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Radon Concentration Measurements and Annual Effective Dose from Drinking Water and Soil of Samawa City-South of Iraq

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master in Physics Science

By

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بسم الله الرحمن الرحيم

يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنْكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ

وَاللَّهُ بِمَا تَعْمَلُونَ خَبِيرٌ ﴿١١﴾

صدق الله العلي العظيم

(سورة المجادلة /الآيه١١)

Certification

I certify that this thesis entitled "***Radon Concentration Measurements and annual effective dose from drinking water and soil surface of Samawa city-South of Iraq*** " was prepared by "***Russel Saheb Mohammed***" under my supervision at the Department of Physics, College of Science, Al-Muthanna University, as a part of the requirements of the Master degree of Science in physics.

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Recommendations of the Head of the Physics Department

In view of the available recommendations, I forward this thesis for debate by the examining committee.

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Abstract

Exposure to radioactive elements from water, soil or having them through drinking water causes many biological risks. Therefore, it is important to investigate the drinking water and soil especially in regions where people lived in it. This study aims to establish the first baseline measurements for radon concentration in the drinking water and soil of Samawa city districts. In the present study, measurements of radon concentration were carried out for drinking water and soil of Samawa City. The measurements are conducted using RAD7 continuous radon monitoring detector manufactured by Durridge company, USA. In the present work, radon concentrations are measured in 167 samples of tap water were collected from 32 districts in the study area in two months extending from December 1st, 2019 to January 31th, 2020. The results show that radon concentrations were varied from (0.015 ± 0.13 Bq/L) to (1.01 ± 0.38 Bq/L) while the average value was (0.175 Bq/L). The annual effective dose due to ingestion and inhalation for child and adult was calculated. Also, the mean of the total annual effective dose for adults and children was determined and found to be (1.282 μSv/yr) and (1.923 μSv/yr) respectively. Radon measurements in the soil of Samawa City were carried out. A total of (100) different locations were chosen in order to determine radon activity in the soil. Radon activity in soil was measured at depth of(40 cm). Radon measurements were carried out for two months, From February 1st, 2020 to March 31th, 2020.

Radon soil gas activity concentration is found to vary from (29 Bq/m^3) to (6820 Bq/m^3) with an average value of (1343.5 Bq/m^3). Associated annual effective dose due to inhalation has been found to be in the range of (1.105$\mu Sv/yr$) to (43.84 μSv/yr), with an average value of (12.76 μSv/yr). The radon concentration from drinking water and soil and annual effective dose which were determined for each district indicate that the Samawa city can be regarded as having normal levels of radon which indicates that does not pose any kind of health hazards or radiological effects for the inhabitant of the study area.

Dedication

To

*Who taught me to give without Waiting .....

(My mother)

*Who bears his name with pride.....

(My father)

*Who his love with the extension of the soul.....

(My husband)

*Who saw innocence in all its meanings.....

(My daughter)

*Who joined me with their love.....

(my brothers and sisters)

*Who was the support in my scientific journey.....

(My colleague Ahmed)

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LIST OF SYMBOLS AND ABBREVIATIONS

Abbreviation	**Key**
RAD7	An electronic radon detector
α	Alpha radiation
AED	Annual Effective Dose
H_{ing}	Annual effective dose due to the ingestion of radon
L	Annual drinking water consumption in liters
H_{inh}	Annual effective dose due to the inhalation of radon
R	Air to water concentration
D_{inh}	Annual effective dose received by the public
β	Beta radiation
D_{ing}	Conversion factor for ingestion
D	Dose conversion factor
DCF	Dose conversion factor for radon exposure
EC	Electric Conductivity
F	Equilibrium factor between indoor radon and its progeny
T	Exposure time in hours for adults and children
D	Exhalation diffusion constant
GPS	Global Positioning System
ICRP	International Commission on Radiological Protection
MCL	Maximum Contamination Level
C_{Rn}	Mean Radon concentration in drinking water

I	Mean outdoor occupancy time per individual
NORM	Naturally Occurring Radioactive Materials
RAD H_2O	RAD7 accessory to determine radon concentration in water
C_{SG}	Radon activity in the soil
USEPA	United States Environmental Protection Agency
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
WHO	World Health Organization

Chapter One

INTRODUCTION

1.1 Introduction

Radiation is energy in the form of waves or streams of particles. There are many sources of radiation around us such as atomic energy, nuclear power, and radioactivity. The radiation has many forms, visible light is a familiar form of radiation, in addition to ultraviolet, infrared, and radio and television signals [1,2]**.** Naturally, radiation is available in our environment since the creation of the earth. Hence, life has evolved in an environment that has significant levels of ionizing radiation. Radiation comes from outer space (cosmic), the ground (terrestrial), and even within our bodies. It exists in the air, food , water, and the construction materials used to build our houses [3]. In physics, radiation is a process in which energetic particles or energetic waves travel through a medium or space. Two types of radiation are commonly detected in the way they interact with normal chemical matter, depending on the radiation energy, these types are ionizing and non-ionizing radiation [4].

The word “radiation” was used until about 1900 to refer to electromagnetic waves, around the beginning of that century, x-ray, electrons, and natural radioactivity were discovered and were also classified under the term “radiation”. These newly discovered types of radiation exhibited characteristics of particles, in contrast to the electromagnetic radiation, which was treated as a wave [5].

The history of ionizing radiation was started with X-ray discovery by **Wilhelm Röntgen** in 1895 [6]. In 1896, **Henri Becquerel** discovered radioactivity. He placed samples of uranium sulfate onto photographic plates, which were enclosed in black paper or aluminum sheet to protect the plates from exposure to light. After developing the photographic plates he noticed that the plate is affected because the uranium salt emitted rays that could pass through the black paper and even a metal sheet or thin glass positioned between the uranium salts and the photographic plates [7]. In 1898, **Ernest Rutherford** carried out experiments that demonstrated two types of radiation existed; one radiation that was most easily absorbed by matter and another that possessed a greater penetrating power and does not be absorbed quickly. And therefore, he named these radiations as "alpha" and "beta" rays.

Not much later, **P. V. Villard** in France discovered in 1900, yet more penetrating radiation, that was named " gamma " ray [8].

Radiation is often separated into two categories, ionizing and nonionizing, to denote the energy and danger of the radiation. Ionization is “the process of removing electrons from atoms, leaving electrically charged particles (ions) behind”. Many forms of radiation such as heat, visible light, microwaves, or radio waves do not have a sufficient energy to remove electrons from atoms and hence, are called non-ionizing radiation. In the case of heat, for objects at room temperature, most of the energy is transmitted at infra-red wavelengths. [9].

1.2 Basic Theory about Radioactivity

Some isotopes are unstable and their number of protons and neutrons do not remain constant [10]. Instead, they transform through different radioactive decay processes. During the radioactive decay, energy-rich particles and radiation are emitted from the nuclei of these unstable atoms that often refer to as radionuclides [11]. As a result of the radioactive decay process, atoms emit different types of radiation and transforms into a new atom with new properties different from parent compounds [12].

Three common types of radioactive processes are alpha decay, beta decay, and gamma-ray emission. Different particles are emitted during these processes. For alpha decay, the particle is a helium nucleus that consists of two neutrons and two protons [13]. On the other hand, several types of beta decay processes emit different particles: electron capture, $\beta^-$and β^+decay processes. An example of the emitted particles is the electron and antineutrino emitted during the β^- decay process. In contrast to alpha and beta decay, gamma decay which is the third type by which photons emitted instead of particles [14]. These decay processes can be combined, and for some radionuclides, alpha and beta decay processes are followed by emission of gamma-ray radiation [10].

The properties of the emitted particles determine their ability to travel through matter. According to particles with higher charge and size have less ability than smaller particles to penetrate materials, for example, alpha particles can be stopped by a piece of paper. On the other hand, gamma-ray radiation requires very dense materials, such as lead, to be hindered to some extent [15]. Moreover, the product from radioactive decay is not necessarily stable, and subsequently, radioactive decay may occur. The so-called decay series describe the stages of radioactive decay until a stable isotope is created [16].

1.3 Radioactivity

Radioactivity is “the process of the spontaneous decay and transformation of unstable atomic nuclei accompanied by the emission of nuclear particles and/ or electromagnetic radiation” [7].

1.4 Particles Radiation

Several types of particles are released during many processes of radiation, with different characteristics such as mass, charge, and the ability to penetrate mediums and materials.

1.4.1 Alpha Particles

An alpha particle is a positively charged particle emitted in the radioactive decay of some unstable atoms. It consists of two protons and two neutrons (it is essentially the nucleus of a helium atom) and thus its heavier and slower-moving than other decay emissions. Alpha particles do not penetrate deep into a material and can be stopped quite easily (e.g. by a thin piece of paper or skin). However, they are capable of breaking chemical bonds (which can cause chemical or biological damage) when they strike a molecule because of their size, mass, and charge. (Penetration distance of alpha particles depends upon the energy with which they are emitted and the material through which they are passing) [17]. Thus, alpha emitters (such as Uranium-238, Radium-226, and Radon-222) are mostly damaging if they are ingested or inhaled into the lungs [9].

α Decay: a nucleus emits an α particle (helium nucleus). The decay process is**:**

$$ {}_{Z}X^{A} \rightarrow {}_{Z-2}Y^{A-4} + {}_{2}He^{4} $$

where X and Y are initial nuclide (parent) and final nuclide (daughter), respectively, A is the mass number, Z is the atomic number.

1.4.2 Beta Particles

A beta particle is emitted during the radioactive decay of some unstable atoms. Beta particles can have either a negative charge (electron) or a positive charge (positron). In addition they have the same very small mass (1/2000 the mass of a neutron) regardless of charge [18]. Beta particles can penetrate deeper than alpha particles (Its penetration distance depends upon the energy of beta particle and material used). However, they can be stopped fairly easily by a sheet of aluminum.

β Decay: The nucleus can correct a proton or a neutron excess by directly converting a proton into a neutron or a neutron into a proton. These processes can occur in three possible ways [19]:

$\beta^{-} decay$: n $\rightarrow p + \beta^{-} + \bar{\nu}$

$\beta^{+} decay$: p $\rightarrow n + \beta^{+} + \nu$

Electron capture: $p + e^{-} \rightarrow n + \nu$

1.5 Electromagnetic Radiation

Two types of electromagnetic radiation are associated with radioactive decay. Electromagnetic radiation is referred to as a gamma-ray (this happens when the nucleus transitions from a higher energy level to a lower energy level). Electromagnetic radiation emitted by an atomic electron changing energy levels is referred to as an x-ray. Gamma rays usually have higher energies than x-rays and both can penetrate matter farther than any particles. They can be stopped by high-density materials such as several feet of concrete or lead [20].

1.6 Neutrons

Neutrons are particles having a mass of 1/4 that of an alpha particle and 2000 times that of a beta particle. The neutron is electrically neutral. It has the potential to penetrate matter deeper than any other charged particles but this depends greatly on the physical and atomic nature of the matter being penetrated [21].

1.7 Types of Radiation

Radiation is classified into two major types depending on the biological effect that can be caused as a result of exposure, these types are: ionizing and non- ionizing radiation

1.7.1 Ionizing Radiation

Ionizing radiation is capable of taking off electrons out of their orbits around atoms giving the atom a positive charge. Electrically charged molecules and atoms are called ions [21,22]. Materials are ionized in two ways (direct or indirect) [23].

1- Direct ionizing radiation: individual particles with adequate kinetic energy (i.e. electrons, protons, alpha particles, and heavy ions) can directly disrupt the atomic structure of the absorbing medium through which they pass producing chemical and biological damage to molecules.

2- Indirect ionizing radiation: photons (x-rays and γ-rays), neutrons, they do not produce chemical and biological damage themselves, but produce secondary electrons (charged particles) after energy absorption in the material.

1.7.2 Non-Ionizing Radiation

The energy of non-ionizing radiation is low, producing no charged ions when passing through matter, the electromagnetic radiation has only sufficient energy to change the rotational, vibrational or electronic valence configurations of molecules and atoms [3].

Non-Ionizing radiation includes several electromagnetic radiations such as radio waves, microwaves, infrared, visible light, and sometimes ultraviolet [24].

1.8 Radioactive Decay

Radioactive materials have an associated half-life, or decay time characteristic of that isotope. As radiation is emitted, the material becomes less radioactive over time, decaying exponentially [25].

Some radioisotopes have a long half-life; for example, ^{14}C takes 5,730 years for any given quantity to decay to half of the original amount of radioactivity. Other radioactive materials have a short half-life; ^{32}P has two weeks half-life, and ^{99}Tc (used in human and animal nuclear medicine diagnostic procedures) has a half-life of 6 hours [26].

1.9 Sources of Radiation

Naturally occurring radioactive materials (NORM) are common in the environment and the human body. These materials are continuously emitting ionizing radiation. In addition to NORM, there is ionizing radiation from outer space (cosmic radiation) bombards the earth constantly. Collectively, the ionizing radiation from these and similar sources is called background radiation. Furthermore, human activities, such as making medical x-rays, generating nuclear power, testing nuclear weapons, and producing smoke detectors that contain radioactive materials, cause additional exposure to ionizing radiation. The sources of radiation can be classified into natural and man-made radiation. The percentage of the average annual radiation exposure contributed by each major source is illustrated in Figure (1.1). About 82 percent is from nature, and 18 percent is from industrial, medical, and consumer sources. The values given in Figure

1.1 are averages for the United States. Actual values vary depending on where people live and how they spend their time [27].

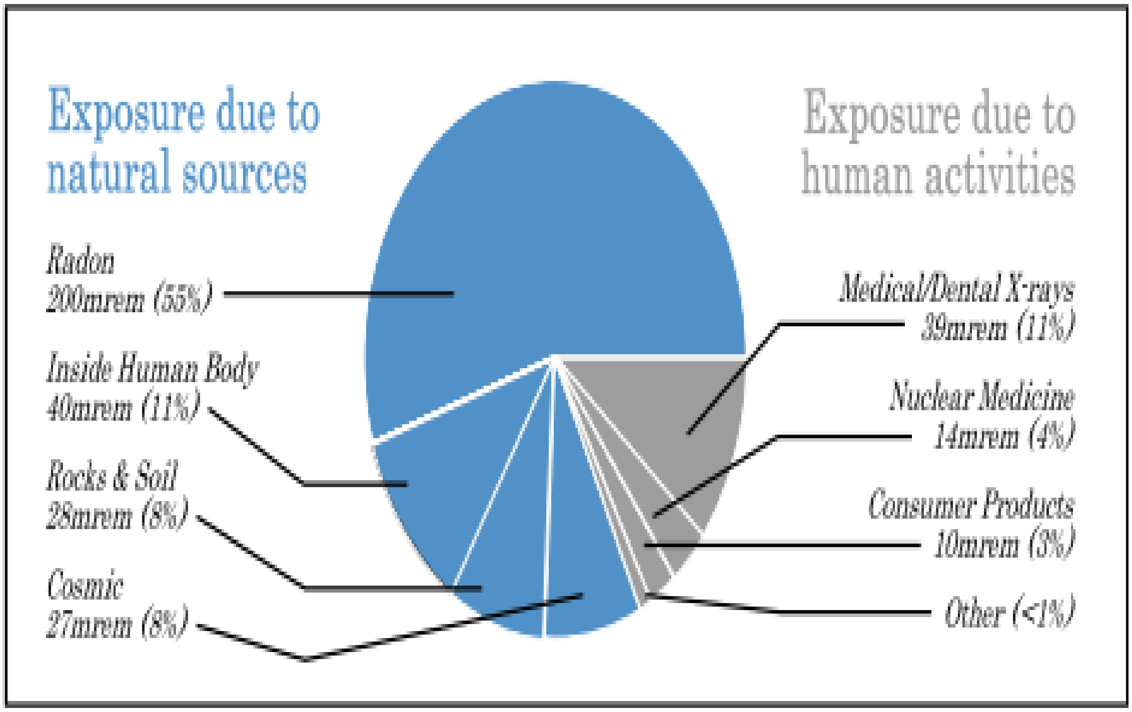


Figure (1.1): Average Annual Exposure to Ionizing Radiation (1Sv = 100rem)[27].

1.9.1 Natural Radiation Sources

Since the creation of the earth, its environment has been exposed to radiation both from outer space and from radioactive material in its crust and core. There is no way to avoid being exposed to these natural sources, which, in fact, cause most of the radiation exposure of the world's population. The global average effective dose per person is about 2.4 mSv and ranges from about 1 to more than 10 mSv depending on where people live. Buildings may trap a particular radioactive gas, called radon, or the building material itself may contain radionuclides that increase radiation exposure [28].

1.9.1.1 Primordial Radionuclides Sources

Primordial radionuclides sources include naturally occurring radioactive materials that exist in rocks, soil, water, and vegetation. The major isotopes of concern for primordial radionuclides radiation are uranium and its decay products, such as thorium, radium, and radon. Some of these materials are ingested with food and water, while others, such as Radon, are inhaled. The dose from a primordial radionuclides sources varies in different parts of the world. Locations with higher concentrations of uranium and thorium in their soil have higher dose levels [17]

These primordial radionuclides are left a long time ago. They are typically long-lived, with half-lives often on the order of hundreds of millions of years. Radionuclides that exist for more than 30 half-lives are not measurable. The progeny or decay products of the long-lived radionuclides are also in this heading. Here is some basic information on some common primordial radionuclides as shown in Table (1.1) [18].

Table (1.1): Primordial Radiation[18].

Nuclide	Symbol	Half-life	Natural Activity
Uranium-235	^{235}U	7.04×10^{8} yr	Of all natural uranium 0.72%
Uranium-238	^{238}U	4.47×10^{9} yr	Of all natural uranium; 99.2745% 0.4 to 4.7 ppm total uranium common rock types
Thorium-232	Th^{232}	1.41×10^{10} yr	1.6 to 20 ppm to common rock types with a crustal average of 10.7 ppm
Radium-226	Ra^{226}	1.60×10^{3} yr	0.42 pCi/g(16 Bq/kg) in limestone 1.3 pCi/g(48 Bq/kg) in igneous rock
Radon-222	Rn^{222}	3.82 day	Nobel Gas; annual average air concentration range in the US from 0.016 pCi/L(0.6 Bq/m^3) to 0.75 pCi/L(28 Bq/m^3)
Potassium-40	^{40}K	1.28×10^{9} yr	Soil -1-30 pCi/g (0.037-1.1Bq/g)

1.9.1.2 Cosmic Radiation

Cosmic rays are high energy charged particles, include high energy electrons, positrons, and other subatomic particles. originating in outer space, that travel at nearly the speed of light and strike the Earth from all directions. Charged particles from the sun and stars interact with the earth’s atmosphere and magnetic field to produce a shower of radiation. The dose from cosmic radiation varies in different parts of the world due to differences in elevations and to the effects of the earth’s magnetic field [29]. The energy of cosmic rays is usually measured in units of MeV, for mega-electron volts, or GeV, for giga-electron volts. Because cosmic rays are electrically charged they are deflected by magnetic fields, and their directions have been randomized, making it impossible to tell where they originated. However, cosmic rays in other regions of the Galaxy can be traced by the electromagnetic radiation they produce. Cosmic radiation is divided into two types, primary and secondary [30].

● **Primary cosmic radiation**:

Primary cosmic radiation is made up of extremely high energy particles (up to 1018 eV), and mostly protons (87%), with some larger particles (alpha radiation 12%). A large percentage of it comes from outside of our solar system and is found throughout space. Some of the primary cosmic radiation is from our sun, produced during solar flares, and some of it penetrates the earth's surface. The vast majority of it interacts with the atmosphere. These reactions produce lower energy radiations in the form of photons, electrons, neutrons, and muons that make it to the surface but are not considered hazardous to health due to their extremely low interaction cross sections [31,32].

● **Secondary cosmic radiation** :

When high energy cosmic rays undergo collisions with atoms of the upper atmosphere, they produce a cascade of "secondary" particles that shower down through the atmosphere to the Earth's surface. Secondary cosmic rays include pions (which quickly decay to produce muons, neutrinos and gamma rays), as well as electrons and positrons, which produced by muon decay and gamma ray interactions with atmospheric atoms. Most secondary cosmic rays reaching the Earth's surface are muons, with an average intensity of about 100 per m^2 per second [33]. Although thousands of cosmic rays pass through our bodies every minute, the resulting radiation levels are relatively low, as cosmic rays are deflected by the magnetic fields in interstellar space, they are also affected by the interplanetary magnetic field embedded in the solar wind (the plasma of ions and electrons blowing from the solar corona at about 400 km/sec), and therefore have difficulty reaching the inner soil system [34].

The Sun is also a sporadic source of cosmic ray nuclei and electrons that are accelerated by shock waves traveling through the corona, and by magnetic energy released in solar flares. Solar energetic particles can be used to measure the elemental and isotopic composition of the sun, thereby complementing spectroscopic studies of solar material [35].

1.9.1.3 Terrestrial Radiation

Only nuclides with half-lives comparable with the age of the earth (or decay products, whose concentration is governed by them) exist in terrestrial materials. In terms of dose, the principal primordial radionuclides are ^{40}K, ^{232}Th and ^{238}U whereas ^{87}Rb and ^{235}U of secondary importance [36].^{40}K of the former the most important, with a half-life of 1.27×10^9 years, which emits both beta and gamma radiation.

Natural potassium consists principally of the stable isotope ^{39}K, and only 0.012% by weight is the radioactive ^{40}K. In contrast, two radionuclides of uranium and one of thorium decay to give rise to families of radionuclides which decay in three distinct series. All three series contain alpha emitters. The first one begins with the decay of ^{238}U (half-life of 4.5×10^9years) and called the uranium series, a second begins with ^{232}Th (half-life of 1.4×10^{10}years), it is called the thorium series, and the third begins with ^{235}U (half-life of 7.1×10^8years), It is called actinium series**.**

All the three decay through three complex chains to stable isotopes of lead, ^{206}Pb, ^{208}Pb, and ^{207}Pb respectively [37,38]. There is the fourth series called Neptunium series ^{237}Np, This series was recreated after ^{241}Pu was made in nuclear reactors. This series does not occur naturally since the half-life of the longest-lived member of the series ^{237} Np is only 2.14 *10^6 y, much shorter than the lifetime of the earth. Hence, any members of this series that were in the original material of the solar system have long since decayed away [39,40].

A: ^{238}U Series

Uranium occurs naturally in the form of ^{234}U, ^{235}U, ^{238}U. The relative abundance of ^{238}U is 99,274% and the equilibrium concentration of granddaughter ^{234}U is 0.0054%. The relative abundance of ^{235}U is 0.7205 % on average. ^{238}U is the longest-lived member of (4n+2) series (n varying from 51 to 59), which includes ^{234} U as a member, with decay series as shown in Table (1.2) [17].

Table (1.2): Uranium-238 Series.

Nuclide	Half-life	Type of decay	Particles Energy (MeV)
U^{238}	4.5 x 10^9 y	α	4.18
Th^{234}	24.1 d	β	0.19
Pa^{234}	1.18 min	β	2.31
U^{234}	2.48 x 10^5 y	α	4.76
Th^{230}	7.52 x 10^4 y	α	4.69
Ra^{226}	1600 y	α	4.78
Rn^{222}	3.825 d	α	5.49
Po^{218}	3.05 min	α	6.0
Pb^{214}	26.8 min	β	0.65
Bi^{214}	19.7 min	β	0.4 – 3.2
Po^{214}	1.64 x 10^{-4} s	α	7.68
Pb^{210}	22 y	β	0.02
Bi^{210}	5.01 d	β	1.16
Po^{210}	138.4 d	α	5.3
Pb^{206}	Stable	…..	…..

B: ^{232}Th Series

Natural thorium consists of almost entirely of ^{232}Th, 1.35*10^{-8} % of ^{228}Th, and extremely small amounts ^{234}Th, ^{230}Th, ^{231}Th, and ^{227}Th. ^{232}Th is the parent of 4n radioactive decay series (n varying from 52 to 58). The decay series is shown in Table (1.3) [6].

Table (1. 3): Thorium-232 Series.

Nuclide	Half-life	Type of decay	Particle Energy (MeV)
Th^{232}	1.4*10^{10} y	α	4.01
Ra^{228}	6.7 y	β	0.05
Ac^{228}	6.13 h	β	1.11
Th^{228}	1.9 y	α	5.43
Ra^{224}	3.64 d	α	5.68
Rn^{220}	54.5 d	α	6.29
Po^{216}	0.158 s	α	6.78
Pb^{212}	10.6 h	β	0.35
Bi^{212}	60.6 min	α β	6.05 2.25
Po^{212} Or Th^{208}	3.0*10^{-7} s 3.1 min	α β	1.57 8.78
Pb^{208}	Stable	---------	---------

C: ^{235}U Series

^{235}U is the longest-lived member of the naturally existing parent of (4n+3) series (n varying from 51 to 58). The decay chain for ^{235}U is shown in Table (1.4) [24].

Table(1.4): Uranium-235 Series.

Nuclide	Half-life	Type of decay	Particle Energy (MeV)
U^{235}	$7.10*10^{8}$ y	α	4.18
Th^{231}	25.6 h	β	0.30
^{231}Pa	$3.98*10^{4}$ y	α	5.0
Ac^{227}	22 y	α β	4.94 0.04
Fr^{223} Or Th^{227}	22 min 18.17 d	β α	1.15 5.97
Ra^{223}	11.7 d	α	5.71
Rn^{219}	3.92 s	α	6.82
Po^{215}	$1.83*10^{-3}$ s	α	7.38
Pb^{211}	36.1 min	β	1.4
Bi^{211}	2.15 min	α	6.62
Po^{211}	0.52 s	α	7.45
TI^{207}	4.79 min	β	1.44
Pb^{207}	Stable	------	-------

1.9.2 Man-Made Radiation Sources

Natural and artificial radiation sources are identical in their nature and their effect. By far, the most significant source of man-made radiation exposure to the general public is from medical procedures, such as diagnostic X-rays, nuclear medicine, and radiation therapy. Some of the major isotopes would be ^{131}I, ^{99}Tc, ^{60}Co, ^{192}Ir, ^{137}Cs, and others.

Besides, members of the public are exposed to radiation from consumer products, such as tobacco (polonium ^{210}Po), building materials, combustible fuels (gas, coal, etc.), ophthalmic glass, televisions, luminous watches and dials (tritium), airport X-ray systems, smoke detectors (americium), road construction materials, electron tubes, fluorescent lamp starters, lantern mantles (thorium), etc [30].

Occupationally exposed individuals are exposed according to their occupations and to the sources with which they work. The exposure of these individuals to radiation is carefully monitored with the use of pocket, pen-sized (two words) dosimeters. Some of the isotopes of concern would be cobalt (^{60}Co), cesium (^{137}Cs), americium (^{241}Am), and others [18].

1.10 Radon

In 1900 the German physicist **Friedrich Ernst Dron** discovered radon. Its atomic number is (86) and mass number is (222) in the periodic table [41]. The sources of radon gas (Rn^{220}, Rn^{219}, Rn^{222}) 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 [42]. Radon is a rare natural element as it is found in gas form, noble and radioactive in its isotopes. Radon gas can be gathered in buildings, especially in closed regions, such as under roofs and basement. It is found in some spring waters and hot springs too [43]. Radon inhalation may be a problem for human health. Since radon is a noble gas, this guarantees that it cannot be frozen through chemical reactions [44]. ^{226}Ra whose half-life is (1600) years can be formed through Uranium-238 decay during four intermediate cases, after that it decays to form ^{222}Rn gas which has a half-life of (3.82) days, which in turn gives sufficient time to be diffused through the soil and then into houses, after that, it disintegrates so that it can produce more radio logically active Radon breeds (Radon daughters) [45].

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 [46]. Fig. (1.2) shows the contribution of radon in radioactive dose.

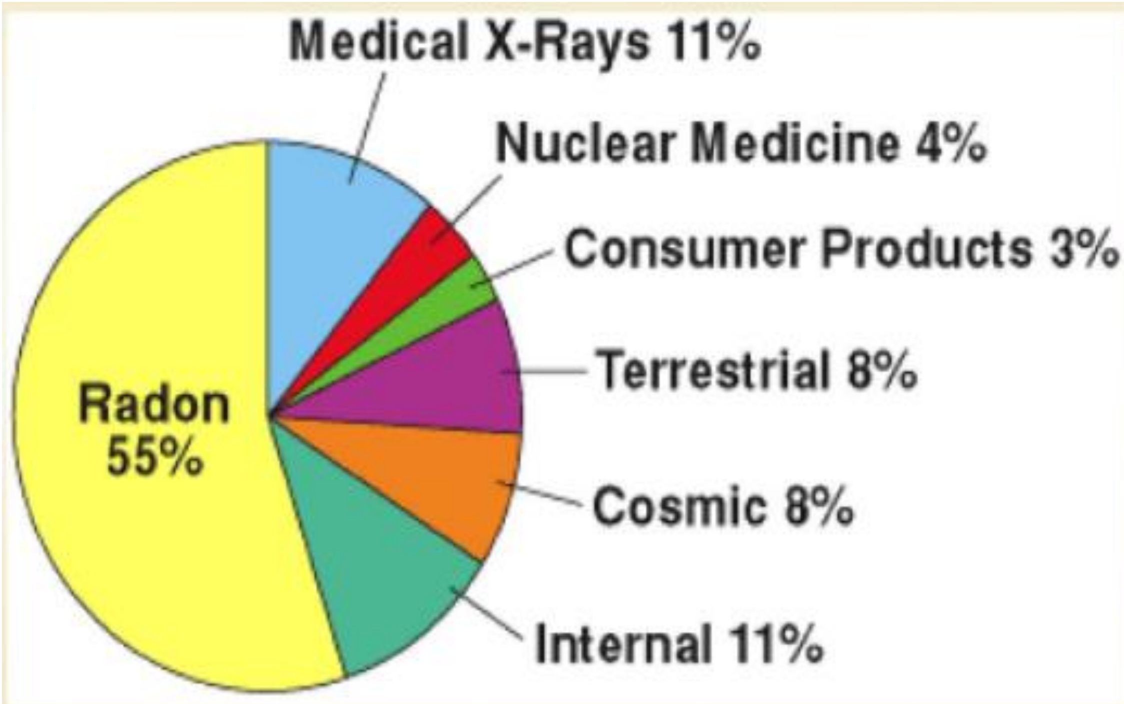


Figure (1.2): Contribution of Radon in Radioactive Dose [46].

1.10.1 Radon Isotopes

An isotope can be defined as one or two of atoms with the same atomic number but different mass numbers. Radon has three unstable isotopes, from three natural radioactive disintegration chains (U^{283}, Th^{232}, and U^{235}). Radon has several isotopes, where radon-222, radon-220, and radon-219 occur naturally. It is common to refer to these isotopes as radon (radon-222), thoron (radon-220) and actinon (radon-219) [15]. They are respectively formed in the Uranium, 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). Generally, radon-222 is perceived as the most important isotope [44]. Radon is a part of the decay series for the radionuclide uranium-238. There are several stages in the U-238 decay series where radon is the direct product of the radionuclide radium-226 as shown inTable(1.2). For the main series, there are several processes of alpha and beta decay between the initial uranium-238 and the final lead-206 isotope [23].

In most cases, thoron exposure is limited and does not pose any problem and the radiation exposure from actinon is insignificant due to their short half-lives. Radon is ^{222}Rn isotope to be distinguished from the other two natural isotopes which are called (Thoron ^{220}Rn and Actinon ^{219}Rn) because Due to these features and dosimetric respects, specific cases might pose a remarkable state of affairs where alpha dose measures are taken from ^{219}Rn and ^{220}Rn could be the major interest, yet these situations are still unique. In 1800, **Owens R.B** and **Ernest Rutherford** were the first who recognized ^{220}Rn. The ^{219}Rn gas was found in 1904 in an independent form by **Friedrich O. Giesel** and **Ander-Louis Debiernce**, to be related to Actinium [44].

The radon isotopes are:

$$^{226}_{88}Ra \rightarrow \ ^{222}_{86}Rn + \ ^{4}_{2}He$$

$$^{224}_{88}Ra \rightarrow \ ^{220}_{86}Rn + \ ^{4}_{2}He$$

$$^{223}_{88}Ra \rightarrow \ ^{219}_{86}Rn + \ ^{4}_{2}He$$

The half-life is an important concept for a radionuclide and is the time it takes for half of the initial amount of a radionuclide to decay [16]. Radon-222 has a half-life of (3.82) days and decays to the short-lived radon progeny: polonium-218, lead-214, bismuth-214, and polonium-214. Their half-lives are short and vary between 165 µs to 26.8 minutes. The product from the decay of polonium-214 is lead-210, which is an effectively stable radionuclide with a half-life of 22 years [34].

1.10.2 Physical Properties

Radon is a radionuclide that is happening in nature spontaneously. It has no color, odor, taste, and also it is an unseen gas with a density of (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 containers. The ability to dissolve in water becomes faster at low temperatures, radon's solubility is great. Its solubility decreases with an increase 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 [47].

1.10.3 Chemical Properties

Radon is chemically considered as 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 valences 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, as shown in Table (1.5) [40,48].

Table (1.5): Physical and Chemical Properties of Radon (^{222}Rn).

Characteristic	**Radon (Rn^{222})**
Chemical series Electron	Inert gas
Electron configuration	[Xe] $4f^{14}$ $5d^{10}$ $6s^2$ $6p^6$
Color	Colorless
Physical state	Gas at 0 Cº and 760 mm Hg
Atomic mass	(222) g . mol^{-1}
Density at 20 Cº	9.96 *10^{-3} g/cm^3
Melting point	202 ºK (-71 Cº)
Boiling point	211.3 ºK (-61.7 Cº)
Heat capacity	(25 Cº) 20.786 J/ (moL . K)
Crystal structure	Face centered cubic
Atomic radius	120 pm
Thermal conductivity	(300K) 3.61 m W·m^{-1} ·K^{-1}
Odor	Odorless
Solubility: Water at 20 Cº	230 cm^3/L
Organic solvents	Organic liquid, slightly soluble in alcohol
Vapor pressure at 25 °C	395.2 mm Hg

1.10.4 Radon Sources

The presence of ^{226}Ra in the ground of the facilities and the building materials is considered the main radon source of radon [49]. The outside air also has a role to radon concentration indoors, through the air ventilation. Other Radon sources can exist 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 [50].

1.11 Radon in Water, Soil, Building Material, and Air

Radon is found in all soils and rocks to some degree, but the amount can vary in different parts of the country and at different times of the year. It is formed in the ground by the radioactive decay of small amounts of radium which is a decay product of uranium itself. The gas rises to the surface and in the open air is quickly diluted to low and harmless concentrations in the atmosphere. However, once it percolates into an enclosed space, such as a building, it can accumulate to dangerous levels, depending on the concentration of radon in the underlying soil and the construction details of the building. Radon may also be introduced indoors by way of groundwater supplied from a well, or building material containing traces of radium.

1.11.1 Radon in Water

Radon can enter homes through water systems. Water in rivers and reservoirs usually contains very little radon, because it escapes into the air; so homes that rely on surface water usually do not have a radon problem from their water. In big cities, water processing in large municipal systems aerates the water, which allows radon to escape, and also delays the use of water until most of the remaining radon has decayed. In many areas, groundwater is used as the main water supply for homes and communities. Small public waterworks and private domestic wells often have closed systems and short transit times that do not remove radon from the water or permit it to decay. This radon escapes from the water to the indoor air as people take showers, wash clothes or dishes, or otherwise use water. A very rough rule of thumb for estimating the contribution of radon in domestic water to indoor air radon is that house water with 10,000 pCi/L of radon contributes about 1 pCi/L to the level of radon in the indoor air [51].

The area's most likely to have problems with radon in groundwater are areas that have high levels of uranium in the underlying rocks. For example, granites in various parts of the United States are sources of high levels of radon in groundwater that is supplied to private water supplies. In areas where the main water supply is from private wells and small public waterworks, radon in groundwater can add radon to the indoor air [52].

1.11.2 Radon in Soil

Radon forms in rocks and soil that contain uranium or thorium rocks have generally been thought to be the major source, radon production and migration in soil and bedrock define radon availability, while specific site and construction characteristics control the radon transfer into houses [53].

Radon moves into houses because of a negative pressure difference and due to a large concentration gradient between the (house) building and bedrock or soil. The radon concentration in houses is likely to relate fairly close to that in the soil although there is no well-established method of estimating radon levels in individual dwellings based on soil radon data. There are direct correlations between uranium, radium, radon in soil gas, and indoor radon concentrations, also suggested that geology and soil gas radon are useful indicators of indoor Radon concentration [54]. We considered that soil radon might provide a reasonable guide for assessing the potential for large radon concentrations in homes. ^{222}Rn and, ^{220}Rn, are usually produced in approximately equal quantities, but the latter is often ignored because its contribution to the overall dose of radiation is relatively small. For both the soil and buildings there are many other factors, in addition to the spatial variation in the source elements, that complicate the spatial variation of Radon emanation. For example, the spatial variation in soil permeability, porosity, Co_2 concentration in the soil gas, moisture content, and atmospheric pressure affect its emanation. Soil moisture content can increase radon emanation but, if the soil pores become saturated, the emission is inhibited. Carbon dioxide acts as a carrier gas for radon in the soil which can enhance its concentration in the soil atmosphere [55]. The values inside buildings depend on structural characteristics ventilation rates, aerosol concentration, central heating, building materials, and the habits of the inhabitants [56].

1.11.3 Radon in Building Materials

The radon emissions from building materials are important to consider in certain cases. In Sweden, concrete produced from alum shale with high uranium concentrations has been linked to elevated radon levels in the indoor air. It was produced between the years 1929-1975 and there was widespread use of this material [15]. For other building materials, the emission of radon can be prevented by the selection of materials with low radium concentrations.

1.11.4 Radon in Air

Radon moving through soil pore spaces and rock fractures near the surface of the earth usually escape into the atmosphere. In constructing a house with a basement, a hole is dug, footings are set, and coarse gravel is usually laid down as a base for the basement slab. Once the basement walls have been built, the gap between the basement walls and the ground outside is filled with material that often is more permeable than the original ground. This filled gap is called a disturbed zone.

Radon moves into the disturbed zone and the gravel bed underneath from the surrounding soil. The backfill material in the disturbed zone is commonly rocks and soil from the foundation site, which also generate and release radon. The amount of radon in the disturbed zone and gravel bed depends on the amount of uranium present in the rock at the site, the type of permeability of soil surrounding the disturbed zone underneath the gravel bed, and the soil's moisture content [57].

1.12 Health Effects Due to Radon Exposure

Exposure to radon has been linked to an increased risk of lung cancer. In Europe, it is estimated that 2 % of the deaths in cancer are due to radon exposure. The main risk groups are smokers and recent non-smokers. The risk for lung cancer is estimated to be

25 times larger for smokers compared to the risk for non-smokers [15]. In Sweden, it is estimated that 500 deaths from lung cancer each year can be linked to radon exposure [58]. The risk for lung cancer is related to radiation in the lungs and in particular the radiation from alpha particles. Generally, the release of alpha particles is not harmful to humans unless it takes place inside the body [16]. Radon emits alpha particles during its decay [34]. However, most of the inhaled radon is exhaled before it decays [59]. Thus, radon is only related to approximately 5 % of the alpha radiation in the lungs [60]. The main cause of alpha exposure is the inhalation of the radon progenies. The radon progenies are atoms that exist in the solid phase. They can be inhaled either as unattached atoms or as attached particles, where the progenies are absorbed to other particles such as dust particles. There is a large risk that they deposit and decay in the lungs before they are exhaled [34]. Two of the radon progeny emit alpha radiation, polonium-218 and polonium-214. It is this dose that is the predominant radioactive dose to the lungs and the dose associated with the risk for lung cancer. Especially, the bronchial and bronchiolar areas receive a large part of the radiation dose [61].

1.13 Literature Review

In the last decades, many previous studies have been conducted to estimate the radon concentration in water, soil, and others. In the following, the most important studies of radon in water and soil have been reviewed in the last two decades.

1.13.1 Literature Review of Radon in Water

S. Ezzulddin et al in (2008) [42], radon-222 and radium-226 activity concentration measurement in Erbil Governorate drinking water resources ,using active and passive detection methods. The measurement has been carried out by using RAD7 as an active method for alpha analyses, the obtained results show that the range of radon (^{222}Rn) concentration values vary from (0.081±0.002 to 14.742±0.262) Bq/L and from (0.069±0.01 to13.062±0.15) Bq/L using passive and active methods respectively.

K. Badhan et al in (2010) [62], used electronic radon monitor (RAD7) for assessment of radon contents in the groundwater of the National Institute of Technology, Jalandhar, Punjab, India. Radon concentrations in drinking water of location have been found to vary from 2.560 to 7.750 Bq/L with an average value of 5.143Bq/L. The PH value of water understudy also has been determined and it is found in the range of 6.69 to 7.0 and the average value is found to be about 6.99. No observed correlation has been recorded between pH values and radon concentrations.

