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College of Science
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GAMMA-RAYS DETECTION OF RADIONUCLIDES IN HUMAN TISSUES

A Thesis

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By

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Abstract

This study is carried out to detect and measure the specific activities of radionuclides in cancerous samples of human tissues that excised from Baghdad city patients. The measurements were done using spectral analysis technique for gamma-ray with 2"×2" NaI(Tl) scintillation detector.

Our present investigations are based on the study of 24 abnormal samples and 8 normal samples for comparing the results. These samples include four types of fresh tissues (kidney, colon, breast, and uterus) that may be obtained with great mass. These samples had been collected from the histopathology department for education laboratories in Madenat Al-Ttib and specialized surgical hospital.

Each sample is taken with 250g in weight, washed with distilled water to remove the formalin liquid (conservator substance), cut, put in the Marenilli Beaker uniformly and then examined with NaI(Tl) detector for a period of 4 hours (14400s) and 530 V as an operating voltage.

Detector efficiency was measured by using Eu-152 source while gamma-ray spectra for tissues samples had been calibrated with respect to spectra of Cs-137, Co-60 and Na-22 sources.

Six radionuclides have been detected in the selected samples where distributed between (2-5) radionuclides in each sample. These radionuclides included: two radionuclides (Bi-214 and Pb-214) belonging to the uranium series; two radionuclides (Ac-228 and Tl-208) belonging to the thorium series; one artificial radionuclide (Cs-137); and the natural radionuclide (K-40).

The specific activity of detected U-238 (U-238 decay products) ranged between (1.02-7.46 Bq/kg) in the abnormal samples and (0.88-2.01 Bq/kg) in the normal samples while the specific activity of detected Th-232 (Th-232 decay products) ranged between (0.59-4.84 Bq/kg) in the abnormal samples and (0.49-2.71 Bq/kg) in the normal samples.

The artificial radionuclide (Cs-137) is detected in all samples with specific activity ranged between (0.64-6.46 Bq/kg) in the abnormal samples and (0.5-3.46 Bq/kg) in the normal samples. The natural radionuclide (K-40) is detected in all samples too, but with largest specific activity compared with other radionuclides where it ranged between (44.18-85.36 Bq/kg) in the abnormal samples and (40.62-56.95 Bq/kg) in the normal samples.

The results indicate that same radionuclides are often appeared in both normal and abnormal samples for the same type of tissue but with least specific activities in the normal samples.

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Mohammed

Supervisor's Certification

I certify that this thesis was prepared under my supervision at AL-Nahrain University as a partial requirement for the degree of Master of Science in Physics.

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1-1 Introduction

Health physics is a systematic organization of knowledge about the interaction between radiation and organic or inorganic mater. It is a versatile science that is based upon physics, chemistry, biology and medicine.

The scientific and engineering aspects of health physics are concerned mainly with: (1) The physical measurements of different types of radiation and radioactive materials; (2) The establishment of quantitative relationships between radiation, exposure and biological damage; (3) The movement of radioactivity through the environments; and (4) The design of radiologically safe equipment, processes, and environments.

As well as, this science deals with the protection of the individual and population groups against the harmful effects of ionizing and non-ionizing radiation [1]. Both the type of radiation to which the person is exposed and the pathway by which they are exposed influence health effects.

Radiation and radiation emitters (radionuclides) can expose the whole body (direct exposure) or expose tissue inside the body when inhaled or ingested. Different types of radiation vary in their ability to damage different kinds of tissue. All kinds of ionizing radiation can cause cancer and other effects. The main difference in the ability of alpha particles, beta particles, gamma-rays and x-rays to cause health effects is the amount of energy they have, their energy determines how far they can penetrate into tissue, it also determines how much energy they are able to transmit directly or indirectly to tissues and the resulting damage [2].

The biological damage resulting from a given absorbed energy may be quite different for different tissues. Fore these reasons, it is necessary to

measure the radiation with an instrument and then translate it into response of tissue. Since different detectors do not have the same efficiency or sensitivity for all types of radiation and at all energies, there is no single instrument that can be used for alphas, betas and gammas [3].

One of the most popular detectors used to study and measure the concentrations of the radionuclides is scintillation detector. Since 1947, these detectors have come into the wide scale use, meeting demands for detectors capable of higher counting rates, higher efficiency for detecting low level radiation and shorter resolving time than were possible with existing instruments, and also making possible gamma-ray spectroscopy [4].

1-2 Types of Radiation

Radiation is the name given to the energetic particles or waves emitted by an atom at the time of radioactive decay [5]. It is produced by radioactive decay, nuclear fission, nuclear fusion, chemical reactions, hot objects, and gases excited by electric currents. Nuclei can undergo a variety of processes which result in the emission of radiation. The most common forms of radiation are alpha and beta particles and gamma-rays [2].

1-2-1 Alpha Particle

Alpha particles are positively charged particles emitted by a heavy radioactive element, such as radium, thorium, uranium, and plutonium. When the ratio of neutrons to protons in the nucleus is too low, certain atoms restore the balance by emitting alpha particles [2]. Alpha emitting atoms tend to be very heavy atoms (that is, they have high atomic numbers). With some exceptions, naturally occurring alpha emitters have atomic numbers of at least 82 (the element lead). The alpha particles are a portion of the parent

nucleus that contains two protons and two neutrons. After alpha particle emission, the daughter nucleus has an atomic number Z reduced by 2, and an atomic mass number reduced by 4, compared to the parent nucleus [6].

Alpha particle is identical to the nucleus of a He-4 atom, and after it has lost its kinetic energy by collision with other atoms in a material it will capture two electrons and become an atom of He-4 [1].

The emitted alpha particles are monoenergetic, their energy is in the range of a few MeV [7]. An alpha particle interacts strongly and has a very short range-a few cm in air. A single piece of paper can stop an alpha ray effectively as shown in figure (1-1a) [2, 8].

1-2-2 Beta Particle

A charged particle emitted from the nucleus of some radioactive atoms during radioactive decay. In this 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. This process must involve another charged particle to conserve electric charge. The first process is known as negative beta decay or negatron decay and involves the creation and emission of an ordinary electron. The second process is positive beta decay or positron decay, in which a positive charge electron is emitted.

$$n \rightarrow p + e^{-} \quad \beta^{-} \text{ decay} \qquad \ldots(1\text{-}1)$$

$$p \rightarrow n + e^{+} \quad \beta^{+} \text{ decay} \qquad \ldots(1\text{-}2)$$

In these processes, yet another particle called a neutrino (in β^{+} decay) or antineutrino (in β^{-} decay) is also emitted, but it has no electric charge.

In these process, Z and N each change by one unit, but the total mass number Z+N remains constant [9]. Since the number of protons in the

nucleus determines the element, the conversion of a neutron to a proton actually changes the radionuclide to a different element [10].

Beta particles are high-speed charged particles with a moderate penetrating power. Beta particles can pass through a sheet of paper, but may be stopped by a thin sheet of aluminum foil or wood as shown in figure (1-1b) [2, 8].

Beta particles lose their initial kinetic energy by collision with electrons in the atoms of the surrounding material. These atoms become ionized. After losing their energy the beta particles become free electrons [11].

1-2-3 Gamma-ray

Gamma-ray is an electromagnetic radiation emitted from the nuclei of some unstable (radioactive) atoms [12]. The nucleus has discrete energy levels, like those of the electrons in an atom. The nuclear force, however, is much stronger than the electromagnetic and hence transitions from one state to the other are characterized by the emission of photons of much larger energy-from a hundred keV to a few MeV. Such photons are called gamma-rays [7].

When a nucleus decays by alpha particle emission, the nucleus is sometimes left in an excited energy state. It usually changes to a ground state, or lowest energy state, emitting one or more gamma rays [13].

Often, gamma ray emission accompanies the emission of a beta particle. When the beta particle ejection does not rid the nucleus of the extra energy, the nucleus releases the remaining excess energy in the form of a gamma photon.

Gamma radiation is very high-energy ionizing radiation. Because of their high energy, gamma photons travel at the speed of light and can cover hundreds to thousands of meters in air before spending their energy. They can pass through many kinds of materials, including human tissue [2]. Very dense materials, such as lead, thick concrete are commonly used as shielding to slow or stop gamma photons as shown in figure (1-1c) [2, 8].

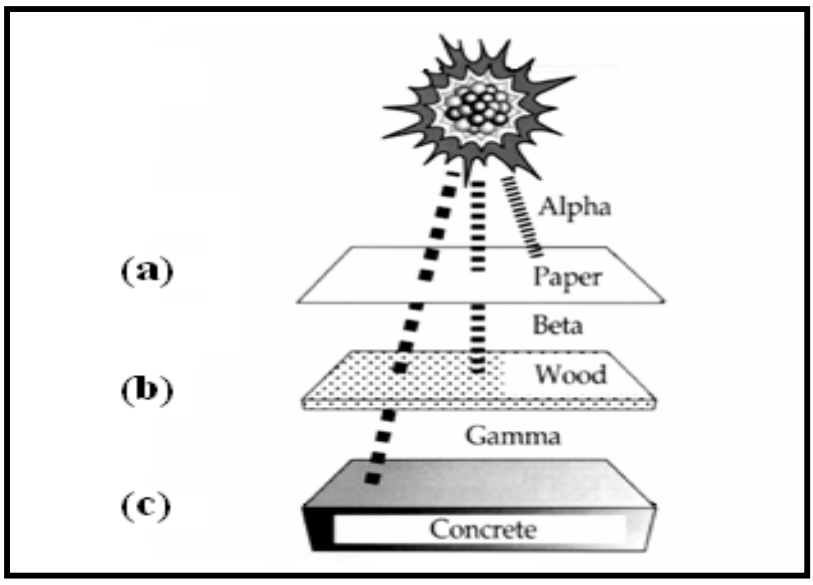

Figure (1- 1) Penetrating ability for alpha, beta and gamma [2]

1-3 Ionization and Excitation

Radiation is often separated into two categories, ionizing and non-ionizing, to denote the energy and the danger of the radiation [5]. When sufficient energy is absorbed by an electrically neutral atom or molecule, an electron may be ejected from it, leaving behind a positively charged residue. This process-known as ionization, leads to the formation of an ion pair.

In some cases the energy received either by collision or by radiation absorption may not be sufficient to form an ion pair. The atom may then be

left in a neutral, unionized but excited electronic state. It is sufficient now to note that an excited atom may radiate the excitation energy and return to its original, undisturbed state of lowest energy, the ground state [14]. Many forms of radiation such as heat, visible light, microwaves, or radiowaves do not have sufficient energy to remove electrons from atoms and hence, are called non-ionizing radiation [2].

Ionization or excitation may occur when either a photon or a charged particle, such as an electron, a proton or an alpha particle, collides with an orbital electron. This mechanism is of great importance in health physics because it is the avenue through which energy is transferred from radiation to mater. When living matter is irradiated, the primary event in the sequence of events leading to biological damage is either excitation or ionization [1].

1-4 Radiation Sources

The radiation comes from two sources: natural or background radiation and human-made radiation.

1-4-1 Natural or Background Radiation

Natural or background radiation is the radiation emitted by radioisotope that exist on or inside the earth, as well as radiation incident upon the earth from outer space [3]. Natural background radiation comes from two primary sources: cosmic and terrestrial sources.

1-4-1-1 Cosmic Radiation

The earth, and all living things on it, are continually bombarded by high-energy particles that originate in outer space called cosmic rays. These

cosmic rays interact with nuclei of atmospheric constituents, producing a cascade of interactions and secondary reaction products that contribute to cosmic ray exposure, which decrease in intensity with the depth in the atmosphere [15].

The cosmic ray consists of 87% protons, 11% alpha particles, about 1% nuclei with low atomic number, and about 1% electrons of high kinetic energy. The cosmic rays have a high penetrating energy 10^{20} eV or more [16]. The interaction of cosmic ray in the atmosphere produces a number of radionuclides called cosmogenic radionuclides, including ^{3}H, ^{7}Be, ^{14}C, ^{22}Na, etc [17].

The dose from cosmic radiation varies in different parts of the world due to many factors including differences in elevation, the effect of the earth's magnetic field and local differences in terrain.

1-4-1-2 Terrestrial Radiation

Radioactive material is found throughout nature. It occurs naturally in the soil, water, and vegetation [5].The primordial radionuclides whose half-lives are sufficiently long to have survived in detectable quantities since the formation of the earth, together with their radioactive daughters. The primordial radionuclides can be divided into those that occur singly and those that are components of chain series [18].

The major isotopes of concern for terrestrial radiation are uranium and its decay products, such as thorium, radium, and radon. Low levels of uranium, thorium, and their decay products are found everywhere. Some of these materials are ingested with food and water, while others, such as radon, are inhaled. The dose from terrestrial sources varies in different parts

of the world. Locations with higher concentrations of uranium and thorium in their soil have higher dose levels [5].

1-4-2 Human Made Radiation

Natural and artificial radiation sources are identical in their nature and their effect [5].

Humans are using the radioactivity for one hundred years, and through its use, added to natural inventories. Its amount is small compared to the natural amount discussed above due to the short half-lives of many of the nuclides, and it demonstrate a marked decrease since the halting of above ground testing of nuclear weapons [16].

Two important categories of artificial radionuclides-include those, which appear in nuclear power plants from the fission of uranium and other nuclear reactions, and the radionuclides and labeled compounds, which are specially produced for application in various fields of human activity. Large varieties of radioactive nuclides are produced in minute amounts in nuclear research laboratories in the form of by products from the investigation of nuclear processes [19].

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 I-131, Co-60, Sr-90, Cs-137, and others. In addition, members of the public are exposed to radiation from consumer products, such as tobacco (polonium-210), building materials, televisions, luminous watches and dials (tritium), airport x-ray systems, smoke detectors (americium), etc. [5].

1-5 Natural Uranium

Uranium is silver-white, lustrous, dense, natural, weakly radioactive element, was discovered in 1789 by the German scientist M. H. Klaproth [20].

It is present in all crystal and mantle rocks in trace amounts and it is as essential constituents of about 100 minerals. Its average content in Earth's crust is about 3 $mg.kg^{-1}$.

In this natural state, uranium consists of three isotopes: U-238 (99.27% by mass, with a half-life of 4.46×10^{9} year and a specific activity of 12.4 $Bq.mg^{-1}$), U-235 (0.72%, half life: 7.03×10^{8} year and specific activity of 80 $Bq.mg^{-1}$) and U-234 (0.0054%, half life: 2.44×10^{5} year and specific activity of 2.3×10^{5} $Bq.mg^{-1}$) [21,22]. About 48.9% of the radioactivity is associated with U-234, 2.2% with U-235 and 48.9% with U-238. Uranium decays into many finally ends up as stable (nonradioactive) isotopes of lead [20].

Some chemical fertilizer contains significant amounts of uranium because of a relatively high content of this element in phosphates that are used in manufacturing the fertilizer. Uranium can be introduced into the soil from fertilizer and is transmitted from plant and thence to food, and subsequently to the human body [19]. Typical gut absorption rates for uranium in food and water are about 2% for soluble and about 0.2% for insoluble uranium compounds.

