radon concentration distribution in governmental schools.

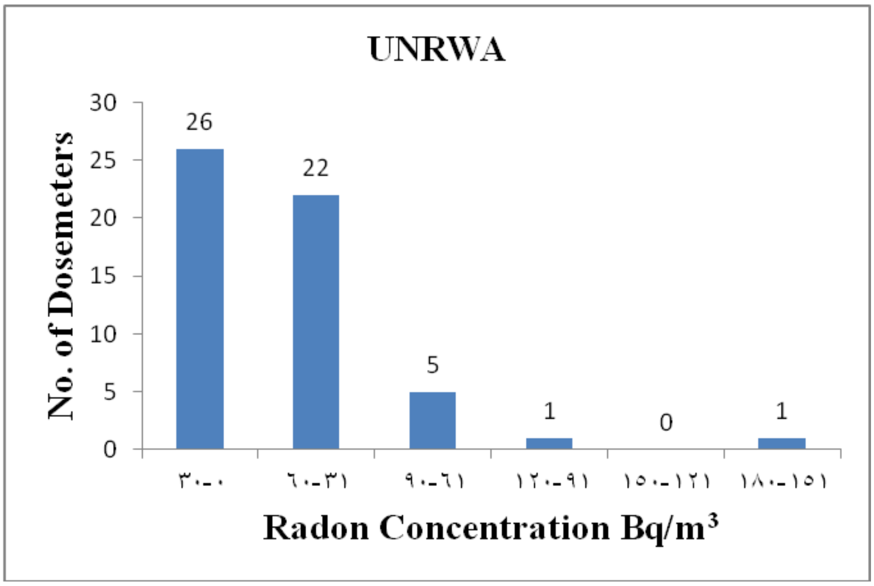

Figure (5.10): Radon concentration distribution in UNRWA schools.

Private schools samples are few (only 9 samples), as shown in Figure 5.11, therefore one cannot draw any conclusion from such few data.

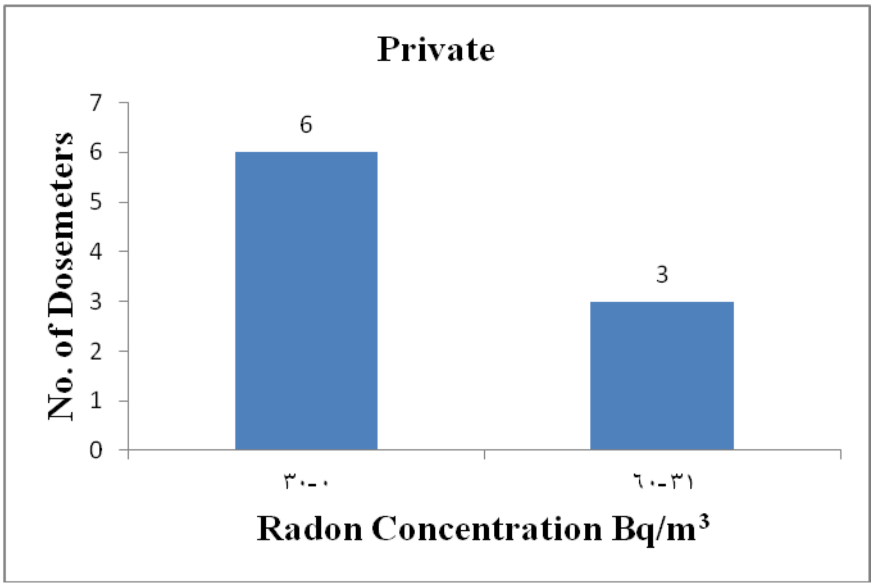

Figure (5.11): Radon concentration distribution in private schools.

Figure 5.12 shows that average radon concentration in the governmental schools was slightly higher than UNRWA and private schools with average concentration of 43.84 Bq/m^3, 35.07 Bq/m^{3}and 24.03 Bq/m^3 respectively.

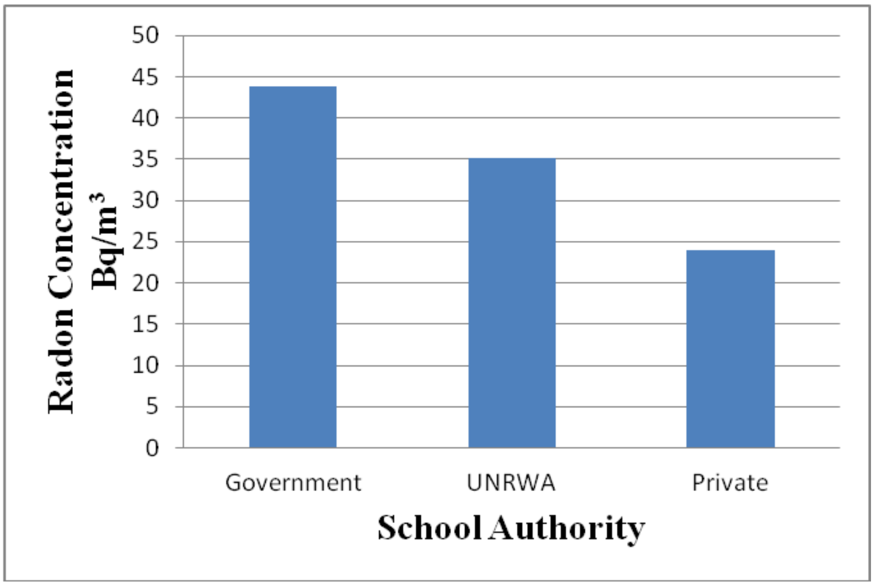

Figure (5.12): The average indoor radon distribution due to school authority.

If t-test is applied on governmental and UNRWA schools distribution then the result would be with a p value of 0.088, which indicates that government and UNRWA schools have different radon concentration but not significantly different.

5.2.4 Average radon concentration and school building age dependence

The probable effects of the age of the school buildings were studied. For this purpose, we classified the schools into two groups: less than 15 years old and greater than 50 years old. The age range for the schools monitored is 4-79 years. 11 schools were less than 15 years old and about 51% of the detectors were distributed in it with an average radon concentration of 35.52 ± 2.85 Bq/m^3 while 9 schools were found to be greater than 50 years old and about 49% of the detectors were distributed in it with an average concentration of 45.58 ± 4.08 Bq/m^3 (see table 5.21 and table 5.25).

Table (5.25): The minimum, mean, standard deviation, standard error of the mean and the maximum values of radon concentrations in new and old school buildings.

Building Age	Min	Max	Mean	SD	SE
New	5.18	186.75	35.52	28.40	2.85
Old	3.48	210.51	45.58	39.59	4.08

From figures 5.13 and 5.14 one can notice that in new school buildings just 3% of the detectors have concentration level more than 90 Bq/m^3 but in old school buildings there are about 11% of the detectors have concentration more than 90 Bq/m^3.

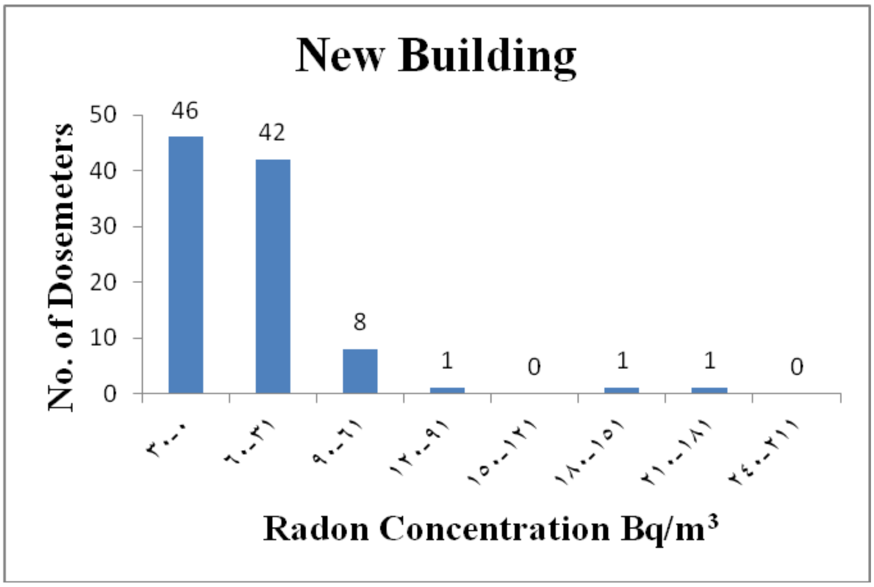

Figure (5.13): Radon concentration distribution in new buildings.

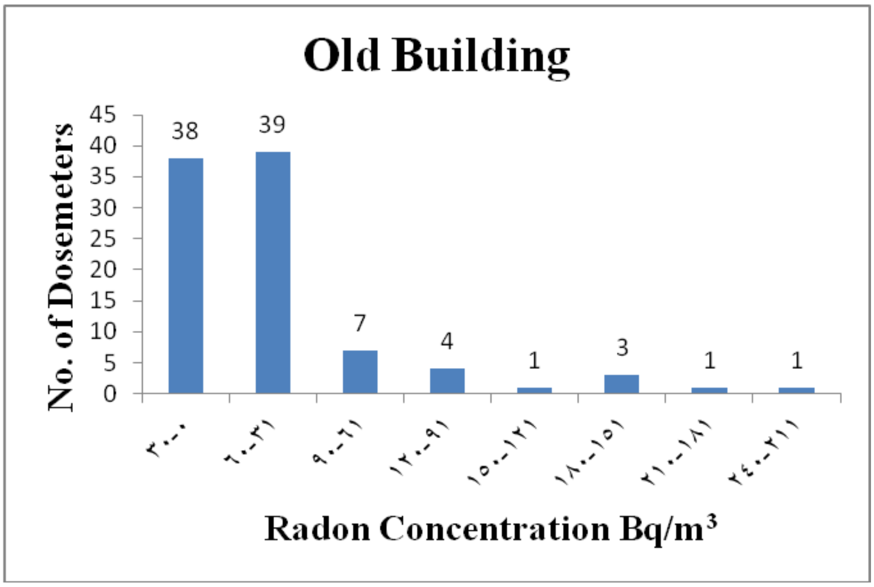

Figure (5.14): Radon concentration distribution in old buildings.

Figure 5.15 shows the average radon concentration distribution in new and old building age. It is clear that radon concentration is higher in old building than new ones.

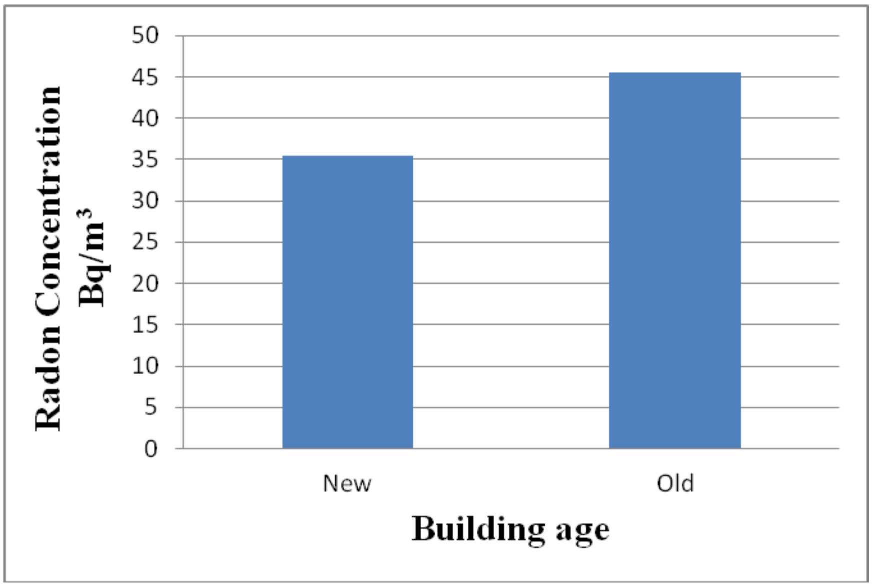

Figure (5.15): The average indoor radon distribution due to building age.

The variation of the age of the schools building with radon concentration levels is considered statistically significant at 95% confidence level (t-test P value = 0.045).

5.2.5 Average radon concentration and floor level dependence

The variation of radon concentration with floor levels was also investigated and this is shown in table 5.26. The average radon concentrations in the ground, first and second floors are: 50.20 ± 4.01 Bq/m^3 , 29.73 ± 1.88 Bq/m^3 and 20.57 ± 5.37 Bq/m^3, respectively. And the maximum values are 210.51, 84.93 and 73.06, respectively.

Table (5.26): The minimum, mean, standard deviation, standard error of the mean and the maximum values of radon concentrations in different floor levels.

Floor Level	Min	Max	Mean	SD	SE
GF	3.48	210.51	50.20	41.48	4.01
F1	5.18	84.93	29.73	15.95	1.88
F2	5.18	73.06	20.57	20.08	5.37

From figures 5.16, 5.17 and 5.18 one can notice that all detectors with radon concentration level more than 90 Bq/m^3 were founded in the ground floors. Neither first floors nor second floors have radon concentration more than 90 Bq/m^3. Also nearly 34% of the detectors have concentration less than 30 Bq/m^3 in the ground floors, while in first floors 51% of the detectors have concentration less than 30 Bq/m^3, but 79% of the detectors have concentration less than 30 Bq/m^3 in the second floors.

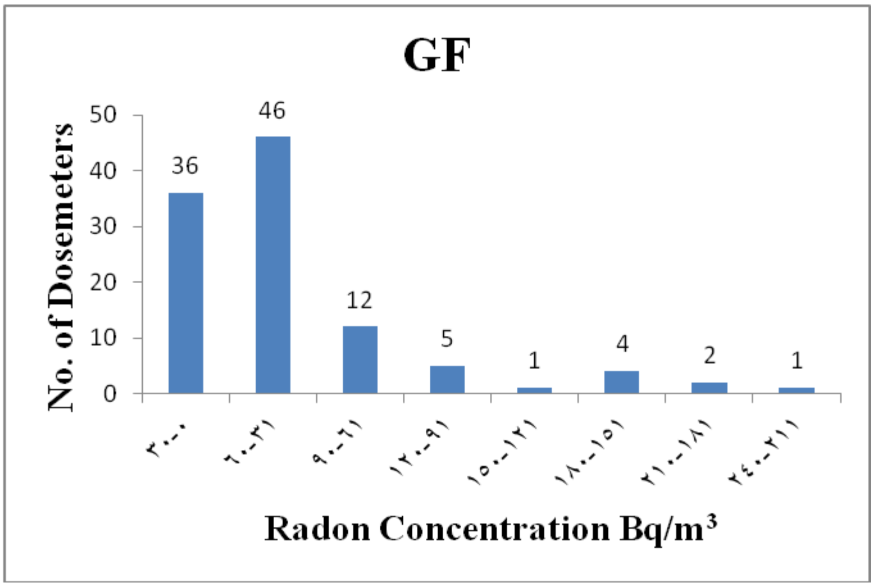

Figure (5.16): Radon concentration distribution in ground floor.