H. Idriss et al in (2011) [1], measured and mapped radon activity concentration within groundwater supplies in Khartoum State, Sudan. Water samples have been collected before and after autumn and analyzed using low-level gamma spectrometry equipped with an HPGe detector. Radon concentration was found to vary from 1.58 to 345.10 Bq/L with an average value of 59.20±6.60 Bq/L. Physiochemical parameters also have been determined for the water samples and no correlation was observed between radon levels and these parameters.

A. Rani et al in (2012) [63], investigated radon concentration in groundwater that was taken from hand pumps over the different areas of Sri Ganganagar, Hanumangarh, Sikar, and Ghuru in northern Rajasthan, India. RAD7 an electronic radon monitor has been used to estimate radon concentration in groundwater. Radon levels were found to range from 0.5±0.3 Bq/L to 85.7±4.9 Bq/L, with an average value of 9.03±1.03 Bq/L in 89% of the samples, while the calculated annual effective dose ranged from 1.34 to 229.68 μSv/y.

I. H.K. Hadi and K.AL-attiyah in (2012) [64], Measurement and study of radioactive radon gas concentrations in the selected Samples of air and water for Hilla city, using the electronic radon detector RAD7. The average concentration of radon in drinking water (0.119 ± 0.048) Bq/L and the highest value (0.193 ± 0.02) Bq/L and the lowest value was (0.0361 ± 0.0001) Bq/L.

A.A. Abojassim and A.R. Shitake (2013), [65] estimated radon levels in drinking water of 24 location in Al-Najaf city, Iraq, by using RAD7 radon detector. It is found that the radon concentrations were varied from 0.00243±0.879 Bq/L to 0.2255±12.657 Bq/L. the annual effective dose due to inhalation has been calculated and is found to be within the range (0.0177 μSv/y) to (1.646 μSv/y).

B.C. Shivakumara et al in (2014) [66], determined radon concentration in naturally occurring groundwater of the Mandya district, Karnataka state. India. The radon concentration in borewell water is found to be within a range of 6.44±0.20 to 44.83±0.54 Bq/L with an average value of 16.42±0.31 Bq/L. While the total annual effective dose has been varied from (26.31 to 178.53) μSv/y.

N. Ahmed et el from Malaysia in (2015) [67], used RAD7 electric radon detector to determine radon activity concentration in drinking and irrigated water samples collected from various regions Sungai Petani, Kedah, Malaysia. The maximum average value of radon concentration among the different types of water samples was found(14.7 ± 1.44) Bq/L in well water and the minimum was found (5.37±0.58) Bq/L in tap water.

A. Jafir et al in (2016) [68], studied the seasonal measurements of radon in Darbandikhan Lake water resources at Kurdistan region, Iraq. The assessment includes 164 water samples collected from the lake and its different resources during the whole year, and the estimation was carried out using the electronic RAD7 detector. The average radon concentrations for spring water during spring, summer, autumn, and winter were found to be 8.21 Bq/L, 8.94 Bq/L , 7.422 Bq/L, and 8.06 Bq/L, respectively. While the average values were found to be 0.43 Bq/L, 0.877 Bq/L, 0.727 Bq/L, and 0.575 Bq/L for the lake and streams. It is observed that the radon concentration was high in summer and low in spring. The mean annual dose is estimated for spring water during the four seasons and it is found to be 0.022 mSv/y while for the lake with streams was 1.57 μSv/y. Also, some physicochemical parameters were measured and no correlation was noted between radon concentration and these parameters except for the conductivity of the spring water which reveals a strong correlation for the whole year.

V. Duggal et al in (2017) [69], measured radon concentration in 59 groundwater samples collected from the Fatehabad district of Haryana, India. The measurements were carried out by the RAD7 radon electronic detector manufactured by Durridge company Inc. Radon levels were found within the range of (1.4-22.6) Bq/L. 14% of the groundwater samples were above the (US EPA) recommended value for radon in water. The total annual effective for ingestion and inhalation dose was evaluated and found to vary from(14.1 to 221.8) μSv/y.

A. Naskar et al (2018) [70], evaluated the radon concentrations for tube-wells samples collected from 173 different locations in Bakreswar and Tantoli, Budapest, Hungary. The radon levels were observed to fluctuate widely between 3.3 and 803.8 Bq/L with an average of 106.8 Bq/L. About 42% of the samples posed radon content above the safe limit of 100 Bq/L proposed by WHO and EU. The corresponding annual effective dose was varied between (16.72 and 4079.47) µSv/y with an average value of 541.92 µSv/y.

O. Günay et al (2019) [45], used Alpha GUARD portable radon detector for measurement of indoor radon concentration and annual effective dose estimation at several locations in Akfirat campus of Istanbul Okan University. The concentration of radon in the basement of the Faculty of Health Sciences is 0.0325±8.5 Bq /L. When the measurements on the ground floor are examined, it is seen that the minimum radon concentration is 0.0132±6.4 Bq /L in the Faculty of Health Sciences (Health-GF). The maximum radon concentration is (0.0243 ± 8.5) Bq /L in the Faculty of Engineering (Engineering-GF). The average radon concentrationis17.4±7.2 on the ground floor and the average radon concentration is 0.0085±3.9 Bq /L on the first floor.

A. Sharrad and A.K.Farhood in (2020) [37], studied the seasonal measurements of radon in Sawa Lake water resources at Samawa City, Iraq. The assessment includes 85 water samples collected from the lake during two seasons, winter and spring for two months for each season, and the estimation was carried out using the electronic RAD7 detector. Radon activity concentrations were ranged from (0.111 Bq/L) to (0.965 Bq/L), while the average value was (0.396 Bq/L), the annual effective dose (AED) of inhalation was estimated from the measured radon concentrations and is found to be ranged from (0.080784 µSv/y) to (0.917136 µSv/y) with a mean value of (0.325764 µSv/y).

1.13.2 Literature Review of Radon in Soil

B. Singh et al in (2010) [71], determined radon concentrations in the soil for 39 locations of Northern Punjab, India, using Alpha GUARD PQ 2000 PRO detector. The soil gas radon concentration was found to vary from 0.3 to 35.8 kBq/m^3. Soil temperature, pressure, and humidity also have been investigated to find out if there was a correlation between these parameters and radon in soil concentration.

A. Hasan et al in (2011) [72], measured the soil gas radon concentrations at 15 sites for different depths in the Najaf Al-Ashraf city, Iraq, using RAD7 active radon detector. The highest value of radon concentration was 9290±400 Bq/m^3 for the depth of 60 cm in Al-Amir district, while the lowest value was 9±17 Bq/m^3 in Al-Shoara district at a depth of 5 cm.

A. Al-hamidawi et al in (2012) [73], conducted a set of measurements of radon concentrations of soil gas in Al-Kufa City, Iraq, RAD7 electric radon meter. Radon concentration levels were measured in 20 locations for depths of 50, 100, and 150 cm. The result showed that the radon concentrations from location to another, depending on the geological formation. For 50 cm depth, the soil gas radon concentrations were varied from 697.5±119.145 Bq/m^3 to 8835±513.703 Bq/m^3 and for the depth of 100 cm, it is found to be within the range of 178.75±25.303 - 12775±386.48 Bq/m^3, while ranged from 41.45±16.500 Bq/m^3 to 9535.5±712.729 Bq/m^3 for 150 cm depth.

K. Szabó et al (2013) [74], studied the seasonal and daily variation of soil radon concentration in a highly permeable sandy-gravelly soil to understand if the temporal variation of radon soil gas concentration can affect radon potential determination. Results showed that the seasonal and daily variations of the measured radon concentration in highly permeable sandy-gravelly soil with definite seasons without obvious long transitional periods. The winter is characterized by 2.5 times higher average soil gas radon concentration with a median of 7.0 kBq/m^3 than the summer with a median of 2.8 kBq/m^3.

V. Duggal et al (2014) [75], investigated soil gas radon concentration in Sri Ganganagar district of Rajasthan, India. A radon survey was carried out using the RAD7 radon electronic detector. Radon concentration in soil gas was conducted for different depths (10, 40, 70, and 100 cm), the radon concentration was in the range of 0.09-4.25 kBq/m^3 for 10 cm depth and varied from 0.15 kBq/m^3 to 6.30 kBq/m^3 for 40 cm depth, while it ranged between 0.50 kBq/m^3 and 9.18 kBq/m^3 and was 0.72-10.40 kBq/m^3 for 100 cm depth.

P. Ravikumar et al (2015) [76], made a radon survey in different sites in the Chitradurga district of Karnataka state, India, using RAD7 an electronic radon monitor to explore the pattern of geological and seasonal changes of radon concentrations in soil gas at different locations. Radon concentration in the soil ranged from 0.5 to 812.9 Bq/m^3 with a mean value of 93.78 Bq/m^3 and 0.8 to 810.4 Bq/m^3 (mean:92.84 Bq/m^3) during pre- and post-monsoon seasons, respectively.

A. Hashim and E. Mohammed in (2016) [77], measured of Radon Concentration and the Effective Dose Rate in the Soil of the City of Karbala, Iraq. Using a long-term technique for alpha particle emission with solid state nuclear track detector type CR-39, the concentrations of radon ranged from (0.05 ± 0.02 to 7.80 ± 3.53) kBq/m^3 with a mean value of 2.87kBq/m^3 .

K. Hatif and M. Muttaleb (2016) [78], determined radon levels in soil at 10 districts in Hilla City, Iraq. RAD7 electronic radon in the air detector has been used for radon estimation. The samples are collected from the soil at a depth of 30 cm for each location. The maximum activity of radon was 12700 Bq/m^3 while the minimum radon activity was 25 Bq/m^3.

A. Cucoş (Dinu) et al (2017) [79], determined soil gas radon concentrations in 5 counties of Romania, using the LUK3C device. Radon concentration in soil was found to range from 0.8 to 169 kBq/m^3 with a mean value of 28.4 kBq/m^3.

Y.Muhsin Zayir Al-bakhat in (2017) [80], measurement of radon activity in soil gas and the geogenic radon potential mapping using RAD7 at Al-Tuwaitha nuclear site and the surrounding Areas, Soil gas radon ^{222}Rn activity was measured in different locations at Al-Tuwaitha Nuclear Site and the surrounding areas using RAD7 (radon detector). Radon activity in the soil gas varied from (866±150 to 16004±521) Bq/m^3,the annual effective doses related to the inhalation of radon gas and its progeny which were calculated from the Concentration of emanation in air near ground ranged from (0.0082305 to 0.152102) mSv/y.

S. Fadel Kadim and H.Najy Hady in (2018) [81], measurement radon gas concentration in selected soil samples of the of Al-Nada district in Najaf, using solid state nuclear track detectors (CR-39) to determined concentration of radon ^{222}Rn . Concentration of radon ^{222}Rn has ranged from (171.237±0.0062) Bq/m^3 to (31.982±0.0027) Bq/m^{3}with average value (99.222±0.2476) Bq/m^3.

P. Huynh Nguyen et al in (2018) [82], determined radon concentration in soil and radium content in the soil of 20 locations in Ho Chi Minh City, Vietnam. Radon concentration in soil gas was determined in the depth of (10-100 cm) of loam, sandy soil, and clay soil samples in the rainy season, using the RAD7 Active radon detector. The mean value of radon concentration was 28.6±2.0 Bq/kg in clay soil and 31.2±2.5 Bq/kg in loam soil, while it was 30.7±2.0 Bq/kg in sandy soil. an unclear linear relation was observed between radon concentration in soil gas and radium contents in soil. Besides, a strong positive correlation was found between soil gas radon concentration and a pH of the soil, leading to conclude that the pH level of the soil to be considered as an indirect dynamic parameter influencing the migration of radon in soil.

F. Subaihi et al in (2019) [83], measured of radon concentration, its exhalation rate, and radium content in soil samples collected from different locations of the northern part of Aden governorate, south of Yemen., Using Plastic Track Detectors, the outdoor radon levels concentrations were found to vary from 264.59Bq/m^3 to 539.72Bq/m^3 with a mean value of 369.29Bq /m^3.

D. Kareem et al (2019) [84], relationship between Radon Gas and Heavy Metals Concentrations in Soil of Selected Farms in Kirkuk City / NE Iraq. Average radon concentrations measured by CR-39 in the samples was 3398.65 Bq/m^3.

A. Sharrad and A.K. Farhood in (2020) [85], Radon concentrations measured in the soil gas and the atmospheric air was carried 30 samples around Sawa lake, samawa City, Southern part of Iraq. During two seasons, winter and spring by using a continuous radon monitoring device RAD7. Radon concentrations were found in the range of (86.9 Bq/m^3) to (6448 Bq/m^3) with an average value of (1963 Bq/m^3).

1.14 Aims and Objectives of this Study

The occurrence of abnormal amount of radioactive nuclides in drinking water and soil represents a potential well-being to the general populace through internal and external radiation exposure from ingested and inhalated of radioactive nuclides and its short lived decay products.

Radon (^{222}Rn) is the only naturally occurring radioactive gas, which occurs from the disintegration of Uranium (U^{238} decay series). It is a chemically inert gas and has no odor, color, or taste. Drinking water and soil were the main contributor of radon to the living environment. Since the inhabitants of the study area are exposed, and therefore, to protect the general society from outcomes of excessive exposure to radiation due to ^{222}Rn, it is important to know the levels of radon from different districts across the study area, as well as, the information obtained might be useful to prepare baseline data for general awareness with further allows radiological mapping assessment in south region of Iraq.

The purposes of the present study are:

1- Evaluate the radon gas concentrations and associated annual effective dose due to ingestion and inhalation of drinking water for living people (child and adult) in Samawa city – south of Iraq.
2- A study of inhaled radon concentrations and its contribution to the annual effective dose of the soil of Samawa city districts.

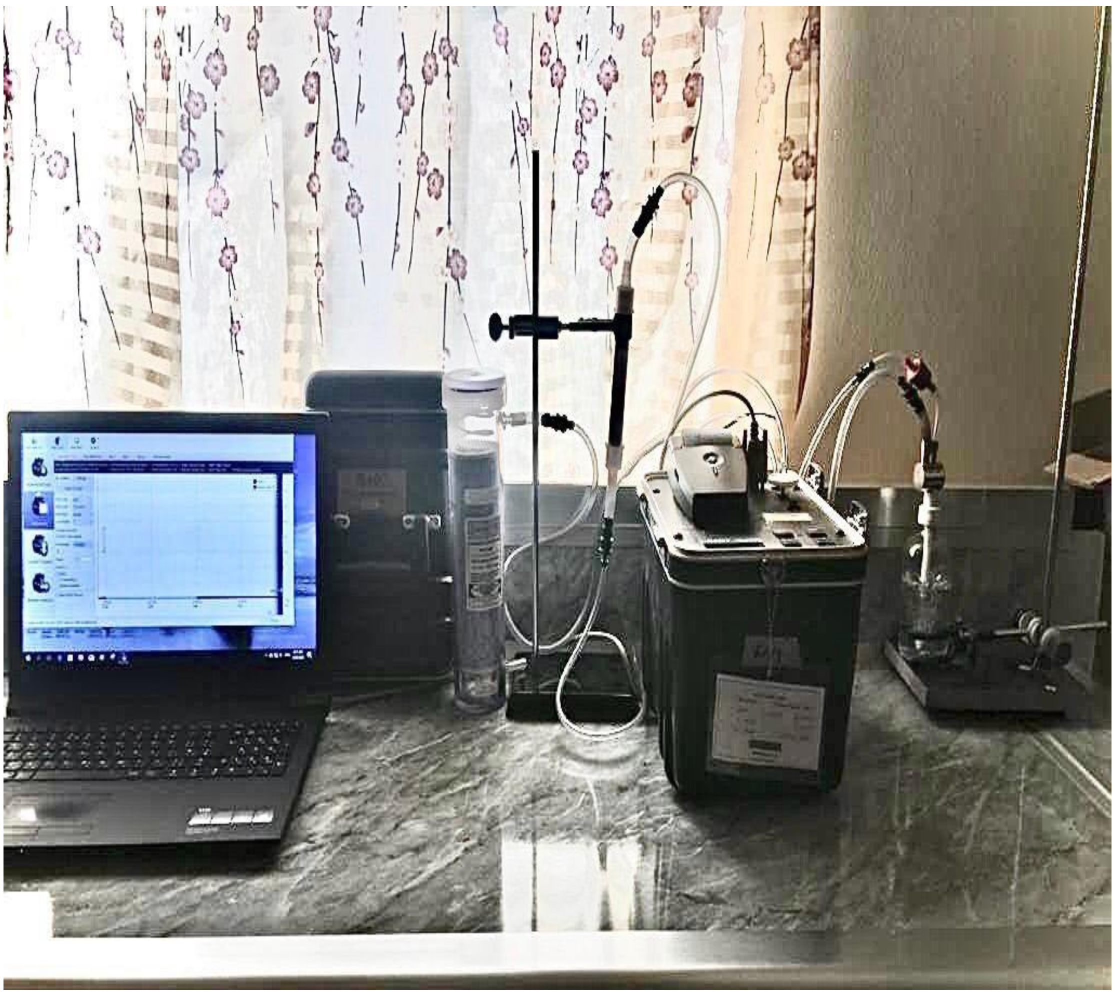
The general aspects of radioactivity and the literature review of recent studies are presented in chapter one. The general characteristics of RAD7 detectors and the experimental procedures for measuring radon (^{222}Rn) concentration in drinking water and soil are given in chapter two. The results of the radon concentration and the annual effective dose for different districts of Samawa city are presented in chapter three. A summary of the experimental results and concentrations are given in chapter four, along with suggestions for future research.

Chapter Two

EXPERIMENTAL METHODS

2.1 Introduction

This chapter deals with the tools and materials used in this study, including a simple review of each one, description of the study area and the processes that took place in present work to provide as much information as possible. These processes: sampling methods for both water and soil, radon concentrations measurements for both water and soil.



Figure(2.1): Photo of Measuring System Used in Present Study.

2.2 Study Area

The present study is carried out in Samawa city, Al-Muthanna province, Iraq, as shown in Fig. (2.2). Samawa is the largest city in Al-Muthanna province which has an area of (680 km^2), with a population of approximately (316.426) people. It is located in geographic coordinates 31° 19′ 0″ N, and 45° 17′ 0″ E, at an elevation of 9 m (29 ft) above the sea level. It is built on both sides of the Euphrates river; and is surrounded by hundreds of palm groves that give it a tropical feel, especially in the southern and northern suburbs.

There are six bridges in the center of town for crossing between the two sides. The west bank of the city contains the commercial heart of it. The most famous attraction of Samawa is the ruins of the ancient Sumerian city of Uruk which dates to 4000BC, and a large salt lake called Sawa Lake

The city is located at 280km southwest of Baghdad the capital of the Republic of Iraq, in the hot region during the summer season and nearly cold during winter. In the late winter and spring, Samawa city can be affected by the strong southerly winds, which may give rise to dust storms. On the contrary, during the long summer months, a moderate northwesterly wind, very hot and dry, which may cause rapid dehydration, and when its more intense, it can raise dust or sand. The water consumption was high and the only water resources in this city are the surface water (Euphrates river), the water of which is pumped out with the purification process. The climate of the city is marked by a large variation of temperature, extreme dryness, and scanty rainfall. The minimum and maximum temperatures are 5℃ and 50℃ respectively. Whereas the average annual temperature is 23.8 °C (74.8 °F). About 106 mm (4.17 in) of precipitation falls annually. The soil of Samawa districts is yellowish-brown in color, clay to silty clay, and calcareous which vary in their characteristics at long distance, and in many places they are intermixed with sandy material. The city of Samawa consists of (32 districts) and it was distributed over the entire area of the city. The area of each districts varies from one to another, as well as the number of residents in it. It was distributed on both sides of the Euphrates river, and in the north and south parts of the city. Fig.(2.3) shows the surveyed districts and locations of the sampling sites.

Figure (2.2): The Map of Iraq Showing the Location of Samawa City.

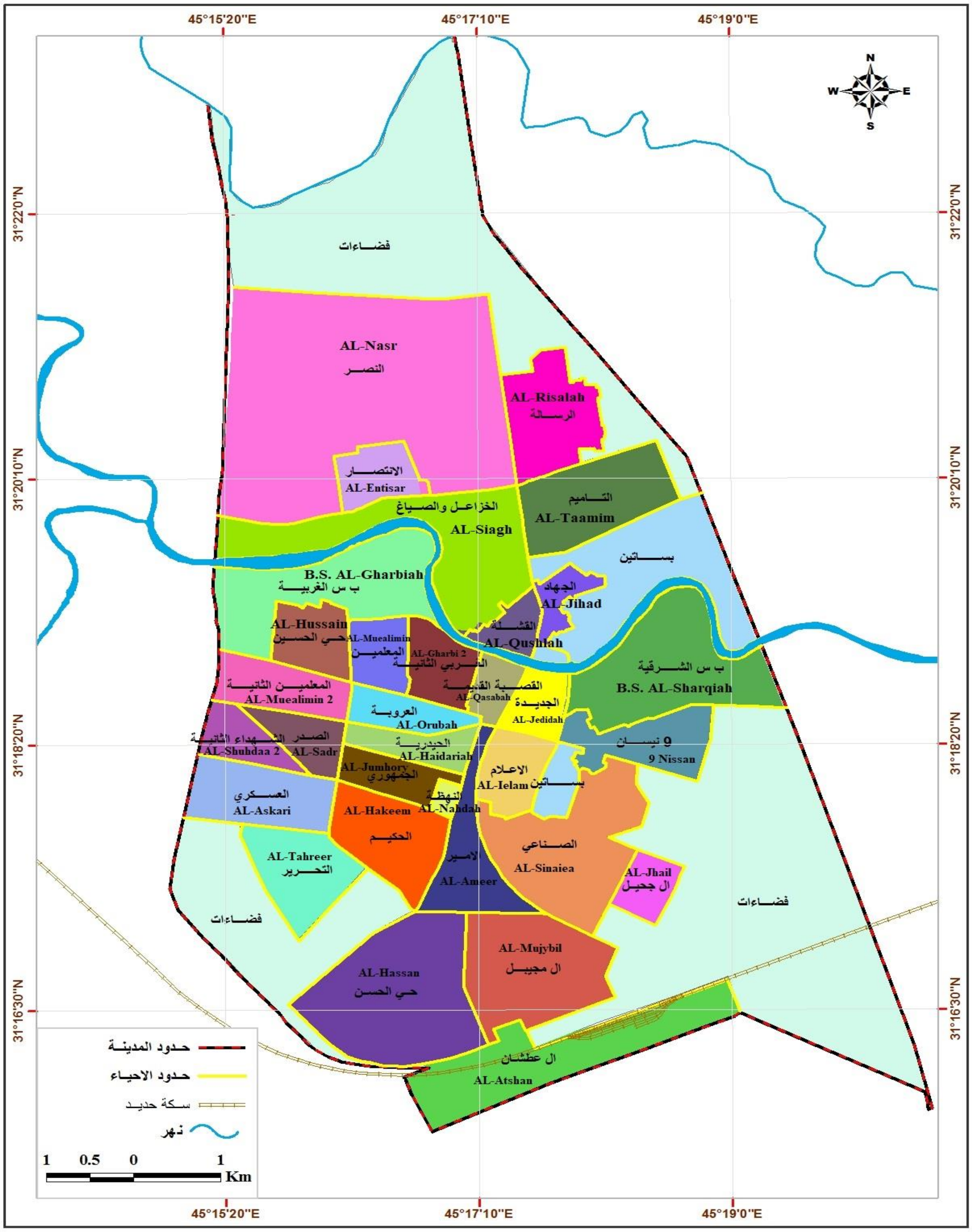


Figure (2.3): Districts of Samawa City.

2.3 Global Positioning System (GPS)

GPS is a positioning system based on a network of satellites that continuously transmit coded information Fig(2.4). The information transmitted from the satellites can be interpreted by receivers to precisely identify locations on earth by measuring distances from the satellites. GPS is funded and controlled by the U.S. Department of Defense (DOD). The system is called NAVSTAR [95]. The GPS device that is used in this study is provided by AL-Muthanna Municipal Directorate.

GPS Constellation:

• The nominal GPS Operational Constellation consists of roughly 24 satellites. Each satellite has a number on your GPS screen. Newer satellites have been sent up to replace the older one.

• The GPS signal communicates information about the precise position of the satellite and the precise time of the signal [95].

Figure(2.4): The GPS receiver

2.4 RAD7 Solid State Detector

In this study, a RAD7 manufactured by Durridge company is used to carry out water and soil-gas radon concentration measurements. Figures (2.5) and (2.6) show the external and internal structures of the device.

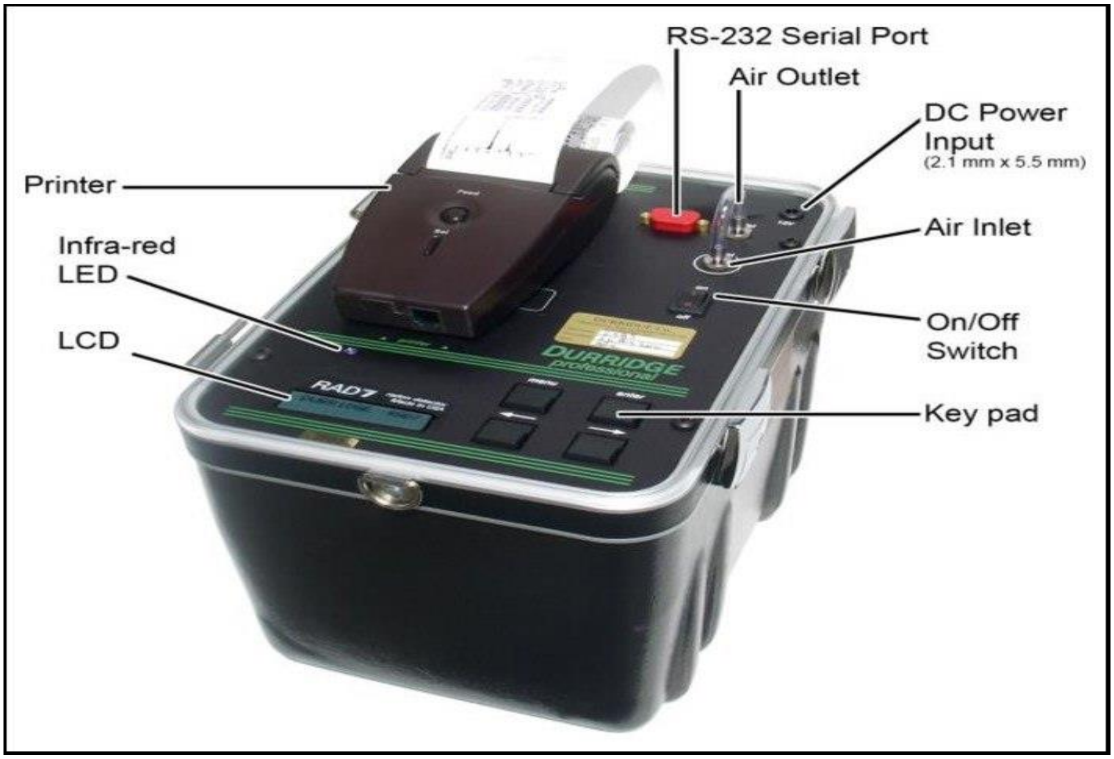


Figure (2.5): The Durridge RAD7 Electronic Radon Monitor with an HP Printer Mounted for the Printing of Results.

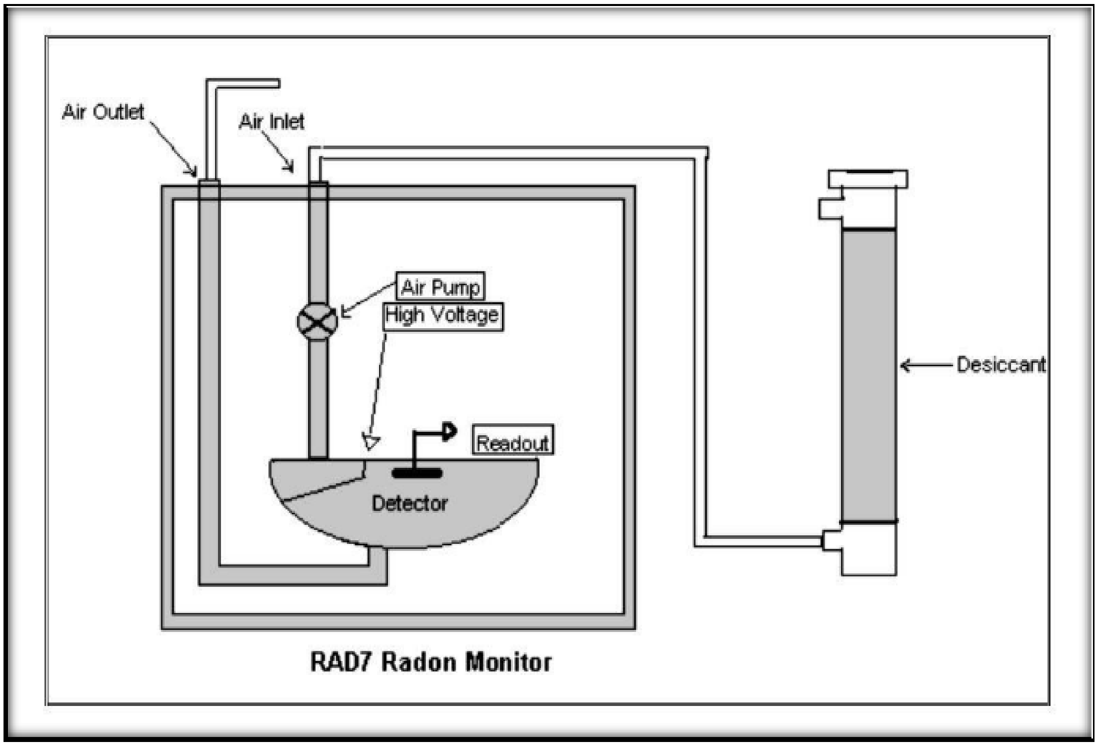


Figure (2.6): Scheme of RAD7 Device.

The RAD7 uses a solid-state alpha detector to detect the alpha particles from ^{222}Rn decay. A solid-state detector is a semiconductor material that converts radiation energy directly to an electrical signal. The RAD7's internal sample cell is a 0.7-liter hemisphere, coated on the inside with an electrical conductor. The silicon alpha detector is at the center of the hemisphere. A high voltage power of 2000 to 2500 volts applied inside the chamber relative to the detector, creating an electric field throughout the volume of the cell [86]. The electric field propels positively charged particles onto the detector.

The radon-222 nucleus that decay within the cell leave its transformed nucleus, polonium (^{218}Po), as a positively charged ion. The electric field within the cell drives this positively charged ion to the detector, to which it sticks. When the short-lived ^{218}Po nucleus decays upon the detector active surface, its alpha particle has a 50 % probability of entering the detector and producing an electrical signal proportional in strength to the energy of the alpha particle.

The RAD7 amplifies, filters, and sorts the signals according to their strength. So, the RAD7 device is based on an electrostatic collection of positively charged alpha particles that formed within its chamber by the radon products, the device can be used for radon or thoron measurements in the air, water, and soil. It has a high radon sensitivity within a measurement range extending from 4 up 4×10^5 Bq/m^3 [87] . In sniff mode, the RAD7 uses only the ^{218}Po signal to determine radon concentration and the ^{216}Po signal to determine thoron concentration, ignoring the subsequent and longer-lived radon daughters. In the measurements described below thoron was not considered, since the study focused on measuring ^{222}Rn concentrations. The RAD7 achieves a fast response to changes in ^{222}Rn concentration and fast recovery from high concentrations [86].

To begin measurements using the RAD7 detector, the detector needs to be purged first. Purging is the process whereby the moisture and the old radon in the chamber of the detector are removed. This is done by a pump in the detector, which pumps fresh air into the chamber through a drying unit. The drying unit is 6 cm in diameter and 28 cm in length Fig. (2.6) [88]. The drying unit consists of granules and the purpose of the granules is to absorb moisture, since the detection efficiency of the RAD7 decreases as humidity increases due to the neutralization of polonium ions by water particles. An air filter at the entrance of the RAD7 prevents dust particles and the solid daughters of ^{222}Rn from entering the radon chamber, which will contaminate the alpha detector. The air in the chamber will pass through the outlet. The purging of the instrument takes 5 to 10 minutes depending on the initial relative humidity in the chamber [86]. The relative humidity in the chamber must be at least 7% or less before use. Normally 10 minutes of purging the instrument were necessary before the start of measurements.

2.4.1 RAD7 Spectrum Analysis

The electrical signal produced in the detector due to alpha radiation is amplified and conditioned by the electronic circuitry of the detector, also convert to a digital form. The RAD7 possesses a microprocessor that receives the signal and stores it in the detector's memory. The signal that is stored is associated with the decay of a specific radionuclide and in the process of accumulating these signals, then a spectrum can be formed [89].

The spectrum of the RAD7 extends on the specific range of energies from 0 – 10 MeV, interest is shown in the 6 – 9 MeV region, since most of the radon and thoron decay products, produce alpha particles energy in that range. The spectrum is divided into 200 channels that correspond to 50 KeV (0.05MeV) per channel. Ideally, in the below spectrum, the 6.00 MeV alpha peaks would only be a needle spike as represented in Fig. (2.7), but this is not the case with the RAD7 because of the electronic noise in the detector as well as the amplifier [42,90].

Another cause for the broadened peaks is the fact that some of the alpha particles enter the detector at a small angle. An increase in the temperature also causes electronic noise, and in turn, affects the tail of the peaks. The analysis of the spectrum is simplified because the electronics of the RAD7 are manufactured to group the 200 channels into 8 windows. Those windows are listed as A – H in alphabetical order [89].

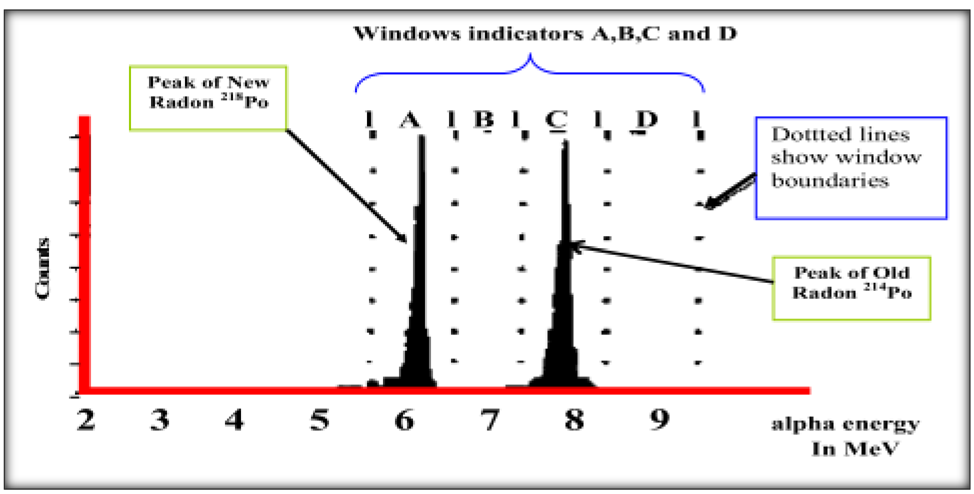


Figure (2.7) Alpha Energy Spectrum.

Windows A and C are for radon and contain ^{218}Po (Ea = 6.00 MeV) and ^{214}Po (Ea = 7.69 MeV) peaks, respectively. Windows B and D are for thoron and contain ^{216}Po (Ea = 6.78 MeV) and ^{212}Po (Ea = 8.78 MeV) peaks, respectively as shown in Fig. (2.7) [91]. The spectrum obtained from drinking water and soil samples are show in appendix (2).

2.4.2 Background and Associated Problems

It is important to determine the background detector reading, since the reading during detecting may not give a true reading (false alarm) if unknowing the detector background correctly. Despite the RAD7 manufacturing company claims that the RAD7 does not affect by background, it also warns of several possible problems [92]. Radon and Thoron disintegration products have a possible role to affect the background in the RAD7. 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 can 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 RAD7, 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 that could involve RAD7 setting up for radon soil-gas measurements. Air may leak into the setup despite some cautions that are taken to reduce it. The manufacturing company advises using Teflon™ tape when collecting the device [44].

It is also noticed after letting the probe into the ground to measure the radon concentration in the soil, the same problem appeared. The probe head diameter is a bit bigger than the probe shaft, so when inserting, a little space is remaining on the shaft side. That can be reduced through flipping down the soil into the open space that surrounding the shaft to stop the soil-gas from becoming diluted as air may be sucked down outside of the shaft [73,86].

2.5 RAD7 Accessories

2.5.1 RAD7 H_2O

The RAD-H2O is an accessory to the RAD7 to find the activity of the radon in a water sample in a short time. It measures the activity of the sample giving results in about 30 minutes, it was connected to a small desiccant and the RAD7 as shown in Figure (2.8). In this system, the air is bubbled through a vial of either 40 ml or 250 ml with a water sample in five minutes, so that the radon is removed from the water sample [52]. The ^{222}Rn diffusing from the water sample continuously circulates through a desiccant column to the RAD7 detector and then back to the water sample to establish equilibrium between the radon in the water and air. As the RAD7 aerates the water sample, radon is stripped from the water, the radon in air and water establishes equilibrium in the first five minutes. The system waits for another five minutes, making it 10 minutes after bubbling so that ^{218}Po and ^{222}Rn are in equilibrium after that, the RAD7 runs a further four five-minute counting cycles, thus making the total analysis time to be 30 minutes [93].

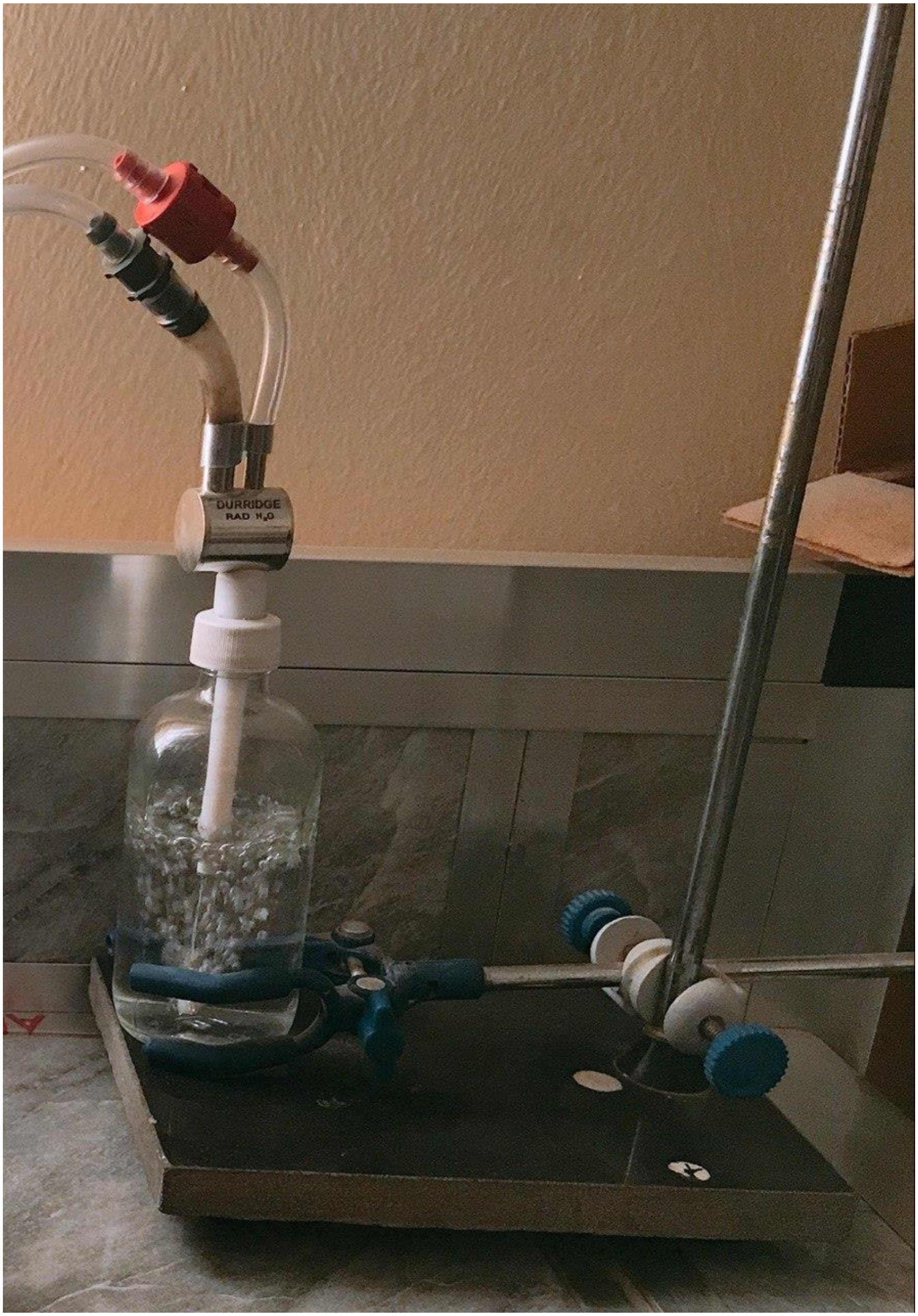


Figure (2.8): RAD H_2O Accessory.