About 98% of uranium entering the body via ingestion is not absorbed, but is eliminated via the faeces. Of the uranium that is absorbed into the blood, approximately 70% will be filtered by the kidney and excreted in the urine within 24 hours; this amount increases to 90% within a few days. On average, approximately 90 micrograms of uranium exist in the

human body from normal intakes of water, food and air, about 66% is found in the skeleton, 16% in the liver, 8% in the kidneys and 10% in other tissues [23].

1-6 Health Effects of Uranium

The physiological behavior of uranium compounds depends mainly on their solubility. Soluble uranium is regulated because of its chemical toxicity, while insoluble (less soluble) uranium is regulated by its radiological properties. But because of its slow absorption through the lungs and the long retention time in the body tissues, its primary damage will be to its radiological damage (risk of cancer death) to internal organs rather than the risk of significant chemical damage to the renal system [24].

Inhalation of uranium dioxide particle forming radioactive hot spot in the lung, this might cause cancer years later.

When ingested, uranium might be concentrated within the bone; it increases the probability of bone cancer, or in the red bone marrow (leukemia). Uranium also resides in soft tissues including gonads increasing the probability of genetic health effects including the berth defects [25].

The kidney is considered the target organ for uranium chemical toxicity, which cases irreversible damage to the kidney and the growth of tumors. A large quantity of uranium in the kidney can impair renal function. The main acute effect of inhalation of soluble uranium compounds is damage to the renal system and the long-term place of these compounds in the body is the bone [24].

Due to all what is mentioned above, there are many outstanding signs and symptoms that may result from uranium (some of them based upon

animal studies) as a systemic chemical toxicant such as headaches, cold sweat, hypertension, anemia, diarrhea, insomnia, bronchitis, renal disorder (may increase the infectious diseases), focal necrosis of the liver, lymph nod fibrosis, loss of the body weight, low birth weight, skeletal abnormalities, and others [24, 25].

1-7 Chain-Series of Radionuclides

There are three chains of naturally radionuclids in nature, these are:

1-7-1 Thorium Series

Thorium series starting with Th-232 which is an alpha-particle emitter of half-life 1.41×10^{10} years and ending with stable Pb-208. The atomic mass number of Th-232 is exactly divisible by 4. Since all disintegrations in the series are accomplished by the emission of either an alpha particle of 4 atomic mass units, or a beta particle of 0 atomic mass units, it follows that the mass numbers of all members of thorium series are exactly divided by 4. This series, therefore, is called the (4n) series [1,26]. The thorium series consists of 13 isotopes shown in table (1-1).

1-7-2 Uranium Series

Uranium series starting with U-238 which is an alpha-particle emitter and ending with stable Pb-206. The uranium series consists of isotopes whose numbers are divided by 4, and leave a remainder of 2. This series, therefore, is called the (4n + 2) series [1,26]. The uranium series consists of 20 isotopes shown in table (1-2).

1-7-3 Actinium Series

Actinium series is called the (4n + 3) series starting with U-235 which is an alpha-particle emitter and ending with stable Pb-207 [1,26], This series consists of 15 isotopes shown in table (1-3).

Table 1-1 Thorium (4n) series [27, 28, 29]

Isotope	Principal decay mode	Half-life ($T_{½}$)	Particle energy (keV)	Gamma energy (keV) - Intensity (%)
$^{232}_{90}Th$	Alpha	1.41×10^{10} y	4010	---
$^{288}_{88}Ra$	Beta	5.7 y	٤0	---
$^{228}_{89}Ac$	Beta	6.13 h	1110	338.4 - 11.4 911 - 27.7 969.1 - 16.6
$^{228}_{90}Th$	Alpha	1.91 y	5430	84 - 1.6
$^{224}_{88}Ra$	Alpha	3.64 d	5680	240.9 - 3.9
$^{220}_{86}Rn$	Alpha	55.3 sec	6290	---
$^{216}_{84}Po$	Beta	0.15 sec	6780	---
$^{216}_{85}At$	Alpha	3×10^{-4} sec	7790	---
$^{212}_{82}Pb$	Beta	10.64 h	350	238.6 - 44.6 300 - 3.4
$^{212}_{83}Bi$	Beta	6.06 m	6050	727 - 7.5 785.4 - 1.2 1080 - 10 1620 - 10
$^{212}_{84}Po$	Alpha	3×10^{-7} sec	8780	---
$^{208}_{81}Tl$	Beta	3.1 m	1800	280 - 3 510 - 8 583.1 - 85.7 860.5 - 12 2614.5 - 99.7
$^{208}_{82}Pb$	---	Stable	---	---

Table 1-2 Uranium (4n + 2) series [27, 28, 29]

Isotope	Principal decay mode	Half-life ($T_{½}$)	Particle energy (keV)	Gamma energy (keV) - Intensity (%)
$^{238}_{92}U$	Alpha	4.5×10^{9} y	4180	---
$^{234}_{90}Th$	Beta	24.1 d	190	63.2 - 43.8 92.3 - 2.7 92.8 - 2.9
$^{234m}_{91}Pa$	Beta	1.18 m	2310	750 - 0.6 1000 - 0.5
$^{234}_{91}Pa$	Beta	6.66 h	500	43 800 and others - weak
$^{234}_{92}U$	Alpha	2.48×10^{5} y	4760	---
$^{230}_{90}Th$	Alpha	7.6×10^{4} y	4690	67 - 0.5 others - very weak
$^{226}_{88}Ra$	Alpha	1620 y	4780	186.2 - 3.2
$^{222}_{86}Rn$	Alpha	3.83 d	5490	---
$^{218}_{84}Po$	Beta	3.05 m	6000	---
$^{218}_{85}At$	Alpha	1.3 sec	6690	---
$^{218}_{86}Rn$	Alpha	1.9×10^{-2}sec	7127	610 - very weak
$^{214}_{82}Pb$	Beta	26.8 m	650	241.9 - 9 258.7 - 0.5 295.2 - 19.7 314.2 - 0.7 351.9 - 38.9 785.9 - 1.1 others - weak
$^{214}_{83}Bi$	Alpha	19.7 m	5500	389.1 - 0.4 609.3 - 43.3 665.4 - 1.2 768.3 - 5 1120.2 - 15.7 1238.1 - 5.9 1746.4 - 17 2264.2 - 4.9 others - weak
$^{214}_{83}Po$	Alpha	4×10^{-4} sec	3200	---
$^{210}_{81}Tl$	Beta	1.3 m	7680	Several - very weak
$^{210}_{82}Pb$	Beta	22 y	1990	47 - 5
$^{210}_{83}Bi$	Alpha	5.01 d	20	---
$^{210}_{84}Po$	Alpha	138.4 d	4700	820 - 0.000012
$^{206}_{81}Tl$	Beta	4.3 m	1570	---

$^{206}_{82}$Pb	---	Stable	---	---

Table 1-3 Actinium (4n + 3) series [27, 28, 29]

Isotope	Principal decay mode	Half-life ($T_{½}$)	Particle energy (keV)	Gamma energy (keV) - Intensity (%)
$^{235}_{92}$U	Alpha	7.13×10^{8} y	4180	143.7 - 10.9 163.3 - 5 185.7 - 57.5 205.3 - 5
$^{231}_{90}$Th	Beta	25.64 h	300	22 - 7 61 - 16
$^{231}_{91}$Pa	Alpha	3.25×10^{4} y	5000	27 - 5 290 - 5
$^{227}_{89}$Ac	Alpha	21.2 y	4940	---
$^{227}_{90}$Th	Alpha	18.17 d	5970	236 - 11 256.2 - 6.7 others - weak
$^{223}_{87}$Fr	Beta	22 m	1150	50 - weak 80 - = 210 - = 310 - =
$^{223}_{88}$Ra	Alpha	11.68 d	5710	120 - 2 140 - 4 150 - 5.5 270 - 10 320 - 2.3 340 - 2.8
$^{219}_{86}$Rn	Alpha	4.0 sec	6820	270 - 9 400 - 5
$^{215}_{84}$Po	Alpha	1.83×10^{-3} sec	7380	---
$^{215}_{85}$At	Alpha	10^{-4} sec	8000	---
$^{211}_{82}$Pb	Beta	36.1m	1400	400 - 6 430 - 6 830 - 13
$^{211}_{83}$Bi	Alpha	2.15 m	6620	350 - 13
$^{211}_{84}$Po	Alpha	0.52 sec	7450	570 - weak 890 - =
$^{207}_{81}$Tl	Beta	4.78 m	1440	870 - 0.5
$^{207}_{82}$Pb	---	Stable	---	---

It will be noticed that one series (4n +1) is missing, that is, it does not occur naturally. The missing series consists of radioactive isotopes which all have half-lives much shorter than the age of the earth (4.5×10^9) years and so, although the chain would have been present after the formation of the earth it has now decayed to unmeasurably small proportions. It is known as the Neptunium series which starts with Pu-241 and ends with stable Bi-209 [26].

1-8 Depleted Uranium

Depleted uranium (DU) has only been available since about 1940. The uranium remaining after removal of the enriched fraction contains about 99.79% U-238, 0.2%~0.3% U-235 and 0.001% U-234 by mass; this is referred to as DU.

The main difference between DU and natural uranium is that the former contains at least three times less U-235 than the latter. U-238 has a longer half-life than either U-235 or U-234 and it is present in a much greater abundance in natural and DU than U-235 or U-234. The number of alpha particles produced per year in one milligram of natural uranium from the decay of U-238, U-235 and U-234 may be calculated to be (3.9×10^{11}), (1.7×10^{10}) and (3.9×10^{11}) respectively [30].

DU has a specific activity of 14.8 $Bq.mg^{-1}$ which is approximately 60% that of natural uranium (25.4 $Bq.mg^{-1}$) with the same mass due to the partial removal of U-234 and U-235, but the behavior of natural uranium and DU in the body is identical radiologically and chemically [23].

Due to the partial removal of the most enriched fraction in DU, gamma-ray spectrum of DU containing limited photo-peaks comparing with

gamma-ray spectrum of U-238 and U-235, where it has limited energies for gamma-rays as shown in table (1-4) [31].

Table 1-4 Gamma energies for DU [31]

Isotope	Energy (keV)
U-238	93
Pa-234	750,1005
U-235	143,185,205

1-9 Interaction of Gamma-ray with Matter

Gamma-rays interact with matter in several ways, depending on their energy. Ordinarily, only three important processes are taken into account, these are the photoelectric effect, Compton effect, and the pair production [32].

1-9-1 Photoelectric Effect

The photoelectric effect is an interaction between a photon and a bound atomic electron. As a result of the interaction, the photon disappears completely and one of the atomic electrons is ejected as a free electron, called the photoelectron [3]. Generally, the photon will interact with the innermost or K-shell of the atom provided that it is energetic enough to ionize the K-shell [26].

In this reaction, energy of the photon (E_γ), minus binding energy of the electron (BE), is given to the free electron as a kinetic energy (T) [3]. This reaction is pictured schematically in figure (1-2).

If the electron, which is free from the original atom, is an inner electron, an outer electron will take its place. An x-ray will be emitted with energy equal to the difference in binding energy of the two electron levels.

This x-ray may act like a gamma-ray and free an electron from another atom by the photoelectric effect, and the process will be repeated until all the x- rays have too little energy to free any other electrons [32].

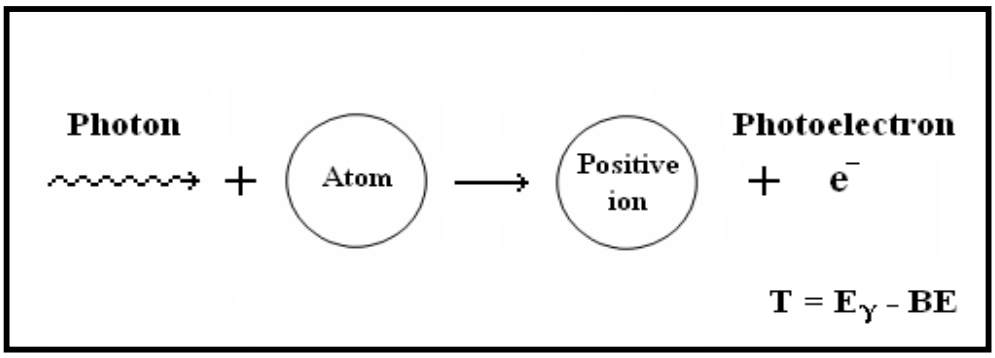

Figure (1-2) Photoelectric effect [3]

The photoelectric effect is stronger for lower energy gamma-rays and for absorber materials of high atomic number [26]. The result of a single gamma ray causing the photoelectric effect is thus a large number of ionized atoms, each with outer electron removed, and a large number of free electrons.

1-9-2 Compton Scattering

Compton scattering is an interaction between gamma-rays and free or only weakly bound electron [9, 26]. In this process, the incoming gamma-ray photon is deflected through an angle θ with respect to its original direction. The photon transfers a portion of its energy to the electron and is scattered at a lower energy, which is then known as a recoil electron. This is illustrated in figure (1-3).

Because all angles of scattering are possible, the energy transferred to the electron can vary from zero to a large fraction of the gamma-ray energy [4, 33].

The expression, which gives the interaction, can be simply derived by writing simultaneous equations for the conservation of energy and momentum. Using the symbols defined in the sketch below, we have [33]

$$h\upsilon' = h\upsilon / [1 + (h\upsilon/m_oc^2)(1- \cos\theta)] \quad \ldots (1\text{-}3)$$

Where, m_oc^2 is the rest mass energy of the electron (0.511 MeV).

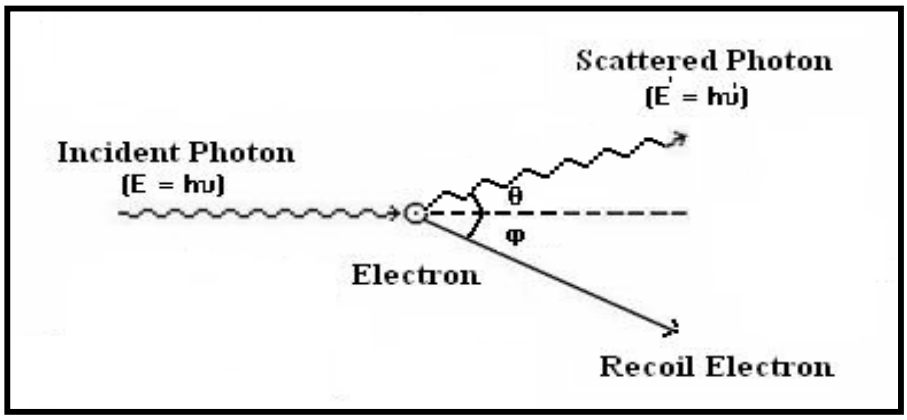

Figure (1-3) Compton scattering of a gamma-ray [33]

Two extreme values are important in Compton scattering. The first is the minimum energy of the scattered gamma-ray that occurs at a scattering angle $\theta = 180^\circ$. This minimum of gamma-ray energy is often called the backscattered gamma-ray and its energy ($E'_{\gamma BC}$) given by:

$$E'_{\gamma BC} = (m_oc^2/2)/ [1+ (m_oc^2/2)/E_\gamma] \quad \ldots (1\text{-}4)$$

From equation (1-4) it can be seen that the energy of the backscattered gamma-ray cannot exceed 0.255 MeV even for very high energy incident gamma-rays.

