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College of Education for Pure Science / Ibn
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Measurement of Radon Concentrations in College of Education / Ibn Al- Haitham Buildings Using CR-39 Detector and RAD-7 Monitor

A thesis by

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بسم الله الرحمن الرحيم

﴿ وَمَا أَرْسَلْنَا مِنْ قَبْلِكَ إِلَّا رِجَالًا
نُوحِي إِلَيْهِمْ فَاسْأَلُوا أَهْلَ الذِّكْرِ إِنْ
كُنْتُمْ لَا تَعْلَمُونَ﴾

صدق الله العلي العظيم

السورة : النحل

(43)

Dedicated to

- ***My Dad***
- ***My Mam***
- ***My Brothers***
- ***My Friends***

Duaa

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ABSTRACT

In this study , indoor radon concentrations have been measured for air buildings in College of Education for Pure Sciences / Ibn Al- Haitham , using two methods CR-39 detector passive method and using Rad-7 monitor the active method . the study concluded deanship , physics , chemistry , biology , psychology and library , mathematics department and the service laboratory along with other random buildings . moreover the parameters radiation calculated for radon concentrations for all samples that radon concentrations measured were calculated .

The CR-39 detector has been used to calculate the tracks of alpha particles , 100 detectors have been distributed in college (two detectors) in each room except one room where four detectors were used , for (30 days) on height (160 cm) , the detectors with area (1 cm^2) . Rad-7 monitor have been measured radon concentration directly for (30 minute) in each room . Where the results were found the radon concentration in the air using a detector CR-39 varied between (17.412±2.192) Bq/m^3 and (445.868±81.966) Bq/m^3 and average was (123.8652) Bq/m^3, where all the results were within the range allowed for all samples except two samples was higher than the allowable limit recorded by (International committee or radiation protection) ICRP (200-300) Bq/m^3, these two samples are F1 and F2 because this places were underground , badly ventilated places and old buildings . While in Rad-7 results were ranged between (0.0) Bq/m^3 and (59.6) Bq/m^3 , all the results were within the global range allowed for all samples .

The parameters radiation have been calculated which represented the annual effective dose (AED) , the lung cancer cases per year per million person (CPPP) , exposure to radon progeny (E_P) , the potential Alpha energy concentration (PAEC) . All results of the effect radiation were within allowable limit except the annual effective dose (AED) were higher than the allowable limit in two samples F1 and F2 because the radon concentration was high in this places .

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List of Symbols & Abbreviations

Symbol	Description
CME	Coronal Mass Ejections
GRB	Gamma-Ray Bursts
PMT	Photo Multiplier Tube
SSNTD	Solid State Nuclear Track Detector
Bq	Becquerel
AED	Annual Effective Dose
CPPP	Lung Cancer Cases Per year Per Million Person
E_P	Exposure to Radon Progeny
PAEC	Potential Alpha Energy Concentration
SI	System International
Ci	Curie
dis	Disintegration
C^o	Degree centigrade
KJ	Kilo Joule
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
TEM	Transmission Electron Microscopy
USA	United States America
ρ_x	Density of Tracks
N_{ave}	Number of Track of sample
A	Area

Symbol	Description
λ	decay constant
A_t	Activity at time t of the sample
A_o	Initial activity.
$t_{1/2}$	half life
A_{Rn}	Activity of ^{222}Rn
A_{Ra}	Activity of ^{226}Ra
E_s	Exposure of Radon
ρ_s	Density of Track of standard source
C_{Rn}	Concentration of Radon
F	Equilibrium Factor
H	Occupancy factor
T	Time in hours
D	Dose Conversion Factor
WL	Work level
n	Fraction of Time Spent
WLM	Working Level Month
Sv	Sievert
RH%	Relative humidity
ICRP	International committee or radiation protection

Chapter one

General introduction

(1 - 1) Introduction:

Radiation can be defined as the energy emission through a space or material medium as a waves or particles formation [1] . These radiations are:

- Electromagnetic, like [radio-waves, microwaves, visible light, x-rays and gamma (γ)].
- Particle radiation like [alpha (α), beta (β), and neutron].
- Acoustic radiation, like [ultrasound, and seismic waves (depending on a physical transmission medium).
- Gravitational radiation, this type has the gravitational waves form or wrinkles in the space-time curving.

Radiation can be classified by either ionization or non-ionization that depends on the radiated particles energy, ionization radiation holds more than 10eV. This energy is capable of ionizing atoms and molecules, and breaking the chemical bonds, this is a vital feature because of the large variation in damaging to living organisms, radioactive materials is commonly the source of ionization radiation ,which emit α, β, or γ radiation, consist of helium nuclei, electrons or photons and positrons. X-rays from medical radiography tests and muons, neutrons, positrons, mesons and other particles that can form the secondary cosmic rays that are created after primary cosmic rays interacted with Earth's atmosphere[2]. The electromagnetic spectrum ionizing part is constituted by X-rays, gamma rays, and the ultraviolet light's higher energy range. The non-ionizing radiation are: the lower-energy, longer-wavelength part of the spectrum including observable light, infrared light, microwaves and radio waves ; their main effectiveness can occur when interacting with tissue ,this sort of radiation can only harm cells when the intensity is sufficient to cause excessive heating, ultraviolet has both ionization and non-ionization radiation features [3]. The ultraviolet spectrum part that goes through the Earth's atmosphere is considered non-ionizing, this radiation has no damages to many molecules in the biological systems but can have heating effects, such as sunburn, these properties come from ultraviolet's power to change chemical chains, even having no quite sufficient energy so as to ionize atoms [4] . The waves radiating phenomenon gave the word radiation for example (the travel outward in all directions) from a source, this part leads to physical units measurements system and that are usable to all kinds of radiation. Since such radiation can extend passing through space, and its energy can be preserved (in vacuum),therefore the radiation intensity from a point source put up with an inverse-square law in relation to the distance from its source, similar to any typical law, the inverse-square law approximates a measured radiation intensity to the range that the source approximates a geometric point [5] .

(1 - 2) Radioactivity :

Nuclei can be subjected to different processes that leads to the radiation emission . Alpha , beta particles (negative and positive) and gamma-rays are considered the main forms. Human bodies own radioactive materials like^{14}C and ^{40}K [6]. After the discovery of uranium radioactivity by" Becquerel" , more successful researches for other naturally radioactive nuclides were made by the hands of "Rutherford" , it was recognized that radioactivity could also include changing in mass , physical and chemical nature of the element . When creating new element in radioactive process , it becomes a radioactive element as well in nature

[7] . there are three radioactive series ^{238}U, ^{235}U and ^{232}Th in which heavy nuclides can lose their mass and change their atomic number , these changes can onley finish when the element becomes a stable isotope of lead . In these spontaneous changing , it can recognise three kinds of nuclear radiation : α-particles (energetic helium nuclei) , β-particles (electrons or positrons) , and γ-rays (electromagnetic waves) . the activity can be defined as the disintegration number per second , in **(System International)** (SI) unit , and the measuring is "Becquerel" (Bq) [8] .

$$\mathbf{1\ Bq = 1\ (dis/s)} \qquad \text{..... (1 - 1)}$$

Some elements like uranium , thorium are naturally unstable , the atoms of elements like these , can obtain stability through disposing of the overflowing energy in electromagnetic radiations form or particles named nuclear radiations or ionizing radiations . In Fig. (1 - 1) , the radioactivity transition from air to human is shown [9] .

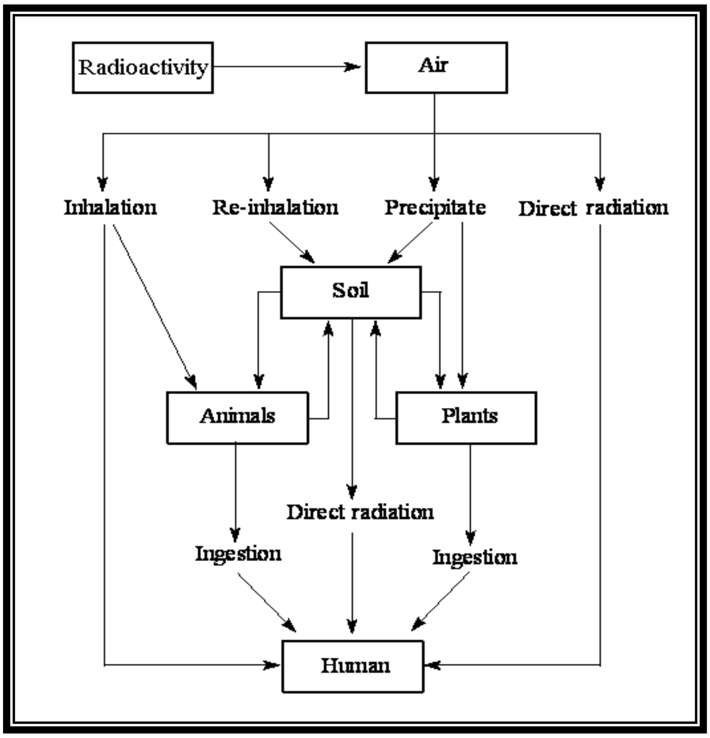


Fig (1 - 1) : Transition of radioactivity from air to human [9] .

(1 - 3) Natural radioactivity sources :

The sun and the deep space are the high energy particles sources that enter the Earth's atmosphere from external space ; in continuous way, the sun emits particles, firstly free protons, in the solar wind, and sometimes increases the flow largely with coronal mass ejections (CME),the particles from deep space (inter- and extra-galactic) are less recurrent, but with higher energies[10]. These particles are foremost protons, with the rest are the ones that consisting of helions (alpha particles), a few ionized nuclei of heavier elements are existent ,the principle of these galactic cosmic rays has no understanding yet, but it looks to be the remains of supernovae and especially gamma-ray bursts (GRB), which can appear a magnetic fields able to hugely be accelerated that is measured from these particles [11] . They can also be created by quasars, which are galaxy-wide jet phenomena like to GRBs but recognized from their large size, and that looks to be a strong part of the universe's early history [12] .

All natural nuclides with atomic numbers Z > 83 are radioactive , regarding the three natural radioactive chains (^{238}U , ^{232}Th and ^{235}U) . The fourth one is neptunium chains , there is also the natural radioactive chain , but this does not happen normally in the nature due to its short half-life (2.14×10^{6}) year [13] , according to the longest lived member of the chains (^{237}Np) which is much shorter than the earth age [14] , as shown in table (1 - 1) radioactive decay series [13] .

Table (1 - 1) : Radioactive decay series , half life (year) and last isotope (stable) [13] .

Series	First isotope	Half -life (year)	Last isotope (stable)
Uranium	^{238}U	4.47×10^{9}	^{206}Pb
Actinium	^{235}U	7.03×10^{8}	^{207}Pb
Thorium	^{232}Th	1.39×10^{10}	^{208}Pb
Neptunium	^{237}Np	2.14×10^{6}	^{209}Bi

(1 - 4) Radioactivity of Radon:

The spontaneous decay of the atom nucleus by emission of particles is called radioactivity, and is generally accompanied by electromagnetic radiation, natural radioactivity is displayed by various elements, such as Uranium, Radium, Radon gas, and the daughters of Radon [12]. There are three typed of radiations: alpha particle which has a weak penetration power, is a nucleus with two protons and two neutrons) of an ordinary atom of helium ; beta particle which has a moderate penetration power, is a high-speed electron or sometimes a positron (the electron's antiparticle); and gamma radiation, which is an electromagnetic radiation type with very short wavelengths and very high penetration power [15]. In order to designate the rate of radioactive substance decay is usually by knowing its half-life (about 92 hours or nearly 4 days), another matter to take into account is the remarkable property of the radioactive decay chain of radium, uranium and radon [16]. This looks uncommon as the gas is made from a radioactive solid element (a rock) and then it turn back into radioactive heavy metallic particles, this procedure and the small atomic size enable the radioactive atoms transportation through a relatively constant environment possible, or it can say that radon's expanded half-life time takes about a month to provide adequate time for the gas to be capable of migrating through cracks and rifts in building foundations, then into the inner air bulk where it turns into the more harmful radioactive heavy metals [17] .

This gas and the resulting very small metallic particles ,which will float in air ,move rapidly all the way through buildings , making the air contaminated [18].

(1 - 5) Previous studies :

- ouf have done study at (1999) about indoor radon concentrations buildings using CR_39 detectors in the Mosul Governorate . the results of radon concentration was (40 - 75) Bq/m^3 [19] .

- Rahman at (2005) have done study about radon concentration in Pakistan in bohwalbor area . the result recorded highest radon concentration which was (96) $Bq/m^3$and minimum value was (29) Bq/m^3 [20] .

- At(2005) Rasas . et were measured radon concentration using solid state nuclear track detectors (SSNTDs) type CR-39 in the homes of the Gaza Strip the results show radon concentrations in the study ranging between (13) Bq/m^3 and (84) Bq/m^3 [21] .

- Al-Mosa was determined radon concentration at (2007) in kindergartens , primary and primer school using solid state nuclear tracks detectors (SSNTDs) type CR-39 in Saudi Arabia Zulfi . the average radon concentration was (74.67 ± 3 .04) Bq/m^3 [22] .

- At (2008) Bouzarjomehri and Ehrampoosh were measured the level of radon using RAD-7 monitor technique in the basement crypt houses Yazd Iranian, radon was measured in (84) home at different parts of the Yazd city ,the results of radon concentration were ranged from (55.5 - 747.4) Bq/m^3 [23] .

- At (2008) Al-Awad was studied radon concentration using solid state nuclear track detectors (SSNTDs) type CR-39, in Saudi Arabia in Najran homes where has been distributed (160) detectors in (20) houses in four villages, the radon concentrations ranged between (9 - 163) Bq/m^3 [24] .

- Al-obedy and Al-jubory at (2009) were measured radon concentration in the Kirkuk Governorate buildings , using nuclear track detector type (CR-39) . The results of radon concentrations in shelters and bathrooms were higher than the levels in the living room (dwelling) , bedroom , kitchens and outdoors, radon concentration ranged between (36.4 - 89.4) $Bq\backslash m^3$[25] .

- Tawfiq . et at (2012) measured radon concentration level indoor homes using solid state nuclear track detectors (SSNTDs) type CR-39 in the Najaf Governorate , radon concentration ranged between (74.2804 ± 42.6048) $Bq\backslash m^3$ and (478.1301 ± 53.325) $Bq\backslash m^3$ [26] .

- The radon concentrations were determined by Al-hamidaoi at (2012) in homes of AL - Najaf and Kufa in Najaf Governorate using Rad-7 monitor , the radon concentration was ranged between (2.75 ± 0.5) Bq/m^3 and (9 ± 0.816) Bq/m^3 for outside Kufa and ranged between (1.25 ± .958) Bq/m^3 and (7.5 ± 0.578) $Bq/m^3$for Najaf city, and the indoors old buildings ranged between (48.42125 ± 2.831) Bq/m^3 and (73.25 ± 2.2173) Bq/m^3 for Kufa city and for Najaf city vary from (19.5 ± 1 291) Bq/m^3 to (85 ± 2 160) Bq/m^3, either at indoors radon concentration for modern buildings Kufa city the range were vary from (22.25 ± 1 708) Bq/m^3 to (68.75 ± 2 754) Bq/m^3, for Najaf city vary from (15.5 ± 1 291) Bq/$m^3$to (54.25 ± .958) Bq/m^3 in addition use CR-39 detector for Compare [27] .

- At (2013) radon levels were determined by Mallah in basic school in Tulkarm in Palestine, using solid state nuclear track detectors (SSNTDs) type CR-39 in addition to using RAD-7 monitor ,The radon levels ranging between (3.48 - 210.51) Bq\$m^3$ for CR-39 . The radon levels ranging between (19.8 ± 1.6 - 195 ± 5) Bq\$m^3$ [28] .

- Al-saadi was measured indoor the radon concentration at (2013) in the multi floors of buildings , also outdoor radon concentration in the campus in the University of Karbala using solid state nuclear track detectors (SSNTDs) type CR-39 . The results shown that the average indoor radon concentration buildings Campus was (70.358) Bq\m3, while the average outdoor radon concentration was (26.974) Bq\m^3 [29] .

- At (2013) Noor was measured radon concentrations in soil, water and air for selected areas of Al - Najaf Governorate using Rad-7 monitor technique . The results radon concentration in old buildings was vary from (4.3 ± 3.04) Bq/m^3 to (51.1 ± 31) Bq/$m^3$and for the New buildings in old Najaf range was between (2.9 ± 1.3) Bq/$m^3$and (31.3 ± 2.8) Bq/m . The range was vary from (4.25 ± 0.49) Bq/m^3 to (221 ± 2) Bq/m^3 for campus of Kufa [30] .

- Muntean . et at (2014) were determined radon concentration indoor home for four seasons in Romania using solid state nuclear track detector type CR-39 , the average radon concentration in the winter season was (149) Bq/m3 and in the summer season was (65) Bq/m^3 [31] .

- At (2015) Scheinin was designed a program semi empirical for measure radon emitted from building materials in residential buildings using semi empirical relationship , and using solid state nuclear track detectors (SSNTDs) type CR-39 , the higher value for the radon concentration was (13.954) Bq/m^3 and the lowest value was (7.150) Bq/m^3in addition to using of Rad - 7 monitor were the highest value was (17.7) Bq/m^3 and the lowest value was (0.0) Bq/m^3 [32] .

- kaream at (2015) was studied radon emissions in some Iraqi provinces using nuclear track detector CR-39 , the results show that the range radon concentration was vary from (51.688 ± 16.7) Bq/m^3 to (153.730 ± 42.4) Bq/m^3 . The average radon concentration in homes of Anbar Governorate was (512.975 ± 74.5 Bq/m^3) [33] .

- At (2015) Fadel was measured radon and daughters concentrations and exposure assessment in buildings of science college mustansiriyah university using solid state nuclear track detectors (SSNTDs) type CR-39 radon concentrations were within the permissible limits globally [34] .

(1 - 6) The aim of the study :

Measurement the indoor Radon concentrations in College of Education for Pure Science / Ibn Al - Haitham buildings using track detector type (CR-39) passive method and radon monitor type (Rad -7) active method because this college is one of old buildings .

In addition to calculation of the parameters radiation which represented by the annual effective dose (AED) , the lung cancer cases per year per million person (CPPP) , exposure to radon progeny (E_P) and the potential Alpha energy concentration (PAEC) . Because this college has not a previous study using the passive and active method , so as the area around this college has seen the events of military , in addition to there are many students and lecturer and employers where the number of students reaches to 7000 student , measurement of the radon concentrations requires in places where people are located such as laboratories and classrooms and rooms for lectures for stand on radiological effects of this gas , in order to ensure the safety of everyone and know that the college buildings need to reduce the concentration of this gas and whether higher than the internationally accepted limit or less than it .

Chapter two

Chapter two

Literature review

(2 - 1) proceed :

Radionuclides traces can commonly be found in (water , soil , air and human bodies) , inhalation and ingestion of radionuclides take place every day . Radioactive materials had been existed on planet earth since its creation . As natural radioactivity are in soil thus , humans can be exposed by them internally and externally . Radioactive nuclides can be categorized into two distinguished families , either from "Cosmogenic" or "Terrestrial" origin . The most commonly ones are ^{238}U , ^{235}U and ^{232}Th and their following radioactive decay products and ^{40}K [9] .

(2 - 2) Radon Element :

In 1900 the German physicist "Friedrich Ernst Dron" first discovered Radon . Its atomic number is (86) and mass number is (222) in the periodic table [35] . The sources of Radon are ^{232}Th and ^{235}U and ^{238}U which are found in low concentration in rock and soil . Whole the gaseous Radon members of the three main chains are ruled by ^{235}U, ^{238}U, and ^{232}Th that are considered the emitters of radioactive alpha particles [36] . Radon is a rare natural element as it is found in gas form , noble and radioactive in its isotopes . Radon gas can gather in buildings , especially in closed regions, such as under roofs and basement . It is found in some spring waters and hot springs too [37] . But from other opinion , inhalation may be a problem to human's health . since Radon is noble gas, this guarantees that it cannot be frozen through chemical reactions [38] . ^{226}Ra whose half-life is (1600) years can be formed through Radon decay with ^{238}U during four intermediate cases in order to form ^{226}Ra , after that it decays to form ^{222}Rn gas which has half - life (3.82) days , which in turn gives sufficient time to be diffused through soil and into houses , where it then disintegrates in order that it can produce more radiologically active Radon breeds (Radon daughters) [37] .