2.5.2 Soil Gas Probe

Radon in soil gas measurements required special care and practice, it is important to make sure that the sample is not exposed to the outside air. This can be done by using the hardened steel soil gas probe supplied by DURRIDGE Company Inc., USA Fig.(2.9). It is one of the RAD7 accessories used for measuring radon soil gas with high efficiency. The soil probe is stainless steel rod (0.5-inch diameter) with a central hollow (0.25-inch diameter) that extends along with the probe, soil gas probe is hammered to the required depth below the soil surface creating a channel through which soil gas may flow upward. Another end of the probe is connected to the RAD7 (through a desiccant and dust filter) by pushing the plug-in connector into the probe [24].

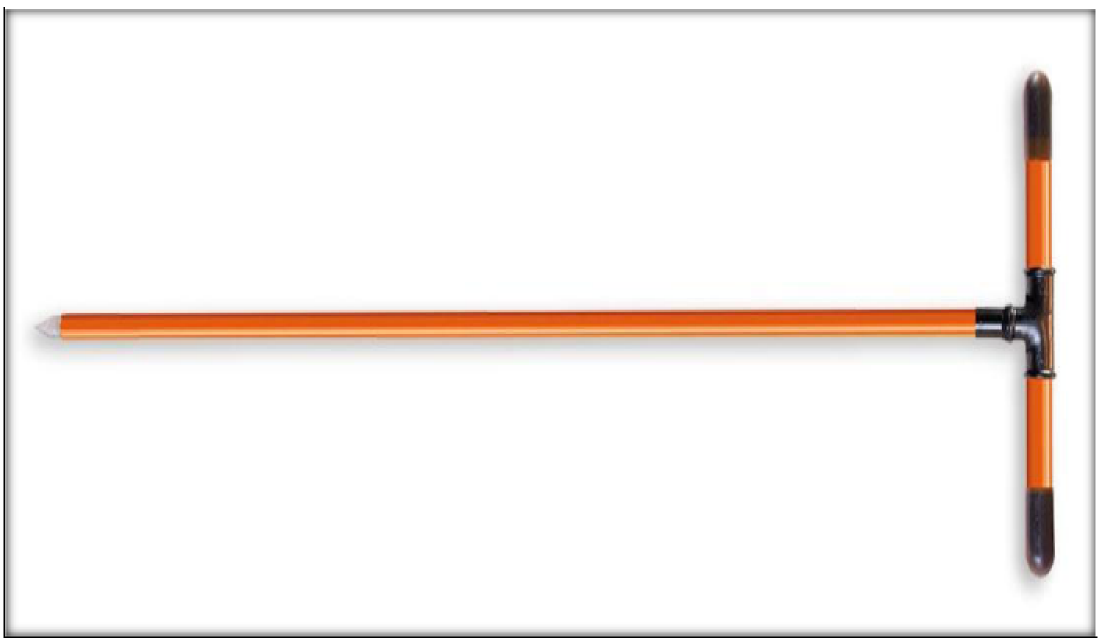


Figure (2.9): Steel Soil Gas Probe .

2.5.3 Durridge Capture Software

Capture software (version 5.6.8) an application that provided by DURRIDG Company Inc., USA (Fig. 2.10) which can download data from RAD7 and save it on the computer (up to 1000 runs), has the ability to display advanced graphs of radon data, showing the cumulative spectrum of radon products, scheduling the RAD7 runs and sorting it by date and time, and offer full control of RAD7 processes. Also, applying the humidity correction on the resulted concentrations in case the humidity has gone up (over 10 %) during the measuring process [94].

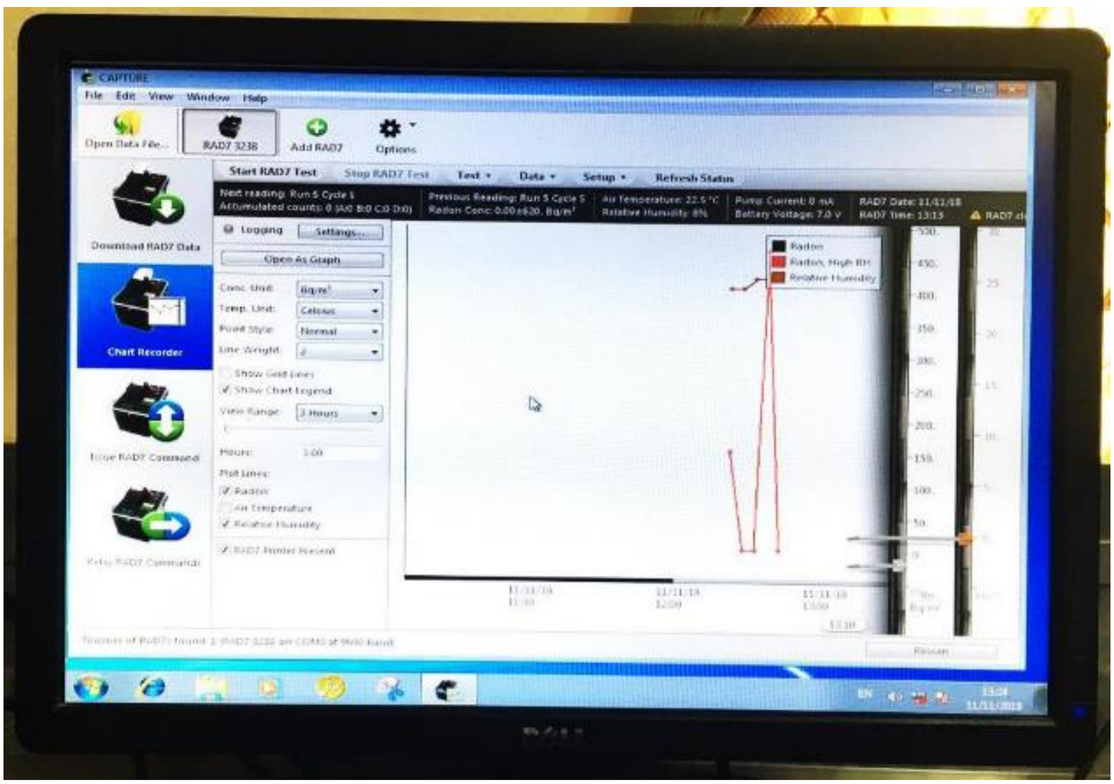


Figure (2.10): Capture Software.

2.6 Drying Process

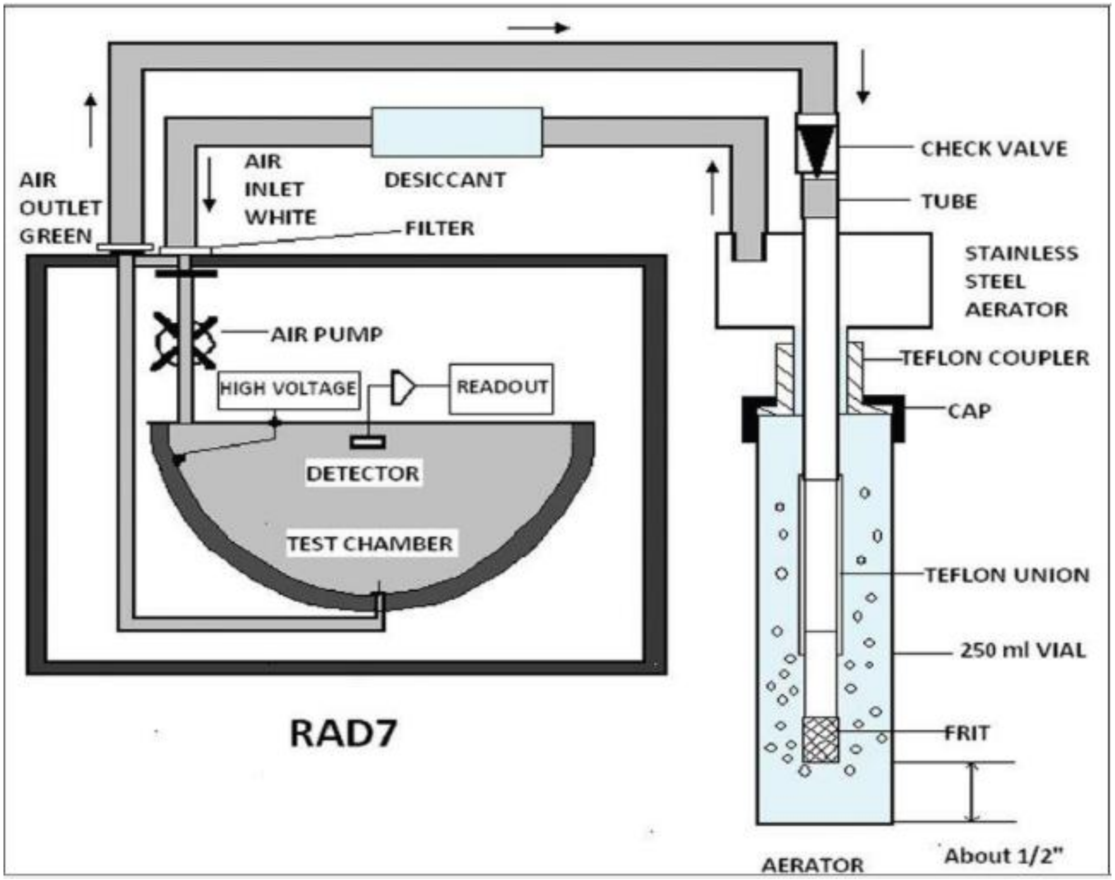
After each measuring process, the 250 ml vials that are filled with a sample need to be washed with pure filtered water and dried to avoid old water residues in the vials which would affect the radon content in the new sample. Memmert heating and drying electric oven (Germany) is used to dry the RAD H_2O vials after being washed. Another use is that for drying the calcium sulfate grains that contained in the desiccant and used to dry the air passes through it.

2.7 Sampling Method and Radon Measurements in Water

The major source of error in the measurements radon levels in water generally back to the mistakes that happened during the samples collection. Hence, getting good samples requires care and practice [86]. Because of the radon content in the water is simply escapes from the samples, the sample must be kept with no contact with air.

In the present study, radon concentrations are measured in 167 drinking water samples collected from 32 different districts in the city of Samawa, the center of AL-Muthanna province – Iraq, for two months. Samples locations coordinates are documented using the Global Positioning System (GPS), Latitude and longitude of sampling location were recorded by GPS device during the collection and used later to draw a map shows the samples locations on the city as shown in appendix (1) . Water samples were collected directly from the tap after 15 minutes of opening the water to ensure that the sample collected served as a representative sample, quality-wise. The samples were collected in a clean (0.5) L bottle previously rinsed with distilled water as shown in Fig. (2.11). During water collection, a conscious effort was taken to prevent bubbling of the water, and sealed with a cap underwater immediately, so as not to allow the escape of dissolved radon in the water. All bottles were labeled with the date and time of sample collection, as well as the district name. After collection, the samples are brought to the laboratory for measuring radon concentration, the measurements are taken place on the same day of collection. A calibrated portable continuous radon monitor, RAD7 (Durridge Company, USA) was used for measurements. The RAD7 protocol used for measuring radon in water is (Grab), with (wat-250 ml) mode, which allows RAD7 to determines the radon concentration in (250 ml) vial connected to the RAD H2O instrument. The RAD7 aerates the sample by pumping the air through a closed-loop for five minutes for extracting the radon content in the sample, the closed-loop carries radon into the cell sample of the RAD7. This is followed by five minutes waiting for reaching the equilibrium, after which the counting period begins. The counting period consists of five cycles with five minutes for each cycle, and five minutes waiting between each cycle and another. Hence, the sample measurement time is about one hour. Fig. (2.12) shows radon measurement in the water.

Figure (2.11): Sample Collection Cans.



Figure(2.12): Schematic Diagram of Radon Measurement in Water.

2.8 Sampling Method and Radon Soil-Gas Measurement

Radon gas concentration was measured in the soil of Al-Samawa city, where radon gas was measured in 100 locations in the city distributed by 3 to 5 locations for each district, as shown in appendix (1) .The samples are taken at the depth of (40 cm) undersurface using a soil gas probe which is one of the RAD7 accessories Fig. (2.13). The undersurface of the soil consists of hard rock which made the probe penetrating a little difficult, and most of the time it is be needed to use a hard iron rod and hummer to get the required depth.

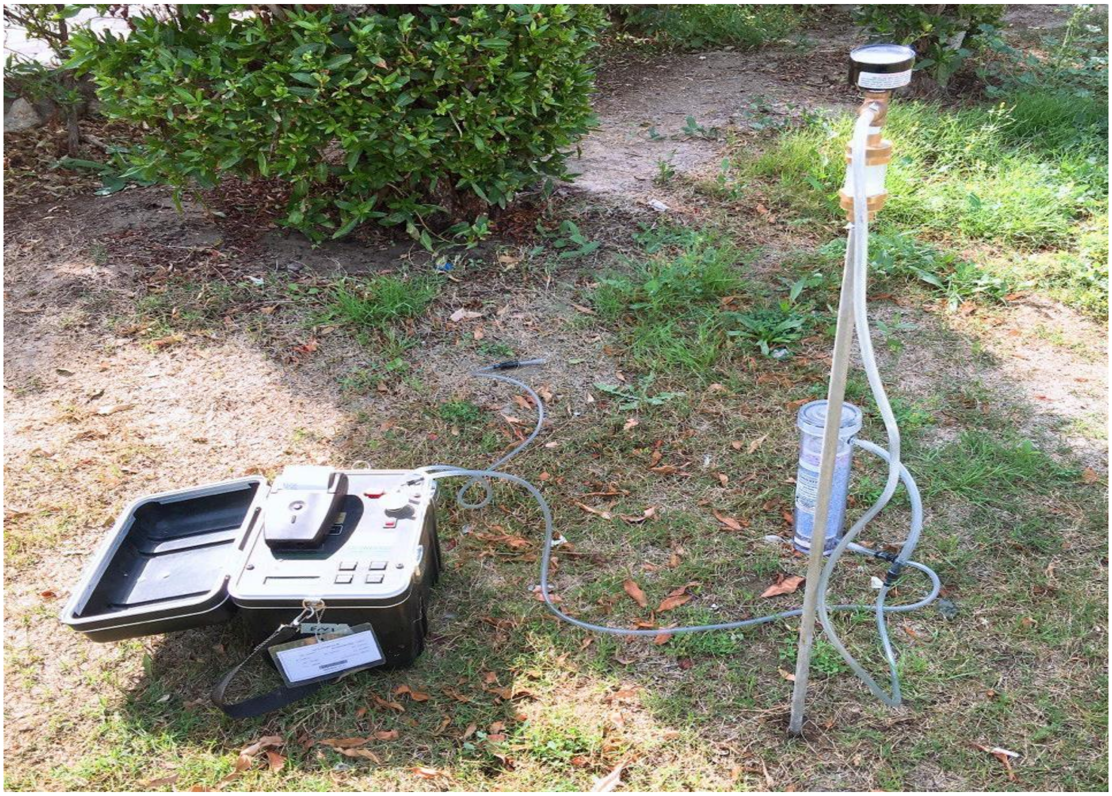


Figure (2.13): Radon Soil-Gas in Situ Measurements.

Geographical coordinates that were obtained using (GPS) for all samples during measurements are used to document sampling points using Google Earth software. To measure the radon levels in the city soil, the free end of soil gas probe was connected to the inlet port of RAD7 through a desiccant a dust filter, and desiccant for decreasing the humidity of the air that is sniffed from the sampling point through the hammered end of the probe. The RAD7 protocol used is (Grab) with (Sniff) mode that allows radon assessment in the soil. After the purging process (which takes usually 15 minutes), the RAD7 begins sniffing air from the sample for five minutes, outlet port left free for air exhalation. Then, the RAD7 waits for another five minutes for reaching the equilibrium between radon and its products. Measurement process of radon products consists of five cycles, five minutes for each cycle with five minutes waiting between every two cycles. Fig. (2.14) shows the scheme of radon measurements in the soil.

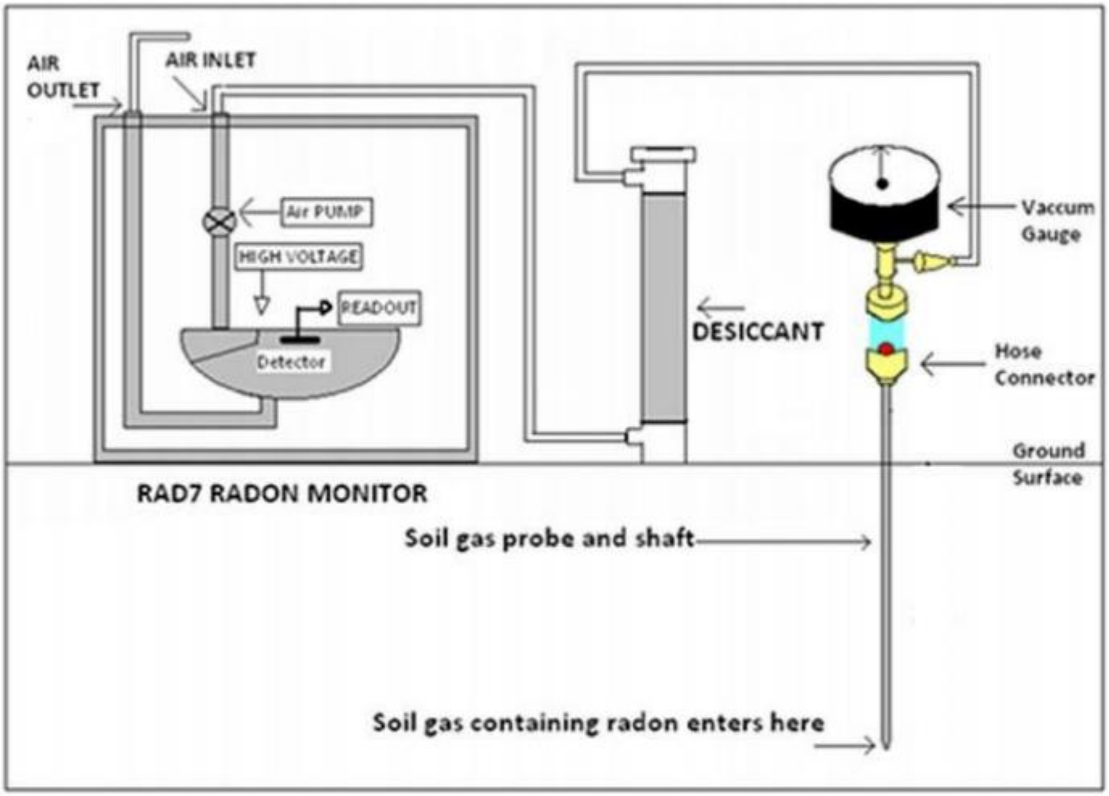


Figure (2.14): Schematic Diagram of Radon Soil-Gas Measurement.

Chapter Three

RESULTS AND DISCUSSION

3.1 Introduction

In the present study, radon concentration was measured in drinking water and soils in Samawa City, south of Iraq. The annual effective dose associated with the radon concentration of both water and soil was calculated. This chapter will be devoted to review and discuss the results that are obtained during this study.

3.2 Radon Concentrations of Drinking Water

Radon concentration of the drinking water was measured using RAD7 an electronic radon detector. A total of (167) samples of drinking water were collected from different locations of Samawa City. The measurements of radon in water were carried out during two months (December 1st,2019 to January 31th, 2020). Samples locations were documented using GPS. The locations of collected water samples are documented and illustrated in Table (3.1).

Table (3.1): Radon Concentrations of Drinking Water Samples

District No.	District name	Sample No.	Coordinate		^{222}Rn Con.(Bq/l)
			Longitude (deg)	latitude (deg)	Mean
1	AL- Hussein	W 1	45°16'7.22"E	31°18'50.89"N	0.260 ± 0.18
		W 2	45°15'56.68"E	31°18'58.57"N	0.0370 ± 0.052
		W 3	45°15'42.09"E	31°18'59.52"N	0.223 ± 0.17
		W 4	45°15'45.25"E	31°19'15.94"N	0.147 ± 0.13
		W 5	45°16'5.83"E	31°19'11.12"N	0.111 ± 0.11
		W 6	45°16'9.49"E	31°19'1.27"N	0.108 ± 0.12
2	AL- Muealimin	W 7	45°16'35.30"E	31°19'8.75"N	0.252 ± 0.18
		W 8	45°16'29.71"E	31°18'58.33"N	0.108 ± 0.11
		W 9	45°16'17.34"E	31°18'52.93"N	0.145 ± 0.13
		W 10	45°16'35.11"E	31°18'44.80"N	0.178 ± 0.15
		W 11	45°16'17.83"E	31°19'8.66"N	0.120 ± 0.11
3	AL- Muealimin 2	W 12	45°16'9.03"E	31°18'36.11"N	0.0357 ± 0.051
		W 13	45°15'47.93"E	31°18'50.15"N	0.0679 ± 0.07
		W 14	45°15'51.68"E	31°18'35.09"N	0.270 ± 0.2
		W 15	45°15'28.12"E	31°18'43.67"N	0.0716 ± 0.08
		W 16	45°16'8.12"E	31°18'44.51"N	0.108 ± 0.11

4	AL- Orouba	W 17	45°16'28.42"E	31°18'33.52"N	0.186 ± 0.14
		W 18	45°16'41.97"E	31°18'36.54"N	0.0619 ± 0.07
		W 19	45°16'19.39"E	31°18'42.13"N	0.0610 ± 0.09
		W 20	45°16'15.27"E	31°18'30.46"N	0.316 ± 0.22
		W 21	45°16'40.36"E	31°18'26.71"N	0.216 ± 0.16
		W 22	45°17'2.55"E	31°18'30.45"N	0.0362 ± 0.051
5	AL- Sader	W 23	45°15'57.87"E	31°18'17.99"N	0.184 ± 0.7
		W 24	45°15'53.20"E	31°18'29.63"N	0.148 ± 0.13
		W 25	45°15'39.79"E	31°18'30.68"N	0.280 ± 0.28
		W 26	45°16'4.18"E	31°18'9.43"N	0.401 ± 0.26
		W 27	45°16'6.89"E	31°18'25.37"N	0.186 ± 0.22
6	AL- Shuhada 2	W 28	45°15'23.65"E	31°18'24.09"N	0.186 ± 0.15
		W 29	45°15'24.29"E	31°18'14.63"N	0.149 ± 0.1
		W 30	45°15'34.84"E	31°18'13.64"N	0.187 ± 0.17
		W 31	45°15'35.82"E	31°18'21.78"N	0.187 ± 0.14
		W 32	45°15'25.34"E	31°18'31.26"N	0.0757 ± 0.09
7	Al- Gharbi 2	W 33	45°16'57.59"E	31°18'55.95"N	0.174 ± 0.17
		W 34	45°16'49.04"E	31°18'44.30"N	0.141 ± 0.13
		W 35	45°17'7.70"E	31°18'36.69"N	0.121 ± 0.14
		W 36	45°17'14.98"E	31°18'53.79"N	0.135 ± 0.14
		W 37	45°17'9.54"E	31°18'47.54"N	0.121 ± 0.14
		W 38	45°16'44.01"E	31°19'9.33"N	0.256 ± 0.18
		W 39	45°16'43.71"E	31°18'54.99"N	0.0926 ± 0.11
8	Al- Qasbuh Alqadiumuh	W 40	45°17'13.70"E	31°18'32.58"N	1.01 ± 0.38
		W 41	45°17'25.74"E	31°18'46.80"N	0.658 ± 0.4
		W 42	45°17'21.67"E	31°18'41.34"N	0.532 ± 0.28
		W 43	45°17'15.70"E	31°18'39.47"N	0.538 ± 0.29
		W 44	45°17'23.43"E	31°18'52.32"N	0.338 ± 0.22
9	Al- Jadiduh	W 45	45°17'35.64"E	31°18'48.14"N	0.109 ± 0.11
		W 46	45°17'40.85"E	31°18'41.70"N	0.0810 ± 0.08
		W 47	45°17'32.00"E	31°18'28.14"N	0.660 ± 0.33
		W 48	45°17'24.79"E	31°18'34.44"N	0.888 ± 0.37
		W 49	45°17'40.28"E	31°18'32.14"N	0.234± 0.18
10	B.S AL sharqayh	W 50	45°18'1.08"E	31°18'46.81"N	0.499 ± 0.28
		W 51	45°18'21.27"E	31°19'2.41"N	0.158 ± 0.14
		W 52	45°18'19.42"E	31°18'39.57"N	0.355 ± 0.22
		W 53	45°18'37.72"E	31°18'45.37"N	0.158 ± 0.14
		W 54	45°18'6.33"E	31°18'31.76"N	0.936 ± 0.39

11	9 Nisan	W 55	45°18'22.30"E	31°18'27.00"N	0.0385 ± 0.054
		W 56	45°17'52.03"E	31°18'28.93"N	0.116 ± 0.12
		4W 57	45°18'40.23"E	31°18'16.50"N	0.0614 ± 0.07
		W 58	45°18'46.88"E	31°18'32.25"N	0.123 ± 0.11
		W 59	45°18'14.00"E	31°18'18.49"N	0.186 ± 0.14
12	AL- Haydari	W 60	45°16'23.56"E	31°18'25.67"N	0.603 ± 0.25
		W 61	45°16'49.64"E	31°18'21.66"N	0.425 ± 0.27
		W 62	45°17'5.27"E	31°18'25.02"N	0.186 ± 0.15
		W 63	45°16'56.03"E	31°18'14.53"N	0.296 ± 0.2
		W 64	45°16'35.73"E	31°18'16.44"N	0.150 ± 0.13
		W 65	45°16'19.67"E	31°18'20.72"N	0.375 ± 0.23
13	AL- Nahdah	W 66	45°16'57.82"E	31°18'1.91"N	0.122 ± 0.16
		W 67	45°16'57.41"E	31°17'58.13"N	0.194 ± 0.16
		W 68	45°16'52.79"E	31°18'1.92"N	0.0768 ± 0.09
		W 69	45°16'56.41"E	31°17'53.40"N	0.0768 ± 0.09
		W 70	45°16'49.72"E	31°17'53.77"N	0.115 ± 0.11
14	AL- Jumhuriu	W 71	45°16'23.37"E	31°18'15.27"N	0.118 ±0.12
		W 72	45°16'32.78"E	31°18'5.10"N	0.157 ± 0.14
		W 73	45°16'21.71"E	31°18'4.24"N	0.0775 ± 0.09
		W 74	45°16'11.34"E	31°18'11.75"N	0.159 ± 0.14
		W 75	45°16'44.06"E	31°17'58.56"N	0.0776 ± 0.09
		W 76	45°16'56.41"E	31°17'53.40"N	0.0383 ± 0.054
15	Al- Easkari	W 77	45°15'25.58"E	31°18'8.75"N	0.453 ± 0.27
		W 78	45°15'57.52"E	31°17'47.54"N	0.279 ± 0.19
		W 79	45°15'53.83"E	31°18'3.60"N	0.609 ± 0.3
		W 80	45°15'20.03"E	31°17'54.07"N	0.335 ± 0.22
		W 81	45°15'42.19"E	31°17'53.04"N	0.441 ± 0.25
16	AL- Hakim	W 82	45°16'15.60"E	31°18'1.17"N	0.264 ± 0.19
		W 83	45°16'28.06"E	31°17'46.91"N	0.257 ± 0.18
		W 84	45°16'39.81"E	31°17'53.77"N	0.223 ± 0.18
		W 85	45°16'50.01"E	31°17'45.99"N	0.0390 ± 0.055
		W 86	45°16'46.08"E	31°17'33.41"N	0.180 ± 0.15
17	AL- Tahryr	W 87	45°16'10.76"E	31°17'52.00"N	0.155 ± 0.13
		W 88	45°16'8.80"E	31°17'44.08"N	0.186 ± 0.14
		W 89	45°16'25.90"E	31°17'37.93"N	0.124 ± 0.11
		W 90	45°16'34.77"E	31°17'31.70"N	0.0923 ± 0.09
		W 91	45°16'21.99"E	31°17'29.26"N	0.0617 ± 0.07

18	Al – Iielam	W 92	45°17'25.15"E	31°18'22.15"N	0.0926 ± 0.09
		W 93	45°17'32.89"E	31°18'10.00"N	0.0925 ± 0.09
		W 94	45°17'14.26"E	31°18'11.27"N	0.0923 ± 0.09
		W 95	45°17'12.53"E	31°17'59.99"N	0.186 ± 0.14
		W 96	45°17'27.00"E	31°17'57.23"N	0.154 ± 0.13
19	AL- Amir	W 97	45°17'12.62"E	31°18'24.93"N	0.149 ± 0.13
		W 98	45°17'3.53"E	31°17'58.61"N	0.118 ± 0.12
		W 99	45°17'2.85"E	31°17'35.04"N	0.113 ± 0.11
		W 100	45°16'51.66"E	31°17'15.96"N	0.156 ± 0.14
		W 101	45°17'22.12"E	31°17'14.35"N	0.0928 ± 0.09
20	AL- Hassan	W 102	45°16'36.97"E	31°17'0.99"N	0.124 ± 0.11
		W 103	45°16'5.51"E	31°16'41.20"N	0.185 ± 0.14
		W 104	45°16'0.05"E	31°16'15.81"N	0.186 ± 0.14
		W 105	45°16'52.31"E	31°16'34.96"N	0.0925 ± 0.09
		W 106	45°16'48.98"E	31°16'11.52"N	0.0929 ± 0.09
21	AL- Mujybil	W 107	45°16'56.64"E	31°17'6.54"N	0.124 ± 0.11
		W 108	45°17'30.88"E	31°17'5.99"N	0.124 ± 0.11
		W 109	45°17'51.72"E	31°16'55.36"N	0.123 ± 0.11
		W 110	45°17'8.28"E	31°16'43.33"N	0.155 ± 0.13
		W 111	45°17'38.72"E	31°16'38.78"N	0.0928 ± 0.09
22	AL- Sinaeiu	W 112	45°17'21.20"E	31°17'43.55"N	0.0375 ± 0.053
		W 113	45°17'42.10"E	31°17'15.11"N	0.151 ± 0.14
		W 114	45°18'8.70"E	31°17'33.69"N	0.0378 ± 0.054
		W 115	45°18'11.70"E	31°17'4.42"N	0.0785 ± 0.09
		W 116	45°17'57.89"E	31°18'4.96"N	0.0746 ± 0.09
23	AL- Jahil	W 117	45°18'29.55"E	31°17'5.80"N	0.0615 ± 0.07
		W 118	45°18'41.53"E	31°16'59.09"N	0.186 ± 0.14
		W 119	45°18'34.29"E	31°16'55.21"N	0.155 ± 0.13
		W 120	45°18'36.18"E	31°16'47.42"N	0.154 ± 0.13
		W 121	45°18'24.06"E	31°16'53.01"N	0.279 ± 0.18
24	AL- Eatshan	W 122	45°17'21.96"E	31°16'15.80"N	0.0620 ± 0.07
		W 123	45°16'59.09"E	31°15'53.50"N	0.184 ± 0.14
		W 124	45°17'42.21"E	31°16'6.82"N	0.0622 ± 0.07
		W 125	45°18'10.31"E	31°16'22.76"N	0.0311 ± 0.044
		W 126	45°18'43.06"E	31°16'29.77"N	0.124 ± 0.11

25	AL- Qashalah	W 127	45°17'4.55"E	31°19'12.40"N	0.0929 ± 0.09
		W 128	45°17'25.20"E	31°19'13.24"N	0.124 ± 0.11
		W 129	45°17'29.22"E	31°18'59.32"N	0.186 ± 0.14
		W 130	45°17'29.84"E	31°19'18.31"N	0.124 ± 0.11
		W 131	45°17'11.21"E	31°19'5.57"N	0.155 ± 0.13
26	AL- Jhad	W 132	45°17'39.32"E	31°19'29.75"N	0.0155 ± 0.13
		W 133	45°17'38.66"E	31°19'22.06"N	0.124 ± 0.11
		W 134	45°17'45.24"E	31°19'17.63"N	0.0309 ± 0.044
		W 135	45°17'50.48"E	31°19'6.56"N	0.0928 ± 0.09
		W 136	45°17'37.38"E	31°19'3.38"N	0.0923 ± 0.09
27	AL- Taamim	W 137	45°17'47.45"E	31°20'10.40"N	0.0615 ± 0.07
		W 138	45°18'5.85"E	31°20'9.14"N	0.0920 ± 0.09
		W 139	45°17'32.16"E	31°20'1.92"N	0.124 ± 0.11
		W 140	45°17'54.89"E	31°19'52.66"N	0.0931 ± 0.09
		W 141	45°17'35.08"E	31°19'44.96"N	0.0615 ± 0.07
28	AL- khazal & AL- Siagh	W 142	45°15'32.73"E	31°19'41.69"N	0.110 ± 0.11
		W 143	45°16'27.89"E	31°19'55.75"N	0.0378 ±0.053
		W 144	45°17'13.53"E	31°20'1.55"N	0.195 ± 0.16
		W 145	45°17'16.91"E	31°19'37.72"N	0.157 ± 0.15
		W 146	45°16'59.52"E	31°19'22.05"N	0.233 ± 0.18
29	AL- Aintisar	W 147	45°16'14.14"E	31°20'22.02"N	0.0620 ± 0.07
		W 148	45°16'38.87"E	31°20'17.07"N	0.0928 ± 0.09
		W 149	45°16'30.77"E	31°20'23.18"N	0.0617 ± 0.07
		W 150	45°16'36.34"E	31°20'10.71"N	0.0615 ± 0.07
		W 151	45°16'11.36"E	31°20'10.21"N	0.123 ± 0.11
30	AL- Risalah	W 152	45°17'36.98"E	31°21'0.06"N	0.0622 ± 0.07
		W 153	45°17'47.53"E	31°20'47.12"N	0.0308 ± 0.044
		W 154	45°17'31.12"E	31°20'32.92"N	0.0617 ± 0.07
		W 155	45°17'30.80"E	31°20'15.02"N	0.124 ± 0.11
		W 156	45°17'49.67"E	31°20'26.34"N	0.0929 ±0.09
		W 157	45°17'59.31"E	31°20'37.15"N	0.0311 ± 0.044
31	AL- Nasr	W 158	45°15'41.26"E	31°20'2.86"N	0.0308 ± 0.044
		W 159	45°16'3.71"E	31°20'37.48"N	0.0928 ±0.09
		W 160	45°16'6.95"E	31°21'20.55"N	0.186 ± 0.14
		W 161	45°17'8.19"E	31°20'50.69"N	0.123 ± 0.11
		W 162	45°17'11.79"E	31°20'17.47"N	0.0615 ± 0.07

32	B.S algharbiuh	W 163	45°16'39.59"E	31°19'39.04"N	0.0381 ± 0.054
		W 164	45°16'38.16"E	31°19'17.27"N	0.260 ± 0.19
		W 165	45°16'10.43"E	31°19'16.13"N	0.0370 ± 0.053
		W 166	45°16'13.08"E	31°19'35.08"N	0.223 ± 0.18
		W 167	45°15'31.41"E	31°18'50.89"N	0.147 ± 0.14
Mean value					0.175 ± 0.13

Radon concentration results in Bq/L for the collected water samples are shown in Table (3.1), on average of five runs for each sample with a final mean value. The mean value of radon concentration distribution for the studied districts is illustrated in Fig. (3.1).

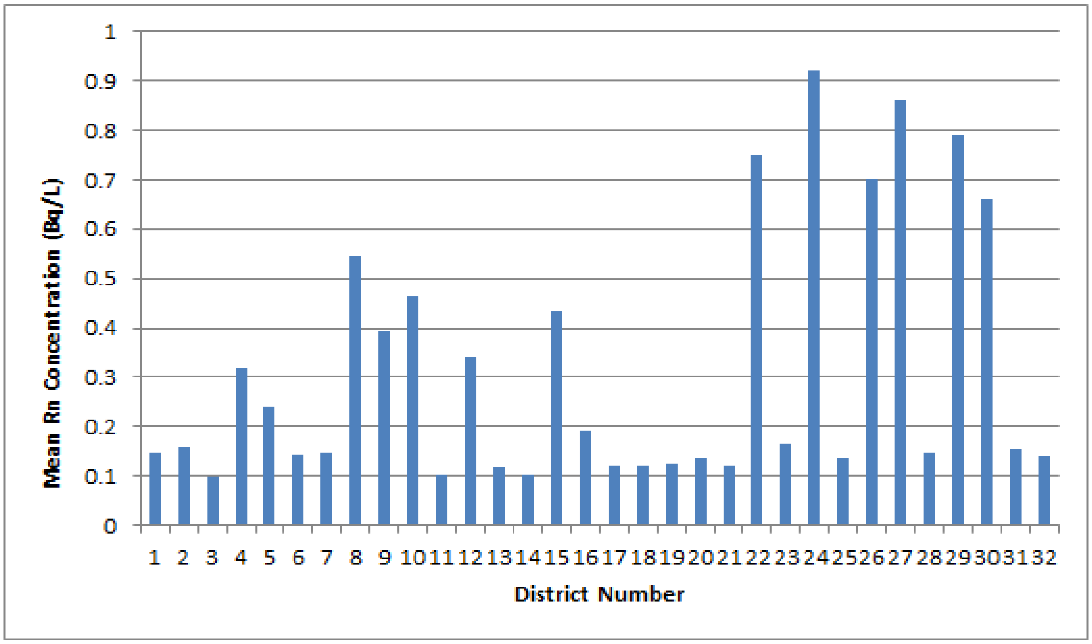


Figure (3.1): Radon Concentration Distribution for the Studied Districts.

Table (3.1) shows the achieved radon concentration in drinking water determined using RAD7. From the Table, radon activity in the water samples shows high variation, where concentrations value ranged from the smaller value of (0.0155 ± 0.13 Bq/L) for sample (W132) to the highest one of (1.01 ± 0.38 Bq/L) for sample (W40) with a mean value of (0.175± 0.13 Bq/L). The higher concentrations of radon in the drinking water are recorded for samples W41, W42, W43, W47, W48, W54, W60, and W79. While the minimum radon concentrations can be observed for the samples W125, W134, W153, W157, and W158. The main reason for large differences in radon concentration in the samples seems to be due to the storage of the mixed water in large reservoirs before distribution [96]. So it is clear that the radon concentration in water samples changed from one location to another. As well as this variation may be due to the type of water, the geological formation, and the difference of geochemical distribution of areas under the study. On the other hand, and up to now, there is no obvious guidelines and regulation for drinking water radon concentration in Iraq and the world. From the radiological protection point of view, the health and environmental protection agencies have recommended a safe limit of radon in drinking water for human beings. The US Environment Protection Agency (USEPA) has proposed that the allowed maximum contamination level for radon concentration in water is 11.1 Bq /L [97]. The UNSCEAR has suggested a value of radon concentration in water for human consumption between 4 and 40 Bq/L [36]. The World Health Organization reported the permissible value of radon in drinking water value of (20 Bq/L) [98]. These levels are set to represent a concentration that does not result in any significant risk to health over lifetimes drinking water. However, it is noticed that all analyzed samples pose radon concentrations much lower than those proposed by international organizations, since the higher value of radon concentration was (1.01 ± 0.38 Bq/L). This value is very well below the maximum contaminant level (MCL) of (11.1 Bq/L) that proposed by the United States Environmental Protection Agency (US EPA), or (20 Bq/L) reported by World Health Organization (WHO) [99]. An average value of radon concentration for each district is shown in Table (3.2).

Table (3.2): Average Radon Concentration of Drinking Water in Each District.