The second extreme value of interest is the energy of the electron recoiling at $\varphi = 0^\circ$, often termed the Compton edge energy (E_{eCE}). This forward scattered electron accompanies the 180° backscattered gamma-ray since there can be no transverse component of momentum in this case and its energy is easily found from conservation of energy to be

$$E_{eCE} = E\gamma / [1 + (m_o c^2/2)/E_\gamma] \quad \ldots (1\text{-}5)$$

From equation (1-5) it can be seen that the Compton edge energy is always less than the incident gamma-ray energy. The probability of Compton scattering depends upon the number of available (weakly bound) electrons as well as on the cross-section and so it increases with both the atomic number of the scatter and the incident gamma-ray energy [26].

1-9-3 Pair Production

Pair production is an interaction between a photon and nucleus coulomb field. As a result of the interaction, the photon disappears completely and an electron-positron pair appears, although the nucleus dose not undergo any change as a result of this interaction [3].

This reaction is only energetically possible provided that the gamma-ray energy exceeds twice the rest mass energy equivalent of the electron (1.022 MeV) [32].

The positron will, after being slowed down to rest, annihilate with the nearest available electron and so release two gamma-ray quanta each of 0.511 MeV as shown in figure (1-4) [34].

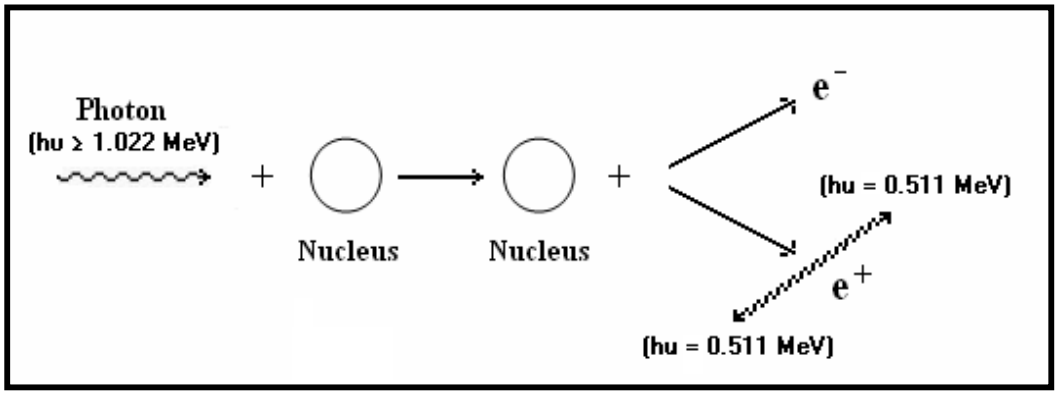

Figure (1-4) Pair production [3]

The probability of pair production is zero for gamma-rays with energy below 1.022 MeV, but it increases rapidly with the increase of energy above this threshold as shown in figure (1-5). So for high energy gamma-rays, pair production is much more probable than either Compton scattering or photoelectric effect. Both the positron and electron will cause ionization by scattering with atomic electrons until they have lost most of their kinetic energy [32,33].

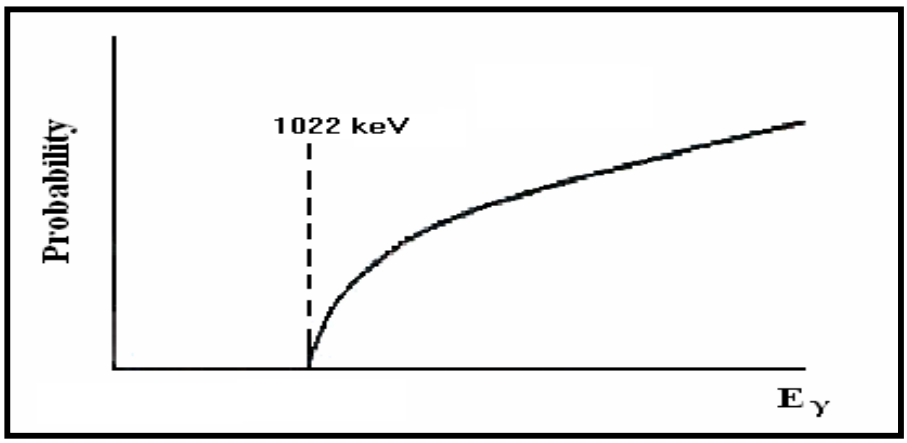

Figure (1-5) Probability of pair production as a function of gamma-ray energy [3]

Thus, the pair production is a process by which a single high-energy gamma-ray may be converted into lower energy gamma-rays and also cause ionization [13].

1-10 Entry of Radionuclides into the Body

Radionuclides may enter the body by inhalation, ingestion, or through intact or wounded skin.

1-10-1 Inhalation

Radioactive gases may enter the body by inhalation. Liquid or solid radioactive compounds inhaled in the form of aerosols have a number of possible fates depending on their physicochemical properties [35].

A part of that inhaled will be deposited in the respiratory tree and the remainder exhaled. The portion deposited in the upper respiratory passages may be expelled by ciliary action into the gastrointestinal tract, and the portion deposited in deeper portions of the lungs may be completely and rapidly absorbed if it is transportable. If it is non-transportable, it will be partially eliminated and partially absorbed at a slow rate. The transportability of inhaled material is related to particle size and perhaps shape, to the individual's dimensions and physiology and to the chemical nature and reactions of the radioactive compound.

1-10-2 Ingestion

When person ingests a radioactive substance, if the material is non-transportable, most of it will traverse the gastrointestinal tract and emerge in the faeces. If the material is transportable, a significant fraction will be absorbed into extracellular fluid, mainly during its passage through the small intestine. Extracellular fluid is the chief vehicle by which transportable materials are transferred from one part of the body to another. A portion of the radionuclides in extracellular fluid will be excreted by kidney, liver, intestine, skin, or lung and the remainder will be deposited in any organs or tissues for which it has a special affinity.

1-10-3 Intact or Wounded Skin

Intact skin provides an effective barrier against the entry of most radioactive materials into the body. Exceptions of practical importance are the absorption through intact skin of tritium oxide as liquid or vapour and iodine as vapour or in solution.

When skin is broken, punctured or abraded, radioactive substances can penetrate to subcutaneous tissues and thence to extracellular fluid, rapidly in the case of transportable compounds, and slowly in the case of non-transportable compounds. Figure (1-6) illustrates the pathways of radionuclides in the body [36].

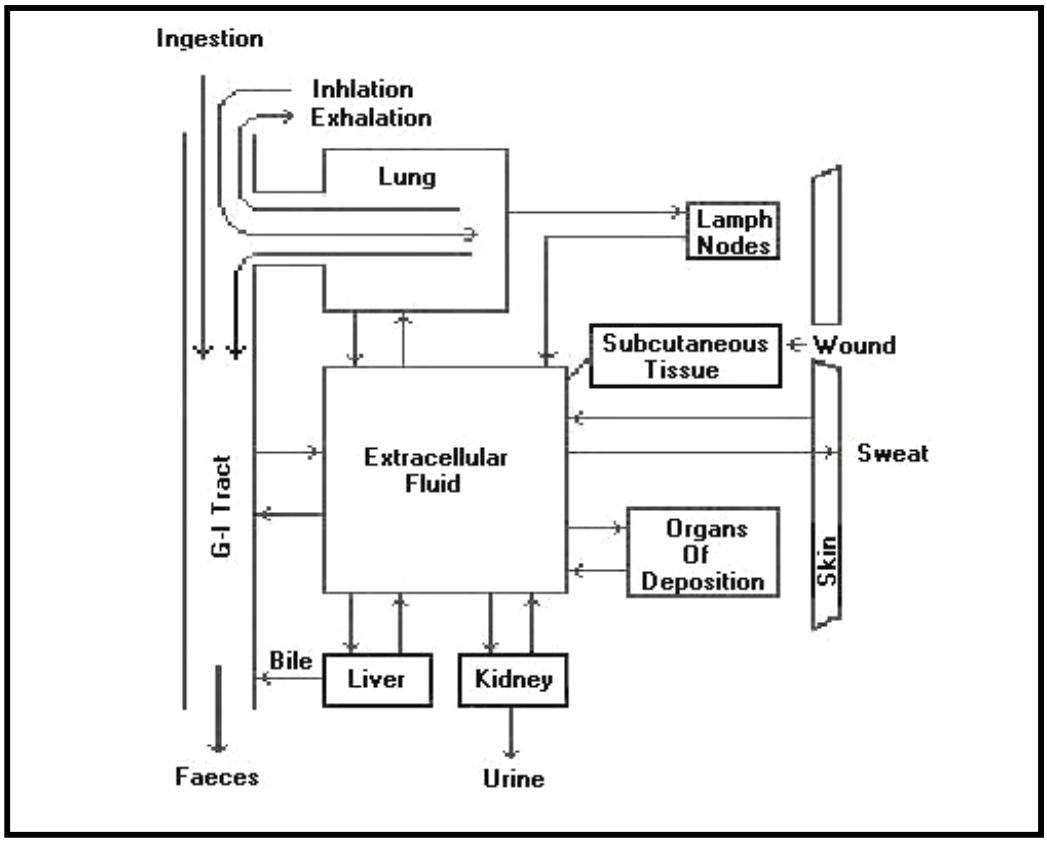

Figure (1-6) Principal pathways of radionuclides in the body [36]

1-11 Behavior of Irradiative Particles in the Body

The solubility of radioactive particles determines the rate that particles move from the site of internalization (lung for inhalation pathway, gastro-intestinal tract for ingestion pathway) into the blood stream and can be stored in the bone, lymph, liver, kidney, or other tissues [37].

The behavior of the irradiative particles in the human body is classified according to their dissolubility as shown in table (1- 5) [38].

Table 1-5 Classification and behavior of irradiative particles in the human body [38]

Dissoluble Particles		**Indissoluble Particles**	
particles behavior	percent	particles behavior	percent
Eliminate outside the body	25%	Expulsion outside the body	25%
Precipitation in the upper respiratory tracts, then travel to the larynx and swallow through 24 hour	50%	Precipitation in the upper respiratory tracts, then travel to the larynx and swallow through 24 hour	50%
Decaying and absorbing in the body liquids	25%	Precipitation in the lower respiratory tracts, then travel to the larynx and swallow through 24 hour	12.5%
		Precipitation in the lower respiratory tracts, then remove by the biological operations of the body	12.5%

1-12 Radioactivity in the Human Beings

In addition to the cosmic and terrestrial sources, all people also have radioactive isotopes inside their bodies from birth [5].

Potassium-40 (K-40) is the primary source of radiation from the human body for two reasons. First, the (K-40) concentration in the body is fairly high (about 2 pCi per gram of soft tissue). Second, when it decays 89 % of the events give rise to the emission of a beta ray with maximum energy of 1.33 MeV. The other 11 % of the decays produce a gamma ray with energy of 1.46 MeV.

Most of (K-40) gamma-rays escape from the body. In other words, the body emits close to 20,000 gamma-rays per minute from (K-40). The vast majority of the beta particles that (K-40) emits do not escape the body. (K-40) content of the body can be obtained from its natural abundance of 0.0117% of potassium which has a specific activity of (30.5 Bq/g). The potassium content of the body is 0.2%, so for a 70 kg man the amount of (K-40) will be about 4.26 kBq [39].

The second important radionuclide is U-238 where, in the regions that have natural activity, its average activity which takes from the body by foods is about (5 Bq) in year, and its activity concentration in the human body is about (0.15 Bq/kg) in the bones and (5×10^{-3} Bq/kg) in the fresh tissues.

The Th-232 radionuclide is concentrated in the bones and increases with age. Its activity concentration is about (4×10^{-2} Bq/kg) in the bones and (3×10^{-4}Bq/kg) in the fresh tissues [17].

There are many other radionuclides in the human body but these are either present at low levels (for example, Ra-226, Bi-214, Po-210, etc.) or they do not emit gamma-rays (for example, H-3 and C-14) [39].

1-13 Sensitivity of Tissues to Radiation

The sensitivity of acceptable tissues to the radiation differs according to the tissue kind, where the slow growth tissues are less susceptible and most resistance to the radiation as follows [40]:

1- Lymphoid cells (most susceptible).
2- Epithelial cells of small intestine.
3- Hematopoietic cells.
4- Germinal cells.
5- Epithelial cells of skin.
6- Connective tissue cells.
7- Cartilage and growing bone cells.
8- Cells of brain and spinal cord.
9- Cells of skeletal muscle and mature bone.

1-14 Biological Elimination Process

The body has defense mechanisms against many types of damage induced by radiation. An isotope which is tightly bound inside the body will essentially decay with physical half-life (time for the radioactivity to decay to half its original value), while a long lived isotope excreted quickly will be removed with a biological half-life (time required for an organ, tissue or the whole body to eliminate one-half of an administered quantity of any substance by regular process of elimination) [2].

For most radioisotopes, the rate of rejection is proportional to the amount of the isotope in the body. A radioisotope is rejected by the body at a rate that depends upon the chemical properties of the elements. All isotopes of the same element are rejected at the same rate, whether they are stable or not as shown in table (1-6) [3].

Table 1-6 Biological half-lives for certain natural isotopes and their localization in the human body [41]

1-15 Review of Previous Studies

There are many studies have been performed to investigate and measure the concentrations of radioactive elements in biological samples (tissues, bone, blood, etc.) by using different techniques, some of these studies are abstracted as follows:

- A study has been presented by Welford & Baird in 1967 to measure the concentrations of uranium in human bones and tissues using CR-39 nuclear track detector to record the tracks of fission fragments, produced in the reaction $^{238}U(n, f)$ by bombarding the samples with neutrons emitted from neutron source. The concentration of uranium in bones and tissues was (0.12 ppm) [42].
- The studies that reviewed by Picer & Strohal in 1968 to determine the concentrations of uranium and thorium in the biological samples, included: bones, blood and urine by using neutron activation analysis. The results of the analysis of uranium and thorium contents for various samples were ($4.1x10^{-10}$gm/kg) and ($2.3x10^{-10}$gm/kg) for grind bones respectively, ($5x10^{-10}$ gm/mol) and ($5x10^{-10}$gm/mol) for blood respectively, ($3.1x10^{-10}$gm/mol) and ($7.4x10^{-11}$gm/mol) for urine respectively. As well as, the authors measured the gamma-ray emission of protactinium-233 and neptunium-239 by using NaI(Tl) scintillation counter [43].

