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Measurement of Radon Concentrations in the Air Buildings for some Schools at Karbala City Using CN-85 and LR-115 Type II Detectors

A Thesis

Submitted to the Council of College of Science, University of Kerbala , in Partial Fulfillment of the Requirements for the Degree of Master of Science in Physics

By

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B. Sc , (2008)

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2019 AD 1440 H

بسم الله الرحمن الرحيم

﴿فَمَنْ يَعْمَلْ مِثْقَالَ ذَرَّةٍ خَيْراً يَرَه ۞
وَمَنْ يَعْمَلْ مِثْقَالَ ذَرَّةٍ شَراً يَرَه﴾

صدق الله العلي العظيم

سورة الزلزلة- آية (7,8)

Certificate

I certify that the preparation of this thesis, entitled "***Measurement of Radon Concentrations in the Air Buildings for some Schools at Karbala City Using CN-85 and LR-115 Type II Detectors***" was made under my supervision by (***Sara Salih Nayif***) at the College of science University of Kerbala in partial fulfilment of the requirements for the degree of Master of Science in Physics.

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Sara

Dedication

- *To the land of peace ,the good and tender land of Hussein (holy Karbala) .*

- *To my parents (my father may God have mercy on him and my mother) .*

- *To my sisters.*

- *To my children (Mohammad and Mahdi) .*

- *To all my relatives and friends .*

Dedicate to you my humble work

Sara

Abstract

Radon is a radioactive gas that is produced naturally from the natural radioactive decay of radium which produces from decomposition of uranium . In this study, radon concentrations were measured in the air of buildings for some schools in the city of Karbala . The study was carried out using closed and open passive radon dosimeters containing two types of solid state nuclear track detectors types of organic detectors such as cellulose nitrate LR-115 Type II and CN-85 with thickness 12 μm for each detectors. Fifty schools were selected randomly from schools in Karbala city, 100 dosimeters were distributed (50 open and 50 closed dosimeters) on the selected schools for period about three month in winter. These dosimeters put at height about two meters from the ground. the detectors were collected and alpha particle traces were appeared after etching the detectors in sodium hydroxide solution at a concentration of 2.5 N for 90 minute at temperature of (60 ± 1) ºC, after that the detectors washed with distilled water and dried for the purpose of counting the effects of alpha particles using an optical microscope with magnification 100X .

The results showed that the mean of radon concentration in air of school buildings was 36.972±11.33 Bq/m^3 and 36.481±9.66 Bq/m^3 in open dosimeters for LR-115 Type II and CN-85 respectively. In closed dosimeters, radon concentrations were found 24.249±5.70 Bq/m^3 and 26.275±6.49 Bq/m^3 for LR-115 Type II and CN-85 respectively. After calculating the radon concentrations in open and closed dosimeters, it found the mean equilibrium factor was 0.143 and 0.089, the mean value of annual effective dose was found 0.064 mSv/y and 0.037 mSv/y in open dosimeters and found 0.035 mSv/y, 0.023 mSv/y in closed dosimeters for LR-115 Type II and CN-85, respectively. In addition, the mean potential alpha energy concentration was calculated as equal to 1.680 mWL and 0.974 mWL in open dosimeters ,either in closed dosimeters were 0.935 mWL and 0.600 mWL for LR-115 Type II and CN-85, respectively . The mean value of exposure to radon progeny were 11.259 $mWLMY^{-1}$ and 6.525 $mWLMY^{-1}$ in open dosimeters ,either in closed dosimeters were 6.258 $mWLMY^{-1}$ and 4.019 $mWLMY^{-1}$ for LR-115 Type II and CN-85, respectively. The mean value of lung cancer cases per year per million person was 1.147 and 0.665 for open dosimeters, 0.638 and 0.410 in closed dosimeters for LR-115Type II and CN-85, respectively. The results were obtained from this study within the international limits (200-300) Bq/m^3according to ICRP, that's mean there is no risk of lung cancer threatening students and educational staff of these schools.

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List of Symbols

DNA	Deoxyribo Nucleic Acid.
UV	Ultraviolet Ray.
IR	Infrared Ray.
MeV	Million electron Volt.
EPA	Environmental Protection Agency.
UNSCEAR	United Nations Scientific Committee on the Effect Atomic Radiation.
WHO	World Health Organization.
ICRP	International Commission on Radiological Protection.
NCRP	National Council on Radiation Protection and Measurement
Bq	Becquerel.
PCi	Pico Curie.
SSNTDs	Solid State Nuclear Track Detectors.
a.m.u	atomic mass unit .
A	Activity
α	Alpha particle
γ	Gamma ray
V_T	Track etch rate Velocity
V_B	Bulk etch rate Velocity
θ_c	Critical angle
$t_{1/2}$	Half-life
C	Concentration of radon
ρ	Track density
K	Calibration Factor
H	Occupancy factor.
T	The number of hours per year.

AED	Annual Effective Dose
D	the dose conversion factor.
PAEC	Potential Alpha Energy Concentration
EP	Exposure to radon Progeny
CPPP	Lung Cancer Cases Per year Per million Person
WL	Working Level
Sv	Severt
WLM	Working Level Month
Y	Year

Chapter one

Overview of Radon

(1.1) Introduction

Radiation is the energy that transport either in the form of electromagnetic waves or particles [1]. Basically, radiation can be classified into two types: The first type is ionizing radiation such as (x-ray ,gamma ray ,alpha and beta particles) that contains high energy to transport electrons from atoms and molecules in the cell [2]. The harmful result of ionizing radiation is biological damage to Deoxyribo Nucleic Acid (DNA) or other parts of the body. Even at low doses of radiation, there is a higher risk of cancer [3].The second type is non-ionizing radiation such as (radio waves ,micro waves , Ultraviolet Ray (UV), Infrared Ray (IR) and visible light) [4] .

The atoms are unstable and changes in the atoms of another element through ionizing radiation process. This process is known as radioactivity which means the spontaneous decay and transformation of unstable atomic nuclei accompanied with the emission of nuclear (particles) or (photons) [5, 6] .

Exposure to natural radiation occurs in two ways. For the first time by gamma ray and radon exhalation. Gamma radiation rises from ^{40}K, ^{238}U and ^{232}T, thus exposing the entire body to that radiation while radon leads to internal dose exposure [7]. Many researchers reported that half of the total annual effective dose received by the population stems from radon and its decaying products [8]. There are many factors that contribute to indoor radon. These factors are the construction of terrestrial, internal or external building materials, soil characteristics, water supply, ambient air, environmental standards (temperature, atmospheric pressure, precipitation) [9].

(1.2) Radioactive Decay Series

There are four radioactive decay series: Uranium, Actinium, Thorium, and Neptunium series which are represented in table(1.1). Neptunium does not occur in nature because its half-life 2.1×10^{6} y is much smaller than the age of the earth 3×10^{9}y [5].

Table (1.1) Radioactive decay series [10].

Series	First element	Half-life(y)	Last element (stable)
Uranium	^{238}U	4.5×10^{9}	^{206}Pb
Thorium	^{232}Th	1.39×10^{10}	^{208}Pb
Actinium	^{235}U	7.10×10^{8}	^{207}Pb
Neptunium	^{237}Np	2.14×10^{6}	^{209}Bi

(1.2.1) Uranium-238 Series

This series begins with Uranium-238 (^{238}U)nuclei with a half-life 4.5×10^{9} y and gradually converted to the ^{206}Pb which is a stable element through sequences of the emission of alpha or beta particles and gamma ray. All nuclides in this series are solid elements except ^{222}Rn nuclei, which is gas. The elements of this series are represented in Figure (1.1) are arranged according to the mass number indicated in (4n+2) system ,n is varying from 51 to 59 [11-13].

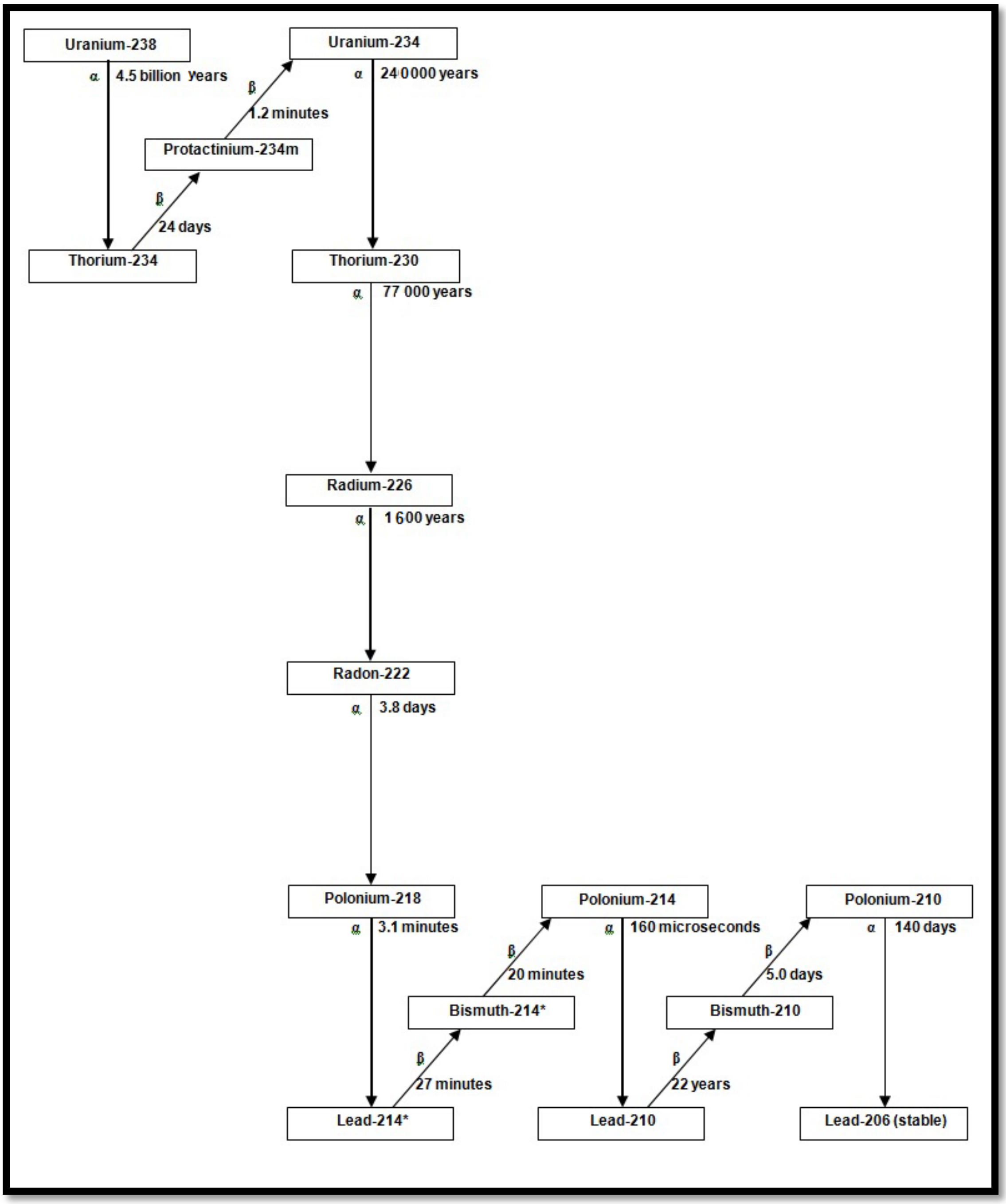


Figure (1.1) Natural Decay Series for Uranium-238 [14].

(1.2.2) Thorium-232 Series

The natural thorium consists of entirely of ^{232}Th ,(1.35 × 10^{-8}%) of ^{228}Th and very small amounts(^{234}Th, ^{230}Th, ^{231}Th and ^{227}Th). ^{232}Th is the origin of the 4n radioactive decay series (n varying from 52 to 58) as shown in figure (1.2) [13] .

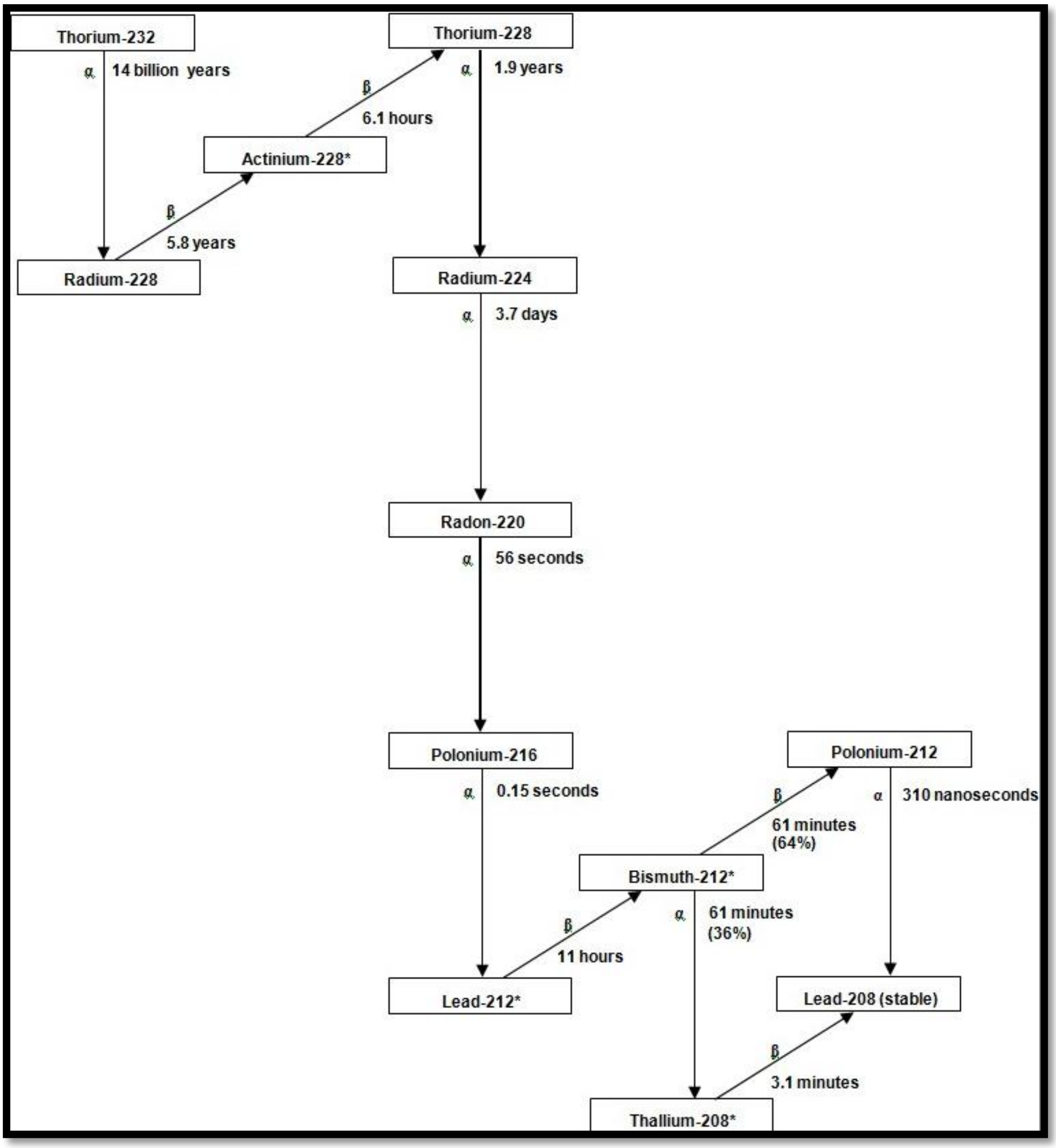


Figure (1.2) Natural decay Series for Thorium-232[14].

(1.2.3) Uranium-235 Series

Uranium-235 (^{235}U) with half- life (7.04×10^{8} y) is the longest – lived member of the naturally existing parent of (4n+3) series (n varying from 51 to 58) as shown in figure (1.3) [14].

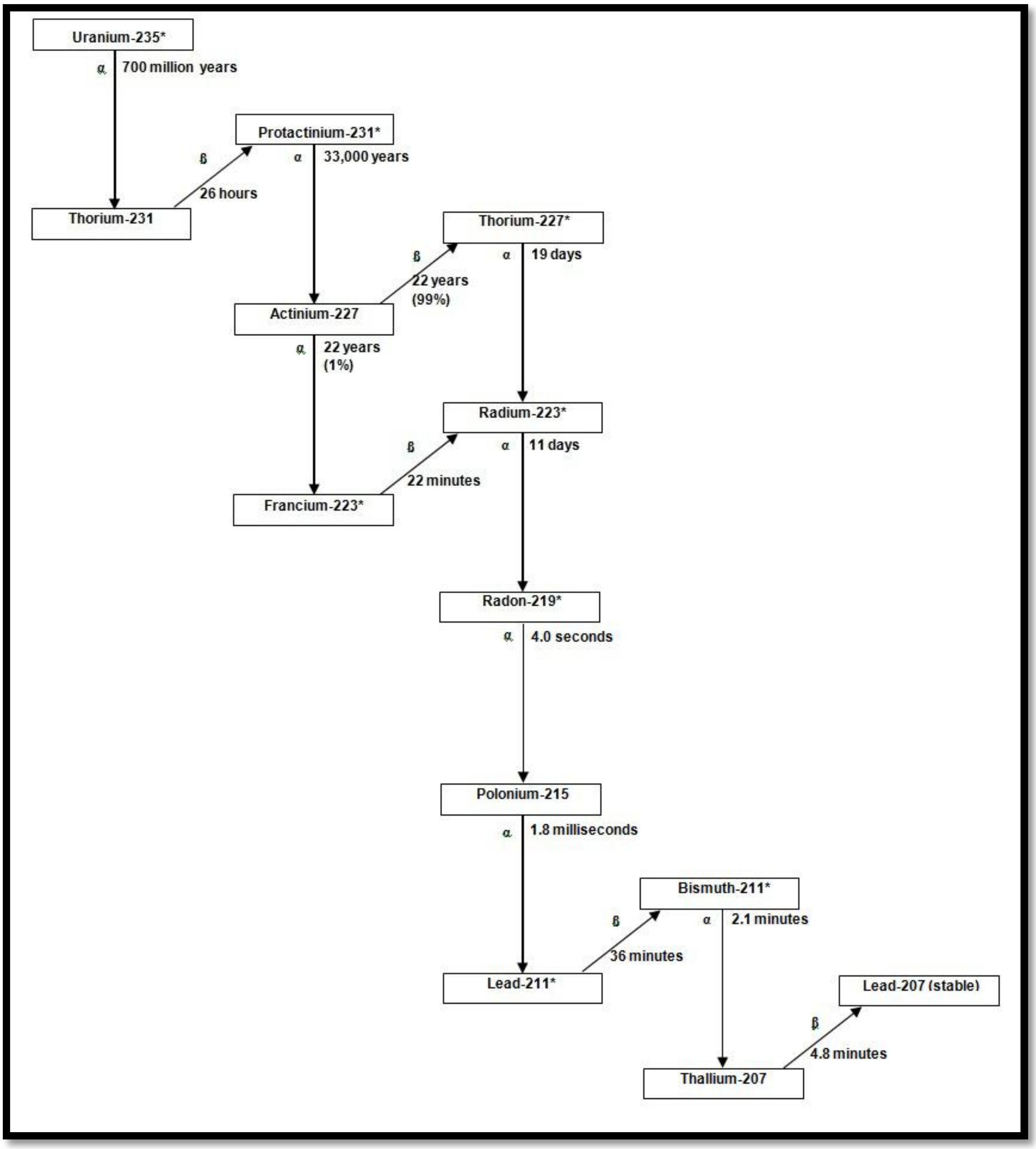


Figure (1.3) Natural Decay Series for Uranium-235 [14].

(1.2.4) Neptunium -237 Series

Neptunium -237 (^{237}Np) with a half-life of 2.2× 10^6 y is much shorter than the geological age of the earth. Virtually all neptunium decayed within the first 50 millions of years after the earth was formed [15]. So Neptunium -237 did not find in nature but it's discovered in some stars spectrum as shown figure (1.4) [16].

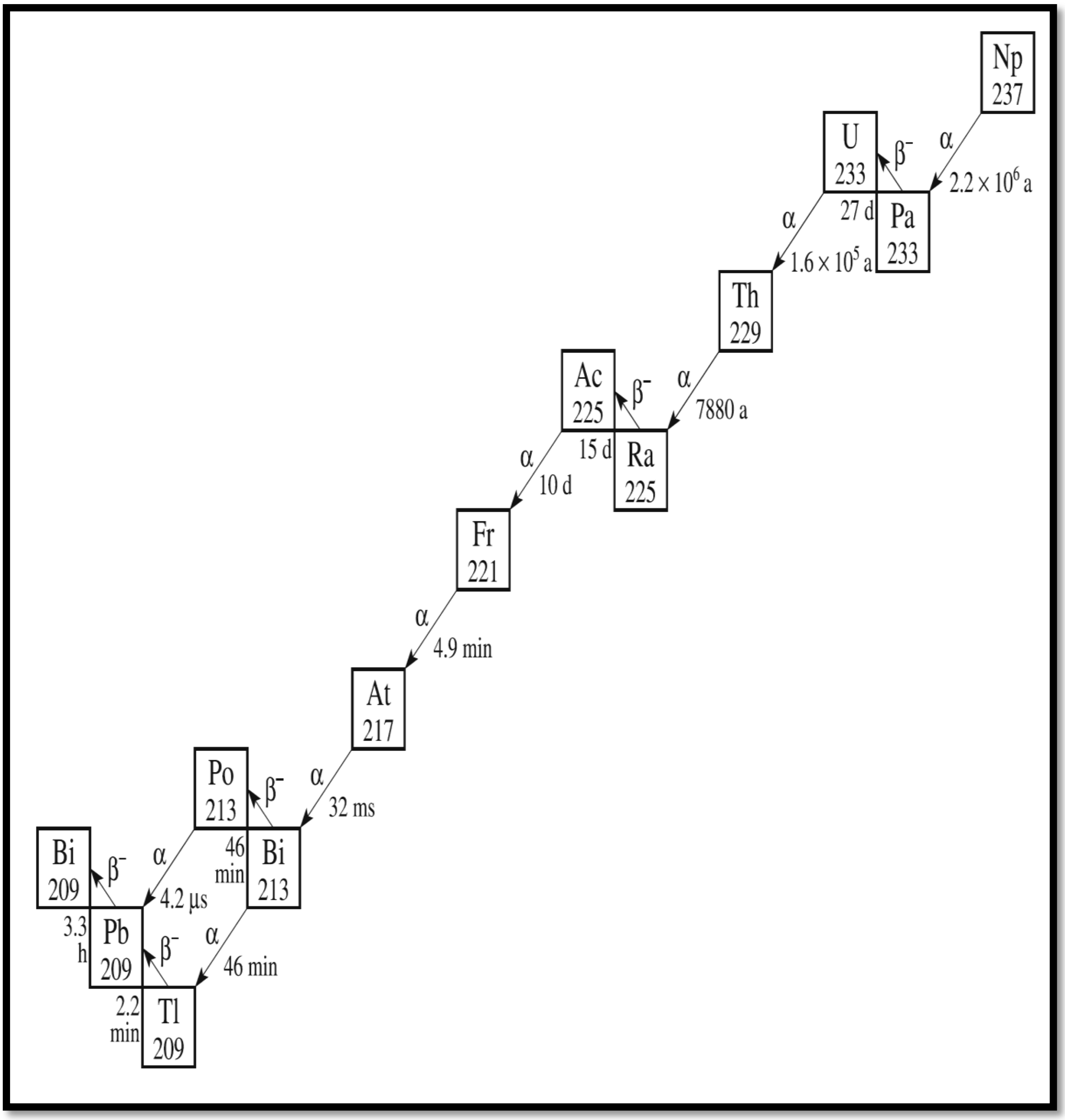
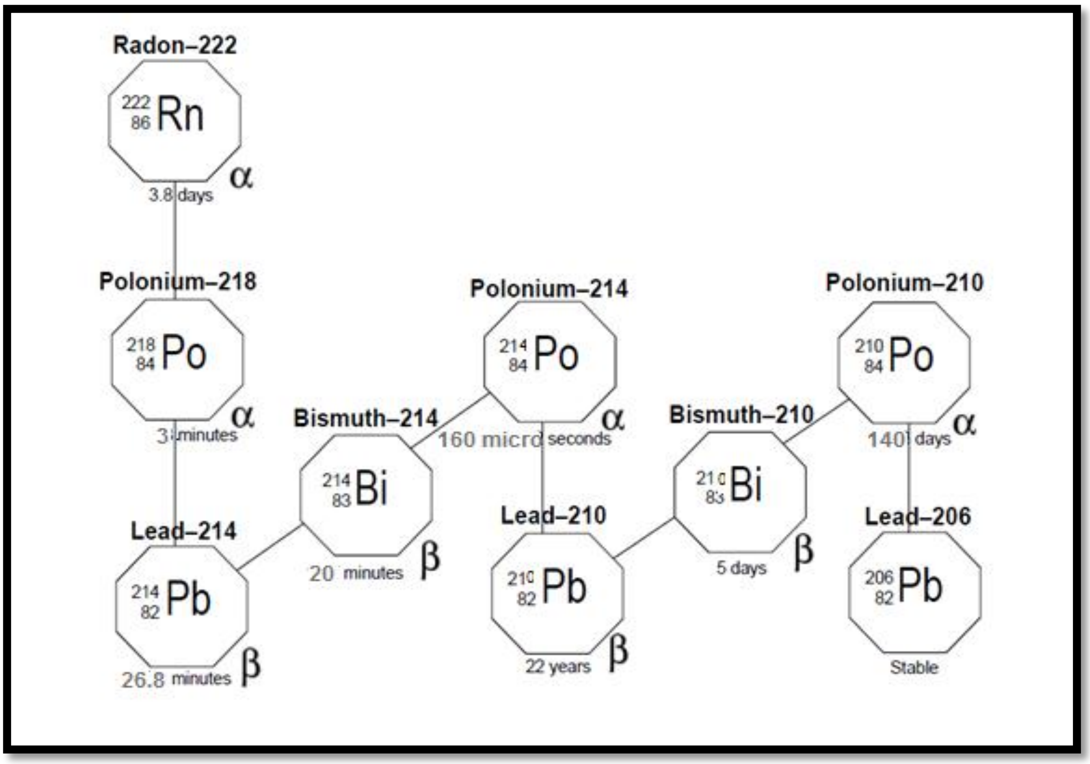