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) estimated that the radon contributes with radioactive nuclides progeny about three quarters of its annual dose equivalent received by each human of Earth's natural resources and more than half of the total dose from all sources of natural and industrial sources and the vast proportion of returns These dose to inhaling these radionuclides with the air in homes and buildings in particular [39, 40] , as shown in Fig. (2-1) contribution of radon in radioactive dose .

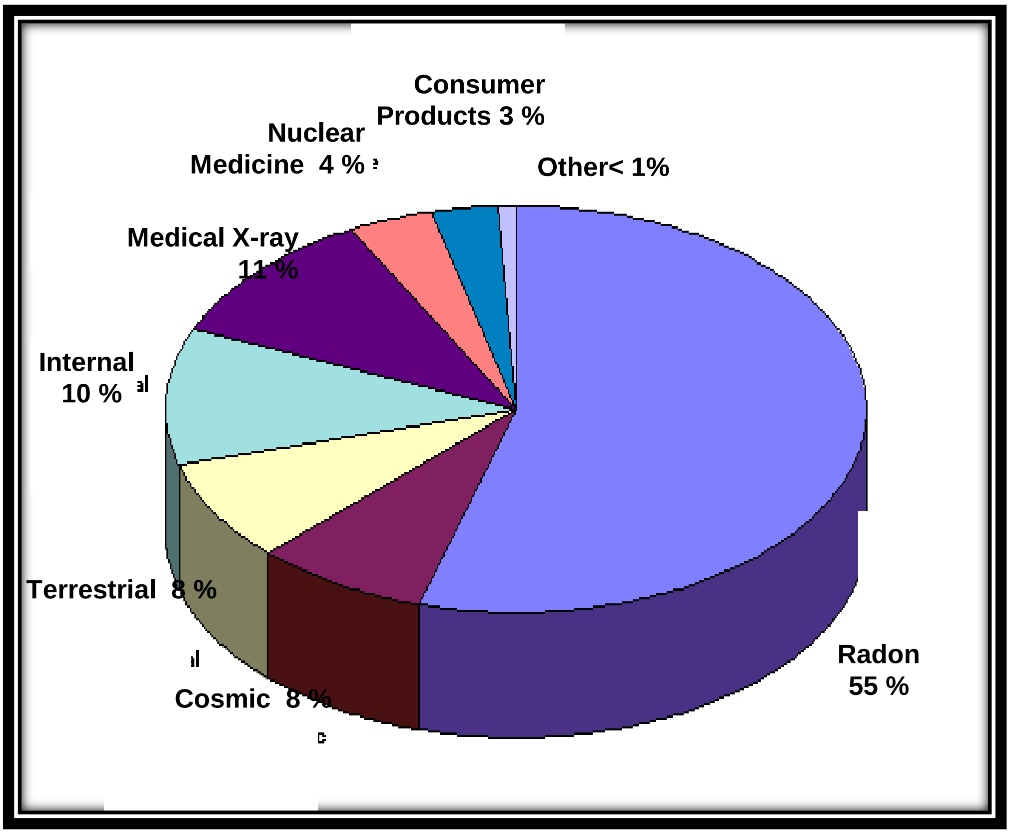


Fig. (2-1) contribution of radon in radioactive dose [35].

(2 - 3) Radon Isotopes :

An isotope can be defined as one or two of atoms with the same atomic number but different mass numbers [41] . Radon has three unstable isotopes , from three natural radioactive disintegration chains (U , Th and Ac).

Radon is ^{222}Rn isotope so as to be distinguished from other two natural isotopes which are called (Thoron ^{220}Rn and Actinon ^{219}Rn) because they respectively form in the Thorium and Actinium series . Radon gas, ^{222}Rn (alpha emitter whose half-life is 3.82 day) ; Thoron gas , ^{220}Rn (alpha emitter with 55.6 s half-life) ; and Actinon gas , ^{219}Rn (alpha emitter of has 3.96 s half-life) . Due to these features and dosimetric respects, specific cases might pose remarkable state of affairs where alpha dose measures taken from ^{219}Rn and ^{220}Rn could be the major interest , yet these situations are still unique [37] . In 1800 , "Owens R.B" and "Ernest Rutherford" were the first who recognized ^{220}Rn in 1899 . The ^{219}Rn gas was found in 1904 in an independent form by "Friedrich O . Giesel" and "Ander-Louis Debiernce" , so as to be related with Actinium [42] . Radon isotopes are [37] :

$$^{226}_{88}\text{Ra} \longrightarrow \, ^{222}_{86}\text{Rn} + \, ^{4}_{2}\text{He} + 4.60 \text{ MeV}$$
$$^{224}_{88}\text{Ra} \longrightarrow \, ^{220}_{86}\text{Rn} + \, ^{4}_{2}\text{He} + 5.69 \text{ MeV}$$
$$^{223}_{88}\text{Ra} \longrightarrow \, ^{219}_{86}\text{Rn} + \, ^{4}_{2}\text{He} + 5.50 \text{ MeV}$$

(2 - 4) Physical Properties :

Radon is a radionuclide that is happening in nature spontaneously . It has no colorless , odor , taste and also it is an unseen gas with density (9.72 gm/ liter) which is about seven times as air intense . Radon can condense to be a clear liquid with no color at its boiling point and then freeze to become yellow , then solid with orange red color . It can also dissolve moderately in water , as a result it can be absorbed by flowing waters through rock and sand that Radon in their contain . Its ability to solve depends on the water temperature , whenever the colder the temperature of water is cold the , Radon's solubility is great . Its solubility decreases fast with an increasing in temperature (510, 230 and 169 cm^3/kg at 0 C°, 20 C° and 30 C° respectively) , Radon is one of the noble gases and has 31 complete valence shell , high ionization energy , in important electric charge and is at room temperature [43] .

(2 - 5) Chemical Properties :

Radon is chemically considered an inert gas . Its chemical isotopes identification numbers are : (^{218}Rn, ^{219}Rn, ^{220}Rn, ^{222}Rn, ^{226}Rn , ^{229}Rn and ^{230}Rn) . As mentioned , it is inert in lots of chemical reactions, such as ignition due to its outer valence shell that owns eight electrons . This makes a steady smallest energy arrangement in which the outer electrons are tightly bound (1037 KJ/mol) and needed to another one electron from its shell [44] , as shown in table (2 - 1) [30,45] .

Table (2 - 1) : Physical and chemical properties of Radon [30,45] .

Characteristic	Radon
Molecular weight	(^{222}Rn) (^{220}Rn) (^{219}Rn)
Color	Colorless
Physical state	Gas at 0 C° and 760 mm Hg
Group , Period , Block	18 , 6 , p
Atomic mass	(222) g.mol^{-1}
Electron configuration	[Xe] 4*f*14 5*d*10 6*s*2 6*p*6
Electrons per shell	2,8,18,32,18,8
Melting point	202 ◦K (-71 C◦)
Boiling point	211.3 ◦K (-61.7 C◦)
Heat of fusion	3.247 KJ. mol^{-1}
Heat of vaporization	18.10 KJ. mol^{-1}
Heat capacity	(25 C◦) 20.786 J / (mol. ◦k)
Density at 20 C°	9.96 * 10^{-3} g/cm^{3}
Odor	Odorless
Solubility: water at 20 C°	230 cm^{3}/L
Organic solvents	Organic liquid , slightly soluble in alcohol
Flammability limits	Noble gas :is not flammable
^{222}Rn decay	Alpha particles : (99.924%) , Gamma rays (0.076%)

(2 - 6) Radon Sources :

The presence of ^{226}Ra in the ground of the facilities and in the building materials is considered the main radon source [46] . The outside air also has a role to Radon concentration indoors , through the air ventilation . Other Radon sources can be existed in tap-water , the domestic gas supplies are generally ^{229}Rn source . It was noticed that high indoor Radon levels are created from Radon that is in the underlying rocks and soils [47] .

(2 - 6 - 1) Soil :

In soil , Radium concentration in soil is about (10 - 50 Bq/kg) , but it may run to hundreds Bq/kg , with an average about (40 Bq/kg) UNSCEAR(1993) (United Nations Scientific Committee on the Effects of Atomic Radiation) [36] . The possibility of Radon entering from the ground mostly depends on ^{226}Ra activity level in the subsoil and its permeability with respect to air flow . Uranium or Phosphate mining processes can also contaminate the ground [48] . Thus , Radon can possibly enter in living areas in home through diffusion or pressure driven flow if the path ways between the soil and living spaces are suitable UNSCEAR(1993) [36] .

(2 - 6 - 2) Building Materials :

In general , building materials are considered the second main Radon indoors source . Radon exhaling from building materials depends on many factors ; for example , Radium concentration , the produced Radon fraction that is sent out from the material, the material porosity , the surface preparation . The Radium and Thorium model values content in building materials are about (40 Bq /kg) or lower . The activity concentrations in brick and concrete can be high if the raw materials are taken from sites with high levels of natural radioactivity [49] .

(2 - 6 - 3) Outdoor Air :

Outdoor air usually works as a diluting factor , because the low Radon concentration in it , however in some situations , in high apartments that are built with materials containing very low Radium , they can work as a real source . Concentration of Radon in outdoor air is generally caused by atmospheric pressure ; it displays an ideal oscillating time style with higher values at night periods . In continental areas and coastal regions , it was changed the mean value of outdoor Radon concentration to be from (5 - 10 Bq /m^3) for UNSCEAR (1993) [36] .

(2 - 6 - 4) Tap-Water :

Radon concentration in water could be high in wells that were drilled in rock if this water is utilized in the house hold , Radon will be partly released into the indoor air , bring out an increasing in Radon concentration. In tap-water that comes from deep wells , Radon concentrations may from (100 kBq/m^3 to 100 MBq/m^3) range [50] . Radon concentration in all waters types in the global average is presumed to be (10 kBq/m^3) . Because of high rates of Radon that enters from the ground , the indoor Radon concentration in these areas could be already be high UNSCEAR (1993) [36] .

(2 - 6 - 5) Domestic Gas:

Radon is found in high concentrations in natural gas that is used in cooking and heating , this gas is released on combustion . Since the Radon level in natural gas is about (1000Bq/m^3) therefore , this source cannot be valuable , and can be monitored at transportation and distribution points . UNSCEAR (1993) [36] .

(2 - 7) Radon Entry into Buildings or Inside Buildings :

It was noticed that through a lot of studies , there can be high average of Radon entering into buildings , the main factor in this case is advection [51,52] . This advection is operated by the pressure differential between the ground around the foundation and building shell that is made by the higher temperatures inside the shell , mechanical ventilation , and by wind blowing on the building . This pressure effectiveness is differential in the way of pulling in Radon loaded soil gas through the foundation and is significally depends on the effectiveness permeability of both the building foundation and the neighboring earth . Wind can also be the reason of decreasing the ratio of Radon concentrations that enters in soil surrounding the house [53] . In particular conditions atmospherically pressure changes can also be a vital mechanism of Radon entry [54] .

Due to the variations in the pressure differentials and permeability , the advection taking part varies highly from structure to structure , at about 35 in cold and temperate climates . The most remarkable participating to indoor Radon comes from the outside air and spreading from the ground [55,56] . Radon can move through soil pore voids and rocks breaks near the earth surface that usually get away into the atmosphere . When a house is existed , however the soil's air oftentimes flows toward its basis for three reasons [57] :

(1) The variation in air pressure between the ground and the house .

(2) The slots existence in the foundation of the house .

(3) The permeability increasing around the ground floor (if there is one) .

Radon proceed to the disturbed area and the gravel bottom underneath from the encirclement soil . The backfill material in the unbalanced zone is usually rocks and soil from the foundation location that can also create and release Radon . The pressure of the air in the ground round most homes is oftentimes better than the one inside . So , air leans to proceed from the unstable area and gravel bottom till enters the houses via lots reaching to the foundation of the house . These foundations own slots like cracks , entrances , crevice between the materials of the foundations , and exposed soil in creep spaces and basements . Most houses drag lower than 1% of their indoor air from the soil , while the rest arrive from outdoor air , which usually has low level of Radon . It can say that houses having low indoor air pressures, their foundations badly sealed , owning many entry points for soil air , yet , might drag about 20% of their indoor air from the soil . Even though the soil air has probably only average Radon levels , the levels inside the house could be still too high [57] .

(2 - 8) Health Effects :

For instance , cell might die , which is in low radiation levels . Damages that happened to the cell which is later on the reason of absolute cell dividing can lead finally to a tumor developing , although this can generally occur after a long time of cumin . The cell that subjected to reproduction and which is damaged , still survives but is possibly will transmit genetic deficiencies to the next generations [58] . The proportional biological harm caused by various sorts of radiation that in turn cause can cause a double fracture in (DNA) strands . The (DNA) strand that was broken is fast repaired (within hours) by cellular enzyme systems , the unbroken one works as a template . For instance, the electrons and positrons in a material depart better distance than α-particles of the same energy , and create nearly the same number of electron-ion pairs . Consequently , Alpha particles ionizations are more closely spaced , and it is more possibly that this particle will harm both strands of a (DNA) molecule , in comparing with Beta particle that has the same energy [57] . Uranium contamination most common ways are mainly through working , ingestion and inhalation which grow the risk of lung and bone cancer [59] .

Regarding risks from ^{222}Rn exposure , it does not mean the exposure to the Radon gas itself , but to its disintegration products . ^{218}Po is the first decay product with only three minutes half-life . This time is enough periods to enable the electrically charged Polonium atoms to bind themselves to microscopic airborne dust particles . When these small particles are inhalated , there will be an opportunity of sticking to the moist epithelial lining of the bronchi . due to the longer range and lower biological effects of gamma rays and beta particles , in comparing with the ones of alpha particles . Most dust particles that were deposited in the bronchi will finally be removed by mucus , but not in that fast so that it can hold the bronchial epithelium from being exposed to alpha particles from the of ^{218}Po and ^{214}Po disintegration . In spite of their inability to depart far , alpha particles that were made in the lungs are capable of damaging sensitive cells . This ionizing radiation passes through strongly and carrying radiation doses to lots types of lung cells . Alpha particles that penetrate the epithelial cells are able to deposit sufficient energy in the cells to kill or to transform it . The transformed cell will in turn interact with other agent and eventually will develop into a lung cancer [42, 60] .

(2 - 9) Radon Measurement Techniques:

(2 - 9 - 1) Active Techniques :

Active techniques can be defined as the technique that need power in order to be operated and are used normally for measuring the short term . Radon concentration can be measured by some of these active methods :

(2 - 9 - 1 - a) Ionization Chamber :

A chamber loaded with filtered radon is used in this technique . The air in the chamber will be ionized by alpha particles that are emitted from radon disintegration , its daughters as well . By applying voltage , the electrons and ions are drifted towards their particular electrodes . The generated current becomes the quantity measurement of radon atoms disintegration . After fulfilling equilibrium between radon and its decay products , the counting is begun and from the pulses number , Radon concentration can be gained [61] .

(2 - 9 - 1 - b) Lucas Cell (scintillation method) :

The tool contains glass vessel that is plated from inside with sparking material like (ZnS) , the bottom end surface not involve plating , which is clear and connected to a photo multiplier tube (PMT) . Its shape like a cylinder but able to become of any shape in depending on the type of MT that is used for counting the resulted gleam . As alpha particles have the ability to depart for only short distances in air before the stoppage , "Lucas" cell volume is often limited to a few hundred cm^3 . An air sample is pulled into the cell , and then Alpha particles are made from Radon disintegration causing sparks in ZnS , which are revealed by the photo multiplier tube and produce an electric pulse [61] . A lot of devices are available that used for measuring Radon depending on the mentioned technologies , for example , Rad - 7 , Alpha Guard and others [62] .

(2 - 9 - 2) Passive Technique :

In order to evaluate Radon exposure on very long time periods , passive techniques are more suitable for that purpose [63] .

Solid State Nuclear Track Detector :

This technique is suitable for long monitoring period measurement. Small piece of plastic or film attached in a container which is called "Solid State Nuclear Track Detector" (SSNTD). The work starts when Radon spreads into the container then, its disintegration products will emit alpha particles which in turn hit the detector making submicroscopic damage paths. After the measurement period is done, the detectors are put in a caustic solution that emerge the damaged tracks in order that they can be counted by using an automated counting system. The number of tracks per unit area is linked with Radon concentration in air [64].The most common member of the SSNTDs family used was CR-39 due to its well sensitivity, stability against different environmental factors, and high grade of optical visibility [63].

(2 - 10) History of Solid State Nuclear Track Detectors :

(SSNTDs) are the materials that will have change in one or more measurable parameters If they expose to a certain dose of radiation. When heavy ionizing nuclear particles pass through most isolated solids , will make narrow routes of strong damages on an atomic scale . By using Transmission Electron Microscopy (TEM) as indirect measure or by chemical etching as a direct measure and by utilizing an ordinary optical microscope , these "tracks" can be detected and made visible [65] . in 1958 "Young" was the first who worked on solid state nuclear track detectors , it was noticed that a number damage areas were detected after treating the bombarded crystal with chemical reagent of (LiF) crystal caught in connect with uranium foil irradiated with thermal neutrons [66] . It was seen that the pits number is a complete accordance with expected fission fragments which bounced 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 [67] , The firs observation on a Transmission Electron Microscope (TEM) was by them . After that , many of experiments were displayed in which the discovery of chemical etching technique and the optimum conditions of etching was done . These experiments made "Fleischer", "Price" and "Walker" extends the etching technique [66] . The previous work by those scientist was repeated and developed [67] , by presenting fission fragments and other greatly charged particles in many solids where they it was seen the tracks in direct way by utilizing an electron microscope [68] . It was shown that the fission fragments in mica can be discovered by etching with a chosen chemical agent of (HF) to monitor the covert tracks with an optical microscope [69] . This successful works of etchable tracks observation led "Fleischer , Price and Walker" to a fact that the nuclear track recording and etching are common phenomena in all dielectrics

[70] . New nuclear track detectors named as (SSNTDs) was appeared according to this fact . In this regard , the solid state nuclear track enrollment method brought the scientists' attention and led to the attendance of wide spread application of (SSNTDs) .

It has been used the solid state nuclear track detectors for nuclear track records since 1960 . A lot of these detectors can be divided into two groups, the first one is the inorganic detectors like (mica and glass) , the other one is the organic detectors such as(plastic) including (CR-39, CN-85, LR-115, Lexan). The detectors characteristic, for example : availability , easiness use and low cost resulted to its fast applications in different science and technology fields like , (nuclear and particle physics , nuclear dose rate measurement , cosmic) and others . Furthermore , these can also be used in other domain for example ; the fields of physics (geology , astronomy , plasma) , medicine , biology and radiography . The (SSNTDs) became a vital instrument in uranium exploration inspection as well as in Radon detection in the environment and so the (SSNTDs) importance have gone up and the largely use of its application was the purpose behind studying the tracks structure formation and the environmental parameters that effects on their properties [71] .

(2 - 11) Solid State Nuclear Track Detectors :

The (SSNTDs) are insulating materials that are able to measure concentration and locative isotopes distribution in assuming they can emit heavy charge particles , whether in direct way or resulting of particular nuclear reactions [72] . The particles' damage along their path is known as track (Latent track) , this might be visible using an normal optical microscope after etching with appropriate chemicals [73] . The damaged track detectors works in inverse comparing with what in scintillation , as , in this situation , the significance quantity is the energy that remained near the particle path , which locates the chemical track reactivity [72] .Two types of solid state nuclear track detectors can be found:-

A - Inorganic Detectors :

They are the compounds that have no Carbon and Hydrogen entrance in their structures , and produce an (Ionic Bond) between its atoms . In table (2 - 2) some inorganic detectors types and their chemical composition [74] .

Table (2 - 2) : Some kinds of inorganic detectors [74] .