Isotopes	Target	Biological half-life (day)	Isotopes	Target	Biological half-life (day)
U	Kidney	15	Pb	Kidney	531
Th	Bone	73000	Bi	Kidney	6
Pa	Bone	73000	Tl	Kidney	7
Ra	Bone	16400	Ac	Bone	73000
Po	Spleen	60	K	Total Body	58

- The studies have been reviewed by Nozaki, et al in 1970 to determine the concentrations of uranium in the bones of normal Japanese by neutron activation analysis technique using the ^{238}U (n, γ)^{239}U reaction. The concentrations of uranium ranged between (0.1-10 ppb) [44].
- The studies that presented by Hamilton in 1970 to determine the concentrations of uranium in natural blood by using the delayed neutrons detection technique, where the average concentration was (0.84 ppb) [45].
- A study has been attempted by Hamilton in 1972 to determine the concentrations of uranium in human tissues and bones by using the neutron activation analysis technique. The values of concentrations were between (0.16-0.6 ppb) in tissues, and (6.94 ppb) in bones [46].
- The research has been estimated by Koul & Chadderton in 1979 to measure the concentrations of uranium in the whole blood and plasma for healthy people and others injured by leukemia using the track etch technique. The concentrations for healthy people ranged between (0.35-0.6 ppb) in whole blood, and (0.11-0.82 ppb) in plasma. For casualty peoples, the concentrations ranged between (1.5-87 ppb) in whole blood, and (12-180 ppb) in plasma [47].
- The studies that reviewed by Parshad & Nagpaul in 1980 to determine the concentrations of uranium in natural blood of human by using track etch technique, where the concentrations ranged between (0.89-1.79 ppb) [48].
- The studies have been attempted by Igarashi, et al in 1985 to determine the concentrations of the natural uranium in tissues and bones samples for Tokyo city people by thermal neutrons irradiation method using mica detector. The lung tissue had the higher average concentration of uranium which equaled to ($170x10^{-7}$ ppm), and then the tissue of each of bone, heart,

muscle, kidney, liver, cerebrum and spleen which reached ($85x10^{-7}$, $49x10^{-7}$, $43x10^{-7}$, $34x10^{-7}$, $24x10^{-7}$, $15x10^{-7}$, $13x10^{-7}$ ppm) respectively [49].

- The studies that presented by Singh, et al in 1986 to determine the concentrations of uranium in some vertebrate fossil bones that they used the alpha-autoradiographic method by using fission track technique. The concentrations of uranium ranged between (12.07-51.65 ppb) [50].
- The studies that reviewed by Segovia, et al in 1986 to determine the concentrations of uranium in whole blood and plasma samples from a group of radiation exposed workers and another of leukemia patients by using the track etch technique. The mean uranium concentration for the worker population was (0.98 ppb) in whole blood and (1.04 ppb) in plasma. For leukemia patients, the mean uranium concentration was (1.71 ppb) in whole blood and (1.79 ppb) in plasma [51].
- The studies have been reviewed by Reitz in 1995 to know the effect range of space radiation which absorbed by the space pioneers with deadly cancer diseases, and studied the possibilities to reduce this effect by increasing protection shielding thickness inside the spacecraft of between (1-30 cm), and this will still be very small in comparison with atmosphere thickness (~10 m water equivalent) that protect the earth from reaching these rays [52].
- The research has been estimated by Al-Timimi in 2000 to measure the concentrations of depleted uranium in the human blood and tissues by using CR-39 nuclear track detector. The concentrations ranged between (0.041-0.073 ppm) in the blood and (0.039-0.046 ppm) in the tissues [53].

- A study has been presented by Hussein in 2001 to determine the concentrations of depleted uranium in human tissues and bones samples by CR-39 nuclear track detector to record the tracks of fission fragments by using the irradiation method. The concentrations of depleted uranium in the selected samples ranged from (0.11-1.94 ppm) [54].
- A study has been attempted by Ibraheem in 2003 to determine the concentrations of depleted uranium in the injured human tissues by using CR-39 nuclear track detector, where the concentrations obtained ranged between (0.031-0.6 ppm) and the average concentration was (0.044 ppm) [55].
- A study has been presented by Al-Rubaii in 2004 to determine the concentrations of depleted uranium and investigate the radionuclide in biological samples; lung, kidney, stomach and colon collected before and after the 3rd gulf war from cancered human living in Baghdad and neighboring cities by CR-39 nuclear track detector using the natural exposure and irradiation method. For samples collected before war, the mean depleted uranium concentrations measured by natural exposure method for ovary, lung and kidney were (0.084 ppm), (077 ppm) and (0.075 ppm) respectively and the mean concentrations measured by irradiation method for the same samples ware (0.094 ppm), (0.094 ppm) and (0.073 ppm) respectively. While, for samples collected after war, the mean concentration measured by natural exposure were (0.976 ppm), (0.884 ppm) and (0.796 ppm) respectively and the mean concentrations measured by irradiation method were (0.991 ppm), (0.817 ppm) and (0.749 ppm) respectively. In the second part many radionuclides were investigated by using NaI(Tl) detector. These nuclides included; K-40 having the highest specific activity, P-234 and U-235 giving evidence about depleted uranium, presence of Cs-137 and Cs-134

industrial radionuclides, Bi-214 short live decay product of Rn-222, Ac-228, Tl-208 and Pb-212 [30].

1-16 Aim of Present Study

The purpose of the present work is to detect and measure the specific activities of radionuclides in certain samples of cancerous tissues that excised from Baghdad city patients by using spectral analysis technique for gamma-ray with NaI(Tl) detector.

2-1 Introduction

The biological effects of radiation are terms in their effect on the living cells. These effects depend on the type of cell, the amount and type of radiation. Consequently, biological effects of radiation on living cells may result in three outcomes: (1) injured or damaged cells repair themselves, resulting in no residual damage; (2) cells die, much like millions of body cells do every day, being replaced through normal biological processes; or (3) cells incorrectly repair themselves resulting in a biophysical change.

High doses can kill so many cells that tissues and organs are damaged immediately. This in turn may cause a rapid whole body response often called acute radiation syndrome. The higher radiation dose, the sooner effects of radiation will appear, and the higher probability of death. This syndrome was observed in many atomic bomb survivors in 1945 and emergency workers responding to the 1986 Chernobyl nuclear power plant accident [56].

All people are chronically exposed to background levels of radiation present in the environment. Many people also receive additional chronic exposures or relatively small acute exposures. For populations receiving such exposures, the primary concern is that radiation could increase the risk of cancers or harmful genetic effects. The probability of a radiation-caused cancer or genetic effect is related to the total amount of radiation accumulated by an individual. Based on current scientific evidence, any exposure to radiation can be harmful (or can increase the risk of cancer); however, at very low exposures, the estimated increases in risk are very small. For this reason, cancer rates in populations receiving very low doses of radiation may not show increases over the rates for unexposed populations [57].

2-2 Exposure and Risk

Radiation and radiation emitters (radionuclides) can expose the whole body (direct exposure) or expose tissues inside the body when inhaled or ingested.

The health effects of alpha particles depend heavily upon how exposure takes place. External exposure is of far less concern than internal exposure, because alpha particles lack the energy to penetrate the outer dead layer of skin. However, if alpha emitters have been inhaled, ingested (swallowed) or absorbed into the blood stream, sensitive living tissue can be exposed to alpha radiation. The result of biological damage increases the risk of cancer; in particular, alpha radiation is known to cause lung cancer in humans when alpha emitters are inhaled [2].

External exposure to beta particles is a hazard, because emissions from strong sources can redden or even burn the skin. However, emissions from inhaled or ingested beta particle emitters are the greatest concern. Because they are much smaller and have less charge than alpha particles, beta particles generally travel further into tissues. As a result, the cellular damage is more dispersed [14].

Both external and internal exposure to gamma-rays or x-rays is of concern. Gamma-rays can travel much farther than alpha or beta particles and have enough energy to pass entirely through the body, potentially exposing all organs [2].

The types of effects and their probability of occurrence can depend on whether the exposure occurs over a large part of a person's lifespan (chronic) or during a very short portion of the lifespan (acute) [57].

2-2-1 Chronic Exposure

Chronic exposure is continuous or intermittent exposure to low levels of radiation over a long period of time. Chronic exposure is considered to produce only effects that can be observed some time following initial exposure [57].

2-2-2 Acute Exposure

Acute exposure is exposure to a large, single dose of radiation, or a series of doses, for a short period of time. Large acute doses can result from accidental or emergency exposures or from special medical procedures (radiation therapy) [57].

2-3 Interaction of Radiation with Cells

Ionizing radiation affects people by depositing energy in body tissue, which can cause changes in the chemical balance of cell [57].

Radiation is thus seen to produce biological effect by two mechanisms, directly by dissociating molecules following their excitation and ionization; and indirectly by the production of free radicals and hydrogen peroxide in the water of the body fluids [1].

2-3-1 Direct Action

The complex molecules making up living organisms are composed of long strands of atoms forming proteins, carbohydrates and fats. They are held together by chemical bonds involving shared electrons. If the ionizing radiation displaces one of the electrons in a chemical bond, it can cause the chain of atoms to break apart, splitting the long molecule into fragments, or

changing its shape by elongation. This is an ungluing of the complex chemical bonds so carefully structured to support and perpetuate life.

The gradual breakdown of these molecular bonds destroys the templates used by the body to make DNA and RNA (the information-carrying molecules in the cell) or causes abnormal cell division. The gradual natural breakdown of DNA and RNA is probably the cellular phenomenon associated with what we know as ageing. It occurs gradually over the years with exposure to natural background radiation from the radioactive substances which have been a part of the earth for all known ages [58, 59].

2-3-2 Indirect Action

Most of the body is water, and most of the direct action of radiation therefore is in water. Ionization of water molecules cause them to split by a process called radiolysis

$$Radiation + H_2O = H_2O^+ + e^- \qquad \ldots (2\text{-}1)$$

while the electron is picked up by the natural molecule

$$H_2O + e^- = H_2O^- \qquad \ldots (2\text{-}2)$$

The net products of radiolysis of water molecules are the formation of highly reactive free radicals (a free radical is fragment of a compound or an element that contains an unpaired electron) as shown in figure (2-1a) [14]

$$H_2O^+ = H^+ + OH^{\cdot} \qquad \ldots (2\text{-}3)$$

$$H_2O^- = H^{\cdot} + OH^- \qquad \ldots (2\text{-}4)$$

The ions H^+ and OH^- are of no consequence, since all body fluids already contain significant concentrations of both these ions. The free radicals $H^{\cdot}$ and $OH^{\cdot}$ may combine with like radicals to form gaseous hydrogen and hydrogen peroxide respectively [60]

$$H^{\cdot} + H^{\cdot} = H_2 \qquad \ldots (2\text{-}5)$$

$$OH^{\cdot} + OH^{\cdot} = H_2O_2 \qquad \ldots (2\text{-}6)$$

The hydrogen peroxide, being a relatively stable compound, persists long enough to diffuse to points quite remote from their point of origin. The hydrogen peroxide, which is a very powerful oxidizing agent, can thus affect molecules or cells that did not suffer radiation damage directly.

The hydrogen radical may combine with oxygen to form the hydroperoxyl radical which is not as reactive.

$$H^{\cdot} + O_2 = HO_2^{\cdot} \qquad \ldots (2\text{-}7)$$

This greater stability allows the hydroperoxyl radical to combine with free hydrogen radical to form hydrogen peroxide, thereby further enhancing the toxicity of the radiation [1].

The free radical $OH^{\cdot}$ may combine with nearby organic molecule R-H to form organic free radical ($R^{\cdot}$)

$$R\text{-}H + OH^{\cdot} = R^{\cdot} + H_2O \qquad \ldots (2\text{-}8)$$

Organic free radical ($R^{\cdot}$) has high reactive ability to combine with other molecules in cell and inactivate it.

Any two nearby organic radicals may decay, and then making an additional chemical links called cross links. These links will decrease the viscosity of the medium. By increasing these links the radiated medium gradually converts to gelatinous medium [39]. Figure (2-1) shows the radiation effects on (a) Cells; (b) Chromosome; and (c) DNA molecule [59].

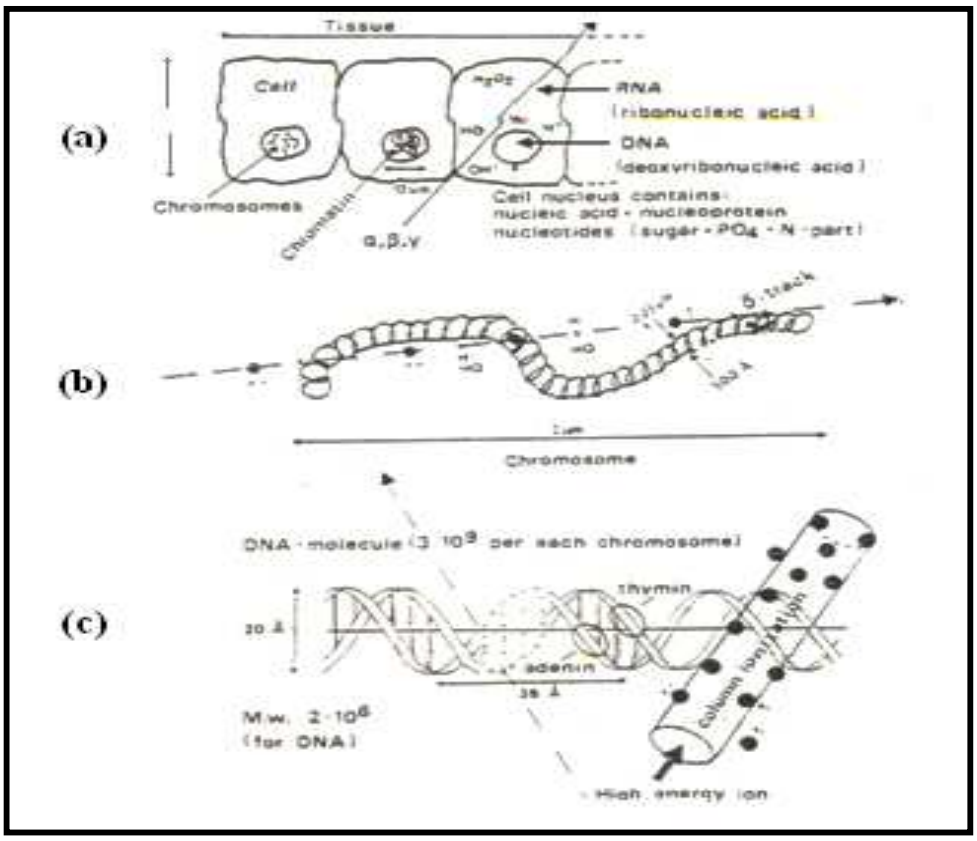

Figure (2-1) Effects of radiation in (a) Cells, (b) Chromosome, and (c) DNA molecule [59]

2-4 Biological Effects of Radiation

The biological effects of radiation divide into two groups: somatic effects, which affect the irradiated person and genetic or hereditary effects, which affect the descendants of the irradiated individual. Genetic effects are those related to the transmission of harmful hereditary information from one generation to the next [3].

The effects are also divided into two categories in terms of the period between irradiation and appearance: short and long term effects.

2-4-1 Long-term Effects

Long-term effects may appear as a result of a chronic low-level exposure over a long period. These include genetic effects and other effects such as cancer, precancerous lesions, benign tumors, cataracts, skin changes, and congenital defects [61].