Figure (1.4) Decay Series for Neptunium - 237 [14]

(1. 3) Radon Gas

Radon was radioactive element discovered by the German Physicist Friedrich Ernst Dron in (1900), who called it Niton. It has been called Radon since (1923) [17]. It is a colorless, odorless and tasteless produced naturally from the natural radioactive decay of uranium. When uranium is present in small quantities in most rocks and soils. This slowly breaks down into other products such as radium, which breaks down into radon. Some radon moves to the soil surface and enters the air, while some uranium remain underground and enter groundwater [18]. Decay chains of radon-222 is given in figure (1.5). Scientifically, radon is known ^{222}Rn the most abundant isotope of the element Radon [19, 20]. ^{219}Rn is of a little importance and is rare in nature, has short half-life ($t_{1/2}$=3.92 s) 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 ($t_{1/2}$=55 s) and can often be eliminated from the monitoring system by introducing filter or other delaying techniques. The most important isotope of radon is ^{222}Rn it's half-life ($t_{1/2}$= 3.82 day) and can move substantial distances from its point of origin [21]. That is why only ^{222}Rn is generally considered as a health danger, when the estimating risk factors from exposure to radon. There are no sinks for radon and it is estimated that only negligible quantities escape to the stratosphere [22].



Figure(1.5) Radon-222 decay chart [23].

(1.4) Properties of Radon

Radon is an inert gas at a high level melting point (-71°C) and boiling point (- 61.7°C)with atomic number 86 makes its a noble element, thus both non-chemical and non-interactive naturally moving at normal temperatures, so it has a greater ability to migration through soil, air, etc. [21]. Radon contains three important isotopes, these are: (1) ^{222}Rn (called Radon) belongs to the decay series ^{238}U. (2) ^{220}Rn (called thoron) belongs to ^{232}Th decay series. (3) ^{219}Rn (called actinion) belongs to the ^{235}U decay series.

Radon daughters are: Polonium-218 (^{218}Po; $t_{1/2}$=3.10 min), Lead -214 (^{214}Pb; $t_{1/2}$=26.8 min.), Bismuth-214 (^{214}Bi, $t_{1/2}$=19.9 min) and Polonium-214 (^{214}Po, $t_{1/2}=1.6\times10^{-4}$ s). Thorium and uranium are both sources of radon and they are common naturally-occurring elements that are found in low concentration in rock and soil [24].

(1.5) Indoor Radon Sources:

One of the most important ways to enter the radon into the building whether schools or homes is from the soil through cracks and other holes in the foundation [25]. Energy sources such as coal, natural gas, etc., are also sources of indoor radon. Coal may bring some uranium content when drilled from the ground . As it is used as fuel in homes, radon may be increased, at the level of radon, indoor and outdoor environments. Another source of indoor radon is groundwater. Drinking water is expected to contribute only 1% to 7% of radon in the indoor air [26].

Any process that exposes water to the air releases radon. Radon is released at building during activities such as bathing, laundry, and toilet cycle. Radon also comes from building materials, but usually at very low levels. Wood materials tend to emit at least radon, cement, and the emitter mass emits more. Radon is released from all these sources at such a low rate that these substances are rarely important contributors to high radon levels, as shown figure (1.6) [17].

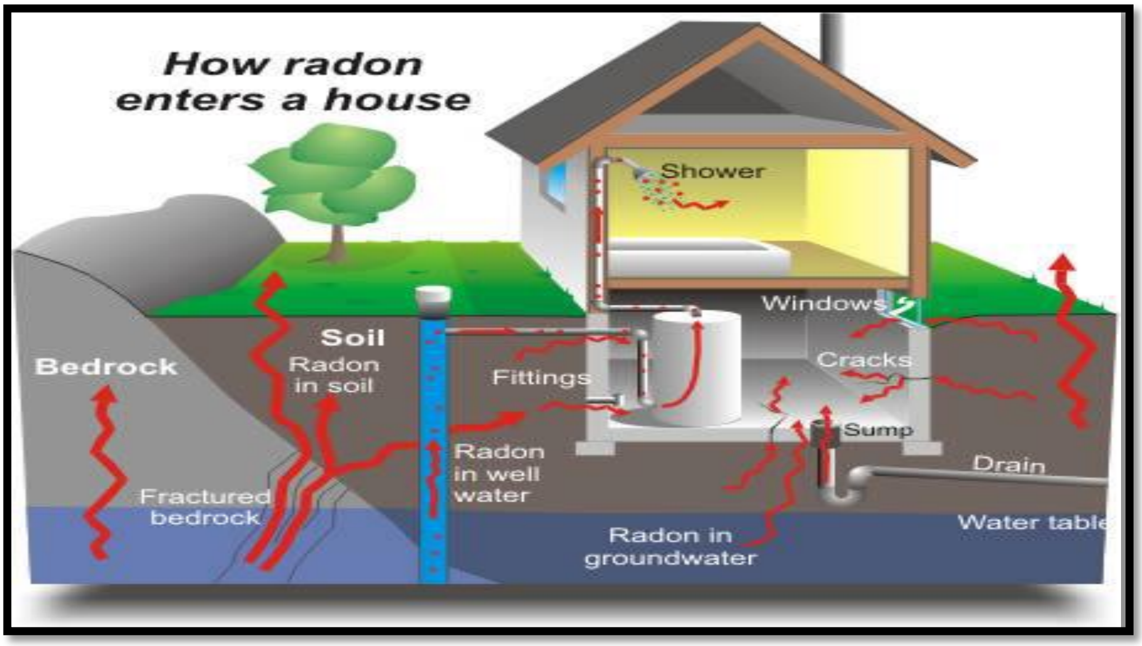


Figure (1.6) How Radon enters a building [27].

(1.6) Exposure to Radon

Because many people - especially children - spend most of their time at home and school, the school is likely to be the most important source of radon exposure after homes. The parents strongly encourage them to test their homes and school for radon and take action to lower the high concentrations of radon there. For most schools and staff, the second largest contributor to radon is likely to be exposure to their school. As a result, those schools are must tested as well as homes for radon. Environmental Protection Agency (EPA) recommends reducing the concentration of radon in the air within the school based on the level of action of EPA radon in 148 Bq/m^3. EPA believes that no radon carries exposure to some risk - no level of safe radon. Radon levels below

148Bq/m^3 pose some risk and can reduce lung cancer risk by lowering radon levels [28].

(1.7) Control of Radon in Schools and Homes

The main radon airborne in most schools and homes is the underlying soil. There are some techniques to reduce radon concentration in schools and homes:

1- Source removal: If the source of elevated radon concentrations is highly active radium bearing material- such as uranium mine waste rock , uranium mill tailings, or uranium refinery wastes, experience has shown that the removal of most of this material adjacent to a building foundation effectively and permanently reduces the indoor radon concentration [29].

2- Occupant life style: The radon concentration in indoor air is influenced by the living style of occupants. The air exchange rate is affected by the human activities such as opening and closing of doors and windows, use of air conditioning, fans, etc., therefore, varying the radon level in school and house. The use of water and natural gas in school and house varies from one place to other. The amount of radon in indoor air due to use of water depends upon amount , time and place of water used . Radon concentration varies with the use of natural gas, which depends upon winter or summer season, the place and duration of its use [29].

3- Closing entry routes: The sub grade portion of the basement or foundation of a building is not airtight for conventional building styles. As a result, there are many opening through which soil gas containing radon can flow freely from the soil into the building interior. The ease of soil gas movement can be significantly reduced by closing these openings [30].

4- Structure ventilation: One of the methods that can be used for reducing the air borne concentrations of this gas and its decay products inside houses is ventilation [30].

5- Design of the building: The design of the building plays its role in indoor level. Air leaks into the building through cracks and interstices, through ceilings, floors, and walls of the building. This process is known as infiltration. Building shape and its orientation to the wind direction also influence the distribution of wind pressure, which cause infiltration. Similarly, the location of doors, windows, and other internal opening not only affect the location and extent of infiltration, but also determine where natural and forced ventilation may occur. Also, building height becomes important due to buoyancy of warm air where indoor radon concentration generally decrease from the base to the first floor and from the first floor to the higher floors for the time of normal activity. The joints between the wall and the floor are the next most common pathways [31].

(1.8) Health Effect of Radon

In many countries, exposure to radon is the largest dose of radiation received by the general population UNSCEAR,2000 [32] . As mentioned earlier, radon (^{222}Rn) is disabled to form very small solid radioactive particles, including ^{218}Po,^{214}Po which becomes associated with aerosol particles and natural dust. These may remain outstanding in air or stability on surfaces. When these particles are inhaled, they radiate cells with alpha and this may increase the risk of lung cancer. Regardless of lung cancer, there is no evidence of an epidemic of radon causing any other type of cancer [33]. Therefore, living in a high level of radon concentration for a long period of time means this possibility increases the incidence of lung cancer [34].

There is a direct evidence from human studies of a link between exposure to radon and lung cancer. This is why radon is classified by the International Agency for Cancer Research, part of the WHO, as a carcinogenic group. This identifies radon in the same group of carcinogens as asbestos and tobacco smoke as a cause of lung cancer . Radon is more likely to develop lung cancer in people who have smoked or smoked in the past than non-smokers throughout their lives. However, it is the leading cause of lung cancer among people who have never smoked. The percentage of all lung cancers associated with radon is estimated to range from 3% to 14%, depending on the radon rate of country concentration and the measurement method ICRP (2010) [35] and WHO(2009) [36]. Not all of the breathing products of radon decay will develop to the lung cancer. The risk of lung cancer from radon depends mostly on three factors [26].

1. Radon level.
2. Duration of exposure.
3. Smoking habits of individuals.

(1-9) Advantages of Radon

There are more information cumulating on the benefit effects of radon as follows:

1- Radon as Medicine (Radon Spas and Radon Therapy)

Rather early, the stimulation of DNA repair was observed upon radon exposure .Similar DNA repair was indicated in lymphocytes of people living in increased radon concentration and also the adaptive response reaction was provoked under 10 mSv “priming” dose[21] . spas evidently containing radon have been used with success for hundreds of years for special illnesses mainly in the pain therapy of chronic rheumatic illnesses. Radon spas are widespread in United States, Japan and Europe (Greece, Germany, Austria, Czech Republic, Hungary, Romania, Slovenia, Russia, etc.). Clinical experience has shown that the long-lasting pain of the patients was considerably reduced with less analgesic pharmaceuticals. The presence of radon in spas, accordingly, cannot be considered as risky to health, just the opposite, more and more information cumulate on its positive health effects completing the other beneficial factors present in health spas [21, 37]. Others support the positive or neutral effects of low dose radiation. The question is whether or how much the radon impacts or damages the tissue . So that any radon spa treatments should give by a medical practitioner[38] .

2- Radon and Mineral Exploration

Over the years, large number of techniques and methods have been developed to measure radon concentration in the "soil gas' and in ground water in selected areas of interest. These measurements can yield a lot of information regarding the subsurface geological features and the presence of mineral and oil / gas reserves[16, 21].

3- Radon and Earthquakes Prediction

The real time radon monitoring is an extensively studied area in order to give premonitory signs prior to earthquakes. The strain change that occurred within the earth surface during earthquake is expected to enhance the radon concentration in soil gas and in groundwater. In addition to continuous radon monitoring in groundwater other geochemical parameters such as electrical conductivity and water temperature should be performed [21, 39, 40].

4- Radon and Volcanic Surveillance

Radon has been recognized for long time as a detectable component of fluids associated with volcanoes (fumaroles, ground waters ,or soil gases). It was reported that radon measurements should be definitely supplemented by measurements of other physical or chemical parameters .Under such circumstances , knowledge of the geochemistry of volcanoes could rapidly increase in the immediate future [21]

5- Radon and Geothermal Energy Prediction

A geothermal source may be defined as the natural heat of the earth trapped close enough to the earth's surface to be extracted economically. Hot water springs and vapors emanation may suggest prospecting geothermal energy sources. The observation of exceptionally high radon levels may indicate the possible existence of a geothermal energy sources lying deep underneath the earth's surface. The method of using radon signal for locating geothermal energy sources has met some success in countries such as New Zealand and Mexico [21].

(1.10) Literature Review

Several previous studies have measured the concentrations of radon in air of schools and homes using nuclear track detectors. The following studies are the most important research available on the study of radon gas.

Tufail ,M., et al. (1991) [41] measured radon concentration in fifty houses in Islamabad and Rawalpindi, Pakistan using CN-85 detectors. The result appeared varies of radon concentrations in same house the average of radon concentration in bed rooms was 29±14 Bq/m^3 , in sitting rooms was 28±11 Bq/m^3 and in stores 33±16 Bq/m^3 .

Kullab, M., et al. (1997) [42] measured indoor radon concentration levels for 74 kindergartens in Amman ,Jordan using CR-39 detectors. They found that the radon concentrations in the classrooms of these schools range from 40.7 to 193.5 Bq/m^3 with an average of 76.8 Bq/m^3.

Malanca, S., et al. (1998) [43] measured indoor radon concentrations in 49 kindergartens and play-schools located in 26 towns of the Italian district of Parma . The measurements used was that involving LR-115 Type II detectors. The indoor radon levels resulted to be generally low, ranging from 10-108 Bq/m^3, with the mean concentration of radon was 30± 19 Bq/m^3. The annual radon effective dose equivalent was estimate to be 0.5mSv/y.

Akram, M., et al. (2005) [44] radon concentrations were measured in some dwellings in Skardu, northern Pakistan . The measurements were based on radon detection using CN-85 detector. Radon concentration was found to range from 76.04 $Bq/m^3$to 152.38 Bq/m^3 with an average value 111.34 Bq/m^3.

Maged, A.F.(2006) [45] measured radon concentrations in 25 classrooms in the capital Al-Kuwait, using CR-39 detectors .Mean dose equivalent rate of case subjects, 0.97± 0.25 mSv/ y, was higher than the equivalent radiation dose rate of control topics, 0.43±0.11 mSv/y. Average radon concentrations found 16 ± 4 Bq/m^3 for the first floor and 19± 4.8 Bq/m^3 for the second floor after subtraction control.

Papaefthymiou, H. and C. Georgiou (2007) [46] studied Radon concentrations in from a total of 66 public primary schools throughout of Patras, Greece, using LR-115 Type II. Radon concentrations was ranging from (10 to 89) Bq/m^3. The arithmetic mean was the internal concentration 35 ± 17 Bq/ m^3 and annual effective dose 0.2 ± 0.1 mSv/y for teacher.

Abel, G. (2008) [47] measured radon concentration in elementary school in Cairo in 50 classrooms using CR-39 detectors, which found the indoor radon levels in the classrooms were 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. The average annual radiation doses obtained on inhalation exposure to ^{222}Rn and its daughter were 0.85± 0.37 mSv/y for classes closed windows and 0.67±0.23 mSv/y for classes open windows.

Venoso, G., et al. (2009) [48] radon was measured in 30 schools located in the urban area around Naples, Italy. Using SSNTD method with LR-115 Type II detectors. The annual arithmetic mean of the radon concentration is 144 Bq/m^3. Room fractions with radon concentrations exceeding the reference levels of 200, 400 and 500 Bq/m^3 are 21.3%, 7.6% and 4.5%, respectively. The results show that radon concentrations in scientific laboratories and offices are higher than during studying semesters.

Khan, H., et al. (2009) [49] radon concentration has been studied of Northern Areas of Pakistan at different altitudes for a period in one year. The average concentration of radon level found at altitudes 3020 m, 3540 m, 3665 m and 4265 m above sea level and ^{222}Rn concentrations were found to be 16.4±2.5 Bq/m^3, 21.7±4.8 Bq/m^3, 13.8±3.2 Bq/m^3 and 19.3±3.4 Bq/m^3, respectively. It observed that there are no major differences in the radon concentrations with different altitudes but differences in concentrations were observed with types of rooms attributed to good ventilation, source of radon present in the soil and atmospheric parameters.

Rafique, M., et al. (2009) [50] measured indoor radon levels in 35 houses in muzaffarabad , Pakistan by using CN-85 detectors .That were found the mean of radon concentration in kitchen 84Bq/m^3 and in drawing rooms 85 Bq/m^3 and bed rooms 93 Bq/m^3 .

Labidi, S.,et al. (2010) [51] measured indoor radon in 30 elementary schools in Tunis. The measurements had been used by nuclear track detectors LR-115 Type II. The results seemed that the concentration of radon levels are low in the range of 6–169 Bq/m^3 with a mean value 26.9 Bq/m^3.The annual effective dose varied between 0.025–0.715 mSv/y for teachers while the range for pupils was from 0.019–0.525 mSv/ y. The values were agree with ICPR recommended values.

Mahmood, A., et al. (2010) [52] radon concentration was calculated in youth hostel buildings and campus in some colleges in Lahore, Pakistan using CN-85 detectors. The concentration of radon gas observed in different parts of controlled buildings was within the range of 18 to 61 Bq/m^3. The estimated alpha dose of radon for students and staff supporters at about 0.34 and 0.91 m Sv/y in campus buildings and hostels, respectively. It was found at the risk of life for cancer lifetime attributed to the students and staff at the college campus to be 0.20%, while the staff and students who reside in the homes of the college may risk 0.53% of cancer due to radon strains.

Obed, R., et al. (2011) [53] performed radon measurements in secondary schools in the Okee -Ogun area, south-west, Nigeria, by using CR-39 detector . The average radon concentration was 45 - 27 Bq/m^3 and the effective dose varied from 0.13 to 0.45 mSv/y with a mean of 0.32 - 0.20 mSv/y for the schools. The results showed no radiological health hazard.

Barescut, J., et al. (2011) [54] studied indoor radon for schools, detailed radon survey was conducted in one hundred three selected schools in Korea using CR-39 detectors. According to the results of average of effective dose assessment 1.35 mSv/y due to inhaled radon of during occupancy time, fourteen schools for requiring urgent mitigation action were selected, and recommended to the government.

Çevik, U., et al. (2013) [55] conducted a survey on environmental radioactivity in 16 high school is located in the northeastern part of Turkey (Black Sea Region, Trabzon Province) using LR-115 Type II detectors.. It was seen to mean radon concentrations in schools ranged from 31 to 157 Bq / m^3 for the spring season and from 38 to 114 Bq/m^3 for the autumn season.

ALkan, T. and Ö. Karadeniz (2014) [56] measured indoor radon concentrations in the arts and sciences college of Dukes at the university of Laayoune, Izmir, Turkey .The arithmetic mean of radon concentration is 161 Bq/ m^3 for a range of 40 to 335 Bq/m^3 in the college. Based on measurement of indoor radon data, estimated annual effective doses received by staff in the college ranging from 0.79 to 4.27 mSv/y, according to UNSCEAR methodology. Annual effective doses of the staff received ranged between 0.78 and 4.20 mSv/y in homes. on average, the college contributed 56% from total annual effective dose.

Damla, N. and K. Aldemir (2014) [57] evaluated the levels of indoor radon and gamma doses in 42 primary schools lied in Batman, southeastern Anatolia, Turkey using CR-39 detector. The overall mean annual ^{222}Rn activity in the surveyed area was found to be 49 Bq/m^3 equivalent to an annual effective dose of 0.25 mSv/y. However, in one of the region (Besiri) the maximum radon value turned out to be 307 Bq/m^3.

Hiwa, H. A., et al. (2015) [58] selected 20 kindergartens of the region of Koya, Iraqi Kurdistan to study radon effect on children health which they used CR-39 detectors. It is found that the average value of indoor radon concentration was 28.306±12.07 Bq/m^3, annual effective dose was 0.281 mSv/y, and potential alpha energy concentration was 0.056 mWL.

Hamzah ,A., et al. (2015) [59] measured indoor radon in the classrooms of 20 elementary schools in Tulkarem Governorate using CR-39 detectors. They found radon concentrations ranging from 3.48 to 210.51 Bq/m^3, with an average of radon concentration 40.42±2.49 Bq/m^3. The average of annual effective dose was found to be 0.17±0.01 mSv/y.

Kurt .A., et. al (2016) [60] measured radon concentration in 25 schools in Fatih District inTurkey by using LR-115 Type II detectors. The results of measurements showed that the radon concentration varies between 40-395 Bq/m^3 with average value 125 Bq/m^3. This results compared with Turkey's limits (400 Bq/m^3) are low, conversely higher compared with WHO's limits (100 Bq/m^3).

Abdalsattar ,K. and Elham J. (2016) [61] measured indoor radon levels in different dwellings in Karbala city , Iraq . The concentrations of radon were evaluated by using CR-39 detectors.. The results showed that, the concentrations of radon varied from 32.21-139.01 Bq/m^3 with an average value 62.07 $Bq/m^3$and 36.70-243.97 Bq/m^3 with an average value 93.36 Bq/m^3 for closed and open dosimeters respectively. The values of the annual effective dose varied from 0.02-2.76 mSv/y with an average value 0.68mSv/y and 0.02-7.49 mSv/y with average value 1.43 mSv/y for closed and open dosimeters respectively.