Dist.No.	District Name	Mean radon concent. (Bq/L)
1	AL-Hussein	0.147667
2	AL-Muealimin	0.1606
3	AL-Muealimin 2	0.11064
4	AL-Orouba	0.146183
5	AL-Sader	0.2398
6	AL-Shuhada 2	0.15694
7	AL-Gharbi 2	0.148657
8	AL-qasabah	0.6152
9	AL- Jadidah	0.3944
10	B.S AL-sharqayh	0.4212
11	9 Nisan	0.10498

12	**AL-Haydariah**	**0.339167**
13	**AL-Nahdah**	**0.11692**
14	**AL-Jumhuriah**	**0.104567**
15	**AL-Askari**	**0.4234**
16	**AL-Hakim**	**0.1926**
17	**AL-Tahryr**	**0.1238**
18	**AL-Iielam**	**0.12348**
19	**AL-Amir**	**0.12576**
20	**AL-Hassan**	**0.13608**
21	**AL-Mujybil**	**0.12376**
22	**AL-Sinaeiah**	**0.07588**
23	**AL-Jahil**	**0.1671**
24	**AL-Eatshan**	**0.09266**
25	**AL-Qushlah**	**0.13638**
26	**AL-Jihad**	**0.0711**
27	**AL-Taamim**	**0.08642**
28	**AL-Siagh**	**0.14656**
29	**AL-Entisar**	**0.0802**
30	**AL-Risalah**	**0.067117**
31	**AL-Nasr**	**0.09882**
32	**B.S Algharbiah**	**0.14102**
Mean value		**0.175**

From Table (3.2), it is possible to say that the higher value of radon concentration is conducted in the AL-qasabah district with a value of (0.6152 Bq/L). The reason for this may be due to the soil and rock structure where the water pipes pass through it, and or the water network that provides this district with water is the oldest in the city (where the district represents the old city), in addition to, the network pipes are made from concrete, and as known the radon content within concrete pipes is higher than PVC or iron pipes. On the other hand, these pipes contain a significant number of fractures and cracks which allow the groundwater to be mixed with transported water (surface water) which increases the radon level within it. Hence, The materials that pipes are made from, as well as the nature of the ground, will affect the concentration of radon gas in drinking water. The value of the lowest radon activity concentration was measured in the water samples taken from the Al-Risalah district (0.067117 Bq/L), this low value is could be due to the district is close to the processing stations which ensure that the received water is provided from the storages directly and the distance that the water travels is relatively short which helps to avoid as much impact as possible from the soil contamination, and or this lack of radon content back to that the water network has been newly created, and hence, its transportation lines are devoid of any cracks or fissures which help to avoid any additional contamination.

From the statistical perspective, and for providing a better perception, the obtained concentrations have been classified into five categories depending on their values. The first category consists of all concentrations that ranged from (0.0671 Bq/L) to (0.1766 Bq/L), the second category included the concentrations varied between (0.1767 Bq/L) and (0.2862 Bq/L), while the concentrations of (0.2863 – 0.3958 Bq/L) are presented by the third category. The fourth one contains the concentrations in the range of (0.3959-0.5054 Bq/L), and finally, the concentrations between (0.5055 Bq/L) and (0.6155 Bq/L) are included within the fifth category. Figure (3.2) shows the frequency distribution of mean radon concentrations value in the studied districts.

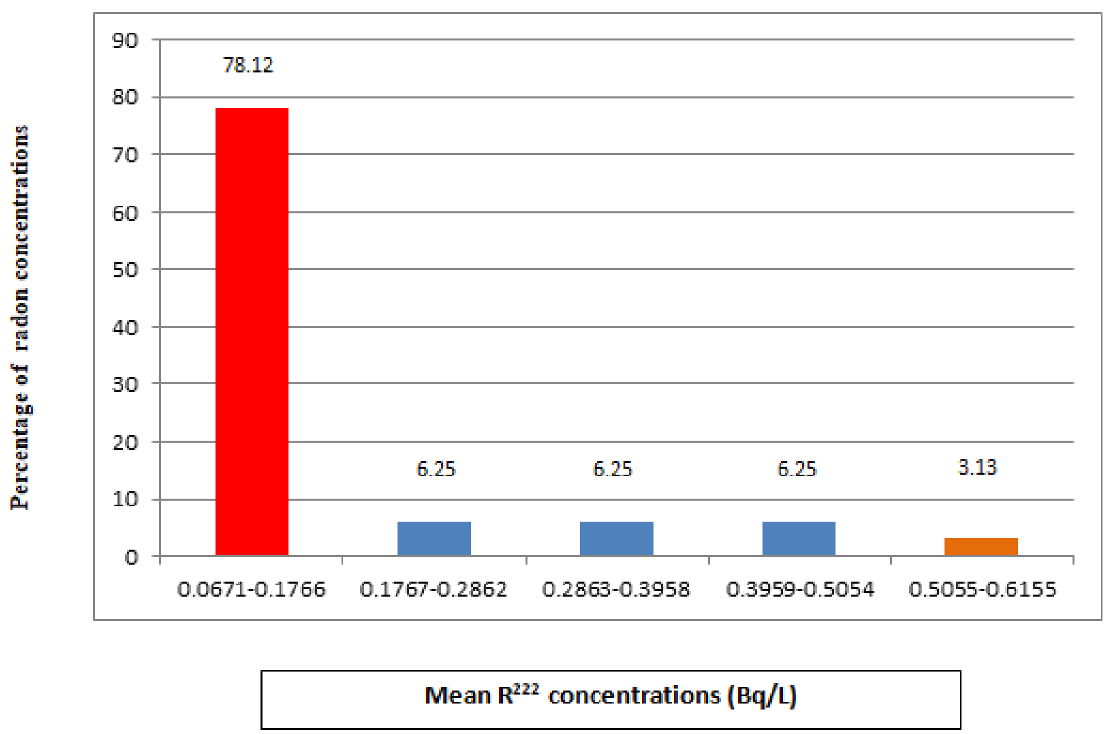


Figure (3.2): Frequency Distribution of Mean Radon Concentration of the Studied Districts.

From the figure above, it is evident that the most concentrations (78 % of the water samples), are within the first category which contains the lower values (lower than or equal to 0.1766 Bq/L) which indicates that the most analyzed samples of different regions in the city pose very low concentrations (have radon concentration far below than MCL recommended by EPA) as compared to other samples in the rest of categories.

However, in the scope of the above results, the high and low value of radon concentration in Samawa city obtained from the present study was compared with the values reported by the other studies carried out in Iraq and the nearest countries. Table (3.3) provides minimum, maximum of radon concentration in Iraq and the other nearest countries.

Table (3.3): Local and regional studies of the measurements of radon in drinking water.

No.	Country	Location	Radon Concent. (Bq/L)		Reference
			Min	Max	
1	Turkey	Kastomonu city	0.39	12.73	[38]
2	Turkey	Adıyaman city	0.39	0.51	[100]
3	Iran	Kerman city	1.2	9.88	[101]
4	Iran	Borujerd	1.339	4.032	[102]
5	Saudi Arabia	Qassim	1.20	15.43	[103]
6	Saudi Arabia	Jazan	2.47	2.95	[53]
11	Jordan	Amman	3.9	117	[104]
12	Lebanon	Beirut	0.91	49.6	[105]
13	Kuwait	Kuwait	1.02	6.05	[26]
14	Palestine	Palestine	0.9	1.3	[106]
15	Iraq	Kurdistan	1.184	7.589	[43]
16	Iraq	Erbil	0.069	13.062	[42]
17	Iraq	Baghdad, Al-Mustansiriyah	0.073	0.190	[107]
18	Iraq	Al-Najaf city	0.33	1.2	[108]
19	Iraq	Abu – Gharaq	0.072	0.688	[109]
20	Iraq	Hilla city	0.0361	0.193	[110]
21	Iraq	Hilla city	0.119	0.193	[64]
22	Iraq	Samawa city	0.067	0.615	Present study

From the table, when the higher value of radon concentration in the present study (0.615 Bq/L) were compared with values from other parts of Iraq, we find that it is lower than the values reported in Kurdistan and higher than the values reported in Hilla city. Further, the present results are remarkably very low than those reported in Jordan, Beriut, Saudi Arabia, and Turkey. However, the minimum value reported in this study (0.067 Bq/L) look lower than the available data reported in the literature.

3.3 Annual Effective Dose of Drinking Water

The “Effective Dose” is a biological dose commonly used in radioprotection, as it determines how dangerous an individual’s exposure to radiation can be. It takes into consideration not only nature at the incoming radiation but also the sensitivities at the body parts affected and represents the stochastic health risk to the whole body. The annual effective dose (AED) due to radon concentration can be classified into two types, the dose from inhalation and the dose from ingestion. It depends on what someone proportions due to inhalation and ingestion will therefore be variable with location and the particular local sources at radiation exposure. In the present study, the annual effective dose received by a human being is estimated due to ingestion (H_{ing}) and inhalation (H_{inh}).

The concentration of Ra^{226} and Rn^{222} radionuclides which are commonly occurring in the water causes severe health hazards to human health. They discharge alpha particles and their respiration and ingestion may result in high radioactive dose to delicate cells in the respiratory tracts, digestive organs, and also other organs of the human body [111]. The Rn^{222} isotope has a half-life of 3.825 days which is enough to stay in the atmosphere of the human environment and causes health risk. Inhalation and ingestion are the two possible routes in which Rn^{222} in water can get into the human body. Here, both lungs and stomach are exposed to radon in water. The radiation dose to the stomach (ingestion) depends on daily water consumption. On the other hand, the radiation dose to the lungs depends on the release of Rn^{222} gas from water during normal human activities. Hence, the radiation dose to the public from waterborne radon is considered to be a higher menace than all other pollutants in water [112].

To evaluate AED due to inhalation and ingestion in the studied area, the UNSCEAR model was adopted. The annual effective dose due to the ingestion of radon from drinking water (H_{ing}), was calculated according to equation (3.1) [113]:

$$\boldsymbol{H}_{ing}\ (mSv/yr) = \boldsymbol{C}_{Rn} \times \boldsymbol{D}_{ing} \times \boldsymbol{L} \text{ ……………(3.1)}$$

Where:

$\boldsymbol{C}_{Rn}$: mean radon concentration in drinking water **(Bq/L)**

$\boldsymbol{D}_{ing}$**:** The conversion factor for ingestion, **($1\times 10^{-8}\ Sv/Bq$ or $1\times 10^{-5}\ mSv/Bq$ for an adult and $2\times 10^{-8}\ Sv/Bq$ or $2\times 10^{-5}\ mSv/Bq$ for a child)**.

L: annual drinking water consumption in liters.

There are controversies over the amount of annual water consumed by individuals in a year. The value of (60 L/y) for the weighted direct annual consumption of tap water has been proposed by UNSCEAR [114]. The total annual water intake for the so-called ‘‘ICRP Standard Man’’ equals to (2L/d) or (730 L/y) for adults, and for children the average water consumption rate (ACR) is (1.5L/d) or (547.5 L/y)(ICRP, IAEA 1996). Because the south-western area of Iraq has a desert climate, and it’s the driest area of the country, in addition to the high temperature in the city of Samawa most days of the year which means that to consume a large quantity of water, and for consistency with most international drinking water guidelines, the amount of (730 L/y) has been applied for calculations of ingestion dose for adults and (547.5 L/y) for children used in this study .

The annual effective dose due to the inhalation of radon (H_{inh}), resulting from the radon concentration in drinking water, was calculated using the following relation [113]:

$$\boldsymbol{H}_{inh}\ (nSv/yr) = \boldsymbol{C}_{Rn} \times \boldsymbol{R} \times \boldsymbol{F} \times \boldsymbol{T} \times \text{D…………...(3.2)}$$

Where:

$\boldsymbol{C}_{Rn}$**:** mean radon concentration in drinking water, **(Bq/L).**

***R*:** air to water concentration **(10^{-4}).**

F: Equilibrium factor between indoor radon and its progeny **(0.4).**

T: Exposure time in hours ($\boldsymbol{7000\ hr/yr}$) for adults and children.

D: Dose conversion factor ($\boldsymbol{9\ nSv/(Bq\ hr/m^3)}$) **or** ($\boldsymbol{9\ \times 10^{-6} mSv/(Bq\ hr/m^3)}$).

Annual effective dose due to ingestion and inhalation from exposure of ^{222}Rn in water for adults and child has been calculated using equations (3.1) and (3.2) and illustrated in Table (3.4) that shows the values of the annual effective dose per person of ingestion and inhalation from radon gas activity concentration of water samples in this study. The calculated total annual effective dose of children ranged from (0.735 μSv/yr) at Al-Risalah district (sample no.30) to (6.737 μSv/yr) at Al-qasabah district (sample no.8), with an average value of (1.923 μSv/yr), while for adults the total annual effective dose ranged from (0.4901 μSv/yr) at Al-Risalah district (sample No.30) to (4.492 μSv/yr) at Al-qasabah district (sample No. 8) with an average value of (1.282 μSv/yr). In the scope of our results, it was found that the total annual effective dose of children higher than of total annual dose for an adult, which is may be due to the ingesting dose conversion factor (a combination of changes in dose conversion factor and water intake with age), or this higher value for children is due to the high sensitivity of tissues of children body [115]. However, the total annual effective dose of children and adults for the whole body (ingestion plus inhalation) as shown in Fig.(3.3) from drinking water are well below the reference level of 0.1 mSv/year of WHO and hence do not pose any health problem from radon dose received from drinking water in the study area.

UNSCEAR has provided the mean dose from radon in water. From ingestion the mean radon dose is 0.002 mSv/yr and from inhalation it is 0.025 mSv/yr [3,113]. Comparison of these results indicates that in the case of water health risk is mainly from inhalation of radon. Our mean annual effective doses of 1.28 µSv/yr (for adults) and 1.922 µSv/yr (for Children) due to ingestion and 0.0044 µSv/yr due to inhalation from radon in water are lower than the mean annual effective dose of 0.002 and 0.025 mSv/yr of UNSCEAR due to ingestion and inhalation respectively.

Table (3.4): Annual Effective Dose Received by Age Groups of Children and Adults caused by the Inhalation of ^{222}Rn and Ingestion of Drinking Water in Samawa City Area.

Dist.No.	District Name	Rn Concentration (Bq/L)			Ingesion AED (μSv/y)		Inhalation AED (μSv/y)	Total AED (μSv/y)	
		Min	Max	Mean	Adult	Child		Adult	Child
1	AL-Hussein	0.00 ± 0.6	0.557 ± 0.9	0.147 ± 0.15	1.0779691	1.6169537	0.000372121	1.078341	1.6173258
2	AL-Muealimin	0.00 ± 0.6	0.542 ± 0.9	0.160 ± 0.13	1.17238	1.75857	0.000404712	1.172785	1.7589747
3	AL-Muealimin 2	0.00 ± 0.6	0.721 ± 1	0.1106 ± 0.1	0.807672	1.211508	0.000278813	0.807951	1.2117868
4	AL-Orouba	0.00 ± 0.6	0.721 ± 1	0.146 ± 0.12	1.0671359	1.6007039	0.000368381	1.067504	1.6010722
5	AL-Sader	0.00 ± 0.6	0.729 ± 1	0.239 ± 0.31	1.75054	2.62581	0.000604296	1.751144	2.6264143
6	AL-Shuhada 2	0.00 ± 0.6	0.561 ± 0.9	0.156 ± 0.13	1.145662	1.718493	0.000395489	1.146057	1.7188885
7	AL-Gharbi 2	0.00 ± 0.6	0.547 ± 0.9	0.148 ± 0.14	1.0851961	1.6277942	0.000374616	1.085571	1.6281688
8	AL-qasabah	0.00 ± 0.6	1.22 ± 1.1	0.615 ± 0.31	4.49096	6.73644	0.001550304	4.49251	6.7379903
9	AL- jadidah	0.00 ± 0.6	1.81 ± 1.3	0.394 ± 0.21	2.87912	4.31868	0.000993888	2.880114	4.3196739
10	B.S AL-sharqayh	0.00 ± 0.6	1.44 ± 1.2	0.421 ± 0.23	3.07476	4.61214	0.001061424	3.075821	4.6132014
11	9 Nisan	0.00 ± 0.6	0.466 ± 0.9	0.104 ± 0.9	0.766354	1.149531	0.00026455	0.766619	1.1497955
12	AL-Haydariah	0.00 ± 0.6	0.947 ± 1.1	0.339 ± 0.2	2.4759191	3.7138787	0.000854701	2.476774	3.7147334
13	AL-Nahdah	0.00 ± 0.6	0.387 ± 0.8	0.116 ± 0.12	0.853516	1.280274	0.000294638	0.853811	1.2805686
14	AL-Jumhuriah	0.00 ± 0.6	0.399 ± 0.8	0.104 ± 0.1	0.7633391	1.1450087	0.000263509	0.763603	1.1452722
15	AL-Askari	0.00 ± 0.6	0.854 ± 1	0.423 ± 0.24	3.09082	4.63623	0.001066968	3.091887	4.637297
16	AL-Hakim	0.00 ± 0.6	0.939 ± 1.1	0.192 ± 0.15	1.40598	2.10897	0.000485352	1.406465	2.1094554
17	AL-Tahryr	0.00 ± 0.6	0.619 ± 1	0.123 ± 0.1	0.90374	1.35561	0.000311976	0.904052	1.355922
18	AL-Iielam	0.00 ± 0.6	0.461 ± 0.9	0.123 ± 0.1	0.901404	1.352106	0.00031117	0.901715	1.3524172
19	AL-Amir	0.00 ± 0.6	0.391 ± 0.8	0.125 ± 0.11	0.918048	1.377072	0.000316915	0.918365	1.3773889
20	AL-Hassan	0.00 ± 0.6	0.461 ± 0.9	0.136 ± 0.11	0.993384	1.490076	0.000342922	0.993727	1.4904189
21	AL-Mujybil	0.00 ± 0.6	0.466 ± 0.9	0.123 ± 0.11	0.903448	1.355172	0.000311875	0.90376	1.3554839
22	AL-Sinaeiah	0.00 ± 0.6	0.373 ± 0.8	0.075 ± 0.8	0.553924	0.830886	0.000191218	0.554115	0.8310772
23	AL-Jahil	0.00 ± 0.6	0.619 ± 1	0.167 ± 0.13	1.21983	1.829745	0.000421092	1.220251	1.8301661
24	AL-Eatshan	0.00 ± 0.6	0.311 ± 0.8	0.092 ± 0.8	0.676418	1.014627	0.000233503	0.676652	1.0148605
25	AL-Qushlah	0.00 ± 0.6	0.464 ± 0.9	0.136 ± 0.11	0.995574	1.493361	0.000343678	0.995918	1.4937047
26	AL-Jihad	0.00 ± 0.6	0.313 ± 0.9	0.071 ± 0.9	0.51903	0.778545	0.000179172	0.519209	0.7787242
27	AL-Taamim	0.00 ± 0.6	0.157 ± 0.8	0.086 ± 0.8	0.630866	0.946299	0.000217778	0.631084	0.9465168
28	AL-Siagh	0.00 ± 0.6	0.391 ± 0.8	0.146 ± 0.13	1.069888	1.604832	0.000369331	1.070257	1.6052013
29	AL-Entisar	0.00 ± 0.6	0.308 ± 0.8	0.080 ± 0.8	0.58546	0.87819	0.000202104	0.585662	0.8783921
30	AL-Risalah	0.00 ± 0.6	0.311 ± 0.8	0.067 ± 0.7	0.4899541	0.7349312	0.000169135	0.490123	0.7351003
31	AL-Nasr	0.00 ± 0.6	0.466 ± 0.9	0.098 ± 0.9	0.721386	1.082079	0.000249026	0.721635	1.082328
32	B.S Algharbiah	0.00 ± 0.6	0.557 ± 0.1	0.141 ± 0.12	1.029446	1.544169	0.00035537	1.029801	1.5445244
Average Value					1.2818476	1.9227714	0.000442501	1.28229	1.9232139

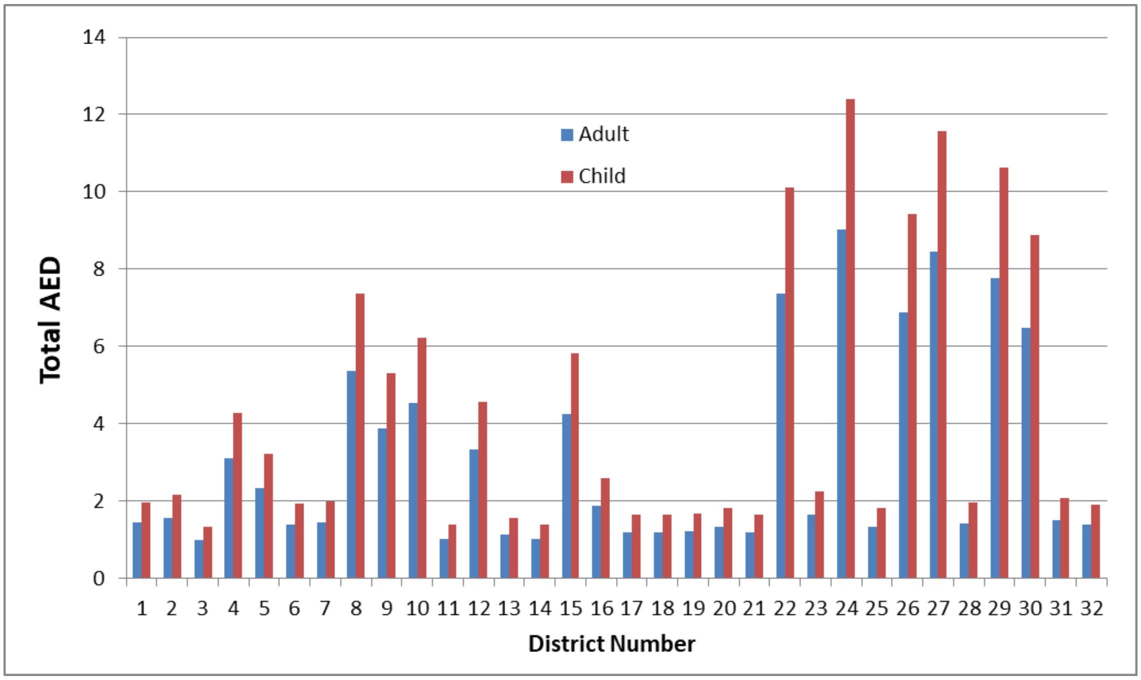


Figure (3.3): A Comparison of AED between Adults and Children.

The World Health Organization (WHO) [98] and the EU Council [116] recommended the action level for annual ingestion dose received from water consumption of 100 μSv/yr. According to WHO, if the total annual effective dose is less than 100 μSv/yr, the water is appropriate for consumption purposes and no further remedial action is necessary. The results of the total annual effective dose from all locations of the studied area are well below the reference level of 100 μSv/yr of WHO, and hence do not cause any health hazards for the inhabitant of the study areas.

3.4 Radon Concentration of Soil in Samawa City

Radon measurements in the soil of Samawa City were carried out. A total of (100) different locations were chosen in order to determine radon activity in the soil. The samples locations were determined using GPS portable instrument and documented as shown in Table (3.5). Radon measurements were in situ conducted using a RAD7 radon monitor provided with a soil gas probe accessory which allows the determination of radon soil gas directly with proper care during the measurements to make sure that the radon will be measured with no contact with outside air as much as possible. Radon activity in soil was measured at depth of (40 cm) under the soil surface. This depth was chosen as an intermediate case, as most studies take different depths [84,117] ,where the highest depth is 60 cm and the lowest depth is 20 cm, and the average case between them is 40 cm. Radon measurements were carried out for two months, From February 1st, 2020 to March 31th, 2020.

Table (3.5): Radon concentration and locations of soil samples.

Dist.No.	District name	Sample No.	Coordinate		Rn Concentration (Bq/m ^{3})
			Latitude	Longitude	
1	AL-Hussein	S 1	31°18'56.26"N	45°16'7.22"E	36.3 ± 30
		S 2	31°19'11.32"N	45°16'3.82"E	3290 ± 310
		S 3	31°19'14.31"N	45°15'44.88"E	5190 ± 390
		S 4	31°19'0.11"N	45°15'43.13"E	626 ± 130
2	AL-Muealimin	S 5	31°19'7.62"N	45°16'19.10"E	174 ± 70
		S 6	31°18'51.37"N	45°16'21.63"E	392 ±110
		S 7	31°18'59.97"N	45°16'35.38"E	985 ± 170
3	AL-Muealimin 2	S 8	31°18'43.10"N	45°16'8.68"E	457 ± 120
		S 9	31°18'35.65"N	45°15'48.99"E	1540 ± 210
		S 10	31°18'52.06"N	45°15'34.41"E	1590 ± 220
4	AL-Orouba	S 11	31°18'31.90"N	45°16'54.31"E	2010 ± 240
		S 12	31°18'32.98"N	45°16'27.55"E	1960 ± 240
		S 13	31°18'42.13"N	45°16'18.03"E	2560 ± 270
5	AL-Sader	S 14	31°18'25.82"N	45°16'0.70"E	617 ± 130
		S 15	31°18'11.82"N	45°15'59.96"E	1720 ± 220
		S 16	31°18'12.06"N	45°16'3.96"E	1010 ±170
6	AL-Shuhada 2	S 17	31°18'16.32"N	45°15'36.63"E	29 ± 30
		S 18	31°18'17.14"N	45°15'21.55"E	661 ± 140
		S 19	31°18'29.64"N	45°15'25.90"E	247 ± 80
7	AL-Gharbi 2	S 20	31°18'41.94"N	45°16'52.01"E	479 ± 120
		S 21	31°18'57.38"N	45°17'6.24"E	269 ± 90
		S 22	31°18'45.06"N	45°17'11.40"E	160 ± 70
		S 23	31°19'6.96"N	45°16'44.47"E	116 ± 56
		S 24	31°18'54.43"N	45°16'43.47"E	298 ± 90
8	AL-qasabah	S 25	31°18'50.92"N	45°17'23.43"E	4200 ± 350
		S 26	31°18'40.05"N	45°17'19.68"E	1190 ± 190
		S 27	31°18'33.31"N	45°17'14.63"E	5080 ± 390
9	AL-jadidah	S 28	31°18'47.16"N	45°17'37.50"E	956 ± 170
		S 29	31°18'36.20"N	45°17'42.70"E	1360 ± 200
		S 30	31°18'30.22"N	45°17'26.14"E	5050 ± 390
10	B.S AL-sharqayh	S 31	31°18'48.47"N	45°18'2.49"E	796 ± 150
		S 32	31°19'5.99"N	45°18'30.55"E	2270 ± 260
		S 33	31°18'37.12"N	45°18'25.14"E	3800 ± 330

11	9 Nisan	S 34	31°18'24.00"N	45°17'57.25"E	443 ± 110
		S 35	31°18'29.22"N	45°18'28.56"E	371 ± 100
		S 36	31°18'13.65"N	45°18'35.79"E	1050 ± 170
12	AL-Haydariah	S 37	31°18'21.77"N	45°16'41.14"E	3360 ± 310
		S 38	31°18'14.53"N	45°16'57.09"E	1770 ± 230
		S 39	31°18'20.04"N	45°16'22.77"E	1970 ± 240
13	AL-Nahdah	S 40	31°17'56.04"N	45°16'56.32"E	1160 ± 180
		S 41	31°18'2.36"N	45°16'56.38"E	931 ± 160
		S 42	31°17'53.38"N	45°16'51.02"E	4670 ± 370
14	AL-Jumhuriah	S 43	31°18'13.61"N	45°16'18.94"E	254 ± 90
		S 44	31°18'1.07"N	45°16'32.85"E	79.9 ± 51
		S 45	31°18'7.74"N	45°16'47.15"E	905 ± 150
15	AL-Askari	S 46	31°18'7.45"N	45°15'39.78"E	2230 ± 260
		S 47	31°17'49.62"N	45°15'54.78"E	5390 ± 400
		S 48	31°17'55.15"N	45°15'27.12"E	160 ± 70
16	AL-Hakim	S 49	31°18'0.31"N	45°16'13.24"E	1660 ± 220
		S 50	31°17'51.05"N	45°16'42.62"E	1100 ± 180
		S 51	31°17'37.54"N	45°16'39.58"E	985 ± 170
17	AL-Tahryr	S 52	31°17'50.65"N	45°16'9.67"E	290 ± 90
		S 53	31°17'36.60"N	45°16'27.00"E	74.6 ± 45
		S 54	31°17'25.39"N	45°16'29.17"E	780 ± 150
18	AL-Iielam	S 55	31°18'21.16"N	45°17'24.72"E	283 ± 90
		S 56	31°18'2.65"N	45°17'28.35"E	932 ± 170
		S 57	31°18'1.02"N	45°17'13.85"E	403 ± 110
19	AL-Amir	S 58	31°18'19.56"N	45°17'10.46"E	1620 ± 200
		S 59	31°17'43.31"N	45°17'2.73"E	1760 ± 230
		S 60	31°17'14.03"N	45°17'4.85"E	1810 ± 230
20	AL-Hussan	S 61	31°16'55.71"N	45°16'36.20"E	1070 ± 180
		S 62	31°16'24.66"N	45°16'54.96"E	174 ± 70
		S 63	31°16'20.41"N	45°16'9.58"E	131 ± 60
21	AL-Mujybil	S 64	31°17'5.22"N	45°17'16.80"E	116 ± 57
		S 65	31°16'51.95"N	45°17'52.49"E	612 ± 130
		S 66	31°16'41.58"N	45°17'12.05"E	211 ± 80
22	AL-Sinaeiah	S 67	31°18'2.79"N	45°17'57.68"E	160 ± 70
		S 68	31°17'41.55"N	45°17'29.79"E	87.1 ± 49
		S 69	31°17'13.00"N	45°17'52.02"E	102 ± 54
23	AL-Jahil	S 70	31°17'1.25"N	45°18'37.57"E	261 ± 90
		S 71	31°16'53.19"N	45°18'37.30"E	138 ± 60
		S 72	31°16'52.67"N	45°18'23.36"E	119 ± 35
24	AL-Eatshan	S 73	31°15'50.76"N	45°16'53.29"E	1400 ± 200
		S 74	31°16'13.99"N	45°17'29.44"E	2290 ± 260
		S 75	31°16'27.54"N	45°18'41.19"E	2340 ± 260

25	AL-Qushlah	S 76	31°19'17.11"N	45°17'28.08"E	1220 ± 190
		S 77	31°19'0.48"N	45°17'28.64"E	1320 ± 200
		S 78	31°19'7.35"N	45°17'8.20"E	5090 ± 390
26	AL-Jihad	S 79	31°19'26.39"N	45°17'38.62"E	196 ± 70
		S 80	31°19'17.60"N	45°17'42.36"E	138 ± 60
		S 81	31°19'4.24"N	45°17'40.82"E	36.3 ± 31
27	AL-Taamim	S 82	31°20'3.90"N	45°17'34.23"E	494 ± 120
		S 83	31°19'47.40"N	45°17'37.73"E	1470 ± 210
		S 84	31°20'5.52"N	45°17'58.76"E	1550 ± 210
28	AL-Siagh	S 85	31°19'46.38"N	45°15'56.97"E	5230 ± 390
		S 86	31°19'52.37"N	45°17'19.82"E	6820 ± 450
		S 87	31°19'25.14"N	45°17'3.33"E	1790 ± 230
29	AL-Entisar	S 88	31°20'22.52"N	45°16'23.43"E	3530 ± 320
		S 89	31°20'12.34"N	45°16'37.25"E	1580 ± 220
		S 90	31°20'11.36"N	45°16'12.37"E	613 ± 140
30	AL-Risalah	S 91	31°20'57.39"N	45°17'41.92"E	196 ± 70
		S 92	31°20'43.88"N	45°17'57.04"E	211 ± 80
		S 93	31°20'33.09"N	45°17'29.61"E	94.4 ± 52
		S 94	31°20'26.01"N	45°17'52.35"E	832 ± 160
31	AL-Nasr	S 95	31°20'23.18"N	45°15'53.13"E	601 ± 116
		S 96	31°21'5.66"N	45°16'18.67"E	356 ± 100
		S 97	31°20'28.37"N	45°17'2.57"E	606 ± 130
32	B.S Algharbiah	S 98	31°19'27.33"N	45°15'36.75"E	479 ± 120
		S 99	31°19'37.19"N	45°16'19.37"E	219 ± 80
		S 100	31°19'18.16"N	45°16'25.42"E	687 ± 130
Mean value					1343.5 ±170.4

The experimental results obtained in this study for radon soil gas concentration levels in 32 distract of Samawa City are presented in Table (3.5). From the Table, it is noticed that the samples have a high spatial variation between one location and another, where the radon concentration values ranged between the smaller value of (29 Bq/m^3) for sample (S17) and a higher value of (6820 Bq/m^3) for sample (S86) with an average value of (1343.5 Bq/m^3). Such variation cannot be explained by climatic factors such as temperature and barometric-pressure variation in a simple way, because all the different sites were interspersed and under similar climatic conditions. It can be say that , the reason may be due to the difference in the underlying bedrocks, or in the other words due to the geological condition of locations and geochemical processes in soil. The big difference in the radon concentration may be due to holes falling exactly on covered fault lines in the earth's crust since radon gas concentration in soil is taken as proportional to fracture opening [24]. Also, it may be attributed to the variation of the concentrations of uranium and radium, since their presence in the bedrock and soil materials controls the amount of radon produced in the soil. In addition to the local variation in the source elements, many factors affect the spatial variation of radon. For example, soil permeability, porosity, CO_2, moisture content, temperature, and atmospheric pressure [11].

The higher concentrations of radon in the soil of Samawa city are recorded for samples S3, S25, S27, S30, S42, S47, S85, and S78. The minimum radon concentrations can be observed from Table (3.5) in the samples S1, S44, S53, S68, and S81. An average value of radon concentration for each district is estimated.

Table (3.6): Average Radon Concentration of Soil in Each District.

Dist.No.	District Name	Mean Radon concent.(Bq/L)
1	AL-Hussein	2285.5 ± 215
2	AL-Muealimin	517 ± 116.6
3	AL-Muealimin 2	1195.6 ± 183.3
4	AL-Oruba	2176.6 ± 250
5	AL-Sader	1115.6 ± 173.3
6	AL-Shuhada 2	312.3 ± 83.3
7	AL-Gharbi 2	264.4 ± 85.2
8	AL-qasabah	3490 ± 310
9	AL-Jadidah	2455.3 ± 253.3
10	B.S AL-sharqauh	2288.6 ± 246.6
11	9 Nisan	621.3 ± 126.6
12	AL-Haudariah	2366.6 ± 260
13	AL-Nahdah	2253.6 ± 236.6
14	AL-Jumhuriah	412.96 ± 97
15	AL-Askari	2593.3 ± 243.3
16	AL-Hakim	1248.3 ± 190
17	AL-Tahrur	381.5 ± 95
18	AL-Iielam	539.3 ± 123.3
19	AL-Amir	1730 ± 220
20	AL-Hassan	458.3 ± 103.3
21	AL-Mujubil	313 ± 89
22	AL-Sinaeiah	116.3 ± 57.6
23	AL-Jahil	172.6 ± 61.6

24	AL-Eatshan	2010 ± 240
25	AL-Qushlah	2543.3 ± 260
26	AL-Jihad	123.4 ± 53.6
27	AL-Taamim	1171.3 ± 180
28	AL-Siagh	4613.3 ± 356.6
29	AL-Entisar	1907.6 ± 226.6
30	AL-Risalah	333.35 ± 90.5
31	AL-Naser	521 ± 115.3
32	B./S Algharbiah	461.6 ± 110
Mean value		1343.5 ± 170.4

From the mean values of radon concentration represented in Table (3.6), it is clear that the AL-Siagh (District No. 28)region poses the higher radon concentration with the value of (4613.6 ± 356.6 Bq/m^3). This may be back to the nature of its agricultural soil, and the fact that is the soil saturated with water significantly. However, because the soil permeability and moisture represents the most important physical characteristic which highly influences radon soil gas emanation and transporting within the soil, as well as, the water content has a large impact on the emanation coefficient and the soil transport parameters for radon gas, we have a wide range of radon concentration in the soil and therefore, affect the radon concentration in the soil [118,136]. However, the high level of radon concentration in this region can be explained according to the high content of water which leading to fill the soil pores and become saturated with water that decreases its permeability and inhibits radon soil gas migration to the upper layers and prevents radon soil gas from escaping easily. On the other hand, and from the same table above, it can be seen that the lower mean value of radon concentration was for the AL-Sinaeiah region (District No. 22) with the value of (116.3 ± 57.6 Bq/m^3), the low radon content in this site may back to the lack of uranium and radium in the bedrock because the radium isotope ^{226}Ra content in soil is the most important factor in determining the level of soil radon and radon exhalation from the soil surface. However, a possible reason may lie in the fact that the sandy nature of the region soil with big grain size as compared with clay. Grain size is one of the important factors that control radon concentration in soil. Furthermore, it was suggested by previous studies that the radioactivity of the soil relate to the grain size of soil, i.e., soil radioactivity decreases with sand content in the soil and increases with clay content. Also, the region is far from the river and agricultural lands, and hence the soil is dry with a low water content which allows radon to escape easily to the air [117]. However, most of the average values of radon concentrations in the soil of Samawa City are lower than the recommended limit (800 Bq/m^3) which was reported by WHO[119], while some of them were much higher than the above permissible value. Further, it was found that about 90.6% of the soil samples have radon concentration higher than the world action level of 200 Bq/m^3 recommended by UNSCEAR [3].

The values of radon concentrations obtained in soil gas compared to those reported by the other investigators in different parts of the world are summarized in Table (3.7).

Table (3.7): Local and Regional Studies of the Mean Radon Concentrations in Soil.

No.	Country	Location	Radon(Bq/m³)		Ref.
			Law	High	
1	Saudi Arabia	Al Qassim Area	26	340	[120]
2	Saudi Arabia	Jazan Region	869.81	302.91	[121]
3	Jordan	Irbid Province	697	6335	[122]
4	Turkey	Dikili Geothermal area	98	8594	[123]
5	Palestine	Gaza	23.48	21361	[18]
6	Egypt	Southwestern Sinai	628	21361	[124]
7	Iraq	Al Tuwaitha Nuclear	866	16004	[80]
8	Iraq	Al-Kufa city	41.45	12775	[73]
9	Iraq	Al-Najaf City	9	9290	[125]
10	Iraq	University of Technology, Baghdad	61.18	2237.77	[126]
11	Iraq	Karbala City	50	7800	[77]
12	Iraq	Hilla City	25	12700	[78]
13	Iraq	Amara City	53.18	2047.51	[127]
14	Iraq	Salahaddin Province	45.25	100.75	[128]
15	Iraq	Baghdad city	362.07	889.53	[136]
16	Iraq	Samawa City	116.3	4613.6	Present study

From the table, the maximum level of radon soil gas was for both Palestine and Egypt with a value of (21361 Bq/m^3), while the minimum value was for Iraq, AL-Najaf city (9 Bq/m^3). The results of this study take a moderate position among the results shown in the table. Besides, it can be observed that most sampling points have radon concentrations below or within the action levels of (0.4 – 4 kBq/m^3) proposed by UNSCEAR (2000) [3].

Radon concentration in soil and hence radon exhalation from soil surface depend on many physical parameters related to soil characters, such as radium contents and the internal structure of soil [125,129] . They may also be affected, directly or indirectly, by the weather factors such as air pressure and air temperature [76]. However, as the direct source of radon, the radium isotope (Ra^{226}) content in soil is the most important factor in determining the level of soil radon. For radon concentration in soil, many mathematical models refer that it has a direct proportion with soil radium content. In previous studies, many authors evaluated the soil radon level on the assumption that (1 Bq/Kgm) radium is equivalent to (1700 Bq/m^3) radon concentration in soil [117,130]. If we relied on this hypothesis in determining the concentrations of radium in soil, we would find that the values of radium content in the studied areas which are shown in table (3.10), where far below the permissible values (safe limit) of 370 Bq/kg recommended by the Organization for Economic Cooperation and Development (OECD) [131,132], and lower than the global value (30 Bq/kg) as quoted by UNSCEAR [29].

Table (3.8): Results of Radon and Radium Concentration in Soil Samples.