Evidence of injury from low or moderate doses of radiation may not show up for months or even years. For leukemia, the minimum time period between the radiation exposure and the appearance of disease (latency period) is 2 years. For solid tumors, the latency period is more than 5 years [57].

2-4-2 Short-term Effects

Short-term effects may appear as a result of an acute irradiation. These include both immediate and delayed effects. High levels of acute radiation exposure can result in death within a few hours, days or weeks [61].

An acute exposure, if large enough, it can cause different health effects depending on the amount and the time to onset of exposure as shown in table (2-1) [2].

2-5 Radiation Induced Cancer

A long-term somatic effect is the damage of cells that are continually reproducing. These cells are the most sensitive to radiation because any changes made in the parent cell's chromosome structure will be transmitted to its daughters [60].

Table 2-1 Health effects due to different amounts of acute exposures [2]

Exposure (rem)	Health Effects	Time to Onset
5-10	changes in blood chemistry	hours
٥٠	nausea	
٥٥	fatigue	2-3 weeks
٧٠	vomiting	
٧٥	hair loss	
٩٠	diarrhea	within 2 months
١٠٠	hemorrhage	
٤٠٠	death from fatal doses	
١٠٠٠	destruction of intestinal lining	1-2 weeks
	internal bleeding	
	death	
٢٠٠٠	damage to central nervous system	minutes
	loss of consciousness	
	death	hours to days

Also, radiation can affect the delicate chemistry of the cell causing changes in the rate of cell division or even the destruction of that cell. An event which causes a somatic cell to behave in this way is called a mutation.

The mutations in the reproductive cells translate the damage effects into future generations. However, a mutation in a somatic cell has consequences only for the individual.

If the mutation in the somatic cell increases the rate of its reproduction in an uncontrolled manner, then the number of daughter cells may increase rapidly in that area. In this case, daughter cells are often divided before reaching their mature state. The result then is an ever increasing number of

cells that have no beneficial function to the body, yet are absorbing body nutrition at an increasing rate. The tissue could now be called a tumor [62].

If the cells remain in their place of origin and do not directly invade surrounding tissues, the tumor is said to be benign. If the tumor invades neighboring tissue and causes distant secondary growths (called metastasis), it is known as malignant or cancer. Whether it is fatal or not depends on the tissue in which it is located, how rapidly it grows, and how soon it is detected [63].

2-6 Gamma-ray Detectors

All nuclear radiation detection is based on the interaction of radiation with matter. The detection methods are in general based on the process of excitation or ionization of atoms in the sensitive volume of the detector by the passage of charged particles [4].

The types of gamma detectors of greatest interest for safeguard work are the gas-filled tube, the sodium iodide (NaI) scintillation and semiconductor detectors [16]. The methods of gamma-ray interaction with matter were discussed in detail in chapter one. Here we will discuss the NaI(Tl) detector used in some detail.

2-7 Scintillation Counter

The scintillation counter is comprised of two main components: firstly, a scintillator that absorbs incident radiation and converts the energy deposited by ionization into a fast pulse of light and, secondly, a photomultiplier. This second component converts the light pulse into a pulse

of electrons and also amplifies the electron pulse by a very large factor by means of a sequence of secondary emission stage [26].

2-8 Scintillation Mechanism in Inorganic Crystals with Activators

When an ionizing particle loses its energy in the scintillator it excites electrons from the valence band across the forbidden gap to the conduction band. These electrons rapidly return to the vacancies left in the valence band and in so doing the cause emissions of quanta of light [3].

If the scintillator is a crystal of pure sodium iodide, the emission of quanta of light is in the ultra–violet region of the spectrum as shown in figure (2-2a). Light of this wavelength, around 200 nm, would be strongly absorbed by the sodium iodide it self since the quantum energy matches the band gap energy. The emitted light can therefor be absorbed by raising an electron across the gap and, since radiationless transitions are also likely to occur, returning the electron to the valence band without emission of radiation, the number of quanta escaping from the scintillator will only be small, so a crystal of pure sodium iodide is not suitable for use as a scintillator. It is therefore necessary to create quanta of visible light with minimal losses [26].

To achieve the production of visible light, a few percent of thallium is included in the solution from which the crystal is grown so that thallium impurities occur within the crystal [33].

The purpose of these impurities is to create intermediate energy levels within the forbidden gap. Electrons returning from the conduction band can now break their return at these intermediate energy levels and so emit quanta

of light of lower energy and longer wavelength, as shown in figure (2-2b) [26].

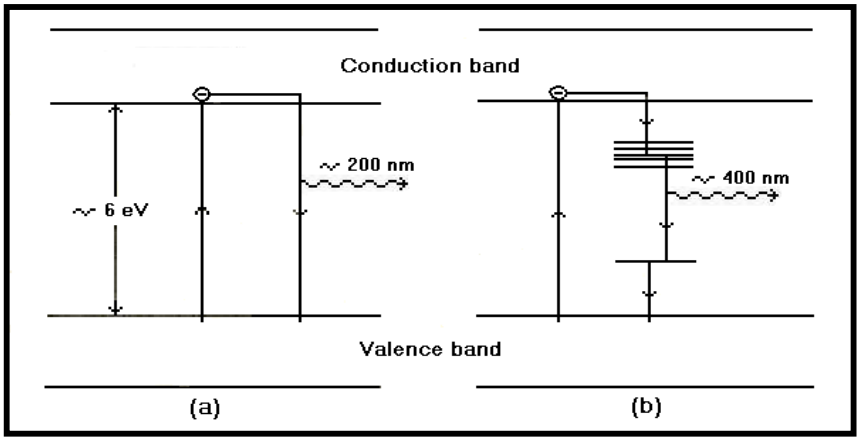

Figure (2-2) Electron energy levels in (a) Pure and (b) Thallium doped sodium iodide [26]

2-9 Mechanism of the Scintillation Counter

When a gamma ray interacts with scintillation crystal, light is released by the process previously described.

The photons of light are transmitted through the transparent crystal and are directed upon the photosensitive cathode (photocathode) of a photomultiplier tube. This light will eject one or more electrons by the well-known photoelectric effect. These electrons will be attracted to the first of a series of dynodes, each of which is maintained at a successively higher positive potential by a voltage source and a potential divider [64].

Each dynode surface consists of a carefully prepared composite layer of cesium and antimony, or other metal combination. These surfaces will emit several electrons when struck with a single electron of sufficient energy.

The dynodes are so shaped and arranged that each secondary electron will move toward the next stage, accelerated by the higher positive potential.

Secondary electron multiplication will take place at each of the 10-12 dynodes that are incorporated in the usual photomultiplier tube. The secondary electrons emitted by the last dynode will be attracted to an anode, connected to the positive voltage supply through a series resistance as shown in figure (2-3) [65].

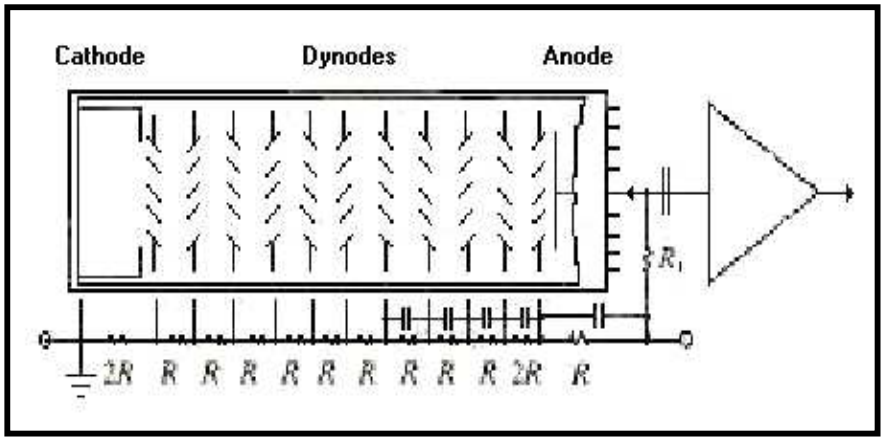

Figure (2-3) Photomultiplier tube with possible resistance chain [26]

The size of the signal at the anode is proportional to the energy dissipated in the detector by the incident radiation [33].

2-10 General Characteristics of NaI(Tl)

The photoelectric effect is quite marked in NaI and is mainly duo to the iodine which has a Z of 53. Higher atomic number atoms have a large photoelectric cross-section than low atomic number atoms [26].

The high density of the scintillator permits the total absorption of many radiations within the crystal. With total absorption, the light output (LO) may be quite accurately proportional to the energy of the incident radiation, and the device may be used as an energy spectrometer [66]. LO is the coefficient of conversion of ionizing radiation into light energy. The LO

of NaI(Tl) is taken to be 100%. LO of other scintillators is determined relatively to that of NaI(Tl) percentage [19].

NaI(Tl) has short decay time for the emission of light so that fast counting is possible and negligible after-glow. It is also so hygroscopic which means it is easily damaged when exposed to moisture in air at humidity levels [3].

NaI(Tl) is used with maximum efficiency region of photomultiplier but a limited energy resolution, the possibility of large-size crystal production, their low prices compared with other scintillation materials and it is therefore suitable in field instrumentation [66]. The general characteristics of NaI(Tl) are shown in table (2-2).

Table 2-2 General characteristics of NaI(Tl) [26,33]

Effective atomic number	٥٠
Emission maximum, [nm]	413
LO, % relative to NaI(Tl)	100
LO, [photons/MeV]	$(4.1\text{-}5.0) \times 10^4$
Decay time, [ns]	230
Density, [g/cm^3]	3.67
Melting point, [^oC]	651
Hardness, [Mho]	٢
Refractive index at I max	1.85
Hygroscopic	Yes

3-1 Introduction

Nuclear spectroscopy is the analysis of radionuclide radiation by measuring the energy distribution of the source. A spectrometer is an instrument that separates the output pulses from a detector, such as a scintillation detector, according to size. Since the size distribution is proportional to the energy of the detected radiation, the output of the spectrometer provides detailed information that is useful in identifying unknown radioisotopes and counting one isotope in the presence of another [1].

This chapter shows the apparatus and experimental details for gamma spectroscopic method adopted in the present work using the NaI(Tl) scintillation detector for detection and measurement of the specific activity of the radioactive elements.

Our present investigations are based on the study of 24 abnormal samples and 8 normal samples for comparing the results. These samples include four types of fresh tissues (kidney, colon, breast, and uterus) that may be obtained with great mass. Both normal and abnormal samples are excised from Baghdad city patients. Some information about these samples had been collected such as age and sex as shown in table (3-1).

3-2 Collection of Samples

All samples of tissues (kidney, colon, breast, and uterus) had been collected from the histopathology department for education laboratories in Madenat Al-Ttib and specialized surgical hospital.

Table 3-1 Normal and abnormal tissues samples that excised from Baghdad city people with their sex and age

Sample		Sample No.	Sex	Age (year)
Kidney	Abnormal	1	female	34
		2	male	61
		3	male	67
		4	male	50
		5	female	59
		6	male	45
	Normal	7	male	23
		8	male	49
Colon	Abnormal	9	male	53
		10	male	32
		11	female	45
		12	male	63
		13	female	69
		14	male	55
	Normal	15	female	57
		16	male	40
Breast	Abnormal	17	female	35
		18	=	48
		19	=	29
		20	=	72
		21	=	65
		22	=	51
	Normal	23	=	47
		24	=	54
Uterus	Abnormal	25	female	56
		26	=	74
		27	=	46
		28	=	50
		29	=	33
		30	=	68
	Normal	31	=	52
		32	=	66

3-3 Apparatus

I. Gamma-ray spectrometry system

It is a fully integrated data acquisition and computation system comprising the following:

- A sodium iodide activated with thallium 2"×2" NaI(Tl) scintillation detector used for gamma-rays detection due to its high efficiency for detecting this ray.
- A high power supply used to prepare high voltage to the detector through an amplifier with a range from (0-1500 V), and must be increased slowly to avoid damaging the detector.
- A personal computer used as multi-channel analyzer (MCA) by using the program Multichannel Pulse Amplitude Analysis (Type: Cassy; Version: 1.11, 1997) to store the number of pulses detected with a given size (voltage) into a memory channel, the contents of which can later be analyzed to find the information about gamma-rays detected.
- A preamplifier and amplifier are usually built into (MCA) shape and amplify the pulse by a factor of several hundred, so they can be analyzed more accurately.
- A thick shield (10 cm) of lead surrounded the detector crystal to reduce the radiation that coming from the background. This element was chosen due to its high atomic number (82) and density ($11 g/cm^3$) [33]. The schematic diagram for gamma spectroscopic system that is applied in the present work is shown in figure (3-1).

II. Balance

Electric balance (Type: Sartorius; Max. reading: 1500g) is used to weigh the fresh tissues before they are examined by NaI(Tl) detector.

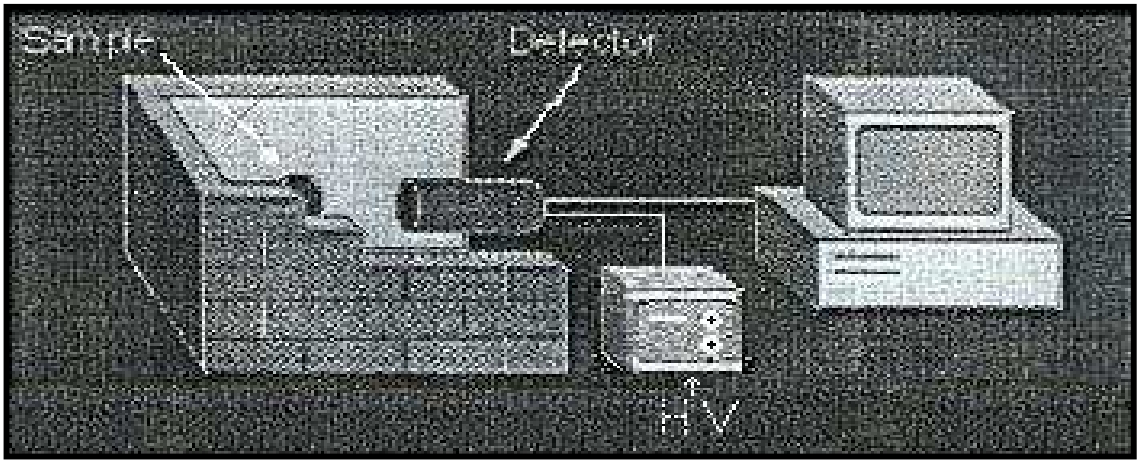

Figure (3-1) Schematic diagram for gamma spectroscopic system with NaI(Tl) detector

3-4 System Calibration

Before any spectroscopic measurement, the detector and the related electronics are arranged for the best operating stability as follows:

3-4-1 Operating Voltage

The best operating voltage for the detector was achieved by finding the plateau region for it. Plateau region is the region, where the detector is operating at maximum sensitivity.

The operating voltage of NaI(Tl) detector is about one-third the distance from the knee of the curve of count rate versus voltage [67].