No.	Detector	Chemical Composition
1	Zircon	$ZrSiO_4$
2	Quartz	SiO_2
3	Mica(Biotite) Mica (Muscovite)	$K(Mg,Fe)_3\ AlSi_3O_{10}\ (OH)_2$ $KaI_3Si_3O_{10}\ (OH)_2$
4	Fluorite	$CaF_{10}\ (OH)_2$
5	Soda Lime Glass	$23SiO_2:5Na_2O:5CaO:Al_2O_3$
6	Olivine	$MgFeSiO_4$
7	Calcite	$CaCO_3$

B - Organic Detectors :

They are the compounds that have Carbon and Hydrogen in their structures , and produce a (Covalent Bond) among their atoms , this (SSNTDs) type have a sensitivity greater than inorganic detectors due to the (C- C) , (C-H) bonds ,which can easily be broken after exposing to the radiation , organic detectors' power is analytically higher than inorganic detectors . Whereas the organic detectors threshold energy are less than in the inorganic ones [75] . As it can be seen in table (2 - 3) that demonstrates some types of organic detectors and their chemical composition [74] .

Table (2 - 3) : Some kinds of organic detectors [74] .

No.	Detectors	Chemical Composition

1	Polyester (HB Pa IT)	$C_{17}H_9O_2$
2	Polyimide	$C_{11}H_4O_4N_2$
3	Cellulose, Cellulose Nitrate Cellulose Triacetate	$C_6H_8O_9N_2$(CN) $C_3H_4O_2$ (CT)
4	Polycarbonate (Lexan , Makrofol)	$C_{16}H_{14}O_3$(PC)
5	Plexiglass	$C_5H_8O_2$
6	Polyallyldiglycol Carbonate	$C_{12}H_{18}O_7$(CR-39)

CR-39 Track Detector :

"Cartwright , Shirk and Price" at (1978) were the first who discovered the organic detector (CR-39) whose chemical composition is ($C_{12}H_{18}O_7$) and density of about (1.32 g.cm^{-3}) . This detector can be manufactured from a liquid monomer which is made by polymerizating in the form of highly cross linked into homo-polymers , copo-lymers (usually methyl metha-crylate and vinyl acetate) or intermediate products . The plastic (CR-39) has a particular name called polyally digycal carbonate and an be obtained by Pershore Moulding , Ltd , company England [76] . The character (CR-39) was set referring to the "Columbia Resins" [77] .

In Fig (2 - 2) , The monomer general structure is consisted of two ally groups (CH_2-CH=CH_2) :

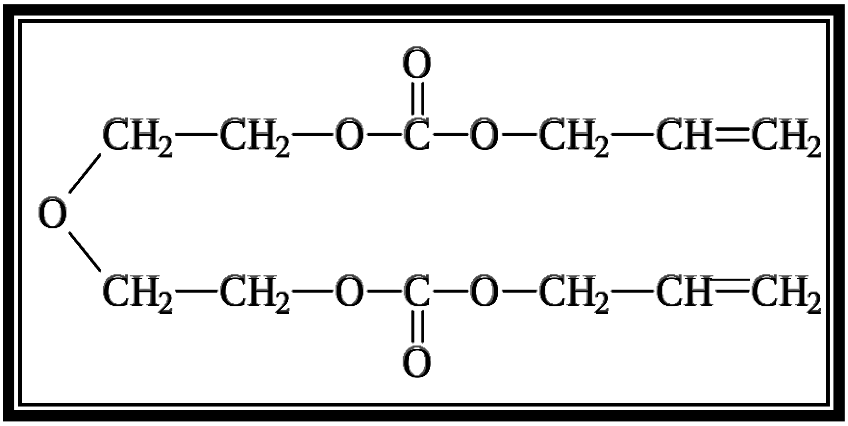


Fig (2 - 2) : CR-39 plastic chemical form [77] .

The (CR-39) detector has a high capacity to the tracks in comparing with other detectors and has some features , like :

1. Optically limpid .
2. Having high sensitivity to radiation .
3. Highly isotropic and homogeneous .
4. Not cross-linking after radiation damage has broken the chemical bonds .
5. It has a non-solvent chemical etchant .
6. Having a resistant nearly for all solvents and heating .

Using (CR-39) as a nuclear particle detector (plastic form) in the dosimetry fields , spectroscopy and environmental science , because of having high sensitivity . Most of its applications are proton , alpha and neutron dosimetry , radiography and for radon dosimetry and cosmic rays studies as well . [78] .

(2 - 12) RAD-7™Continuous Monitor of Radon (Continuous Monitors of Radon) :

The RAD-7 is a device , continuous monitor of radon . that means from measurement period can be observed varied level concentration of radon . that is very helpful, in other words can be investigate the effect factors on the concentration of radon with time . This factors is (changes of temperature , humidity , wind speeds and give insight in the room into air movements [79] . Fig. (2 - 3) shows the devices of RAD- 7.

Fig (2 - 3) : The RAD-7™ electronic continuous monitor of radon with a HP printer mounted for immediate printing of results [80].

many types of continuous monitors of radon are being sold today, ranging from invariant devices to portable detection devices such the RAD-7™. The device portability increases in versatility , cannot only take at a specific point one measurements, but it can also be used to identify entry points of radon into a room , via cracks or fissures . Continuous monitors of radon work on the principle of particle detection . There are many radionuclides in the decay of (^{238}U) series that decay via alpha radiation and can be easily detected using an a-detector .

There are three general types are used to measure radon of alpha particle detectors [81] . that Namely :

- Solid state alpha detectors.
- Ionization chambers.
- Scintillation cells.

RAD-7 Solid State Detector:

This device is designed to detect Radon using a solid state detector which detects alpha using detector of planted silicon ions. These ions that is semiconductor substances can transform alpha radiation from the radionuclide disintegration for example (^{218}Po or ^{214}Po) into an electrical signal. One benefit of this detector in radon or radon strain detection is that is the ability of electronically determining the energy related with the incoming alpha particle. Thus in this way, the particular radionuclide can be identified, (^{218}Po) with 6.00 MeV of alpha or ^{214}Po with 7.69 MeV energy. RAD-7 device has an inner sample cell about 0.7 liter and a hemispherical shape as in fig . (2 - 4) . This hemisphere is plated with an electrical conductor and a power supply of high voltage charges inside the conductor about (2000-2500) Volts [82] . This generates an electrical field everywhere in the cell . This field drives the positive charged particles over the detector in the cyclic-fill cell . A decayed ^{222}Rn atom within the cell departs behind a positive charged ^{218}Po , which is quickened on the detector and sticks to it . The half life of ^{218}Po nucleus is short and when it decays , will have a 50 percent opportunity to enter in the detector where it can produce an electrical signal [79] , and identify the alpha particle energy. Then the electrical signal that is recorded from the radionuclide disintegration is then enlarged, filtered and then classified due to its strength . Many various modes of RAD-7 operations permit to detect Radon from the ^{218}Po signal ; it is also able to determine Thoron (^{220}Rn) concentration from the (^{216}Po) signal . The (^{218}Po) and (^{216}Po) signals grow from (6.00 and 6.78 MeV) alpha disintegration respectively, alpha energies from the other decay products can be neglected. From ^{232}Th disintegration chains , ^{220}Rn is formed . The next nuclei from other disintegrations include beta emitters . The RAD-7 can determine Radon concentrations through measuring the radioactivity of disintegration products [83] . This detector makes a spectrum and this will be clarify later , this spectrum has very important quality is the non-attendance of (5.49 MeV) peak , since ^{222}Rn decays in the air and in the detector cell , not on the surface or close to the detector . The desiccant functions in Fig. (2 - 4) is to absorb any humidity that was pumped into the tube so as to keep the air relatively dry.

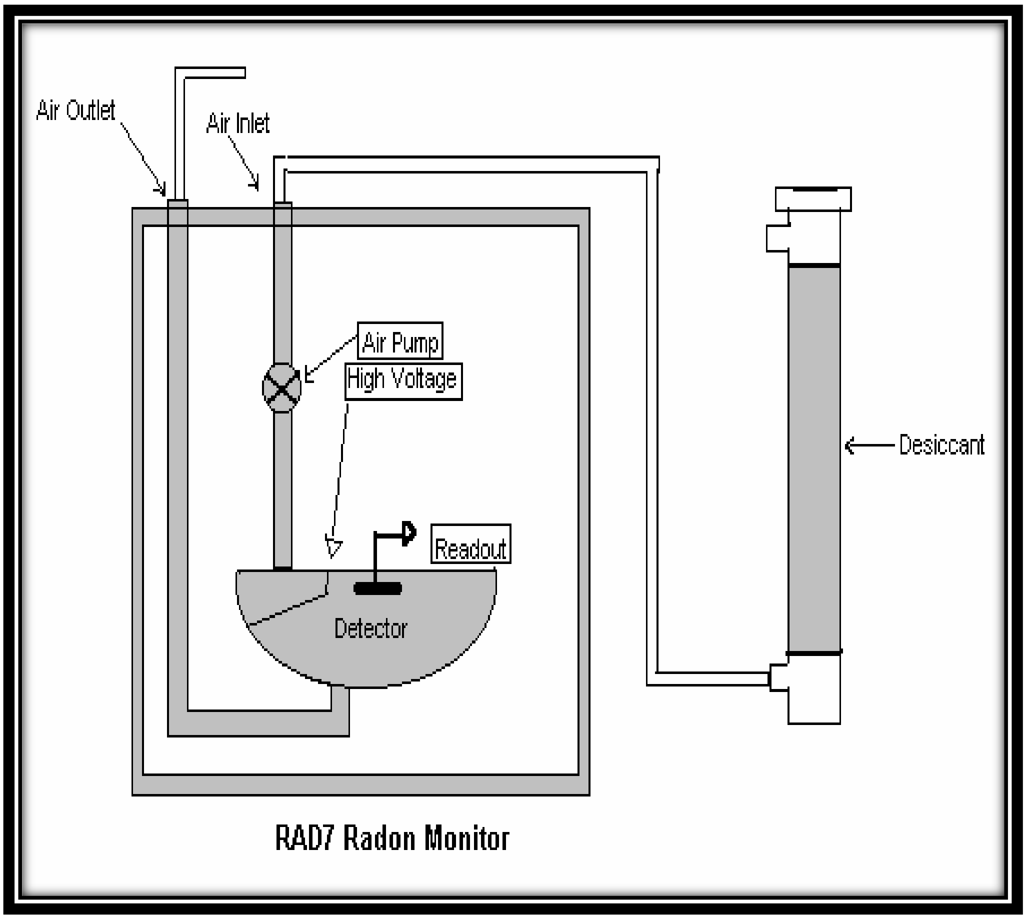


Fig (2 - 4) : RAD-7 schematic Special affirmation is put on the hemispherical shaped periodic-fill cell , the high voltage power supply inside the detector as well as the air pump that samples the air to be analyzed [83] .

However , the radon could also be adsorbed on the desiccant grain , this can be a problem at the very high Radon concentrations , in this case the RAD-7 must be purified [80, 83] .

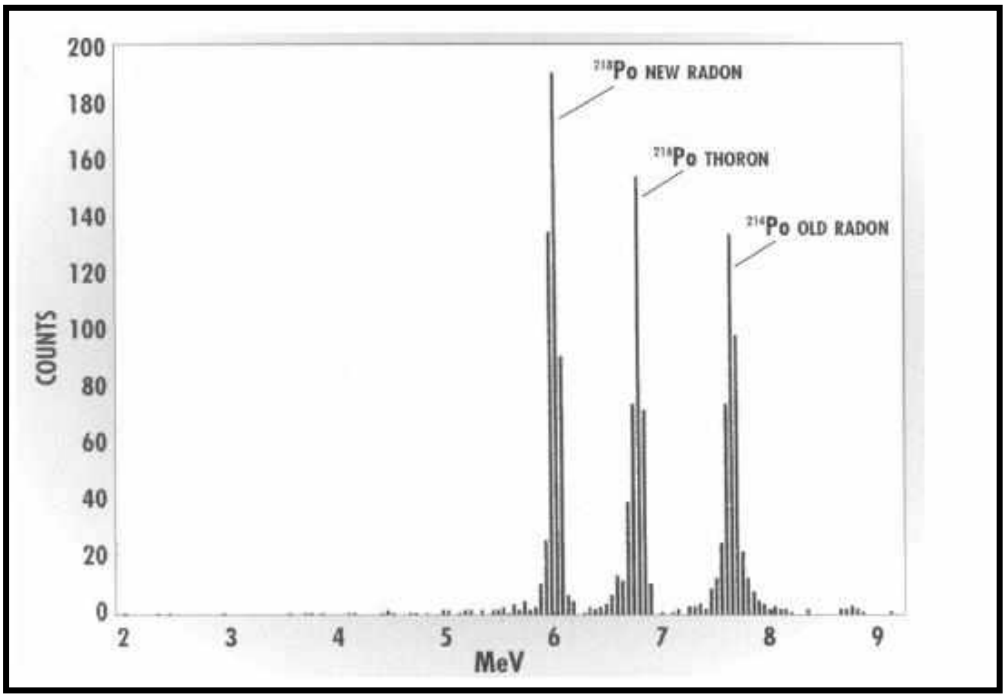


Fig (2 - 5) : A perfect high-resolution alpha energy spectrum [27] .

The RAD-7A can print the spectrum after the running that has windows A - D . This is explained in Fig. (2 - 5) Windows E - H make up the complex window O . Window O is the total of all the counts appear from energy of windows E – H domains . The various windows contain :

1- Window A: Total counts from ^{218}Po decay
2- Window B: Total counts from ^{216}Po decay
3- Window C: Total counts from ^{214}Po decay
4- Window D: Total counts from ^{212}Po decay

Window A is used to derive the radon concentration , while windows B and D account for the ^{220}Th . The counts from the composite window are due to noise in the system [27, 84] .

(2 - 13) Background and Associated Problems :

It is important to determine the background detector reading , since the reading during detecting may not give true reading (false alarm) if unknowing the detector background correctly . Despite the RAD-7 manufacture company claims that the RAD-7 does not affected by background , it also warns of several possible problems [79] . Radon and Thoron disintegration products have possible role to affect the background in the RAD-7. These elements can cause problems in the process of measuring the low radon concentration soon after a high reading . This issue can be partially solved as the detector is able to recognize their energies . Another worthy problem to mention is ^{210}Pb which is a determining factor in many tools because of its (long half-life) ; however , this is not a problem with the RAD-7, as ^{210}Pb is a beta-emitter . ^{210}Po (alpha-emitter) is one of the radionuclides that follows ^{210}Pb disintegration . In the final result , this can be neglected in the calculation due to its energy variation in the spectrum . There might be another problem noticed in the data analysis could involve RAD-7 setting up for radon soil-gas measurements. Air may leak into the setup despite of some cautions that were taken to reduce it . The manufacturing company advises to use Teflon™ tape when collecting the device [84] . It was also noticed after letting the probe into the ground so as to measure the radon concentration in the soil , same problem appeared . The probe head diameter is a bit bigger than the probe shaft , so when inserting , a little space is remains on the shaft side . That can be reduced through flipping down the soil into the open space that surrounding the shaft in order to stop the soil-gas from becoming diluted as air may be sucked down outside of the shaft [27, 83] .

(2 - 14) Purging the System :

After implementing the measuring on water , soil or air , RAD-7 is inner sample cell will be continuing to hold the measured radon . Presence this radon when starting a new measurement , will mistakenly affect the following measurement , this has a concerning when the radon concentration of the last measurement was high relating to the next measurement , In order to prepare the next water measurement, It has to take out as completely as possible the radon from the RAD-7 with its air parts, this includes , the aerator head , tubes , and desiccant . This method is called as " system purification." To clean the system, there must be a radon-free source air or inert gas . RAD-7 is put into a purification cycle using "Test Purge" allowing the RAD-7 pump to flush the cleaning air across the entire system at least for ten minutes . After taking the measurement of very high radon concentrations , it should clean the system for 20 minutes . A purging time must be thirty minutes in order to remove almost all the radon after measuring a sample at (100,000 $pCi.L^{-1}$) [83] .

<u>(2 - 15) The RAD-7 detector efficiency:</u>

It is very provisional for the chamber moisture . High humidity can cause a smaller count average . The purpose behind this dependency is that the ionized particle can reach a small range at high humidity due to the Bethe-Bloch-Ionization which is depended on particles density . Assuming the work is at high humidity, the particles density will become great and consequently the range reduces. The humidity in the chamber has to be less than 10% . During each measurement, the sample air should be dried out with a cold trap [83, 84] .

Chapter three

Chapter three

Materials and methods

(3 - 1) proceed :

This chapter contains the experimental part of this work , where describes devices and materials used in this research in addition to calibration of (CR-39) detector passive method for measure of radon concentration in air .

(3 - 2) Description of Study Area :

The study was measure indoor radon concentrations in the air of College of Education for Pure Sciences / Ibn Al - Haitham buildings University of Baghdad , because there is no other previous study to determine radon concentrations . The concentration of radon gas for 49 samples of air collected at different places (indoors of old buildings and indoors of new buildings) and at different relative humidity was measured by using CR-39 which consider passive method and using RAD-7 technique which is active method . The samples were selected in the places where the staffs and students attending for long time in addition to places that does not have ventilation . The detectors CR-39 were used to get radon concentration by counting the number of tracks which are on the CR-39 detector that exposed to air for (30) days . The (Rad-7) monitor was used to get the radon concentration directly . The detectors were distributed in the college were inserted in the tables (3 - 1) (3 - 2) (3 - 3) (3 - 4) (3 - 5) (3 - 6) (3 - 7) (3 - 8) . Fig (3 - 1) The map of College of Education for Pure Science Ibn Al - Haitham . Fig (3 - 2) scheme of the service laboratory in College of Education for Pure Science Ibn Al - Haitham .

Table (3 - 1) : Selected rooms in deanship building .

Deanship			
Sample number	**Sample code**	**Room name**	**Sample location**
1	**D1**	**Planning**	**Basement**
2	**D2**	**Engineering**	**Basement**
3	**D3**	**Graduate studies**	**Ground floor**
4	**D4**	**Scientific associate**	**Ground floor**
5	**D5**	**Student Affairs**	**Ground floor**

Table (3 - 2) : Selected rooms in department of physics .

Department of physics			
Sample number	**Sample code**	**Room name**	**Sample location**
6	**PH1**	**Secretarial store**	**First floor**
7	**PH2**	**Lecturer room**	**First floor**
8	**PH3**	**Nuclear lab**	**First floor**
9	**PH4**	**Hardware lab**	**First floor**

Table (3 - 3) : Selected rooms in department of chemistry building .

Department of chemistry			
Sample number	**Sample code**	**Room name**	**Sample location**
10	**CH1**	**Life lab**	**Ground floor**
11	**CH2**	**Lecturer room**	**Ground floor**
12	**CH3**	**Diagnostics lab**	**Ground floor**
13	**CH4**	**Secretariat of chemistry department**	**Ground floor**
14	**CH5**	**Corridor of secretarial department**	**Ground floor**
15	**CH6**	**General Chemistry Lab**	**Ground floor**
16	**CH7**	**Lecturer room**	**First floor**

Table (3 - 4) : Selected rooms in department of biology building .

department of biology			
Sample number	**Sample code**	**Room name**	**Sample location**
17	BIO1	Primary environment lab	Ground floor
18	BIO2	Lecturer room	Ground floor
19	BIO3	Advanced environment lab	Ground floor
20	BIO4	Lecturer room	Ground floor

Table (3 - 5) : Selected rooms in department of psychology and library building .

Department of psychology and library			
Sample number	**Sample code**	**Room name**	**Sample location**
21	PS1	Lecturer room	Ground floor
22	PS2	Lecturer room	Ground floor
23	B1	Book unit	First floor
24	B2	Thesis unit	First floor
25	B3	IC3	First floor
26	B4	Lecturer room	First floor
27	B5	Lecturer room	First floor

Table (3 - 6) : Selected rooms in department of mathematic building .

Department of mathematic			
Sample number	**Sample code**	**Room name**	**Sample location**
28	M1	Lecturer room	Ground floor
29	M2	Lecturer room	Ground floor
30	M3	Lecturer room	Ground floor
31	M4	Lecturer room	Ground floor
32	M5	Computer lab	First floor

Table (3 - 7) : Selected rooms in the service laboratory building .

The service laboratory			
Sample number	**Sample code**	**Room name**	**Sample location**
33	L1	Advanced chemist	Ground floor
34	L2	Lecturer room	Ground floor
35	L3	HPLC	Ground floor
36	L4	DSC	First floor
37	L5	Robot lab	First floor
38	L6	Advanced physics	First floor

Table (3 - 8) : Selected rooms in the random buildings .