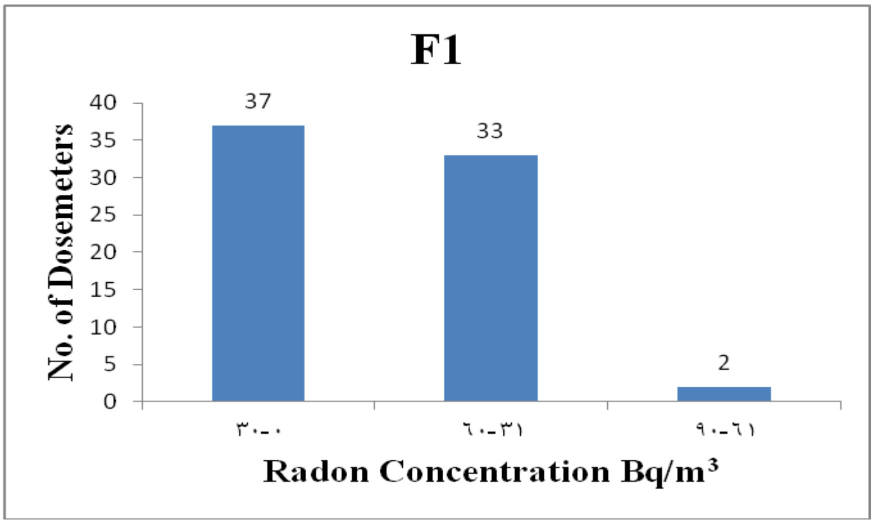

Figure (5.17): Radon concentration distribution in first floor.

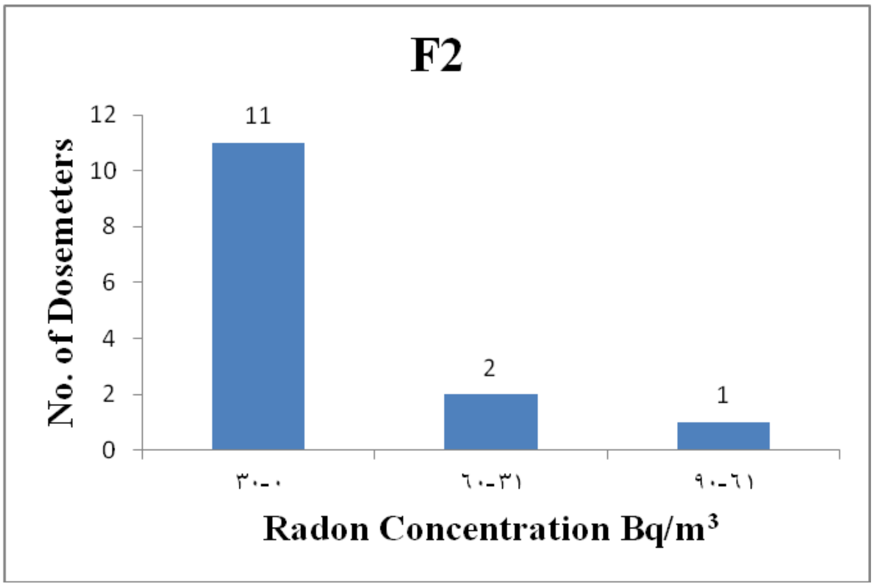

Figure (5.18): Radon concentration distribution in second floor.

Differences in radon concentration levels between the ground floors and first floors (see figure 5.19) were not statistically significant at 95% confidence level but between the ground floors and the second floors were highly statistically significant (t-test, P-value = 0.000).However, there was no significant difference between the first and the second floors.

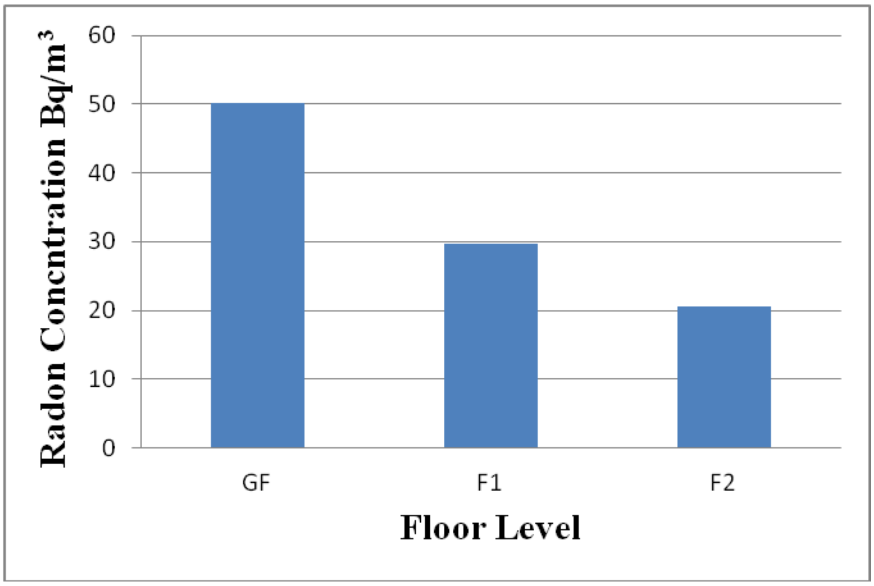

Figure (5.19): The average indoor radon distribution due to floor level.

5.2.6 Result of duplicate and blank CR-39 measurements

In order to analyze the duplicate measurements, the average relative percent difference (ARPD) for each duplicate pair that exceeds 148 Bq/m^3 (4.0 pCi/L) was calculated in table 45.27 and founds to be 11.54% which is far from the limit of EPA (EPA: if the ARPD exceeds 25% then the result is questionable; see section 4.11.1). Also for those with an average pair of less than 148 Bq/m^3, the difference in readings seems to be less than 18.5 Bq/m^3 (0.5 pCi/L) for all pairs, just in one pair the difference exceeds the permissible level of 18.5 Bq/m^3.

In the present study the maximum result of blank measurements was 6.79 Bq/m^3. Therefore, the background radiation was very low. On the contrary, if any of the blank measurements is equal to or greater than 37 Bq/m^3 (1.0 pCi/L), then the accuracy is questionable (EPA, 1998). However, the average number of track was 0.13 (track per field of view) which is subtracted from the average number of tracks for each detector to eliminate any effective background radiation from radon concentration measurements.

Table (5.27): Result of duplicate measurements.

D_1	D_2	Difference	Mean	M ≥ 148	RPD-%
32.33	30.63	1.70	31.48		
15.36	20.45	5.09	17.91		
40.81	52.69	11.88	46.75		
139.24	161.30	22.06	**150.27**	X	14.68
54.39	40.81	13.58	47.60		
20.45	34.02	13.58	27.24		
23.84	40.81	16.97	32.33		
28.93	27.24	1.70	28.09		
193.54	210.51	16.97	**202.03**	X	8.40
86.63	100.21	13.58	93.42		
59.48	91.72	32.24	75.60		
23.84	27.24	3.39	25.54		
35.72	32.33	3.39	34.02		
28.93	35.72	6.79	32.33		
6.87	8.57	1.70	7.72		
20.45	34.02	13.58	27.24		
32.33	40.81	8.48	36.57		
18.75	27.24	8.48	22.99		
13.66	11.96	1.70	12.81		
74.75	86.63	11.88	80.69		
				N=2	23.08

ARPD= TRPD/N

ARPD= 23.08 /2 = 11.54 %

5.3 Average radon concentration in the elementary schools in Tulkarem province by using RAD7 detector.

Five of the twenty elementary schools have successfully completed measurements of indoor radon in four classrooms in each school by using RAD7 continuous monitor (Durridge Company, USA) (see section 4.7.1). All the results which transmitted from RAD7 apparatus by CAPTURE software program were listed in table 5.29 with displayed graph windows shown in figures 5.21, 5.22 and 5.23 and the data summary was summarized in table 5.28. It shows that the average radon concentration in the 20 runs (960 cycles) from 48 hours exposure is 53.0 ± 0.6 Bq/m^3. The uncertainty values calculated and reported by the RAD7 are estimates of precision based on counting statistics alone, and are two-sigma values (or 95% confidence interval) (Durridge Co., 2012).

Table (5.28):RAD7 Data summary

RAD7:	**2627**
'NORMAL' Sensitivity:	0.0130 cpm/(Bq/m^3)
'SNIFF' Sensitivity:	0.00624 cpm/(Bq/m^3)
Num. Data Pts:	960 (Tests 1 to 960)
Time Duration:	2 Months, 4 Days, 21 Hrs., 30 Min.
Avg. Radon:	53.0 +/- 0.6 Bq/m^3
Avg. RH:	4.68%
Avg. Temp:	30.1 ^0C

Table (5.29):RAD7 Run Summaries.

Run #	School Name	Classroom name	# of Cycles	Run Start	Run Stop	Avg. Radon Bq/m^3		
1	Hasan Al Qaisy Basic	1A	48	3/6/2012 8:47	5/6/2012 8:47	195	±	5.0
2	Hasan Al Qaisy Basic	1B	48	5/6/2012 9:43	7/6/2012 9:43	53.1	±	2.5
3	Hasan Al Qaisy Basic	10A	48	7/6/2012 10:57	9/6/2012 10:57	48.9	±	2.4
4	Hasan Al Qaisy Basic	5A	48	10/6/2012 9:37	12/6/2012 9:38	76.9	±	3.0
5	Nur shams Basic Girls	3A	48	12/6/2012 10:55	14/06/12 10:56	44.8	±	2.3
6	Nur shams Basic Girls	1A	48	17/06/12 11:02	19/06/12 11:02	26.6	±	1.8
7	Nur shams Basic Girls	1B	48	19/06/12 11:14	21/06/12 11:14	23.0	±	1.7
8	Nur shams Basic Girls	1C	48	21/06/12 11:22	23/06/12 11:22	20.8	±	1.6
9	Tulkarem B. Boys No.2	1C	48	24/06/12 10:17	26/06/12 10:18	124	±	4.0
10	Tulkarem B. Boys No.2	1A	48	26/06/12 11:53	28/06/12 11:53	63.7	±	2.7
11	Tulkarem B. Boys No.2	1B	48	28/06/12 12:31	30/06/12 12:31	54.0	±	2.5
12	Tulkarem B. Boys No.2	1B	48	1/7/2012 10:22	3/7/2012 10:22	49.3	±	2.4
13	Tulkarem B. Girls No.1	7B	48	5/7/2012 13:03	7/7/2012 13:04	50.1	±	2.4
14	Tulkarem B. Girls No.1	7C	48	8/7/2012 10:51	10/7/2012 10:51	37.2	±	2.1
15	Tulkarem B. Girls No.1	7A	48	10/7/2012 11:26	12/7/2012 11:26	69.9	±	2.9
16	Tulkarem B. Girls No.1	9A	48	15/07/12 10:52	17/07/12 10:52	32.6	±	2.0
17	Mah. Hamshary B. Girls	8B	48	18/07/12 10:42	20/07/12 10:43	24.3	±	1.7
18	Mah. Hamshary B. Girls	8C	48	24/07/12 10:28	26/07/12 10:28	24.0	±	1.7
19	Mah. Hamshary B. Girls	7B	48	26/07/12 11:36	28/07/12 11:37	19.8	±	1.6
20	Mah. Hamshary B. Girls	4A	48	2/8/2012 9:59	4/8/2012 10:00	27.7	±	1.8

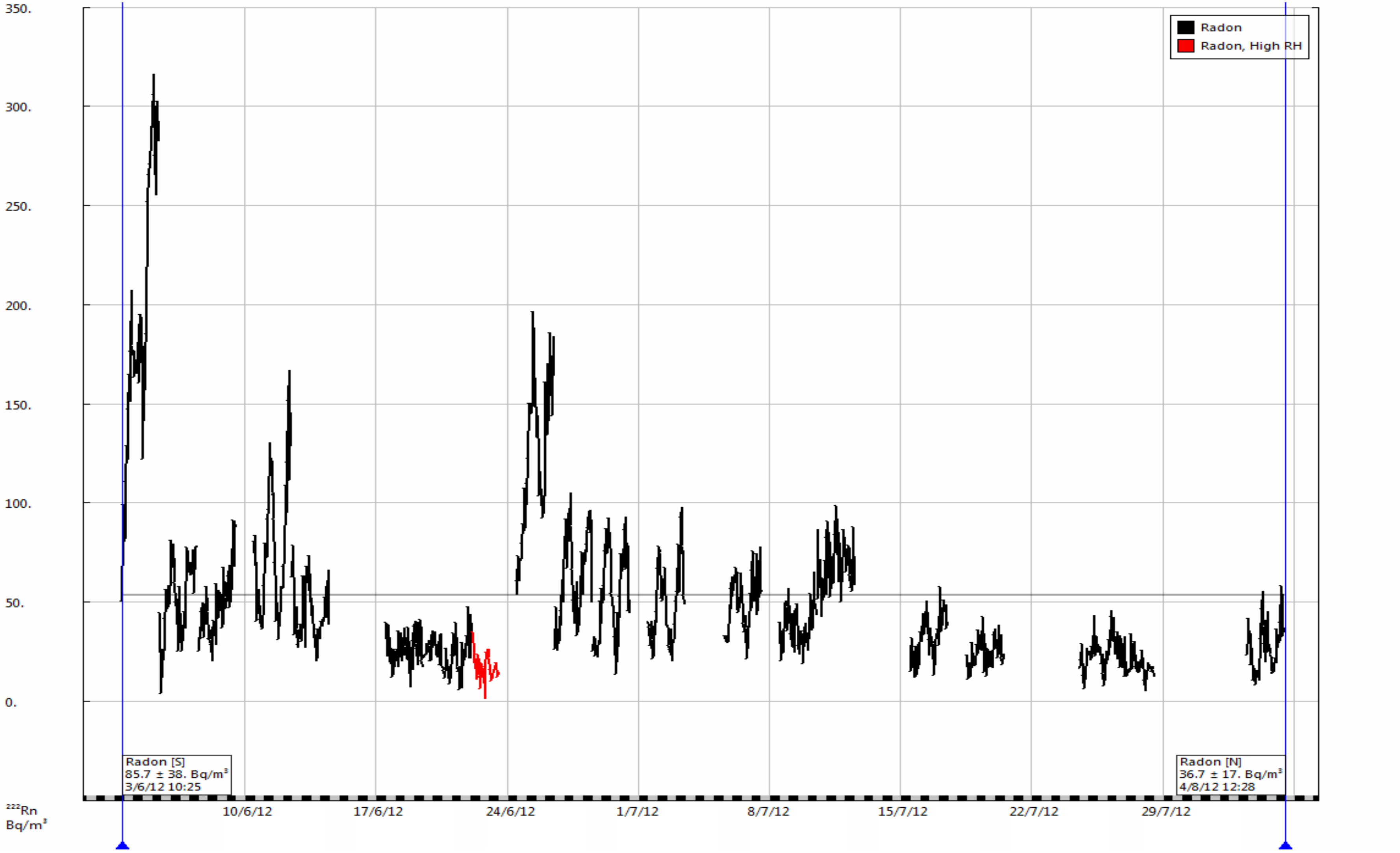

Figure (5.20): RAD7 data displayed in the CAPTURE Graph Window.