In the present work, the standard radioactive source Cs-137 was used to find the relation between the count rate and the applied voltage to determine the plateau region. The applied operating voltage is found to be 530 V as shown in figure (3-2).

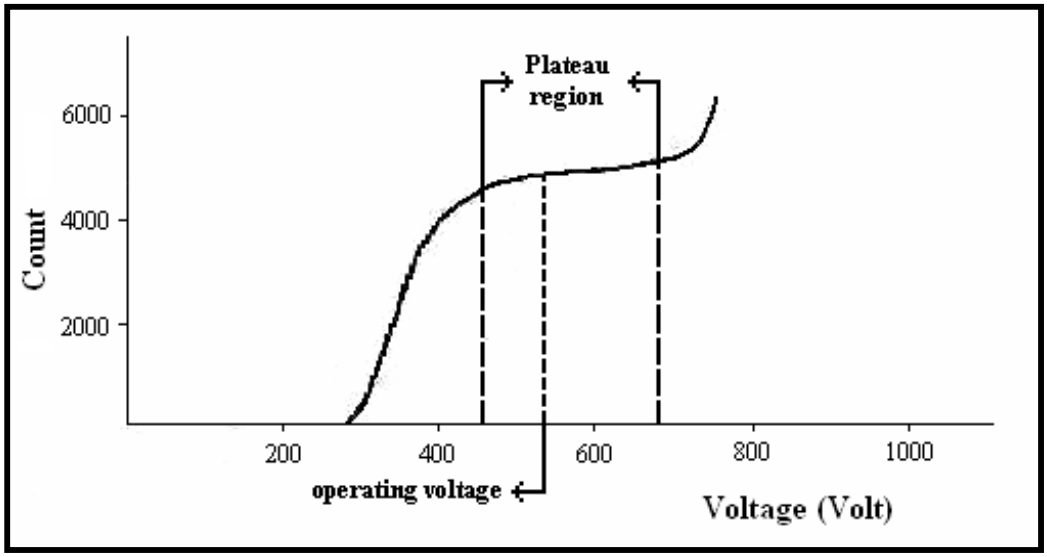

Figure (3-2) Plateau region and operating voltage for NaI(Tl) detector

3-4-2 Energy Resolution

Energy resolution (R) shows the ability of a detector to distinguish gamma sources with slightly different energies. The R of the detector is defined as the full width at half maximum (FWHM) divided by the location of the peak centroid (n) [33].

A formal definition of FWHM and peak centroid (n) are shown in figure (3-3), where R is expressed as percentage [67]

$$R = \frac{FWHM}{n} \times 100\% \qquad \ldots (3\text{-}1)$$

In the present work, the resolution of the detector is found about 8.7% measured by using Cs-137 (662 keV) source.

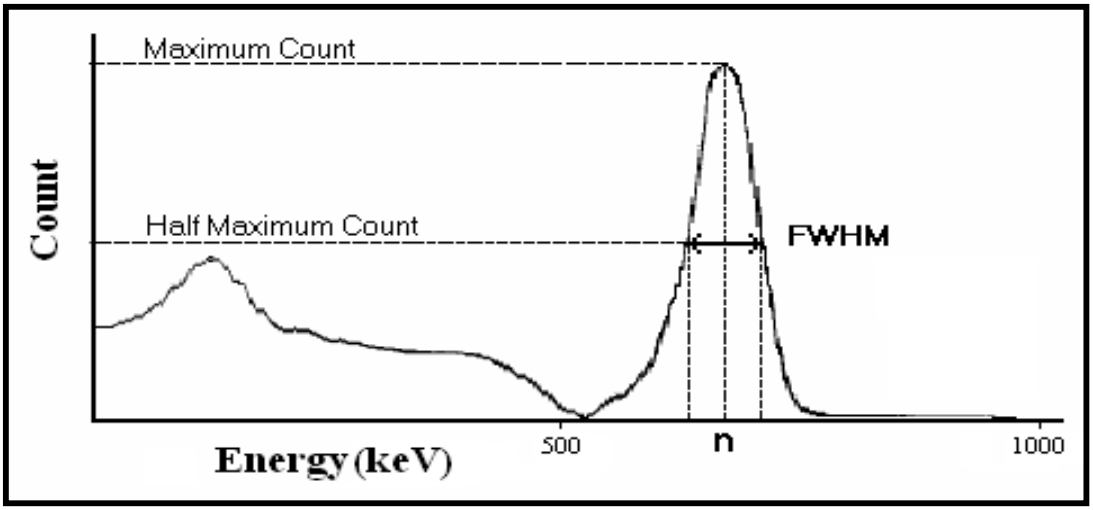

Figure (3-3) Formal definition of (FWHM) and peak centroid (n) in gamma-ray spectrum of Cs-137 by using NaI(Tl) detector

3-4-3 Energy Calibration

An essential requirement for the measurement of gamma emitters is the exact identity of photopeaks present in a spectrum produced by the detector system [27].

The energy calibration of NaI(Tl) detector system is found by counting some standard radioactive sources with known energies. These sources should be counted long enough period to produce well-defined photopeaks and then calibrated according to their energies [10].

In the present work, three standard radioactive sources including: Cs-137, Co-60 and Na-22 with a period 900s used for system calibration. Gamma-ray spectra for these sources are shown in figures (3-4), (3-5) and (3-6) respectively.

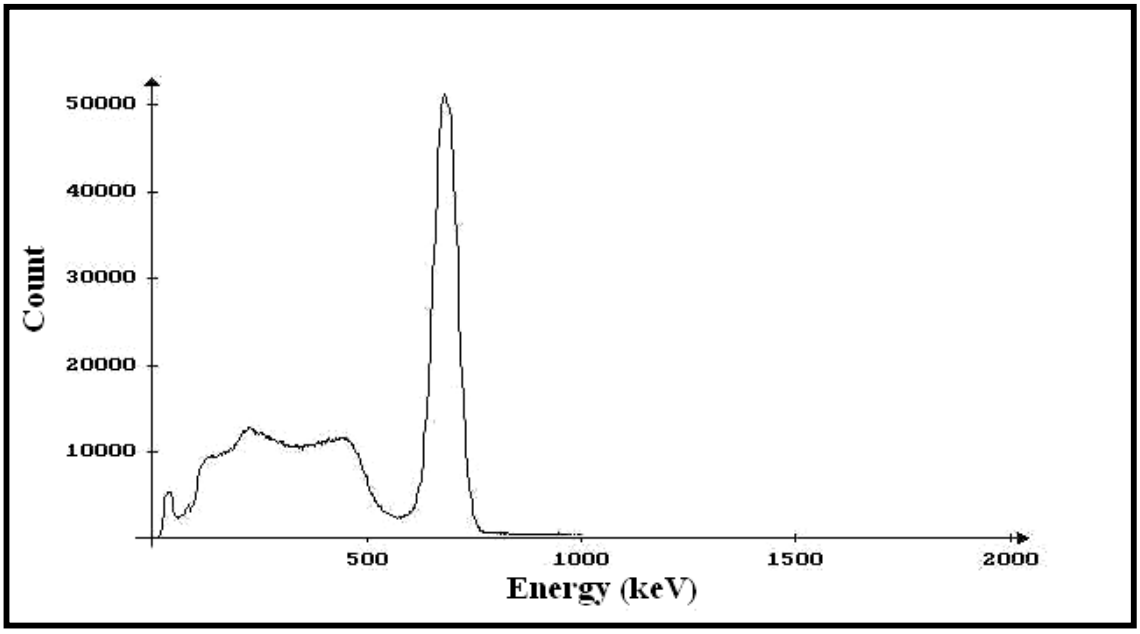

Figure (3-4) Gamma-ray spectrum for Cs-137 source by using NaI(Tl) detector

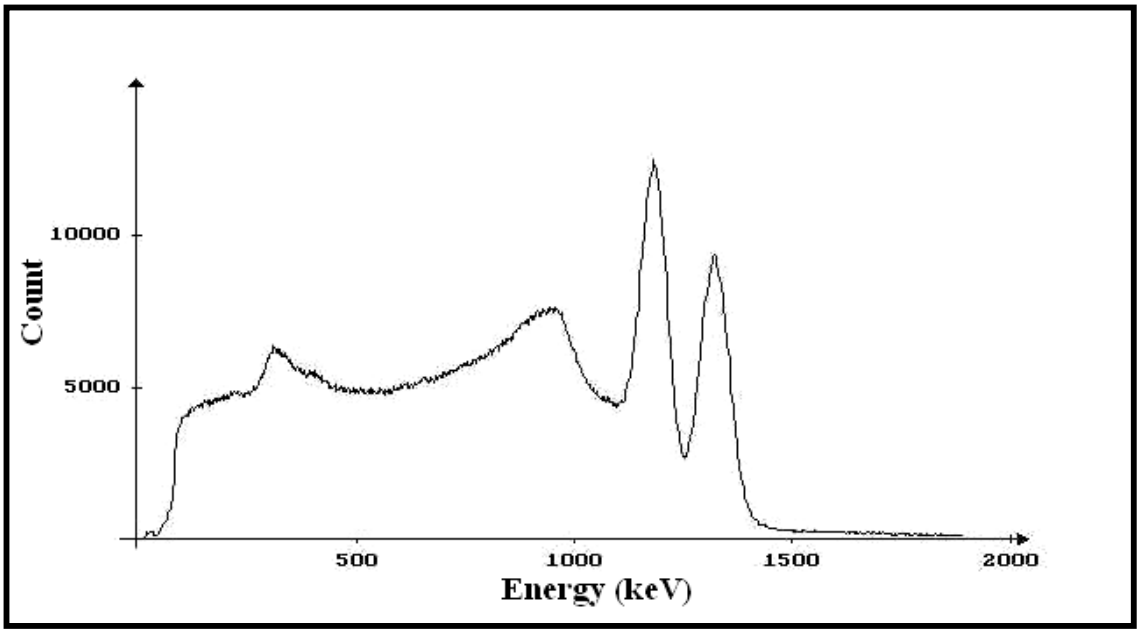

Figure (3-5) Gamma-ray spectrum for Co-60 source by using NaI(Tl) detector

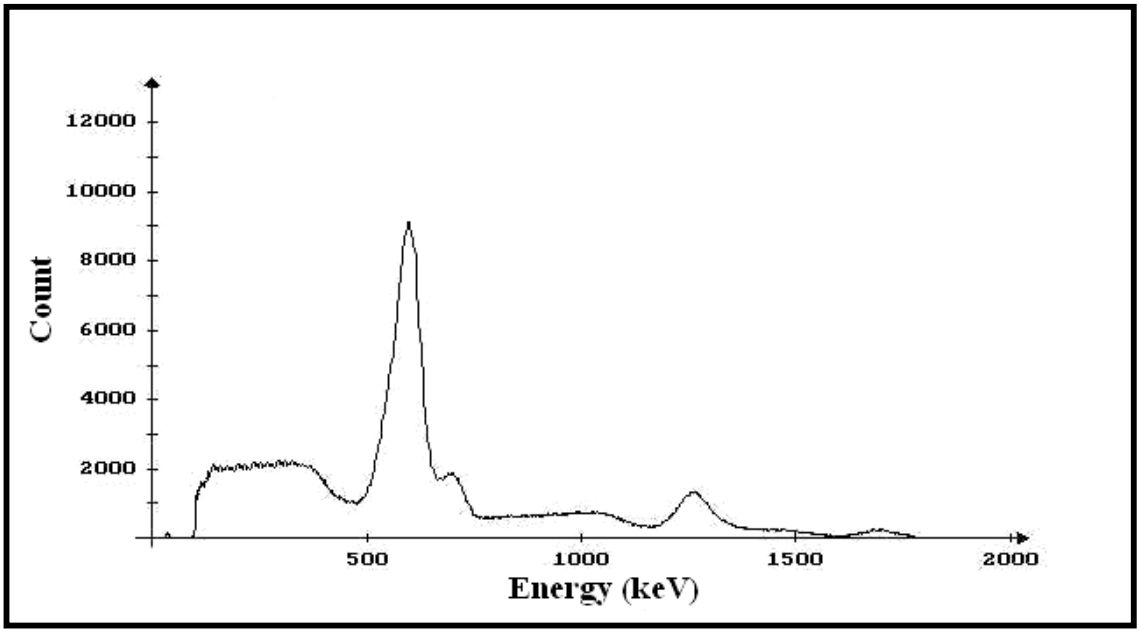

Figure (3-6) Gamma-ray spectrum for Na-22 source by using NaI(Tl) detector

3-4-4 Efficiency Calibration

The efficiency of scintillation detector is define as the ratio of the number of pulses (counts) recorded by the detector to the number of radiation quanta (photons) emitted by the source [67]

$$\textit{Efficiency (\%)} = \frac{cps}{dps} \times 100\% \qquad \ldots (3\text{-}2)$$

where

cps : count per second

dps : disintegration per second (activity of source in measuring time)

For this purpose, spectra of standard radioactive sources with known energies and activities are accumulated for long enough time by the detector to produce well-defined photopeaks.

To correct the activities of those sources at the date of measurement, the nuclear disintegration equation is used as follows [1]

$$dps = dps_o\, e^{-\lambda t} = dps_o\, e^{-0.693 t/t_{1/2}} \qquad \ldots (3\text{-}3)$$

where

dps_o: initial activity

λ : decay constant

$t_{1/2}$: half-life

In the present work, the Eu-152 source (0.122, 0.245, 0.344, 0.444, 0.779, 0.964, 1.085, 1.112, 1.408 MeV) is used with a collection period 900s to find the efficiency curve for NaI(Tl) detector as shown in figure (3-7).