Ali, A., et al. (2017) [62] studied radon concentrations in Kufa Technical Institute buildings using different radon measurement methods such as active (RAD-7) and passive methods (LR-115 Type II). The result showed that radon concentrations were generally low ranging from 38.4 to 77.2 Bq/m^3, with mean value 50 Bq /m^3. The mean of equilibrium equivalent of radon concentration and annual effective dose were assessed to be 19.9 Bq /m^3 and 1.2 mSv/y respectively. The risk of lung cancer throughout life was about 11.6 per million people. The results showed that radon concentration was lower than the United State (US) Environmental Protection Agency (EPA) of 148 Bq/m^3. The values appeared that there is no risk to the health of radiation. However, relatively high concentrations in some classrooms can be handled by natural ventilation or classroom that is provided with suction fan.

(1-11) The Aim of Study

The aim of this study was measurements radon concentrations in the air of some buildings schools in Karbala city and calculation the annual effective dose in these buildings in order to evaluate the safety of the school buildings from the risk of radon and conduct measures if necessary. In addition to compare the results was obtained from the detectors LR-115 Type II and CN-85 in these schools, also determine the equilibrium factor between radon concentrations in open and closed dosimeters, potential alpha energy concentration, exposure to radon and its progeny and knowledge the number of people who are likely to have lung cancer.

Chapter Two

Solid State Nuclear Track Detectors

(2.1) Introduction

Solid state nuclear track detectors (SSNTDs) can be defined as those materials, when exposed to certain dose of radiation one or more measurable parameters will be changed. SSNTDs are the most commonly used for the analysis of alpha particles emitted by radon decomposition. The work of SSNTDs depends on the fact that charged heavy particles will ionize a wide range of materials when passing through matter [63]. The passage of heavy ionizing nuclear particles through most solids creates a buffer of narrow pathways for severe damage to an atomic scale. These "tracks" can be detected and made visible either directly using an electron microscope or indirectly by a chemical using an optical microscope [64] .

The idea of solid nuclear track detectors began in 1958, by Young at the atomic energy research institute in Harwell, England, observed that lithum fluoride (LiF) crystal held in contact with Uranium foil irradiated with thermal neutrons, a number of pits (damage regions) were revealed after treating the bombarded crystal with chemical reagent [65]. The number of these pits showed a complete correspondence with estimated fission fragments which have recoiled into the crystal from the uranium foil. In 1959, Silk and Barnes working in the same establishment had recorded direct observations of damage regions, as hair-like tracks, in mica [66] .They were the first to be observed electron microscope transmission. Then, in a very short period of time, a number of experiments have been carried out that have led to the discovery of chemical etching techniques and optimum conditions for etching. These experiments have led Fleischer, Price and Walker together at the General Electric Research Laboratories (GERL) in Schenectady, New York, to extend the etching technology of Young (his work was unknown to them at the time) [65]. Repeat and notes developed by Silk and Barnes [66], by introducing fission fragments and other heavily charged particles in many solids where they observed the tracks directly using an electron microscope. They also showed that the fission fragments in mica can be revealed by etching with a selective chemical agent of hydrogen fluoride (HF) to observe the latent tracks with an optical microscope. The successive studies of etch able tracks observation led the team (Fleischer, Price and Walker) to a fact that the nuclear track registration and etching are general phenomena in all dielectrics. According to this fact, they introduced a new nuclear track detectors termed as (SSNTDs) [67, 68] .

After the publication of the first review article by Fleischer, his co-authors Price and Walker published their report on the application of (SSNTDs) in nuclear science and geophysics. In this respect, the solid state nuclear track registration technique caught the attention of scientists in different laboratories and universities all over the world and led to the present wide spread application of (SSNTDs) [68] .

Since 1960, solid state nuclear track detectors have been widely used for nuclear track registration. Many types of these detectors which have been introduced are grouped in two categories one is the inorganic detectors such as mica , glass. and the other is the organic detectors (plastic) including (CR-39, CN-85, LR-115, Lexan, Makrofol). The properties of the detectors such as availability, ease of use and low cost led to its rapid applications in a wide variety of fields of science and technology, mostly in nuclear and particle physics, nuclear dosimeter, cosmic rays, etc. Moreover, these also are used in other fields such as geophysics, astrophysics, plasma physics, medicine, biological science and radiography. Significant nuclear physics experiments began to be carried out in an increasing speed after the discovery of track detectors.

SSNTDs have become an important tool in the investigation of uranium exploration and in the detection of radon gas environmentally. The increased importance of SSNTDs and their wide application rendered them to study the tracks structure formation, their properties and the extreme influence of environmental parameters on them [69].

(2.2) Types of Solid State Nuclear Track Detectors

(2.2.1) Inorganic Detectors

Inorganic detectors are compounds that do not have carbon and hydrogen in their composition and creating ionic bond between its atoms [70]. There are many inorganic detectors such as: (glass, mica, etc.)، mica is used to record the tracks of neutrons and fission fragments, it has a high sensibility for the charged particles that have a mass greater than (30 a.m.u); and also has a high sensibility for the recording of the charged particles until the temperature (400 °C).

The glass detector is one of the good detectors for the detection of neutrons particularly in the nuclear reactors; because of its ability to withstand high temperatures and sense of fission fragments have the same specifications as the detector of mica, tracks were introduced in the same method used in mica [71] . Table (2.1) shows some types of the inorganic detectors and their chemical formula [70].

Table (2.1) The types of inorganic detectors [70].

No	Detector	Chemical formula
1	Fluorite	CaF_2
2	Quartz	SiO_2
3	Olivine	$MgFeSiO_4$
4	Zircon	$ZrSiO_4$
5	Soda Lime Glass	$23SiO_2:5Na_2O:5CaO:Al_2O_3$

6	Mica (Biotite) Mica (Muscovite)	$K(Mg.Fe)_3AlSi_3O_{10}(OH)_2$ $KaI_3Si_3O_{10}(OH)_2$
7	Calcite	$CaCO_3$

(2.2.2) Organic Detectors

The organic detectors are compounds where carbon and hydrogen enter in their structures and created a "covalent bond" between its atoms. This type of (SSNTDs) has a sensibility greater than inorganic detectors; because the bonds of (C-C, C-H) which are readily broken after exposure to the radiation; also the organic detectors have a high analytic power greater than inorganic detectors. The threshold energy for organic detectors is less than inorganic detectors. Table (2.2) shows some kinds of the organic detectors and chemical formula [72].

Table (2.2) The types of organic detectors [72].

No.	Detector		Chemical formula
1	Polycarbonate (Lexan , Makrofol)		$C_{17}H_9O_2$
2	Polyimide		$C_{11}H_4O_4N_2$
3	Polyallyl diglycol Carbonate		$C_{12}H_{18}O_7$ (CR-39)
4	Polyester (HB Pa IT)		$C_{16}H_{14}O_3$(PC)
5	Plexiglass		$C_5H_8O_2$
6	Cellulose	Cellulose Nitrate Cellulose Nitrate	$C_6H_8O_9N_2$(CN-85) $C_6H_9O_9N_2$ (LR-115)
		Cellulose Triacetate	$C_3H_4O_2$(CT)

(2.3) LR-115 Track Detector

It is a Kodak-Pathe of France produces different kinds of cellulose nitrate films to be used as SSNTDs, chiefly for radon dosimetry and neutron radiography. Recording tracks of ionizing particles and very heavy ions in cosmic rays and for detecting spallation products arising from very heavy energy particles.in them. These films are coated with lithium borate dispersed in a water soluble binder and are widely used to obtain neutron radiographic images by means of neutron and alpha particles reaction. LR-115 films consist of a thin red layer of cellulose nitrate colored deep red coated on 100 μm thick polyester base . Only the cellulose nitrate layer 6 μm for Type I and 12 μm for Type-II films having chemical composition ($C_6H_9O_9N_2$) as shown in figure(2.1). Another types of LR-115 films Type IB and Type 2B have lithium borate converter screen coated on sensitive cellulose nitrate layer .LR-115 films are sensitive to alpha particles of energy range 0.5 MeV to 8 MeV [69]. It is unaffected by electrons, X-rays, γ-rays and IR radiation. They are to be handled with care due to the possible abrasion by mechanical rubbing, folding or pressure. Surface active of LR-115 Type II agents like detergents, organic solvents, etc. can lead to adverse reactions with the sensitive film. Depending on the type of the film, cellulose nitrate can have etching conditions (1-12) N Sodium hydroxide at 40-70 C^o for different duration [69]. The optimized condition for LR-115 Type II film is 2.5N from Sodium hydroxide at 60 c^o for 90 minute. The scanning of the detector can be done with an optical microscope or spark counter. The top sensitive thin layer of LR-115 Type II can be floated off its polyester base by soaking in warm water or can be used for spark counting [73].

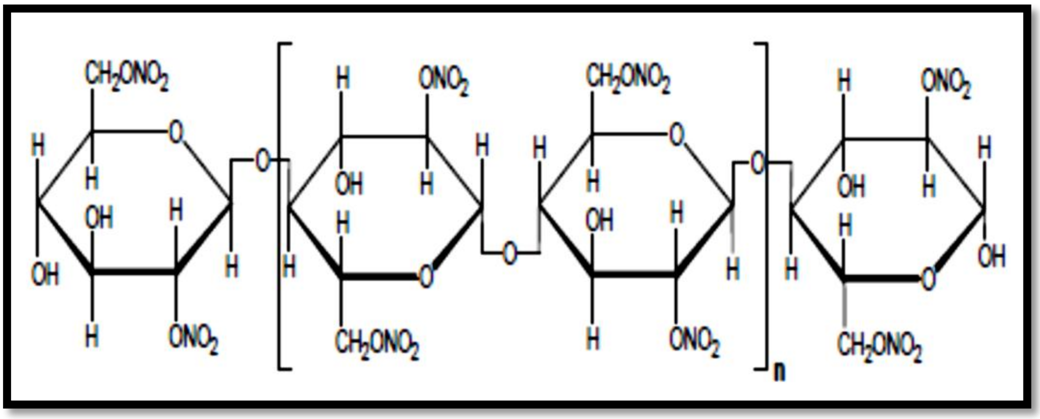


Figure (2.1) Chemical formula of LR-115 $(C_6H_9O_9N_2)_n$ [74].

(2.4) CN -85 Track Detector

CN-85 consist of 12 μm thick sheet of cellulose nitrate capable of recording tracks of ionizing particles in them. These films are coated with lithium borate dispersed in a water soluble binder and are widely used to obtain neutron radiographic images by means of neutron and alpha particles reaction. It is a Kodak-Pathe of France produces different kinds of cellulose nitrate films to be used as solid state nuclear track detectors, chiefly for radon dosimetry and neutron radiography.. It is also used for recording very heavy ions in cosmic rays and for detecting spallation products arising from very heavy energy. CN-85 films is made to convert each track by an ionizing particle to a perforation in the sensitive cellulose nitrate layer. The scanning of the tracks under a microscope is facilitated by the great contract between the perforation and background. Chemical composition for CN-85 is $(C_6H_8O_9N_2)$ as shown figure (2.2). It is used to detect alpha particles ranging from(0.5- 8)MeV[69]. The optimized condition for CN-85 is etch in hydroxide Sodium concentrations of 2.5N, at temperature 60 c^o for time 90 minute. The scanning of the detector can be done with an optical microscope or a spark counter [69].

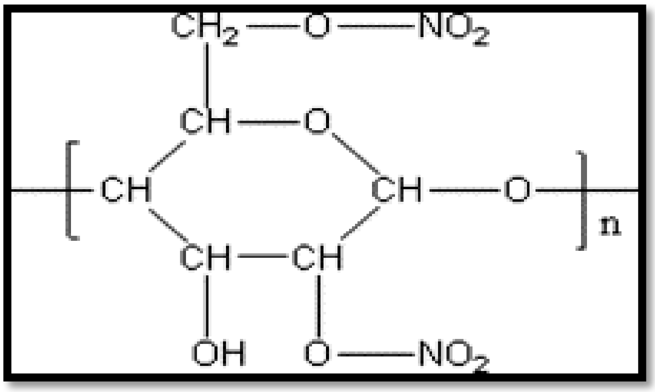


Figure (2.2) Chemical formula of CN-85 ($C_6H_8O_9N_2$) [6].

(2.5) Advantages of SSNTDs

There are many advantages of SSNTDs that are given below [75]:

1. These detectors are extremely simple to construct as compared with other track detectors mainly, bubble chamber, cloud chamber, spark chamber and nuclear emulsions.
2. These detectors are cheap and available in different sizes.
3. The tracks formed in these detectors are permanent and stable. They are mostly unaffected by humidity, low and high temperatures, pressure, light, and mechanical vibrations.
4. These detectors are capable of recording fission fragments due to its small size.
5. These detectors are placed in direct contact with the sources of fission fragments.
6. These detectors have geometrical flexibility that makes them suitable for angular distribution measurements in nuclear reactors.

(2.6) Models of Track Formation

A detailed theory of how tracks formed should fit the facts of the passage of highly ionized nuclear particles during most insulation solids creates stable and narrow paths of severe damage on an atomic scale. These damage are chemically reactive centers from strain that are consisting mainly of displaced atoms rather than electronic defects [76] .

Many theories have been proposed for the production of tracks before ionizing particles in solids, but none explains all the phenomena involved both organic and inorganic [77] .Some of the older models proposed for track formation include:

(2.6.1) Direct Atomic Displacement

Direct atomic displacement which considers the direct atomic collision which produces interstellar atoms and vacant atomic sites either as evidence of nearby discrete defects or as a final group of damage at the end of the path. But the model of direct atomic displacement is a special class for tracks formed by heavy particles with very low energy [78] .

(2.6.2) Thermal Spike Model

The energy loss mechanism of the projectile-ion leads to electronic and atomic collision cascades, the atomic collision-cascade deposits its energy in the close vicinity of the ion trajectory while the electronic collision-cascade has long range so its thermal effects may be neglected. The thermal spike model simplifies the complex effects of the atomic collision-cascade by assuming a simple thermal distribution. According to the thermal spike model the deposited energy correspond to an sudden temperature rise, in a small cylindrical volume around the ion trajectory at the time of passage (t=0); after the passage of the ion i.e. for (t > 0); the thermal energy diffuses away from the ion trajectory, the thermal spike creates defects by thermal activation which are remaining as frozen defects along the ion trajectory due to rapid quenching of the temperature. If ($\alpha-$particle) deposits an energy(Q) per unit (length) at the time (t =0); then the temperature (T) as a function of (t) and of radial distance r from the axis of the ion path is given by [79] .

$$T(r, t) = \frac{Q}{4c\rho\pi Dt}\exp\left(-\frac{r^2}{4Dt}\right) + T_o \qquad (2.1)$$

Where (T_0) is the initial temperature of the lattice, (c) is the capacity of the medium,(ρ)is its density, and (D) is the thermal diffusivity. If it is assumed that a high temperature is maintained (many thousands of degrees Kelvin) for a short time by an incident fission fragment; processes such as (melting and recrystallization) would occur and thus point defects (e.g., vacancies and interstitials) would be highly probable [80]. For all this to happen; conductivity in the material should be low. This explains the inability of metals to produce tracks as the thermal spike becomes broad and diffuses in the metal lattice, where as in insulators, a narrow, intense spike is produced. This leads to sufficient localized radiation damage capable of producing an etch able track [75].

(2.6.3) Ion Explosion Spike Model

Ion explosion spike model which is based on mechanisms loss of energy. According to this model, fast charged particles lose energy through excitation and ionization. Ionization creates charge centers in any solid and unstable group of neighboring ions. The electrons emitted are called delta rays. If it holds enough energy, it can lead to more excitation and ionization. Initial ionization and excitation occur near the path of the ion, while secondary ionization and excitation are greater radial distances than the heart of the path. In organic matter, such as polymers, removing excitation removal may remove long molecular chains free radicals are produced as shown in figure(2.2) [67, 77, 81]. As ions slow down, it begins to capture electrons, thus reducing its charge.

Close to the end of its path, atomic rather than electronic collisions are the dominant mode of energy loss. The result of atomic collisions is atom displacement and creation of vacancy [77]. The distribution of ionization or deposited energy as a function of distance from the particle trajectory is largely a function of the particle velocity and its charge. A low velocity particle loses its energy through many low energy collisions; this energy is confined to a small cylindrical volume around the particle trajectory [21] .

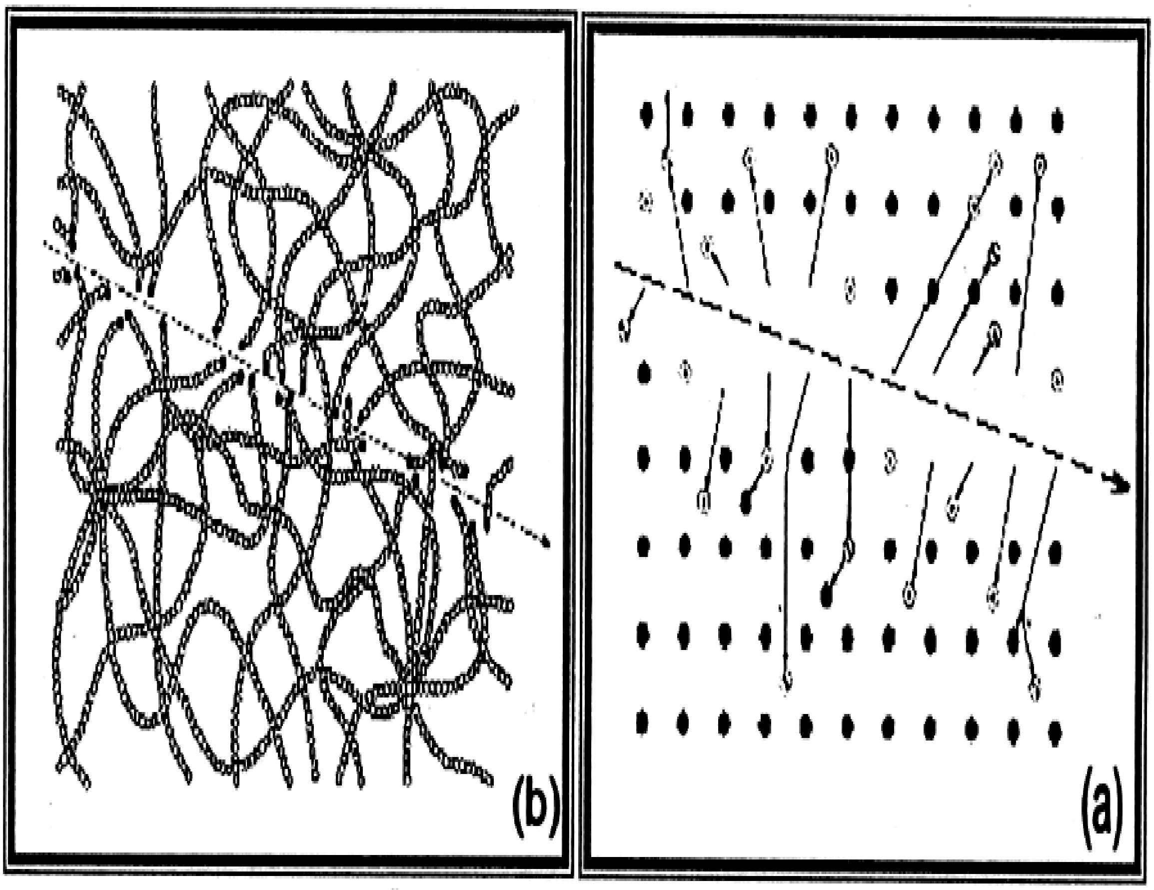


Figure (2.2) Formations of track particles in (a) a crystal and (b) a polymer [82]

(2.7) The Chemical Etching

The ionizing particles passing through polymeric track detectors produce latent tracks, are trails of radiation harm. The best means of observing the tracks is via etching SSNTDs material with a chemical solution; which preferentially attacks the damaged material and enlarge the original track to a size which is visible in the optical microscope [83].

The chemical etching of plastic detectors is usually carried out in thermostatically controlled bath (kept constant to ~ ± 0.1 °C). For plastics the most frequently used etchant is the aqueous solution of Soduim hydroxide (NaOH), with concentrations of 2.5 N, the temperatures usually employed (60±0.1) °C. A large glass, beaker contains the etching solution is usually placed inside the temperature- controlled bath. Into hanging, with a lid covering the top of the beaker to reduce the evaporation and the resulting increase of the solute concentration of the etchant solution . NaOH solution with 2.5 N has been used for the etching process. Normality is calculated using the following formula [83]:

$$W = W_{eq} \times N \times V \qquad (2.2)$$

where

W: is the weight of NaOH.

W_{eq} :is the equivalent weight of NaOH.

N is the normality = 2.5

V is the volume of distilled water.

In the current study and based on the equation (2.2) has been the use of 10 gm from NaOH and 100 ml of distilled water for the purpose of chemical etching.

(2.8) Track Formation Mechanism

When a highly charged nuclear particle passes through an electrical insulator, it transfers part or all of its energy to linear medium electrons. The energy loss rate (dE / dx), which is a function of particle properties such as mass, material charge, energy and the detector used. Physical, chemical and other solid properties along and around the path of particle change and narrow pathway are creating serious damage. This radiation damage may consist of broken joints, displacement atoms, electronic and ionic defects, gaps, defects, etc [81]. This narrow path is called the track.

When the energy loss is higher than the critical value (dE / dx) mJ, the recording is called threshold , without which the tracks are not composed of the solids used for detection. The basic track of the typical diameter is about 1 nm to 10 nm [78].Due to their size, basic tracks can only be visualized under extremely high magnification by electronic microscopes or other equivalent instruments. The embossing process is performed to maximize the tracks up to the micro-diameter (μm) with the help of a suitable and concentrated hot chemical such as a simple alkaline substance (eg, NaOH or KOH) or acid (eg, HF or HNO3) depending on the SSNTD nature used. Based on experimental tests conducted. Two separate pathways have been concluded, one for inorganic solids, glasses and other solids or organic polymers. One on the measurement of electron irradiation effects on the rates of chemical solubility of solids and other on measurement of radial distribution of transportable damage in solids.For inorganic solids and inorganic materials, Fleischer suggests the rise of the ionic explosion model [84], provides a largely satisfactory explanation for the formation of the path mechanism. According to the proposed model, the positively charged particle is multiplied outside the orbital electrons of the atom near its track , thereby producing a cylindrical region filled with positive ions. These positive ions are present when each other repels another violent, and therefore annoying, distortion of the normal grid in a crystalline solid and producing a more or less cylindrical area [85] .

(2.9) Track Geometry

Geometry track etching is presented in simplest case via the simultaneous action of two etching operation chemical dissolution along the particle track: a linear rate (V_T) and general attack on the etched surface and on the inside surface of the etched track at a lower rate (V_B) as shown in figure (2.3).

There are several parameters used to describe the geometry etched track, are [31]:

a. The full length of the latent track (L').

b. The thickness of the surface removed by etching (h).

c. The diameter of the etch pit (D).

The track length (L') at the etching time (t) given by the following relation[21] :

$$L' = V_T.t \qquad (2.3)$$

The surface is also begun removed at a rate (V_B), so that the length of track is:

$$L = V_T.\ t - V_B.\ t \qquad (2.4)$$

Where; V_T: track etch rate.

V_B**:** bulk etch rate.