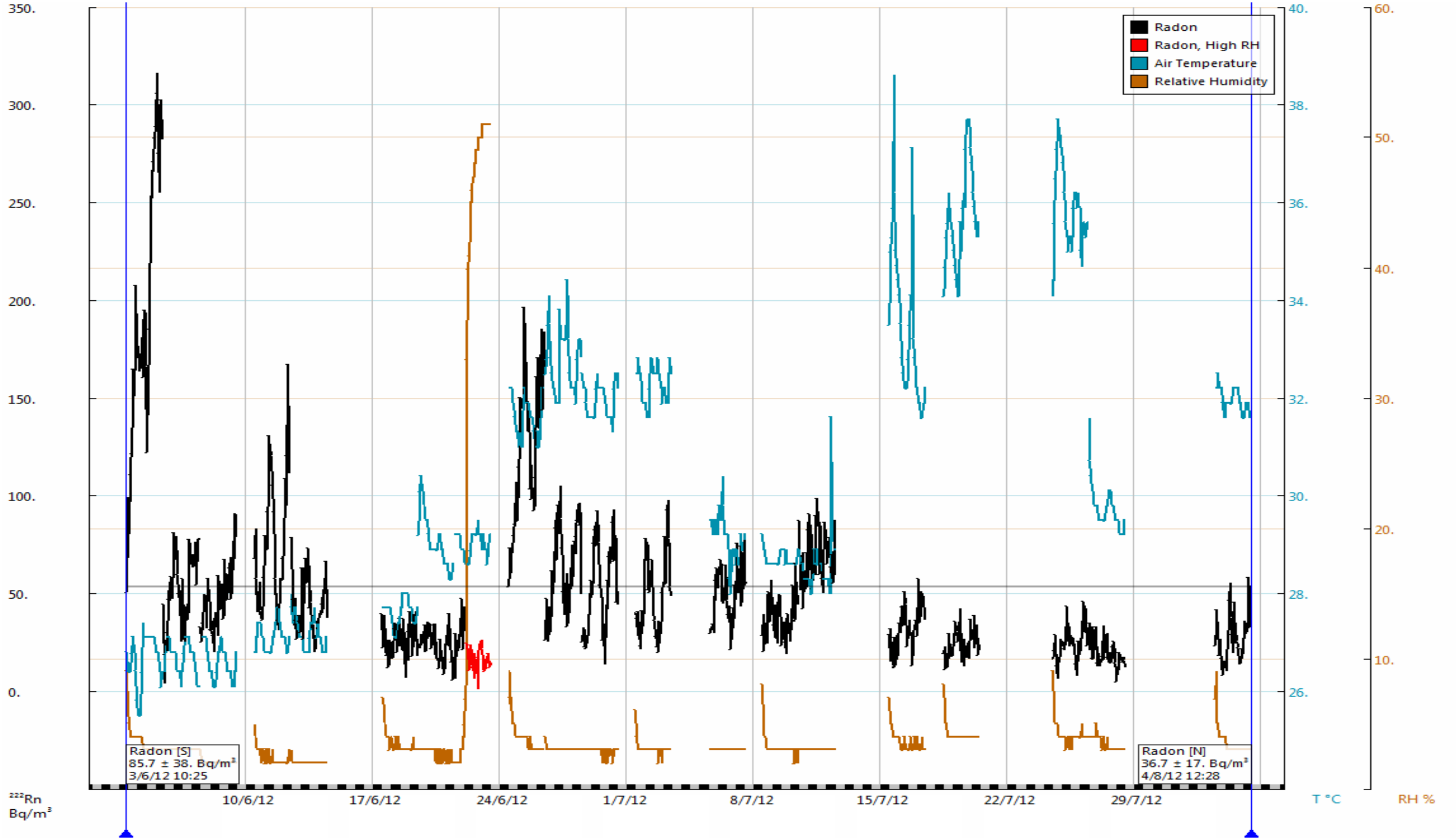

Figure (5.21): RAD7 data with air temperature (T ^{0}C) and relative humidity (RH %) displayed in the CAPTURE Graph Window.

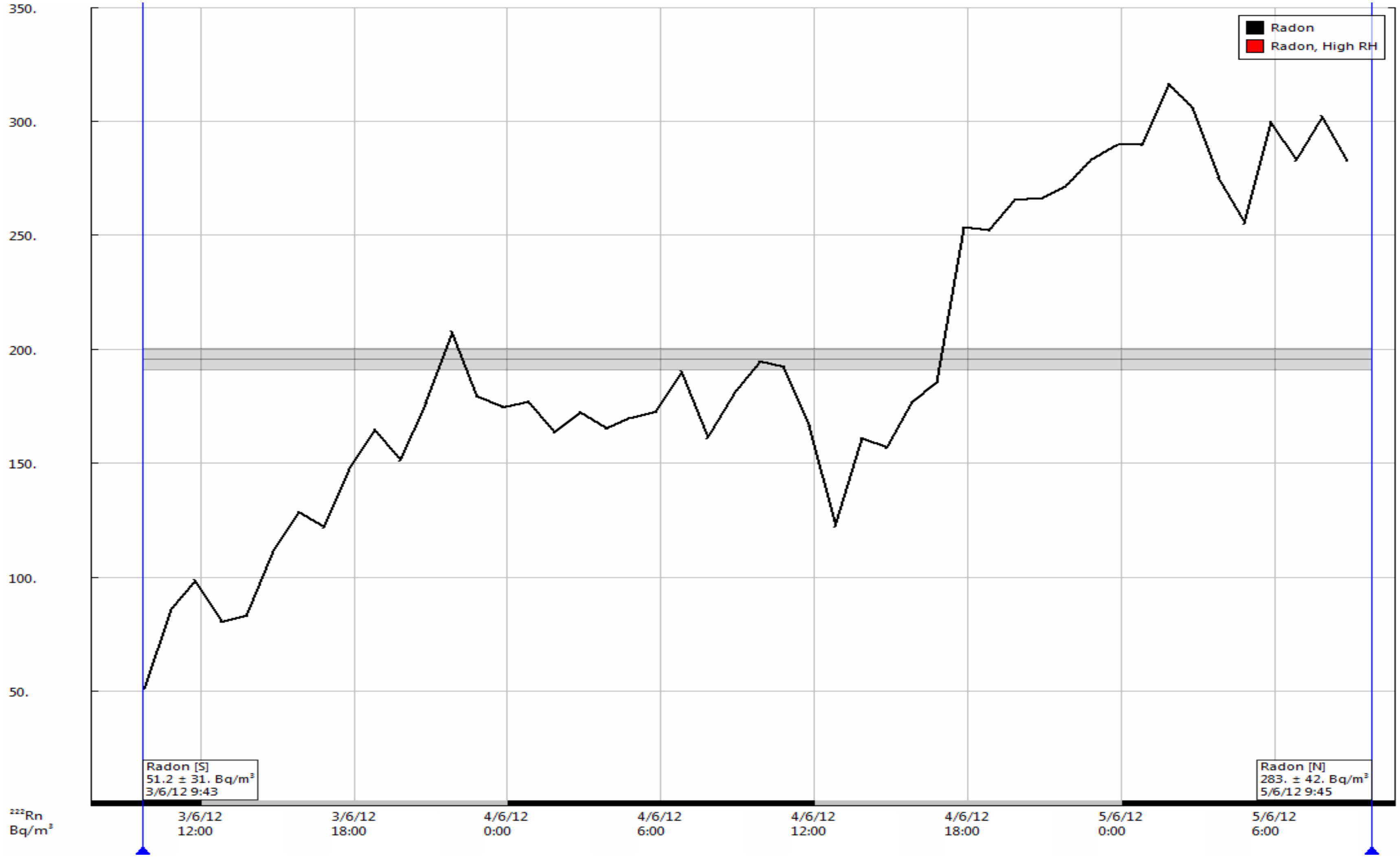

Figure (5.22): RAD7 data of run # 1 displayed in the CAPTURE Graph Window.

The main graph in figure 5.20 displays all data points of the 20 runs it consists of short measurement runs of 48 hours separated by long intervals. Time axis is a black and white line. It is black during morning hours, from midnight to noon and white during afternoon hours from noon to midnight. This can be clearly seen in one run graph as in figure 5.22. The vertical axis scales refer to the radon concentration. Good radon data gives a black line as can be seen in figure 5.21.just in one run the line converts to red because the relative humidity in the measurement chamber rises above 14% then the line color for radon data changes to red.

5.4 Comparison between CR-39 and RAD7 measurements of radon concentration

As can be seen from the data plotted in figure 5.24, a highly linear correlation (R^2 = 0.97) between long term passive detectors by CR-39 and short term active detector by RAD7 for measurements indoor radon concentration. The slope of the linear relation between long and short measurements is 0.96. For CR-39 the measurements were for 3 months, and for RAD7 the measurement was for 48 hours.

The average radon concentrations obtained by CR-39 and RAD7 are illustrated in table 5.30 and they are close to unity which reflect a better average radon concentration of individual measurement.

Table (5.30): Correlation between the radon concentration of RAD7 monitor and the corresponding concentration of CR-39 detectors.

Measurement Place		Run #	Sample #	Radon Concentration Bq/m^3					
School Name	**Classroom name**	**RAD7**	**CR-39**	**RAD7**			**CR-39**		
Hasan Al Qaisy Basic	1A	1	50	195.0	±	5.0	186.8	±	11.6
Hasan Al Qaisy Basic	1B	2	48	53.1	±	2.5	44.2	±	6.5
Hasan Al Qaisy Basic	10A	3	49	48.9	±	2.4	34.0	±	5.5
Hasan Al Qaisy Basic	5A	4	47	76.9	±	3.0	61.2	±	12.1
Nur shams Basic Girls	3A	5	91 & 92	44.8	±	2.3	36.6	±	4.2
Nur shams Basic Girls	1A	6	100	26.6	±	1.8	17.1	±	7.1
Nur shams Basic Girls	1B	7	99	23.0	±	1.7	Lost		
Nur shams Basic Girls	1C	8	97 & 98	20.8	±	1.6	27.2	±	6.8
Tulkarem B. Boys No.2	1C	9	117	124	±	4.0	112.1	±	8.9
Tulkarem B. Boys No.2	1A	10	127	63.7	±	2.7	52.7	±	9.4
Tulkarem B. Boys No.2	1B	11*	119	54.0	±	2.5	44.2	±	10.8
Tulkarem B. Boys No.2	1B	12*	119	49.3	±	2.4	44.2	±	10.8
Tulkarem B. Girls No.1	7B	13	66	50.1	±	2.4	52.7	±	11.2
Tulkarem B. Girls No.1	7C	14	68	37.2	±	2.1	40.8	±	8.4
Tulkarem B. Girls No.1	7A	15	65&67	69.9	±	2.9	80.7	±	5.9
Tulkarem B. Girls No.1	9A	16	62	32.6	±	2.0	23.8	±	5.8
Mah. Hamshary B. Girls	8B	17	27	24.3	±	1.7	Lost		
Mah. Hamshary B. Girls	8C	18	28	24.0	±	1.7	Lost		
Mah. Hamshary B. Girls	7B	19	24	19.8	±	1.6	15.4	±	5.8
Mah. Hamshary B. Girls	4A	20	20 & 30	27.7	±	1.8	25.5	±	1.7

*** Replicate measurement in the same classroom.**

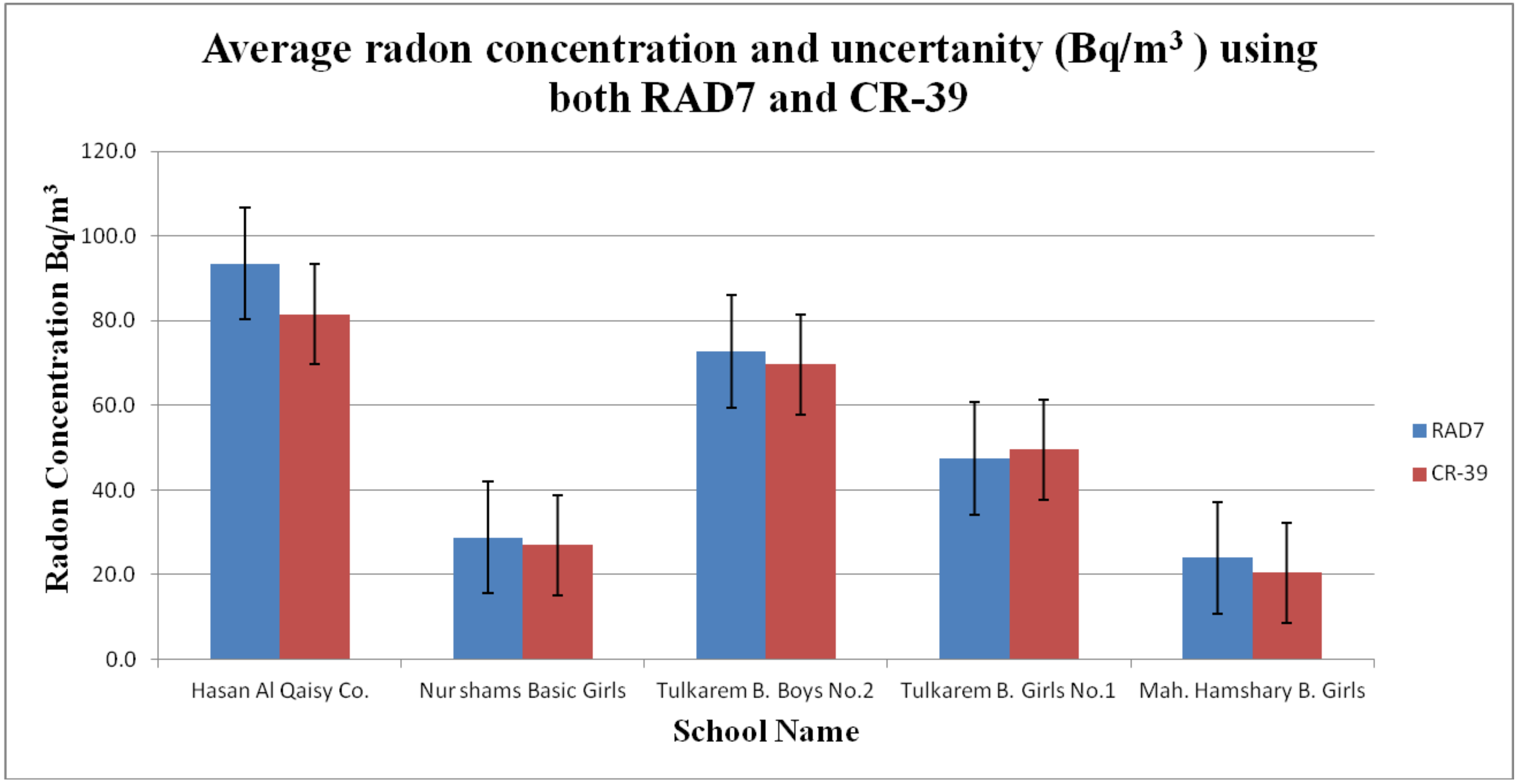

Figure (5.23): Comparison of RAD7 and CR-39 results.