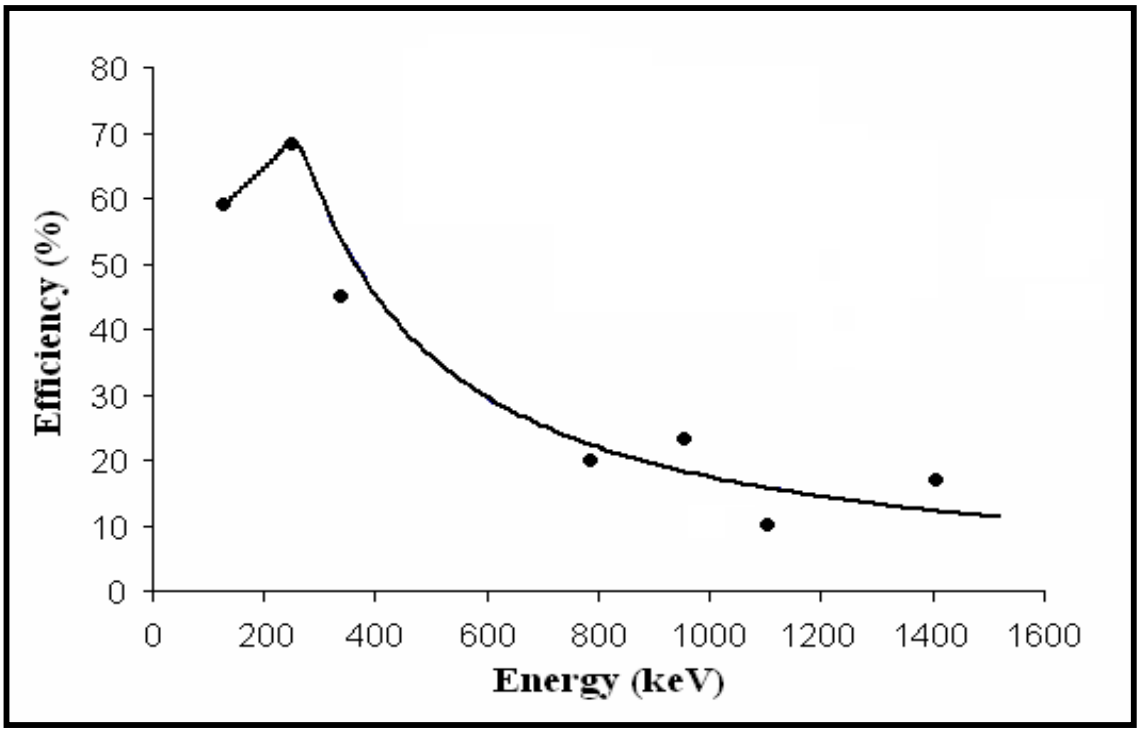

Figure (3-7) Efficiency curve for NaI(Tl) detector

3-5 Methods and Measurements

3-5-1 Samples Preparation

Each sample of tissue (kidney, colon, breast or uterus) taken with 250g in weight, washed with distilled water to remove the formalin liquid (conservator substance), cut, put in the Marenilli Beaker uniformly and then examined with NaI(Tl) detector for a period of 4 hours (14400s) and 530 V as an operating voltage.

3-5-2 Background Measurement

The environmental gamma emitters at the laboratory site had been determined with empty Marenilli Beaker put on the NaI(Tl) detector crystal and then counted the energy spectrum of gamma-rays with same period and operating voltage which were used for the determination of energy spectra of gamma-rays for the biological samples. The background spectrum is shown in figure (3-8).

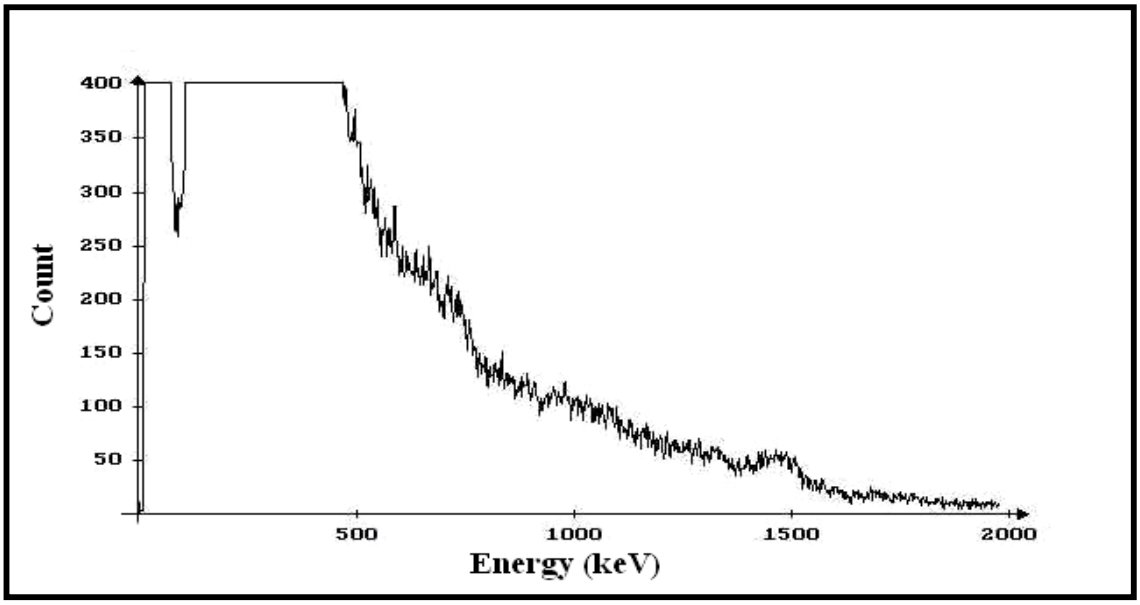

Figure (3-8) Background spectrum using NaI(Tl) detector

3-5-3 Specific Activity Measurement

The specific activity is defined as the concentration of radioactivity or the relationship between the mass of radioactive material and the activity. It is the number of Becquerels (or Curies) per unit mass or volume [1].

The specific activity for each detected radionuclide had been calculated using the following equation:

$$\textbf{Specific Activity} = \frac{\textbf{Net area under the peak}}{W \times I_{\gamma} \times Eff. \times T} \qquad \ldots (3\text{-}4)$$

where,

T : Measuring time (sec.)

Eff.: Percentage efficiency

I_{γ} : Percentage intensity of gamma-ray

W : Weight of the sample (kg)

Net area under the peak: Total counts – Background

4-1 Introduction

This chapter shows gamma-ray spectra for normal and abnormal tissues samples which had been obtained with gamma-ray spectroscopy (NaI(Tl) detector). Also, it shows the radionuclides and their specific activities which had been detected in these samples, then discusses the results and gives the conclusions.

4-2 Results and Discussion

Gamma-ray spectrum for each tissue sample had been calibrated with respect to the spectra of standard radioactive sources (Cs-137, Co-60, and Na-22) as shown in figures (3-4, 3-5 and 3-6) respectively.

Each spectrum of tissue had been amplified for several times to illustrate the peaks on it, where the first part of spectrum is negligible because it represents backscattered region (noise region) for gamma-ray in the spectrum which cannot exceed 0.255 MeV according to equation (1-4).

The radionuclides had been detected depending on the energies that subtend the peaks in each spectrum. The specific activity for each observed radionuclide had been measured by using the equation (3-4). It should be mentioned that the background spectrum was taken into consideration by subtracting it from all the collected spectra for tissues samples. The sample number and its information are shown in table (3-1).

4-2-1 Kidney Samples

Gamma-ray spectra for abnormal and normal samples of kidney are shown in figures (4-1 to 4-6) and (4-7 and 4-8) respectively. The specific activities for each detected radionuclide in both samples are shown in tables (4-1) and (4-2) respectively.