Random buildings			
Sample number	**Sample code**	**Room name**	**Sample location**
39	F1	Free education left room	Basement
40	F2	Free education right room	Basement
41	C1	autoimmune disease lab	Ground floor
42	C2	physicist lab	Ground floor
43	E1	Online small room	Ground floor
44	E2	Online big room	Ground floor
45	H	Health	Ground floor
46	A	Artistic activity	Ground floor
47	CH	Computer lab	Ground floor
48	R1	Outgoing and incoming	Ground floor
49	R2	Morning study	First floor

Fig (3 - 1) : The map of College of Education for Pure Science Ibn Al - Haitham .

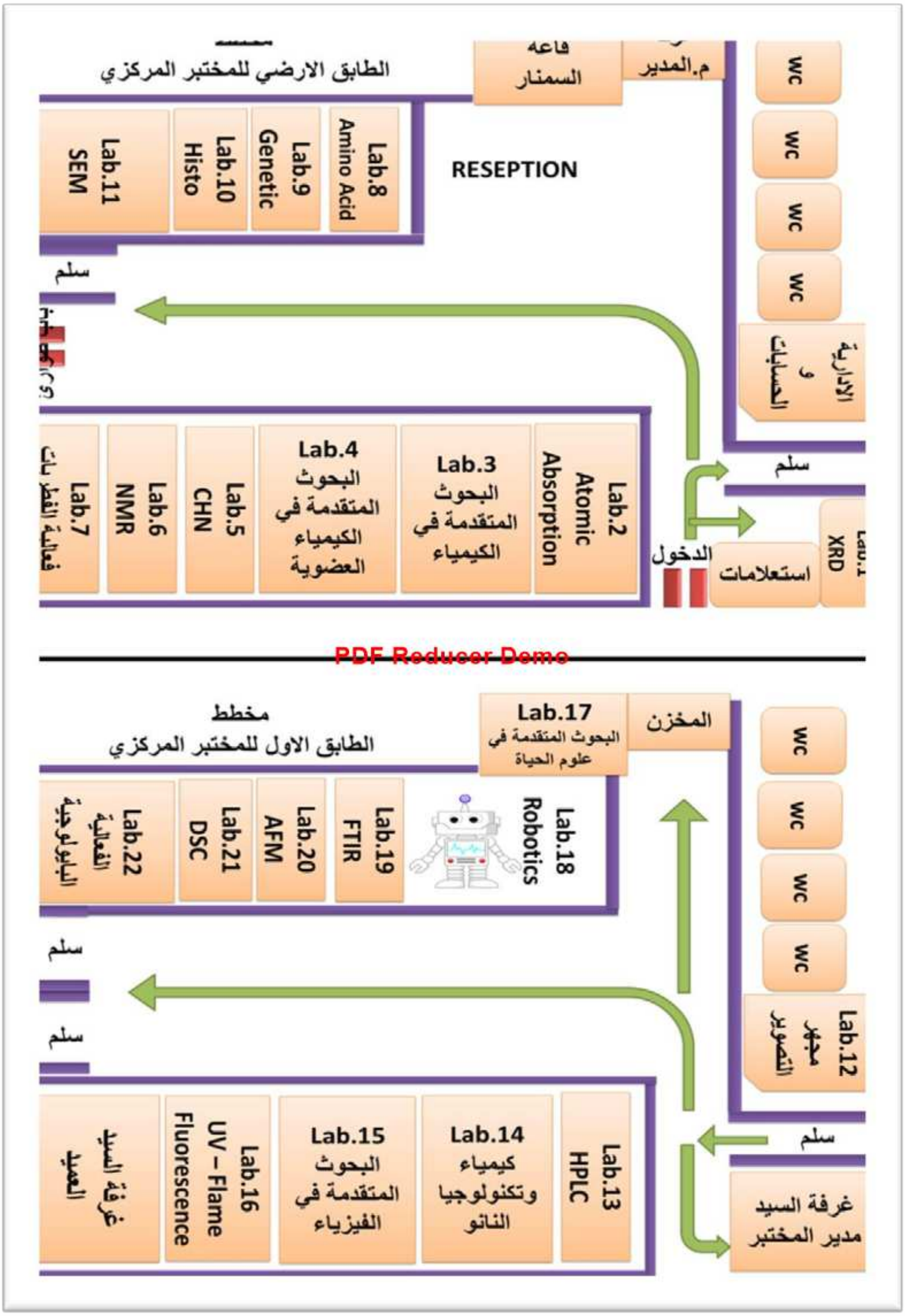


Fig (3 - 2) : Scheme of the service laboratory in College of Education for Pure Science Ibn Al - Haitham .

(3 - 3) Devices and materials used :

1 - CR-39 detector :

Solid state nuclear track detectors type CR-39 detector with a thickness of (250 μm) and the approximate area (1 cm^2) were used in this work . The detectors are covered from both sides with plastic and this plastic is removed when the detector is used to prevent detector from radiation background and it there distortions that occur as a result of exposure to external stresses as shown in Fig (3 - 3) . The detectors were placed appropriately within the building or out side it to be exposed to air for a specific time period for (30) days , then they were lifted from the measurement location to observe the alpha particles tracks resulting from decay of radon on these plastic detectors , they leave unseen traces , these detectors were etched by chemical processing by sodium hydroxide solution with a specific concentration , and heat for a certain period and show the tracks of alpha particles and it becomes possible to enumerate by using the microscope . Where (100) detectors were distributed in College of Education , in every room placed two detector except one room placed inside it four detectors . The detectors were placed within pieces of sponge and on high (160cm) for (30) days . After it has been collected for the configured to chemical etching process afterward previewed microscopically to count number of track for Alpha per unit area and calculate concentration of radon after the comparison process with standard source .

2 - Sensitive Balance :

The balance was an English - made stanlon type (462al) which was a very sensitive used to calculate the weight of sodium hydroxide granules **(NaOH)** . As shown in Fig (3 - 4) .

3 - Etching Solution :

Sodium hydroxide granules **(NaOH)** which were used as white small spherical discs with 97% purity are dissolved in distilled water in a volumetric flask , it capacity (1/4 liter) for purpose chemical etching detectors after thermal equilibrium solution . As shown in Fig (3 - 5) .

4 - water bath :

Water bath from type (Memmert) German-made used for heat sodium hydroxide solution **(NaOH)** . The bath contains a thermometer to measure the temperature so that the temperatures are range temperature (100 - 0) C° and thoroughly, also contains a circular disk installed on this disk temperatures by rotation this disk on the appropriate degree of temperature , the temperature was suitable for etching process of CR-39 detectors (60) C° .

The etching process of CR-39 detectors comment by copper wire inside the flask glass which that contains sodium hydroxide solution and put that flask glass in water bath and this should be flask glass tightly closed not to evaporates solution and change it focus during the process of etching , after etching process washing detectors in distilled water and dried and then start reading on the microscope. As shown in Fig (3 - 6) .

5 - Optical Microscope :

Microscope type (Novel) Chinese-made used for counting the tracks , the microscope contains four basics lenses and power zoom for these lenses (10X, 20X, 40X, 100X) , also contains the binoculars lenses and power zoom (10X) . As shown in Fig (3 - 7) .

To determine the power zoom to the microscope using the relation From :

Power zoom = (Zoom lens eyepiece) * (Zoom lens basics)

Fig (3 - 3) : CR-39 detector .

Fig (3 - 4) : Sensitive Balance .

Fig (3 - 5) : Sodium hydroxide (NaOH) .

Fig (3 - 6) : water bath .

Fig (3 - 7) : Optical Microscope .

6 - Rad- 7 DURRIDGE :

RAD-7 DURRIDGE made in United States (USA) , which is the direct or effective method to measure concentration of radon , radon is measured by this device in the air, water and soil , which represent the direct method was used in this study . The device connecting to dried tube which it a plastic cylinder contains inside it calcium sulfate **($CaSo_4$)** .

The dried tube has two holes one at the top to inter the air and other in the bottom for the exit dried air which comes to inlet of the device , in the case of drying linking hole top in other channel device (outlet) as shown in Fig (3 - 8) .

The device also contains four buttons to control and also contains a printer separated working on infrared button **(ON-OFF)** when finished cycle session start print at work as shown in Fig (3 - 9). It's important to be channels **(outlet)** and **(inlet)** closed in a plastic pipe in the device because of open one of the two channels become , the device cannot measure radon were the room filled by humidity.

Rad-7 device watching control continue so have been were selected measurable time as per day there are 48 cycle and each half hour session , the duration of measurement half an hour in the each room and every time measurement detector compartment were drying up humidity to less than 6% , about half an hour after the printer begins Print data from concentration of radon , standard deviation , measurement time , humidity and temperature as well as the measurement date . Features of this device is capable of identifying serious energy indignity Alpha in electronic form as well as it is possible to distinguish between isotopes of polonium (^{218}Po) gross alpha card 6.00 MeV and (^{214}Po) 7.69 MeV alpha particle card… Etc and between the radon and Thoron [85] . This device was used to compare the direct method and indirect method .

Fig (3 - 8) : Rad - 7 in purging state .

Fig (3 - 9) : Rad -7 in work state .

(3 - 4) Etching solution preparation :

Sodium hydroxide solution **(NaOH)** that is a strong alkaline as published studies confirmed , that solution has the ability to interact with solid state nuclear track detectors (polymers) plastic , in this study etching solution **(NaOH)** was prepared with normality of (6.25 mole/liter) we can get it by melt granulated sodium hydroxide **(NaOH)** with weight (62.5 gm) in (1/4 liter) of distilled water using volumetric flask we added distilled water after thermal equilibrium of solution with surrounding to complete (1/4 liter) .

Weight of Sodium hydroxide granules weight was calculated using the following equation [86] :

$$W(gm) = N * V_w * W_{eq} \qquad ..... (3 - 1)$$

Where V_w is the distilled water volume which was (1/4 liter) .

N is required Normality (6.25 mole/liter) .

Weq The molecular weight of (NaOH) which was calculated by following equation :

$$\mathbf{W_{eq} = m(Na) + m(O) + m(H)} \quad \text{..... (3 - 2)}$$

where m is represent mass of elements

W_{eq} = 22.98977 + 15.9994 + 1.00794 = 39.99711 gm/mole

So (W(gm)) = 6.25 mole/liter *0.25 liter *40 gm/mole = 62.5(gm)

(3 - 5) Chemical Etching :

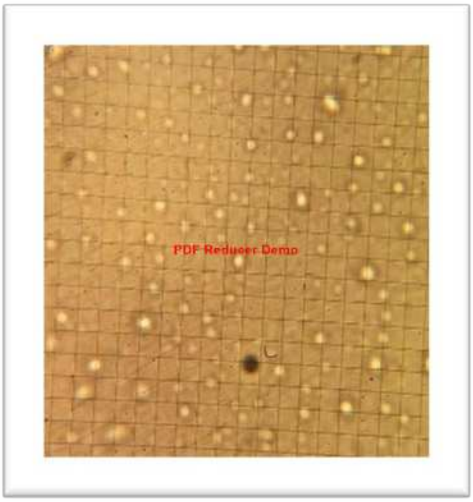
After exposure time for (30) days , these detectors taken to chemical etching using sodium hydroxide solution **(NaOH)** with normality of (6.25 mole/liter) by put this etching solution in glass flask into the water bath which heated (60) °C , then CR-39 detector was hung in inside the glass flask carafe conical thread in water bath with copper wire for four hours , as shown in Fig (3 - 10) . With continuing shake the solution to prevent deposition solution and consider closing stopper glass flask was tightly closed to prevent evaporation of the solution that change in concentration during the chemical etching process . After chemical etching the detectors were washed with distilled water then were dried .

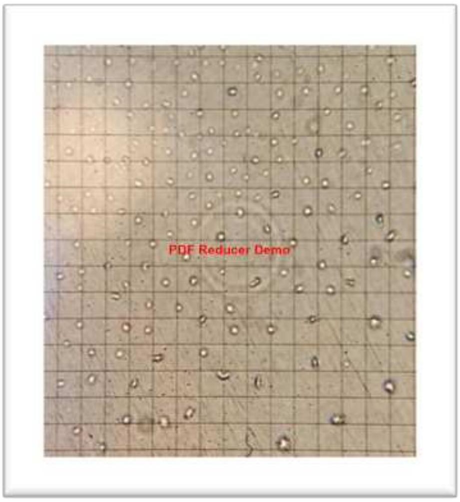
Fig (3 - 10) : Chemical etching of CR-39 detector .

(3 - 6) Microscopic Viewing :

After the process chemical etching , the detectors were put under microscope to calculated the number of tracks by choosing appropriate zoom of (400 X) . The track density was calculated by taken 10 attempts (deferent views) , then the average and standard deviation were calculated by dividing the average number of tracks on the area that obtain by special lens , compute the area of the square and divides the number of track (N_{ave}) of the sample (x) on the calculated area unit (A) to obtain the density of tracks ρ_x (track N.of/mm^2) [32] .

$$\rho_x = \frac{N_{ave}}{A} \quad \text{..... (3 - 3)}$$





(A) **(B)**

Fig (3 - 11) : The photograph of tracks corresponding to one location in sample (D2) .

(3 -7) Calibration of CR-39 Detector :

The CR -39 detector was Calibrated by obtain the relation between the exposure of radon and the track density , in the present work standard source (^{226}Ra) was used with activity of (5μCi) , the manufactured at (8-7-1977) , the standard source and (CR-39) detectors were put into cylindrical container with volume of (0.01825 m^3) as shown in Fig (3 - 12) .The activity of standard source was corrected to (A = 181781.92 Bq) at (17-1-2018) using the following equation [87] :

$$\mathbf{A_t = A_o\, e^{-\lambda t}} \qquad \text{..... (3 - 4)}$$

Where :

(λ) : is the decay constant ($\lambda = 0.693/ t_{1/2}$) .

A_t: is the activity at time t of the sample .

A_o: is the initial activity at time t=0 .

$t_{1/2}$: is the half life of ^{226}Ra

$t_{1/2}$ (^{226}Ra) =1600 y.

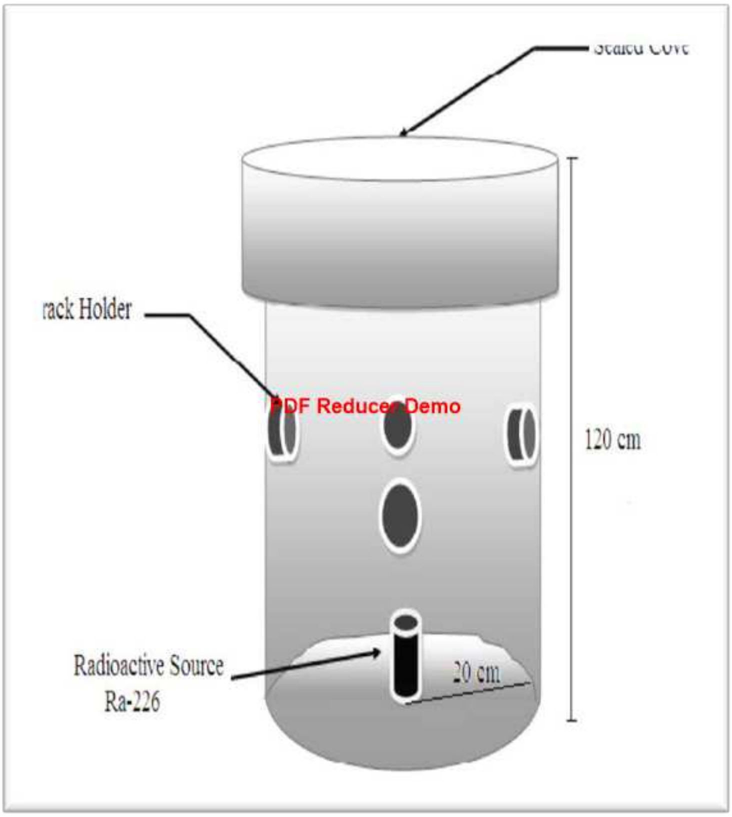


Fig (3 - 12) : The calibration for radon gas container in dwellings [31] .

The activity of radon (A_{radon}) can be calculated at any time inside container by using the following equation [88] :

$$\mathbf{A_{Rn} = A_{Ra}(1 - Exp(-\lambda_{Rn} t))} \qquad \text{..... (3 - 5)}$$

Where $\mathbf{A_{Rn}}$ is the activity of ^{222}Rn and $\mathbf{A_{Ra}}$ is the activity of ^{226}Ra which A_{Ra}=181781.92Bq as a standard source.

The half life of radon $t_{1/2}$(^{222}Rn) =3.8253 day.

λ_{Rn} is the decay constant of ^{222}Rn=0.1812 day^{-1}.

t is the time of exposure in day

The exposure time of detectors was different times (0.0416, 0.0833, 0.125, and 0.1666 day), the exposure to radon was calculated using the following equation [88] :

$$E_s\,(Bq.day/m^3) = [A_{Rn}\,(Bq) / V\,(m^3)] * t\,(day) \quad ..... (3-6)$$

where:

E_s is the exposure of Radon gas in standard source (i.e. concentration).

A_{Rn} is the radon (^{222}Rn) radioactivity calculated by equation (3 - 5) .

V : is the volume of container in m^3; t is the exposure time in day.

The exposure to radon calculated for deferent exposure time (0.0416, 0.0833, 0.125, and 0.1666 day) as show in fig (3 – 11) then slope represent the factor K which was (0.2568) [89 ,90] .

Fig (3 - 11) shows the relation between the exposure of Radon (E_s) and the density of track (ρ_s) .

$$Slope= \rho_s / E_s \quad ..... (3-7)$$

where:

ρ_s is the density of track of standard source (tracks/mm^2).

E_s is the exposure of Radon of standard source (Bq/m^3).days

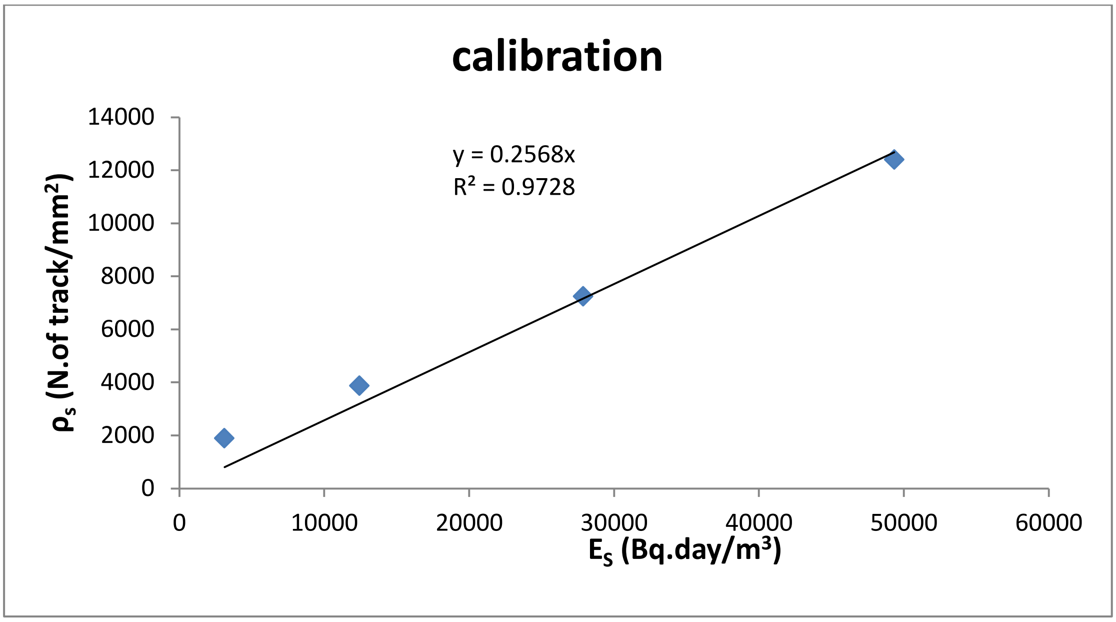


Fig (3 - 13) : The relation between the exposure of Radon (E_s) and the track density (ρ_s) .

The concentration of radon was determined by using the following equation [91,92] :

$$C_{Rn}\,(Bq/m^3) = 1/slop^* \, (\rho_x/t) \qquad ..... (3 - 8)$$

since.

1/slop= E_s (Bq.d/m^3) /ρ_s (track/mm^2)

where :

$$slope = \rho_s\,(track/mm^2)\,/\,E_s\,(Bq.d/m^3) \qquad ..... (3 - 9)$$

Where slope is called the calibration factor in terms of (track. m^3 / Bq.d. mm^2) .