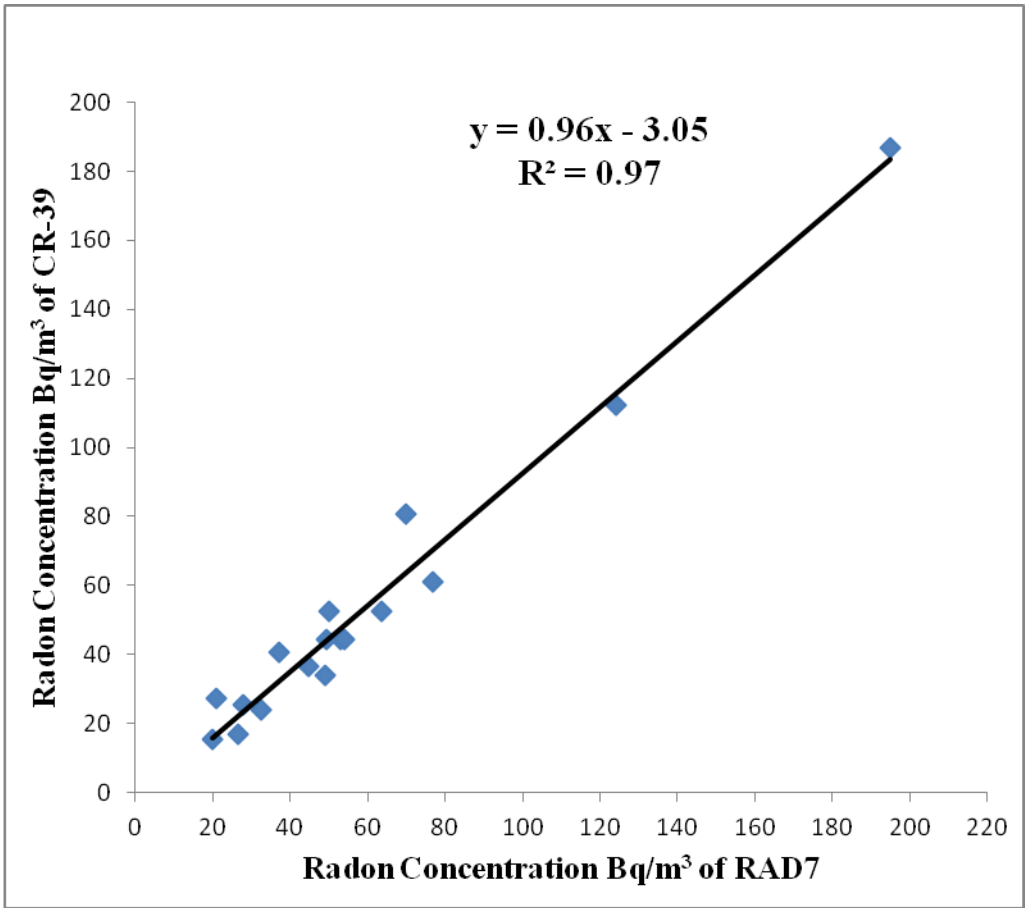

Figure (5.24): Correlation between CR-39 and RAD7 measurements of indoor radon concentration.

Chapter Six

Discussion

6.1 Main study results

The following sections provide the main study outcomes. However, in order to provide further light on the results of this study, table 5.21 which presents most of our data arranged in 5 different subsets could be reviewed.

6.1.1 Average indoor radon concentration, effective dose and lifetime risk

The results obtained from the 193 CR-39 detectors that had been measured show that, the radon concentration in Tulkarem province elementary schools varied from 3.48 to 210.51 with a verage of 40.42 ± 2.49 Bq/m^3, which is within the worldwide average indoor radon concentration of 39 Bq/m^3 and within the level reported in previous studies in other parts of Palestine that carried out in dwellings and work places (Hasan, 1996; Dwaikat, 2001; Daragmeh, 2001; Rasas et al., 2005; Dabayneh, 2006). However, this result is still within normal limits and below the action level of schools set by the international environment organizations 148 Bq/m^3 (EPA, 1993).

The average radon concentration obtained in this study was compared with other similar studies in literature and this is presented in table 6.1. The results vary because different factors determine indoor radon concentrations and one important factor is the geology. Indeed, the present study is the first attempt to evaluate the risk related to radon presence in

Tulkarem schools. The total number of locations measured should be extended in the future.

Table (6.1): Comparison of the present study results in the schools with previous studies.

Country (region)	Reference	Radon concentration (Bq/m^3)
Palestine (Tulkarem)	Present study	40.4± 2.5
Palestine (Hebron)	(Dabayneh, 2006)	34.1
Jordan (Amman)	(Kullab et al., 1997)	76.8
Iraq (Iraqi Kurdistan)	(Ismail, 2006)	97±27
Saudi Arabia (Zulfi)	(Al-Mosa, 2007)	74.7 ±3.0
Tunisia (Tunis)	(Labidi et al., 2010)	26.9
Nigeria (Oke-Ogun)	(Obed et al., 2011)	45±27
Italy (Parma)	(Malanca et al., 1998)	30±19
Greece (Xanthi)	(Clouvas et al., 2009)	231

Obviously, the radon concentrations in the present study were obtained in the summer time period, in demi-close conditions. At least 60 days under close conditions during the summer holiday, and the rest 30 days under normal operating conditions of schools. These demi-close conditions may be the same conditions of normal operation in winter season as windows and doors are kept close for children's safety and conservation of heating energy (see chapter four).

However, there are some high radon sites (4%) which had concentrations above 148 Bq/m^3. This high radon sites may be due to radon gas diffusion from the earth through the noticeable cracks in the floors and the walls of the classrooms, since all these classrooms were located in the ground floor level. While it is known that cracks through the building shell, caused by shrinkage or by ground packing, represent important routes of radon gas entry (Malanca *et al*., 1998).

The effective dose value of 0.17 ± 0.01 mSv/y is indeed low compared to the global limit of 1.3 mSv/y (UNSCEAR, 2000). We think that this low value of the effective dose is related to the very low occupancy rate as the students and the teachers spend just 13% of the year in the schools, while in other studies the occupancy factor of the students was 14% (Clouvas et al., 2011), 18% (Clouvas et al., 2009) and was overestimated 80% (Abel-Ghany, 2008). On the other hand, one must remember that the students < 12 years old may receive the same dose multiplied by a factor of 1.5 (Abumurad and Al-Omari, 2008).

The teachers of the elementary schools in Tulkarem province are subjected on the average to a lifetime lung cancer risk of about 0.09% associated to a chronic exposure to indoor radon. While in another study in Palestine in Nablus city the lifetime lung cancer risk was vary from 0.02% to 0.09% (Dwaikat, 2001).

6.1.2 Effects of geographic location, school authority, building age and floor level

Radon concentration measured in the five regions (see figure 5.8) show small differences between regions. This may be due to similar soil and rock formation except in Wad Al Shaeer Villages region which recorded the significantly lower radon concentration value than other regions and all sites in this region have radon concentration less than 60

Bq/m^3. The variation of radon concentrations between Wad Al Shaeer Villages region and other regions can be attributed to the geological structure of the sites. However, the higher average radon concentration was founded in Al Kafriaat villages region. 10% of the detectors distributed in this region have concentration more than 150 Bq/m^3. This may due to cracks and poor painting of the classrooms building.

Another factor, the school authority was studied. We found that government and UNRWA schools have different radon concentration (43.84 vs. 35.07 Bq/m^3) but not significantly different. So, the building style of UNRWA schools didn't affect the results of radon concentrations.

The probable effects of the age of the school buildings were studied and the variation of the age of the schools with radon concentration levels was considered statistically significant. This variation may be due to noticeable cracks in the floors and the walls of the old buildings schools and that it could be related to poor painting. It is reasonable to expect that old buildings are likely to present larger and more numerous cracks than modern ones (Malanca *et al*., 1998). Another factor explaining the high level of radon in the old building is that before five decades different building materials had been used. The various types of building materials used for the construction of the schools may influence the indoor radon concentration (Kullab et al., 1997).

Differences in radon concentration levels between the ground floors and the second floors were highly statistically significant (t-test, P-value =

0.000). This difference could be due to the different air exchange rate with the outdoor environment in the different floors (Obed et al., 2011) which confirmed the influence of soil as main source of indoor radon (Abd El-Zaher and Fahmi, 2008).

6.1.3 Quality assurance

This is the first study in Palestine that take the duplicate measurements into account and described the quality assurance in details, which is an essential part of any radon measurements according to the EPA (EPA, 1998; EPA, 1993).

The duplicate measurements indicated that the present data is highly precise. Just in one pair of the duplicate measurements (less than 148 Bq/m^3) the difference exceeds the permissible level of 18.5 Bq/m^3 (Condon et al, 1995). This may be refereed to that one dosimeter of that pair was moved from their location.

The maximum result of blank measurements was 6.79 Bq/m^3. Therefore, the background radiation was very low and it was already eliminated from radon concentration measurements.

6.1.4 The correlation between the active method and the passive method

The results of the present work indicate that the schools under investigation have comparable radon concentrations in the five schools tested form both methods (as shown in figure 5.23). A highly significant correlation (R^2 = 0.97) between the results of the passive method and active method for measure radon concentration in the selected schools. This may indicate that the radon concentrations in case of schools can be estimated either from long measurements using CR-39 or from short measurements using RAD7. As the risk of lung cancer increases with increasing radon exposure, the preferred measure of this risk is the long term average radon level.

The correlation between passive method and active method was calculated in previous works (Ismail and Jaafar, 2010), (Condon et al., 1995) and (Al-Jarallah et al., 2008) and found to be R^2 = 0.78, 0.65 and 0.38 respectively.

6.2 Conclusions

On the basis of this study the following conclusions were drawn:

1. This study is the first indoor radon concentration measurement that is performed in the area of Tulkarem province (West Bank- Palestine). Therefore it provides preliminary data about indoor radon levels in Tulkarem province elementary schools as a baseline study for a wider future national survey in the whole West Bank schools.

2. The overall average indoor radon concentration of the twenty schools monitored using the SSNTDs technique was 40.42 ± 2.49 Bq/m^3. This is much lower than the USA intervention radon level of 150 Bq/m^3. Hence there are no high potential hazards in the schools investigated in this study.

3. The radon concentrations measured in this study are nearly close to the concentration level reported in previous works in Palestine (Dabayneh, 2006; Rasas et al., 2005; Hasan, 1996). But they are lower than those reported in other studies (Abu-Samreh, 2005) and (Daragmeh, 2001). The higher radon concentration may be attributed to the geographical location and to the ventilation as well as the climate condition.

4. The average annual effective dose that students and teachers exposed to was found to be 0.17 ± 0.01 mSv/y which is lower than the global limit of 1.3 mSv/y. This dose corresponds to an excess lifetime lung cancer risk of about 0.09%.

5. In exception of Wad Al Shaeer region there was no strong correlation between radon concentrations and geographic location of the schools. This may due to little differences in the geological formation of the selected locations.

6. No relation is observed between radon concentrations and schools authorities as well as building style of the schools.

7. Old buildings schools have significantly higher radon concentrations than new ones.

8. The variation of radon concentration levels with the floors confirmed the influence of soil as main source of indoor radon.

9. The results of indoor radon passive detectors are in agreement with the indoor radon active monitor.

10. Average radon concentrations, obtained by three-month exposures of some distributed etched track detectors type CR-39 were correlated with average radon concentrations obtained from twenty runs by two day continuous measurements performed by RAD7 apparatus. The correlation between the two measurements was highly significant showing a linear correlation coefficient of 0.97.

11. Quality assurance measurements indicated that the data obtained are of the required precision and accuracy.

6.3 Recommendations

1. Long-term (CR-39) measurements is the most reliable method for measuring long-term average radon levels in schools, and should be used in deciding the need for mitigation.

2. Short-term (RAD7) measurements are useful in identifying areas within a school with elevated radon levels, but may not always accurately estimate the long-term average radon level.

3. The relatively high concentrations in some classrooms can be reduced by increasing the natural ventilation by opening the windows and doors or by supplying these classrooms with suction fans.

4. A summary of this study should be made available to the schools authorities for reference.

5. Continue radon studies in Tulkarem province especially in dwellings to determine the extent and severity of radon problems in this province.

6. There are some districts in West Bank that have not been yet tested for radon, i.e. Jenin , Jericho, and Qalqilia. Therefore, it is recommended that those areas should be studied.

7. Quality assurance tests (duplicate and blank detectors) must be an integral part of any radon measurements study in the future to insure the reliability of the results.

8. In estimation of the effective dose in case of schools the occupancy factor must be correctly calculated to avoid overestimation of the effective dose.