Dist.No.	District name	Mean Radon Conc. (Bq/m^3)	Mean Radium Conc. (Bq/kg)
1	AL-Hussein	2285.5	1.34441
2	AL-Muealimin	517	0.30411
3	AL-Muealimin 2	1195.6	0.70329
4	AL-OrOuba	2176.6	1.28035
5	AL-Sader	1115.6	0.65623
6	AL-Shuhada 2	312.3	0.18370
7	AL-Gharbi 2	264.4	0.15552
8	AL-qasabah	3490	2.05294
9	AL-Jadidah	2455.3	1.44429
10	B.S AL-sharqauh	2288.6	1.34623
11	9 Nisan	621.3	0.36547
12	AL-Haudariah	2366.6	1.39211
13	AL-Nahdah	2253.6	1.32564
14	AL-Jumhuriah	412.96	0.24291
15	AL-Askari	2593.3	1.52547
16	AL-Hakim	1248.3	0.73429

17	AL-Tahryr	381.5	0.22441
18	AL-Iielam	539.3	0.31723
19	AL-Amir	1730	1.01764
20	AL-Hassan	458.3	0.26958
21	AL-Mujubil	313	0.18411
22	AL-Sinaeiah	116.3	0.06841
23	AL-Jahil	172.6	0.10152
24	AL-Eatshan	2010	1.18235
25	AL-Qushlah	2543.3	1.49605
26	AL-Jihad	123.4	0.07258
27	AL-Taamim	1171.3	0.689
28	AL-Siagh	4613.3	2.71370
29	AL-Entisar	1907.6	1.12176
30	AL-Risalah	333.35	0.19608
31	AL-Naser	521	0.30647
32	B.S Algharbiah	461.6	0.27152

These results show a strong positive correlation between soil radon concentration and radium content. The highest radon and radium concentrations have been found in sample No.28 (AL-Siagh district). The lower value of radon and radium concentrations have been found in sample No.22(AL-Sinaeiah district). The results reveal that the area is safe as for as the health hazard effects of radon and radium were concerned.

3.5 Annual Effective Dose of Samawa City Soil

The annual effective dose received by the public due to inhalation is assessed regarding radon soil gas concentration at the surface of the soil. Because a particular amount of radon content penetrates the soil up to the surface which contributes later to inhalation effective dose. Therefore, the accumulated quantity of radon at the soil surface is adopted in this investigation to estimate the annual effective dose received by individuals in the study area due to inhalation. The annual effective dose (AED, mSv/y) has been calculated using the formula proposed by UNSCEAR 2000 which is [3]:

$$D_{inh} = C_{Rn} \times F \times I \times (DCF) \quad \ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

Where D_{inh} is the annual effective dose received by the public, C_{Rn} is the radon concentration in the air near the soil surface, F is the equilibrium factor between radon and its products (= 0.6), I is the mean outdoor occupancy time per individual (= 1760 h/y), and DCF is the dose conversion factor for radon exposure 9 nSv (Bq h/ m^3). Radon concentration at the surface of the soil (C_{Rn}) is given by the relation [80]:

$$C_{Rn} = C_{SG} \sqrt{\frac{d}{D}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3.4)$$

Where C_{SG} is the radon activity in the soil, d is the exhalation diffusion constant (= 0.05 cm^2/s), and D is the Eddy diffusion coefficient (= 5×10^4 cm^2/s). Table (3.9) shows the highest effective dose of soil as a result of inhalation is equal to 0.0438 mSv/y in AL-Siagh (District No.28) and the lower value of effective dose is equal to 0.0011 mSv/y in AL-Sinaeiah (District No.22) with a mean value of 0.0127 mSv/y.

Table (3.9): Radon concentration in the soil of Samawa districts (C_{SG}) , and the soil surface (C_{Rn}) with the associated annual effective dose (D_{inh}).

Dist.No.	District No.	C_{SG} (Bq/m³)	C_{Rn} (Bq/m³)	Effective Dose (mSv/y)
1	AL-Hussein	2285.5	2.2855	0.02172
2	AL-Muealimin	517	0.517	0.00491
3	AL-Muealimin 2	1195.6	1.1956	0.01136
4	AL-Orouba	2176.6	2.1766	0.02068
5	AL-Sader	1115.6	1.1156	0.0106
6	AL-Shuhada 2	312.3	0.3123	0.00296
7	AL-Gharbi 2	264.4	0.2644	0.00251
8	AL-qasabah	3490	3.49	0.03316
9	AL-Jadidah	2455.3	2.4553	0.02333
10	B.S AL-sharqauh	2288.6	2.2886	0.02175
11	9 Nisan	621.3	0.6213	0.00595
12	AL-Haudariah	2366.6	2.3666	0.02249
13	AL-Nahdah	2253.6	2.2536	0.02141
14	AL-Jumhuriah	412.96	0.41296	0.00392
15	AL-Askari	2593.3	2.5933	0.02464
16	AL-Hakim	1248.3	1.2483	0.01186
17	AL-Tahryr	381.5	0.3815	0.00362
18	AL-Iielam	539.3	0.5393	0.00512

19	AL-Amir	1730	1.73	0.01644
20	AL-Hassan	458.3	0.4583	0.00435
21	AL-Mujubil	313	0.313	0.00297
22	AL-Sinaeiah	116.3	0.1163	0.0011
23	AL-Jahil	172.6	0.1726	0.00164
24	AL-Eatshan	2010	2.01	0.0191
25	AL-Qushlah	2543.3	2.5433	0.02417
26	AL-Jihad	123.4	0.1234	0.00117
27	AL-Taamim	1171.3	1.1713	0.01113
28	AL-Siagh	4613.3	4.6133	0.04384
29	AL-Entisar	1907.6	1.9076	0.01812
30	AL-Risalah	333.35	0.33335	0.00316
31	AL-Naser	521	0.521	0.00495
32	B./S Algharbiah	461.6	0.4616	0.00438
Mean value		1343.52531	1.34352	0.01276

Table (3.9) indicates that the annual effective dose received ranged between (0.0011 mSv/y) and (0.0438 mSv/y), with an average value of (0.0127 mSv/y). The obtained values of annual effective dose were found to be well within the safe limit of (0.1 mSv/y) as recommended by World Health Organisation (WHO, 2004) and European Council (EU, 1998) [133], or below the recommended worldwide [3,134], and far below from the reference levels proposed by ICRP of (1 mSv/y) [135]. The results of inhalation dose revel that these areas are safe from the health hazard point of view and show no significant radiological risk for the inhabitant as far as the radon is concerned.

Chapter Four

CONCLUSIONS

4.1 Conclusions

Natural radioactivity is the largest contributor of ionizing radiation to the population. Radon is present in trace amount almost everywhere on the earth, being distributed in water, soil and occupies from the natural radiation sources more than half of the dose exposure ($\sim \geq 50\%$). Public exposure to waterborne Rn^{222} and its short-lived radioactive progenies/decay products may occur by ingestion (drinking water containing Rn^{222}) and by inhalation (breathing Rn^{222} gas in air which has been released from household water or soil.

From the present study, it can be concluded the following:

4.1.1 Radon Concentration in Drinking Water of Samawa City.

1-The results of the radon concentration in 167 drinking water samples collected from Samawa districts indicate well that the radon concentrations in drinking water are mostly very low, and about 100% of the measured samples were lower than the level permitted by some international organization which are (11.1 Bq/L) proposed by the US Environmental Protection Agency (EPA), or (20 Bq/L) reported by the World Health Organization (WHO).

2-The results of the annual effective dose due to ingestion of radon in drinking water for adults and children show that the dose of children was increased vulnerability which is may be due to the ingestion dose conversion factor, or according to the high sensitivity of tissues of children body. Furthermore, the annual effective dose due to inhalation of radon in drinking water, show the same values for adults and children.

3-The total annual effective dose received due to inhalation and ingestion from radon in drinking water which intake by adults and children indicated that the dose from all samples are significantly lower than the maximum contaminant levels of 0.1 *mSv/y* for public proposed by WHO, UNSCEAR and EU council.

4-The high concentration in the water sample (W40) from Al-qasbuh may be due to the soil and rock structure where the water pipes pass through it, and or the water network that provides this district with water is the oldest in the city. In addition, the network pipes are made from concrete, and as known the radon content within concrete pipes is higher than PVC or iron pipes. On the other hand, these pipes contain a significant number of fractures and cracks which allow the ground water to be mixed with transported water which increase the radon level within pipes. Hence, The materials that pipes made from, as well as the nature of the ground, will affect the concentration of radon gas in drinking water. As well as, the high radon concentration in water samples (W41, W42, W43, W47, W48, W54, W60, and W79) seems to be due to mixing of drinking water with ground water in the districts mentioned earlier, or due to geological structure of the areas studied.

5-The results show that before drinking water usage in public network, it must be stored in a large basin for a period in order to allows any radon present in the water to escape and decay away from it.

4.1.2 Radon Concentration in Soil of Samawa City.

1- The results of radon concentrations obtained in this study in the soil of Samawa city based on the portable device RAD7, are found to be within or under the safe limit of (0.4 – 40KBq/m^3) recommended by United Nations Scientific Committee on Atomic Radiations (UNSCEAR).

2- Radon concentrations in soil gas fluctuated from location and another clearly, which indicates a local variation of radon distribution between different locations. As same as radon in water, the highest radon in soil concentrations were found in the sample (S86) at AL-Siagh, while the lowest concentrations were observed in the sample (S17) at AL-Shuhada 2.

3- Annual inhalation dose received by individuals due to radon concentrations at the soil surface of Samawa city districts has been estimated and it was found to be far below the allowed limit of (1 *mSv/yr*) reported by UNSCEAR or WHO, which means that the study area is safe from health hazard of radon point of view.

4- The comparison of the measured radon concentrations for the soil of Samawa city districts with the results of similar studies under-taken in Iraq and other parts of the world indicate that the present results are comparable to or lower than those obtained in Iraq or different parts of the world.

4.2 Recommendations and Future Work

Further work needs to be done to enhancement knowledge generated in this study, which are:

1- Determination of the activity of radium , thoron and uranium in drinking water and soil in the same region by using gamma spectrometry and correlate their concentrations with the present results.

2- Measuring radon concentrations in the drinking water of Samawa City using passive methods (SSNTD's) and make a comparison between the active method that we used in the present study and the passive method.

3- Investigate and mapping Uranium-238 and Thorium-232 levels in the soil of Samawa city using gamma spectrometry.

4- Investigation into radon concentrations emanating from building materials used for construction of Samawa houses and buildings which are often rich in different naturally occurring radioactive elements, particularly with the resent UNSCEAR and WHO reference level for radon and gamma radiation emission from building materials.

5-The present study suggests that more investigation are requested to survey the radon concentration in other regions of Samawa city, or Al-Muthanna province and to map the radon gas in the soil of Samawa city, which would give a good data base and motivation to study the areas from radiation contamination point of view to protect people from radon risks.

REFERENCES

[1]. Idriss H., Salih I., Sam A. K.,"Study of radon in ground water and physicochemical parameters in Khartoum state" , J Radioanal Nucl Chem. 2011.Vol. 290. No.2, pp.(333-338).

[2]. Jebur L. A., Khadhum N. F., "Studying Different Etching Methods for Several Types of Solid State Nuclear Track Detectors", 2016. M.Sc. Thesis, University of Al – Mustansiriyah, Iraq.

[3]. UNSCEAR.,"Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes", 2000. Vol. I: sources, vol II: Effects, New York, pp.(1-17).

[4]. Rajendra J., Najendra S., Sanjay S., Sisodia R., "Effects of Microave Radations(2.45 GHZ) on Biochemical Alteration in Brain of Swiss Albino Mice and its Amelioration by Melatonin", 2018. Vol.9. No.1, pp.(23263-23269).

[5]. Tsoulfanidis N., Landsberger S.," Measurement and Detection of Radiation", 4th Edition, CRCP Press Taylor and Francis Group. 2015, pp.(1-563).

[6]. Shafik S. S., Mohammed A. A., "Concentration Measurements of Radon, Uranium and Background of Gamma Rays in Air at the University of Baghdad – Al-Jadiriyah Site", M.Sc. Thesis, University of Baghdad , Iraq. 2013. Vol. 2. No.5 , pp.(455-462).

[7]. L'Annunziata M. F., "Introduction: Radioactivity and Our Well-Being", Radioactivity, 2007, pp.(1- 45).

[8]. L'Annunziata M., F., "Handbook of Radioactivity Analysis", Second Ed Sci. 2003.

[9]. Rich S. E., Dharmarajan K. V., "Introduction to Radiation", The Canadian Nuclear Safety Commission. 2012, pp.(1-38).

[10]. Force N., Nuclides S., Nuclides R., "Radiation Theory", 1990, pp.(17-70).

[11]. Sharrad A. A., Farhood A. K., "Radon Concentration Measurments in Soil Gas of Sawa Lake, Samawa City – South of Iraq", 2019. Vol.7. No.6, pp. (170 - 177).

[12]. Corrigan R., Brand K., " Lung Cancer Risks to Canadians from Residential Radon Exposure". PhD. Thesis, University of Ottawa. Faculty, 2017, pp.100.

[13]. Airey J., Linder C.," Social semiotics in university physics education : Leveraging critical constellations of disciplinary representations", Astronomy Uppsala University, 2015, Sweden .

[14]. Marshall J., "Fundamental concepts", Wiley-VCH Verlag GmbH & Co. KGaA. 2013. pp.(1-23).

[15]. Wiking V., "A study of naturally occurring radon in Swedish water purification

plants", Kthroyal institute of technology school of architecture and the buil tenvironment. Swedish. PhD. Thesis, 2016, pp.(1-56).

[16]. Burchfield L. A., "Radiation Safety: Protection and Management for Homeland Security and Emergency Response", Radiat Saf Prot Manag Homel Secur Emerg Response, 2009, pp.(1-287).

[17]. Ishnayyin H. G., Mahd K. H., "Find an Empirical Formula for Indoor Radon Measurement Emitting from Building Materials", M.Sc.Thesis, University of Baghdad , Iraq, 2015, pp.(25 - 27).

[18]. Hamed N., M., A., Shabat M. M., Yassin S. S., " Measurement of Radon Concentration in Soil at North Gaza", M.Sc.Thesis, University of Athens – Greece Supervised , 2005, pp.(86).

[19]. H., C., Berg, "Biological and Medical Physics, biomedical engineering" Second Edition. Tennessee, USA ., 2006, pp.(1-745).

[20]. Alaboodi A. S., Kadhim N. A., Abojassim A. A., Hassan A. B., "Radiological hazards due to natural radioactivity and radon concentrations in water samples at Al-Hurrah city, Iraq", 2020. Vol.18. No.1, pp.(1-11).

[21]. Laurence H., "Handbook of Radioactivity Analysis, 3rd edition", University of Reading, UK. 2012. Vol. 44, No. 22, pp. (1379).

[22]. Patra A. C., Mohapatra S., Sahoo S. K., Lenka P., Dubey J. S., Thakur V. K., Kumar A. V., Ravi P. M., and Tripathi R. M., "Assessment of ingestion dose due to radioactivity in selected food matrices and water near Vizag, India", J Radioanal Nucl Chem. 2014.Vol.300. No.3, pp.(903-910).

[23]. Hall E. J., "Radiation Biology: A Handbook for Teachers and Students VIENNA" 2010. No.42.

[24]. Sharrad A. A., Farhood A. K., " Seasonal Radon Concentration Measurements at Sawa Lake, Samawa City-South of Iraq", 2020. M.Sc. Thesis, AL Muthanna University, Iraq.

[25]. Al-attiyah K. H. H., Kadhim I. H., "Measurement and Study of Radioactive Radon Gas Concentrations in the Selected Samples of water for AL-Shomaly / Iraq", Aust J Basic Appl Sci. 2013. Vol.3.No.14, pp.(156-160).

[26]. Seoud M. S., "Measurement of Radon-222 Concentration in Bottled Natural Mineral Drinking Water in Kuwait Using the Nuclear Track Detector (CR-39)" , 2017. Vol.5. No.6, pp.(201-207).

[27]. Environmental Sciences Training Center., "What Are the Sources of Ionizing Radiation? " , American. 1996, pp.(1-3).

[28]. Nations U., Programme E., " Radiation Effects and Sources", Printed in Austria. 2016. pp.(1-55).

[29]. United Nation Scientific Committee on the Effects of Atomic Radiation . "Sources and effects of ionizing radiation. : Report to the General Assembly, with Scientific Annexes", United Nations. editor. 1993. New York: United Nations.

[30]. Queen's S. N. A., "Physics and Engineering of Radiation Detection ", 2007. Queen's University, Kingston, Ontario.

[31]. Martin A., "Natural and Man-Made Radiation Sources", USNRC Technical Training Center. 2020. pp.(51-58).

[32]. Strand T., "Printed by support from the Norwegian Cancer Society" , Norwegian Cancer .1987. PP.(1-219).

[33]. United Nations Scientific Committee on the Effects of Atomic Radiation, "Sources and Effects of Ionizing Radiation", United Nations, editor. New York: 2010. United Nations.

[34]. Martin J. E., "Physics for Radiation Protection", Physics for Radiation Protection, Second Edition. 2013. Vol. 3.

[35]. UNSCEAR. "UNSCEAR 2013 Report: Volume II. Effects of radiation exposure of children", 2013. Vol. II, Unscear.Org.

[36]. UNSCEAR 2008 Report., "Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation ", 2008. Vol. I, No.1, pp.(187).United Nation.

[37]. Sharrad A. A., Farhood A. K., "Radon concentration measurements and physiochemical parameters of Sawa Lake water-Samawa city, south of Iraq", J Glob Pharma Technol. 2019. Vol.11. pp.(532-543).

[38]. Yalcin S., Gurler O., Tarim U. A., Incirci F., Kaynak G., Gundogdu O., "Measurements of radon concentration in drinking water samples from Kastamonu (Turkey)", Isotopes Environ Health Stud.2011. Vol. 47, No.4, pp.(438-445).

[39]. Shultis J. K., Faw R. E.,"Fundamentals of Nuclear Science and Engineering", Newyork 10016 , 2002, Basel.

[40]. Technology I., "Measurement of Indoor Radon Levels, Natural Radioactivity and Lung Cancer Risks Estimation", PhD. Thesis, Technology Islamabad University of Pakistan, 2010. pp.(1-151).

[41]. Nayif S. S., Hashim A. K., "Measurement of Radon Concentrations in the Air Buildings for some Schools at Karbala City Using CN - 85 and LR - 115 Type II Detectors", M.Sc. Thesis , University of Kerbala. Iraq. 2019, pp.(89).

[42]. Ezzulddin S. K., "Radon-222 and Radium-226 Activity Concentration Measurement in Erbil Governorate Drinking Water Resources Using Active and Passive Detection Methods", M.Sc. Thesis, Salahaddin University of Erbil , Iraq

.2008. pp.(119).

[43]. Yousuf R. M., Abullah K. O., "Measurement of Uranium and Radon Concentrations in Resources of Water from Sulaimany Governorate -Kurdistan Region-Iraq", ARPN J Sci Technol .2013. Vol.3. No.6, pp.(632-638).

[44]. Hussein D. A. S., Ebrahiem S. A., "Measurement of Radon Concentrations in College of Education / Ibn Al- Haitham Buildings Using CR-39 Detector and RAD-7 Monitor" 2018. M.Sc. Thesis , College of Education / Ibn Al- Haitham , University of Baghdad. Iraq.

[45]. Günay O., Aközcan S., Kulalı F., "Measurement of indoor radon concentration and annual effective dose estimation for a university campus in Istanbul", Arab J Geosci. 2019. Vol.12, No.5.

[46]. Abojassim A. A., Gazaly H., Al-Taweel M. H. and Kadhim S. H., "Radon Concentrations in Selected Samples of Tap Water in Baghdad Government/Iraq", Res J Appl Sci Eng Technol. 2015. Vol.11, No. 12 , pp.(1358-1364).

[47]. Lewis R. K., Houle P. N., "A Living Radon Reference Manual", 2009. PhD. Thesis, University Educational Services, Inc..

[48]. Services H., "Toxicological Profile For Radon", ATSDR’s Toxicological Profiles. 2012.

[49]. Nero A. V., "Radon and Its Decay Products in Indoor Air", University of California Berkeley, CA 94720 .J Environ Qual. 1987. Vol. 18 , No.1.

[50]. Hutri K. L., Makelainen I., "Indoor radon in houses built on gravel and sand deposits in southern Finland " 1993. Vol. 65. No. 1, pp.(49-58). Bulletin - Geological Society of Finland.

[51]. Whitte R. F., Free T., "Iron & Manganese in Drinking Water" 2003. Eai Anal Lab. No. 603 , pp. (1-18).

[52]. Khattak N. U., Khan M. A., Shah M. T., and Javed M. W., "Radon concentration in drinking water sources of the Main Campus of the University of Peshawar and surrounding areas, Khyber Pakhtunkhwa, Pakistan", J Radioanal Nucl Chem.2011. Vol.290, No. 2, pp.(493-505).

[53]. El-Araby E. H., Soliman H. A., Elmagd A. M., "Measurement of radon levels in water and the associated health hazards in Jazan, Saudi Arabia", J Radiat Res Appl Sci. 2019. Vol. 12, No. 1 , pp. (31-36).

[54]. Salavati M., Falahinia G., Vardanjani A. E., Rafiei H.,and Moosavi S., "Effective Dose Radon 222 of the Tap Water in Children and Adults People; Minab City, Iran", 2016. Vol.8, No.4, pp.(196-202).

[55]. Chavarria I., "Survey of in-Soil Radon Concentrations Around the EAST Franklin Mountain Fault",2017. PhD. Thesis , University of Texas Atel Paso.

[56]. Omer I., Mohameed B., "Investigation of radon concentration in some house's in Soba", 2013. M.Sc.Thesis, Sudan Academy of Sciences, Sudan.

[57]. Villanueva J. L. G., Huerga E. C., Calzada M. N., "Radon concentrations in air , soil, and water in a granitic area : instrumental development and measurements",2008. Ph.D. Thesis, Universidad de Valladolid.

[58]. Axelsson, G., Andersson, E. M., Barregard L.,"Lung cancer risk from radon exposure in dwellings in Sweden: how many cases can be prevented if radon levels are lowered?" 2015. Vol. 26, No.4, pp. (541 - 547).

[59]. Tirmarche M., Harrison J. D., Laurier D., Paquet F., Blanchardon E., and Marsh J. W., "Part 1: Lung Cancer Risk from Radon and Progeny and Statement on Radon", Ann ICRP , 2010. Vol.40. No.1 , pp.(11).

[60]. Sahu P., Panigrahi D. C., Mishra D. P., "Evaluation of effect of ventilation on radon concentration and occupational exposure to radon daughters in low ore grade underground uranium mine",J Radioanal Nucl Chem, 2015. Vol.303 , No.3 , pp. (1933-1941).

[61]. Lecomte J. F., Solomon S., Takala J., Jung T., Strand P., Murith C., et al. ,"ICRP Publication 126: Radiological Protection against Radon Exposure", Annals of the ICRP, 2010. Vol. 43, No.3, pp. (5-73).

[62]. Badhan K., Mehra R., Sonkawade R. G., "Measurement of radon concentration in ground water using RAD7 and assessment of average annual dose in the environs of NITJ, Punjab, India", Indian J Pure Appl Phys, 2010. Vol. 48, No. 7, pp. (508-511).

[63]. Rani A., Mehra R., Duggal V., Rani A., Mehra R., Duggal V., "Radon monitoring in groundwater samples from some areas of northern Rajasthan, India, using a RAD7 detector", Radiat Prot Dosimetry. 2012. Vol. 153, No. 4, pp. (1-6).

[64]. Hadi I. H. K., Atiya K. H., "Measurement and study of radioactive radon gas concentrations in the selected Samples of air and water for Hilla city",2012. M.Sc. Thesis ,University of Babylon.

[65]. Abojassim A. A., Shitake A. R., "Estimated the mean of annual effective dose of radon gases for drinking water in some locations at Al-Najaf city", J Kufa-Physics. 2013. Vol. 5, No. 2,pp.(53-58).

[66]. Shivakumara B. C., Chandrashekara M. S., Kavitha E., Paramesh L., "Studies on 226 Ra and 222 Rn concentration in drinking water of Mandya region, Karnataka State, India" , J Radiat Res Appl Sci. 2014. Vol.7, No.4, pp. (491-498).

[67]. Ahmad N., Jaafar M. S., Alsaffar M. S., "Study of radon concentration and toxic elements indrinking and irrigated water and its implications in Sungai Petani, Kedah, Malaysia", J Radiat Res Appl Sci.2015. Vol. 8, No. 3, pp. (294-299).

[68]. Jafir A. O., Ahmad A. H., Saridan W. M., "Seasonal radon measurements in

Darbandikhan Lake water resources at Kurdistan region-northeastern of Iraq", AIP Conf Proc. 2016. Vol. (1718), 050001.

[69]. Stelzhammer V., Ozcan S., Michael G., Steeb H., Hodes G. E., Guest C., et al., "Radon levels in drinking water of Fatehabad district of Haryana, India", Diagnostics in Neuropsychiatry, 2017. pp. (88-93).

[70]. Naskar A. K., Gazi M., Barman C., Chowdhury S., Mondal M., Ghosh D., et al., "Estimation of underground water radon danger in Bakreswar and Tantloi Geothermal Region, India",J Radioanal Nucl Chem. 2018. Vol. 315, No. 2, pp. (273-283).

[71]. Singh B., Singh S., Bajwa B. S., Singh J., Kumar A., "Soil gas radon analysis in some areas of Northern Punjab, India", Environ Monit Assess. 2010. Vol. 174, pp. (209-217).

[72]. Hasan A. K., Subber A. R. H., Shaltakh A. R., "Measurement of Radon Concentration in Soil Gas using RAD7 in the Environs of Al-Najaf Al-Ashraf City-Iraq", Adv Appl Sci Res. 2011. Vol.2, No. 5, pp. (273-278).

[73]. Al-hamidawi A. A., Jabar Q. S., Mashhadani A. H., Bayati A. A., "Measurement of radon and thoron concentrations of soil- gas in Al-Kufa city using RAD-7 detector", Iraqi J Phys. 2012. Vol.10, No. 19, pp. (110-116) .

[74]. Szabo K. Z., Jordan G., Horváth A., Szabo C., "Dynamics of soil gas radon concentration in a highly permeable soil based on a long-term high temporal resolution observation series", J Environ Radioact . 2013. Vol.124, pp. (74-83).

[75]. Duggal V, Rani A, Mehra R. "Measurement of soil-gas radon in some areas of northern Rajasthan, India". J Earth Syst Sci. 2014. Vol.123, No.6, pp. (1241-1247).

[76]. Ravikumar P., Davis D., Somashekar R. K., Prakash K., L., " Measurement of radon activity in soil gas using RAD7 in the Environs of Chitradurga District , Karnataka , India", Earth Sci. 2015. Vol.80, pp. (31078 - 31082).

[77]. Hashim A. K., Mohammed E. J., "Measurement of Radon Concentration and the Effective Dose Rate in the Soil of the City of Karbala, Iraq", J Radiat Nucl Appl. 2016. Vol.1, No. 1, pp. (17-23).

[78]. Hatif K. H., Muttaleb M. K., "Determination of Natural Radioactivity and Radon, Thoron Concentrations of Soil in Hilla City - Iraq", J Babylon Univ pure Appl Sci. 2016. Vol.24, No. 5,pp.(1295 - 1308).

[79]. Cucos A., Papp B., Dicu T., Moldovan M., Burghele D. B., Moraru I. T., et al., "Residential, soil and water radon surveys in north-western part of Romania". J Environ Radioact. 2017. Vol.166, pp. (412-416).

[80]. Al-bakhat Y. M. Z., Al-Ani N. H. K., Mohammed B Ameen N. H., Jabr Z. A., "Measurement of Radon Activity in Soil Gas and the Geogenic Radon Potential

Mapping Using RAD7 at Al-Tuwaitha Nuclear Site and the Surrounding Areas",Radiat Sci Technol.2017. Vol. 3, No. 3, pp. (29-34).

[81]. Kadim S. F., Najy Hady H. N., " Measurement Radon Gas Concentration in Selected Soil Samples of Al-Nada District in Najaf", Int J Eng Technol. 2018. Vol. 7, N0. 4, pp. (678-680).

[82]. Nguyen P. H. T., Nguyen V. T., Ngoc B. V., Nguyen V. D., Cong H., "Soil radon gas in some soil types in the rainy season in Ho Chi Minh City, Vietnam", J Environ Radioact. 2018. Vol. 193-194, PP. (27-35).

[83]. Subaihi F. A., Harb S. R., Abdulgabar T. A., " Measurement of Radium Concentration and Radon Exhalation Rates of Soil Samples Collected fromSelected Area of Aden Governorate,Yemen, Using Plastic Track Detectors", Int J High Energy Phys. 2019. Vol.4, No. 2, pp.(34-41).

[84]. Kareem D. O., Ibrahim A. A., Ibrahiem O. S., "Relationship between Radon Gas and Heavy Metals Concentrations in Soil of Selected Farms in Kirkuk City / NE Iraq", 2019. Vol. XII, No.I,pp.(2277-8322).

[85]. Sharrad A. A., and Farhood A. K., "Radon Concentration Mesurements in Soil Gas of Sawa Lake, Samawa City – South of Iraq", Int J Adv Res. 2019. Vol. 7, No. 6,pp. (170-177) .

[86]. DURRIDGE Company Inc. ,"Electronic Radon Detector ", 2000. Vol. 37.

[87]. Mazed D., Ciolini R., Curzio G., Del Gratta A., "A new active method for continuous radon measurements based on a multiple cell proportional counter", Nucl Instruments Methods Phys Res Sect A Accel Spectrometers, Detect Assoc Equip. 2007. Vol. 582, No. 2, pp. (535-545).

[88]. Fijiant R., "In-situ measurements of radon concentrations in soil gas at a site on the Cape Flats",2007. M.Sc.Thesis, University of the Western Cape Supervisor.

[89]. DURRIDGE Company Inc., "RAD H2O User Manual", USA., 2011.

[90]. Abdalla A. S. T., Lindsay R., Meijer R. J., Newman R. T., "Measurements and Applications of Radon in South African Aquifer and River Waters", 2009. PhD.Thesis, University of the Western Cape. Supervisors.

[91]. Al-hamidawi A., A., "Determining the concentrations of radon and the rate of annual effective dose in some types of drinking water available in the Iraqi markts", 2013. Vol.11, No. 20, pp. (75-80).

[92]. United States Environmental Protection Agency, "Protocols for Radon and Radon Decay Product Measurements in Homes". US Environ Prot Agency EPA 402-R-(92-003), 1993.

[93]. Duggal V., Rani A., Mehra R.,"In situ measurements of radon levels in groundwater in Northern", 2012. Vol. 3, No. 6, pp. (3825-3830).

[94]. DURRIDGE Company, "Rad H2O User Manual", 2016.

[95]. Usda P., " Introduction to Global Positioning Systems (GPS)", 2007.

[96]. Binesh A., Mohammadi S., Mowlavi A. A., Parvaresh P., Arabshahi H., "Evaluation of the radiation dose from radon ingestion and inhalation in drinking water sources of Mashhad",Res J Appl Sci. 2010. Vol. 2, No. 7, pp. (174 - 178).

[97]. Mehra1 R., Badhan K., Sonkawade R. G., "Radon Activity Measurements in Drinking Water and in Indoors of Dwellings, Using RAD7", Tenth Radiat Phys Prot Conf., 2010. pp. (27-30).

[98]. World Health Organisation (WHO), "Guidelines for Drinking-water Quality", Encyclopedia of Earth Sciences Series, 2011.

[99]. World Health Organization, "Guidelines for drinking water Quality", 1985. Vol. 1. Recommendations. Environ Pollut Ser A, Ecol Biol.

[100]. Sogut O., Aydin M. F., "Measurement of radon gas activity concentrations in drinking water in the city center of Adıyaman, Turkey", 2019. Radiat Prot Environ,pp. (59-60).

[101]. Malakootian M., Soltani N. Y., "Determination of radon concentration in drinking water of Bam villages and evaluation of the annual effective dose", Int J Radiat Res. 2017. Vol. 15, No. 1, pp. (81-89).

[102]. Adinehvand K., Azadbakht B., Fallahi Y. M., "Dose assessment and measurement of radon concentration in water supplies of Borujerd County in Iran",Int J Radiat Res. 2019. Vol. 17, No. 3, pp. (507-511).

[103]. Najam L. A., El-Taher A., Abojassim A., Mraity H., "Assessment of Annual effective Dose for Different Age Groups Due to Radon Concentrations in Groundwater Samples at Qassim, Saudi Arabia", 2019. J Med Phys.

[104]. Al-Kazwini A. T., Hasan M. A., "Radon concentration in Jordanian drinking water and hot springs", J Radiol Prot. 2003. Vol. 23, No. 3, pp. (439-448).

[105]. Abdallah S. M., Habib R. R., Nuwayhid R. Y., Chatila M., Katul G., "Radon measurements in well and spring water in Lebanon", Radiat Meas. 2007. Vol. 42, No. 2, pp. (298-303).

[106]. Al Zabadi H., Musmar S., Issa S., Dwaikat N., Saffarini G., "Exposure assessment of radon in the drinking water supplies: A descriptive study in Palestine", BMC Res Notes. 2012. Vol. 5,pp.(1-8).

[107]. Tawfiq N. F., Mansour H. L., Karim M. S., "Measurement of Radon Gas Concentrations in Tap Water for Baghdad Governorate by Using Nuclear Track Detector (CR-39)", Int J Phys. 2015. Vol. 3, No. 6, pp. (233-238).

[108]. Ibrahim A. A. H., Abojassim A., Hssan A. M., "Radon Concentrations in

Drinking Water Samples for Some Area at AL-Najaf City", Int Sci J Theor. 2018. Vol.67, No. 11.

[109]. Hatif K. H., Muttaleb M. K., Abass A. H., "Measurement of Radioactive Radon Gas Concentrations of Water in the schools for Abu-Gharaq",J Univ Babylon Pure Appl Sci. 2018. Vol. 26, No. 1, pp. (174-180).

[110]. Al-jnaby M. K. M., "Radon Concentration in Drinking Water Samples at Hilla city, Iraq", World Sci News. 2016. Vol. 52, pp. (130-142).

[111]. Podgorsak, E. B., "Radiation Physics for Medical Physicists", 2010. Vol. 49, pp.(6221).

[112]. Suresh S. D., Rangaswamy D. R., Srinivasa E. J., Sannappa, "Measurement of radon concentration in drinking water and natural radioactivity in soil and their radiological hazards", J Radiat Res Appl Sci., 2020. Vol. 13, No. 1, pp. (12-26).

[113]. 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. editor. New York: United Nations; 1993.

[114]. Sharma S., Kumar A., Mehra R., Kaur R.," Ingestion and Inhalation Doses Due To Intake of Radon in Drinking Water Samples of Amritsar Province, Punjab, India", Radiat Prot Dosimetry, 2019. pp. (1-13).

[115]. Abojassim A. A.," Annual effective dose of gamma emitters in infants, children and adults for frozen chicken samples consumed in Iraq",Curr Pediatr Res. 2017. Vol. 21, No. 3, pp. (520-525).

[116]. European Council. "Special meeting of the European Council Conclusions", 2020. No.10, pp.(1-68).

[117]. Sun K., Guo Q., Cheng J., "The effect of some soil characteristics on soil radon concentration and radon exhalation from soil surface", J Nucl Sci Technol. 2004. Vol. 41, No. 11, pp. (1113-1117).

[118]. Prasad Y., Prasad G., Gusain G. S., Choubey V. M., Ramola R. C., " Seasonal variation on radon emission from soil and water", Indian J Phys. 2009. Vol. 83, No. 7, pp. (1001-1010).

[119]. World Health Organisation (WHO)., "Basic epidemology", 1993. University of Aukland New Zealand.

[120]. Alharbi W. R., Abbady A. G. E., "Measurement of radon concentrations in soil and the extent of their impact on the environment from Al-Qassim, Saudi Arabia", Nat Sci. 2013. Vol. 5, No. 1, pp.(93-98).

[121]. Aseeri R. A., Arishi A. A., Elaraby E. H., "Estimation of primeval radio nuclei concentration in soil in Jazan region", AIP Conf Proc. 2018. Vol. 1976.

[122]. Ershaidat N., Almomani R., Al-Bataina B., Al-Rayashi W., "Periodicity of Diurnal Variation of Soil Radon Concntration Levels and Temperature", 2013. Vol. 6, No. 2, pp. (47-54).

[123]. Tabar E., Kumru M. N., Ichedef M., Sac M. M., "Radioactivity level and the measurement of soil gas radon concentration in Dikili geothermal area, Turkey", Int J Radiat Res. 2013. Vol. 11, No. 4,pp.(253-261).

[124]. Korany K. A., "Depth and Seasonal Variations for the Soil Radon-Gas Concentration Levels at Wadi Naseib Area, Southwestern Sinai, Egypt", J Phys Chem Biophys. 2013. Vol. 3, No. 4, pp. (124 - 134).

[125]. Hasan A. K., Subber A. R. H., Shaltakh A. R., "Measurement of Radon Concentration in Soil Gas using RAD7 in the Environs of Al-Najaf Al-Ashraf City-Iraq", Adv Appl Sci Res. 2011. Vol. 2, No. 5, pp. (273-278).

[126]. Amin S. A., Al-Obiady A. H., Alwan A., "Radon Level Measurements in Soil and Sediments at Oil Field Area and Its Impact on the Environment",Eng Technol J Part B Technol J Part B. 2017. Vol. 35, No. 1, pp. (1 - 7).

[127]. Abojassim A. A., Kadhimand S. H., Alasadi A. H., Ali A. A. H., "Radon, Radium Concentrations and Radiological Parameters in Soil Samples of Amara at Maysan, Iraq". Asian J Earth Sci. 2017. Vol. 10, No. 2, pp. (44-49).

[128]. Journal B. S., "Measurement of Radon Gas Concentration in Soil and Water Samples in Salahaddin Governorate-Iraq Using Nuclear Track Detector (CR-39)", Baghdad Sci J. 2015. Vol. 12, No. 3, pp. (603-610).

[129]. Abumurad K. M., Al-Tamimi M., "Emanation power of radon and its concentration in soil and rocks",Radiat Meas. 2001. Vol. 34, pp. (423-426).

[130]. Endoscopy S. A., "Soil Radon Levels Measured with SSNTD'S and the Soil Radium Content", 1999. Vol. 31, pp. (291-294).

[131]. OECD., "Organization for Economic Cooperation and Development,Report by a group of experts of the OECD nuclear energy agency,Paris,France", 1979.

[132]. Nsiah A. I., Andam A. B., Akiti T. T., Flectcher J. J., "Study of radium and radon exhalation rate in soil samples, Offinso municipality", AIP Conf Proc. 2019. pp. (3-8).

[133]. World Health Organization (WHO), "Guidelines for Drinking-Water Quality". 1989.

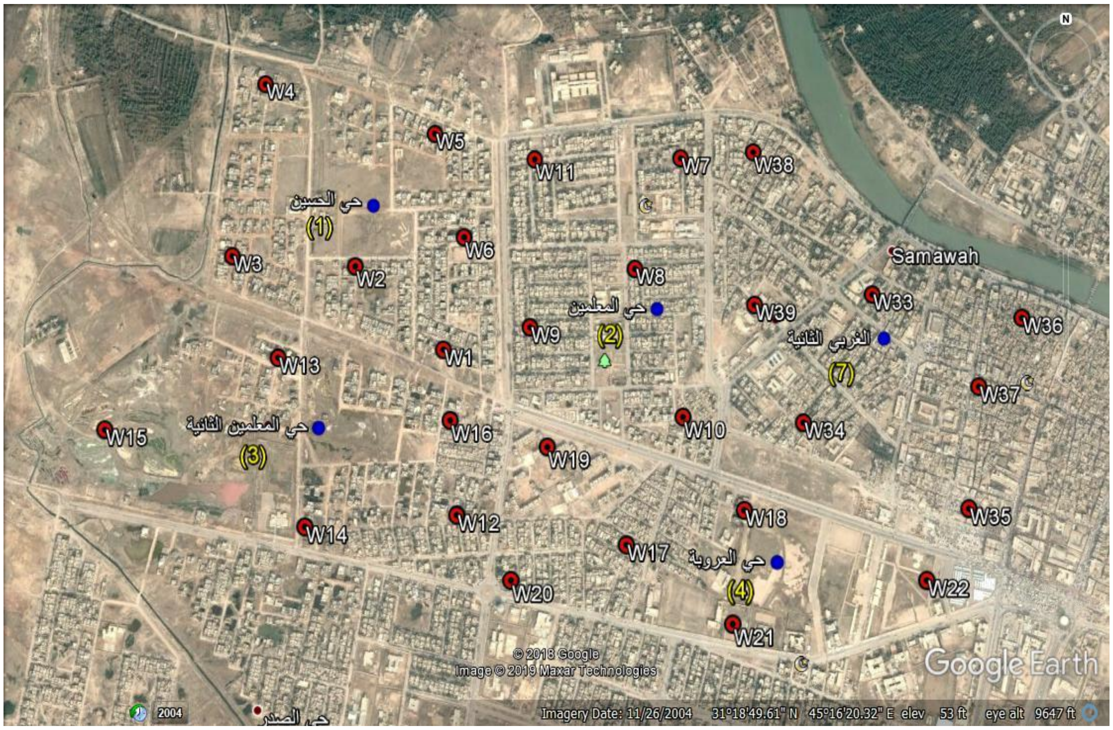
[134]. United States Environmental Protection Agenc (EPA), "Assessment of Risks from Radon in Homes", Off Radiat Indoor Air. 2003.