(3- 8) Determination of some radon parameters in dwellings:

1. The annual effective dose (AED) in terms of (mSv/y) units was obtained using the following equation [93] :

$$\mathbf{AED\ (m\ Sv/y)\ = C_{Rn} * F * H * T * D} \quad \text{….. (3 - 9)}$$

Where (F) is the equilibrium factor and it is equal to (0.4) , (H) is the occupancy factor which is equal to (0.8) [41], (T) is the time in hours in one year, (T=8760 h/y), and (D) is the dose conversion factor which is equal to [$9*10^{-6}$ (m Sv) / ($Bq.h.m^{-3}$)] [41].

2. The lung cancer cases per year per million person (CPPP), was obtained using the following equation [94,95]:

$$\mathbf{(CPPP) = AED * (18*10^{-6}\ mSv^{-1}.y)} \quad \text{….. (3 - 10)}$$

3. The Potential Alpha Energy Concentration (PAEC) in terms of (WL) units was obtained using the following equation [94,96] :

$$\mathbf{PAEC\ (WL) = F * C_{Rn} / 3700} \quad \text{….. (3 - 11)}$$

Where (F) is the equilibrium factor between radon and its progeny and it is equal to (0.4) as suggested by (UNSCEAR, 2000) [41] and (C_{Rn}) is the radon concentration in ($Bq.m^{-3}$) units .

4. Exposure to radon progeny (E_P) (sometime it is called annual effective dose equivalent) is then related to the radon concentration (C_{Rn}) by following following equation [97] :

$$\mathbf{E_P\ (WLM\ Y^{-1}) = 8760 * n * F * C_{Rn} / 170 * 3700} \quad \text{….. (3 - 12)}$$

where (C_{Rn}) is the radon concentration in $Bq.m^{-3}$ units , (n) is the fraction of time spent indoors which is equal to (0.8) , (8760) is the number of hours per year , (170) is the number of hours per working month and (F) is the equilibrium factor and it is equal to (0.4) [41] .

Chapter four

Chapter four

Results and discussion

(4 - 1) proceed :

In this chapter, we present the results obtained from the study indoor Radon concentration in air of College of Education for Pure Sciences / Ibn Al - Haitham buildings using CR-39 detector for 30 days and using Rad-7 monitor for half hour , the chapter contains conclusions and future studies within of the results of this study .

(4 - 2) Results :

After the distribution of solid state nuclear track detectors type CR-39 that exposure for (30) days , mentioned in chapter three tables have been collecting detectors , make chemical etching process by using solution sodium hydroxide **(NaOH)** and microscopic preview , afterwards to get the track density per unit area and then measure radon concentration by comparison with the standard sources (^{226}Ra) using the relation between the track density and exposure to radon from the standard source , where the relation was linear as in Fig. (3 - 3) and from slope chart radon concentrations were calculated for samples of unknown use relations (3 - 10) (3 - 11) so that the inserted radon concentration as in tables (4 - 1) (4 - 2) (4 - 3) (4 - 4) (4 - 5) (4 - 6) (4 - 7) :

(4 - 2 - 1) The Radon concentrations Results using CR-39 detector :

1- Deanship and department of physics building

Result in table (4 - 1) indoor radon concentrations in air and track density for deanship and physics buildings , where was lowest value of radon concentration (35.01±7.88) Bq/m^3 for sample PH2 in physics building in the first floor , either the highest value of radon concentration (177.458±29.129) Bq/m^3 for sample D2 in basement in deanship building .

2 - Department of chemistry building .

Results in table (4 - 2) indoor radon concentrations in air and track density for chemistry building , where was the lowest value of radon concentration (95.397±12.037)Bq/m^3 for sample CH1 in the ground floor , either the highest value of radon concentration (170.974±28.972) Bq/m^3 for sample CH6 in the ground floor .

3 - Department of biology building .

Results in table (4 - 3) indoor radon concentrations in air and track density for biology building , where was lowest value of radon concentration (101.881±17.812) Bq/m^3 for sample BIO1 in the ground floor , but the highest value of radon concentration (202.465±37.374) Bq/m^3 for sample BIO2 in the ground floor .

4 - Department of psychology and library building .

Results in table (4 - 4) indoor radon concentrations in air and track density for psychology and library building , where was lowest value of radon concentration (65.944±10.632) Bq/m^3 for sample B1 in the first floor in the library and the highest value of radon concentration is (142.262±22.511) Bq/m^3 for sample B3 in the first floor in the library .

5 - Department of mathematics building

Results in table (4 - 5) indoor radon concentrations in air and track density for mathematics building , where was lowest value of radon concentration (75.577±11.33) Bq/m^3 for sample M4 in the ground floor , but the highest value of radon concentration (149±25.912) Bq/m^3 for sample M3 in the ground floor .

6 - The service laboratory building .

Results in table (4 - 6) indoor radon concentrations in air and track density for Laboratory the service building , where was lowest value of radon concentration (34.639±6.074) Bq/m^3 for sample L6 in the first floor , but the highest value of radon concentration (159.±25.912) Bq/m^3 for sample L1 in the ground floor .

7 - The random buildings of college .

Results in table (4 - 7) indoor radon concentrations in air and track density for dispersedly building , where the lowest value of radon concentration was (17.412±2.192) Bq/m^3 for sample C1 in the ground floor in the compound building , but the highest value of radon concentration was (445.868±81.966) Bq/m^3 for sample F1 in the basement in the free education .

Table (4 - 1) : Indoor radon concentrations and track density using CR-39 in deanship and department of physics buildings .

Sample code	Sample location	Track density (N.of track/mm^2)	Radon concentration (Bq/m^3)
D1	Basement	1067.143	138.372±20.457
D2	Basement	1368.571	177.458±29.129
D3	Ground floor	784.285	101.695±14.252
D4	Ground floor	1172.857	152.08±30.104
D5	Ground floor	660	85.58±14.041
PH1	First floor	308.571	40.011±5.413
PH2	First floor	270	35.01±7.88
PH3	First floor	715.714	92.804±14.267
PH4	First floor	471.429	61.128±13.642

Table (4 - 2) : Indoor radon concentrations and track density using CR-39 in department of chemistry building .

Sample code	Sample location	Track density (N.of track/mm^2)	Radon concentration (Bq/m^3)
CH1	Ground floor	735.714	95.397±12.037
CH2	Ground floor	838.571	108.734±21.58
CH3	Ground floor	1520	197.093±48.859
CH4	Ground floor	942.857	122.257±24.298
CH5	Ground floor	967.142	125.406±22.279
CH6	Ground floor	1318.571	170.974±28.972
CH7	first floor	1268.571	164.491±25.499

Table (4 - 3) : Indoor radon concentrations and track density using CR-39 in department of biology building .

Sample code	Sample location	Track density (N.of track/mm^2)	Radon concentration (Bq/m^3)
BIO1	Ground floor	785.714	101.881±17.812
BIO2	Ground floor	1561.425	202.465±37.374
BIO3	Ground floor	787.142	102.066±17.556
BIO4	Ground floor	1015.714	131.704±17.556

Table (4 - 4) : Indoor radon concentrations and track density using CR-39 in department of psychology and library buildings .

Sample code	Sample location	Track density (N.of track/mm^2)	Radon concentration (Bq/m^3)
PS1	Ground floor	927.142	120.219±22.496
PS2	Ground floor	1018.571	132.074±10.4
B1	First floor	508.571	65.944±10.632
B2	First floor	751.428	97.435±11.695
B3	First floor	1097.143	142.262±22.511
B4	First floor	1047.143	135.779±21.266
B5	First floor	671.428	87.061±12.254

Table (4 - 5) : Indoor radon concentrations and track density using CR-39 in department of mathematics building .

Sample code	Sample location	Track density (N.of track/mm^2)	Radon concentration (Bq/m^3)
M1	Ground floor	1134.286	147.079±24.201
M2	Ground floor	1081.429	140.225±16.115
M3	Ground floor	1152.142	149.394±25.912
M4	Ground floor	582.857	75.577±11.33
M5	First floor	604.285	78.355±16.439

Table (4 - 6) : Indoor radon concentrations and track density using CR-39 in the service laboratory building .

Sample code	Sample location	Track density (N.of track/mm^2)	Radon concentration (Bq/m^3)
L1	Ground floor	1231.428	159.675±24.62
L2	Ground floor	575.714	74.65±14.873
L3	Ground floor	454.285	58.905±7.913
L4	First floor	370	47.976±8.802
L5	First floor	352.857	45.753±3.913
L6	First floor	267.142	34.639±6.074

Table (4 - 7) : Indoor radon concentrations and track density using CR-39 in the random buildings of college .

Sample code	Sample location	Track density (N.of track/mm^2)	Radon concentration (Bq/m^3)
F1	Basement	3438.571	445.868±81.966
F2	Basement	3368.571	436.791±71.812
C1	Ground floor	134.285	17.412±2.192
C2	Ground floor	1650	213.95±35.653
E1	Ground floor	164.285	21.302±2.971
E2	Ground floor	456.714	60.387±10.959
H	Ground floor	467.142	60.572±9.47
A	Ground floor	1025.714	133±20.026
CH8	Ground floor	904.285	117.255±14.343
R1	Ground floor	1362.857	176.717±32.145
R2	first floor	1438.571	186.534±39.072

Table (4 - 8) : The annual effective dose (AED) , the lung cancer cases per year per million person (CPPP) , exposure to radon progeny (E_P) , the potential Alpha energy concentration (PAEC) for radon concentrations in deanship and department of physics building .

Sample code	Sample location	Radon concentration (Bq/m^3)	AED (mSv/Y)	CPPP *10^{-6}	Ep (WLM/Y)	PAEC (WL)
D1	Basement	138.372	3.490	62.83	0.616	0.0149
D2	Basement	177.458	4.477	80.58	0.790	0.0191
D3	Ground floor	101.695	2.565	46.18	0.453	0.0109
D4	Ground floor	152.08	3.836	69.06	0.677	0.0164
D5	Ground floor	85.58	2.159	38.86	0.381	0.0092
PH1	First floor	40.011	1.009	18.16	0.178	0.0043
PH2	First floor	35.01	0.883	15.89	0.156	0.0037
PH3	First floor	92.804	2.341	42.14	0.413	0.0100
PH4	First floor	61.128	1.542	27.75	0.272	0.0066

Table (4 - 9) : The annual effective dose (AED) , the lung cancer cases per year per million person (CPPP) , exposure to radon progeny (E_P) , the potential Alpha energy concentration (PAEC) for radon concentrations in department of chemistry building .

Sample code	Sample location	Radon concentration (Bq/m^3)	AED (mSv/Y)	CPPP *10^{-6}	Ep (WLM/Y)	PAEC (WL)
CH1	Ground floor	95.397	2.406	43.32	0.425	0.0103
CH2	Ground floor	108.734	2.743	49.37	0.484	0.0117
CH3	Ground floor	197.093	4.972	89.50	0.878	0.0213
CH4	Ground floor	122.257	3.084	55.51	0.544	0.0132
CH5	Ground floor	125.406	3.163	56.94	0.558	0.0135
CH6	Ground floor	170.974	4.313	77.64	0.761	0.0184
CH7	first floor	164.491	4.149	74.69	0.733	0.0177

Table (4 - 10) : The annual effective dose (AED) , the lung cancer cases per year per million person (CPPP) , exposure to radon progeny (E_P) , the potential Alpha energy concentration (PAEC) for radon concentrations in department of biology building .

Sample code	Sample location	Radon concentration (Bq/m^3)	AED (mSv/Y)	CPPP $*10^{-6}$	Ep (WLM/Y)	PAEC (WL)
BIO1	Ground floor	101.881	101.881	46.26	0.454	0.0110
BIO2	Ground floor	202.465	5.107	91.94	0.902	0.0218
BIO3	Ground floor	102.066	2.575	46.35	0.454	0.0110
BIO4	Ground floor	131.704	3.322	59.80	0.586	0.0142

Table (4 - 11) : The annual effective dose (AED) , the lung cancer cases per year per million person (CPPP) , exposure to radon progeny (E_P) , the potential Alpha energy concentration (PAEC) for radon concentrations in department of psychology and library building .

Sample code	Sample location	Radon concentration (Bq/m^3)	AED (mSv/Y)	CPPP $*10^{-6}$	Ep (WLM/Y)	PAEC (WL)
PS1	Ground floor	120.219	3.032	54.59	0.535	0.0129
PS2	Ground floor	132.074	3.332	59.97	0.588	0.0142
B1	First floor	65.944	1.663	29.94	0.293	0.0071
B2	First floor	97.435	2.458	44.24	0.434	0.0105
B3	First floor	142.262	3.589	64.60	0.634	0.0153
B4	First floor	135.779	3.425	61.65	0.605	0.0146
B5	First floor	87.061	2.196	39.53	0.387	0.0094

Table (4 - 12) : The annual effective dose (AED) , the lung cancer cases per year per million person (CPPP) , exposure to radon progeny (E_P) , the potential Alpha energy concentration (PAEC) for radon concentrations in department of mathematics building .

Sample code	Sample location	Radon concentration (Bq/m^3)	AED (mSv/Y)	CPPP *10^{-6}	Ep (WLM/Y)	PAEC (WL)
M1	Ground floor	147.079	3.710	66.79	0.655	0.0159
M2	Ground floor	140.225	3.537	63.67	0.624	0.0151
M3	Ground floor	149.394	3.769	67.84	0.665	0.0161
M4	Ground floor	75.577	1.906	34.32	0.336	0.0081
M5	First floor	78.355	1.976	35.58	0.349	0.0084

Table (4 - 13) : The annual effective dose (AED) , the lung cancer cases per year per million person (CPPP) , exposure to radon progeny (E_P) , the potential Alpha energy concentration (PAEC) for radon concentrations in The service Laboratory building .

Sample code	Sample location	Radon concentration (Bq/m^3)	AED (mSv/Y)	CPPP *10^{-6}	Ep (WLM/Y)	PAEC (WL)
L1	Ground floor	159.675	4.028	72.51	0.711	0.0172
L2	Ground floor	74.65	1.883	33.89	0.332	0.008
L3	Ground floor	58.905	1.486	26.74	0.262	0.0063
L4	First floor	47.976	1.210	21.78	0.213	0.0051
L5	First floor	45.753	1.154	20.77	0.203	0.0049
L6	First floor	34.639	0.873	15.73	0.154	0.0037

Table (4 - 14) : The annual effective dose (AED) , the lung cancer cases per year per million person (CPPP) , exposure to radon progeny (E_P) , the potential Alpha energy concentration (PAEC) for radon concentrations in the random buildings of college .

Sample code	Sample location	Radon concentration (Bq/m^3)	AED (mSv/Y)	CPPP $*10^{-6}$	Ep (WLM/Y)	PAEC (WL)
F1	Basement	445.868	11.248	202.47	1.987	0.0482
F2	Basement	436.791	11.019	198.35	1.946	0.0472
C1	Ground floor	17.412	0.439	7.90	0.077	0.0018
C2	Ground floor	213.95	5.397	97.15	0.953	0.0231
E1	Ground floor	21.302	0.537	96.73	0.094	0.0023
E2	Ground floor	60.387	1.5234	27.42	0.269	0.0065
H	Ground floor	60.572	1.528	27.50	0.269	0.0065
A	Ground floor	133	3.355	60.39	0.592	0.0143
CH8	Ground floor	117.255	2.958	53.24	0.522	0.0126
R1	Ground floor	176.717	4.458	80.25	0.787	0.0191
R2	First floor	186.534	4.706	84.70	0.831	0.0201

(4 - 2 - 2) The Radon concentration Results using Rad- 7 monitor :

The results obtained of radon concentration has been inserted in the tables following (4 - 15) (4 - 16) (4 - 17) (4- 18) (4 - 19) (4 - 20) (4 - 21) using Rad-7 monitor for 30 minutes in each room and results included the Radon concentration , Humidity RH , the total counting and temperature °C.

Table (4 - 15) : The radon concentrations , Humidity RH , the total count and temperature ºC using Rad- 7 in deanship and department of physics building .

Sample code	Sample location	Radon concentration (Bq/m^3)	Humidity RH	The total count	Temperature ºC
D1	Basement	10.9	7%	5	19.4
D2	Basement	32.6	7%	9	20.7
D3	Ground floor	21.7	7%	10	18.5
D4	Ground floor	16.1	9%	5	18.2
D5	Ground floor	21.7	6%	10	20
PH1	First floor	10.7	6%	5	19.7
PH2	First floor	5.43	5%	7	19.4
PH3	First floor	27.2	8%	7	19.7
PH4	First floor	10.7	6%	3	19.7

Table (4 - 16) : The radon concentrations , Humidity RH , the total count and temperature ºC using Rad- 7 in department of chemistry building .

Sample code	Sample location	Radon concentration (Bq/m^3)	Humidity RH	The total count	Temperature ºC
CH1	Ground floor	5.44	7%	7	21
CH2	Ground floor	16.3	7%	3	21.3
CH3	Ground floor	16.1	6%	5	21.9
CH4	Ground floor	5.36	8%	4	22.8
CH5	Ground floor	16.3	7%	6	22.5
CH6	Ground floor	10.7	7%	2	19.7
CH7	first floor	21.8	13%	6	20.4

Table (4 - 17) : The radon concentrations , Humidity RH , the total count and temperature ºC using Rad- 7 in department of biology building .

Sample code	Sample location	Radon concentration (Bq/m^3)	Humidity RH	The total count	Temperature ºC
BIO1	Ground floor	5.36	7%	4	21
BIO2	Ground floor	21.4	6%	9	20
BIO3	Ground floor	16.1	6%	7	20.4
BIO4	Ground floor	10.2	6%	2	19.1

Table (4 - 18) : The radon concentrations , Humidity RH , the total count and temperature ºC using Rad- 7 in department of psychology and library buildings .

Sample code	Sample location	Radon concentration (Bq/m^3)	Humidity RH	The total count	Temperature ºC
PS1	Ground floor	26.8	7%	11	22.2
PS2	Ground floor	0	7%	7	21.6
B1	First floor	0	7%	2	22.2
B2	First floor	5.43	9%	8	23.1
B3	First floor	16.3	9%	3	23.1
B4	First floor	5.36	8%	6	20.7
B5	First floor	5.43	7%	3	21.9

Table (4 - 19) : The radon concentrations , Humidity RH , the total count and temperature ºC using Rad- 7 in department of mathematics building .

Sample code	Sample location	Radon concentration (Bq/m^3)	Humidity RH	The total count	Temperature ºC
M1	Ground floor	37.5	11%	11	18.5
M2	Ground floor	27.2	9%	11	19.4
M3	Ground floor	54.3	8%	15	20
M5	Ground floor	10.9	9%	8	20.7
M4	first floor	21.7	8%	6	19.4

Table (4 - 20) : The radon concentrations , Humidity RH , the total count and temperature ºC using Rad- 7 in The service Laboratory building .

Sample code	Sample location	Radon concentration (Bq/m^3)	Humidity RH	The total count	Temperature ºC
L1	Ground floor	27.2	7%	8	23.1
L2	Ground floor	10.7	8%	2	17.9
L3	Ground floor	0	7%	3	21.6
L4	First floor	0	7%	3	24
L5	First floor	5.43	6%	1	27.7
L6	First floor	5.43	6%	5	24.9

Table (4 - 21) : The radon concentrations , Humidity RH , total count and temperature ºC using Rad- 7 in the random buildings of college.