When track etch rate (V_T) is constant and the particle penetrates normally; then the surface thickness (h) is given by:

$$h = V_B.\ t \qquad (2.5)$$

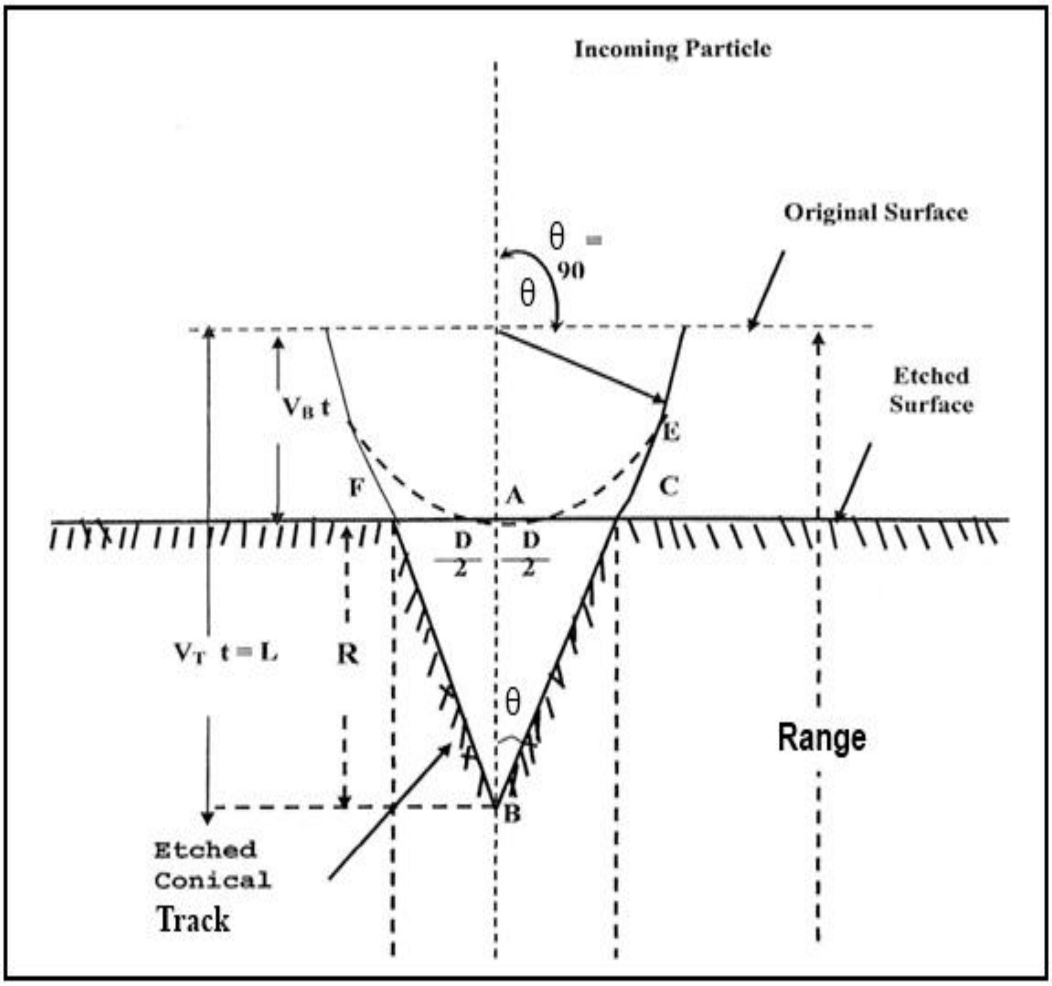


Figure (2.3) Track geometry for particle penetrates a detector material normally [86]

The diameter of each pit is related to (V_B) and (V_T) according to the following equation [21]:

$$D = 2\,V_B\,.\,t\,[(V_T - V_B) / (V_T + V_B)]^{1/2} \qquad (2.6)$$

Equation (2.6) shows that, the diameter of track (D) and the length of the track (L), depend basically on the competitive effect of(V_T) and (V_B). When ($V_T = V_B$), both (L) and (D) vanishes and then no track produces. For the track tilted at angle (θ) to the surface the component of (V_T) sin(θ) must exceed (V_B) in order to produce an etched track .

$V_T \sin(\theta) > V_B$

or

$\sin(\theta) > V_B/V_T$

However; if we increase the angle of the incidence of the track forming particle with respect to the normal of the detector surface; the stage is reached where the etching is:

$$\theta_c = \sin^{-1}[V_B/V_T] \qquad (2.7)$$

where the harm trail is not developed into a track. The ratio (V_T/V_B) is called the (etching rate) ratio and denoted by (V), the higher the value of this ratio (V_T/V_B) the smaller is (θ_c) and the faster and more efficient is the damaged trail evolved into a track. In general, due to the different energy loss rate along the track, (V_T) is not constant and the acute critical angle does not exist [21, 86].

(2.10) Track Affecting Parameters

There are two important factors that affect the appearance of a track, the track etch rate velocity V_T and the bulk etch rate velocity V_B

(2.10.1) The Track Etch Rate Velocity (V_T)

The track etch rate may be defined as the ratio of the dissolution of a detector along the line of the track. Its value depends on: the detector type, the particle velocity, etching conditions and its energy. experiments establish that(V_T) increased with increasing the average of ionization for different organic and inorganic detector.

The relation between (V_T) and the temperature of the etching solution is [87] .

$$V_T\ (\mu m/h) = B \exp[-E_T / k\,T] \qquad (2.8)$$

where: (B)is constant; (k) is the Boltzmann constant =$1.38\times10^{-23} J\, mol/K$ T; is the temperature of the etching solution (K); (E_T) is the activation energy of the track etch (J).

(2.10.2) The Bulk Etch Rate Velocity (V_B)

The bulk etching velocity (V_B) is the rate of chemical etchant that attacks the undamaged region surrounding the track. It is defined as the thickness that is removed from one of the surfaces of the detector per time as a result of chemical etching effect [72] . It is an important parameter for the determining the track sensibility of (SSNTDs). It depends on the construction of the plastic, the constituents of the etching solution, its concentration and temperature. It is found that for a given homogenous and isotropic solid, the bulk etch rate velocity (V_B) increases exponentially with etching temperature and concentration of the etching solution. The bulk etch rate is found to satisfy the following relation[87]:

$$V_B\ (\mu m/h) = A \exp(-E_B / k\,T) \qquad (2.9)$$

Where:

A = constant.

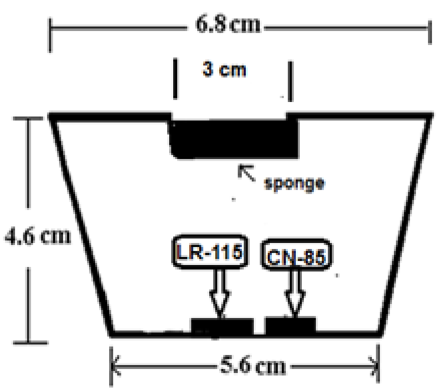
E_B = activation energy of the bulk etch.

Chapter Three

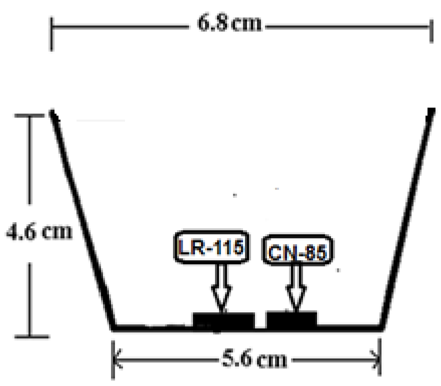
Experimental Method

(3.1) Introduction

The integrated passive radon dosimeter was used to measure radon concentration in air of some schools in Karbala city, which included solid state nuclear track detectors LR-115 Type II and CN-85 with dimensions of (1 ×1) cm^2. A specific number was engraved on the upper right corner of the detector to collect information more easily and recognize the detectors in the different sites. The detector was fixed at the bottom of a plastic container by a two sided adhesive tape. The side with the number was directed upward then the container was closed with a tight cover containing a hole of a diameter (3) cm and covered with a piece of sponge with thickness is (0.5) cm to prevent other radon progeny, while some other containers remained uncovered .Two containers, one open is inter ^{222}Rn+^{220}Rn , and the other is closed enters only ^{222}Rn, are placed in each school. The container were tightly sealed with a cover and its bottom is placed upwards. Figure (3.1) show a cross-section of integrated passive radon closed and open dosimeters respectively, and figure(3.2) shows the vertical and side images of open and closed dosimeters .



(a)



(b)

Figure (3.1) Cross section of integrated passive radon (a) closed dosimeter (b) open dosimeter

(a)

(b)

Figure (3.2) closed and open dosimeters a- Vertical image b- Side image

(3.2) Field of Study

Karbala is the center of Karbala province, which is the located in the middle of Iraq as a part of the (alluvial plain), Al-Husseineya river, a branch of the Euphrates (29 km), runs across its land. Geographically, it is bordered by the capital Baghdad at (105 km) from the city center to the north; Al-Anbar governorate at (112 km) to the north and the western north; Al-Najaf governorate at (74 km) to the south and the western south and Babylon governorate at (45 km) to the South and the eastern South. Karbala city occupies the northern east part of Karbala governorate. In the north, it is neighborhood by Al-Hur district; the south by desert, at the east Al-Husseineya district and Al-Hindeya; while the desert and Al-Razzazah lake borders the west indicated as in figure(3.3). With location of latitude (32`,34º- 32`.37º N), and longitude (58`,43º- 60`,44º E). Karbala city resides on(2793km^2) [61] .

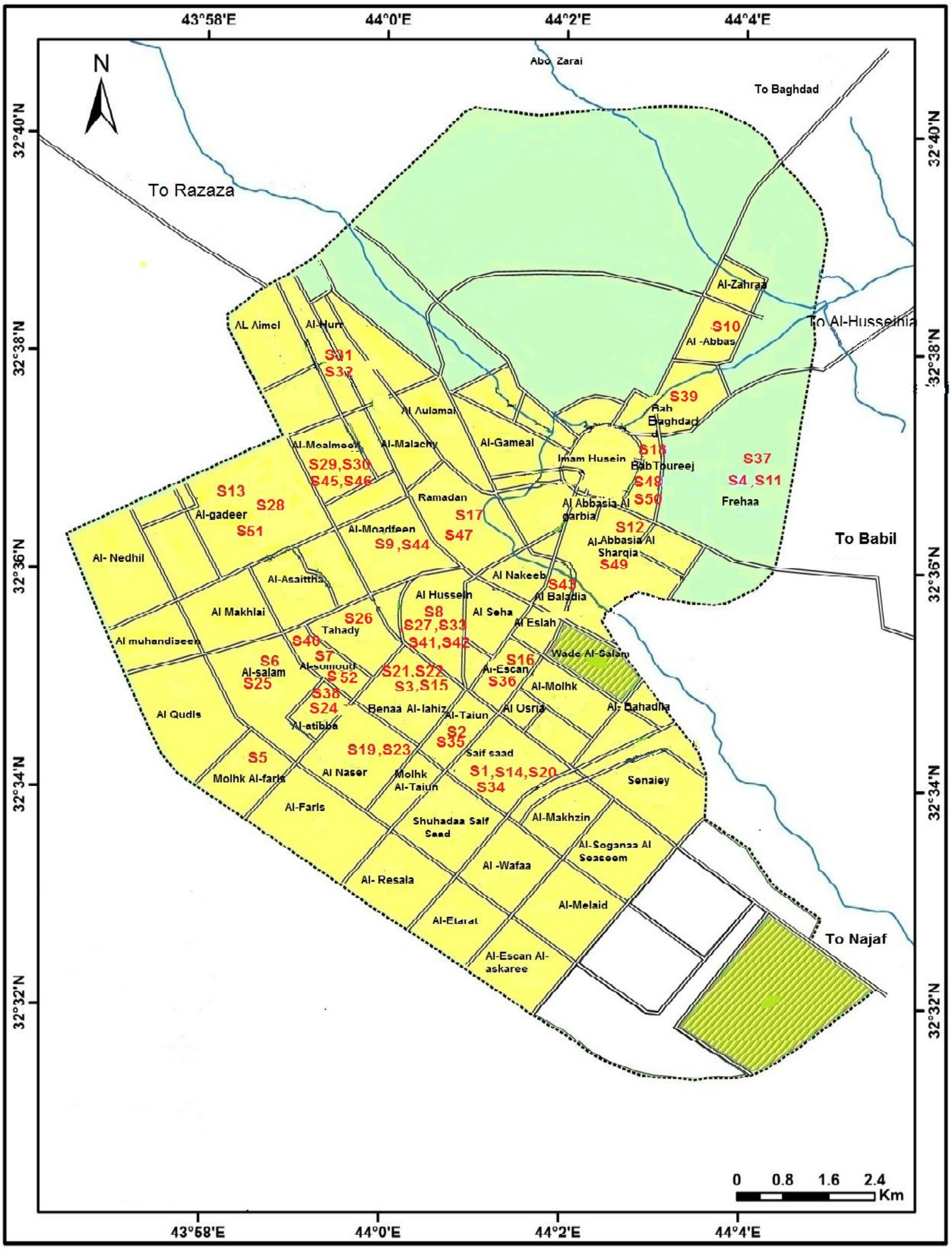


Figure (3.3) Map of neighborhoods in Karbala city illustration samples selected of this study.

(3.3) Preparing ,Distribution and Collection Dosimeters

The cumulative passive dosimeter was used to measure the concentration of radon in the air of the buildings of some selected schools in Karbala city, Iraq. These included solid-state nuclear track detectors LR-115Type II with a chemical formula ($C_6H_9O_9N_2$) and CN-85 has chemical formula ($C_6H_8O_9N_2$) made by the Kodak, pathe, France, with thickness12 μm . Each detectors (LR-115 Type II and CN-85) were cut into square pieces (1 × 1) cm^2 and installed in the bottom of the plastic cup in a two-sided adhesive placed at a height of 2 meters above the floor. A number was placed on all the detectors (LR-115 Type II and CN-85) for the purpose of distinguishing between them when making calculations and results. Two hundred detectors were distributed in 50 randomly selected elementary and secondary schools in Karbala city. Table (3.1) showed the name schools, locations , codes which represented these schools , numbers of student and date of establishment. Table (3.2) showed neighborhood name, schools number in each neighborhood and the number of dosimeters . Measurements were made for about three months in winter from period 27/11/2017 to 1/3/2018 in the schools. After time exposure ended the dosimeters collected and processed to count the track on surface detectors after etching.

Table (3.1) The schools , locations , code numbers (Cod.), number of student and staff (No.) and date of establishment (D) in Karbala city .

School name	Location	Cod.	No.	D
Ramallah primary girls	Saif Saad	S1	495	1984
Fatima Al-zahra primary girls	Taiun	S2	335	2002
Nahj Al-Balaghah primary girls	Benaa Al-Jahiz	S3	380	1998
Al-Kawakeb primary girls	Frehaa	S4	773	1973

Al - Wadq primary girls	Molhk Al-Faris	S5	846	2011
Al- Fatat primary girls	Salam	S6	667	2009
Al - Maysam primary girls	Sumod	S7	450	2001
Al- Wydad primary girls	Al-Hussein	S8	356	1971
Ashab Al-kesaa primary girls	Moadafeen	S9	300	1980
Ouhran primary girls	Al-Gadeer	S10	510	1988
Al Qimah primary girls	Frehaa	S11	559	2013
Al- Sharqia primary girls	Al- abassia Al- Sharqia	S12	375	1983
Al-Sahaba primary girls	Al-Gadeer	S13	520	1990
Shuhada Mouatah secondary girls	Saif Saad	S14	548	2007
Nahj Al-Balaghah	Benaa Al-Jahiz	S15	350	1989
Al- Nagah secondary girls	Al-Eskan	S16	611	1967
Nazik Al-Malayikih secondary girls	Ramadan	S17	562	2007
Al-Rawdatain secondary girls	Bab Toureej	S18	510	1988
Al Thurai secondary girls	Al-Naser	S19	454	2009
Banu Hashim primary boys	Saif Saad	S20	480	1989
Kortoba primary boys	Benaa Al-Jahiz	S21	593	1962
Al-Mahabh primary boys	Benaa Al-Jahiz	S22	700	1989
Al-Mohannad primary boys	Al-Naser	S23	548	2016
Al -Tasami primary boys	Al-Atibba	S24	325	2014
Ekraa primary boys	Salam	S25	768	2014

Al - Tawfiq primary boys	Tahady	S26	429	2012
Ard Al- Hussein primary boys	Al-Hussein	S27	482	2003
Badr Al-Kubraa primary boys	Al-Gadeer	S28	605	1990
Al- Alaws primary boys	Moulmein	S29	658	1968
Ibn Hayyan primary boys	Moulmein	S30	436	1977
Abu Talib primary boys	Al Hur	S31	500	1990
Al -Tawjih primary boys	Al Hur	S32	587	1964
Khayr Al-Bariya primary boys	Al-Hussein	S33	562	2014
Mohammad bin Abi Bakar secondary boys	Saif Saad	S34	422	2006
Thurat Al-Husein secondary boys	Taiun	S35	550	2008
Rayat Al-Islam secondary boys	Al-Eskan	S36	342	1999
Al bayan secondary boys	Frehaa	S37	508	1991
Al-shahid John secondary boys	Al-Atibba	S38	650	2011
Al ghad Al 'afdal secondary boys	Somoud	S39	466	2010
Al –Abbas vocational secondary	Somoud	S40	343	2010
Al-Shahid Abu al-Maali secondary	Al-Hussein	S41	680	1976
Ammar Ibn Yasser secondary boys	Al-Hussein	S42	457	1996
Euthman Ibn Saeid secondary boys	Al-Baladia	S43	700	1988
All-umran secondary boys	Moadafeen	S44	726	2007
Al- Eqdam secondary boys	Moelmeen	S45	473	1985
Ibn Hayyan secondary boys	Moelmeen	S46	441	1968
Luqman Al-Hakim secondary boys	Ramadan	S47	413	1977
Nynwa vocational secondary boys	Bab Tourej	S48	376	1996
Al-Thurah Al-Asasia secondary boys	Al-Abassia Al- Sharqia	S49	452	1959
Al -Ghaith accelerated education	Bab Tourej	S50	283	1961

Table (3.2) Neighborhood name, schools number in each neighborhood and the number of dosimeters in Karbala city.

Neighborhood name	Schools number	Dosimeter distributed	Neighborhood name	Schools number	Dosimeter distributed
Saif Saad	4	16	Tahady	1	4
Taiun	2	8	Al-Abassia Al Sharqia	2	8
Benaa Al-jahiz	4	16	Al-Naser	2	8
Frehaa	3	12	Al-Atibba	2	8
MahaqAl-Faris	1	4	Al-Hur	2	8
Salam	2	8	Al-Eskan	2	8
Somoud	3	12	Ramadan	2	8
Al Hussein	5	20	Bab Tourej	3	12
Moadafeen	2	8	Moelmeen	4	16
Al gadeer	3	12	Al-Baladia	1	4

(3.4) Process of Chemical Etching

After collecting the samples from the school buildings in Karbala city and removing the detectors from dosimeters, it installed the pathways resulting from the alpha particles emitted from the radon and its progeny to the detector materials. In order for endorsement of the tracks, it used sodium hydroxide for concentration (2.5N), placed in a heat resistant glass container in a water bath (Schwabach, Germany) and equipped with an electric heater as shown in Figure (3.4) at temperature $(60 \mp 0.1) C^o$ for 90 minutes [62]. the detectors from the water bath was removed and wash them thoroughly with distilled water using a magnetic stirrer for 20 minutes to remove the drill residue from the surface as shown figure (3.5), then dried it's on fine paper.

Figure (3.4) Water Path

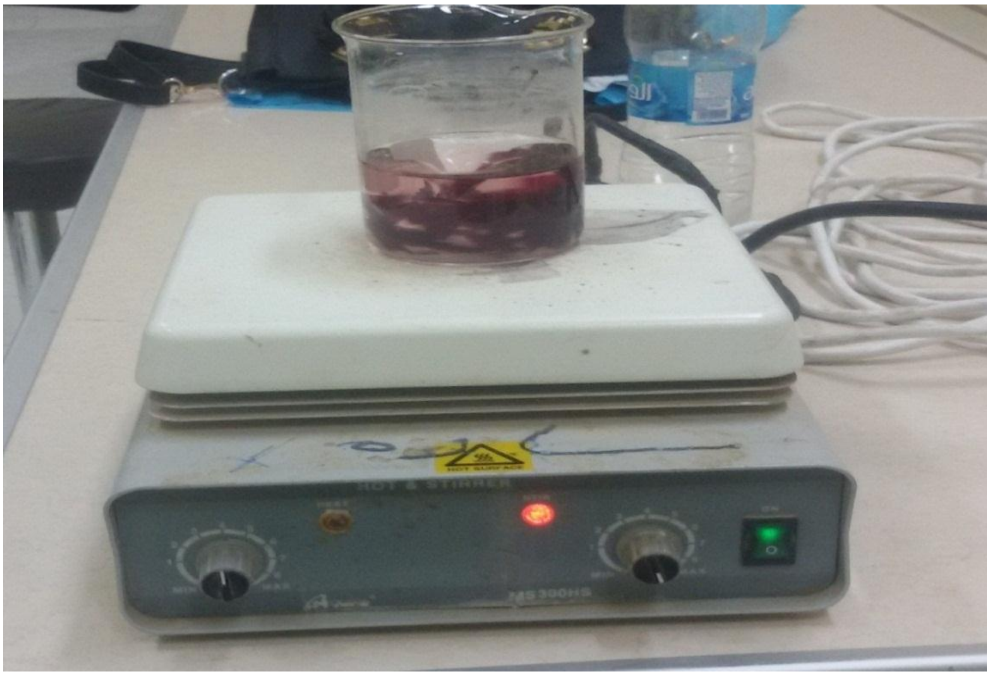


Figure (3.5) Magnetic Stirrer

(3.5) Calculation Alpha Particles Tracks on the Surface of Detectors

To enumerate the alpha particle tracks on the detector surface, we used an optical microscope (KRUSS-mbl 2000) as shown in figure (3.6).

It was used with 100X magnification force which it has an area of viewing ($1x10^{-2}cm^2$). Tracks were counted in (30) different picture at least for each detector. Radiation caused by radon decay is a purely random statistical phenomenon , figure(3.7) appears tracks density of alpha particles on the surface of CN-85 detectors and figure(3.8) shows tracks density of alpha particles on the surface of LR-115Type II detectors.

Figure (3.6) Optical microscope was used in this study

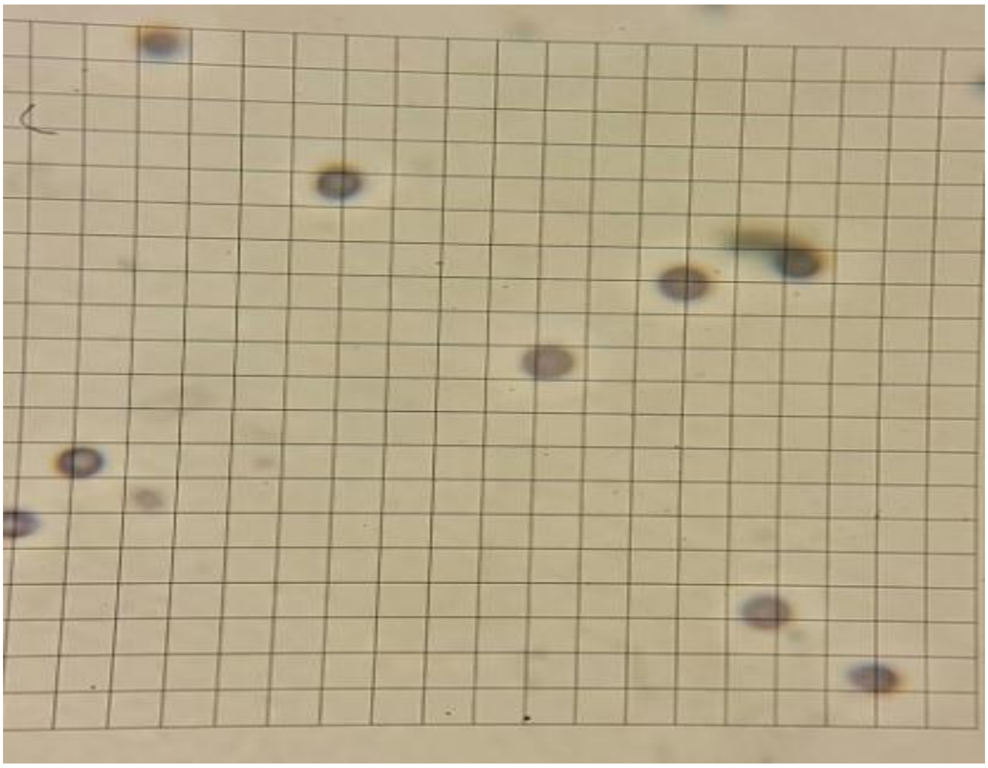


Figure (3.7) The tracks density of alpha particles on the surface of CN-85 detectors in magnification 100X.