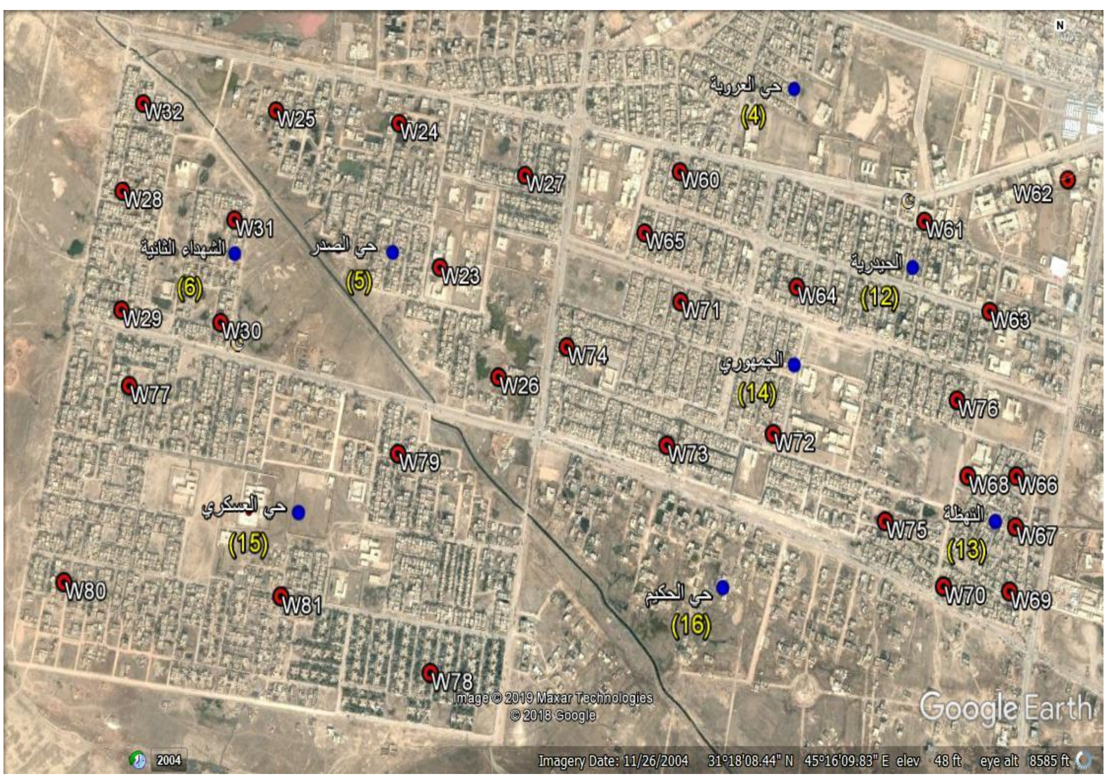
[135]. ICRP., "The ICRP 2007 Recommendations of the International Commission on Radiological Protection", Revemat: Revista Eletronica de Educacao Matematica. 2018. Vol. 37, No. 1, pp. (1689-1699).

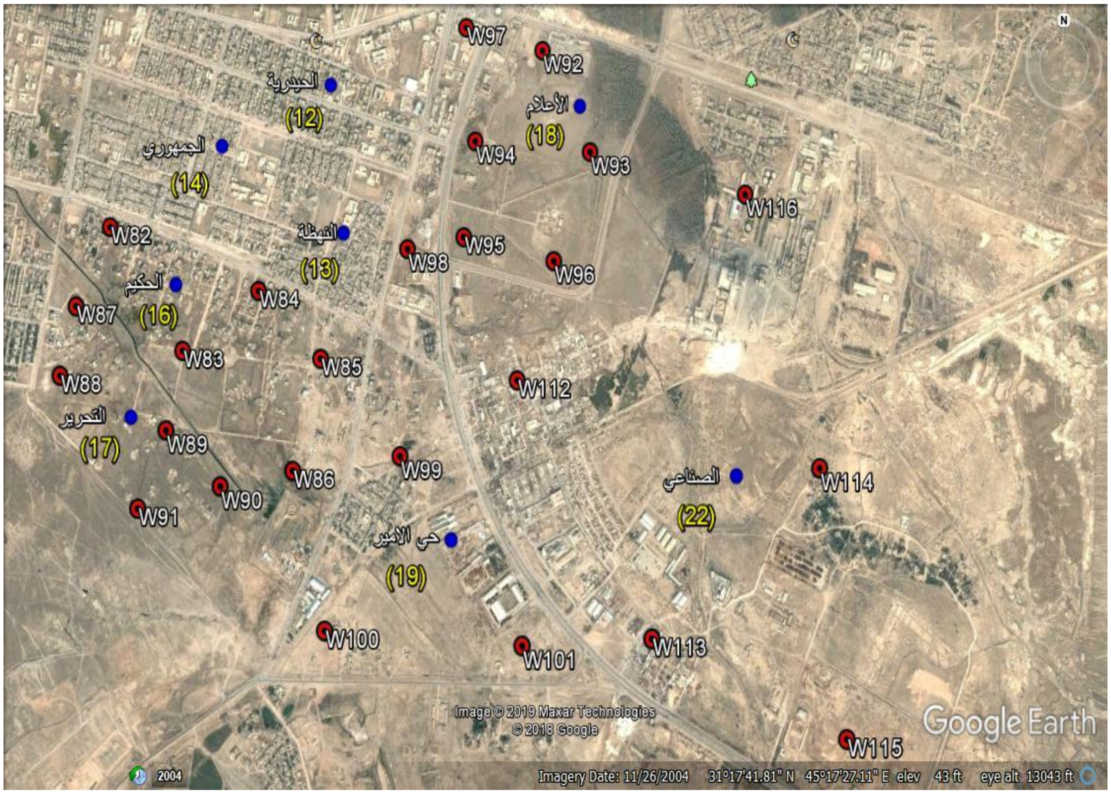
[136]. Tawfiq N. F., Jaleel J., "Radon concentration in soil and radon exhalation rate at Al-Dora refinery and surrounding area in Baghdad", Detection . 2015. vol. (03), no. (04), pp. (37 - 44).

Appendix (1): Water and Soil Samples Locations

(1) Water Samples Locations



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الحكيم
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التحرير
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الصناعي
(22)
W114
حي الامير
(19)
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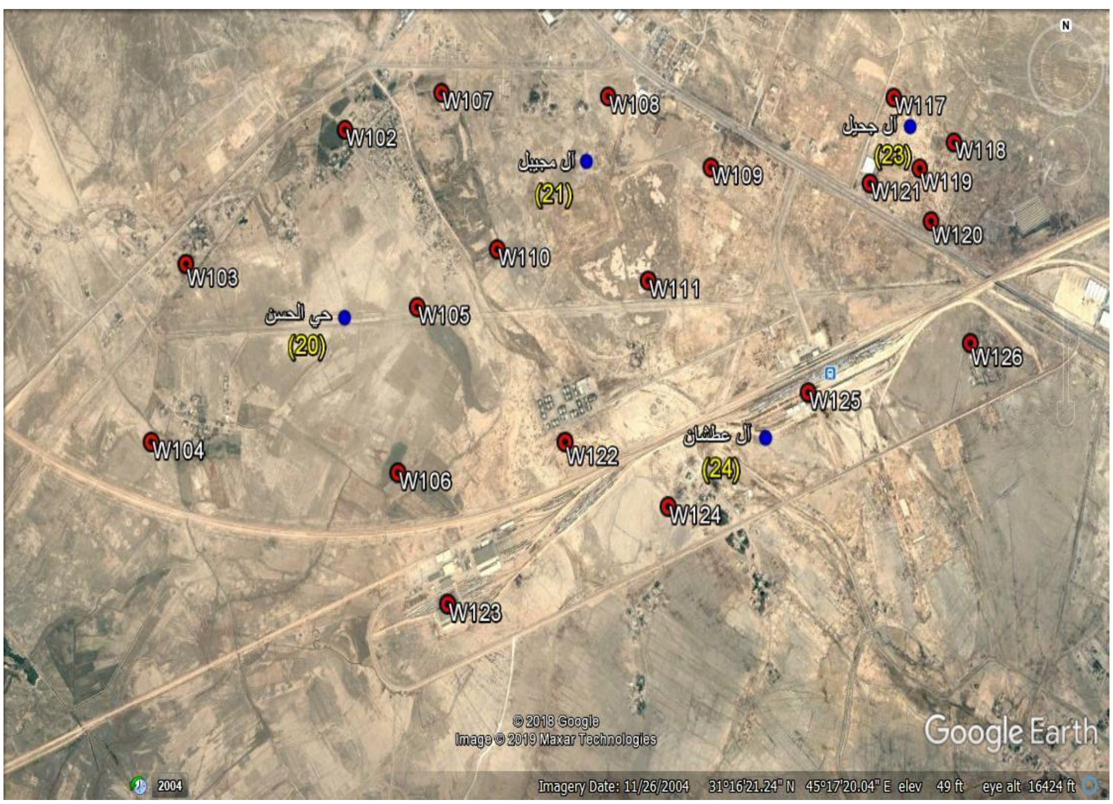
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حي الحسن
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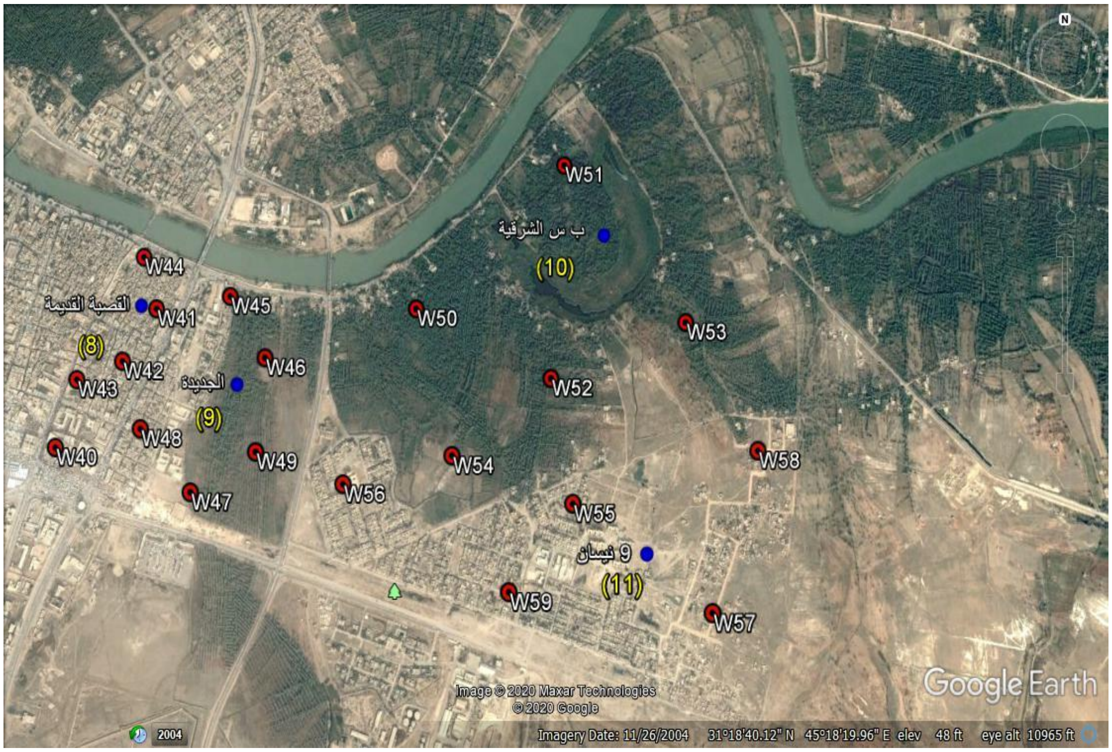
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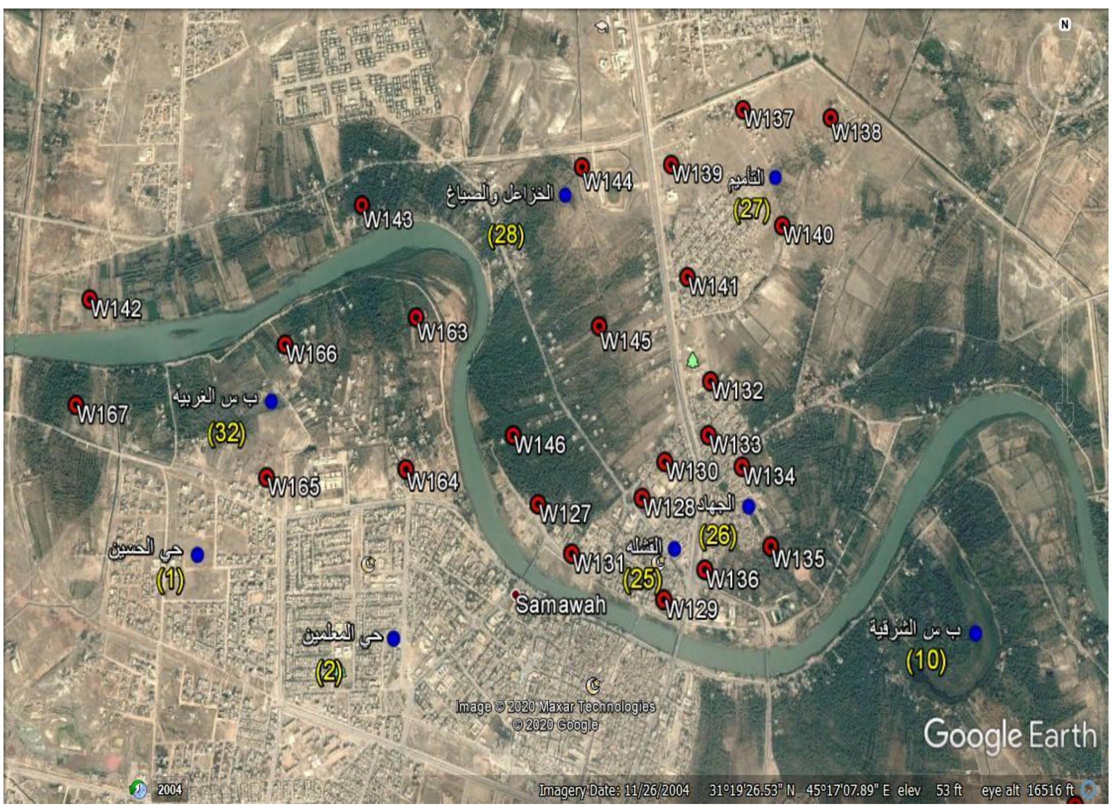
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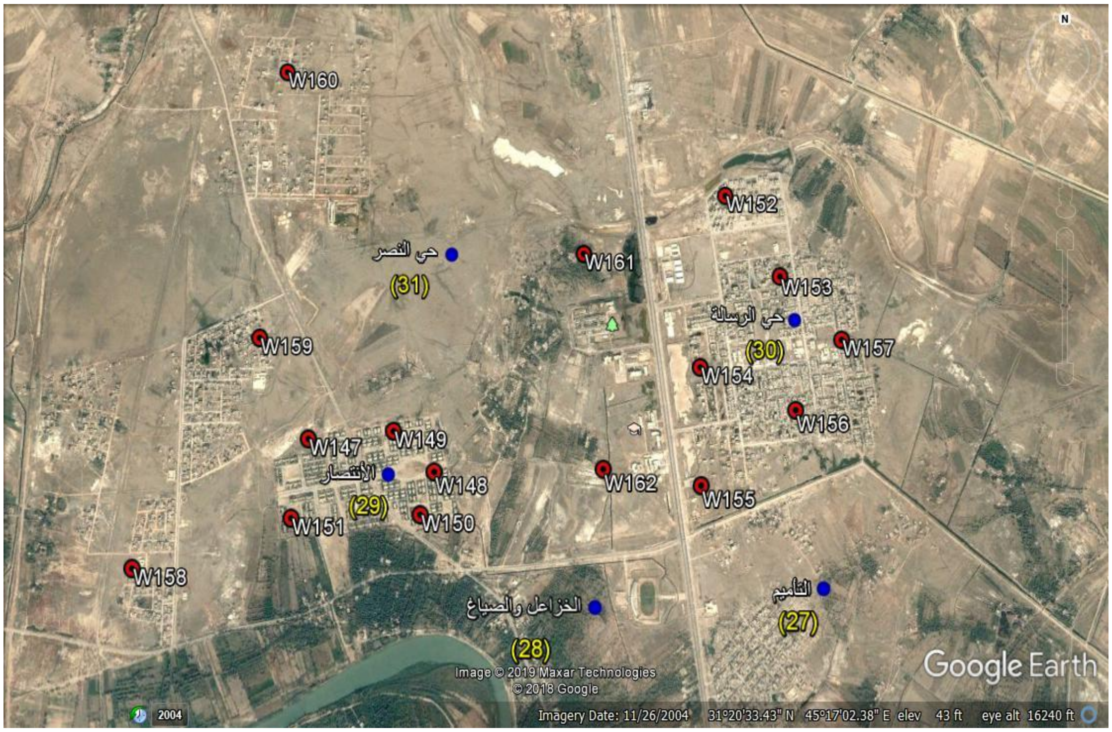

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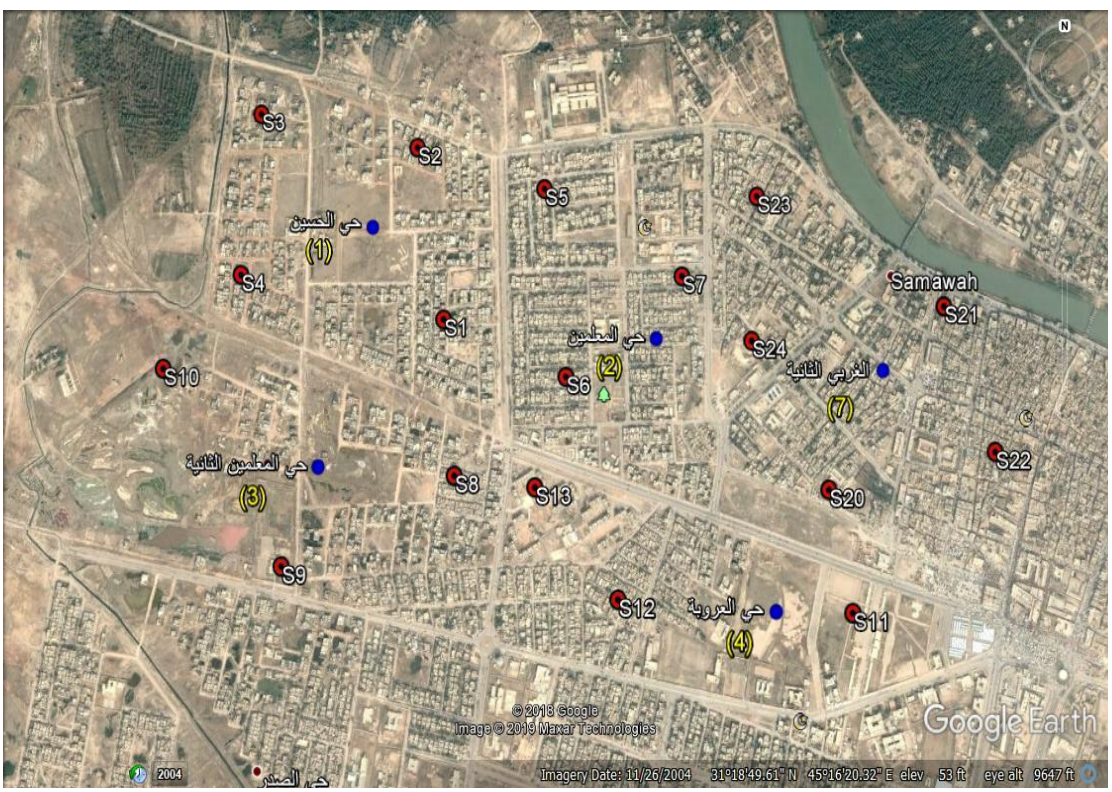

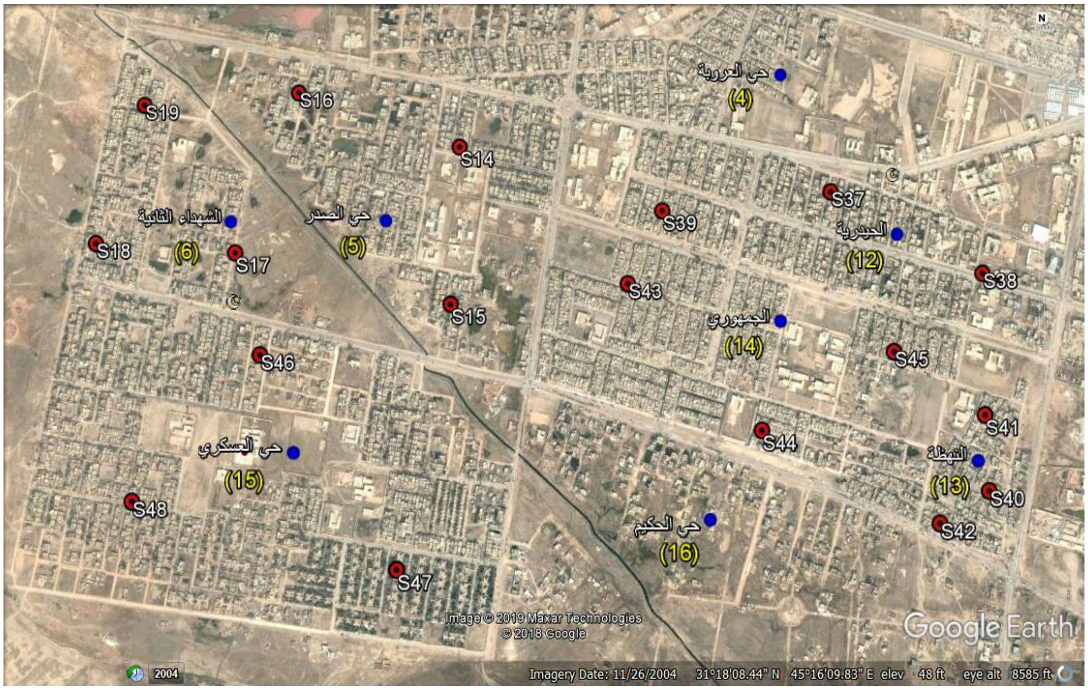

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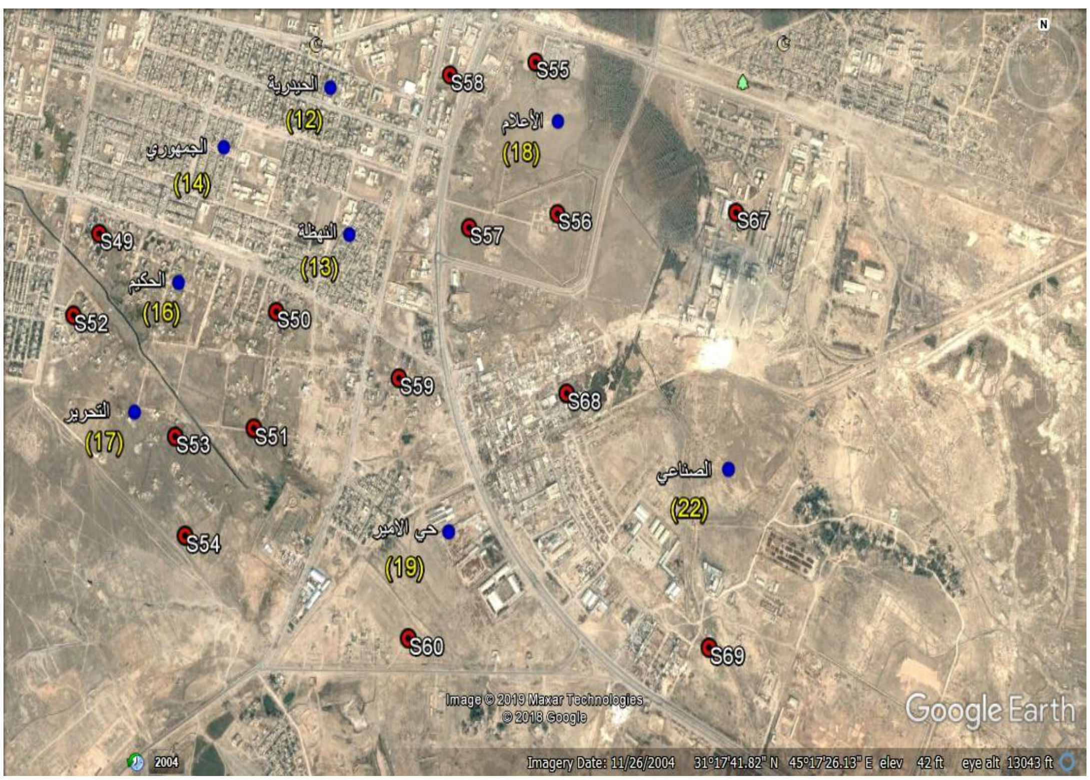

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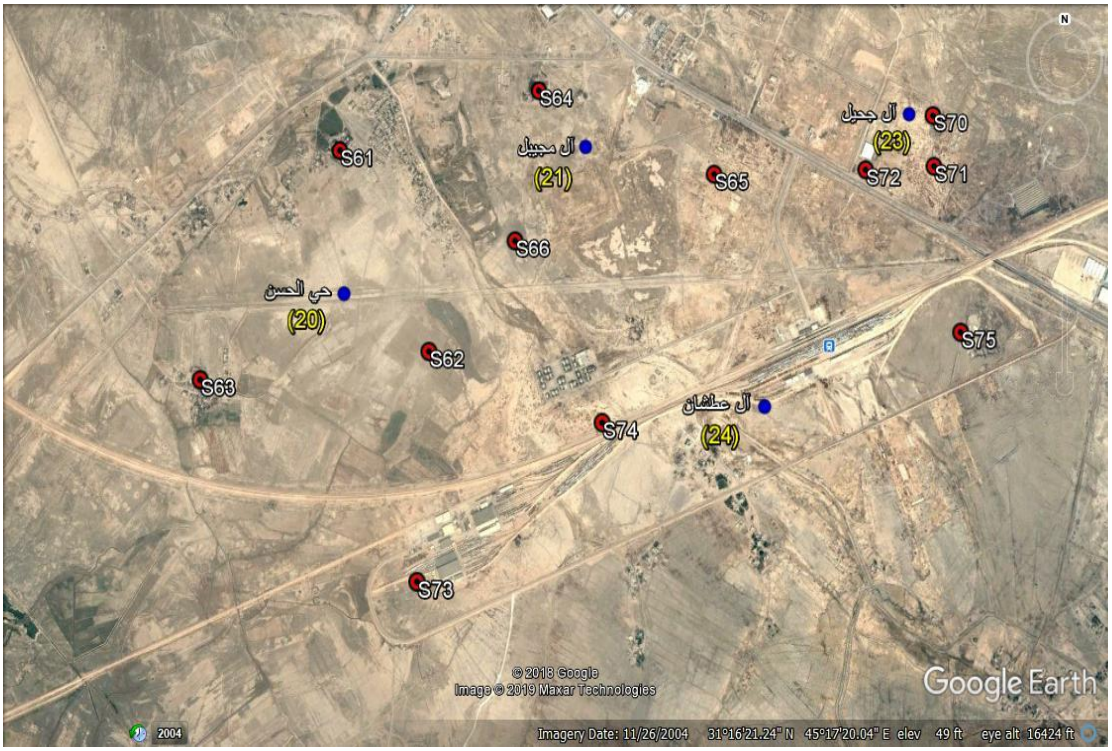
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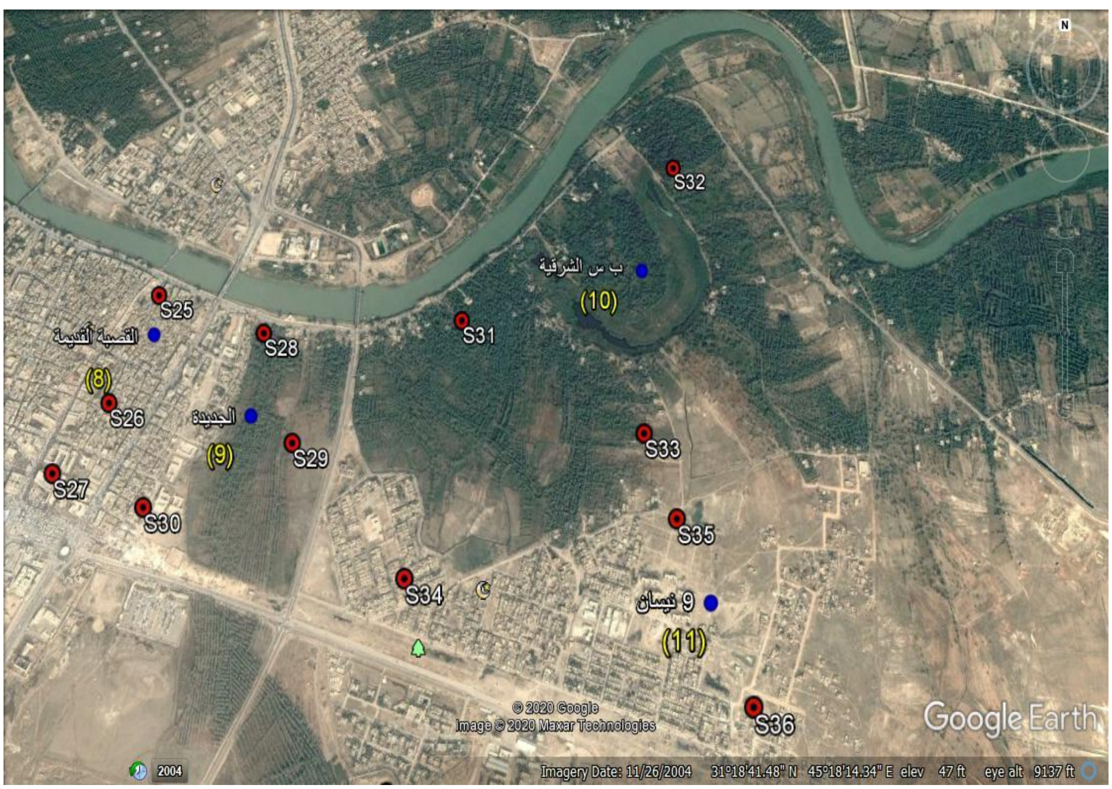
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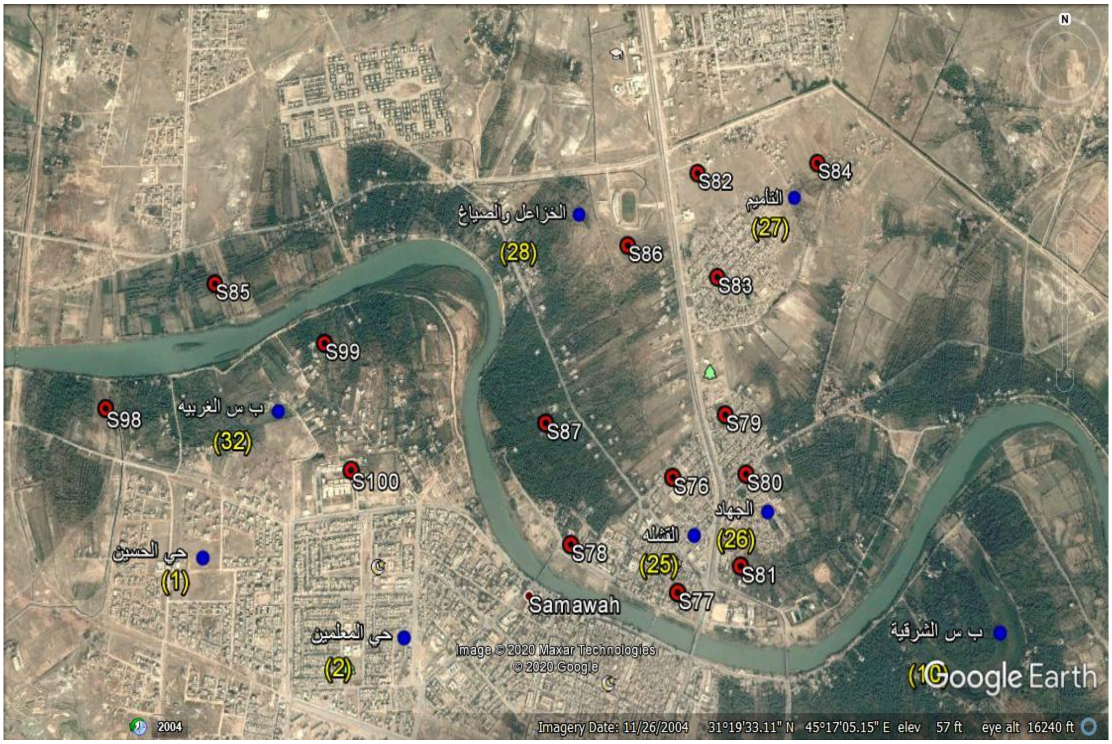
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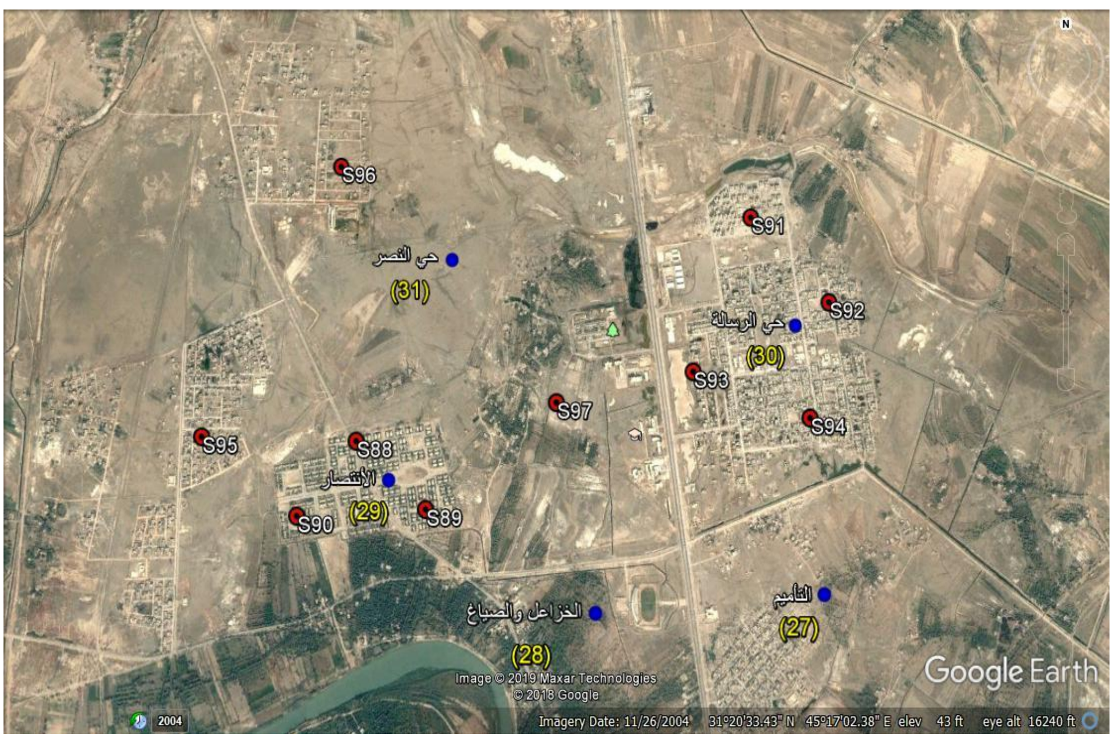
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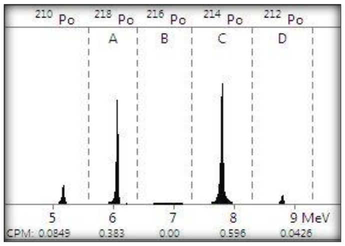
Appendix (2): RAD7 Spectrums

(1) Spectrums Obtained from Drinking Water Samples.