Sample code	Sample location	Radon concentration (Bq/m^3)	Humidity RH	The total count	Temperature ºC
F1	Basement	59.6	6%	19	20.4
F2	Basement	48.2	7%	9	20.4
C1	Ground floor	10.9	9%	4	20.7
C2	Ground floor	10.7	8%	7	20.4
E1	Ground floor	5.43	9%	4	19.7
E2	Ground floor	5.44	7%	3	21.9
H	Ground floor	10.7	8%	3	20
A	Ground floor	37.5	6%	9	20
CH8	Ground floor	10.7	11%	9	22.8
R1	Ground floor	10.7	8%	8	21
R2	First floor	16.1	7%	11	21.6

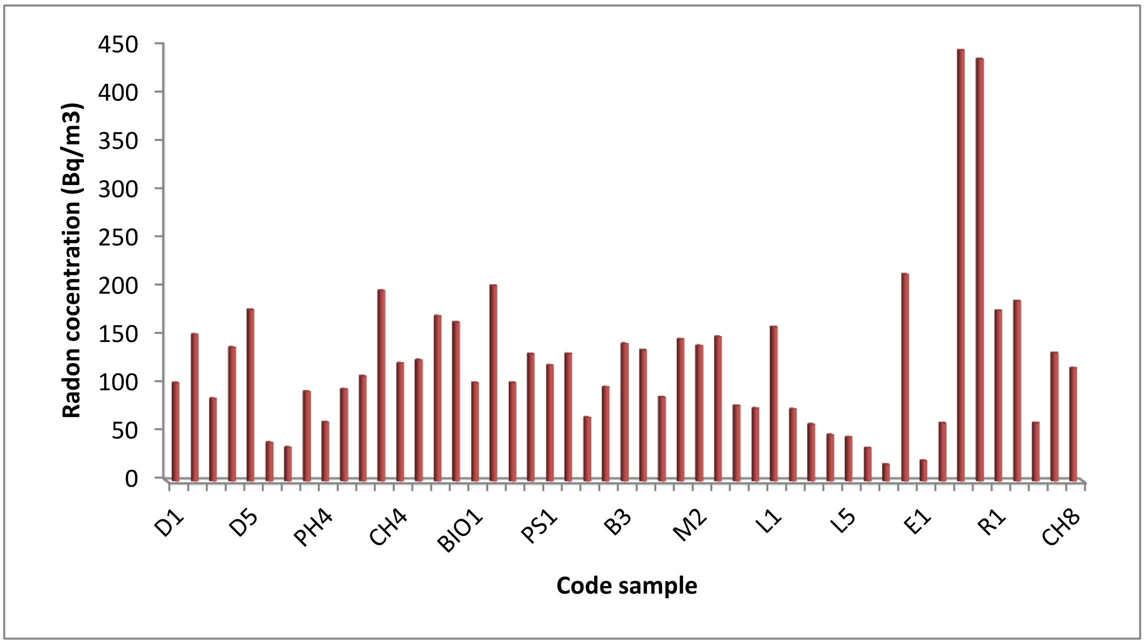


Fig (4 - 1) : Indoor radon concentration using CR-39 in college buildings .

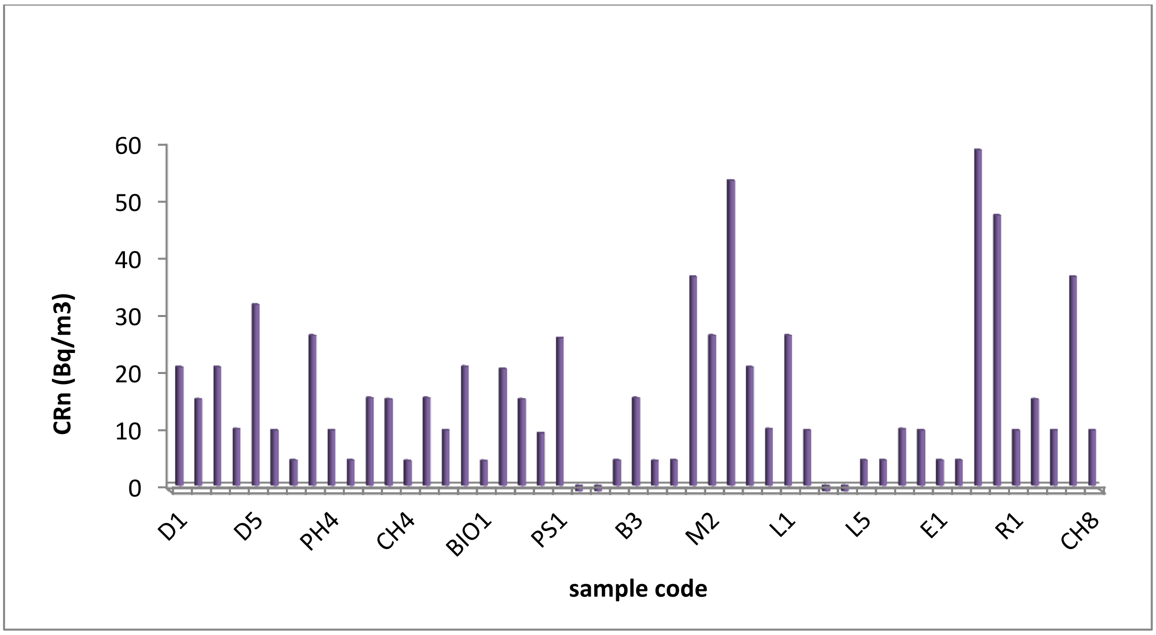


Fig (4 - 2): Indoor radon concentration using Rad-7 in college buildings.

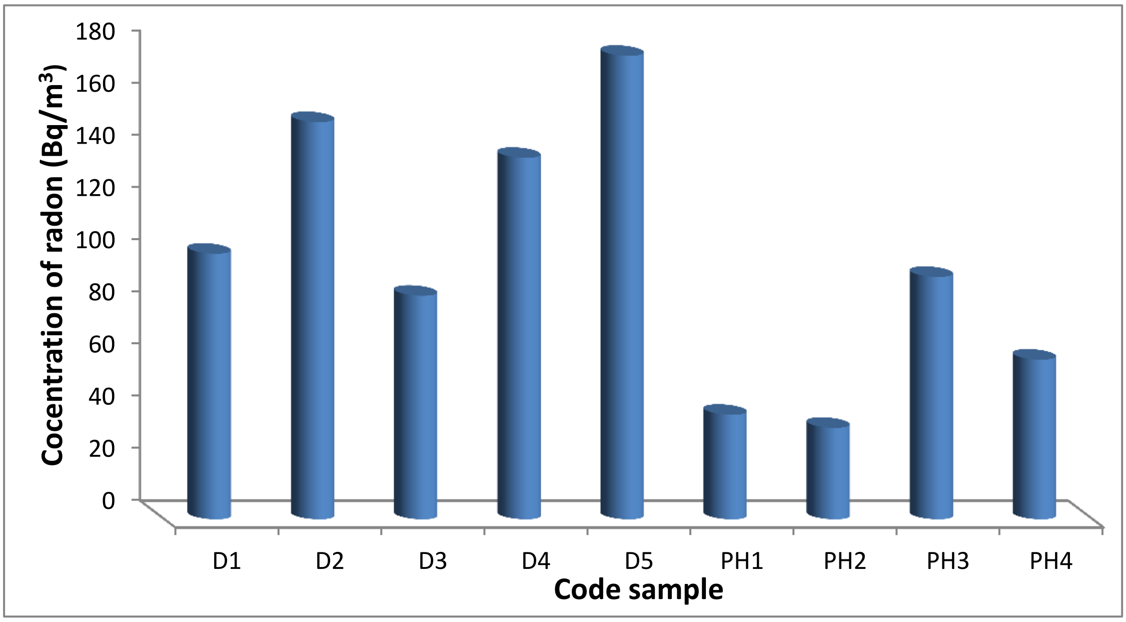


Fig (4 - 3) : Indoor radon concentration in deanship and department of Physics buildings .

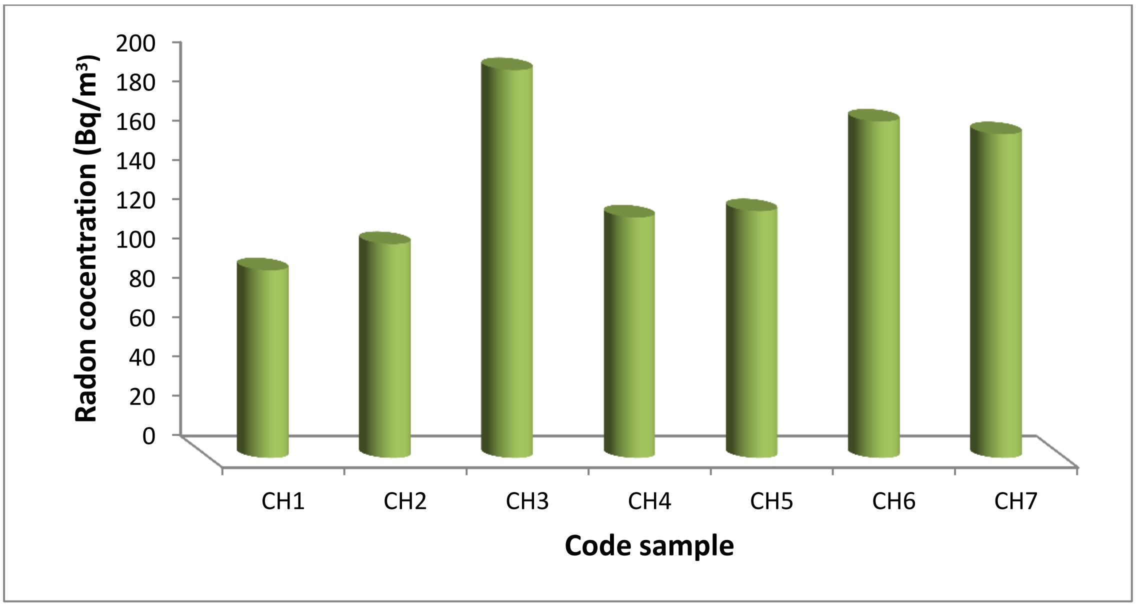


Fig (4 - 4) : Indoor radon concentration in department of chemistry building .

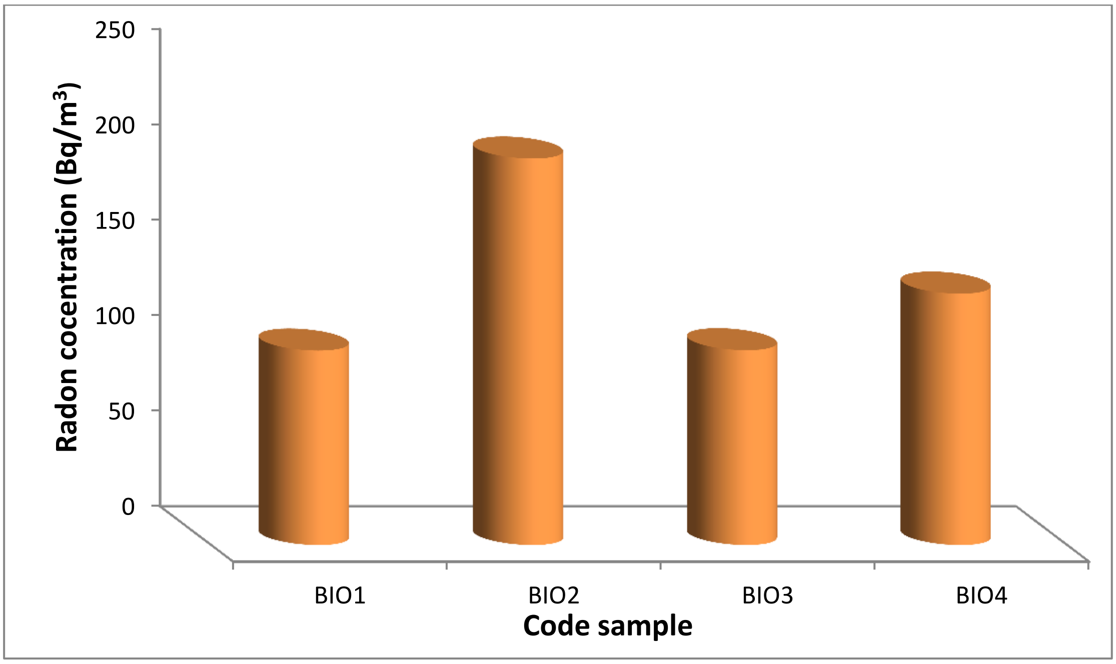


Fig (4 - 5) : Indoor radon concentrations in department of biology building .

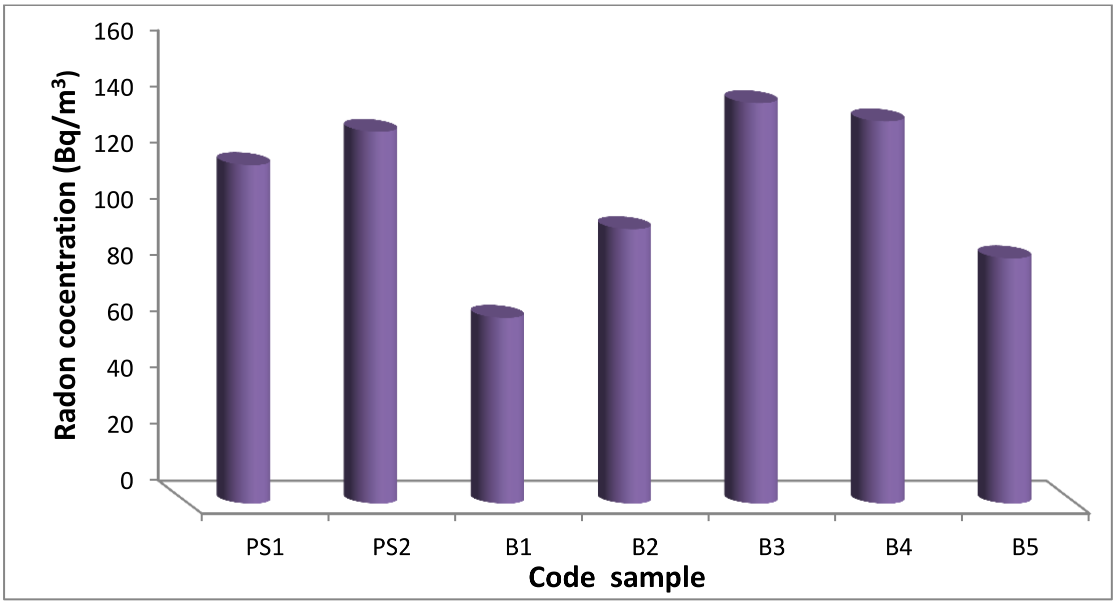


Fig (4 - 6) : Indoor radon concentrations in department of psychology and library buildings .

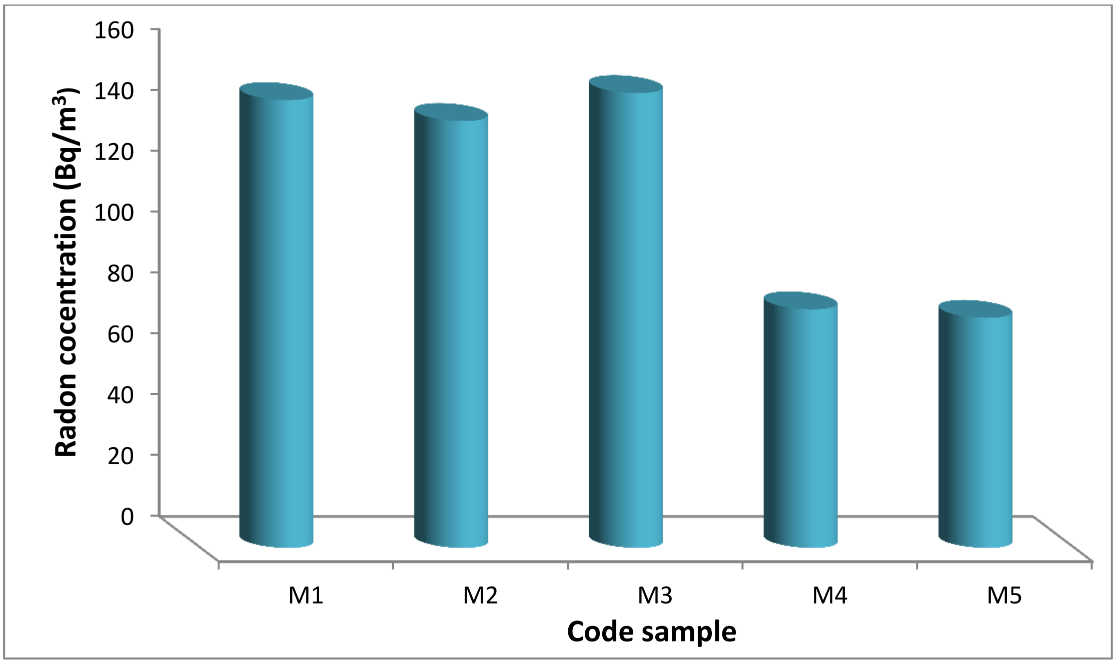


Fig (4 - 7) : Indoor radon concentrations in department of mathematics building .

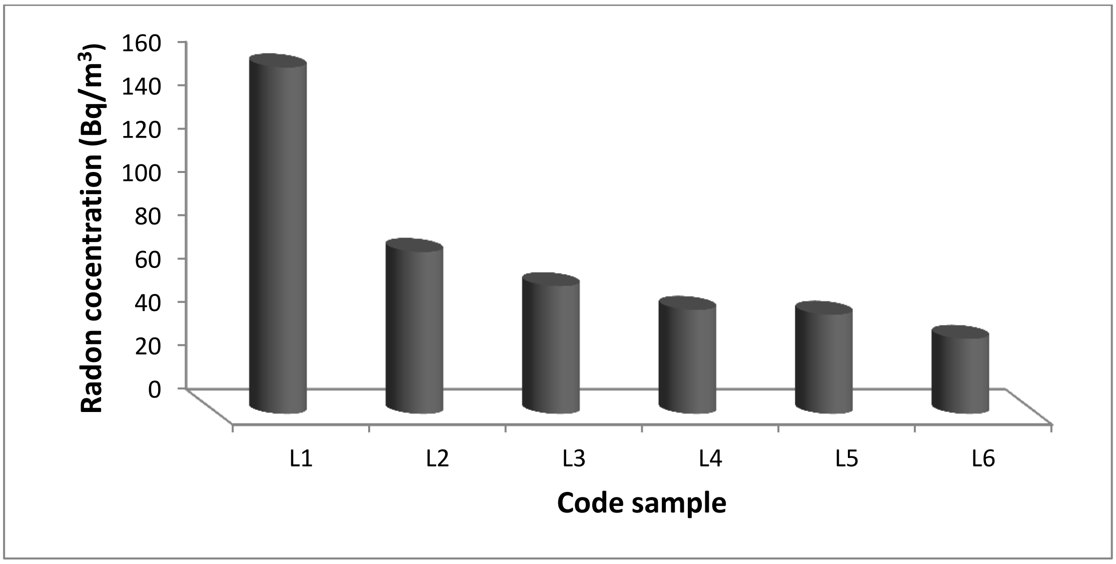


Fig (4 - 8) : Indoor radon concentrations in the service Laboratory building .

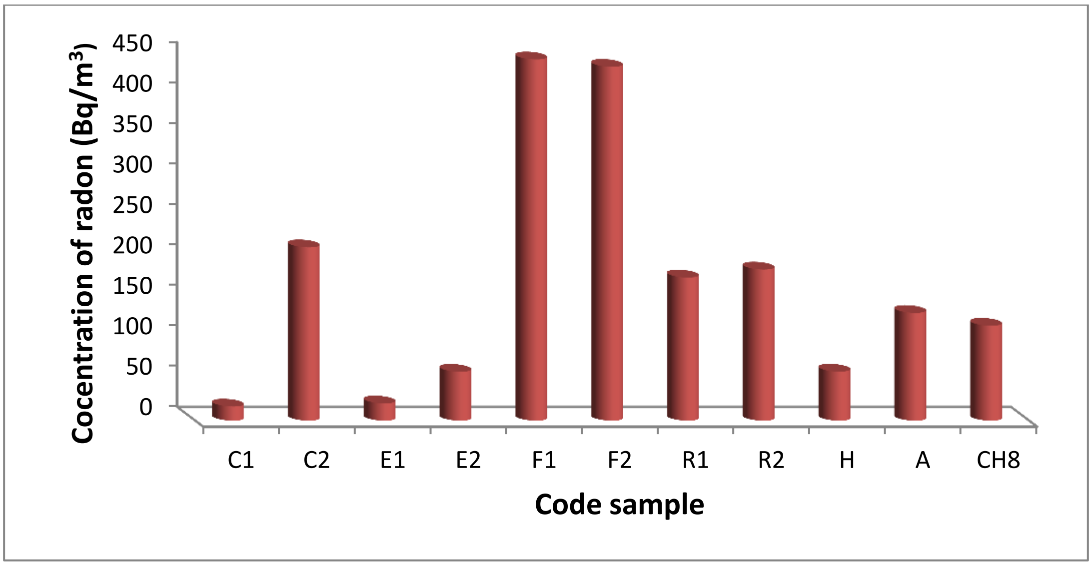


Fig (4 - 9) : Indoor radon concentrations in the random buildings .