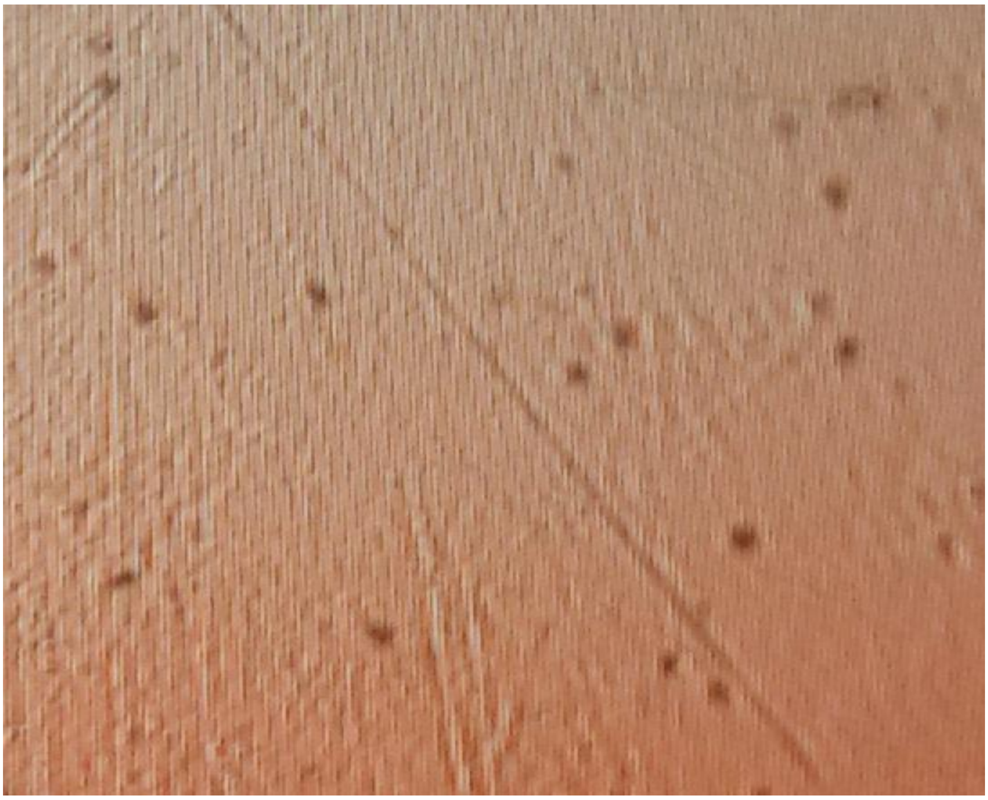


Figure (3.8) The tracks density of alpha particles on the surface of LR-115 Type II detectors in magnification 100X.

(3.6) Calibration LR-115 Type II and CN-85 detectors

The calibration process for dosimeters used in this study was carried out at a nuclear lab in the physics department at the Faculty of Science at Kerbala university of Iraq. To calculate the calibration factor (K), it prepared (5) small pieces from detectors(LR-115 Type II and CN-85) and exposed for period 35 minutes of radium (^{226}Ra) name UL 299 production date 9/2012 which had activity concentration 4KBq . To calculate the activity of the source at present (A) by the following equation [88]:

$$A = A_0 e^{-\lambda t} \qquad (3.1)$$

A_0: Activity source 4 KBq

t:Time from product date 9/2012 to 1/2018 which equal 6.333 y

λ :Decay constant that is calculated

$\lambda = \frac{\ln 2}{t_{1/2}} = \frac{0.693}{t_{1/2}}$ $4.33125\times10^{-4}\ y^{-1}$

$t_{1/2}$:Half –life for ^{226}Ra (1600 y)

By applied equation (3.1) it found A equal 3.989 KBq .

The detectors were calibrated using radium-226 with an activity 3.989 KBq. The detectors were exposed after placing them in a barrel length of 11 cm and a diameter of 10 cm to the radioactive element after placing it distance (L= 5 cm) from the detectors for period 35 minutes. After that to appear the tracks we used NaOH of concentration (2.5N), botteled in a flask and placed in a water bath and equiped with an electrical heater at $(60 \mp 0.1)C^o$ for 90 minute.

it can calculate the calibration factor (K) using the following equations [70]:

$$K = \frac{\rho_o}{C_o\, t_o} \frac{Track/cm^2}{Bq\, d/m^3} \qquad (3.2)$$

Where C_o is the activity density of the calibration chamber in Bq/m^3

$C_o = A / V$

Where: A=3.989 KBq (activity), V (dosimeter volume) $V=\pi\times r^2\times L$

Where: r=5 cm, L=5 cm

ρ_o : Track density of calibrated detectors ($tracks/cm^2$) , which is given in the formula: $\rho_o = \frac{\overline{x_o}}{a}$, $\overline{x_o}$: The average of track number on calibrated detector for every microscopic viewing; which equal LR-115 Type II (47.88 tracks) and CN-85 (43.82 tracks).

a : Viewing area under optical microscope during the calibration; it equals (6.25×10^{-4}) for the used microscope with objective lens magnification power 400X.

t_o : Exposure period of calibrated detectors (35 min=0.024 d).

After completed the calculation of Calibration factor were K=0.285 for LR-115Type II and K=0.256 for CN-85 in term ($Track.cm^{-2}$ / $Bq.m^{-3}$ day).

Table (3.3) shows that the calibration factor of CN-85 is approximated to each results of the researchers in Pakistan [49] , [52] and in Egypt [89], whereas the calibration factor of LR-115type II detector was less than result in Ethiopia [90]and higher than result in Italian [37],Turkey [91] and India [92].

Table (3.3) Comparison between value of calibration factor(K) that was used in this study and other studies in other countries.

CN-85 ($T.cm^{-2}$ / $Bq.m^{-3}$.d)	Ref.	LR-115 Type II ($T.cm^{-2}$ /$Bq.m^{-3}$.d)	Ref.
0.22	[49]	0.012	[43]

0.220	[52]	1.61	[90]
0.283	[89]	0.05	[91]
0.256	this study	0.017	[92]
		0.285	this study

(3.7) Measurement of Radon Concentrations

Radon concentrations are measured in the air of some building schools in Karbala, in unit (Bq / m^3), where the highest regulatory reference levels are determined in this unit. Radon concentration is calculated using the following equations [93, 94]:

$$C = \frac{\rho}{K\,t} \qquad (3.3)$$

ρ is the measured number of tracks per cm^2 on the LR-115 Type II and CN-85 detectors that were inside our dosimeters used in the studies, t is the exposure time on the distributed dosimeters and K is a calibration factor LR-115 Type II and CN -85 detectors ,the value of K(0.285 and 0.256) Track.cm^{-2} / Bq.m^{-3} .day, respectively.

Equation (3.3) becomes after compensation value of calibration factor K and t (95d) for each detectors.

$C = 0.037 \times \rho$ (3.4) for LR-115 Type II detector

$C = 0.041 \times \rho$ (3.5) for CN-85 detector

(3.8) Calculation of Equilibrium Factor (F) and Annual Effective Dose (AED)

After account concentrations of radon in closed and open dosimeters in all schools in this study , we were able to calculate the equilibrium factor (F), using the following relationship [93, 95] :

$$F = a \exp\left(b \frac{C_c}{C_o} \right) \qquad (3.6)$$

where a and b are constants magnitude 14.958 and -7.436 respectively.

C_c: concentration radon passive closed dosimeter (Bq/m^3).

C_o : concentration radon passive open dosimeter (Bq/m^3).

The annual effective dose (AED) in terms of (mSv /y) units depends on occupancy factor (H). Occupancy factor for students and teachers in schools was calculated using the following equation:

30 h/wk × 37 wk /y = 1110 h/ y

The school occupancy factor (H) = 1110 / 8760 = 13% ,so annual effective dose was obtained using the relation [32, 96]:

$$\text{AED (m Sv/y)} = C \times F \times H \times T \times D \qquad (3.7)$$

Where (H) is the occupancy factor in schools which is equal to (0.13) .

(T) is the time in hours in a year, T=8760 h/y and (D) is the dose conversion factor which is equal to[9×10^{-6}(m *Sv*) /($Bq.h.m^{-3}$)].

(3.9) Potential Alpha Energy Concentration (PAEC), Exposure to radon progeny (EP), Lung cancer cases per year per million person (CPPP).

Potential Alpha Energy Concentration (PAEC) in working level(WL) was obtained using the relation [97-99]:

$$PAEC\ (WL) = F \times C / 3700 \qquad (3.8)$$

Exposure to radon progeny is calculated by following equation [100] :

$$EP\ (WLM\ Y^{-1}) = T \times H \times F \times C / 170 \times 3700 \qquad (3.9)$$

T: is the number of hours per year which equal (8760) .

(170) : is the number of hours per working month.

Where(1WL = 3.7 Bq / L= 3.7×10^{3} Bq / m^{3}) .

The lung cancer cases per year per million person (CPPP), was obtained using the relation [97, 101, 102]:

$$(CPPP) = AED \times (18\times10^{-6}\ mSv^{-1}.y) \qquad (3.10)$$

Chapter Four

Results , discussions and Conclusions

(4.1) Introduction

In this chapter, the concentrations of radon in the air of buildings of some schools in Karbala were calculated using the following equations (3.4),(3.5),(3.6),(3.7),(3.8),(3.9) and (3.10). From observation of results, radon concentrations varied from place to place depending on changing ventilation conditions, building materials used, age of schools and behaviour of students in schools. This will be clarified for each of the detectors as follows.

(4.2) Radon Concentrations and Equilibrium Factors

(4.2.1) LR-115 Type II Detector

Table (4.1) shows nuclear track densities on surface of detector LR-115Type II ,and radon concentrations for open and closed dosimeters. In addition equilibrium factors between radon and its progeny.

From the observation of the results ,we found radon concentrations in closed dosimeters ranged from 13.140±4.11 Bq/m^3 to 38.439±6.49 Bq/m^3 with an average value 24.249±5.70Bq/m^3. As for open dosimeters ranged from 15.719±7.30 Bq/m^3 to 56±7.44 Bq/m^3 with an average value 36.972±11.33 Bq/m^3.The values of equilibrium factors ranged from 0.012 to 0.523 with an average 0.143 . All results showed that the highest concentration of radon was in Al-Sahaba primary girls school (S13) in Al Gadeer and lower concentration was in Al-Wadq primary girls school (S5) in Molhk Al-Faris in closed dosimeters. The highest concentration of radon was in Al-Towjih primary boys (S32) in Al-Hur , the lowest concentration in Al-Wadq primary girls school (S5) in Molhk Al-Faris in the open dosimeters. From the results it noticed that old schools were higher concentrations of radon than modern schools because of the holes , cracks , the quality of building materials and defects in the floors and walls , in addition to the poor ventilation in these schools, but all results are lower than the radon levels (200-300) Bq/m^3 which are recommended by ICRP ,2009 [103] .While the highest value of the equilibrium factor exists in Al-Thurah Al-Asasia secondary boys (S49) in Al-abassia Al-Sharqia , and the lowest value is in Thurat Al-Husein secondary boys in (S35) in Al-Taiun as shown figure(4.1). In all the schools included in the present study, the equilibrium factor was less than lower limit of the recommended range (0.4-1) by UNSCEAR,2000 [1] while the values which were obtained in (S18, S29 ,S46 and S49) ,were within the range (0.4-1) [32] as shown figure(4.2). From the results it noticed that old schools were higher concentrations of radon than modern schools because of the holes , cracks , the quality of building materials and defects in the floors and walls , in addition to the poor ventilation in these schools.

Table (4.1) Track density(ρ), radon concentration (C) for open and closed dosimeter and equilibrium factor (F) for the selected schools using LR-115 Type II Detectors.

Codes	Dosimeter Kinds.	ρ (Track/cm^2)	C (Bq/m^3)	F
S1	Open	1173.333	43.228±6.37	0.048
	Closed	900.000	33.158±5.95	
S2	Open	926.667	34.140±4.23	0.074
	Closed	656.667	24.193±4.29	
S3	Open	1070.000	39.421±5.93	0.053
	Closed	803.333	29.596±5.28	
S4	Open	1303.333	48.018±6.01	0.115
	Closed	846.667	31.193±5.75	
S5	Open	426.667	15.719±7.30	0.028

	Closed	356.667	13.140±4.11	
S6	Open	630.000	23.211±6.11	0.049
	Closed	480.000	17.684±9.51	
S7	Open	640.000	23.579±3.69	0.024
	Closed	550.000	20.263±3.11	
S8	Open	1363	50.228±5.80	0.140
	Closed	850	31.315±6.62	
S9	Open	1130	41.632±7.69	0.026
	Closed	960	35.358±7.12	
S10	Open	1150	42.368±7.03	0.153
	Closed	703.333	25.912±3.57	
S11	Open	740.000	27.263±3.82	0.023
	Closed	1200.000	23.579±3.16	
S12	Open	1200.000	44.211±3.33	0.167
	Closed	720.000	26.526±5.72	
S13	Open	1203.000	44.333±7.24	0.022
	Closed	1043.000	38.439±6.79	
S14	Open	853.333	31.439±3.69	0.027
	Closed	720.000	26.526±2.87	
S15	Open	1090.000	40.158±5.82	0.391
	Closed	530.000	19.526±4.17	
S16	Open	1406.000	51.825±7.74	0.280
	Closed	746.000	27.50±5.06	
S17	Open	586.667	21.614±2.44	0.015
	Closed	540.000	19.895±2.17	

S18	Open	1193.000	43.925±5.61	0.417
	Closed	570.000	21.000±3.84	
S19	Open	610.000	22.474±6.13	0.038
	Closed	486.667	17.930±3.52	
S20	Open	1226.667	45.193±6.77	0.122
	Closed	786.667	28.982±3.51	
S21	Open	1276.000	47.035±6.58	0.270
	Closed	683.333	25.175±3.04	
S22	Open	1460.000	53.789±7.84	0.324
	Closed	746.000	27.509±3.81	
S23	Open	666.667	24.561±4.94	0.167
	Closed	400.000	14.737±3.53	
S24	Open	646.667	23.825±5.44	0.055
	Closed	483.333	17.807±3.55	
S25	Open	650.000	23.947±4.99	0.033
	Closed	530.000	19.526±3.07	
S26	Open	636.667	23.456±3.76	0.020
	Closed	560.000	20.632±3.95	
S27	Open	546.667	20.140±5.61	0.015
	Closed	503.333	18.544±5.10	
S28	Open	1120.000	41.263±6.20	0.081
	Closed	780.000	28.737±4.49	
S29	Open	1303.333	48.018±7.81	0.407
	Closed	626.667	23..088±3.14	
S30	Open	1426.667	52.561±7.84	0.244

	Closed	783.333	28.860±3.93	
S31	Open	1263.333	46.544±5.35	0.240
	Closed	696.667	25.667±3.52	
S32	Open	1520.000	56.00±7.44	0.250
	Closed	830.000	30.579±4.80	
S33	Open	610.000	22.474±4.95	0.062
	Closed	446.667	16.456±3.47	
S34	Open	843.333	31.070±6.25	0.034
	Closed	683.333	25.175±3.33	
S35	Open	916.667	33.772±5.52	0.012
	Closed	866.667	31.930±3.51	
S36	Open	1123.333	41.386±5.88	0.150
	Closed	690.000	25.421±4.40	
S37	Open	1080.000	39.789±5.67	0.222
	Closed	606.667	22.351±4.93	
S38	Open	600.000	22.105±5.73	0.052
	Closed	453.333	16.702±5.04	
S39	Open	666.667	24.561±5.65	0.032
	Closed	546.667	20.140±4.38	
S40	Open	673.333	24.807±5.25	0.035
	Closed	543.333	20.018±4.21	
S41	Open	465.517	33.649±5.06	0.100
	Closed	403.333	22.473±5.98	
S42	Open	1096.667	40.404±6.15	0.055
	Closed	820.000	30.211±4.68	

S43	Open	1173.000	43.228±6.63	0.251
	Closed	640.000	23.579±5.24	
S44	Open	776.666	19.895±3.80	0.036
	Closed	623.333	17.070±2.12	
S45	Open	1133.333	41.754±7.18	0.237
	Closed	626.667	23.088±4.32	
S46	Open	933.333	36.596±6.62	0.410
	Closed	476.667	17.561±2.84	
S47	Open	1290.000	47.526±6.73	0.233
	Closed	716.667	26.404±4.31	
S48	Open	1210.000	44.579±5.50	0.231
	Closed	673.333	24.807±4.76	
S49	Open	1400.000	51.579±7.50	0.523
	Closed	626.667	23.088±4.55	
S50	Open	1473.333	54.281±6.80	0.148
	Closed	609.667	33.404±5.02	
AV	Open	1003.533	36.972±11.33	0.143
	Closed	658.200	24.249±5.70	
Min	Open	426.667	15.719±7.30	0.012
	Closed	356.667	13.140±4.11	
Max	Open	1520.000	56.00±7.44	0.523
	Closed	1043.000	38.439±6.79	

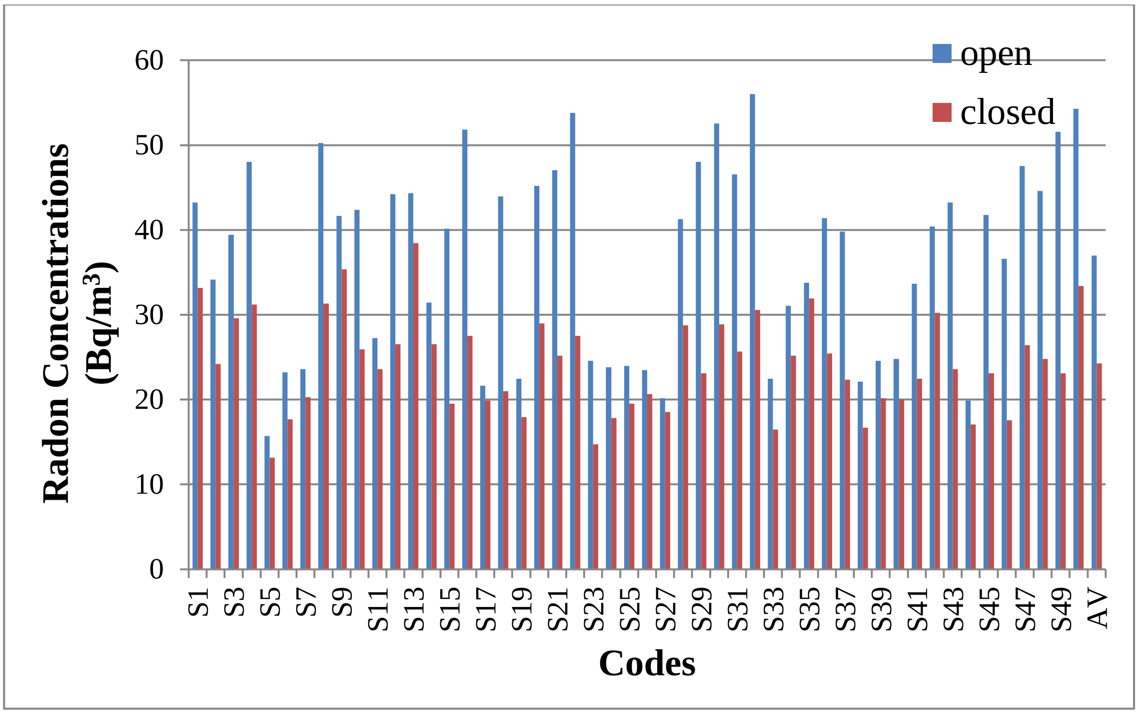


Figure (4.1) Radon concentrations for open and closed dosimeters in the air of selected schools by LR-115 Type II detectors.

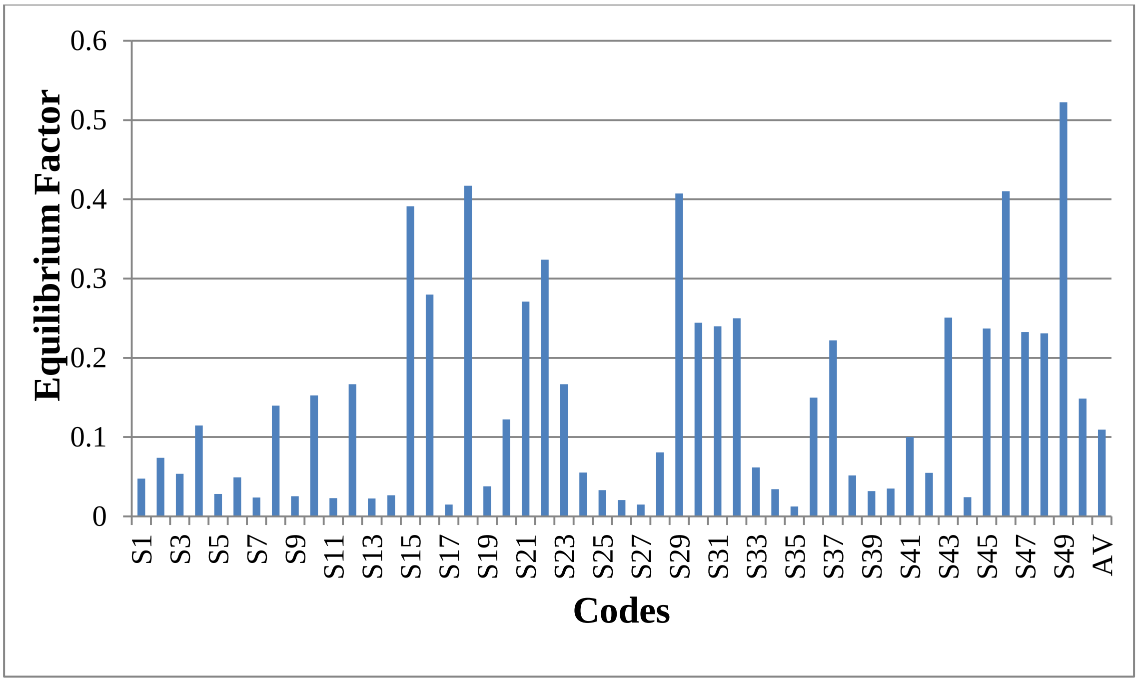


Figure (4.2) Equilibrium factor for open and closed dosimeters in the air of selected schools by LR-115 Type II detectors.

(4.2.2) CN-85 Detector

Table (4.2) shows nuclear track densities on surface of detector CN-85 and radon concentrations for open and closed dosimeters, in addition equilibrium factors between radon and its progeny.

From the observation ,the results show radon concentrations in closed dosimeters ranged from 13.842±2.35 Bq/m^3 to 38.101±4.85 Bq/m^3 with an average value 26.275±6.49 Bq/m^3. As for open dosimeters ranged from 17.269±3.90 Bq/m^3 to 50.709±6.72 Bq/m^3 with an average value 36.481±9.66 Bq/m^3 .The values of equilibrium factors ranged from 0.012 to 0.561 with an average 0.089 . All the results showed that the highest concentration of radon was in Rayat Al-Islam secondary boys (S36) in Al-Eskan and lower concentration was in Nazik Al-Malayikih secondary girls school (S17) in Ramadan in the closed dosimeters, while the highest concentration of radon was in Ibn Hayyan primary boys (S30) in Al-Moulmein , the lowest concentration of radon in Nazik Al-Malayikih secondary girls school (S17) in Ramadan in the open dosimeters. It also noticed that old schools were higher concentrations of radon than modern schools because of the holes and cracks and defects in the floors and walls and the quality of building materials in addition to the poor ventilation in these schools. How here, all results are lower than the radon levels (200-300) Bq/m^3 which are recommended by ICRP ,2009 [103].While the highest value of the equilibrium factor in Al-Bayan secondary boys (S37) in Frehaa ,and the lowest value in Al Rawdatain secondary girls in (S18) in Bab Toureej , in all the schools included by the present study, the equilibrium factor was less than the lower limit of the recommended range (0.4-1) except the values was obtained in(S37) were within the range(0.4-1) [32]. Figure (4.3) shows the distribution of radon concentration in the selected schools for open and closed dosimeters .Figure (4.4) shows the equilibrium factor in the selected schools for open and closed dosimeters.