9. The RAD7 manual must be read carefully before using the RAD7 apparatus in order to get reliable data, to avoid measurements repeating and to improve the machine.

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Annexes

Annex A: Tracks density of CR-39 detectors.

		Tracks Density (FoV)															Average Tracks		Average Tracks Density					Radon Concentration		
		Number of Field of View															Tracks / FoV									
Serial No.	**Sample No.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**Average**	**± Error**	**Net average**	**(T/cm²)**	**± (T/cm²)**	**(T/cm².d)**	**± (T/cm².d)**	**Bq/m³**	**±**	**Error**
1	1	1	2	2	0	3	1	0	1	1	0	3	2	4	3	0	1.53	0.34	1.40	264.28	63.31	2.90	0.70	35.72	±	8.56
2	2	0	0	0	1	1	1	2	0	1	2	2	0	1	0	1	0.80	0.20	0.67	126.18	37.66	1.39	0.41	17.05	±	5.09
3	3	0	0	0	0	0	1	0	0	0	1	1	2	0	1	1	0.47	0.17	0.34	63.40	31.12	0.70	0.34	8.57	±	4.21
4	4	0	1	0	1	0	1	0	1	0	1	0	0	0	1	0	0.40	0.13	0.27	50.85	24.66	0.56	0.27	6.87	±	3.33
5	5	1	0	2	0	1	0	0	0	3	0	2	0	1	1	2	0.87	0.26	0.74	138.73	48.16	1.52	0.53	18.75	±	6.51
6	6	0	1	2	0	3	0	1	1	0	1	3	2	4	0	3	1.40	0.35	1.27	239.17	65.75	2.63	0.72	32.33	±	8.89
7	7	1	1	1	1	2	1	0	0	1	1	0	1	0	0	3	0.87	0.22	0.74	138.73	40.54	1.52	0.45	18.75	±	5.48
8	8	3	3	0	3	0	1	2	0	0	0	2	1	2	1	0	1.20	0.31	1.07	201.51	58.70	2.21	0.65	27.24	±	7.93
9	9	2	2	2	1	2	2	1	3	2	5	2	1	2	2	3	2.13	0.26	2.00	377.28	48.16	4.15	0.53	50.99	±	6.51
10	10B	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0.13	0.09	0.13	25.11	17.11	0.28	0.19	3.39	±	2.31
11	11	0	1	2	0	1	3	0	0	1	2	1	1	1	4	2	1.27	0.30	1.14	214.06	56.55	2.35	0.62	28.93	±	7.64
12	12	0	0	1	2	1	1	0	0	1	1	0	0	0	0	0	0.47	0.17	0.34	63.40	31.12	0.70	0.34	8.57	±	4.21
13	13	0	0	0	1	0	0	0	3	0	0	1	0	0	1	0	0.40	0.21	0.27	50.85	40.27	0.56	0.44	6.87	±	5.44
14	14	0	1	0	0	0	0	1	2	0	1	1	0	0	0	1	0.47	0.17	0.34	63.40	31.12	0.70	0.34	8.57	±	4.21

		Tracks Density (FoV)															Average Tracks		Average Tracks Density					Radon Concentration		
		Number of Field of View															Tracks / FoV									
Serial No.	Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average	± Error	Net average	(T/cm²)	± (T/cm²)	(T/cm².d)	± (T/cm².d)	Bq/m³	±	Error
15	15	1	3	0	0	0	3	1	0	0	1	1	1	4	1	0	1.07	0.33	0.94	176.40	62.23	1.94	0.68	23.84	±	8.41
16	16	0	0	1	0	2	3	1	2	4	1	2	1	1	3	1	1.47	0.31	1.34	251.73	57.73	2.77	0.63	34.02	±	7.80
17	17	1	0	2	1	2	1	0	2	2	2	1	1	2	1	0	1.20	0.20	1.07	201.51	37.66	2.21	0.41	27.24	±	5.09
18	18	0	0	0	0	0	1	2	2	0	0	2	3	0	0	1	0.73	0.27	0.60	113.62	50.22	1.25	0.55	15.36	±	6.79
19	19	0	0	0	1	0	3	3	0	0	1	1	0	0	1	1	0.73	0.27	0.60	113.62	50.22	1.25	0.55	15.36	±	6.79
20	20	0	1	2	1	2	0	2	2	0	1	2	0	0	1	2	1.07	0.23	0.94	176.40	42.97	1.94	0.47	23.84	±	5.81
21	21	0	0	2	0	1	1	1	2	0	1	2	1	0	2	1	0.93	0.21	0.80	151.29	38.84	1.66	0.43	20.45	±	5.25
22	23	6	2	1	0	0	1	2	1	3	2	1	3	0	3	0	1.67	0.42	1.54	289.39	79.40	3.18	0.87	39.12	±	10.73
23	24	0	0	0	1	0	1	0	1	3	0	2	1	0	1	1	0.73	0.23	0.60	113.62	42.97	1.25	0.47	15.36	±	5.81
24	25	1	0	1	0	1	1	1	0	2	0	0	1	3	0	1	0.80	0.22	0.67	126.18	41.91	1.39	0.46	17.05	±	5.66
25	26	3	2	0	1	3	2	2	5	3	2	2	3	2	1	1	2.13	0.31	2.00	377.28	57.73	4.15	0.63	50.99	±	7.80
26	29	0	5	3	4	4	5	6	6	4	2	0	1	2	2	4	3.20	0.51	3.07	578.15	95.85	6.35	1.05	78.15	±	12.96
27	30	2	0	1	2	2	1	2	0	1	2	1	1	0	1	2	1.20	0.20	1.07	201.51	37.66	2.21	0.41	27.24	±	5.09
28	36	2	2	3	6	3	3	1	1	0	3	4	2	1	2	4	2.47	0.39	2.34	440.05	73.21	4.84	0.80	59.48	±	9.90
29	37	3	4	5	1	3	3	3	2	2	7	3	5	4	5	6	3.73	0.42	3.60	678.59	78.98	7.46	0.87	91.72	±	10.68
30	38	2	0	2	0	1	2	1	3	2	2	2	1	0	2	1	1.40	0.24	1.27	239.17	44.26	2.63	0.49	32.33	±	5.98
31	39	1	1	2	1	2	2	1	3	1	0	0	0	0	1	2	1.13	0.24	1.00	188.95	44.52	2.08	0.49	25.54	±	6.02

		Tracks Density (FoV)															Average Tracks		Average Tracks Density					Radon Concentration		
		Number of Field of View															Tracks / FoV									
Serial No.	Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average	± Error	Net average	(T/cm^2)	$\pm (T/cm^2)$	$(T/cm^2.d)$	$\pm (T/cm^2.d)$	Bq/m^3	±	Error
32	41	2	0	1	4	2	6	2	1	1	1	4	2	2	3	3	2.27	0.40	2.14	402.39	74.58	4.42	0.82	54.39	±	10.08
33	42	1	0	2	2	2	0	1	1	0	0	1	0	1	2	0	0.87	0.22	0.74	138.73	40.54	1.52	0.45	18.75	±	5.48
34	43	3	2	7	1	0	3	1	1	1	2	5	2	0	1	3	2.13	0.49	2.00	377.28	91.65	4.15	1.01	50.99	±	12.39
35	44	2	0	3	3	2	2	0	2	1	0	3	1	3	2	0	1.60	0.31	1.47	276.84	57.53	3.04	0.63	37.42	±	7.78
36	45	1	0	2	2	1	0	3	2	2	0	1	1	2	2	1	1.33	0.23	1.20	226.62	43.75	2.49	0.48	30.63	±	5.91
37	46	1	1	3	1	2	0	0	1	2	2	0	1	0	3	2	1.27	0.27	1.14	214.06	50.22	2.35	0.55	28.93	±	6.79
38	47	3	2	1	3	3	2	5	1	0	4	6	0	1	2	5	2.53	0.48	2.40	452.61	89.79	4.97	0.99	61.18	±	12.14
39	48	2	0	2	3	1	4	2	1	1	2	2	1	3	2	2	1.87	0.26	1.74	327.06	48.16	3.59	0.53	44.21	±	6.51
40	49	1	2	2	3	2	2	1	1	2	0	2	0	1	1	2	1.47	0.22	1.34	251.73	40.54	2.77	0.45	34.02	±	5.48
41	50	7	8	6	9	6	9	6	5	10	11	7	7	6	9	6	7.47	0.46	7.34	1381.67	85.94	15.18	0.94	186.75	±	11.62
42	52	1	0	0	0	1	0	1	1	0	2	1	0	0	1	0	0.53	0.17	0.40	75.96	31.12	0.83	0.34	10.27	±	4.21
43	53	0	1	1	0	1	1	1	0	0	1	1	0	1	0	1	0.60	0.13	0.47	88.51	24.66	0.97	0.27	11.96	±	3.33
44	54	0	0	0	1	0	2	0	0	1	0	1	0	0	1	0	0.40	0.16	0.27	50.85	30.75	0.56	0.34	6.87	±	4.16
45	55	0	1	0	0	0	1	1	1	0	0	0	1	1	0	1	0.47	0.13	0.34	63.40	25.11	0.70	0.28	8.57	±	3.39
46	56	0	0	0	1	0	0	0	1	1	1	0	0	1	0	0	0.33	0.13	0.20	38.29	23.73	0.42	0.26	5.18	±	3.21
47	57	0	1	0	1	1	0	0	1	0	1	1	0	0	0	0	0.40	0.13	0.27	50.85	24.66	0.56	0.27	6.87	±	3.33
48	58	0	1	0	0	0	1	1	0	0	1	0	1	0	1	1	0.47	0.13	0.34	63.40	25.11	0.70	0.28	8.57	±	3.39

		Tracks Density (FoV)															Average Tracks		Average Tracks Density					Radon Concentration		
		Number of Field of View															Tracks / FoV									
Serial No.	Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average	± Error	Net average	(T/cm²)	± (T/cm²)	(T/cm².d)	± (T/cm².d)	Bq/m³	±	Error
49	59	3	4	2	3	1	2	2	2	0	1	1	2	1	0	2	1.73	0.28	1.60	301.95	53.48	3.32	0.59	40.81	±	7.23
50	61	1	1	1	1	0	1	0	0	1	2	1	0	0	1	1	0.73	0.15	0.60	113.62	28.86	1.25	0.32	15.36	±	3.90
51	62	0	0	2	1	1	1	0	3	0	2	1	1	2	1	1	1.07	0.23	0.94	176.40	42.97	1.94	0.47	23.84	±	5.81
52	63	1	1	2	2	1	1	1	0	1	1	2	1	2	2	2	1.33	0.16	1.20	226.62	30.01	2.49	0.33	30.63	±	4.06
53	64	1	0	4	0	1	0	2	0	1	1	1	2	0	1	1	1.00	0.28	0.87	163.84	51.98	1.80	0.57	22.15	±	7.03
54	65	6	3	5	4	5	2	2	1	2	3	2	3	4	2	2	3.07	0.37	2.94	553.04	69.90	6.08	0.77	74.75	±	9.45
55	66	3	4	4	0	1	0	5	1	3	1	2	5	2	1	1	2.20	0.44	2.07	389.83	82.60	4.28	0.91	52.69	±	11.16
56	67	4	4	3	5	2	7	2	2	4	2	2	5	4	3	4	3.53	0.38	3.40	640.93	70.86	7.04	0.78	86.63	±	9.58
57	68	2	4	1	1	2	0	3	2	0	1	0	4	2	2	2	1.73	0.33	1.60	301.95	62.23	3.32	0.68	40.81	±	8.41
58	69	1	0	1	1	0	1	1	0	0	0	0	2	1	1	1	0.67	0.16	0.54	101.07	30.01	1.11	0.33	13.66	±	4.06
59	70	0	0	1	0	2	1	1	1	0	1	1	0	1	0	0	0.60	0.16	0.47	88.51	30.75	0.97	0.34	11.96	±	4.16
60	71	3	0	1	0	1	2	1	0	1	1	2	0	0	2	0	0.93	0.25	0.80	151.29	46.74	1.66	0.51	20.45	±	6.32
61	72	3	0	0	0	1	2	4	2	2	0	4	4	4	0	1	1.80	0.43	1.67	314.50	80.53	3.46	0.88	42.51	±	10.88
62	73	0	0	0	0	1	0	1	0	0	1	0	0	2	0	0	0.33	0.16	0.20	38.29	30.01	0.42	0.33	5.18	±	4.06
63	75	1	0	0	0	2	0	1	0	2	0	1	0	1	0	0	0.53	0.19	0.40	75.96	36.14	0.83	0.40	10.27	±	4.88
64	77	0	0	0	1	0	1	0	1	1	1	0	0	0	0	1	0.40	0.13	0.27	50.85	24.66	0.56	0.27	6.87	±	3.33
65	78	2	0	0	0	1	1	0	0	0	0	1	1	0	1	0	0.47	0.17	0.34	63.40	31.12	0.70	0.34	8.57	±	4.21

		Tracks Density (FoV)															Average Tracks		Average Tracks Density					Radon Concentration		
		Number of Field of View															Tracks / FoV									
Serial No.	Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average	± Error	Net average	(T/cm²)	± (T/cm²)	(T/cm².d)	± (T/cm².d)	Bq/m³	±	Error
66	80	4	5	3	0	0	3	2	2	0	0	2	3	0	4	4	2.13	0.46	2.00	377.28	85.94	4.15	0.94	50.99	±	11.62
67	81	1	2	1	0	0	2	2	1	0	2	1	0	2	1	4	1.27	0.28	1.14	214.06	53.48	2.35	0.59	28.93	±	7.23
68	82	0	0	1	0	2	0	1	2	2	3	1	6	0	2	3	1.53	0.42	1.40	264.28	79.83	2.90	0.88	35.72	±	10.79
69	83	3	0	2	1	3	0	1	2	0	1	0	2	2	3	1	1.40	0.29	1.27	239.17	54.52	2.63	0.60	32.33	±	7.37
70	85	2	2	2	5	2	1	7	1	1	2	0	4	3	2	4	2.53	0.47	2.40	452.61	87.88	4.97	0.97	61.18	±	11.88
71	86	1	0	2	0	2	2	3	1	0	0	2	1	3	1	2	1.33	0.27	1.20	226.62	50.89	2.49	0.56	30.63	±	6.88
72	87B	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0.20	0.11	0.20	37.66	20.13	0.41	0.22	5.09	±	2.72
73	88	3	1	2	1	2	1	1	1	1	2	1	1	1	3	0	1.40	0.21	1.27	239.17	40.27	2.63	0.44	32.33	±	5.44
74	89	3	0	0	0	2	1	1	2	2	1	2	1	2	0	5	1.47	0.35	1.34	251.73	65.92	2.77	0.72	34.02	±	8.91
75	90	4	1	1	2	2	1	1	2	3	1	2	4	1	2	1	1.87	0.27	1.74	327.06	51.55	3.59	0.57	44.21	±	6.97
76	91	0	0	1	0	3	4	4	1	0	4	2	0	0	2	0	1.40	0.42	1.27	239.17	79.69	2.63	0.88	32.33	±	10.77
77	92	2	1	2	2	3	1	2	2	1	1	2	2	2	2	1	1.73	0.15	1.60	301.95	28.86	3.32	0.32	40.81	±	3.90
78	93	0	0	0	0	0	1	0	0	1	1	1	2	1	0	0	0.47	0.17	0.34	63.40	31.12	0.70	0.34	8.57	±	4.21
79	94B	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0.20	0.14	0.20	37.66	27.26	0.41	0.30	5.09	±	3.68
80	95	2	1	0	2	1	2	2	0	2	2	1	0	1	1	3	1.33	0.23	1.20	226.62	43.75	2.49	0.48	30.63	±	5.91
81	96	0	0	2	0	1	0	1	2	1	2	3	1	0	1	1	1.00	0.24	0.87	163.84	45.02	1.80	0.49	22.15	±	6.08
82	97	0	0	3	1	0	0	1	0	1	1	0	2	1	2	2	0.93	0.25	0.80	151.29	46.74	1.66	0.51	20.45	±	6.32