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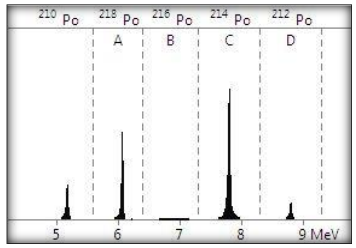

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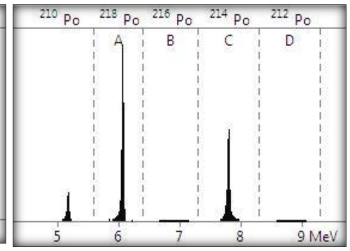

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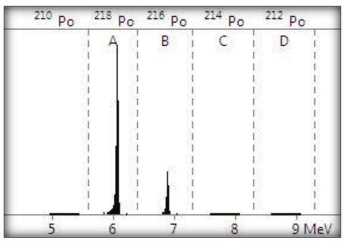

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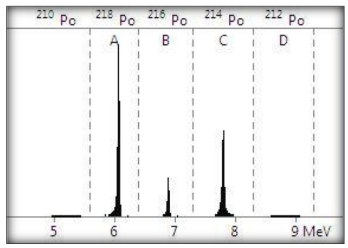

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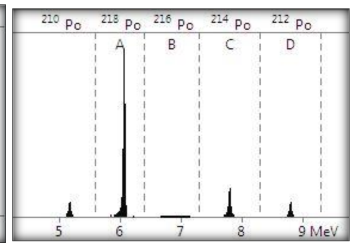

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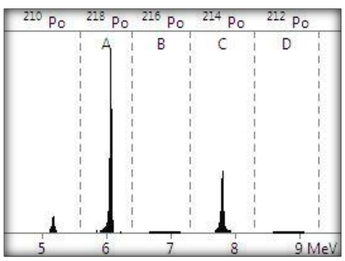

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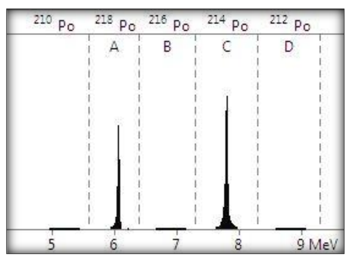

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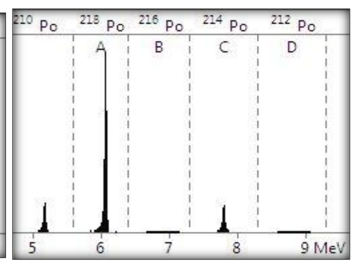

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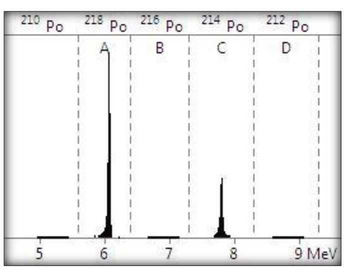

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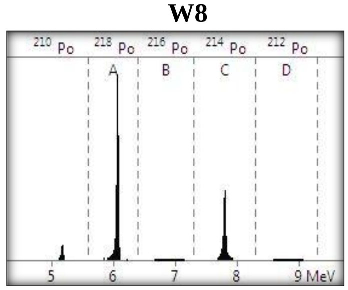

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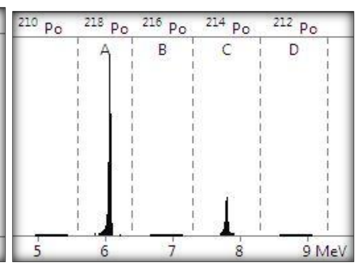

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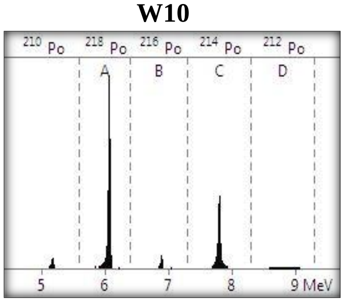

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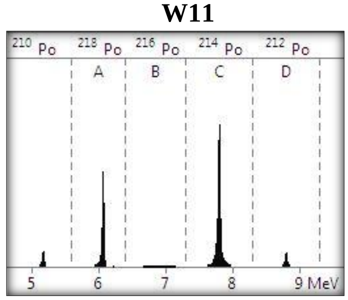

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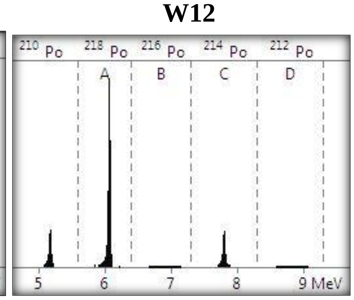

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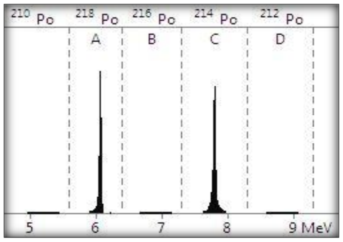

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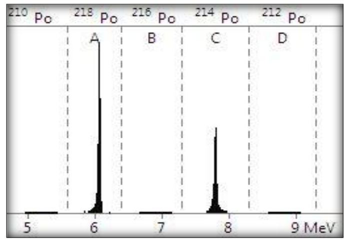

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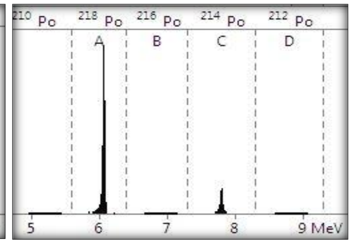

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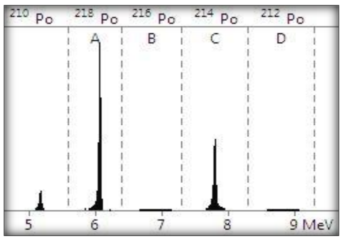

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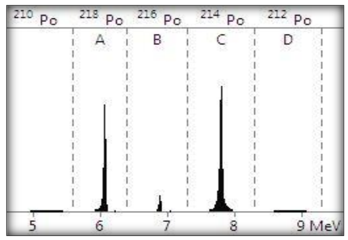

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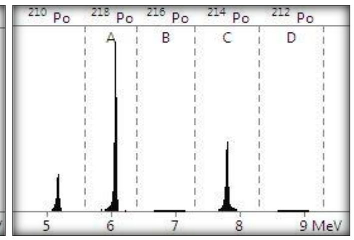

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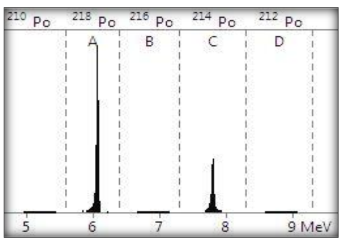

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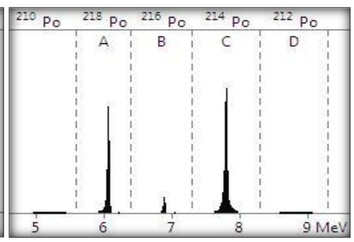

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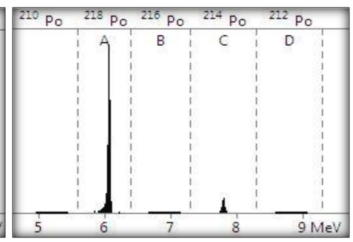

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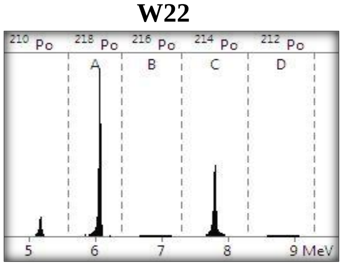

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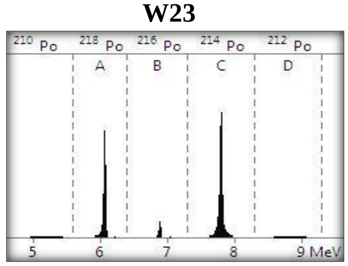

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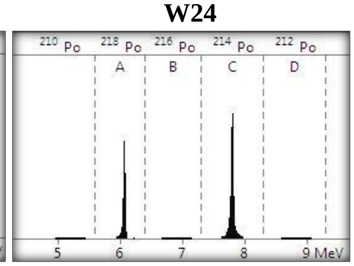

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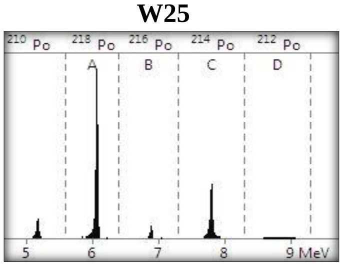

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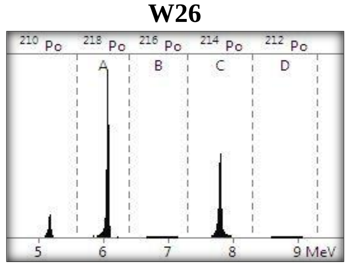

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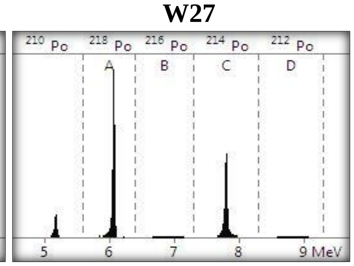

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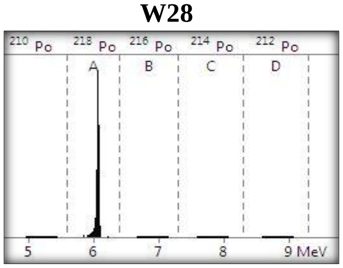

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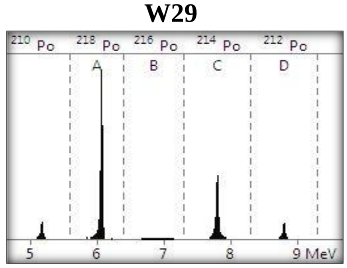

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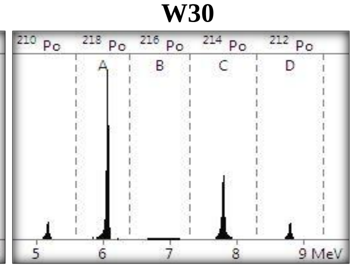

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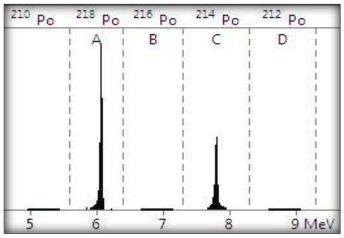

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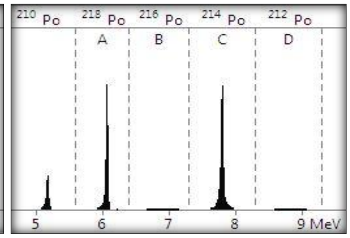

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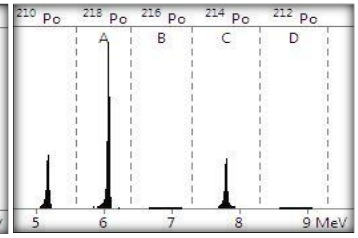

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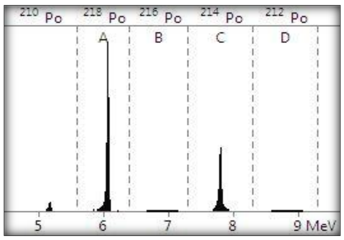

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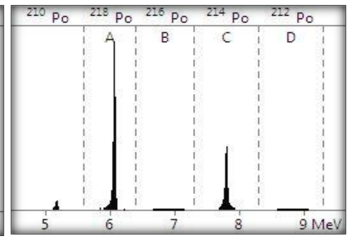

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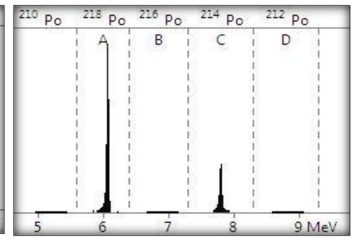

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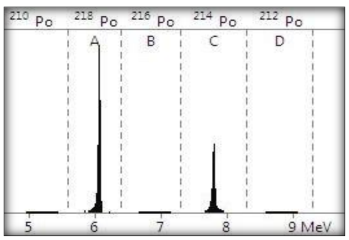

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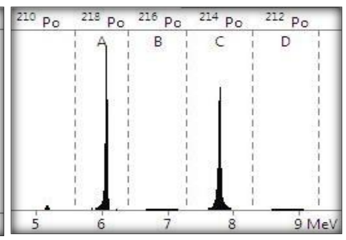

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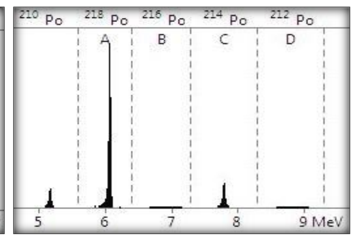

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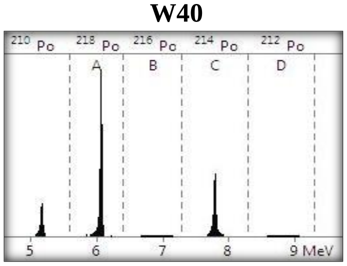

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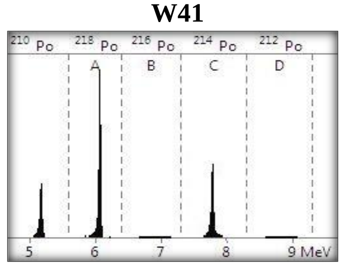

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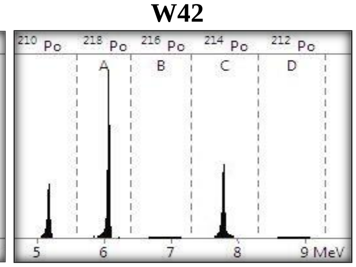

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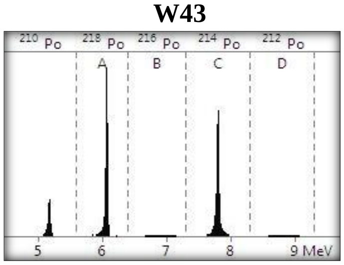

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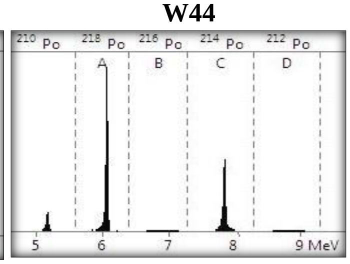

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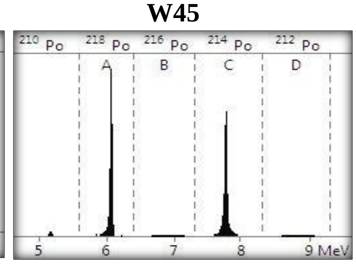

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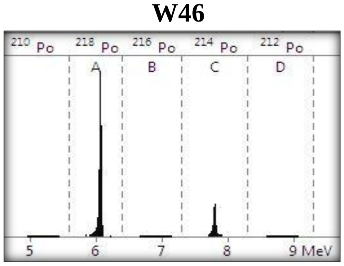

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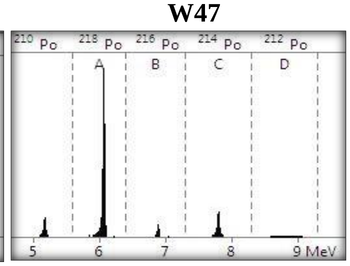

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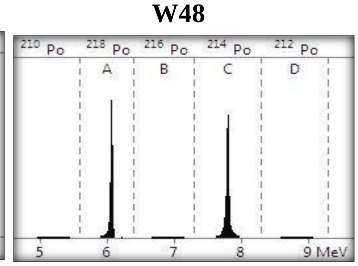

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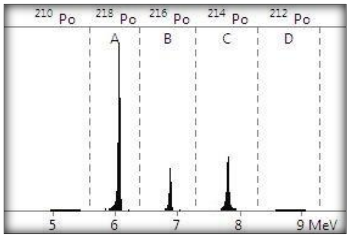

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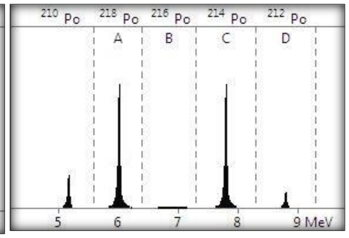

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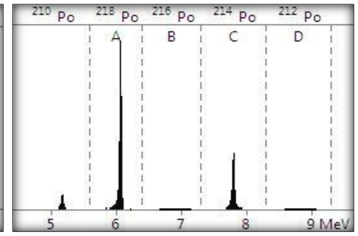

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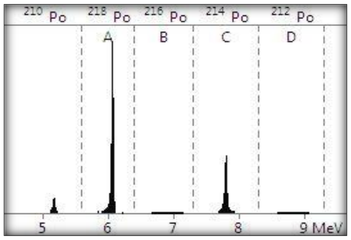

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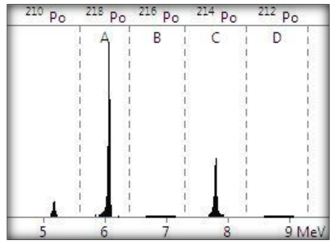

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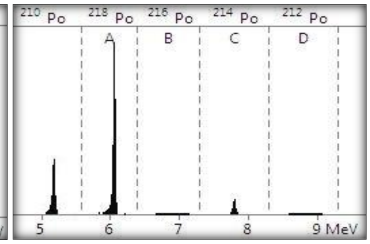

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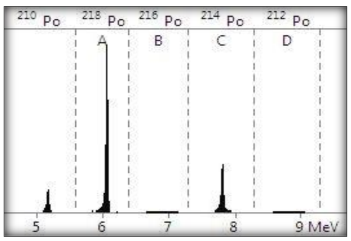

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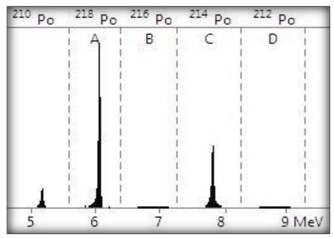

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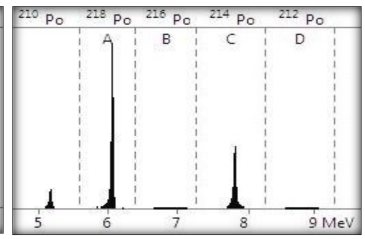

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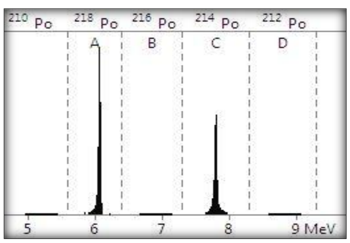

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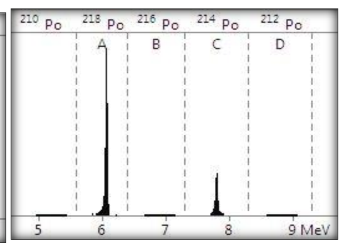

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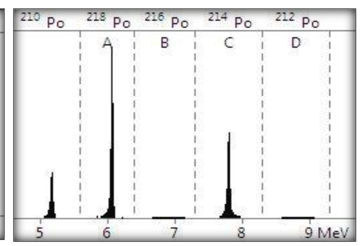

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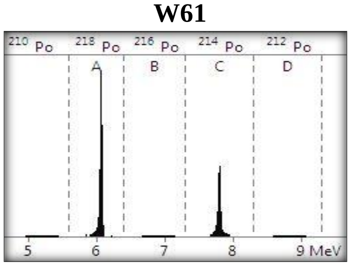

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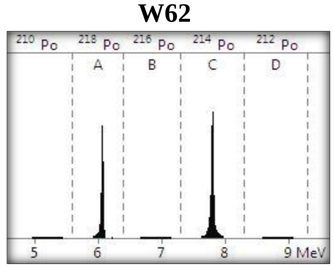

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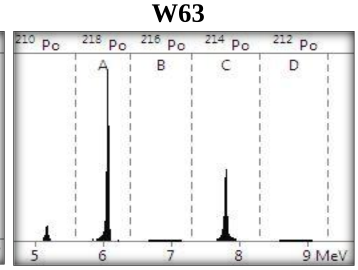

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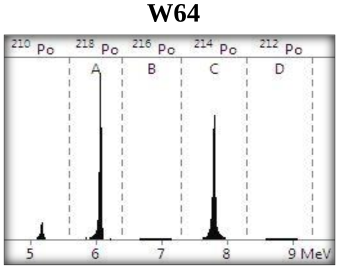

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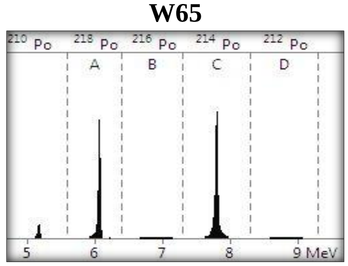

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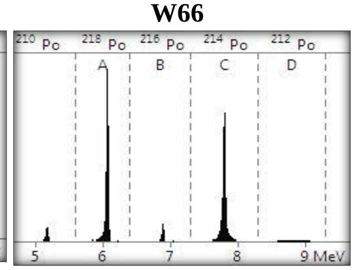

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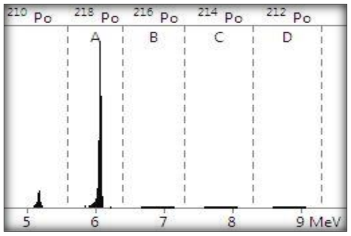

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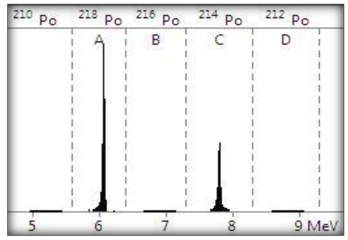

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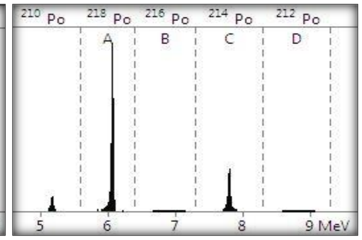

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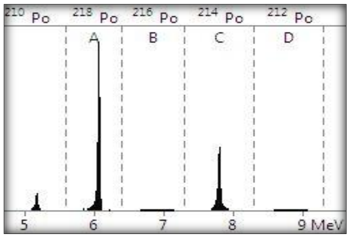

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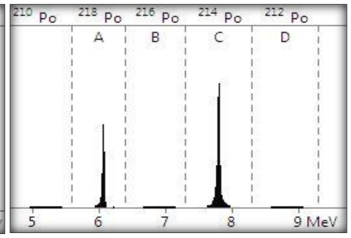

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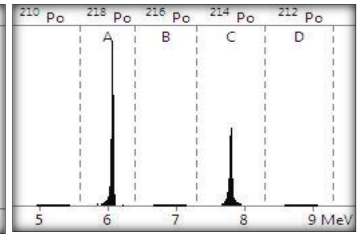

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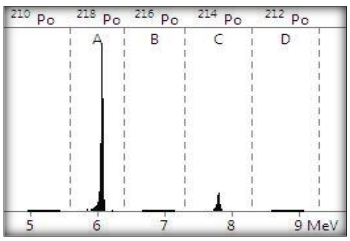

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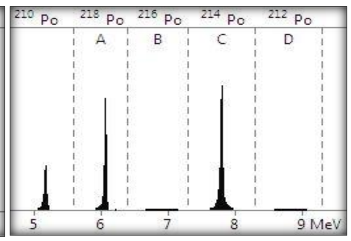

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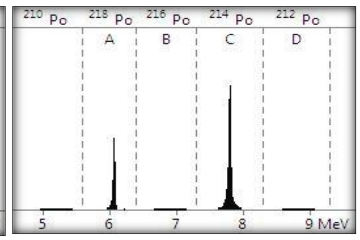

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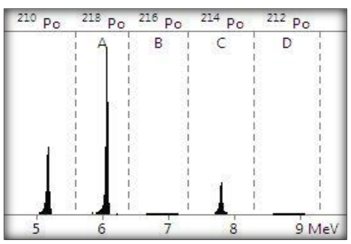

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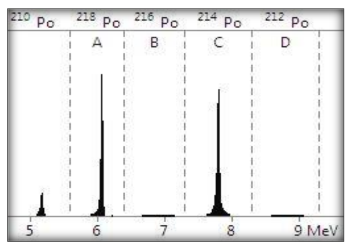

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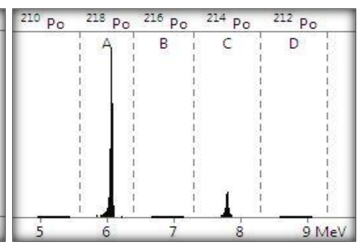

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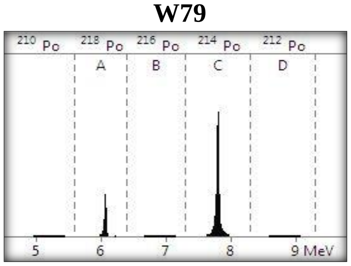

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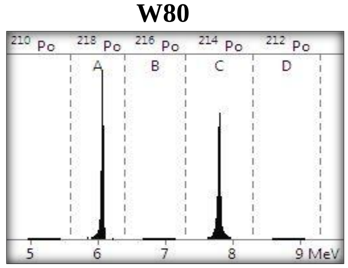

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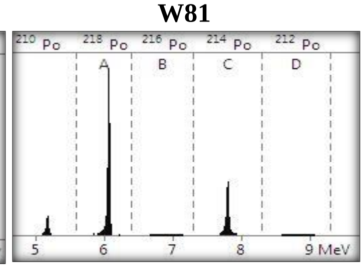

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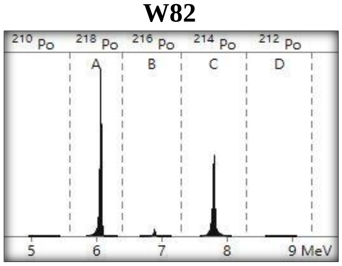

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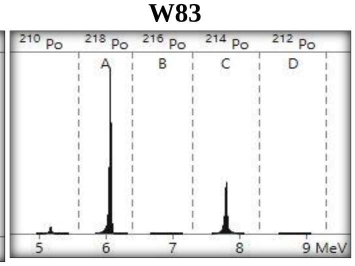

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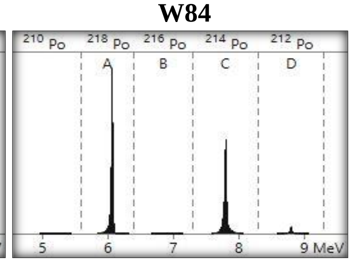

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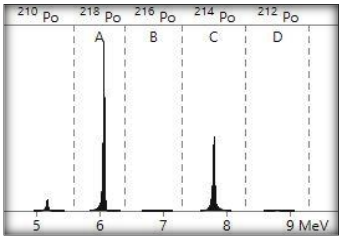

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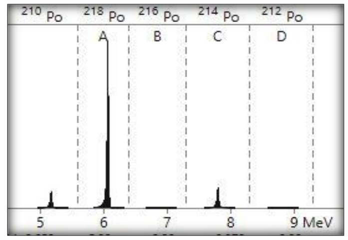

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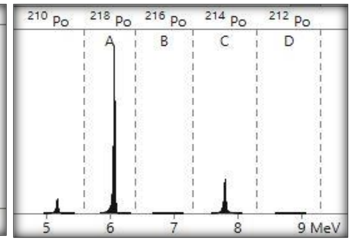

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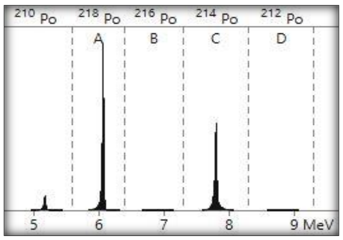

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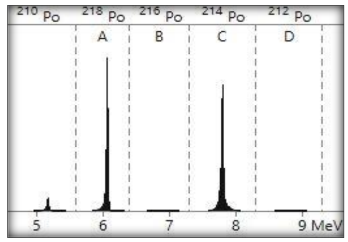

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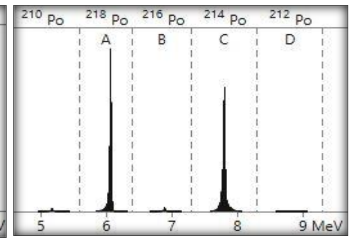

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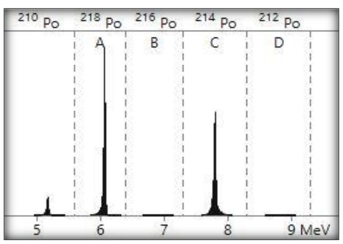

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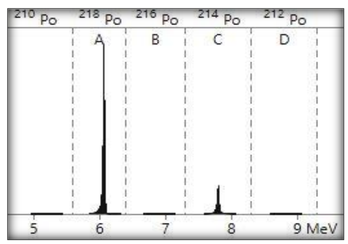

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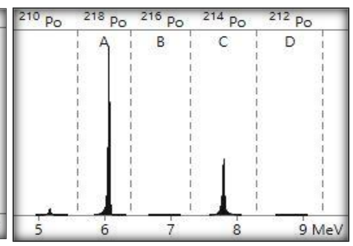

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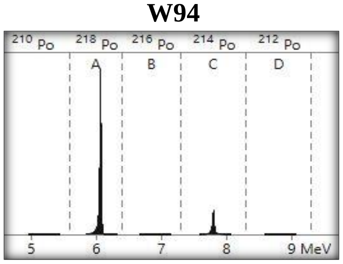

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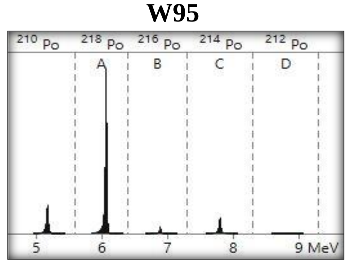

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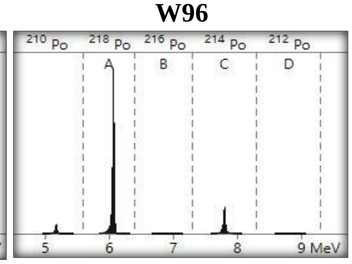

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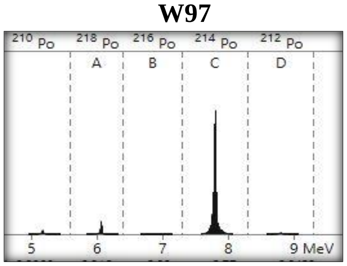

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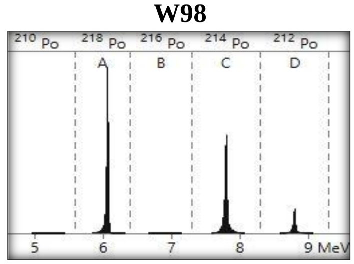

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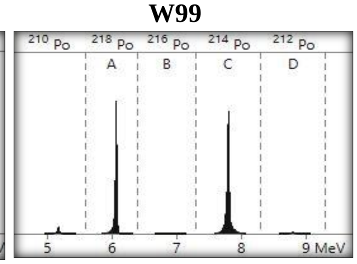

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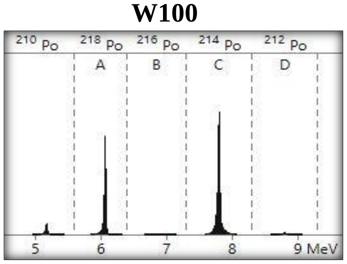

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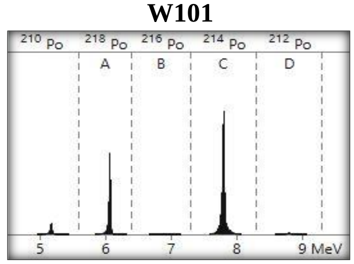

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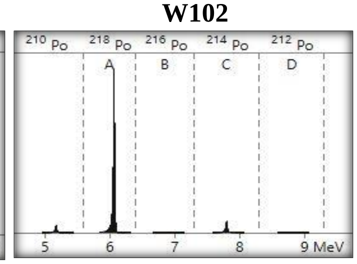

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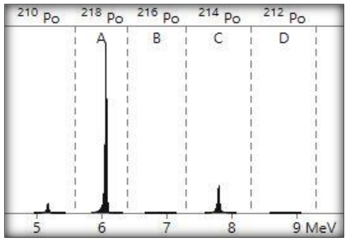

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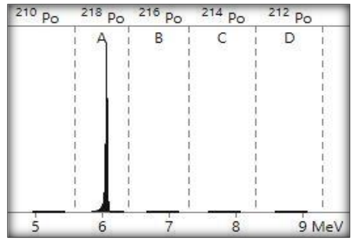

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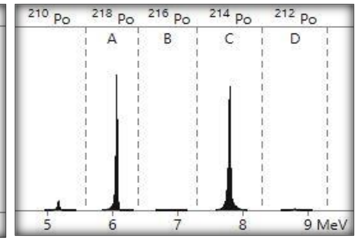

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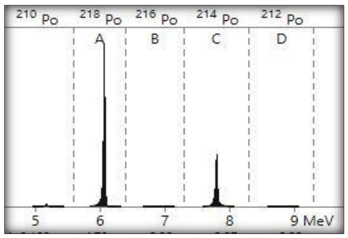

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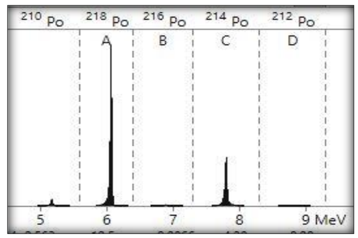

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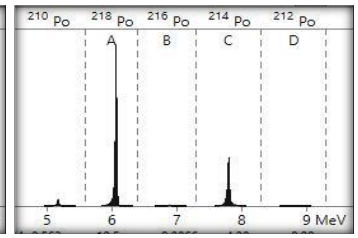

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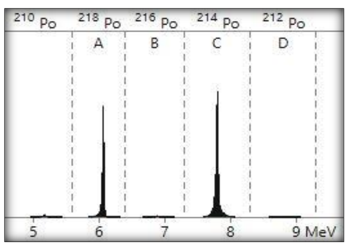

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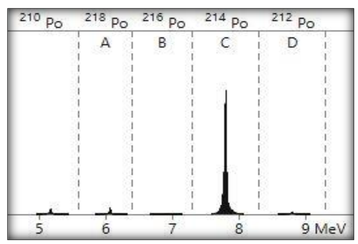

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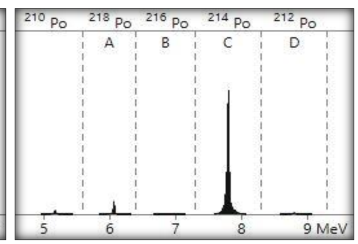

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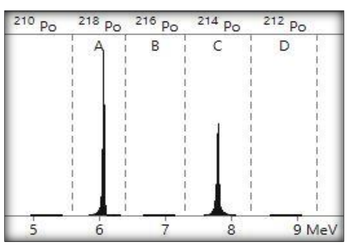

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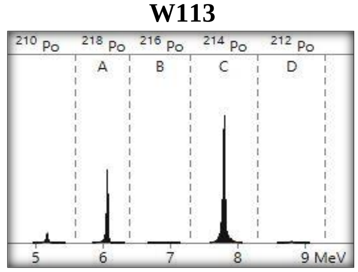

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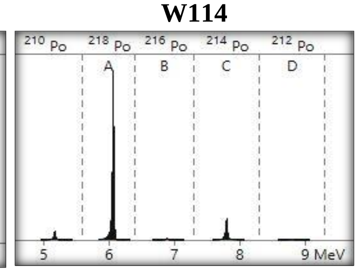

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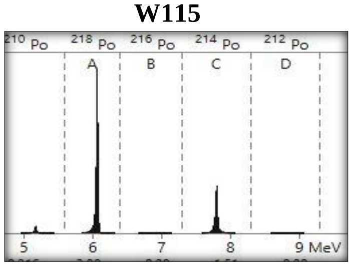

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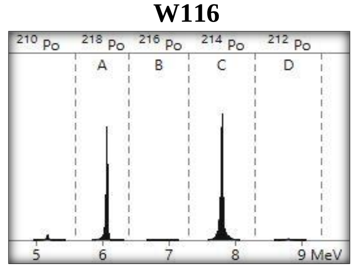

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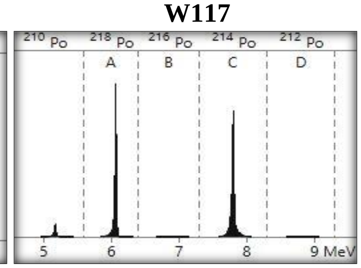

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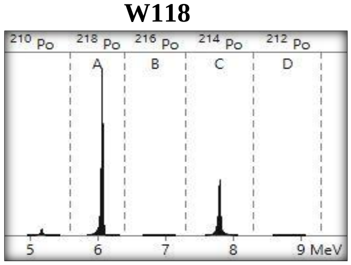

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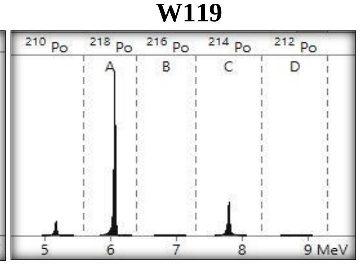

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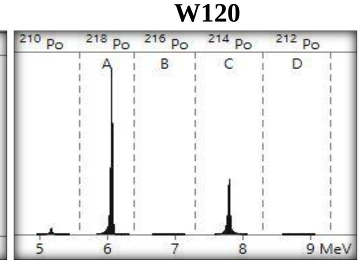

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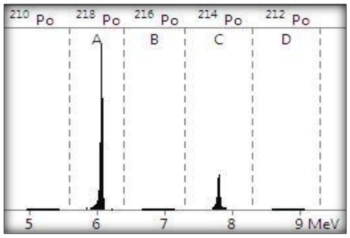

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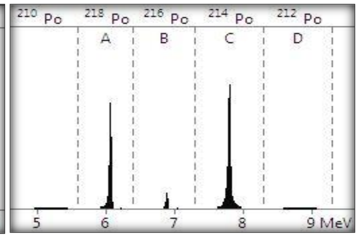

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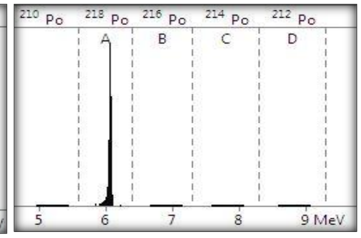

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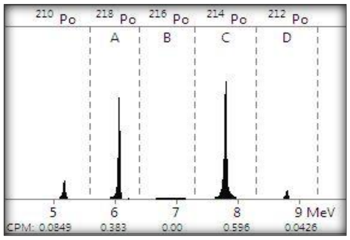

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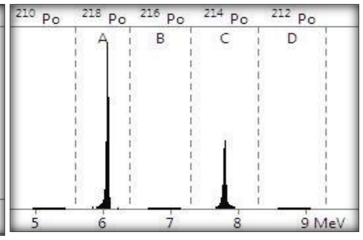

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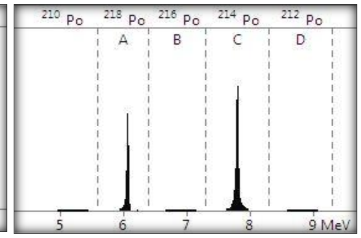

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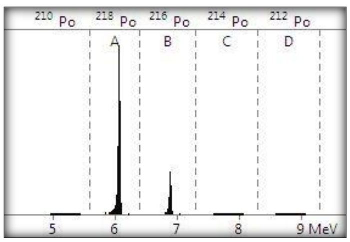

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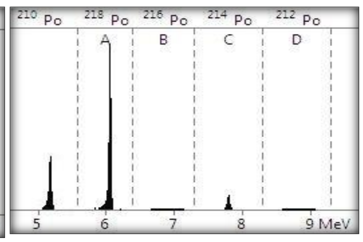

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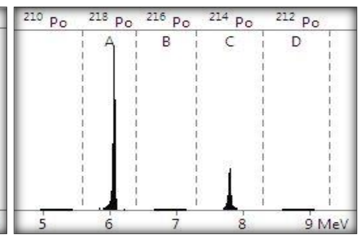

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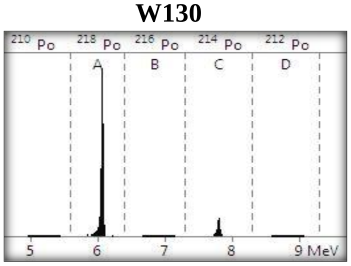

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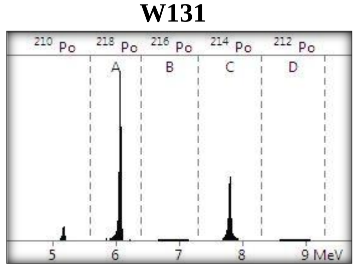

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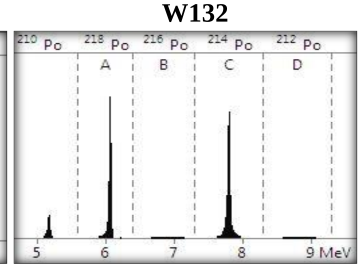

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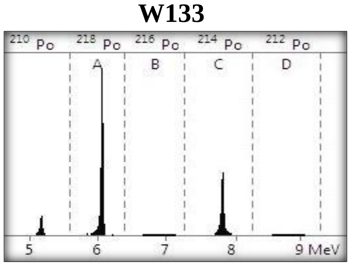

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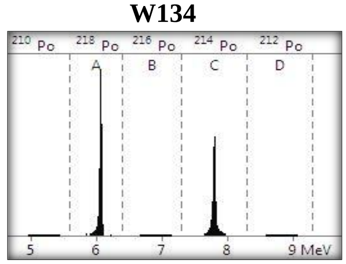

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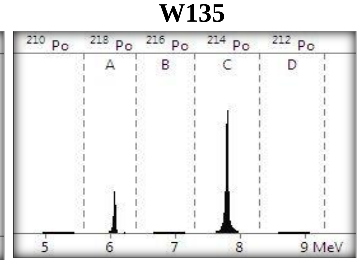

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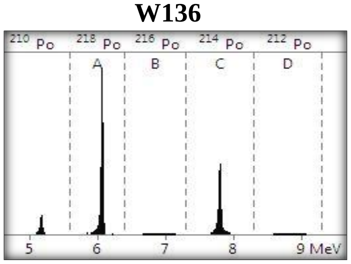

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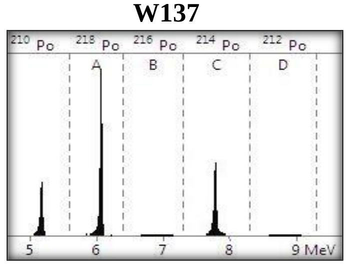

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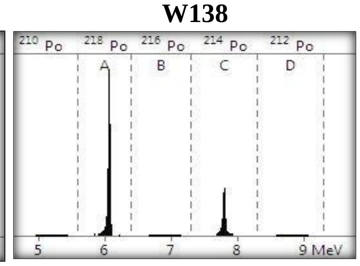

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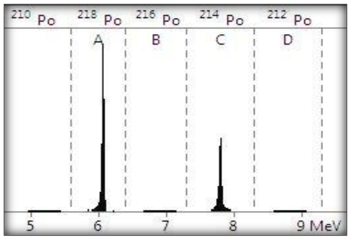

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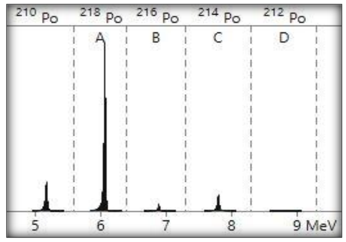

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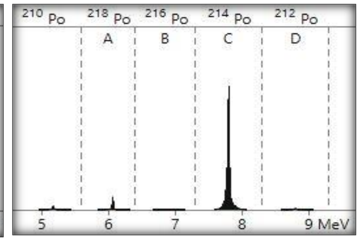

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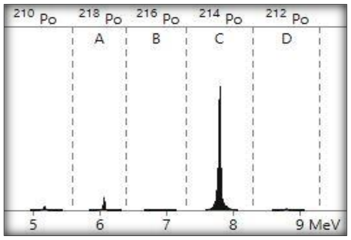

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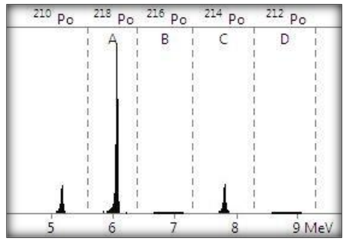

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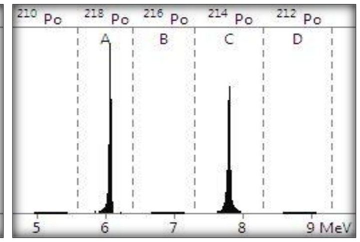

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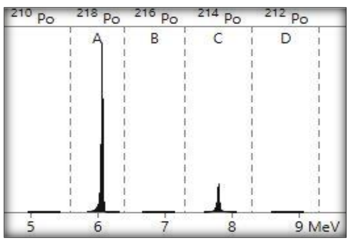