Table (4.2) Track density(ρ), radon concentration (C) for open and closed dosimeter and equilibrium factor (F) for the selected schools using CN-85 Detectors.

Codes	Dosimeter Kinds	ρ (track/cm^2)	C (Bq/m^3)	F
S1	Open	1040	42.760±4.43	0.065
	Closed	753.33	30.973±4.84	
S2	Open	813.333	33.441±5.24	0.051
	Closed	616.667	25.355±4.56	
S3	Open	870.000	35.771±3.34	0.026
	Closed	733.333	30.152±4.20	
S4	Open	986.667	40.568±4.45	0.027
	Closed	826.667	33.989±4.73	
S5	Open	440.000	18.091±4.86	0.023
	Closed	379.310	15.596±5.11	
S6	Open	560.000	23.025±6.03	0.038
	Closed	446.667	18.365±4.23	
S7	Open	636.667	26.177±4.69	0.069
	Closed	456.667	18.776±3.12	
S8	Open	1140.000	46.872±4.45	0.081
	Closed	793.333	27.548±3.93	
S9	Open	1046.667	43.035±5.53	0.123
	Closed	670.000	27.548±4.34	
S10	Open	1076.667	44.268±6.10	0.173
	Closed	640.000	26.314±3.02	

S11	Open	613.333	25.218±4.88	0.054
	Closed	460.000	18.913±2.47	
S12	Open	960.000	39.471±4.34	0.070
	Closed	686.666	28.232±3.72	
S13	Open	1113.333	45.776±4.85	0.046
	Closed	856.667	35.223±3.88	
S14	Open	706.667	29.055±5.93	0.039
	Closed	560.000	23.025±2.56	
S15	Open	1080.000	44.405±5.66	0.387
	Closed	526.666	21.654±2.86	
S16	Open	1140.000	46.872±4.74	0.041
	Closed	896.666	36.867±4.28	
S17	Open	420.000	17.269±3.90	0.037
	Closed	336.667	13.842±2.35	
S18	Open	650.000	26.725±4.64	0.012
	Closed	616.667	25.355±3.15	
S19	Open	756.667	31.111±4.12	0.185
	Closed	443.333	18.228±2.99	
S20	Open	1196.666	49.201±6.82	0.092
	Closed	813.333	33.440±5.04	
S21	Open	1010	41.526±4.98	0.071
	Closed	720	29.603±3.58	
S22	Open	1056.666	43.445±5.52	0.071
	Closed	753.333	30.973±4.53	
S23	Open	640.000	26.314±4.37	0.097
	Closed	430.000	17.680±3.84	

S24	Open	670.000	27.548±4.41	0.072
	Closed	476.667	19.599±3.16	
S25	Open	540.000	22.203±4.71	0.013
	Closed	506.667	20.832±2.92	
S26	Open	880.000	36.182±3.78	0.098
	Closed	590.000	24.258±3.76	
S27	Open	620.000	25.492±4.51	0.023
	Closed	536.667	22.065±4.33	
S28	Open	966.666	39.745±5.60	0.139
	Closed	603.333	24.806±4.33	
S29	Open	973.333	40.019±5.33	0.041
	Closed	766.667	31.522±4.40	
S30	Open	1233.333	50.709±6.72	0.160
	Closed	746.667	30.700±4.49	
S31	Open	1060	43.582±4.19	0.030
	Closed	876.666	36.044±3.95	
S32	Open	1213.333	49.887±7.40	0.168
	Closed	726.666	29.877±5.34	
S33	Open	466.667	19.187±3.88	0.014
	Closed	433.333	17.817±2.39	
S34	Open	726.667	29.877±3.66	0.032
	Closed	596.667	24.532±3.17	
S35	Open	866.667	35.634±2.69	0.034
	Closed	703.333	28.918±2.63	
S36	Open	1073.333	44.131±7.88	0.023
	Closed	926.667	38.101±4.85	

S37	Open	1156.667	47.557±6.80	0.561
	Closed	506.667	20.832±2.86	
S38	Open	470.000	19.324±6.92	0.033
	Closed	383.333	15.761±4.30	
S39	Open	636.667	26.177±6.65	0.059
	Closed	470.000	19.324±3.13	
S40	Open	603.333	24.807±3.65	0.024
	Closed	516.667	21.243±1.89	
S41	Open	1083.333	44.542±5.69	0.070
	Closed	733.333	31.796±3.67	
S42	Open	983.333	40.431±5.65	0.072
	Closed	700.000	28.781±4.28	
S43	Open	956.667	39.334±6.22	0.113
	Closed	623.333	25.629±3.78	
S44	Open	806.667	33.167±3.77	0.080
	Closed	563.333	23.162±2.73	
S45	Open	1050	43.171±6.80	0.077
	Closed	736.666	30.288±4.30	
S46	Open	1013.333	41.662±5.55	0.020
	Closed	890	36.593±5.85	
S47	Open	1130	46.460±5.13	0.039
	Closed	896.666	36.867±3.93	
S48	Open	2310.333	42.075±5.72	0.348
	Closed	513.333	21.106±4.51	
S49	Open	1146.666	47.146±5.65	0.097
	Closed	770.000	31.659±4.38	

S50	Open	1060	43.582±6.18	0.103
	Closed	703.333	28.918±5.25	
AV	Open	887.267	36.481±9.66	0.089
	Closed	639.053	26.275±6.49	
Min	Open	420.000	17.269±3.90	0.012
	Closed	336.667	13.842±2.35	
Max	Open	1233.333	50.709±6.72	0.561
	Closed	926.667	38.101±4.85	

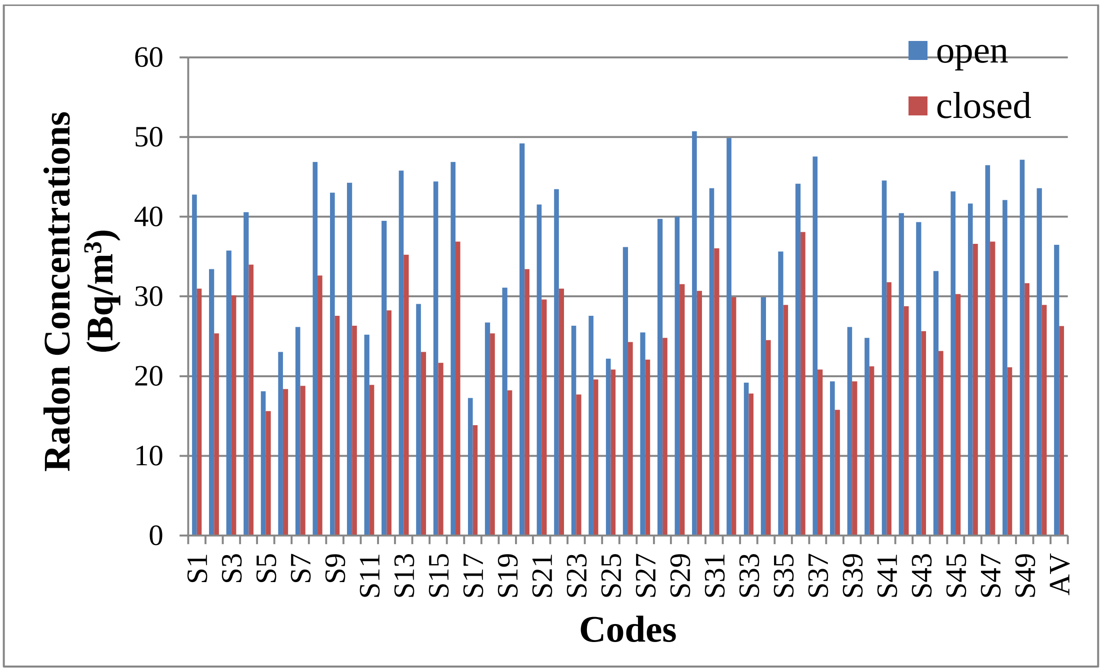


Figure (4.3) Radon concentrations for open and closed dosimeters in the air of selected schools by CN-85 detectors.

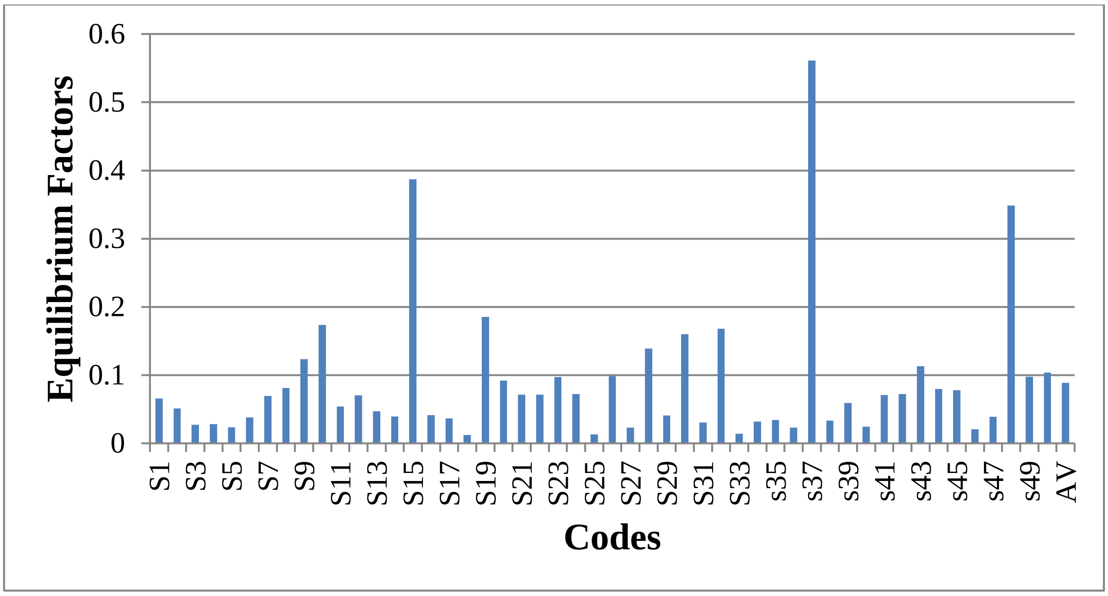


Figure (4.4) Equilibrium factor for open and closed dosimeters in the air of selected schools by CN-85 detectors.

(4.3)Annual Effective Dose(AED),Potential Alpha Energy Concentration(PAEC),Exposure to Radon Progeny (EP) ,Lung Cancer Cases Per year Per million Person(CPPP)

(4.3.1) LR-115 Type II Detector

Table (4.3) displays the results of both AED , PAEC, EP, and CPPP. Annual effective dose ranged from 0.003 mSv/y to 0.124 mSv/y with an average value 0.035mSv/y in closed dosimeters and varied from 0.003 mSv/y to 0.276 mSv/y with an average value 0.064 mSv/y in open dosimeters . The result obtained in present study appears that annual effective dose was less than even the lower limit of the recommended between (3-10) (ICRP,1993) [104] as shown in figure(4.5). PAEC varied from 0.075 mWL to 3.260 mWL with mean value 0.935 mWL in closed dosimeters ,while in open dosimeters they vary from 0.082 mWL to 7.284 mWL with mean value 1.680 mWL. The results were less than the minimum recommended value (53.33 mWL) given by UNSCEAR, 1993 [105] as shown in figure(4.6) .

EP varied from 0.505 $mWLMY^{-1}$ to 21.841 $mWLMY^{-1}$ with an average value 6,258 $mWLMY^{-1}$ and varied from 0.548 $mWLMY^{-1}$ to 48.795 $mWLMY^{-1}$ with an average value 11.259 $mWLMY^{-1}$ for open dosimeters .In all the schools covered by the present study the internal exposure of radon progeny was below the recommended range of (1-2)$WLMY^{-1}$ according to NCRP,1989) [99] as shown in figure(4.7), and CPPP ranged from 0.051 to 2.226 with mean value 0.638 for closed dosimeters and ranged from 0.056 to 4.972 with mean value 1.147 in open dosimeters .These results were less than the lower limit of the range (170-230) per million person recommended by ICRP,1993 [104] as shown in figure(4.9).

The results show the highest values for each AED, PAEC, EP, CPPP for open and closed dosimeters in Al-Thurah Al- Asasia secondary boys school in (S49) Al-Abassia Al-Sharqia ,and the lowest values in Ard Al- Hussein primary boys school in (S27) Al- Hussein. Figure (4.9) shows frequency of radon concentrations for open and closed dosimeters in the air of selected schools by LR-115 Type II detectors.

Table (4.3) Annual Effective Dose (AED), Potential Alpha Energy Concentration (PAEC), Exposure to radon and its progeny (EP) and lung cancer cases per year per million person(CPPP) in the selected schools by using LR-115 Type II detectors.

Codes	**Dosimeter Kinds**	**AED mSv/y**	**PAEC mWL**	**EP $mWLMY^{-1}$**	**CPPP/10^6**
S1	Open	0.021	0.556	3.726	0.380
	Closed	0.016	0.427	2.858	0.291
S2	Open	0.026	0.681	4.560	0.465

	Closed	0.018	0.482	3.232	0.329
S3	Open	0.022	0.573	3.839	0.391
	Closed	0.016	0.430	2.882	0.294
S4	Open	0.057	1.491	9.985	1.017
	Closed	0.037	0.968	6.486	0.661
S5	Open	0.005	0.121	0.808	0.082
	Closed	0.004	0.101	0.676	0.069
S6	Open	0.012	0.310	2.079	0.212
	Closed	0.009	0.236	1.584	0.161
S7	Open	0.006	0.152	1.017	0.104
	Closed	0.005	0.130	0.874	0.089
S8	Open	0.072	1.897	12.707	1.295
	Closed	0.045	1.183	7.923	0.807
S9	Open	0.011	0.288	1.933	0.197
	Closed	0.009	0.245	1.642	0.167
S10	Open	0.066	1.749	11.718	1.194
	Closed	0.041	1.070	7.166	0.730
S11	Open	0.006	0.168	1.128	0.115
	Closed	0.006	0.146	0.976	0.099
S12	Open	0.076	1.991	13.338	1.359
	Closed	0.045	1.195	8.003	0.815
S13	Open	0.010	0.269	1.805	0.184
	Closed	0.009	0.234	1.565	0.159
S14	Open	0.009	0.228	1.524	0.155
	Closed	0.007	0.192	1.286	0.131

S15	Open	0.161	4.245	28.437	2.898
	Closed	0.078	2.064	13.827	1.409
S16	Open	0.149	3.922	26.271	2.677
	Closed	0.079	2.082	13.945	1.421
S17	Open	0.003	0.088	0.590	0.060
	Closed	0.003	0.081	0.543	0.055
S18	Open	0.011	0.301	2.015	0.205
	Closed	0.009	0.234	1.570	0.160
S19	Open	0.009	0.230	1.538	0.157
	Closed	0.007	0.183	1.227	0.125
S20	Open	0.057	1.493	10.002	1.019
	Closed	0.036	0.958	6.414	0.654
S21	Open	0.131	3.443	23.062	2.350
	Closed	0.070	1.843	12.344	1.258
S22	Open	0.179	4.708	31.535	3.213
	Closed	0.091	2.408	16.127	1.643
S23	Open	0.042	1.106	7.410	0.755
	Closed	0.025	0.664	4.446	0.453
S24	Open	0.013	0.355	2.379	0.242
	Closed	0.010	0.265	1.778	0.181
S25	Open	0.008	0.214	1.436	0.146
	Closed	0.007	0.175	1.171	0.119
S26	Open	0.005	0.130	0.869	0.089
	Closed	0.004	0.114	0.765	0.078

S27	Open	0.003	0.082	0.548	0.056
	Closed	0.003	0.075	0.505	0.051
S28	Open	0.034	0.902	6.040	0.615
	Closed	0.024	0.628	4.206	0.429
S29	Open	0.200	5.286	35.413	3.609
	Closed	0.096	2.542	17.027	1.735
S30	Open	0.132	3.468	23.235	2.368
	Closed	0.072	1.904	12.757	1.300
S31	Open	0.114	3.017	20.210	2.059
	Closed	0.063	1.664	11.145	1.136
S32	Open	0.143	3.780	25.320	2.580
	Closed	0.078	2.064	13.826	1.409
S33	Open	0.014	0.375	2.515	0.256
	Closed	0.010	0.275	1.841	0.188
S34	Open	0.011	0.289	1.936	0.197
	Closed	0.009	0.234	1.569	0.160
S35	Open	0.004	0.114	0.764	0.078
	Closed	0.004	0.108	0.722	0.074
S36	Open	0.064	1.675	11.221	1.143
	Closed	0.039	1.029	6.892	0.702
S37	Open	0.091	2.388	15.995	1.630
	Closed	0.051	1.341	8.985	0.916
S38	Open	0.012	0.310	2.077	0.212
	Closed	0.009	0.234	1.569	0.160
S39	Open	0.008	0.212	1.423	0.145

	Closed	0.007	0.174	1.167	0.119
S40	Open	0.009	0.237	1.585	0.162
	Closed	0.007	0.191	1.279	0.130
S41	Open	0.035	0.911	6.101	0.622
	Closed	0.023	0.608	4.075	0.415
S42	Open	0.023	0.601	4.026	0.410
	Closed	0.017	0.449	3.010	0.307
S43	Open	0.111	2.931	19.633	2.001
	Closed	0.061	1.599	10.709	1.091
S44	Open	0.005	0.129	0.867	0.088
	Closed	0.004	0.111	0.744	0.076
S45	Open	0.101	2.676	17.929	1.827
	Closed	0.056	1.480	9.913	1.010
S46	Open	0.154	4.058	27.183	2.770
	Closed	0.074	1.947	13.044	1.329
S47	Open	0.113	2.987	20.011	2.039
	Closed	0.063	1.660	11.117	1.133
S48	Open	0.106	2.783	18.641	1.899
	Closed	0.059	1.549	10.373	1.057
S49	Open	0.276	7.284	48.795	4.972
	Closed	0.124	3.260	21.841	2.226
S50	Open	0.083	2.178	14.591	1.487
	Closed	0.051	1.340	8.979	0.915
AV	Open	0.064	1.680	11.259	1.147
	Closed	0.035	0.935	6.258	0.638

Min	Open	0.003	0.082	0.548	0.056
	Closed	0.003	0.075	0.505	0.051
Max	Open	0.276	7.284	48.795	4.972
	Closed	0.124	3.260	21.841	2.226

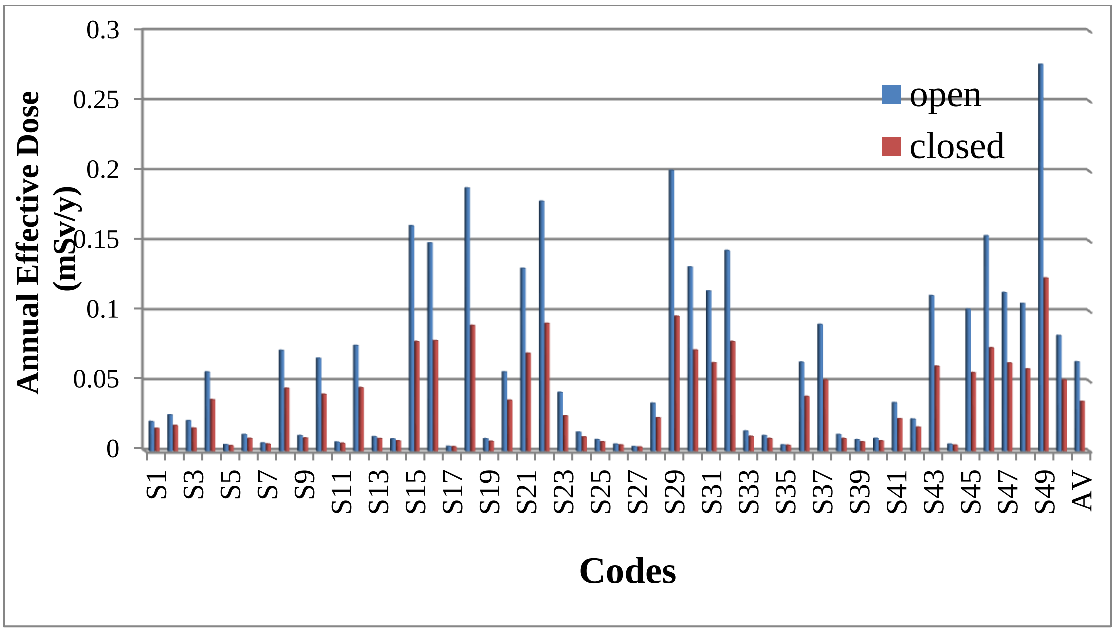


Figure (4.5) Annual Effective Dose for open and closed dosimeters in the air of selected schools by LR-115 Type II detectors.

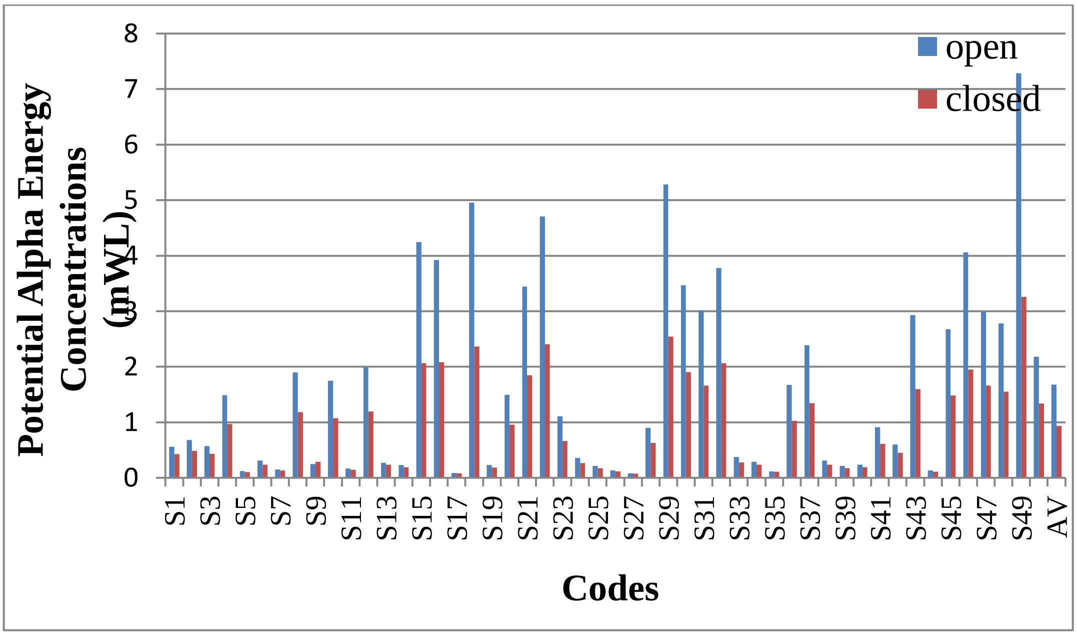
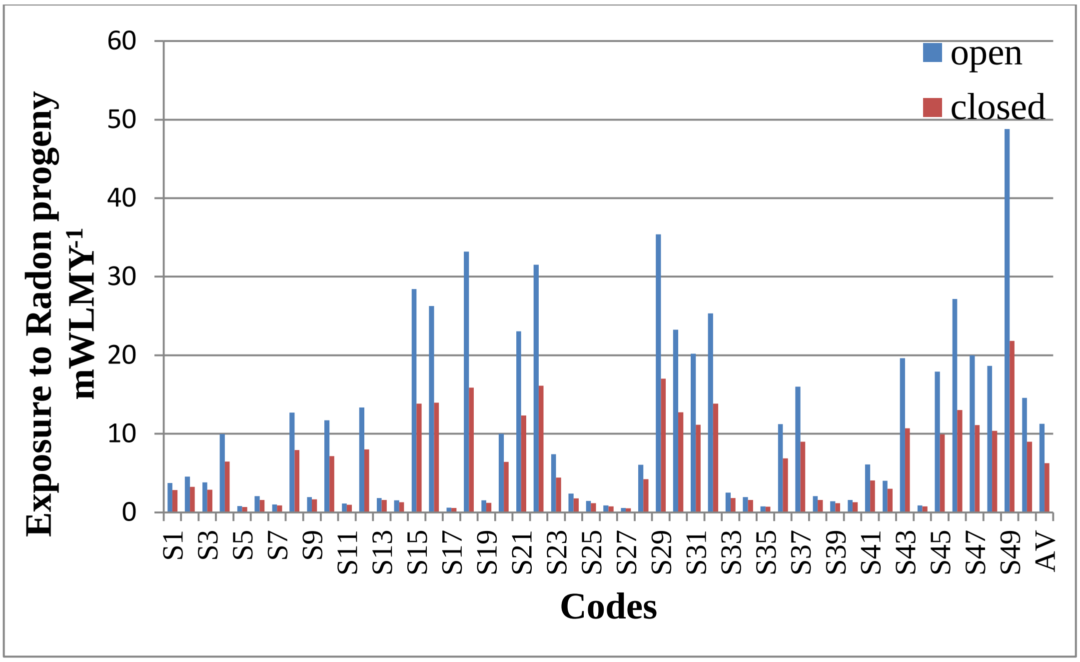


Figure (4.6) Potential Alpha Energy Concentrations for open and closed dosimeters in the air of selected schools by LR-115 Type II detectors.