		Tracks Density (FoV) Number of Field of View															Average Tracks Tracks / FoV		Average Tracks Density					Radon Concentration		
Serial No.	Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average	± Error	Net average	(T/cm²)	± (T/cm²)	(T/cm².d)	± (T/cm².d)	Bq/m³	±	Error
83	98	1	1	1	6	1	2	0	2	1	0	2	1	2	0	2	1.47	0.38	1.34	251.73	70.86	2.77	0.78	34.02	±	9.58
84	100	0	1	0	3	0	1	1	1	0	0	2	0	0	3	0	0.80	0.28	0.67	126.18	52.63	1.39	0.58	17.05	±	7.11
85	101	0	0	2	2	1	1	0	2	0	0	0	1	1	2	1	0.87	0.22	0.74	138.73	40.54	1.52	0.45	18.75	±	5.48
86	102	1	0	2	2	2	1	3	1	2	2	1	1	1	3	2	1.60	0.21	1.47	276.84	40.27	3.04	0.44	37.42	±	5.44
87	103	0	0	4	0	1	0	5	0	0	1	1	0	1	3	3	1.27	0.43	1.14	214.06	81.09	2.35	0.89	28.93	±	10.96
88	105	1	3	1	0	1	0	3	2	1	0	2	3	0	1	0	1.20	0.30	1.07	201.51	55.74	2.21	0.61	27.24	±	7.53
89	106	1	0	3	3	1	3	1	4	3	1	1	1	4	3	4	2.20	0.35	2.07	389.83	66.77	4.28	0.73	52.69	±	9.03
90	107	2	3	0	1	3	1	3	1	1	1	2	2	3	4	1	1.87	0.29	1.74	327.06	54.73	3.59	0.60	44.21	±	7.40
91	108	1	2	3	2	1	0	1	1	1	0	2	5	2	1	4	1.73	0.36	1.60	301.95	67.44	3.32	0.74	40.81	±	9.12
92	109	3	1	3	1	2	3	2	1	1	3	1	5	1	4	2	2.20	0.33	2.07	389.83	61.51	4.28	0.68	52.69	±	8.31
93	110	1	4	1	6	4	3	1	2	3	3	1	2	3	5	5	2.93	0.42	2.80	527.93	78.98	5.80	0.87	71.36	±	10.68
94	111	3	4	4	6	1	3	3	2	5	2	4	6	5	1	4	3.53	0.41	3.40	640.93	77.68	7.04	0.85	86.63	±	10.50
95	112	0	2	2	2	1	0	1	3	1	2	1	1	1	4	1	1.47	0.27	1.34	251.73	51.55	2.77	0.57	34.02	±	6.97
96	113	0	0	1	2	0	6	2	0	2	3	0	5	4	2	2	1.93	0.49	1.80	339.61	92.75	3.73	1.02	45.90	±	12.54
97	114	5	1	4	6	4	4	2	1	4	5	1	1	2	7	5	3.47	0.52	3.34	628.37	97.02	6.91	1.07	84.93	±	13.11
98	115	0	0	1	1	1	0	1	1	3	0	3	3	2	1	0	1.13	0.29	1.00	188.95	54.73	2.08	0.60	25.54	±	7.40
99	116	2	1	1	0	0	4	2	1	0	2	2	0	1	2	3	1.40	0.31	1.27	239.17	57.53	2.63	0.63	32.33	±	7.78

		Tracks Density (FoV)															**Average Tracks**		**Average Tracks Density**					**Radon Concentration**		
		Number of Field of View															**Tracks / FoV**									
Serial No.	**Sample No.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**Average**	**± Error**	**Net average**	**(T/cm²)**	**± (T/cm²)**	**(T/cm².d)**	**± (T/cm².d)**	**Bq/m³**	**±**	**Error**
100	117	4	6	7	6	4	4	4	6	5	3	2	4	3	5	5	4.53	0.35	4.40	829.25	65.92	9.11	0.72	112.09	±	8.91
101	118	1	1	3	4	3	0	4	5	3	2	2	3	3	3	5	2.80	0.37	2.67	502.82	69.26	5.53	0.76	67.96	±	9.36
102	119	2	1	1	5	6	2	3	2	0	1	1	1	1	1	1	1.87	0.42	1.74	327.06	79.83	3.59	0.88	44.21	±	10.79
103	120	2	4	5	2	4	2	1	0	1	3	1	1	4	5	2	2.47	0.41	2.34	440.05	77.68	4.84	0.85	59.48	±	10.50
104	121 B	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0.07	0.07	0.07	12.55	12.55	0.14	0.14	1.70	±	1.70
105	122 B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	±	0.00
106	123 B	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0.13	0.09	0.13	25.11	17.11	0.28	0.19	3.39	±	2.31
107	124	4	3	6	4	8	10	5	4	4	7	8	2	9	6	4	5.60	0.61	5.47	1030.13	114.48	11.32	1.26	139.24	±	15.47
108	125	1	4	3	8	5	3	1	4	1	0	0	1	0	2	1	2.27	0.58	2.14	402.39	109.45	4.42	1.20	54.39	±	14.79
109	126	0	1	0	0	0	0	0	2	1	0	2	1	2	0	3	0.80	0.26	0.67	126.18	49.31	1.39	0.54	17.05	±	6.67
110	127	5	0	1	4	0	2	2	2	3	3	4	2	2	2	1	2.20	0.37	2.07	389.83	69.26	4.28	0.76	52.69	±	9.36
111	128	2	0	4	3	1	5	2	2	0	2	1	0	2	1	3	1.87	0.38	1.74	327.06	70.86	3.59	0.78	44.21	±	9.58
112	129	7	2	8	5	8	9	7	13	7	8	1	5	9	3	6	6.53	0.79	6.40	1205.90	148.02	13.25	1.63	163.00	±	20.01
113	130	2	0	1	2	3	2	2	2	5	3	0	3	2	5	4	2.40	0.39	2.27	427.50	73.05	4.70	0.80	57.78	±	9.87
114	131	1	2	2	0	1	3	0	0	1	1	0	0	2	0	1	0.93	0.25	0.80	151.29	46.74	1.66	0.51	20.45	±	6.32
115	132	6	7	7	4	1	8	13	8	6	3	9	8	3	7	7	6.47	0.75	6.34	1193.35	141.01	13.11	1.55	161.30	±	19.06

		Tracks Density (FoV)															Average Tracks		Average Tracks Density					Radon Concentration		
		Number of Field of View															Tracks / FoV									
Serial No.	**Sample No.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**Average**	**± Error**	**Net average**	**(T/cm^2)**	**± (T/cm^2)**	**(T/cm^2.d)**	**± (T/cm^2.d)**	**Bq/m^3**	**±**	**Error**
116	133	4	6	7	4	3	5	9	11	6	8	7	12	5	9	5	6.73	0.68	6.60	1243.57	127.95	13.67	1.41	168.09	±	17.29
117	134	0	3	0	2	2	2	2	1	0	1	1	1	0	0	0	1.00	0.26	0.87	163.84	48.63	1.80	0.53	22.15	±	6.57
118	135	1	1	1	1	0	2	0	1	1	1	0	2	0	3	2	1.07	0.23	0.94	176.40	42.97	1.94	0.47	23.84	±	5.81
119	136	6	2	3	0	1	3	11	6	3	0	1	4	1	1	1	2.87	0.76	2.74	515.38	143.38	5.66	1.58	69.66	±	19.38
120	137	4	0	0	2	2	2	2	0	3	2	3	0	1	1	1	1.53	0.32	1.40	264.28	60.58	2.90	0.67	35.72	±	8.19
121	138	0	1	3	3	1	2	2	0	3	4	5	2	1	4	4	2.33	0.40	2.20	414.94	75.03	4.56	0.82	56.09	±	10.14
122	139	1	2	1	2	1	2	4	1	1	3	2	2	1	1	2	1.73	0.23	1.60	301.95	42.97	3.32	0.47	40.81	±	5.81
123	140	4	7	6	4	3	3	2	1	3	3	6	2	2	9	5	4.00	0.57	3.87	728.81	107.16	8.01	1.18	98.51	±	14.48
124	141	3	2	3	4	5	4	2	1	3	1	4	4	1	3	2	2.80	0.33	2.67	502.82	61.51	5.53	0.68	67.96	±	8.31
125	142	3	3	0	5	2	0	2	8	3	5	5	9	4	5	3	3.80	0.65	3.67	691.15	122.19	7.60	1.34	93.42	±	16.52
126	143	2	0	0	1	3	0	1	3	0	0	3	0	0	2	1	1.07	0.32	0.94	176.40	59.46	1.94	0.65	23.84	±	8.04
127	144	1	1	0	2	1	2	4	2	2	1	2	0	2	2	4	1.73	0.30	1.60	301.95	56.55	3.32	0.62	40.81	±	7.64
128	145	1	0	0	2	1	1	0	1	0	1	1	1	0	0	0	0.60	0.16	0.47	88.51	30.75	0.97	0.34	11.96	±	4.16
129	146	1	1	0	0	0	1	0	1	1	1	1	0	0	1	0	0.53	0.13	0.40	75.96	25.11	0.83	0.28	10.27	±	3.39
130	147	2	0	1	2	0	1	1	2	1	2	3	1	1	0	1	1.20	0.22	1.07	201.51	41.91	2.21	0.46	27.24	±	5.66
131	148	0	2	0	1	0	1	2	0	2	1	1	2	0	0	3	1.00	0.26	0.87	163.84	48.63	1.80	0.53	22.15	±	6.57
132	149	1	1	0	2	1	0	0	1	1	0	0	0	0	2	0	0.60	0.19	0.47	88.51	35.83	0.97	0.39	11.96	±	4.84

		Tracks Density (FoV) Number of Field of View															Average Tracks Tracks / FoV		Average Tracks Density					Radon Concentration		
Serial No.	**Sample No.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**Average**	**± Error**	**Net average**	**(T/cm^2)**	**± (T/cm^2)**	**($T/cm^2.d$)**	**± ($T/cm^2.d$)**	**Bq/m^3**	**±**	**Error**
133	150	1	0	1	0	1	1	1	0	1	0	1	2	1	2	1	0.87	0.17	0.74	138.73	31.12	1.52	0.34	18.75	±	4.21
134	151	1	0	1	2	2	1	0	3	2	3	1	4	1	4	1	1.73	0.33	1.60	301.95	62.23	3.32	0.68	40.81	±	8.41
135	152	1	1	3	2	2	1	1	2	1	1	1	3	2	0	1	1.47	0.22	1.34	251.73	40.54	2.77	0.45	34.02	±	5.48
136	154	0	0	1	1	0	1	0	1	2	2	1	1	1	1	2	0.93	0.18	0.80	151.29	34.22	1.66	0.38	20.45	±	4.63
137	155	3	2	2	1	3	2	0	1	0	1	0	2	2	0	3	1.47	0.29	1.34	251.73	54.73	2.77	0.60	34.02	±	7.40
138	156	0	0	1	1	1	0	0	3	5	1	0	2	1	0	1	1.07	0.36	0.94	176.40	67.44	1.94	0.74	23.84	±	9.12
139	157	1	2	2	3	3	2	2	2	1	0	1	0	1	1	0	1.40	0.25	1.27	239.17	47.93	2.63	0.53	32.33	±	6.48
140	158	1	0	3	0	0	2	1	2	0	1	4	2	3	2	3	1.60	0.34	1.47	276.84	63.13	3.04	0.69	37.42	±	8.53
141	161	1	1	5	5	2	1	2	3	0	2	1	1	2	4	0	2.00	0.41	1.87	352.17	77.97	3.87	0.86	47.60	±	10.54
142	162	2	1	2	1	1	3	4	1	2	1	1	1	0	3	1	1.60	0.27	1.47	276.84	51.33	3.04	0.56	37.42	±	6.94
143	163	3	0	2	1	2	3	0	0	2	1	2	5	1	3	2	1.80	0.35	1.67	314.50	66.77	3.46	0.73	42.51	±	9.03
144	164	1	0	0	4	0	3	2	2	1	0	0	2	1	3	2	1.40	0.34	1.27	239.17	63.13	2.63	0.69	32.33	±	8.53
145	166	1	1	1	2	2	2	1	2	2	0	3	4	1	2	0	1.60	0.27	1.47	276.84	51.33	3.04	0.56	37.42	±	6.94
146	167	2	2	2	2	0	2	2	2	5	3	3	3	5	2	5	2.67	0.36	2.54	477.72	67.94	5.25	0.75	64.57	±	9.18
147	168	3	1	1	1	2	1	1	2	0	4	0	2	3	2	2	1.67	0.29	1.54	289.39	54.10	3.18	0.59	39.12	±	7.31
148	169	0	0	0	1	1	0	0	1	4	0	1	1	0	3	1	0.87	0.31	0.74	138.73	57.73	1.52	0.63	18.75	±	7.80
149	170	0	0	1	1	0	2	2	1	1	1	1	3	1	1	2	1.13	0.22	1.00	188.95	40.54	2.08	0.45	25.54	±	5.48