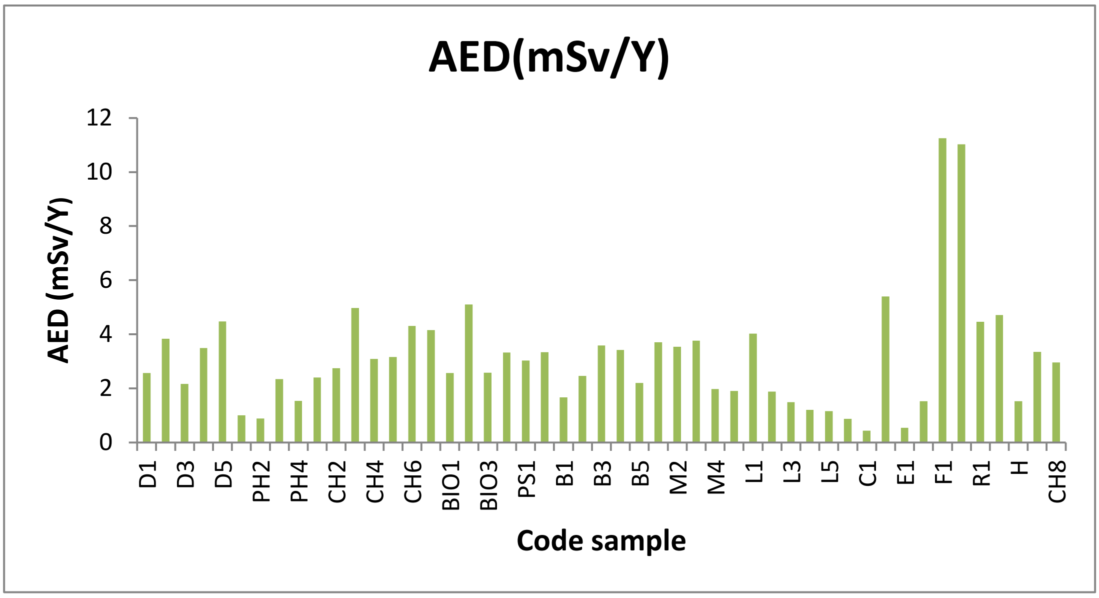


Fig (4 - 10) : The annual effective dose (AED) in college buildings .

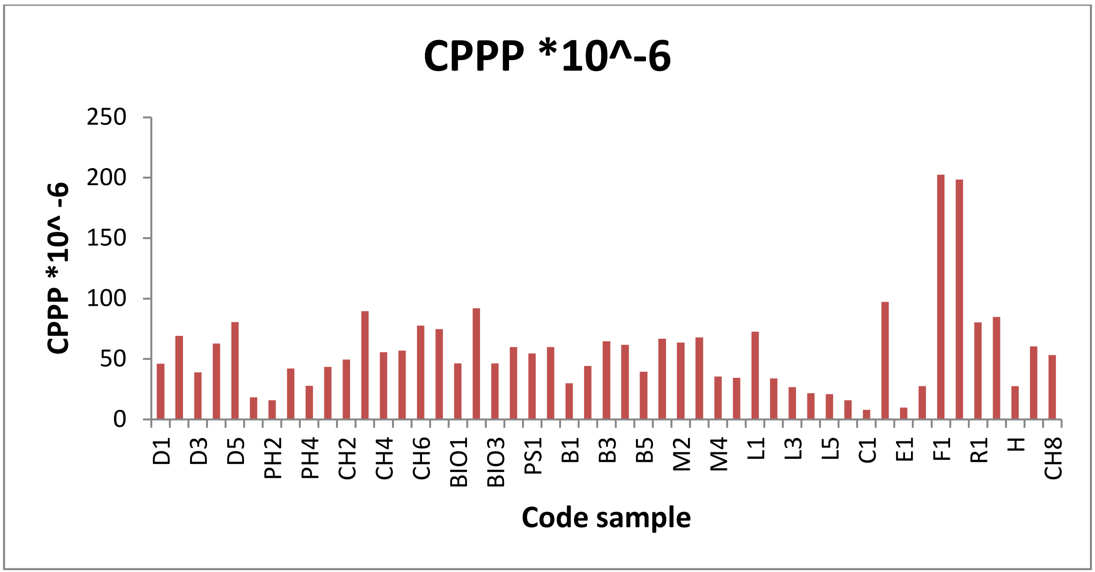


Fig (4 - 11) : The lung cancer cases per year per million person (CPPP) in college buildings .

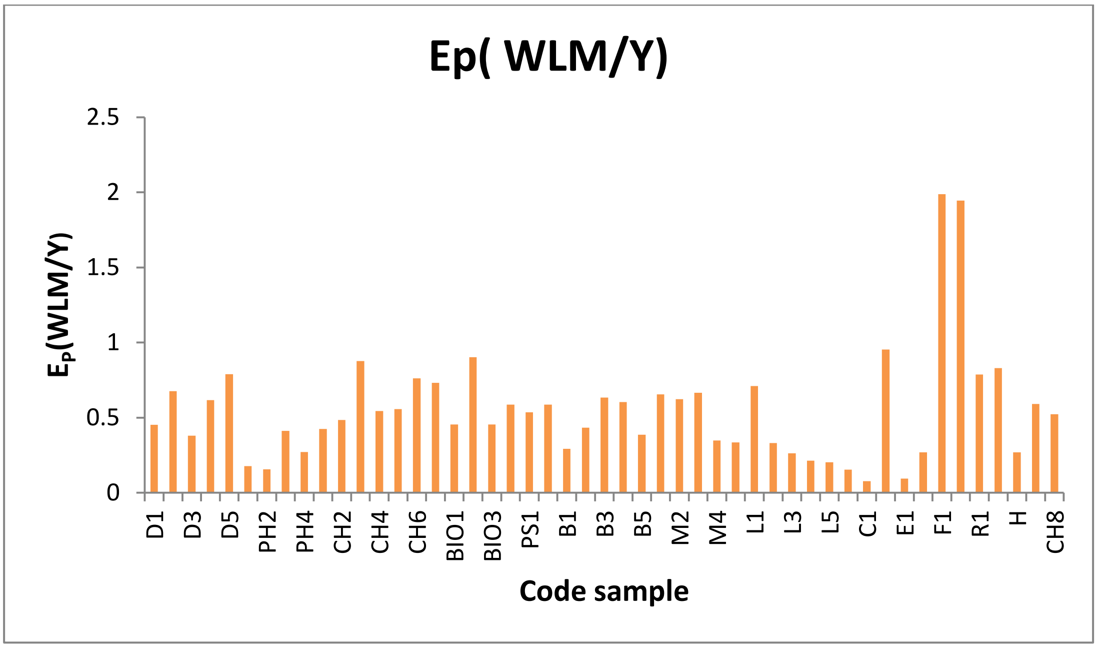


Fig (4 - 12) : The exposure to radon progeny (E_P) in college buildings .

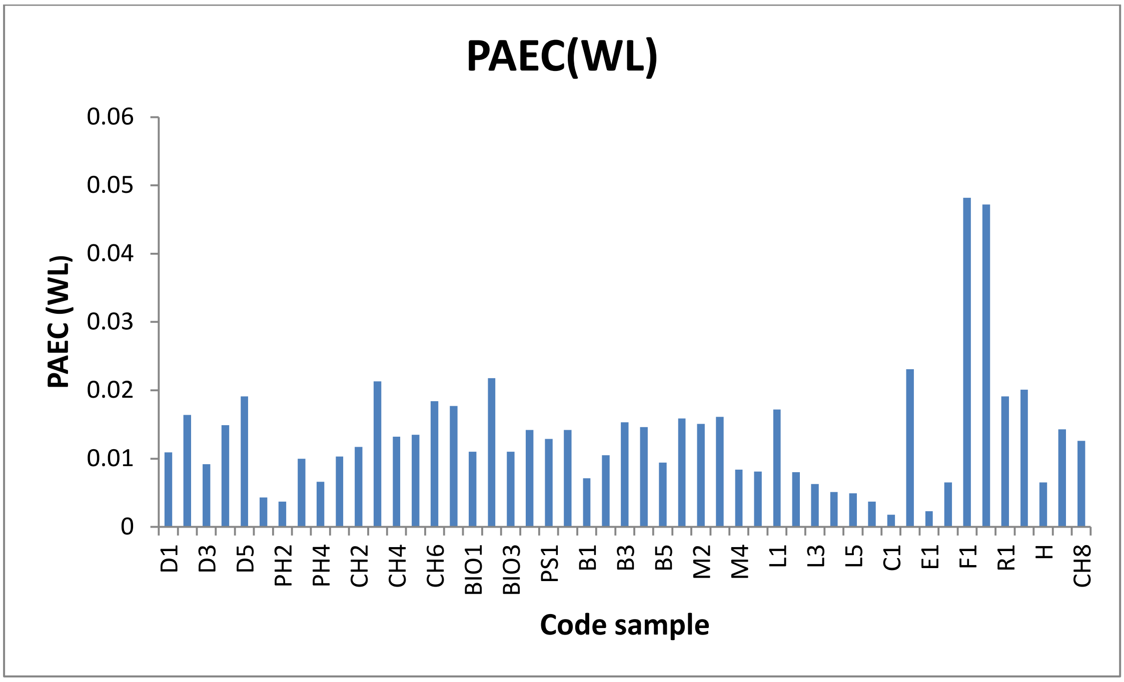


Fig (4 - 13) :The potential alpha energy concentration (PAEC) in college buildings .

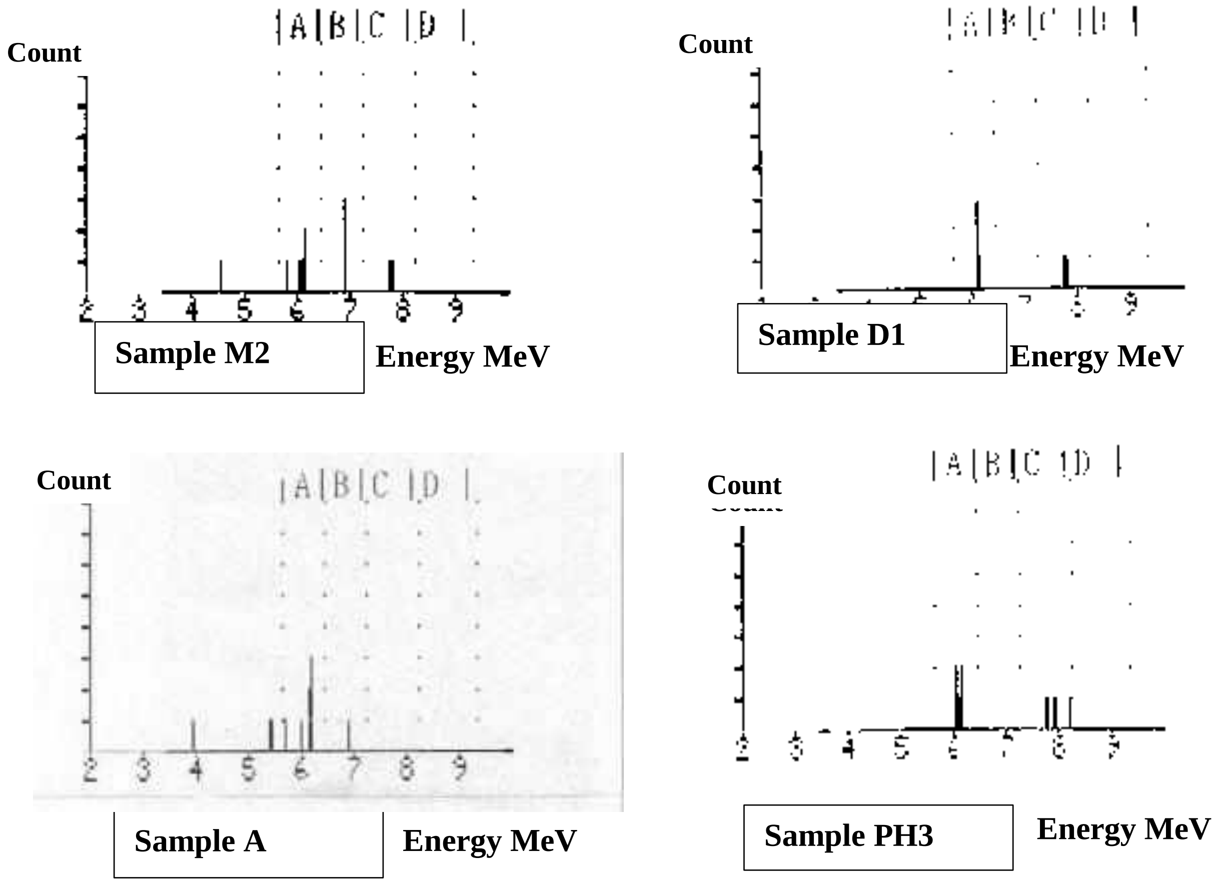


Fig (4 - 14) : Alpha energy spectrum for samples ; M2 , D1 , A , PH3 .

(4 - 3) Discussion :

The results of the indoor radon concentration in air for 49 locations were shown in the tables (4 - 1) to (4 - 14) using CR-39 and tables (4 - 15) to (4 - 21) using Rad-7 and figures (4 - 1) to (4 - 9) . Tables were showed the radon concentration increase in the basement more than the ground floor and first floor , because the intensity of radon gas is about seven times as air intense .

Radon concentrations were calculated using solid state nuclear track detectors CR-39 and Rad-7 for compare between them . The highest value were in samples F1 And F2 in free education building with rate of (445.868 ± 81.966) Bq/m^3 and (436.791 ± 71.812) Bq/m^3 respectively ,the lowest value was in sample C1 with rate of (17.412 ± 2 .192) Bq/m^3 using CR-39 detector , these results of radon concentrations were reliable measurement , also it was adding all the values of the standard deviation , which represents the rate root . Some measurements were found that there is no reading when using Rad-7 monitor , while there were readings when using CR-39 detectors , Rad-7 may recorded some values (0.0) Bq/m^3 for places which the code sample of these places PS2 in department of psychology building , B1 in library building (L3, L4) in the service laboratory, while the CR-39 detector was recorded values of (132.074 ± 10.4) Bq/m^3 , (65.944 ± 10.632) Bq/m^3, (58.905 ± 7.913) Bq/m^3 , (47.976 ± 8.802) Bq/m^3 respectively , the results of radon concentration that recorded by Rad-7 have the same increase in radon concentrations which it were recorded by CR-39 detectors . The parameters effect were calculated values were mostly within the range allowed . Except two values of concentrations were higher than the allowed level of samples F1, F2 and values were (445.868 ± 81.966) Bq/m^3 and (436.791 ± 71.812) Bq/m^3 respectively for being underground and were badly ventilated of the place . Also note Fig (4 - 1) and (4 - 2) the samples F1 and F2 concentrations are higher than other samples . From the table (4 -

20) note that the humidity and radon concentrations were equal for the samples (L4 , L5) in the service laboratory were on same floor for the same building , but there is a difference in the total count because there is a difference in the nature of the place and ventilation differ from place to place . From the table (4 - 21) it can be seen that the total count were equal in samples (F2 , A , CH8) for different buildings at different humidity we find the humidity affect in measurement of radon concentrations , this means that the radon concentrations decreased with humidity increases , either samples (C1 , E1) for different places it can be shown that the measurements were equal in total count and humidity but there is a difference in the radon concentrations because ventilation conditions vary from place to place as well as the nature of the materials used in construction were also different . Radiation effects have been calculated concentrates of radon only CR-39 detector , because that readings of CR-39 detector were higher than all readings of Rad- 7 and to be more safely taken larger readings of CR-39 detector , for this reason the readings of CR-39 adopted as radiation effects , Fig (4 - 11) shows that the risk of lung cancer each year for every million person where using the relation (3 - 10) it was noted that in high concentration and the samples F1 and F2 and the values of (202.47) and (198.35) per year per million person respectively in the free education building , because old building , there are some old books inside it , below the surface of earth and a few ventilation all these reasons as a results of increased radiation background also radon found in these places in high concentration either less value to lung cancer was found in the sample C1 (4.39) . Fig (4 - 10) shows the annual effective dose where the relation is used (3 - 9) notes that in high concentration places the dose was high F1 and F2 (11.248) mSv/Y and (11.019) mSv/Y . The less effective dose value found in the sample C1 where equals (0.439) mSv/Y . Fig (4 -

12) shows the exposure to radon atomic E_P and sometimes it is called annual equivalent effective dose where the relation was used (3 - 12) , it was found high in high concentrations places . Note Fig (4 - 13) found that the highest values recorded for the potential alpha energy concentration in samples F1 and F2 where their the potential alpha energy concentration values were (0.0482) WL (0.0472) WL respectively . Have been using the relation (3 - 11) for the potential Alpha energy concentration either the lowest value of the potential Alpha energy concentration was in sample C1 and value of (0.0018) WL .

(4 - 4) Conclusion :

The tables obtained radon concentrations recorded by solid state nuclear track detector CR-39 were within the acceptable level or less than it , except two samples F1 and F2 values of (445.868 ± 81.966) Bq/m^3 and (436.791 ± 71.812) Bq/m^3 respectively in free education building . The acceptable level recorded by ICRP.2009 which was within range between (200-300) Bq/m^3 [98] . When Rad-7 was using all values of the concentrations were less than the acceptable term that recorded by (ICRP,2009) [98] , so concluded that these results were higher than the accepted levels due to the nature of the materials used in construction , it was underground , they were old buildings and with badly ventilated .The results obtained using the Rad-7 were mostly approaching measurements of detectors and close with solid state CR-39 in increase and decrease for this we conclude that the solid state of nuclear track detector CR-39 recorders are reliable to detect radon and for a long time to reach the actual concentrations values by comparing different techniques including Rad-7 . From the tables we concluded the radon concentrations increase in the basement more than the ground floor and first floor . From the tables were concluded the effective annual dose was higher than the acceptable level , where the values of samples F1 and F2 were (11.248) mSv/Y and (11.019) mSv/Y respectively where the accepted term was within (3 - 10) mSv/Y and recorder by (ICRP, 1993) [99] . Tables obtained were concluded that the risk of lung cancer (CPPP) were within the acceptable range and which was within the range between (170 - 230) recorded by (ICRP, 1993) [99] . From the tables obtained were conclude exposure to radon progeny (Ep) were within average limited (1 - 2WLMY^{-1}) recorded by (NCRP, 1989) [94] . Also have been conclude from the tables of the potential alpha energy concentration for all the samples were under average (53.33 mWL) recorded by (UNSCEAR, 1 993) [42] .

(4 - 5) Future studies :

- A study broader and more comprehensive to college with study the effect of humidity and ventilation factors on the readings .
- New measurements of the latest methods available by using the Sarad monitor which is one of the latest devices and recording of radon concentration in different air conditions of humidity and temperature .
- The use of other detectors such as (SR and PM) detectors more efficient of detector CR-39 to record radon concentrations.

(4 - 6) Recommendations :

- We suggest dye the walls by materials that can prevent spread of radon .
- Building design towards increased ventilation .

References

References :

1- Weisstein, Eric W. "Radiation". Eric Weisstein's World of Physics. Wolfram Research. Retrieved 2014-01-11.

2- Radiation". The free dictionary by Farlex. Farlex, Inc. Retrieved 2014-01-11.

3- Kwan-Hoong. "Non-Ionizing Radiations – Sources, Biological Effects, Emissions and Exposures". October 2003

4- "Physics - Waves". www-jcsu.jesus.cam.ac.uk. Archived from the original on 4 September 2017. Retrieved 4 September 2017.

5- "ICRP Publication 103 The 2007 Recommendations of the International Commission on Protection" (PDF). ICRP. Retrieved 12 December 2013.

6 - Cameron J.R. and Skofronick J.G. "Medical Physics", New York, Canada, John Wiley and sons, Inc., 47, pp.56-67, (1992).

7- Durance M.E. "Radioactivity in geology", John Wiley and Sons, New York, Elsiever, 67, pp.96-110, (1986).