Figure(4.7) Exposure to radon progeny concentrations for open and closed dosimeters in the air of selected schools by LR-115 Type II detectors.

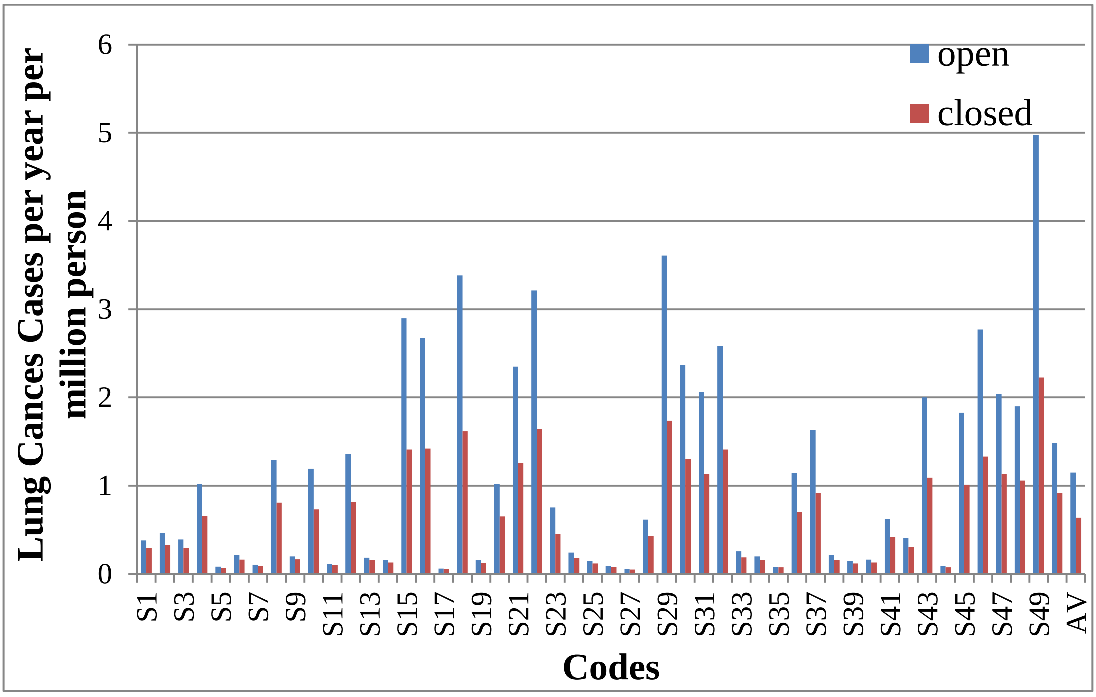


Figure (4.8) Lung cancer cases per year per million person for open and closed dosimeters in the air of selected schools by LR-115 Type II detectors.

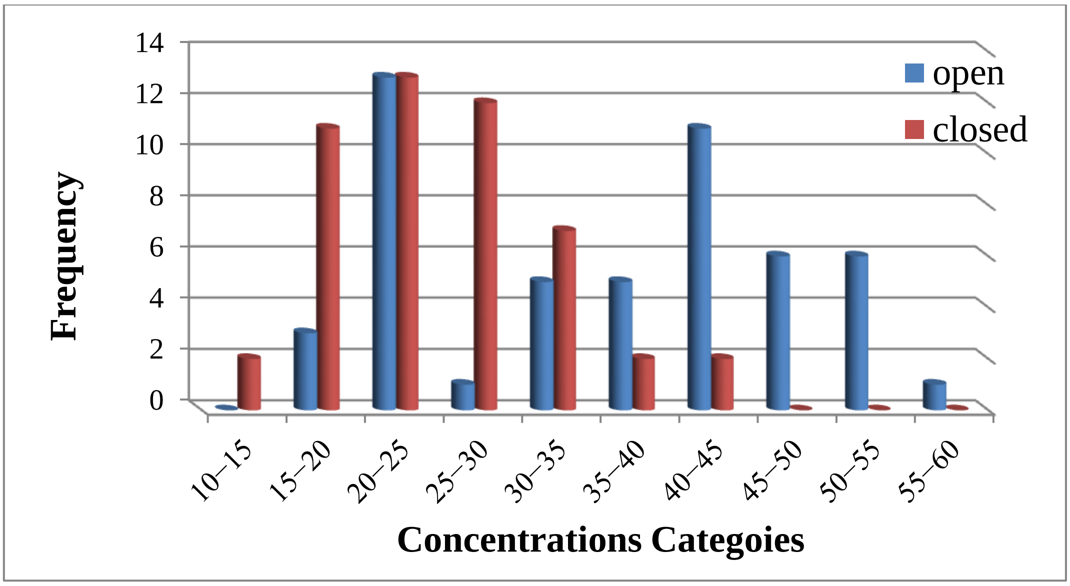


Figure (4.9) Frequency of radon concentrations for open and closed dosimeters in the air of selected schools by LR-115 Type II detectors .

(4.3.2) CN-85 Detector

Table (4.4) displays the results of both AED , PAEC, EP, CPPP ,annual effective dose ranged from 0.003 mSv/y to 0.120 mSv/y with an average value 0.023mSv/y in closed dosimeters and varied from 0.003 mSv/y to 0.274 mSv/y with an average value 0.057 mSv/y in open dosimeters . The results obtained in present study show that annual effective dose was less than even the lower limit of the recommended between (3-10) according to ICRP,1993 [104] as shown in figure(4.10). As potential alpha energy concentration varied from 0.068 mWL to 3.161 mWL with mean value 0.6 mWL in closed dosimeters ,while in open dosimeters varied from 0.074 mWL to 7.216 mWL with mean value 0.974 mWL in open dosimeters. The results were less than the minimum recommended value (53.33 mWL) given by UNSCEAR,1993 [105] as shown in figure(4.11).

Exposure to radon progeny varied from 0.457 $mWLMY^{-1}$ to 21.175 $mWLMY^{-1}$ with an average value 6.525 $mWLMY^{-1}$ in closed dosimeters and varied from 0.492 $mWLMY^{-1}$ to 48.341 $mWLMY^{-1}$

with an average value 4.019 $mWLMY^{-1}$ for open dosimeters as. In all the schools covered by the present study the internal exposure of radon progeny was below the recommended range of (1-2)$WLMY^{-1}$ (NCRP,1989) [99] as shown in figure(4.12) .Lung cancer cases per year per million person ranged from 0.047 to 2.158 mean value 0.410 for closed dosimeters and ranged from 0.050 to 4.925 with mean value 0.665 in open dosimeters .These results were less than the lower limit of the range (170-230) per million person recommended by the (ICRP,1993) [104] as shown in figure(4.13).

By reviewing ,the results show the highest values for each AED or open and closed dosimeters in Al bayan secondary boys school (S37) in Frehaa , and the lowest values in Khayr Al-Bariya primary boys school (S33) in Al-Hussein and in Al-Rawdatain secondary girls school (S18) in Bab Toureej and in Ekraa primary boys school (S25) Salam . Figure (4.14) shows a frequency of radon concentrations for open and closed dosimeters in the air of selected schools by CN-85 detectors.

Table (4.4) Annual Effective Dose (AED),Potential Alpha Energy Concentration (PAEC), Exposure to Radon and its progeny (EP) and lung cancer cases per year per million person(CPPP) in the selected schools by using CN-85 detectors.

Codes	Dosimeter Kinds	AED mSv/y	PAEC mWL	EP $mWLMY^{-1}$	CPPP/10^6
S1	Open	0.029	0.758	5.076	0.517
	Closed	0.021	0.549	3.677	0.375
S2	Open	0.017	0.460	3.080	0.314
	Closed	0.013	0.349	2.335	0.238
S3	Open	0.010	0.261	1.745	0.178

	Closed	0.008	0.220	1.471	0.150
S4	Open	0.012	0.307	2.056	0.210
	Closed	0.010	0.257	1.723	0.176
S5	Open	0.004	0.114	0.765	0.078
	Closed	0.004	0.098	0.659	0.067
S6	Open	0.009	0.236	1.578	0.161
	Closed	0.007	0.188	1.259	0.128
S7	Open	0.019	0.489	3.277	0.334
	Closed	0.013	0.351	2.351	0.240
S8	Open	0.039	1.028	6.888	0.702
	Closed	0.027	0.716	4.793	0.488
S9	Open	0.054	1.434	9.609	0.979
	Closed	0.035	0.918	6.151	0.627
S10	Open	0.079	2.079	13.925	1.419
	Closed	0.047	1.236	8.278	0.843
S11	Open	0.014	0.369	2.470	0.252
	Closed	0.010	0.277	1.852	0.189
S12	Open	0.028	0.749	5.016	0.511
	Closed	0.020	0.536	3.588	0.366
S13	Open	0.022	0.578	3.875	0.395
	Closed	0.017	0.445	2.981	0.304
S14	Open	0.012	0.309	2.070	0.211
	Closed	0.009	0.245	1.640	0.167
S15	Open	0.176	4.644	31.112	3.170
	Closed	0.086	2.265	15.172	1.546

S16	Open	0.020	0.521	3.490	0.356
	Closed	0.016	0.410	2.745	0.280
S17	Open	0.007	0.171	1.149	0.117
	Closed	0.005	0.137	0.921	0.094
S18	Open	0.003	0.088	0.590	0.060
	Closed	0.003	0.084	0.559	0.057
S19	Open	0.059	1.557	10.433	1.063
	Closed	0.035	0.912	6.112	0.623
S20	Open	0.046	1.219	8.167	0.832
	Closed	0.031	0.829	5.551	0.566
S21	Open	0.030	0.802	5.373	0.548
	Closed	0.022	0.572	3.831	0.390
S22	Open	0.032	0.839	5.619	0.573
	Closed	0.023	0.598	4.006	0.408
S23	Open	0.026	0.691	4.631	0.472
	Closed	0.018	0.464	3.111	0.317
S24	Open	0.020	0.538	3.603	0.367
	Closed	0.015	0.383	2.563	0.261
S25	Open	0.003	0.079	0.530	0.054
	Closed	0.003	0.074	0.4971	0.051
S26	Open	0.036	0.961	6.435	0.656
	Closed	0.024	0.644	4.315	0.440
S27	Open	0.006	0.157	1.049	0.107
	Closed	0.005	0.136	0.908	0.093
S28	Open	0.057	1.494	10.005	1.020

	Closed	0.035	0.932	6.245	0.636
S29	Open	0.017	0.441	2.955	0.301
	Closed	0.013	0.347	2.328	0.237
S30	Open	0.083	2.193	14.691	1.497
	Closed	0.050	1.328	8.894	0.906
S31	Open	0.014	0.358	2.395	0.244
	Closed	0.011	0.296	1.981	0.202
S32	Open	0.086	2.265	15.175	1.546
	Closed	0.051	1.357	9.088	0.926
S33	Open	0.003	0.074	0.492	0.050
	Closed	0.003	0.068	0.457	0.047
S34	Open	0.010	0.256	1.717	0.175
	Closed	0.008	0.210	1.410	0.144
S35	Open	0.012	0.328	2.200	0.224
	Closed	0.010	0.267	1.785	0.182
S36	Open	0.010	0.276	1.847	0.188
	Closed	0.009	0.238	1.595	0.163
S37	Open	0.274	7.216	48.341	4.926
	Closed	0.120	3.161	21.175	2.158
S38	Open	0.007	0.173	1.157	0.118
	Closed	0.005	0.141	0.944	0.096
S39	Open	0.016	0.418	2.801	0.285
	Closed	0.012	0.309	2.068	0.211
S40	Open	0.006	0.163	1.094	0.112
	Closed	0.005	0.140	0.937	0.095

S41	Open	0.032	0.854	5.722	0.583
	Closed	0.023	0.610	4.084	0.416
S42	Open	0.030	0.787	5.271	0.537
	Closed	0.021	0.560	3.752	0.382
S43	Open	0.046	1.203	8.061	0.821
	Closed	0.030	0.784	5.252	0.535
S44	Open	0.027	0.714	4.786	0.488
	Closed	0.019	0.499	3.342	0.341
S45	Open	0.034	0.908	6.080	0.619
	Closed	0.024	0.637	4.265	0.435
S46	Open	0.009	0.233	1.559	0.159
	Closed	0.008	0.204	1.369	0.140
S47	Open	0.019	0.490	3.284	0.335
	Closed	0.015	0.389	2.606	0.266
S48	Open	0.150	3.963	26.546	2.705
	Closed	0.075	1.988	13.316	1.357
S49	Open	0.047	1.242	8.319	0.848
	Closed	0.032	0.834	5.586	0.569
S50	Open	0.046	1.219	8.165	0.832
	Closed	0.031	0.809	5.418	0.552
AV	Open	0.037	0.974	6.525	0.665
	Closed	0.023	0.600	4.019	0.410
Min	Open	0.003	0.074	0.492	0.050
	Closed	0.003	0.068	0.457	0.047
Max	Open	0.274	7.216	48.341	4.926

	Closed	0.120	3.161	21.175	2.158

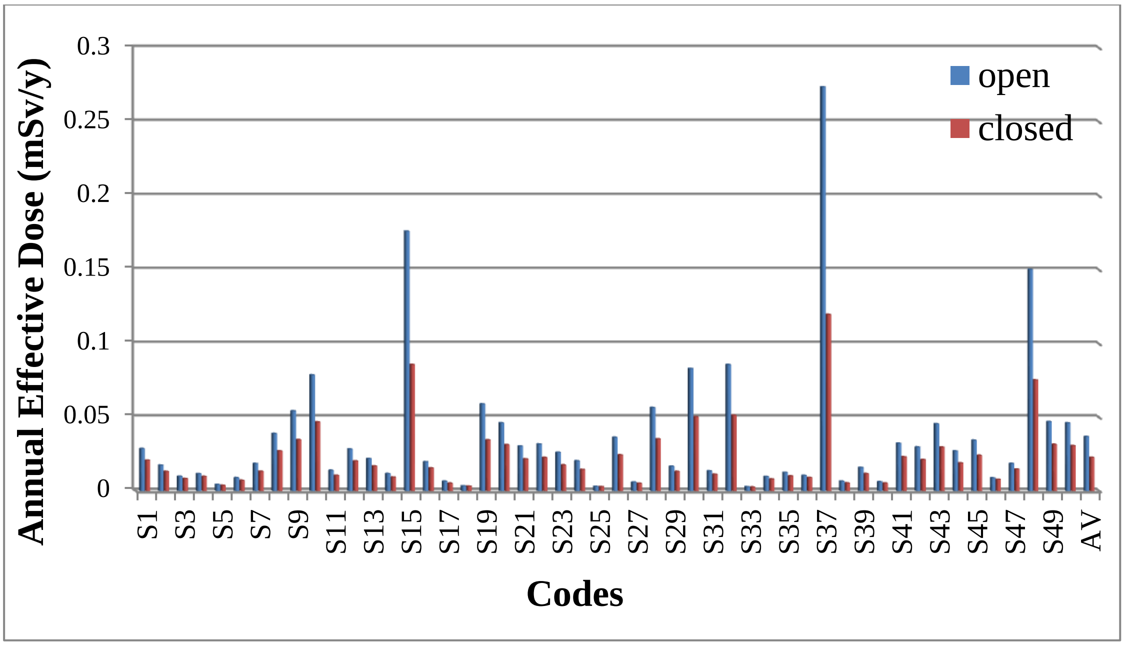


Figure (4.10) Annual Effective Dose for open and closed dosimeters in the air of selected schools by CN-85 detectors.

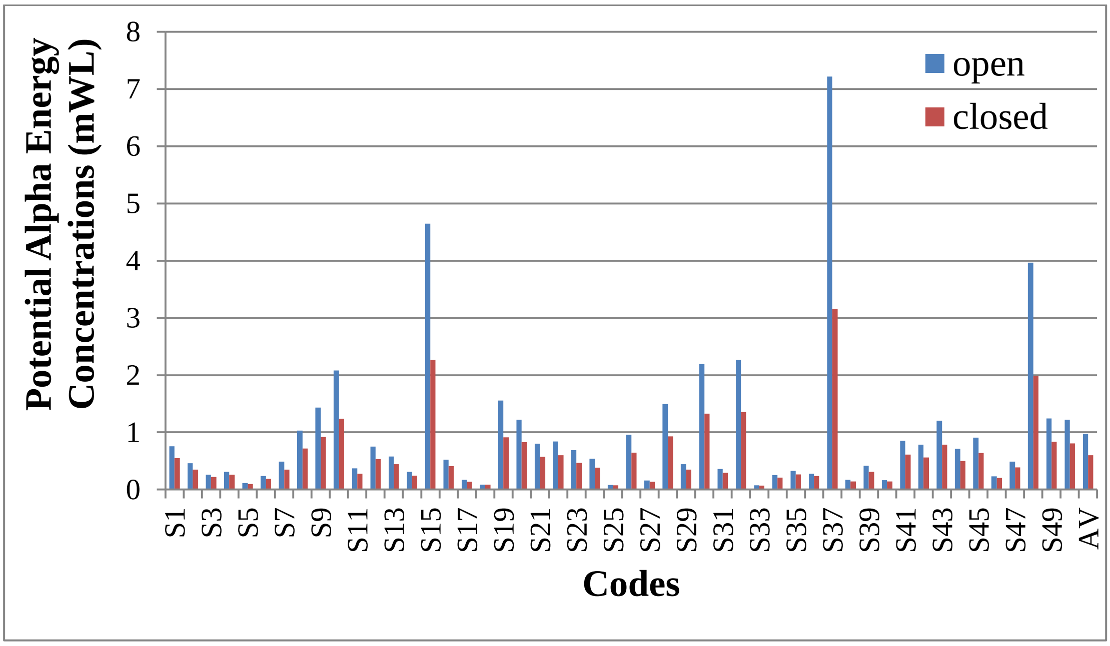
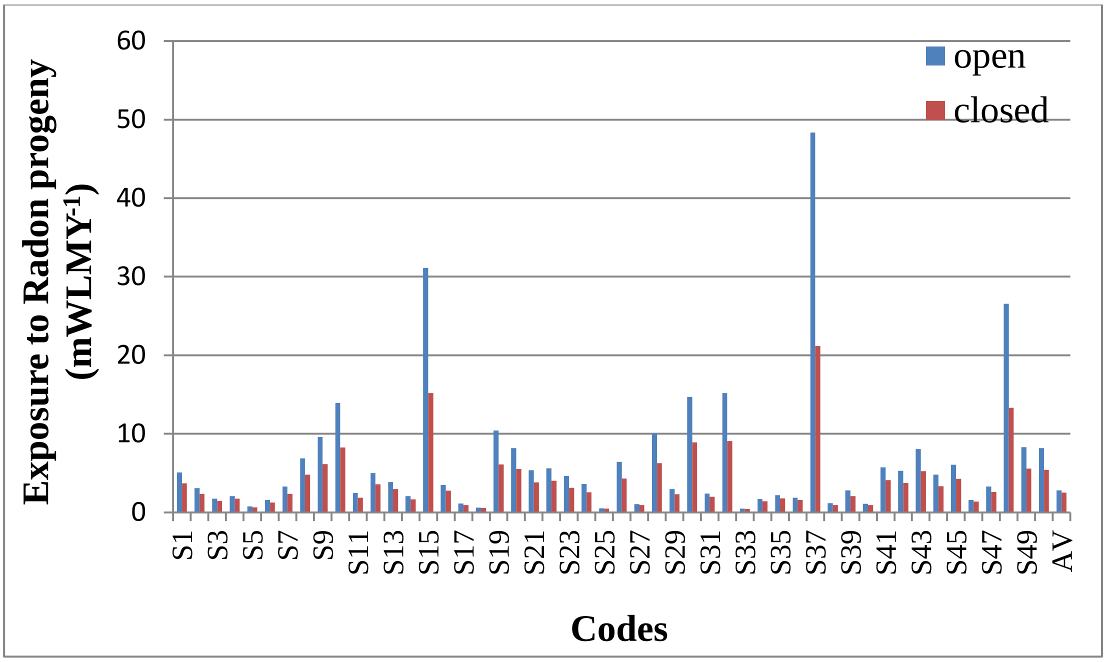
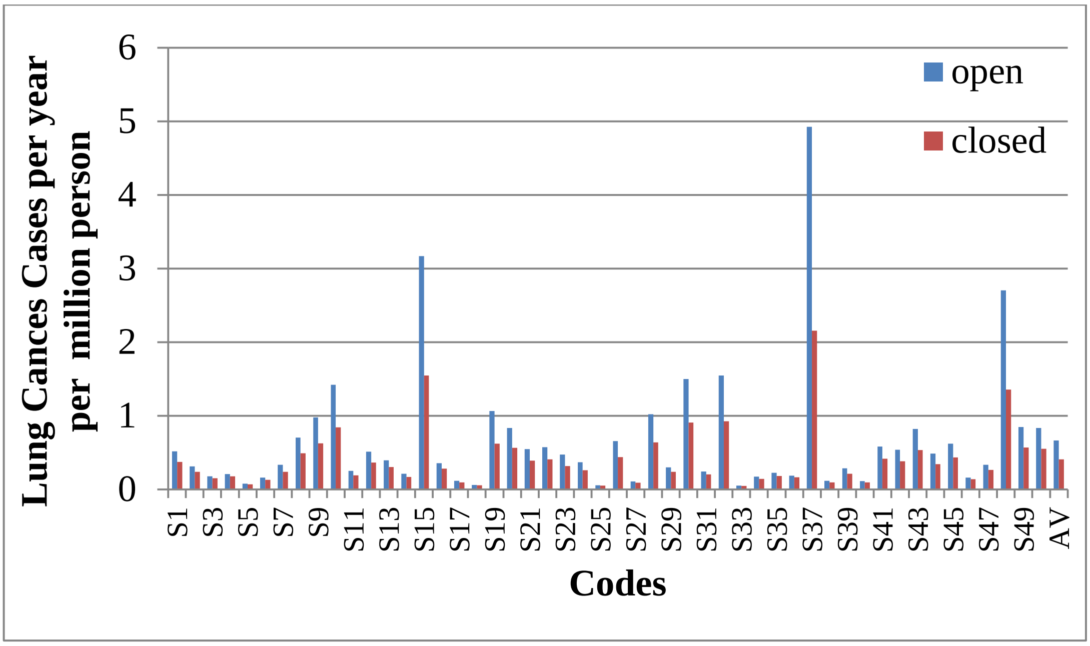


Figure (4.11) Potential Alpha Energy Concentrations for open and closed dosimeters in the air of selected schools by CN-85 detectors.