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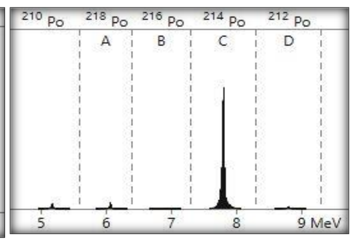

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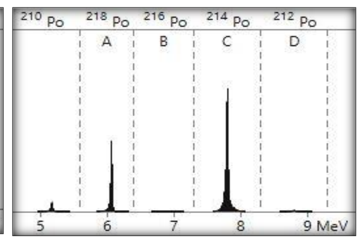

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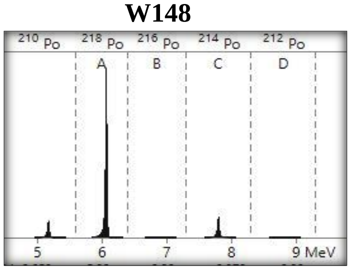

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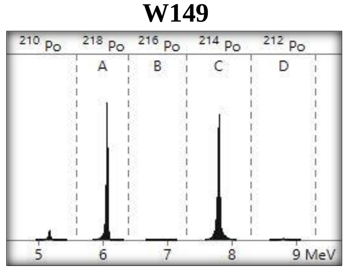

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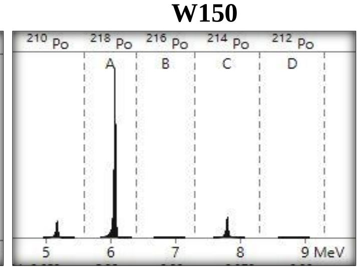

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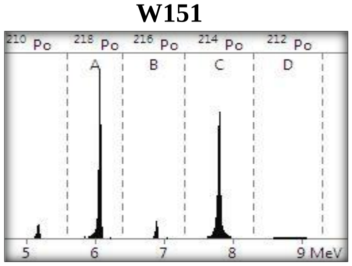

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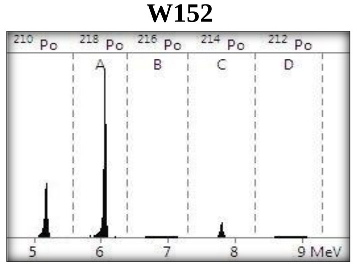

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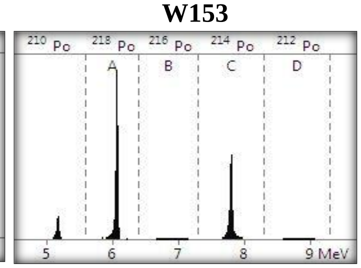

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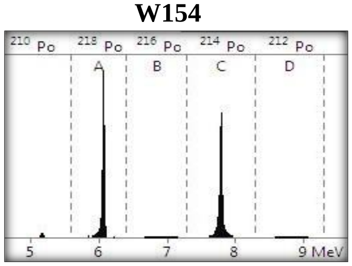

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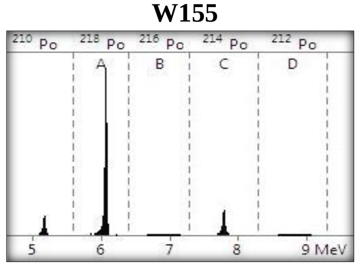

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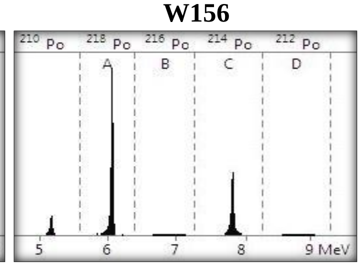

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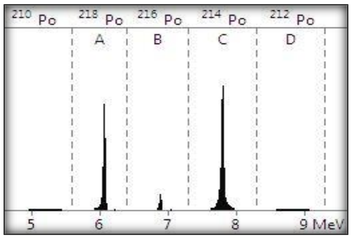

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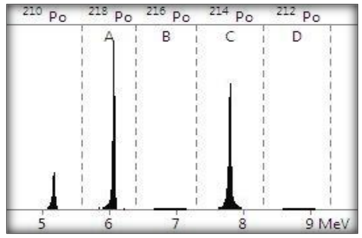

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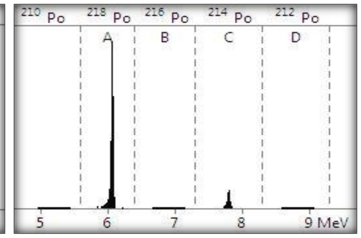

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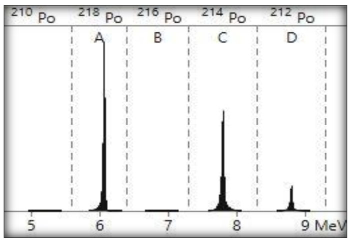

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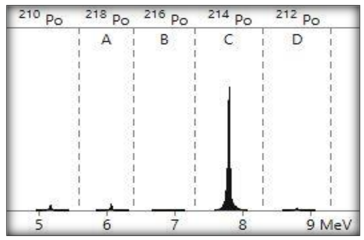

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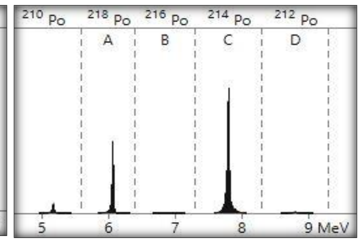

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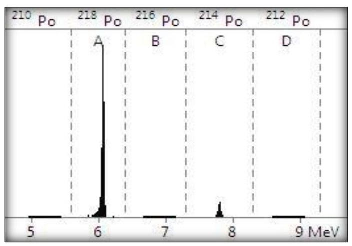

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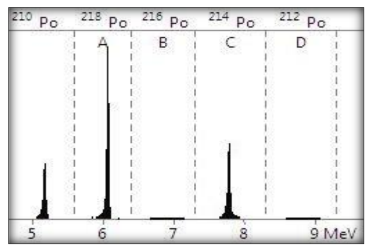
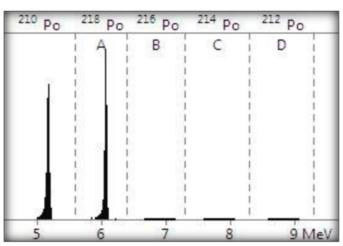


W167

(2) Spectrums Obtained from Soil samples.



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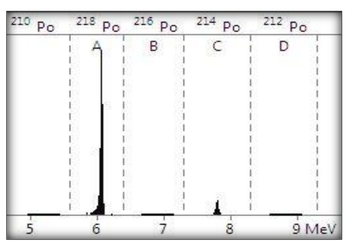

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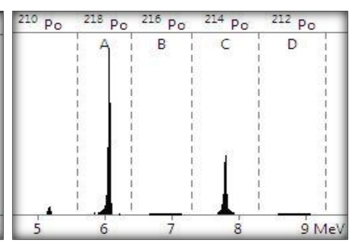

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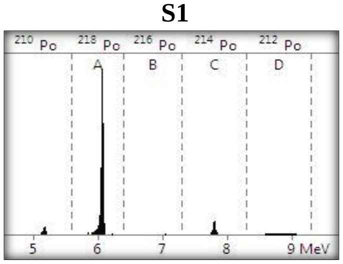

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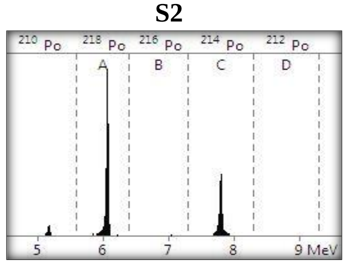

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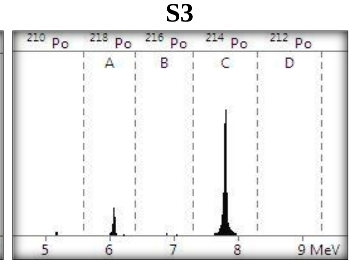

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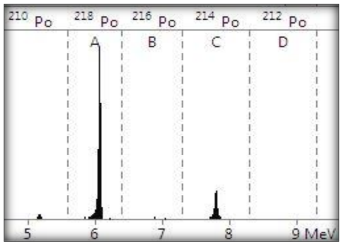

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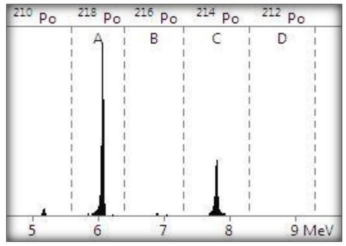

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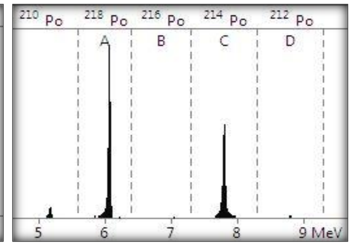

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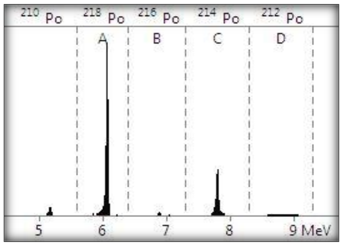

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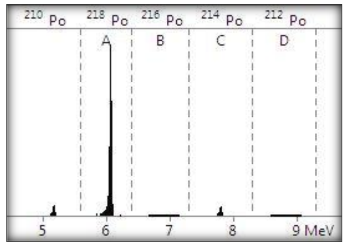

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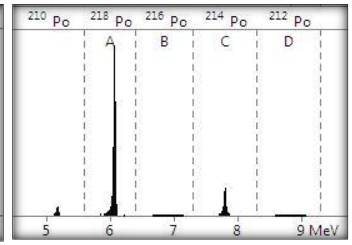

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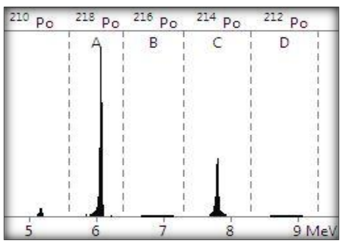

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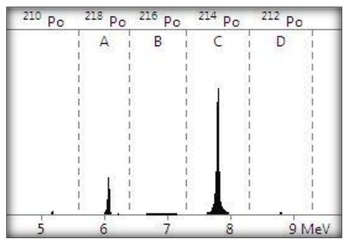

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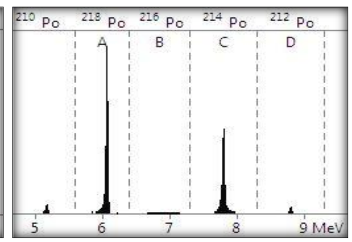

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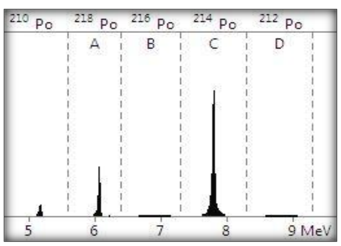

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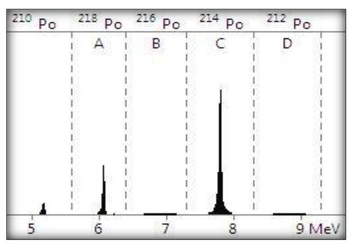

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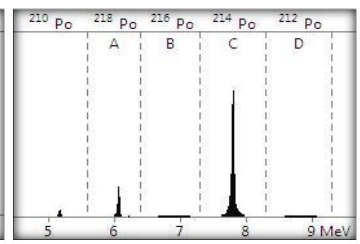

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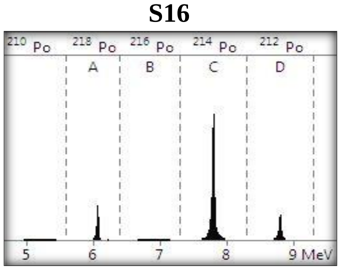

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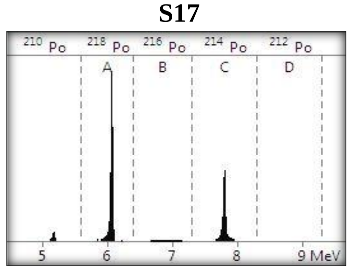

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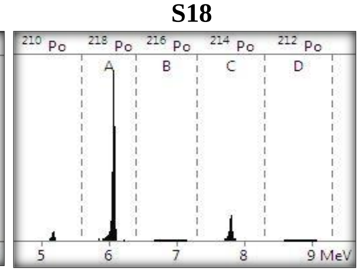

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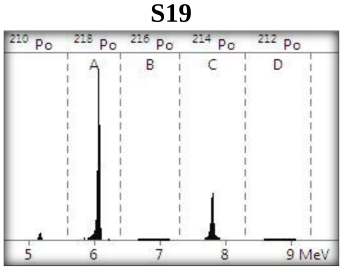

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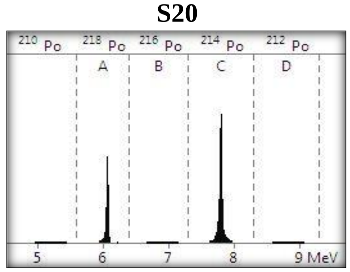

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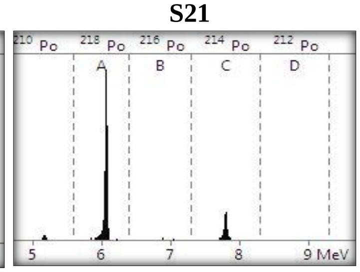

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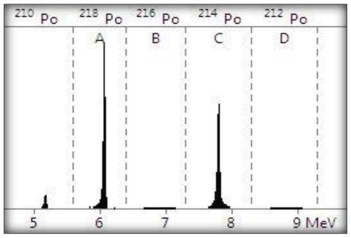

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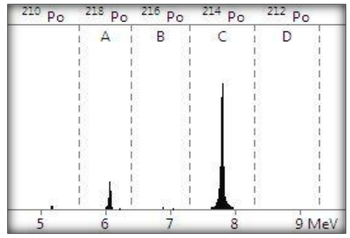

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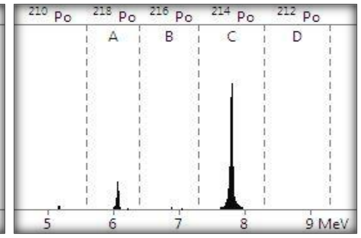

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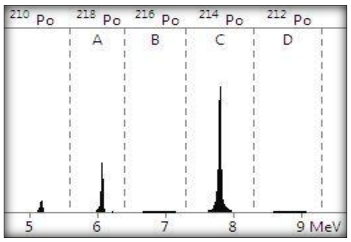

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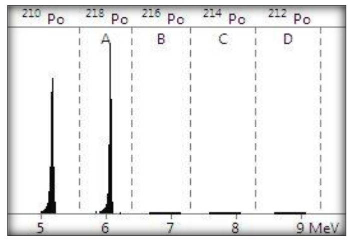

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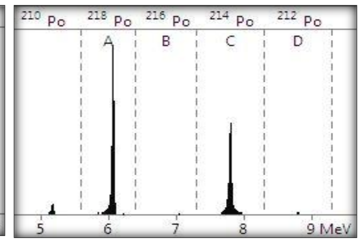

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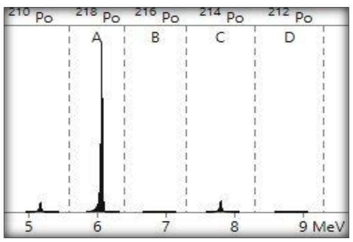

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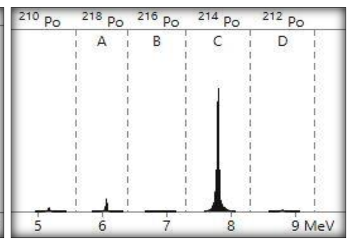

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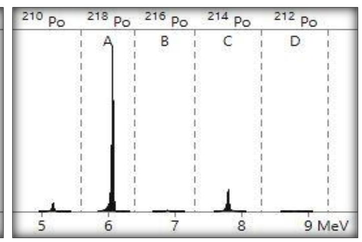

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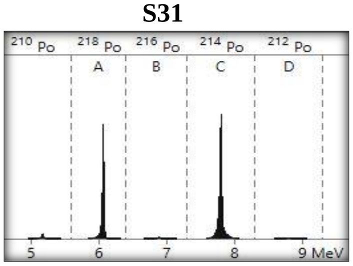

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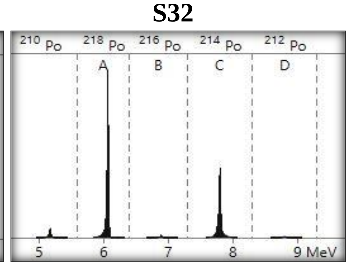

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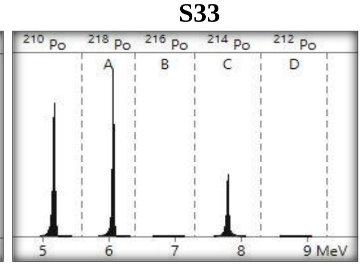

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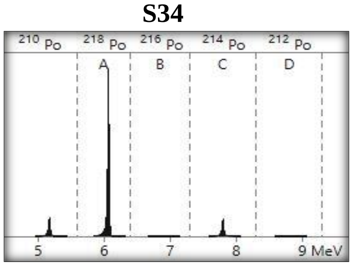

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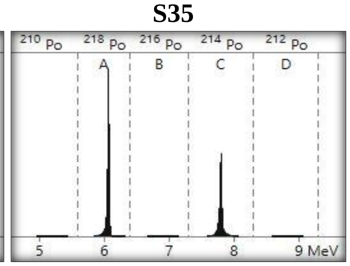

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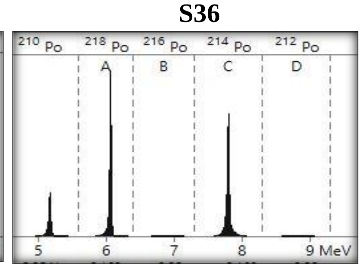

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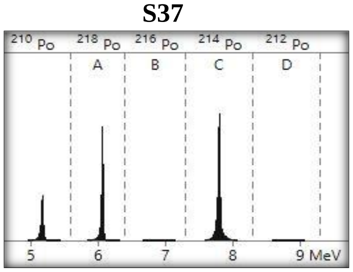

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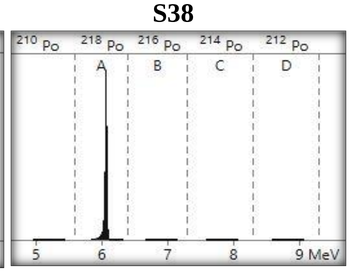

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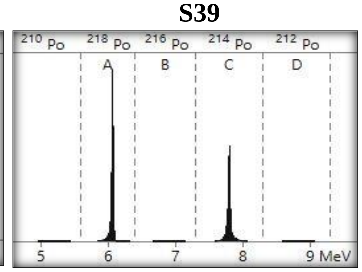

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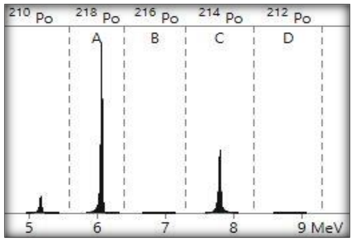

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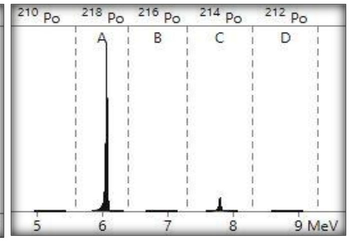

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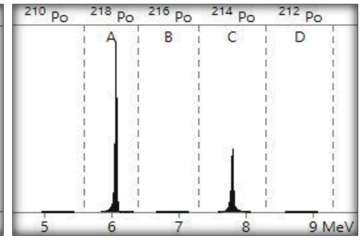

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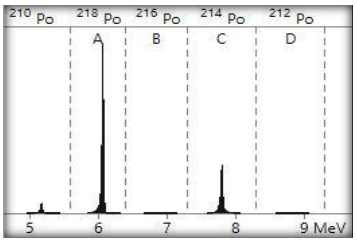

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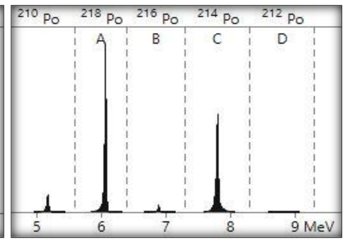

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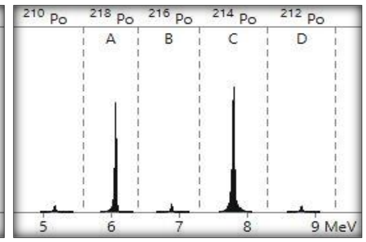

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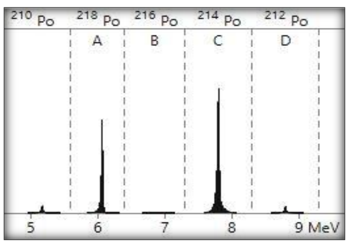

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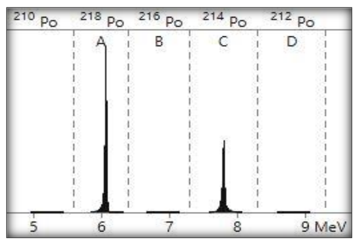

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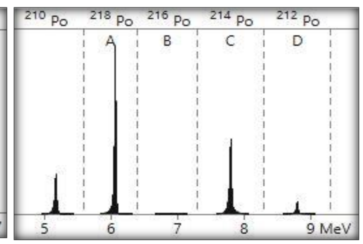

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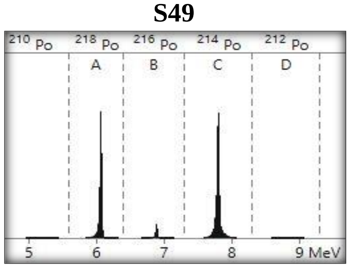

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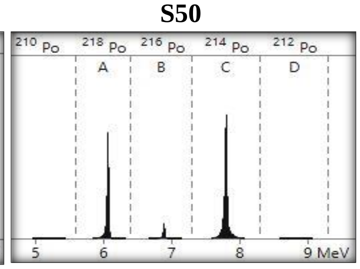

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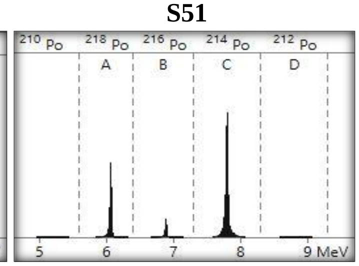

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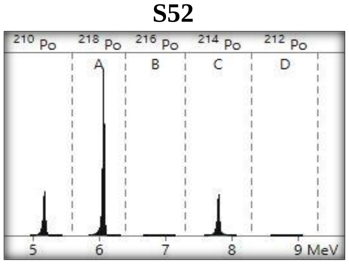

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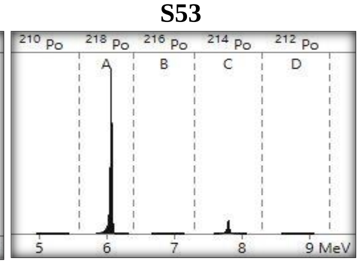

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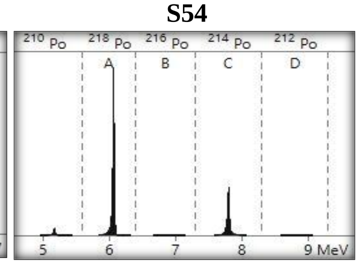

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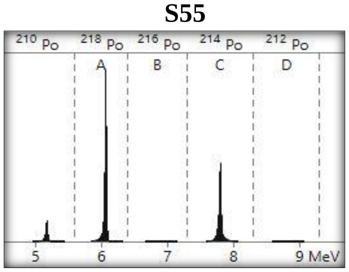

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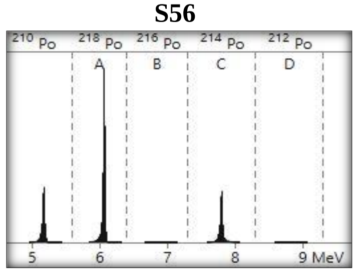

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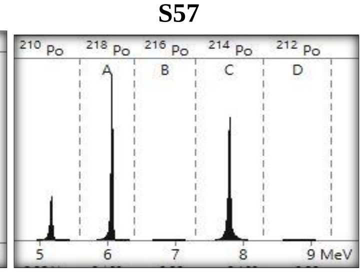

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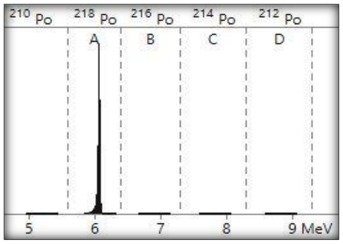

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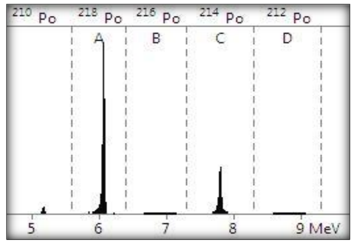

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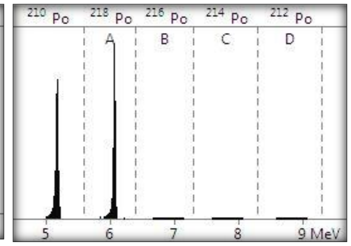

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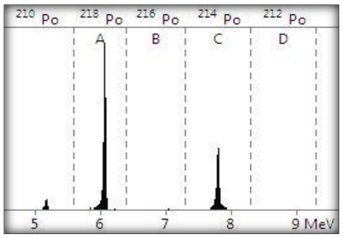

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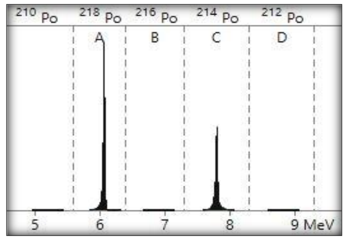

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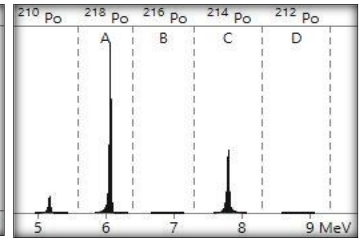

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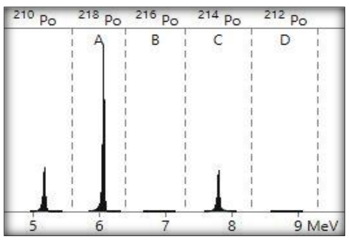
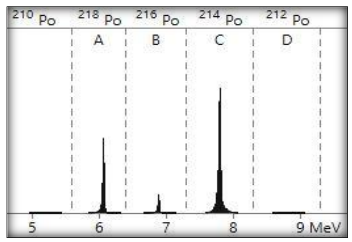


S67



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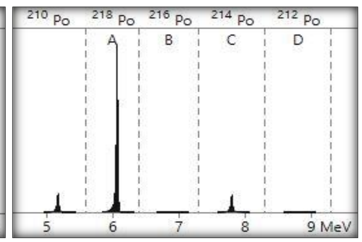

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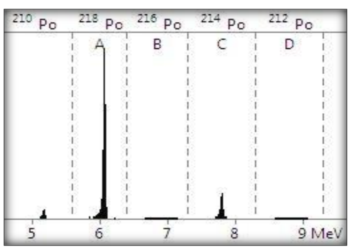

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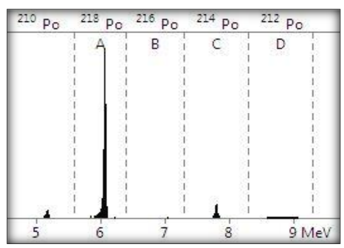

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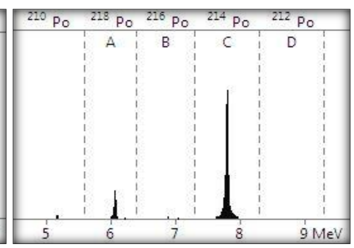

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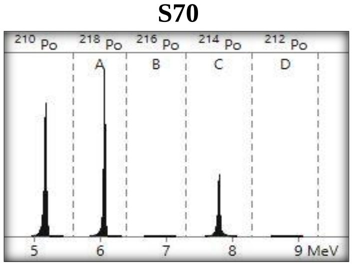

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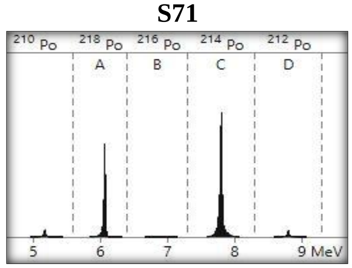

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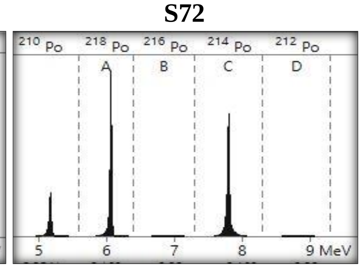

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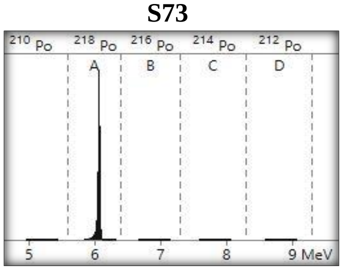

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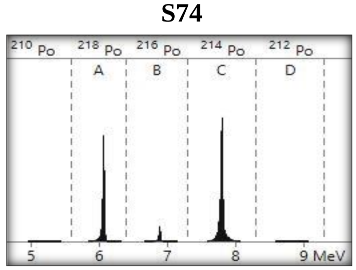

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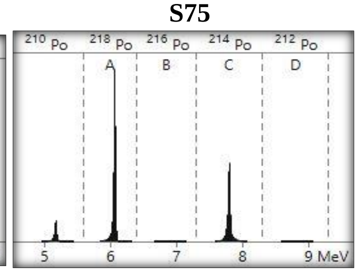

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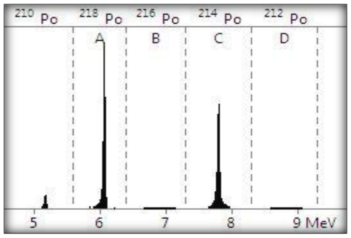

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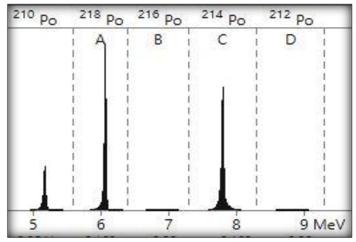

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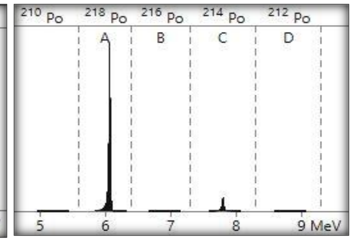

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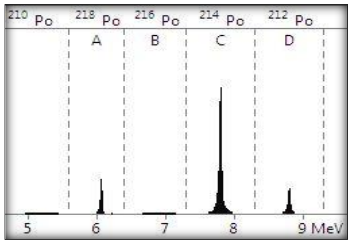

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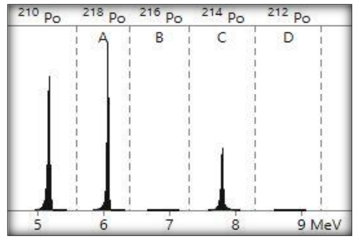

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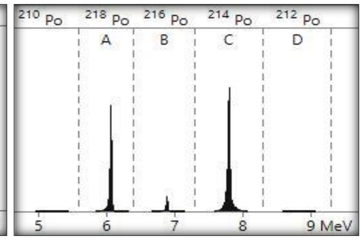

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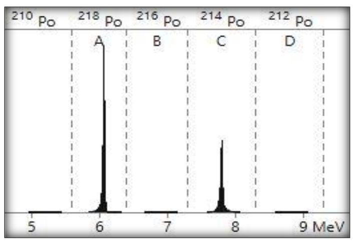

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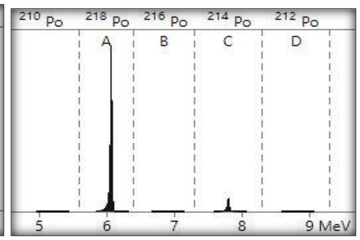

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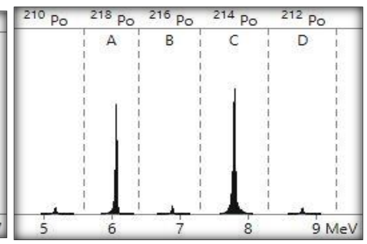

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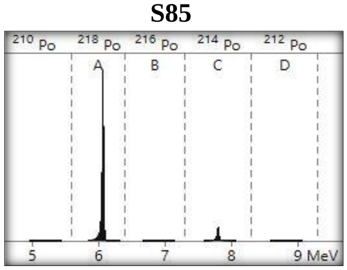

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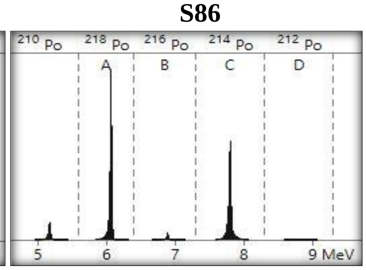

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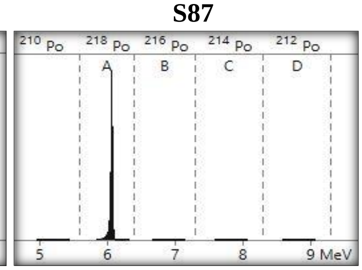

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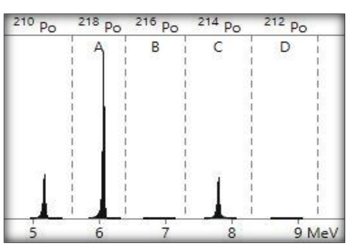

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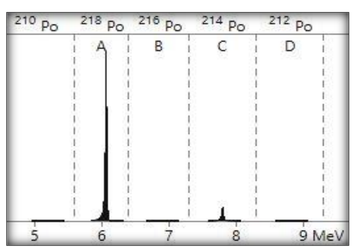

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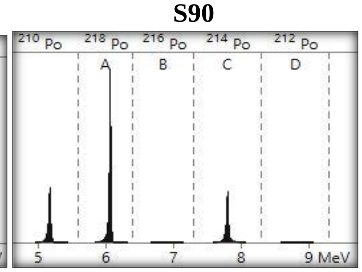

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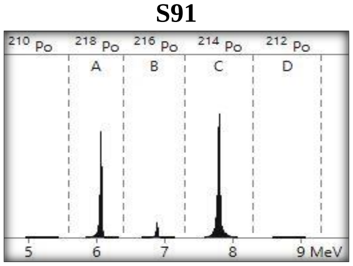

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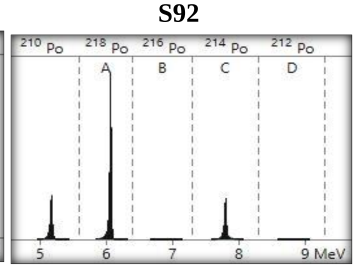

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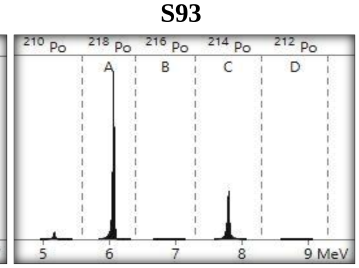

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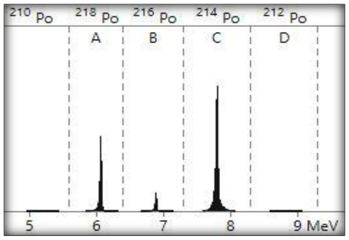

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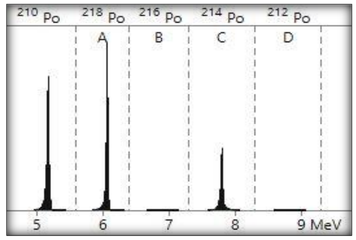

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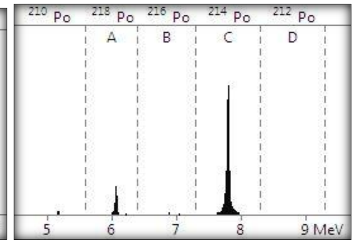

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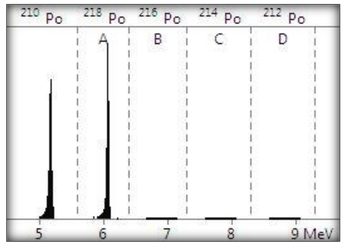

S100

List of Publications

(1) Mohammed R. S. , Farhood A. K. , “Evaluation of Radon Concentrations and Associated Annual Effective Dose from Drinking Water in Samawa City- South of Iraq ” , J. of Poll. Res. 40 (30) , pp (43 – 49) , 2021.

(2) Russel S. Mohammed, Abdulameer K. Farhood," A Study of Radon Concentration and the Annual Effective Dose in the Soil of Samawa city districts – South of Iraq**.** Submit for 1st International Conference on Advanced Research in Pure and Applied Science (ICARPAS) in March 2021.

الخلاصة

التعرض للعناصر المشعة في التربة والمياه ،أو تناولها من خلال مياه الشرب يسبب العديد من المخاطر الصحية والبيولوجية،لذلك من المهم دراسة وفحص مياه الشرب والتربة خاصة في المناطق السكنية، مدينة السماوة هي أكبر مدن محافظة المثنى بمساحة أجمالية تصل الى ($680km^2$) وتقع على تكوين جيولوجي مؤلف من الطين ،الرمل ،الحجر الكلسي والجبس،

يهدف هذا العمل الى أيجاد أول قاعدة بيانات عن تراكيز غاز الرادون في مياه الشرب وترب أحياء مدينة السماوة،في هذه الدراسة تم قياس تراكيز غاز الرادون في مياه الشرب وترب هذه المدينة الواقعة في جنوب العراق، أجريت القياسات باستخدام جهاز كاشف غاز الرادون (RAD7) المصنع من قبل شركة (Durridge-USA)،في الدراسة الحالية تم جمع (167) نموذج لمياه الشرب أخذت من (32) حي في منطقة الدراسة (مدينة السماوة) للفترة من الأول من كانون الأول 2019 الى الحادي والثلاثين من كانون الثاني 2020،لقد أظهرت النتائج أن تراكيز غاز الرادون كانت متفاوتة وتتراوح من (0.13 ± 0.015 Bq/L) الى (1.01 ± 0.38Bq/L)،بينما كان معدل التراكيز يساوي (0.175 Bq/L) .بالاعتماد على تراكيز غاز الرادون تم حساب الجرعة الفعالة السنوية الناتجة عن الابتلاع والاستنشاق للأطفال والبالغين، وقد وجد أن معدل الجرعة الفعالة السنوية للبالغين والأطفال تساوي الى($1.282 \mu Sv/yr$) و ($1.923 \mu Sv/yr$) على التوالي،

وفي هذه الدراسة أيضا أجريت قياسات لتراكيز غاز الرادون في ترب أحياء مدينة السماوة،لقد تم اختيار ودراسة (100) موقع في كافة أحياء المدينة ،حيث قيست التراكيز في التربة على عمق(40cm)،وللفترة من الأول من شباط 2020 الى الحادي والثلاثين من أذار2020. لقد وجد ان تراكيز غاز الرادون تتغير من ($29 Bq/m^3$) الى ($6820 Bq/m^3$) وبمعدل تركيز وصل الى ($1343.5 Bq/m^3$). بالاعتماد على تراكيز غاز الرادون تم حساب الجرعة الفعالة السنوية الناتجة عن استنشاق الغاز عند سطح التربة حيث وجد أنها تتراوح بين ($1.105 \mu Sv/yr$) الى ($43.84 \mu Sv/yr$) وبمعدل يساوي الى ($12.76 \mu Sv/yr$)،تشير النتائج الى أن تراكيز غاز الرادون في مياه الشرب والترب وكذلك الجرعة الفعالة السنوية التي حسبت لكل حي من أحياء مدينة السماوة الى أنها ضمن حدود مستويات التراكيز الطبيعية المسموح بها من قبل المنظمات العالمية مما يدل على أنها لا تشكل أي تهديد أو خطورة صحية أو بيولوجية على السكان،

وزارة التعليم العالي والبحث العلمي
جامعة المثنى
كلية العلوم
قسم الفيزياء

قياس تركيز غاز الرادون والجرعة الفعالة السنوية لمياه الشرب وترب مدينة السماوة- جنوب العراق

رسالة مقدمة كجزء من متطلبات نيل شهادة الماجستير في علوم الفيزياء

من قبل
رسل صاحب محمد
بكلوريوس علوم فيزياء ،٢٠٠٧

باشراف
أ. د. عبد الامير كاظم فرهود

٢٠٢١ م ١٤٤٢ هـ