		Tracks Density (FoV)															Average Tracks		Average Tracks Density					Radon Concentration		
		Number of Field of View															Tracks / FoV									
Serial No.	**Sample No.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**Average**	**± Error**	**Net average**	**(T/cm²)**	**± (T/cm²)**	**(T/cm².d)**	**± (T/cm².d)**	**Bq/m³**	**±**	**Error**
150	172	5	0	1	0	1	0	1	0	1	0	0	2	0	1	2	0.93	0.34	0.80	151.29	64.89	1.66	0.71	20.45	±	8.77
151	173	2	1	2	1	2	0	1	0	0	2	3	0	1	0	0	1.00	0.26	0.87	163.84	48.63	1.80	0.53	22.15	±	6.57
152	174	0	1	5	0	0	3	1	2	2	0	2	1	3	1	2	1.53	0.36	1.40	264.28	68.44	2.90	0.75	35.72	±	9.25
153	175	0	0	0	0	0	1	2	2	0	0	1	0	3	4	1	0.93	0.33	0.80	151.29	62.23	1.66	0.68	20.45	±	8.41
154	176	0	1	1	0	0	0	2	1	2	0	2	0	1	0	1	0.73	0.21	0.60	113.62	38.84	1.25	0.43	15.36	±	5.25
155	177	6	3	10	12	9	8	8	13	5	9	7	6	8	8	4	7.73	0.71	7.60	1431.89	133.12	15.74	1.46	193.54	±	17.99
156	178	4	3	0	2	1	2	1	0	2	2	3	1	3	0	1	1.67	0.32	1.54	289.39	60.02	3.18	0.66	39.12	±	8.11
157	179	0	0	0	0	1	0	1	0	0	0	0	1	1	0	0	0.27	0.12	0.14	25.74	22.26	0.28	0.24	3.48	±	3.01
158	180	0	0	0	1	1	3	1	6	3	1	0	0	0	4	1	1.40	0.47	1.27	239.17	87.76	2.63	0.96	32.33	±	11.86
159	181	2	4	2	2	3	3	4	3	5	5	0	0	2	8	2	3.00	0.53	2.87	540.49	98.97	5.94	1.09	73.06	±	13.38
160	182	0	1	0	2	1	4	3	0	0	1	0	0	1	0	1	0.93	0.32	0.80	151.29	59.46	1.66	0.65	20.45	±	8.04
161	183	1	4	1	2	1	1	1	1	0	2	0	1	3	3	1	1.47	0.29	1.34	251.73	54.73	2.77	0.60	34.02	±	7.40
162	184	4	1	1	0	0	1	1	2	1	0	1	2	2	2	1	1.27	0.27	1.14	214.06	50.22	2.35	0.55	28.93	±	6.79
163	185	4	3	2	2	3	0	1	9	5	1	1	8	3	2	3	3.13	0.65	3.00	565.60	123.10	6.22	1.35	76.45	±	16.64
164	186	7	6	9	8	2	9	6	14	10	5	9	13	11	7	10	8.40	0.80	8.27	1557.44	150.21	17.11	1.65	210.51	±	20.30
165	187	5	6	5	2	2	6	5	10	11	7	8	5	7	6	7	6.13	0.63	6.00	1130.57	118.92	12.42	1.31	152.81	±	16.07

		Tracks Density (FoV)															Average Tracks		Average Tracks Density					Radon Concentration		
		Number of Field of View															Tracks / FoV									
Serial No.	Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average	± Error	Net average	(T/cm²)	± (T/cm²)	(T/cm².d)	± (T/cm².d)	Bq/m³	±	Error
166	188	2	2	5	3	4	5	3	4	4	3	1	4	5	5	3	3.53	0.32	3.40	640.93	60.58	7.04	0.67	86.63	±	8.19
167	189	1	2	4	3	2	2	1	1	1	2	2	4	4	3	0	2.13	0.32	2.00	377.28	60.58	4.15	0.67	50.99	±	8.19
168	191	0	1	1	1	4	1	0	1	1	1	2	2	1	2	1	1.27	0.25	1.14	214.06	46.74	2.35	0.51	28.93	±	6.32
169	193	3	1	1	1	2	3	2	0	1	0	2	0	0	1	0	1.13	0.27	1.00	188.95	51.55	2.08	0.57	25.54	±	6.97
170	194	1	0	3	2	1	3	2	1	6	1	2	1	0	1	1	1.67	0.39	1.54	289.39	72.74	3.18	0.80	39.12	±	9.83
171	195	2	1	6	1	1	1	1	2	1	4	5	1	4	1	2	2.20	0.44	2.07	389.83	82.60	4.28	0.91	52.69	±	11.16
172	196	1	1	2	1	2	1	2	0	1	5	2	2	1	2	2	1.67	0.29	1.54	289.39	54.10	3.18	0.59	39.12	±	7.31
173	197	2	1	1	4	2	2	3	2	3	2	0	2	1	3	3	2.07	0.27	1.94	364.72	50.22	4.01	0.55	49.30	±	6.79
174	198	3	6	4	2	6	3	4	5	5	4	4	4	3	4	4	4.07	0.28	3.94	741.37	53.48	8.15	0.59	100.21	±	7.23
175	199	1	1	1	2	2	2	2	2	0	1	2	4	3	2	1	1.73	0.25	1.60	301.95	46.74	3.32	0.51	40.81	±	6.32
176	200	1	0	1	1	1	1	0	1	0	2	3	0	2	0	1	0.93	0.23	0.80	151.29	42.97	1.66	0.47	20.45	±	5.81
177	201	0	1	1	1	2	0	3	1	2	2	2	1	1	1	3	1.40	0.24	1.27	239.17	44.26	2.63	0.49	32.33	±	5.98
178	202	0	3	1	3	1	2	1	3	3	1	0	2	3	1	1	1.67	0.29	1.54	289.39	54.10	3.18	0.59	39.12	±	7.31
179	203	1	2	1	1	0	2	1	2	1	1	1	2	1	1	1	1.20	0.14	1.07	201.51	27.26	2.21	0.30	27.24	±	3.68
180	204	4	2	0	3	2	2	0	1	2	1	0	0	1	1	2	1.40	0.31	1.27	239.17	57.53	2.63	0.63	32.33	±	7.78
181	205	2	1	2	2	2	3	1	2	2	3	1	2	2	3	1	1.93	0.18	1.80	339.61	34.22	3.73	0.38	45.90	±	4.63
182	206	1	2	1	1	2	1	2	1	2	0	3	1	1	1	1	1.33	0.19	1.20	226.62	35.19	2.49	0.39	30.63	±	4.76

		Tracks Density (FoV)															Average Tracks		Average Tracks Density					Radon Concentration		
		Number of Field of View															Tracks / FoV									
Serial No.	Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average	± Error	Net average	(T/cm^2)	± (T/cm^2)	($T/cm^2.d$)	± ($T/cm^2.d$)	Bq/m^3	±	Error
183	207	1	1	1	0	1	1	1	1	3	0	2	2	4	0	1	1.27	0.28	1.14	214.06	53.48	2.35	0.59	28.93	±	7.23
184	208	0	2	0	1	0	1	1	1	0	1	2	1	1	2	1	0.93	0.18	0.80	151.29	34.22	1.66	0.38	20.45	±	4.63
185	209	1	2	1	2	2	1	1	1	3	3	1	3	2	2	3	1.87	0.22	1.74	327.06	40.54	3.59	0.45	44.21	±	5.48
186	211	0	1	2	1	1	1	0	1	1	2	1	0	2	2	1	1.07	0.18	0.94	176.40	34.22	1.94	0.38	23.84	±	4.63
187	212	1	2	0	1	3	0	1	1	2	2	3	1	2	1	0	1.33	0.25	1.20	226.62	47.45	2.49	0.52	30.63	±	6.41
188	213	1	1	0	2	1	0	1	1	2	0	0	1	2	1	1	0.93	0.18	0.80	151.29	34.22	1.66	0.38	20.45	±	4.63
189	214	0	0	1	1	1	1	2	1	0	0	0	2	1	0	1	0.73	0.18	0.60	113.62	34.22	1.25	0.38	15.36	±	4.63
190	215	1	1	0	1	1	0	0	1	0	0	0	0	1	1	0	0.47	0.13	0.34	63.40	25.11	0.70	0.28	8.57	±	3.39
191	216	2	1	2	2	1	1	1	2	1	1	0	1	2	2	3	1.47	0.19	1.34	251.73	36.14	2.77	0.40	34.02	±	4.88
192	217	1	0	0	1	0	0	1	0	0	1	1	1	0	1	1	0.53	0.13	0.40	75.96	25.11	0.83	0.28	10.27	±	3.39
193	218	0	1	1	1	1	1	0	1	3	1	2	0	1	0	0	0.87	0.22	0.74	138.73	40.54	1.52	0.45	18.75	±	5.48
194	219	2	0	0	1	2	0	1	6	2	0	0	1	1	2	2	1.33	0.40	1.20	226.62	75.03	2.49	0.82	30.63	±	10.14
195	220	0	1	2	0	0	0	0	1	1	1	0	1	0	0	1	0.53	0.17	0.40	75.96	31.12	0.83	0.34	10.27	±	4.21
196	221	2	3	2	2	0	3	3	1	1	2	0	0	0	1	1	1.40	0.29	1.27	239.17	54.52	2.63	0.60	32.33	±	7.37
197	222	5	5	1	2	2	4	0	0	3	1	5	2	2	0	2	2.27	0.46	2.14	402.39	87.11	4.42	0.96	54.39	±	11.77
198	223	3	3	3	1	2	2	1	1	4	1	2	1	2	0	4	2.00	0.31	1.87	352.17	58.12	3.87	0.64	47.60	±	7.86
199	225	3	2	0	2	0	1	1	1	2	2	2	0	0	0	1	1.13	0.26	1.00	188.95	48.16	2.08	0.53	25.54	±	6.51

		Tracks Density (FoV)															Average Tracks		Average Tracks Density					Radon Concentration		
		Number of Field of View															Tracks / FoV									
Serial No.	Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average	± Error	Net average	(T/cm²)	± (T/cm²)	(T/cm².d)	± (T/cm².d)	Bq/m³	±	Error
200	226 B	0	0	0	2	0	0	1	0	0	0	0	0	1	0	0	0.27	0.15	0.27	50.22	28.86	0.55	0.32	6.79	±	3.90
201	227 B	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0.20	0.11	0.20	37.66	20.13	0.41	0.22	5.09	±	2.72
202	228 B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	±	0.00
203	229 B	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0.20	0.11	0.20	37.66	20.13	0.41	0.22	5.09	±	2.72
204	230 B	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0.07	0.07	0.07	12.55	12.55	0.14	0.14	1.70	±	1.70

Annex B: RAD7 Run # 1 printer output.

0101 51.4+-30.6 b Sniff

SUN 03-JUN-12 09:47

26.8`C RH:9.00% B:7.09V

0102 85.7+-37.5 b Sniff

SUN 03-JUN-12 10:47

26.4`C RH:6.00% B:7.09V

0103 97.2+-40.0 b Sniff

SUN 03-JUN-12 11:47

26.4`C RH:6.00% B:7.03V

0104 80.7+-23.9 b Normal

SUN 03-JUN-12 12:47

26.4`C RH:5.00% B:7.12V

0105 83.4+-24.3 b Normal

SUN 03-JUN-12 13:47

26.4`C RH:5.00% B:7.03V

0106 111.+-27.7 b Normal

SUN 03-JUN-12 14:47

26.4`C RH:4.00% B:7.03V

0107 129.+-29.4 b Normal

SUN 03-JUN-12 15:47

26.8`C RH:4.00% B:7.03V

0108 123.+-29.1 b Normal

SUN 03-JUN-12 16:47

26.8`C RH:4.00% B:7.03V

0109 148.+-31.3 b Normal

SUN 03-JUN-12 17:47

27.1`C RH:4.00% B:7.06V

0110 165.+-32.9 b Normal

SUN 03-JUN-12 18:47

27.1`C RH:4.00% B:7.00V

0111 152.+-31.8 b Normal

SUN 03-JUN-12 19:47

26.8`C RH:4.00% B:7.03V

0112 178.+-34.0 b Normal

SUN 03-JUN-12 20:47

26.8`C RH:4.00% B:7.03V

0113 208.+-36.7 b Normal

SUN 03-JUN-12 21:47

26.4`C RH:4.00% B:6.21V

0114 179.+-34.3 b Normal

SUN 03-JUN-12 22:47

25.8`C RH:4.00% B:6.24V

0115 175.+-34.0 b Normal

SUN 03-JUN-12 23:47

25.8`C RH:4.00% B:6.27V

0116 176.+-34.0 b Normal

MON 04-JUN-12 00:47

25.5`C RH:4.00% B:6.27V

0117 164.+-32.9 b Normal

MON 04-JUN-12 01:47

25.5`C RH:4.00% B:6.27V

0118 172.+-33.6 b Normal

MON 04-JUN-12 02:47

25.5`C RH:4.00% B:6.24V

0119 165.+-32.9 b Normal

MON 04-JUN-12 03:47

25.5`C RH:4.00% B:6.27V

0120 171.+-33.4 b Normal

MON 04-JUN-12 04:47

25.5`C RH:4.00% B:6.27V

0121 174.+-33.7 b Normal

MON 04-JUN-12 05:47

26.4`C RH:4.00% B:6.88V

0122 190.+-35.1 b Normal

MON 04-JUN-12 06:47

27.4`C RH:3.00% B:6.97V

0123 161.+-32.7 b Normal

MON 04-JUN-12 07:47

27.1`C RH:3.00% B:7.00V

0124 181.+-34.3 b Normal

MON 04-JUN-12 08:47

27.1`C RH:3.00% B:7.00V

0125 196.+-35.6 b Normal

MON 04-JUN-12 09:47

27.1`C RH:3.00% B:7.00V

0126 193.+-35.7 b Normal

MON 04-JUN-12 10:47

27.1`C RH:3.00% B:7.00V

0127 167.+-33.1 b Normal

MON 04-JUN-12 11:47

27.1`C RH:3.00% B:7.03V

0128 123.+-28.8 b Normal

MON 04-JUN-12 12:47

27.1`C RH:3.00% B:7.03V

0129 161.+-32.6 b Normal

MON 04-JUN-12 13:47

27.1`C RH:3.00% B:7.03V

0130 157.+-32.2 b Normal

MON 04-JUN-12 14:47

27.1`C RH:3.00% B:7.03V

0131 178.+-34.0 b Normal

MON 04-JUN-12 15:47

27.1`C RH:3.00% B:7.03V

0132 186.+-34.8 b Normal

MON 04-JUN-12 16:47

27.1`C RH:3.00% B:7.03V

0133 253.+-40.4 b Normal

MON 04-JUN-12 17:47

27.1`C RH:3.00% B:7.03V

0134 253.+-40.3 b Normal

MON 04-JUN-12 18:47

27.1`C RH:3.00% B:7.03V

0135 266.+-41.1 b Normal

MON 04-JUN-12 19:47

27.1`C RH:3.00% B:7.03V

0136 267.+-41.1 b Normal

MON 04-JUN-12 20:47

27.1`C RH:3.00% B:7.03V

0137 271.+-41.4 b Normal

MON 04-JUN-12 21:47

27.1`C RH:3.00% B:7.03V

0138 283.+-42.3 b Normal

MON 04-JUN-12 22:47

27.1`C RH:3.00% B:7.03V

0139 290.+-43.0 b Normal

MON 04-JUN-12 23:47

26.8`C RH:3.00% B:7.06V

0140 290.+-42.7 b Normal

TUE 05-JUN-12 00:47

26.8`C RH:3.00% B:7.00V

0141 316.+-44.5 b Normal

TUE 05-JUN-12 01:47

26.8`C RH:3.00% B:7.06V

0142 307.+-44.0 b Normal

TUE 05-JUN-12 02:47

26.8`C RH:3.00% B:7.03V

0143 275.+-41.9 b Normal

TUE 05-JUN-12 03:47

26.8`C RH:3.00% B:7.03V

0144 256.+-40.5 b Normal

TUE 05-JUN-12 04:47

26.4`C RH:3.00% B:7.03V

0145 300.+-43.4 b Normal

TUE 05-JUN-12 05:47

26.4`C RH:3.00% B:7.03V

0146 283.+-42.2 b Normal

TUE 05-JUN-12 06:47

26.4`C RH:3.00% B:7.03V

0147 303.+-43.8 b Normal

TUE 05-JUN-12 07:47

26.1`C RH:3.00% B:7.03V

0148 283.+-42.4 b Normal

TUE 05-JUN-12 08:47

26.4`C RH:3.00% B:7.03V

Annex C: The IRB Approval letter.