Figure(4.12) Exposure to radon progeny concentrations for open and closed dosimeters in the air of some selected schools by CN-85 detectors.



Figure(4.13) Lung cancer cases per year per million person for open and closed dosimeters in the air of selected schools by CN-85 detectors .

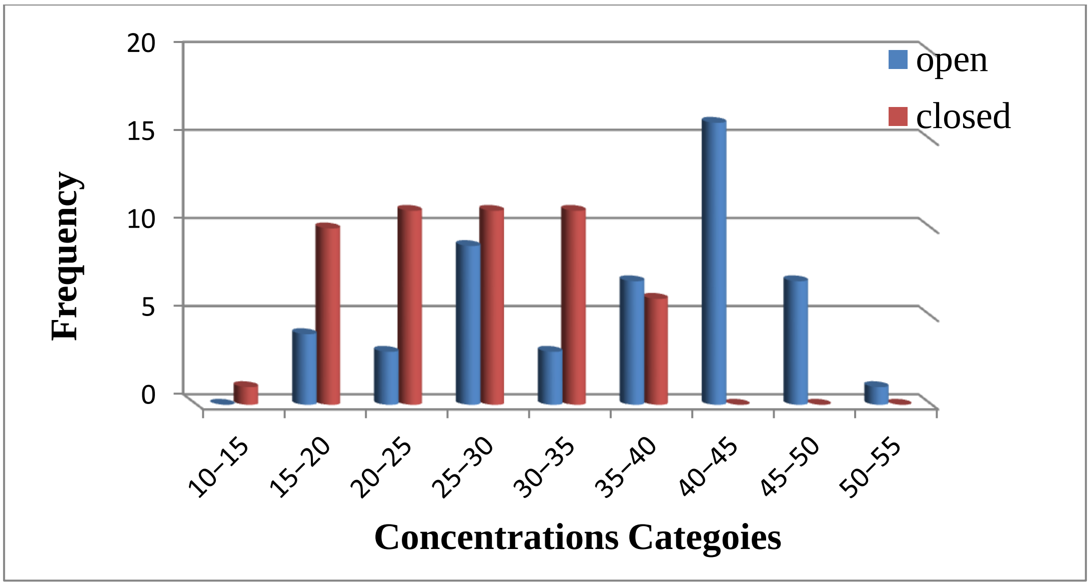


Figure (4.14) Frequency of radon concentrations for open and closed dosimeters in the air of selected schools by CN-85 detectors.

(4.4) Comparison between LR-115 Type II and CN-85 detectors.

In table (4.5) ,it compared the highest value and the lowest values for each of concentrations of radon , equilibrium factor, potential alpha energy concentration , exposure to radon and its progeny and the number of people who are likely to have lung cancer. From the observation of the results, we found a correlation between the values of two detectors (LR-115Type II and CN-85) with minor differences. Figure(4.15) shows positive correlation between radon concentration in LR-115 Type II and CN-85 detectors which was found in open dosimeters equal 0.86 and figure (4.16) also shows positive correlation between radon concentration in LR-115 Type II and CN-85 detectors which was found in closed dosimeters equal 0.72. Figures (4.17) and (4.18) show relation of average radon concentrations measured by LR-115 Type II and CN-85 in old and new buildings schools in open and closed, respectively which appear higher concentrations of radon in old schools that are date of establishment less than 2000 than new schools.

Table (4.5) Comparison results between LR-115 Type II and CN-85 detectors in Open(O)and Closed (C) Dosimeters(D) .

		LR-115 Type II			CN-85		
	D	Min	Max	AV	Min	Max	AV
C_{Rn}	O	15.719	56	36.972	17.269	50.709	36.481
	C	13.140	38.439	24.249	13.842	38.101	26.275
F		0.12	0.523	0.143	0.012	0.561	0.089
AED	O	0.003	0.276	0.064	0.003	0.274	0.037
	C	0.003	0.124	0.035	0.003	0.120	0.023
PAEC	O	0.082	7.284	1.680	0.074	7.216	0.974
	C	0.075	3.260	0.935	0.068	3.161	0.600
EP	O	0.548	48.795	11.259	0.492	48.341	6.525
	C	0.505	21.841	6.258	0.457	21.175	4.019
CPPP	O	0.056	4.972	1.147	0.050	4.926	0.665
	C	0.051	2.226	0.638	0.047	2.158	0.410

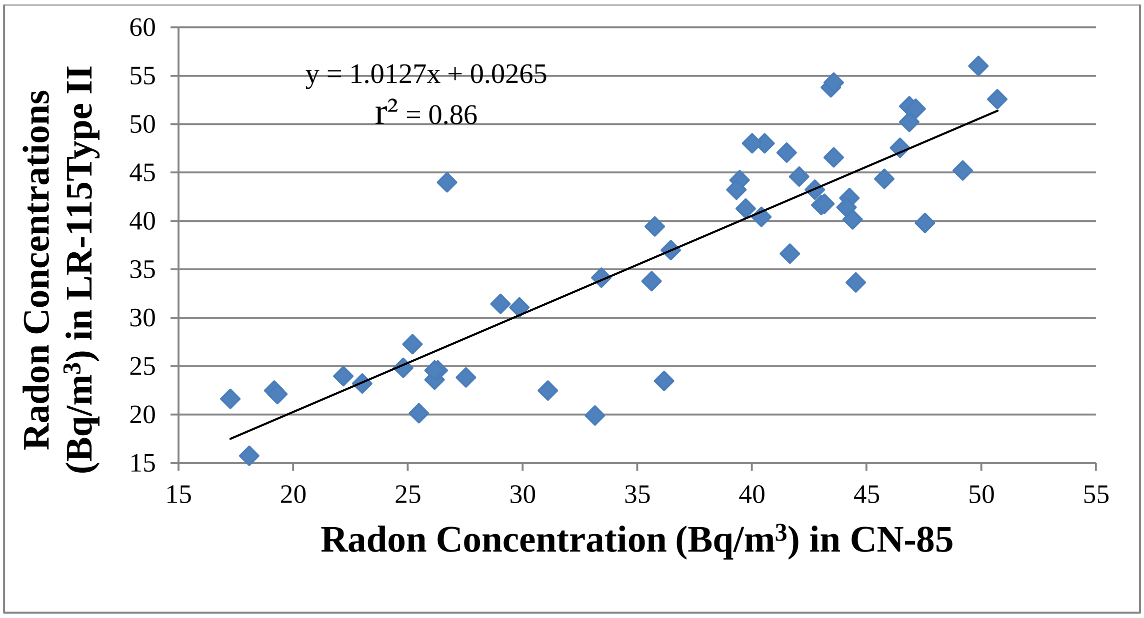


Figure (4.15) Correlation between radon concentration in open dosimeters for LR-115 Type II and CN-85 detectors.

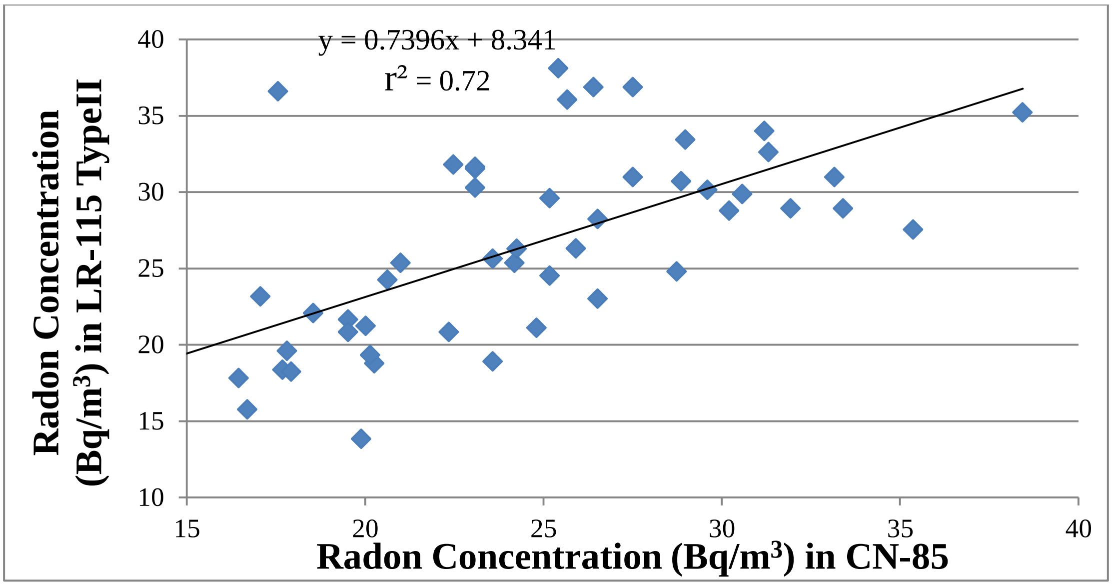


Figure (4.16) Correlation between radon concentration in closed dosimeters for LR-115 Type II and CN-85 detectors.

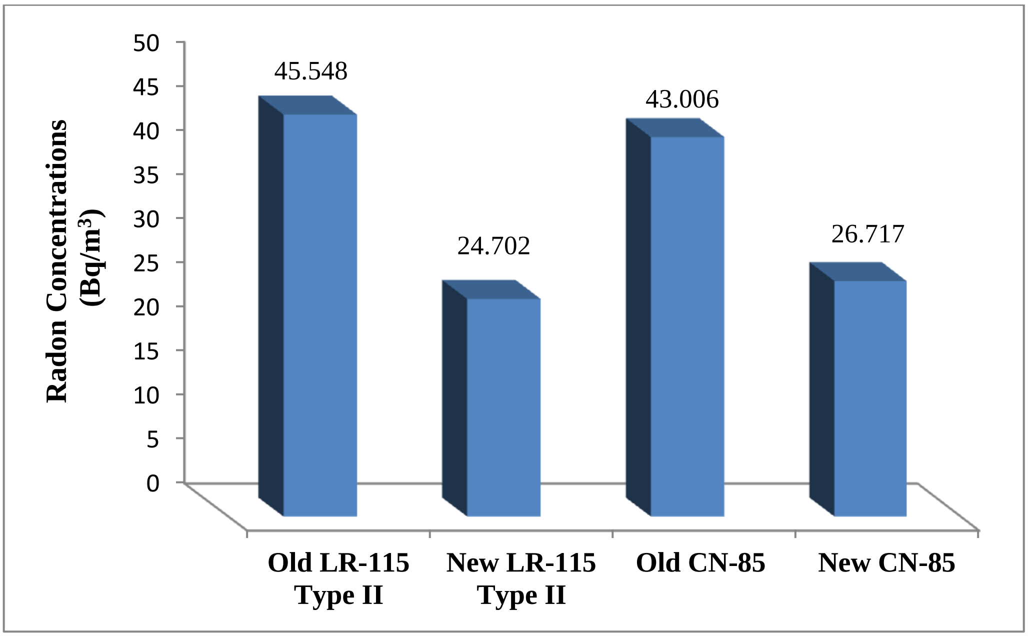


Figure (4.17) Average radon concentrations in old and new buildings schools in open dosimeters.

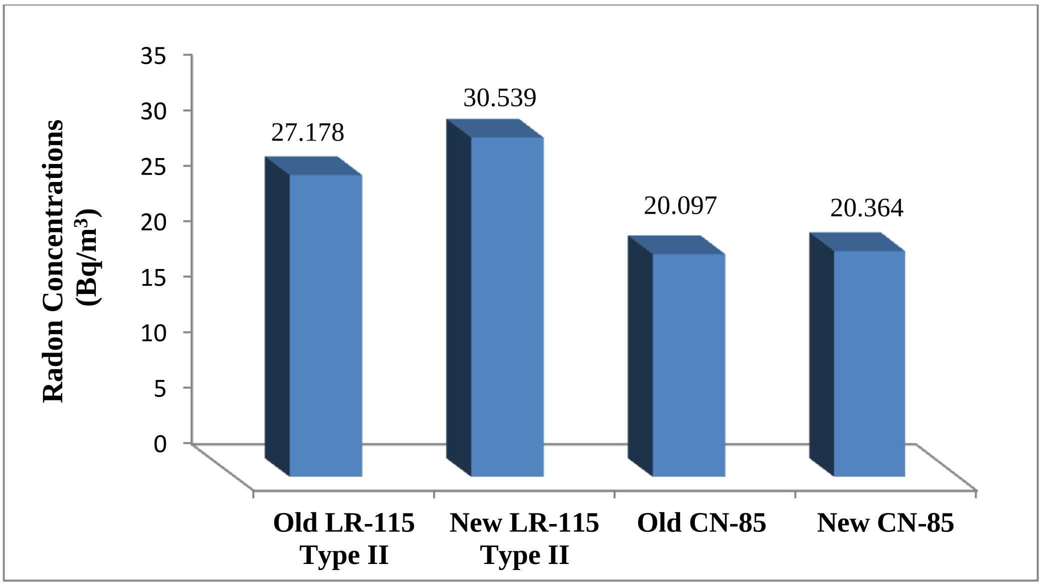


Figure (4.18) Average radon concentrations in old and new buildings schools in closed dosimeters.

(4.5) Comparison between our results with others studied

When comparing the result of radon concentration in this study with previous local , arab and international studies using LR-115 type II , it was observed that the results of the present study are close to the results of some countries , including Iraq (Kufa) [106] , Italian (Parma) [43] , Greece (Patras) [46]and Tunis [51], while they were lower than the radon concentration in Turkey (Istanbul) [60], Egypt (Cario) [47], Greece (Patras) [107] , Turkey (Izmir) [56] . In the case of CN-85 the radon concentration were higher than the radon concentration of the group of researchers in Pakistan [41] and less than those of other researchers in and Pakistan (Muzaffarabad) [50] , Pakistan (Skardu) [44] , Pakistan [108] and Pakistan (Bahimber) [109] .When comparing the results of the current study with other studies using the nuclear track detectors CR-39 ,it was found the results were close to the results of previous studies in Palestine (Hebron) [110] , Iraqi Kurdistan (Koya) [58], Kuwait [45], Serbia [111] . While the results of our studies were lower than from other studies in Iraq (Karbala) [61], Saudi Arabia [26], Jordon (Amman) [42], Turkey(Batman) [57], Pakistan (Punjab) [112] ,Nigeria(Oke- Ogun) [53], Palestine (Tulkarem) [59] and Iraq(Karbala) [113]. While the results of annual effective dose in all present study was lower than the results of the other studies, as shown in the table below.

Table (4.6) Comparison of the present study in schools with others studied in different places for other countries.

No	Country	Detector	Place of study	C (Bq/m^3)	AED (mSy^{-1})	Ref.
1	Iraq , Kufa	LR-115 Type II	Technical Institute	21.567	0.544	[106]
2	Italian ,Parma	LR-115 Type II	kindergartens and schools	30	0.5	[43]
3	Greece, Patras	LR-115 Type II	Schools	35	0.2	[46]
4	Tunis ,Tunisia	LR-115 Type II	Schools	26.9	0.084	[51]
5	Turkey (Istanbul)	LR-115 Type II	Schools	125	-	[60]
6	Egypt, Cairo	LR-115 Type II	Schools	57.6	0.85	[47]
7	Greece, Patras	LR-115 Type II	Dwellings	38	0.9	[107]
8	Turkey, Izmir	LR-115 Type II	University	161	0.79-4.27	[56]
9	Pakistan	CN-85	sitting rooms	28	-	[41]
10	Pakistan,Skardu	CN-85	Dwellings	111.34	-	[44]
11	Pakistan, Muzaffarabad	CN-85	Drawing rooms	85	-	[50]
12	Pakistan	CN-85	Dwellings	95.1	2.38	[108]
13	Pakistan (Bahimber)	CN-85	Dwellings	48	1.05	[109]
14	Palestine (Hebron)	CR-39	Schools	34.1	1.76	[110]
15	Iraqi Kurdistan (Koya)	CR-39	Kindergarten	28.306	0.281	[58]

16	Kuwait	CR-39		Schools	16	0.97	[45]
17	Serbia	CR-39		Schools	28.8	-	[111]
18	Iraq ,Karbala	CR-39		Dwellings	62.07	0.68	[61]
19	Saudi Arabia	CR-39		kindergartens and schools	74.67	0.68	[26]
20	Jordon, Amman	CR-39		kindergartens	76.8	-	[42]
21	Turkey, Batman	CR-39		Schools	49	0.25	[57]
22	Pakistan ,Punjab	CR-39		Schools	52	0.49	[112]
23	Nigeria, Oke-Ogun	CR-39		Schools	45	0.32-0.2	[53]
24	Palestine, Tulkarem	CR-39		Schools	40.4	0.17	[59]
25	Iraq ,Karbala	CR-39		University	70.35	1.77	[113]
26	Iraq , Karbala	CN-85	O	Schools	36.481	0.037	This study
			C		26.275	0.023	
		LR-115 Type II	O	Schools	36.972	0.064	
			C		24.249	0.035	

(4.6) Conclusions

From results obtained. It can be inferred the following :

1-Radon concentrations in air of all schools in present study that are less than the recommended limit (200-300) Bq/m^3 according to ICRP,2009.

2- Radon concentrations in older schools are higher than the concentration of radon in schools of modern construction because radon emits from the cracks in the floors and walls.

3- The effective annual dose was calculated for all the schools under study and it was found to be less than the permissible limit(3-10) mSv/y due to the school occupancy factor, which is 13%, while the occupancy factor in dwelling is 80% .

4- Equilibrium factor was found within or less than the allowed limit (0.4 – 1), potential alpha energy concentrations were found less than the recommended limit (53.33 mWL) according to UNSCEAR, 1993.

5- Exposure to radon progeny was found less than the allowed limit (1-2) $WLMY^{-1}$, lung cancer cases per year per million was found less than the allowed limit (170 – 230) .

6- Through the above results it can be said that the selected schools of the city of Karbala are free from the risk of radon and does not pose a threat to the lives of teachers and students.

(4.7) Recommendations

Regardless of the results obtained from the study, which show a decrease in concentrations of radon in the air of schools in the city of Karbala, however, caution must be taken of the danger of radon and its wolves because of the 55% of the environment contaminated by radiation, so we will make several recommendations to be taken to reduce concentrations of radon in buildings :

1- In order to reduce radon and maintain low levels, ventilation must be good in the school buildings, so the Ministry of Education provides fans and maintenance of existing ones .

2- Renovating the schools of old construction and repairing them continuously and filling the cracks in the floors and ceilings in order to get rid of the high concentrations because, as is known, the main source of radon is the soil .

3 - In the case of effective annual dose calculation, the occupancy factor should be calculated correctly to obtain accurate results and to avoid overstating the effective dose**.**

4- Make measurements of radon concentrations using the positive method as well as the negative integrative method periodically and find the correlation factor between the two methods.

(4.8) Future Work

1- To conduct field survey of areas that have not been studied and measure radon concentrations in order to complete map for all areas of Karbala province.

2- To use the active method to calculate radon concentration and compare them with the passive method to see the difference between them.

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الخلاصة

الرادون هو غاز مشع ينتج بشكل طبيعي من الاضمحلال الإشعاعي الطبيعي للراديوم الذي ينتج عن تحلل اليورانيوم . في هذه الدراسة ، في هذه الدراسة ، تم حساب تراكيز الرادون في هواء بنايات بعض مدارس مدينة كربلاء واجريت الدراسة باستعمال مجراعات الرادون السلبية التراكمية المغلقة والمفتوحة والتي تحتوي على نوعين من كواشف الاثر النووي للحالة الصلبة LR-115 Type II وCN-85 وهما من الكواشف العضوية نوع نترات السليلوز وبسمك لكل منهما 12 μm. تم توزيع ٢٠٠ مجراع وبواقع مئة مجراع مفتوح ومئة مغلق على المدارس المشمولة بالدراسة ، حيث وضع مجراعان في كل مدرسة احدهما مغلق والاخر مفتوح في تاريخ 2017/11/27 في داخل المدارس وعلى ارتفاع حوالي مترين من الأرضية وبعد فترة تعرض حوالي ثلاثة اشهر جمعت المجراعات وتم انتزاع الكواشف منها لغرض اجراء عملية القشط الكهروكيميائي من اجل تظهير اثار جسيمات الفا الموجودة على سطح الكواشف تمت عملية قشط الكواشف باستخدام محلول هيدروكسيد الصوديوم بتركيز 2.5N لمدة ٩٠ دقيقة وبدرجة حرارة ^{o}C (60±1) بعد ذلك تم غسلها بالماء المقطر وتجفيفها لغرض عد اثار جسيمات الفا باستعمال مجهر ضوئي وبتكبير X 100.

اظهرت النتائج ان معدل تركيز غاز الرادون في هواء بنايات المدارس المختارة هو $36.972 \pm 11.33\ Bq/m^3$ و $36.481 \pm 9.66\ Bq/m^3$ للمجراعات المفتوحة لكل من الكواشفLR-115 Type II وCN-85 على التوالي ، اما بالنسبه للمجراعات المغلقة فان معدل تركيز الرادون هو $24.249 \pm\ Bq/m^3$ ، $26.275 \pm 6.49\ Bq/m^3$ لكل من الكواشف Type LR-115 II وCN-85 على التوالي . بعد حساب تراكيز الرادون للمجاريع المفتوحة و المغلقة وجد معدل عامل الاتزان 0.089 و0.143 . في المجراعات المفتوحة وجد معدل الجرعة السنوية الفعالة $0.064\ mSv/y$ و $0.037\ mSv/y$ ، كذلك وجد ان معدل الجرعة السنوية الفعالة $0.035\ mSv/y$ و $0.023\ mSv/y$ للمجراعات المغلقة لكل من LR-115 Type II وCN -85 على التوالي. بالإضافة الى ذلك تم حساب معدل تركيز طاقة جهد الفا ووجدت بانها مساوية الى 1.680mWL و 0.974 mWL في المجراعات المفتوحة، أما في المجراعات المغلقة كانت 0.935mWL و 0.600 mWL لكل من LR-115Type II وCN- 85 على التوالي. معدل التعرض لوليدات الرادون هو $11.259\ mWLMY^{-1}$ و $6.525\ mWLMY^{-1}$ للمجراعات المفتوحة ، أما في المجراعات المغلقة كانت $6.258 mWLMY^{-1}$ و $4.019\ mWLMY^{-1}$ لكل من LR-115 Type II وCN-85 على التوالي . معدل حالات سرطان الرئة سنويا لكل مليون

شخص هو 1.147 و 0.665 للمجراعات المفتوحة ، اما للمجراعات المغلقة كان معدل حالات سرطان الرئة سنويا لكل مليون شخص هو 0.638 و 0.410 لكل من LR-115 Type II وCN-85 على التوالي . النتائج التي تم الحصول عليها كانت ضمن الحدود الدولية حسب اللجنة الدولية للوقاية من الاشعاع (ICRP) Bq/m^3 (200-300) وهذا يعني لا يوجد خطر من سرطان الرئة يهدد الطلبة والكادر التعليمي في هذه المدارس .

وزارة التعليم العالي والبحث العلمي

جامعة كربلاء

كلية العلوم

قسم الفيزياء

قياس تراكيز الرادون في هواء بنايات بعض مدارس مدينة كربلاء باستخدام الكواشف CN-85 وLR-115 TypeII

رسالة

مقدمة الى مجلس كلية العلوم/جامعة كربلاء

كجزء من متطلبات درجة الماجستير في الفيزياء

مقدمة من قبل

سارة صالح نايف

بكالوريوس جامعة كربلاء

بإشراف

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