8- Chase G. and Rabinowitch J. "Principle of radioisotope methodology", 3rd edition, Mineapolis, Burgess Publishing Co.,17, pp.46-60,(1967).

9- United Nations Environmental Programme, UNEP "Radiation Doses, Effects, and Risks", United Nations, 13, pp.21-40, (1985).

10- "Detecting cosmic rays from a galaxy far, far away". Science Daily. 21 September 2017. Retrieved 26 December 2017.

11- Ginger Pinholster . "Evidence Shows that Cosmic Rays Come from Exploding Stars" Retrieved (2013-02-13).

12- A Citizen's Guide to Radon" United States Environmental Protection Agency. October 12, 2010. Retrieved January 29, 2012.

13- Jones R.R. and Southwood R., Radiation and Health: "The Biological effect of low-level exposure to ionizing radiation", John Wiley and Sons, Chaichester, 147, pp.176-190, (1987).

14- Shultis J.K. and Faw R.E. " Fundamentals of nuclear science and engineering" Marcel Dekker,Inc ,U.S.A. , (2001).

15- Keller, Cornelius; Wolf, Walter; Shani, Jashovam, "Radionuclides, 2. Radioactive Elements and Artificial Radionuclides", Ullmann's Encyclopedia of Industrial Chemistry, Weinheim: Wiley-VCH, doi:10.1002/14356007.o22_o15 , (2005)

16- Pitzer, Kenneth S. "Fluorides of radon and element 118".ChemicalCommunications (18): 760–1. doi:10.1039/C3975000760b ,(1975).

17- Stein, Lawrence (1983). "The Chemistry of Radon". RadiochimicaActa. 32: 163–171. doi:10.1524/ract.1983.32.13.163.

18- Sperrin, Malcolm; Gillmore, Gavin; Denman, Tony (2001). "Radon concentration variations in a Mendip cave cluster". Environmental Management and Health. 12 (5): 476. doi:10.1108/09566160110404881.

19- عطارد مطر عوف " تحديد تراكيز غاز الرادون في مناطق محددة من مدينة الموصل باستخدام كواشف الأثر النووي العضوية " رسالة ماجستير , الجامعة المستنصرية–كلية التربية (1999) .

20- Rahman S." Radon measurement with CR-39 detectors-implication for uranium ore analysis and risk assessment" ,Ph.D ,Thesis, Department of physics and applied mathematics ,Pakistan institute of engineering and applied sciences, (2005).

21- Rasas M. F., Yassin S. S., and Shabat M. M., "Journal of The Islamic University of Gaza (Natural Sciences Series)", No.2, Vol.13, (2005).

22- Al-Mosa T. M. A., " Indoor Radon Concentration in Kindergartens, Play- and Elementary Schools in Zulfy City ,Saudi Arabia" M. Sc. Thesis, King Saud University, College of Science, (2007).

23- Bouzarjomehri F.and Ehrampoosh M.H.," Radon level in dwellings basement of Yazd-Iran" Iran .J.Radiat ,6(3):141-144, (2008)

24- Al-Awad S.H.M., "Measurement of Radon Concentration in Houses in Najran Region , Saudi Arabia " M. Sc. Thesis, King Saud University, College of Science, (2008).

25- Al-obedy A. A. I. and Al-jubory R. A. M., " Measurements of Radon-222 concentrations in dwellings of Kirkuk city, Iraq" Kirkuk University Journal Scientific Studies,Vol.4(2), (2009).

26- Tawfiq N.F., Nasir H.M. and Khalid "Determination of Radon Concentrations in AL-Najaf Governorate by Using Nuclear Track Detector CR-39" Journal of Al-Nahrain University, Vol.15 (1), March, pp.83-87, (2012).

27- Hamidawi A., "Radon and Thoron Concentrations Measurement in Al-Najaf and Al-Kufa Area" PhD Thesis, University of Baghdad, Iraq, (2012).

28- Mallah K.B.Y.," Indoor Exposure Assessment and Health Hazard of Radon in the Elementary Schools of Tulkarem Province , Palestine " M. Sc. Thesis, An-Najah National University, Faculty of Graduate Studies, (2013).

29- Ridha A.A., " Determination of Radionuclides Concentrations in Construction Materials Used in Iraq" PhD thesis, the College of Science, AL-Mustansiriyah University, (2013).

30- Muntathar Adnan Noor " Concentration Measurement of Radon Gas in Soil, Water and Air for selected Regions of Al-Najaf Al Ashraf Province by Using RAD-7 " A thesis, submitted to the Faculty of Sciences University of Kufa (2013 A.D).

31- Muntean L.E., Cosma C., Cucos (Dinu)A., Dicu T.and Moldovan D., "Assessment of Annual and Seasonal Variation of Indoor Radon Levels in Dwelling Houses From Alba County, Romania " Romania Journal Physics, Vol. 59, Nos. 1–2, P. 163–171, Bucharest, (2014).

32- Hadeel Ghali Ishnayyin " Find an Empirical Formula for Indoor Radon Measurement Emitting from Building Materials " A thesis, Submitted to the College of Education for Pure SciencesIbn AL-Haitham, University of Baghdad (2015 A.D).

33- Mahmood Salim Karim Al-Rakabi " Study of Radioactivity and Radon gas Emanation in Some Iraqi Governorates " A Thesis , Submitted to the Council of College of Education
AL-Mustansiriyah University (2015 A .D).

34- Haider Rayed Fadhil " Measurement of Radon and Daughters Concentration and Exposure Assessment in the buildings of Science College at AL-Mustansiriyah University " A Thesis , Submitted to the College of Science AL-Mustansiriyah University (2015 A .D).

35- (UNSCEAR 2000)United Nations Scientific Committee on the Effects of Atomic Radiation "Sources and Effects of Ionizing Radiation”, the General Assembly, with scientific annexes, United Nations Sales Publication, United Nations, New York, Report Vol.1 (2000).

36- (UNSCEAR 1993) United Nations Scientific Committee on the Effects of Atomic Radiation, "Sources and Effects of Ionizing Radiation. ", Report to the General Assembly, with scientific annexes. United Nations sales publication United Nations, New York (1993).

References

37- (NCRP 1988) National Council on Radiation Protection and Measurements, "Measurement of Radon and Daughters in Air" NCRP, Bethesda, (M.D.), No.97, U.S.A. November 15, (1988).

38- (EPA1992) Environmental Protection Agency, "A Citizens Guide to Radon, The Guide to Protecting yourself and your Family from Radon", U.S. Department of Health and Human Services, 402-k92-001, May (1992).

39- الجنابي ، د. موسى ، ومحمد ، وهاب أحمد ، "مصادر الإشعاع والجرع الإشعاعية" . مترجم ، منشورات الطاقة الذرية العراقية، طبعة ثانية ، (1990).

40- Ali A. and Durrani S.A., Nucl. Track Detection, Vol.1, No.2, 107,(1977) .

41 - Walter E. M., "elements of nuclear physics", McGraw-Hill Book Company (1967).

42 - (EPA2003) Environmental Protection Agency, "Assessment of Risks from Radon in Homes", (EPA 402-R-03-003), (Numbers of deaths from Radon) (2003).

43- (EPA1987) Environmental Protection Agency, "Radon Reference Manual" Office of Radiation Programs Washington DC 20460, EPA 520/1-87-20, September (1987).

44 - (EPA1990) Environmental Protection Agency, "Toxological Profile for Radon Agency for Toxic Substances and Disease Registry", U.S. public Health Service in collaboration with U.S. Environmental Protection Agency (1990).

45 - U.S. Department of Health and Human Services "Toxicological Profile for Radon" Public Health Service Agency for Toxic Substances and Disease Registry (2012).

46 - Nero A.V., "Radon and its Decay Products in Indoor Air: an Overview", Chapter 1 of "Radon and its decay products in Indoor Air", Wiley Inter science, PP.1-53 (1988).

47 - Castrkn O., Voutilainen A., Winqist K. and Miikelainen I. "Studies of High Indoor Radon Areas in Finland", Journal of the Science of the Total Environmental Vol.45, No.18, PP. 311-318 (1985).

48- Tyson J. L., Fairey P.W. and Withers C. R., "Elevated Radon Levels in Ambient Air", Indoor air 93, Proceedings of the 6th International Conference on Indoor Air Quality and Climate, Helsinki, Finland, Vol. 4, PP. 443-448 (1993).

49- (NEAIOECD) Nuclear Energy Agency I Organization for Economic Co-operation and Development, "Exposure to Radiation from the Natural Radioactivity in Building Materials", Expert Group Report, OECD, Paris (1979).

50- (UNSCEAR 1988) United Nations Scientific Committee on the Effects of Atomic Radiation, Report to the General Assembly: Exposure from Natural Sources of Radiation, New York (1988).

51- European Commission, "Radon Research", Review of CEC EUR-17628 (1997).

52- Megumi K., Matsunami T., and Kiyoda S., "A Study on Seasonal Variation of Radon Concentration in Indoor Air in Osaka District", Atmospheric Radon Families and Environmental Radioactivity III (S. Okabe,ed.). Japan Atomic Energy Society, PP. 111-115 (1995).

53- Riley W. J., Gadgil and A.J., Bonnefous Y.C., "The Effect of Steady Winds on Radon-222 Entry from Soil into Houses", Journal of Atmospheric Environment Vol.30, No.7, PP.1167-1176 (1996).

54- Robinson, A.L., Sextro R.G. and Fisk W.J., "Soil-gas Entry into an Experimental Basement Driven by Atmospheric Pressure Fluctuations - Measurements, Spectral Analysis and Model Comparison", Journal of Atmospheric Environment Vol.31, No.10, PP. 1477- 1495 (1997).

55 - Gammage R.B., Dudney C.S., and Wilson D.L., "Subterranean Transport of Radon and Elevated Indoor Radon in Hilly Karst Terrains", Journal of Atmospheric Environment Vol.26A, No. 12, PP 2237-2246 (1992).

56- Rose A.W. and Guo W. "Thermal Convection of Soil Air on Hillsides", Journal of Environmental Geology, Vol.25, No. 4 PP. 258-262 (1995).

57- U.S. Department of the interior, "Geologic Radon Potential of Guam and Puerto Rico", U.S. geological survey Prepared in Cooperation with the U.S. Environmental Protection Agency, Report 93-292-K (1995).

58- Cottingham W.N. and Greenwood D.A., "An Introduction to Nuclear Physics", second edition, Cambridge University Press, PP. 214-215 (2004).

59- Todorov P. T . and Ilieva E. N., "Contamination with Uranium from natural and Anthropological source " , Journal of Romanian Physics , Vol.51, No13, PP .27-34 (2006).

60- Khan H.A., " Radon: A Friend or a Foe?", Journal of Radiation Applications and Instrumentation. Part D. Nuclear Tracks and Radiation Measurements Vol.19, No.1-4, PP. 353-362 (1991).

61- Shafi-ur-Rehman, "Radon Measurement with CR-39 Detectors-Implications for Uranium Ore Analysis and Risk Assessment", Ph.D. Thesis, Pakistan Institute of Engineering and Applied Sciences, Pakistan, 2005.

62-Mazed D., Ciolini R., Curzio G. and Del Gratta A., "A New Active Method for Continuous Radon Measurements based on a Multiple Cell

Proportional Counter", Nuclear Instruments and Methods in Physics Research, A582 (2007) 535-545.

63- Ahn G. H. and Lee J., "Construction of an Environmental Radon Monitoring System using CR-39 Nuclear Track Detectors", Nuclear Engineering and Technology, 37, 4 (2005) 395 - 400.

64-Teklu T. B., "Indoor and outdoor variation of radon concentration", M.Sc. Thesis, Addis Ababa University, Ethiopia, 2007.

65- Hushemi S.R. and Durrani S.M., Nuclear Tracks, **3**, P.189, (1981).

66- Muller R.F. and Young I.D., "Emery’s Elements of Medical Genetics, 10th Ed.", USA, Harcourt brace and company limited,(1998).

67- Silk E.C.H. and Barnes R.S., Phil. Mag., 4 , P.970, (1959).

68- Price P.B. and Walker R.M., Phy. Rev. Lett., 8 , P.217, (1969).

69- Fuji M. and Yokota R., Nuclear Tracks and Radiation Measurement, 15, P.107, (1990).

70- Fleischer R.L., Price P.B., Walker R.M., and Hubbard E.L., Physical Review, 133A, P.1443, (1964).

71- Fleischer R.L., Price P.B. and Walker R.M.,Ann. Rev. Nucl. Sci.,15, P.15 ,(1965).

72-Velickovic D., Miric I. and Bojoric P., "Proceeding of the 11th Inter. Conf. on Solid State Nuclear Track Detector ", Lyon, P.583, (1981).

73- Gohn C.E. and Golden R., Rev. Sci. Inst., **43** , P.13, (1972) .

74- Monnin M.M., Nuclear Inst. and Meth., **173** , P.1, (1980).

75- Hepburn c. and Windle A.H., J. Material Science, **15**, P.279 (1980).

76- Mohammed A.A., "Polymer chemistry", Mosul Press, Iraq (In Arabic), (1993).

77- Durrani S.A., and Bull R.K., "Solid State Nuclear Detection; Principles, Methods and Applications ", Pergamon Press, U.K., (1987).

78- Nichulas T., " Measurement and Detection of Radiation ", Pergamon Press, University of Missouri-Rolla, U.K., (1987).

79- Hayes R., Cheng C. H., Preliminary evaluation of real time false CAM alarm through continuous radon monitoring, J.of Health Physics, 84, 5, 589 – 592, (2003).

80- Durridge Company Inc., Reference Manual version 6.0.1, RAD7™ Electronic Radon Detector, (2000).

81- EPA Environmental Protection Agency, Office of Air and Radiation,6604J,Indoor radon and radon decay product measurement deviceprotocols,USA,1992(Online) http://www.epa.gov/radon/pubs/devprot1.html. Last updated 24 March (2003).

82- Tsoulfanidis N.,"Measurement and detection of radiation" Hemisphere Publishing Corporation, (1983).

83- Durridge Company Inc., Reference Manual version 6.0.1, RAD-7 Electronic Radon Detector, (2010).

84- Speelman w.j.," modelling and measuerment of radon diffusion through soil for application on mine tilling dams" master Thiess , University of the Western Cape,(2004).

85- المقدادي،كاظم" التلوث الإشعاعي و إضراره... ليست شائعات " موسوعة النهرين http://nahrain.com

86- (National Council on Radiation Protection and Measurements) "Measurement of Radon and Daughters in Air "NCRPT No.97, Bethesda, (M.D.) U.S.A. November 15, (1988).

87- Michael F.,"Radioactivity introduction and history"1st edition, Elsevier (2007).

88- Chen J.,Rahman N.M. and Atiya I.A.,"Radon exhalation from building materials for decorative use ",Journal of Environmental Radioactivity,**101**,pp.17-22, (2010).

89- EL-Araby, E. H. and EL-Sayed A., " Study of indoor ^{222}Rn concentrations in different classes in faculty of science - Jazan university " Journal of Applied Science, **8**, No.2, pp.1585-1588, (2012).

90- Al-Fifim Z., El-Araby E.H. and Elhaes H.,"Monitoring of Radon Concentrations in Jazan Beach Soil " Journal of Applied Science, **8**, No.2, pp.823-827, (2012).

91- Wiegand J. "A Guideline for the Evaluation of the soil Radon Potential Based on Geogenic and Anthropogenic parameters " Journal of Environmental Geology,Vol40, PP949-963 (2001).

92- Mahmoud R. " Measurement of radon and Its Daughter's Concentration in indoor and outdoor throughout Gaza Strip " theses is M.Sc. Islamic University of Gaza (2003).

93- Mowlavi A.,M., Fornasier M.R., Binesh A. and de Denaro M. " Indoor radon measurement and effective dose assessment of 150 apartments in Mashhad, Iran" Environ Monit Assess, **184**, pp.1085-1088, (2012) .

94- Ismail A.,H. and Jaafar M.,S., " Indoor Radon concentration and its Health Risks in Selected Locations in Iraqi Kurdistan using CR-39 NTDs" Bioinformatics and Biomedical Engineering (iCBBE) , ldo 4th international Conference in Cheng du ,18-20 June, (2010).

95- Abdullah,A.A., "Internal and external radiation exposure evaluation amongst selected workers and locations in Iraq" Ph.D. Thesis, University Sains Malaysia, Malaysia, (2013).

96- Kansal S., Mehra R. and Singh N.,P. " Life time fatality risk assessment due to variation of indoor radon concentration in dwellings in western Haryana, India" Applied Radiation and Isotopes, **70**, pp.1110-1112, (2012).

References

97- ICRP "International Commission on Radiological Protection Publication", Protection against Radon-222 at home and at work, Annals of ICRP: Oxford: Pergamon press, (1994).

98- (ICRP) (International Commission on Radiological Protection Statement on Radon), ICRP, Ref. 00/902/09, (2009).

99- ICRP, "Protection Against Rn-222 at Home and at Work" International Commission on Radiological Protection Publication, 65, Annals of ICRP 23 (2), Pergamon Press; Oxford, (1993).

الخلاصة

في هذه الدراسة تم قياس تركيز الرادون في الهواء داخل بنايات كلية التربية للعلوم الصرفة / ابن الهيثم باستعمال طريقتين CR-39 التي تعتبر الطريقة الغير فعالة وطريقة Rad-7 التي تعتبر الطريقة الفعالة . حيث شملت الدراسة بنايات العمادة وقسم الفيزياء ، قسم الكيمياء ، قسم الاحياء ، قسم علم النفس والمكتبة ، قسم الرياضيات ، المختبر الخدمي اضافة الى بنايات متفرقة داخل الكلية . كما تم حساب المؤثرات الاشعاعية لتراكيز الرادون داخل هذه الابنية التي تم حساب تركيز الرادون فيها .

تم استعمال كاشف CR-39 لتسجيل اثار جسيمات الفا المنبعثة من غاز الرادون ، حيث تم توزيع (100) كاشف داخل الكلية كاشفين في كل غرفة عدا غرفة واحدة وضع فيها اربعة كواشف لمدة (30) يوم وعلى ارتفاع (160 cm) ، الكواشف بمساحة ($1\ cm^2$) . تم قياس تركيز الرادون باستعمال كاشف Rad-7 مباشرة خلال (30) دقيقة في كل غرفة . حيث كانت النتائج لتركيز الرادون في الهواء والتي سجلت باستعمال كاشف CR-39 تتراوح بين ($17.412\pm2.192\ Bq/m^3$) و($445.868\pm81.966\ Bq/m^3$) وبمعدل ($123.8652\ Bq/m^3$) حيث كانت كل النتائج ضمن المدى المقبول به والمسجل من قبل (ICRP) ($200\text{-}300\ Bq/m^3$) عدا نموذجين كانت النتائج لهما اعلى من الحد المقبول وهذين النموذجين هما F1 و F2 في بناية التعليم المجاني لأن هذه الاماكن كانت تحت الارض ، واماكن قليلة التهوية وبنايات قديمة . اما باستعمال Rad-7 فان النتائج كانت تتراوح بين ($0.0\ Bq/m^3$) و ($59.6\ Bq/m^3$) فكانت جميع النتائج لكل البنايات ضمن المدى المقبول به عالميا .

كما تم حساب المؤثرات الاشعاعية والتي تمثلت بالجرعة الاشعاعية المؤثرة ، سرطان الرئة لكل سنة لكل مليون شخص ، التعرض لوليدات الرادون وكذلك تركيز طاقة الفا المجهدة . كل نتائج المؤثرات الاشعاعية التي تم حسابها كانت ضمن الحد المقبول عدا الجرعة الاشعاعية المؤثرة كانت اعلى من المدى المقبول به في نموذجين F1 و F2 لان تركيز الرادون في تلك الاماكن كان عاليا .

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة بغداد
كلية التربية للعلوم الصرفة /ابن الهيثم

حساب تراكيز الرادون في ابنية كلية التربية / ابن الهيثم باستعمال كاشف الأثر النووي CR-39 ومرقاب Rad-7

رسالة الطالبة

دعاء عبد سالم حسين

تقدمت بها الى مجلس كلية التربية للعلوم الصرفة /ابن الهيثم / جامعة بغداد
وهي جزء من متطلبات نيل شهادة الماجستير في علوم الفيزياء

بإشراف

أ . م . د سميره احمد ابراهيم

2018 ميلادي

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