An-Najah
National University
Faculty of Medicine

بسم الله الرحمن الرحيم

جامعة
النجاح الوطنية
كلية الطب

IRB Approval letter

Study title:
Indoor Radon levels Measurement in the Elementary Schools of Tulkarem Province Palestine .

Submitted by:
Khaled Mallah

Date Reviewed:
March 20, 2012

Date approved:
April 10, 2012

Your study titled". Indoor Radon levels Measurement in the Elementary Schools of Tulkarem Province Palestine . ." Was reviewed by An-Najah National University IRB committee & approved on April 10, 2012

Samar Musmar,MD, FAAFP

IRB Committee Chairman,
An-Najah National University

IRB

نابلس - ص.ب ٧,٧٠٧ هاتف: ١٤/٨/٧/٤/٢٣٤٢٩٠٢(٠٩)(٩٧٢)، فاكسميل ٢٣٤٩٧٣٩(٠٩)(٩٧٢)
Nablus - P.O.Box 7,707 - Tel. (972)(09)2342902/4/7/8/14 - Facximile (972)(09)2349739

Annex D: An-Najah National University letter to the MoE.

An-Najah
National University
Faculty of Graduate Studies
Dean's Office

جامعة
النجــاح الوطنية
كلية الدراسات العليا
مكتب العميد

التاريخ : 2012/4/29م

حضرة السيد مدير عام التعليم العام المحترم
الادارة العامة للتعليم العام
وزارة التربية والتعليم العالي
فاكس: 2983222 – 2 – 00972
رام الله

الموضوع : تسهيل مهمة الطالب/ خالد بسام يوسف ملاح، رقم تسجيل (10853321)
تخصص ماجستير الصحة العامة

تحية طيبة وبعد،

الطالب/ خالد بسام يوسف ملاح، رقم تسجيل 10853321 تخصص ماجستير الصحة العامة في كلية الدراسات العليا، وهو وهي بصدد إعداد الاطروحة الخاصة به بعنوان:

(تقييم التعرض والأثر الصحي لغاز الرادون في الهواء المغلق في المدارس الأساسية في محافظة طولكرم، فلسطين)

يرجى من حضرتكم تسهيل مهمته في جمع معلومات تتعلق في الاطروحة، لقياس تراكيز غاز الرادون داخل الغرف الصفية لمدارس محافظة طولكرم للمرحلة الاساسية في المدارس الحكومية والمدارس الخاصة والمدارس التابعة لوكالة الغوث في محافظة طولكرم لاستكمال مشروع البحث.

شاكرين لكم حسن تعاونكم.

مع وافر الاحترام ،،،

خالد بسام ملاح
0569 100137

جامعة النجاح الوطنية
كلية الدراسات العليا
نابلس - فلسطين

عميد كلية الدراسات العليا
د. محمد أبو جعفر

فلسطين، نابلس، ص.ب 7،707 هاتف:/2345115، 2345114، 2345113 (09)(972)* فاكسميل:2342907(09)(972)
3200 (5) هاتف داخلي Nablus, P. O. Box (7) *Tel. 972 9 2345113, 2345114, 2345115
* Facsimile 972 92342907 *www.najah.edu - email fgs@najah.edu

Annex E: Minster of Education Approval letter.

Palestinian National Authority
Ministry of Education & Higher Education
Directorate of Education – Tulkarm

بسم الله الرحمن الرحيم

السلطة الوطنية الفلسطينية
وزارة التربية والتعليم العالي
مديرية التربية والتعليم / طولكرم

الرقم : م ت ط/١/٣/ ١٧٩٦
التاريخ :٢٠١٢/٥/١٤ م
الموافق: ٢٣/جمادى الأخرة/١٤٣٣ هـ

حضرة مدير/ة بنات محمود الهمشري الأساسية **المحترم/ة**

تحية طيبة وبعد،،،،

الموضوع : الدراسة الميدانية

الإشارة : كتاب معالي وزيرة التربية والتعليم العالي رقم و ت/٤/٤٦/١٦٦٨

بتاريخ :٢٠١٢/٥/١٤م

لامانع من قيام الطالب " **خالد بسام يوسف الملاح** " ، بإجراء دراسته الميدانية بعنوان (**تقييم التعرض والأثر الصحي لغاز الرادون في الهواء المغلق في المدارس الأساسية في محافظة طولكرم**) ، وتوزيع ٢٠٠ كاشف لغاز الرادون لمدة ثلاثة اشهر خلال العطلة الصيفية ، شريطة أن لا يؤثر ذلك على سير العملية التعليمية .

مع الاحترام ،،،،،

أ. حسني سلامة
/مدير التربية والتعليم

قسم التعليم العام

هـ.ع /ط.أ

Annex F: Information form of each school.

"Indoor Radon Measurements in the Elementary Schools of Tulkarem Province"

Plan Sheet

SECTION 1: SCHOOL AND OWNER INFORMATION

1- School Name:
2- School #:
3- School phone:
4- School Headmaster:
5- School Location:
6- School Address:
7- School Authority:
8- Name of Contact Person:
9- Phone # of Contact Person:
10- # of Student & # of Team:

SECTION 2: BUILDING INFORMATION

1. No. of stories:
2. No. of classrooms:
3. No of occupied classrooms:
4. No of floor levels:
5. Type of floor levels:
6. Building age:
7. Building type outside:
8. Cooling system:
9. Heating system:
10. School area:
11. Classroom area:
12. Average No. of students in each C.R.:
13. No of windows in the C.R.:

SECTION 3: DOSIMETERS INFORMATION

1. No. of required dosimeters:
2. Duplicate rooms:
3. RAD7 Device rooms:
4. Start test date, time:
5. End test date, time:

School name:………………………………………………………..							
Serial #	**Room # & Name**	**Location & Floor**	**Start Date**	**Start Time**	**Stop Date**	**Stop Time**	**Comments**
1.							
2.							
3.							
4.							
5.							
6.							
7.							
8.							
9.							
10.							
11.							
12.							
13.							
14.							

Annex G: A map of the selected 20 elementary schools in Tulkarem province.

Key for the map:

a= Al Israa Ideal Girls School

b= Mahmoud Hamshary Basic Girls School

c= Helmi Hannon Higher Basic Boys School

d= Hasan Al Qaisy Basic School

e= Tulkarem Basic Girls School No.1

f= Tulkarem Basic Girls School No.2

g= Tulkarem Basic Boys School No.1

h= Tulkarem Basic Boys School No.2

i= Nur Shams Basic Boys School

j= Nur Shams Basic Girls School

k= Shuwaikah Basic Girls School

l= Zieta Basic Girls School

m= Illar Basic Boys School

n= Baqa Al-Sharqiah Basic Boys School

o= Irtah Basic Girls School

p= Kufor Sur Elementary School

q= Shofah Basic Girls School

r= Beit Leed Basic Boys School

s= Anabta Basic Boys School

t= Balaa High Basic Girls School

جامعة النجاح الوطنية
كلية الدراسات العليا

تقييم التعرض والأثر الصحي لغاز الرادون في الهواء المغلق في المدارس الأساسية في محافظة طولكرم، فلسطين

إعداد
خالد بسام يوسف ملاح

إشراف
د. حمزة الزبدي

قدمت هذه الأطروحة إستكمالا لمتطلبات الحصول على درجة الماجستير في الصحة العامة بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس، فلسطين.

2013م

تقييم التعرض والأثر الصحي لغاز الرادون في الهواء المغلق في المدارس الأساسية في محافظة طولكرم، فلسطين

إعداد

خالد بسام يوسف ملاح

إشراف

د. حمزة الزبدي

الملخص

خلفية الدراسة

العديد من الهيئات الصحية العالمية تصنف التعرض لغاز الرادون أنه ثانٍ مسبب لسرطان الرئة بعد التدخين. وقد تبين أن معامل خطر الاصابة بسرطان الرئة عند الاطفال أعلى منه عند الكبار. لذلك هناك إهتمام خاص في قياس غاز الرادون في رياض الاطفال والمدارس الابتدائية في مختلف بلدان العالم. تهدف هذه الدراسة الى التعرف على مستويات غاز الرادون في الأماكن المغلقة في المدارس الاساسية في محافظة طولكرم للمرة الأولى. وكذلك لتحديد البيانات الأساسية لمستويات غاز الرادون في مدارس طولكرم التي ستكون عونا كبيرا ل "مسح الرادون في مدارس الضفة الغربية" في المستقبل القريب. وتهدف هذه الدراسة أيضا إلى التحقيق في المعايير المختلفة التي قد تؤثر على تراكيز غاز الرادون داخل المباني.

المنهجية

استخدم في هذه الدراسة 230 كاشفا من كواشف الاثار النووية الصلبة (SSNTDs) المعروفة تجاريا باسم (CR-39)، وقد وزعت هذه الكواشف داخل الغرف الصفية في عشرين مدرسة اساسية تقع جميعها في محافظة طولكرم، تم اخيار عينة المدارس بالطريقة الطبقية العشوائية من مدارس حكومية ومدارس وكالة الغوث الدولية (UNRWA) ومدارس خاصة. واستخدم نحو ثلاثون كاشفا منها لغرض ضمان الجودة (10٪ duplicate و 5٪blank). تعرضت كاشفات (CR-39) للهواء المغلق في المدارس لمدة ثلاثة أشهر خلال العطلة الصيفية المدرسية في الفترة من حزيران 2012 إلى آب 2012 ثم تم جمعها وتظهيرها كيميائيا في

محلول هيدروكسيد الصوديوم بتركيز (N 6.25) ودرجة حرارة مقدارها (75C°) لمدة 6 ساعات. احصيت المسارات يدويا عن طريق المجهر الرقمي. وفي موازاة ذلك، تم تنفيذ 20 قياسا بواسطة جهاز ال RAD7 في 20 غرفة صفية من نفس الغرف الصفية المختارة في العينة لغاية ضمان الجودة وتحليل الارتباط بين هذين النوعين من القياسات (السلبية والإيجابية).

النتائج

كانت مستويات غاز الرادون في الأماكن المغلقة منخفضة عموما، وتتغير بدءا من 3,48 حتى 210,51 بيكريل/م ٣ (بيكريل لكل متر مكعب)، وقد وجد ايضا ان المعدل الكلي هو 2.49 ±40.42 بيكريل/م ٣ . وينتج عن هذا التركيز جرعة فعالة سنوية تساوي ± 0.17 0.01 ملي سيفرت / سنة. بينما بلغت قيمة الزيادة في خطر الاصابة بسرطان الرئة بسبب هذه الجرعة على مدى الحياة ما يقرب من 0.09٪. ركزت الدراسة أيضا على العوامل التي تؤثر على تركيز غاز الرادون مثل الموقع الجغرافي وعمر المبنى ومستوى الطابق الذي توجد به الغرفة الصفية. وأظهرت نتائج الدراسة أن تركيز الرادون في الطوابق الأرضية كان أعلى مما كان عليه في الطوابق العليا. كما تبين ان تركيز غاز الرادون في المباني المدرسية القديمة أعلى بكثير من المباني الجديدة. أما بالنسبة للموقع الجغرافي فقد كان أعلى تركيز لغاز الرادون في منطقة الكفريات وأقل تركيز كان في منطقة وادي الشعير. أيضاً أظهرت الدراسة ان طريقتي القياس (CR-39 وRAD7) يوجد بينهما ارتباط عالي بلغ 0.97 = (R^2).

الاستنتاجات

إن العلاقة الإيجابية بين القياسين (CR-39 وRAD7) تشير إلى أن الكاشف(CR-39) كان في كفاءة عالية. وكانت نتائجنا ضمن الحدود الآمنة دوليا(148 بيكريل/م٣). مع ذلك فقد تم الكشف عن بعض الغرف الصفية والتي بلغت تراكيز غاز الرادون فيها اعلى من الحد المسموح به، ويمكن خفض هذه التراكيز من خلال زيادة التهوية الطبيعية أو تزويد هذه الصفوف بمراوح شفط. أكدت الدراسة أن هناك تباين في مستويات تركيز الرادون بين الطوابق

لا سيما زيادة التركيز في الطوابق الأرضية. كما أكدت الدراسة ايضاً تأثير عمر المبنى على تركيز الرادون داخل المدارس. من ناحية أخرى لم يكن تأثير الموقع الجغرافي على تركيز الرادون واضحا عدا منطقة واد الشعير، اذ كانت الأقل تركيزاً.