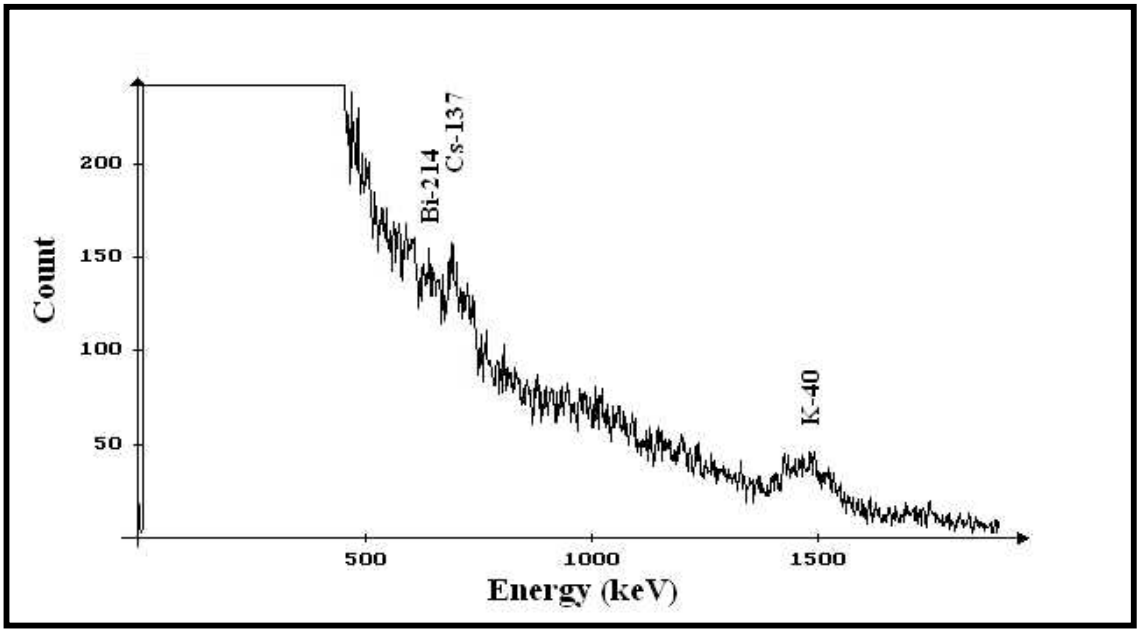

Figure (4-1) Gamma-ray spectrum for abnormal sample of kidney No. 1

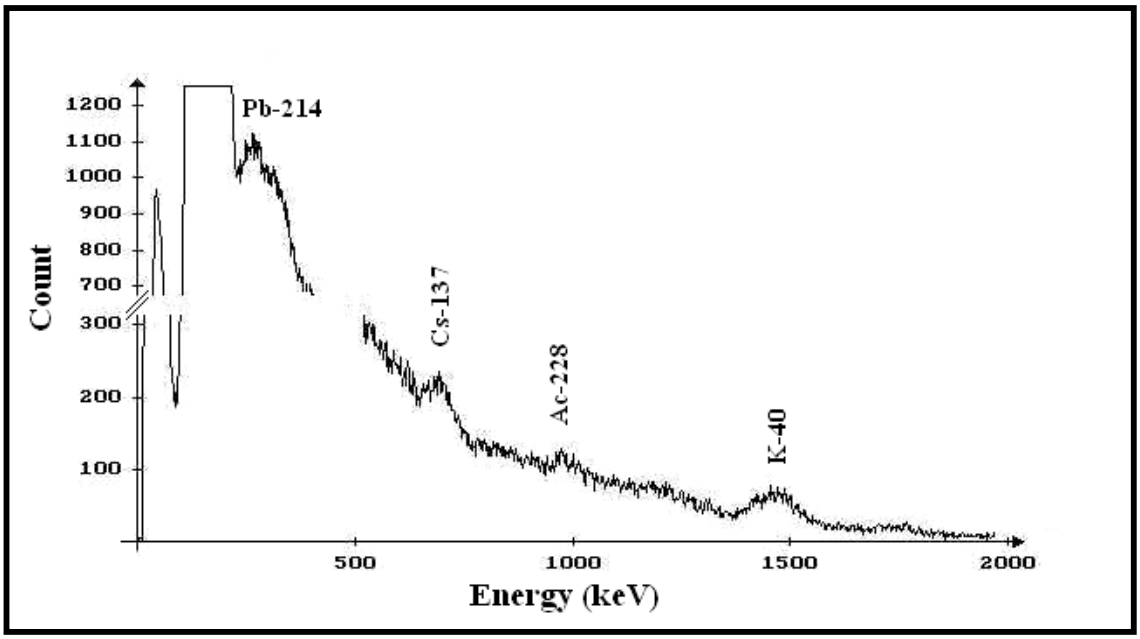

Figure (4-2) Gamma-ray spectrum for abnormal sample of kidney No. 2

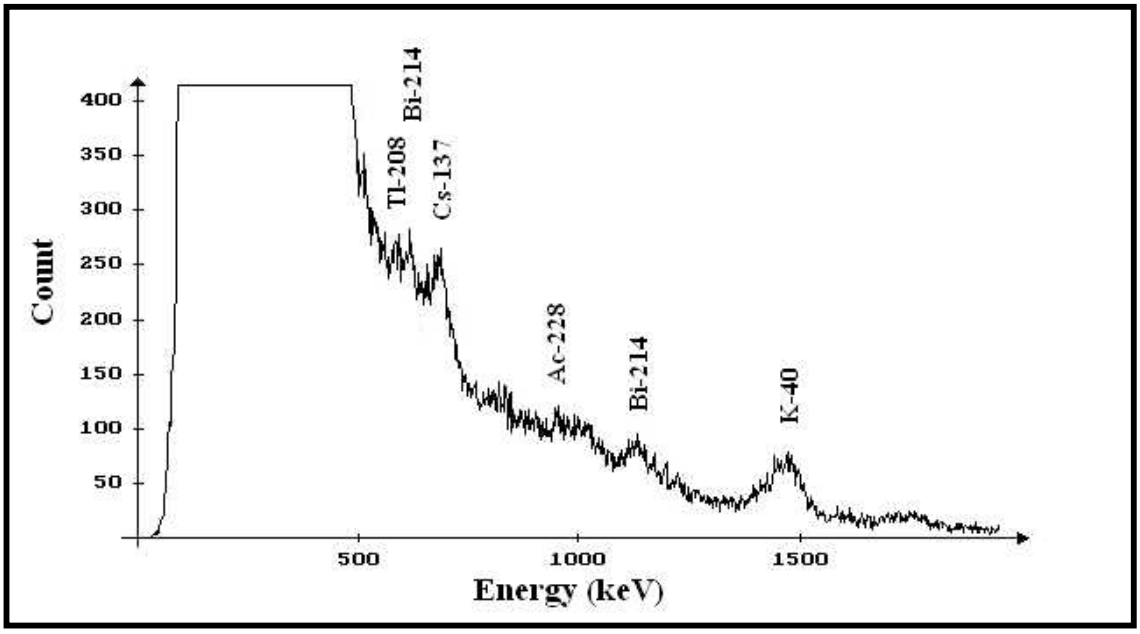

Figure (4-3) Gamma-ray spectrum for abnormal sample of kidney No. 3

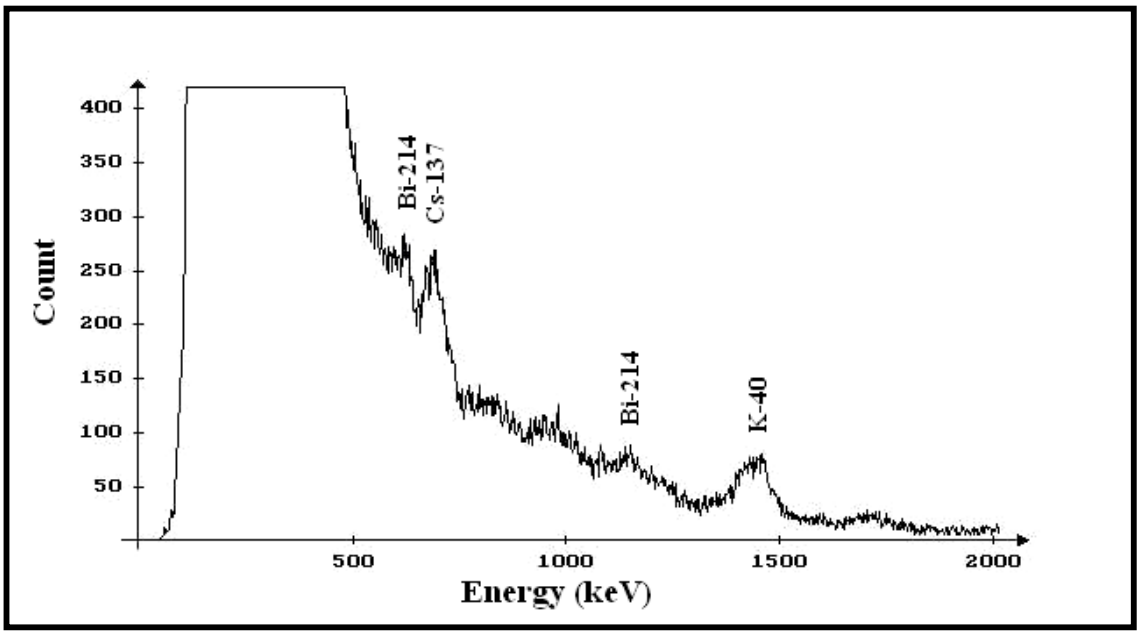

Figure (4-4) Gamma-ray spectrum for abnormal sample of kidney No. 4

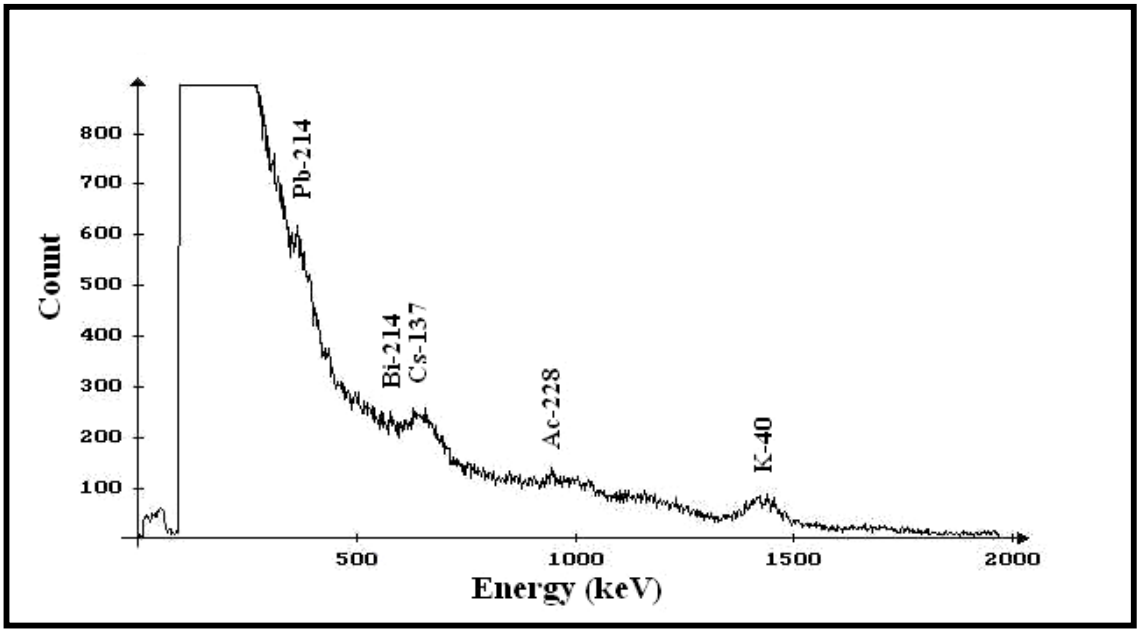

Figure (4-5) Gamma-ray spectrum for abnormal sample of kidney No. 5

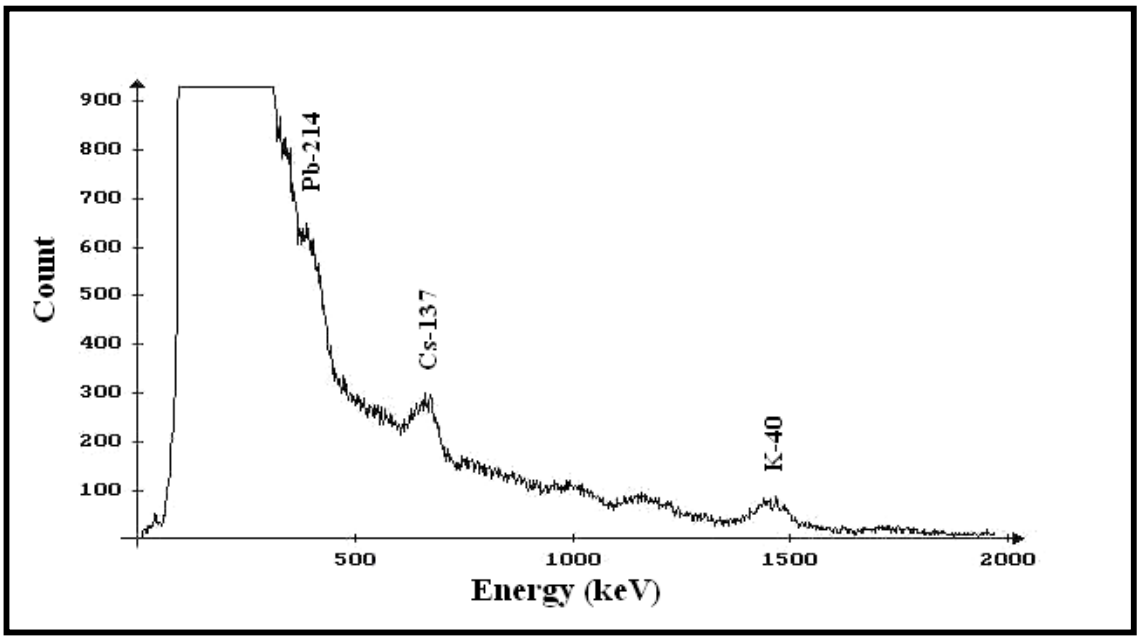

Figure (4-6) Gamma-ray spectrum for abnormal sample of kidney No. 6

Table 4-1 Specific activities of radionuclides in the abnormal samples of kidney

Sample No.	Energy (keV)	Nuclide	Net Area under the peak (count/energy)	Efficiency (%)	Intensity (%)	Activity (Bq/kg)
1	609.3 661.6 1460.7	Bi-214 Cs-137 K-40	651 1860 2097	29 27 11	43.3 85.2 10.7	1.4 2.25 49.49
2	295.2 661.6 911 1460.7	Pb-214 Cs-137 Ac-228 K-40	2308 2547 631 2685	63 27 21.3 11	19.7 85.2 27.7 10.7	5.17 3.08 2.97 63.37
3	583.1 609.3 661.6 911 1120.2 1460.7	Tl-208 Bi-214 Cs-137 Ac-228 Bi-214 K-40	841 1417 3752 750 664 2835	30.8 29 27 21.3 15.8 11	85.7 43.3 85.2 27.7 15.7 10.7	0.89 3.13 4.53 3.53 7.46 66.9
4	609.3 661.6 1120.2 1460.7	Bi-214 Cs-137 Bi-214 K-40	2098 4768 586 3310	29 27 15.8 11	43.3 85.2 15.7 10.7	4.64 5.76 6.56 78.11
5	351.9 609.3 661.6 911 1460.7	Pb-214 Bi-214 Cs-137 Ac-228 K-40	1571 940 3410 705 3191	53 29 27 21.3 11	38.9 43.3 85.2 27.7 10.7	2.12 2.08 4.12 3.32 75.31
6	351.9 661.6 1460.7	Pb-214 Cs-137 K-40	756 3864 2179	53 27 11	38.9 85.2 10.7	1.02 4.67 51.43

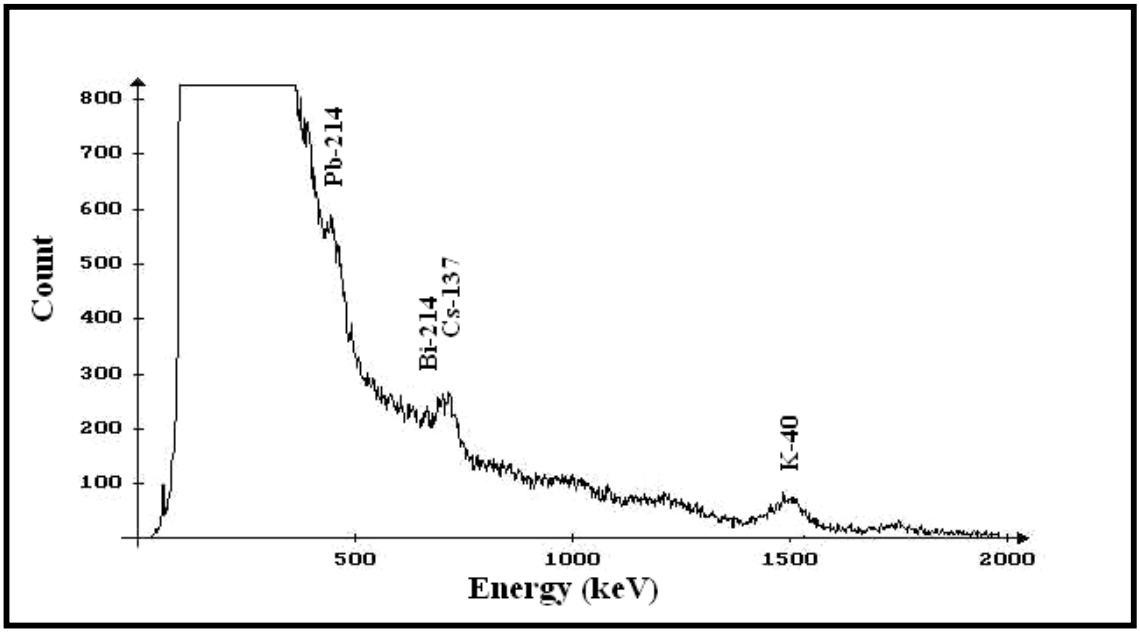

Figure (4-7) Gamma-ray spectrum for normal sample of kidney No. 7

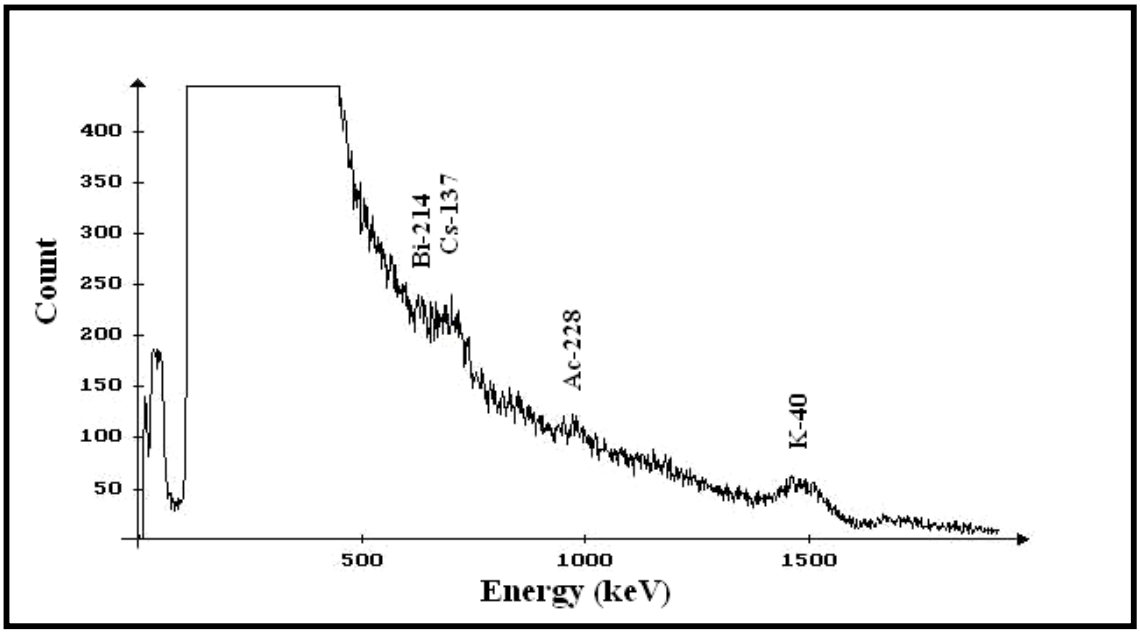

Figure (4-8) Gamma-ray spectrum for normal sample of kidney No. 8

Table 4-2 Specific activities of radionuclides in the normal samples of kidney

Sample No.	Energy (keV)	Nuclide	Net Area under the peak (count/energy)	Efficiency (%)	Intensity (%)	Activity (Bq/kg)
7	351.9 609.3 661.6 1460.7	Pb-214 Bi-214 Cs-137 K-40	1159 649 2641 2357	53 29 27 11	38.9 43.3 85.2 10.7	1.56 1.44 3.19 55.63
8	609.3 661.6 911 1460.7	Bi-214 Cs-137 Ac-228 K-40	908 418 576 2062	29 27 21.3 11	43.3 85.2 27.7 10.7	2.01 0.5 2.71 48.66

From table (4-1), six radionuclides (Bi-214, Pb-214, Ac-228, Tl-208, Cs-137 and K-40) had been detected in the abnormal samples of kidney where distributed between (3 - 5) radionuclides in the selected samples.

The appearance of Ac-228 and Tl-208 radionuclides in sample No.3 show the high concentration of the Th-232 radionuclide in this sample. this result indicate that high concentrations of the radionuclides in the abnormal sample.

The Bi-214 radionuclide detected in four samples (sample No.1, 3, 4 and 5) with range (1.4 - 7.46 Bq/kg) where it appeared with two energy lines (609.3 and 1120.2 keV) in sample No.3 and 4 due to the high concentration of it in these samples. Also the Pb-214 radionuclide detected in three samples (sample No.2, 5 and 6) with range (1.02 - 4.64 Bq/kg), these results indicate that high concentration of the uranium in the kidney samples, because approximately 70% of the uranium that is absorbed into the blood will be filtrated by this organ [23]. As well, one can conclude that sample which belongs to the oldest patient (sample No. 3 that excised from male, 67

years in age) had the largest specific activity of U-238 and Th-232 comparing with other samples.

The artificial radionuclide (Cs-137) appeared in all samples with range (2.25 - 5.76 Bq/kg) because, after Chernobyl nuclear reactor accident in the Soviet Union (1986), many foods (powdered milk, canned meat, tea, etc.) which imported from Europe countries into Iraq were contaminated with Cs-137 and Cs-134 radionuclides [68,69]. In addition, that both soils and plants for many regions in Baghdad were contaminated by these radionuclides [19], but Cs-134 radionuclide was not existing in the tissues samples because it has small physical half-life (2.04 year) comparing with Cs-137 radionuclide which has (30 year).

The natural radionuclide (K-40) appeared in all samples with range (49.49 – 78.11 Bq/kg), it had largest specific activity comparing with other radionuclides because the natural potassium is one of the mainly elements in the human body structure.

Same radionuclides (Bi-214, Pb-214, Ac-228, Cs-137, and K-40) are often detected in the normal samples of kidney as shown in table (4-2), but these radionuclides are often appeared with least specific activities comparing with the abnormal samples.

4-2-2 Colon Samples

Gamma-ray spectra for abnormal and normal samples of kidney are shown in figures (4-9 to 4-14) and (4-15 and 4-16) respectively. The specific activities for each detected radionuclide in both samples are shown in tables (4-3) and (4-4) respectively.

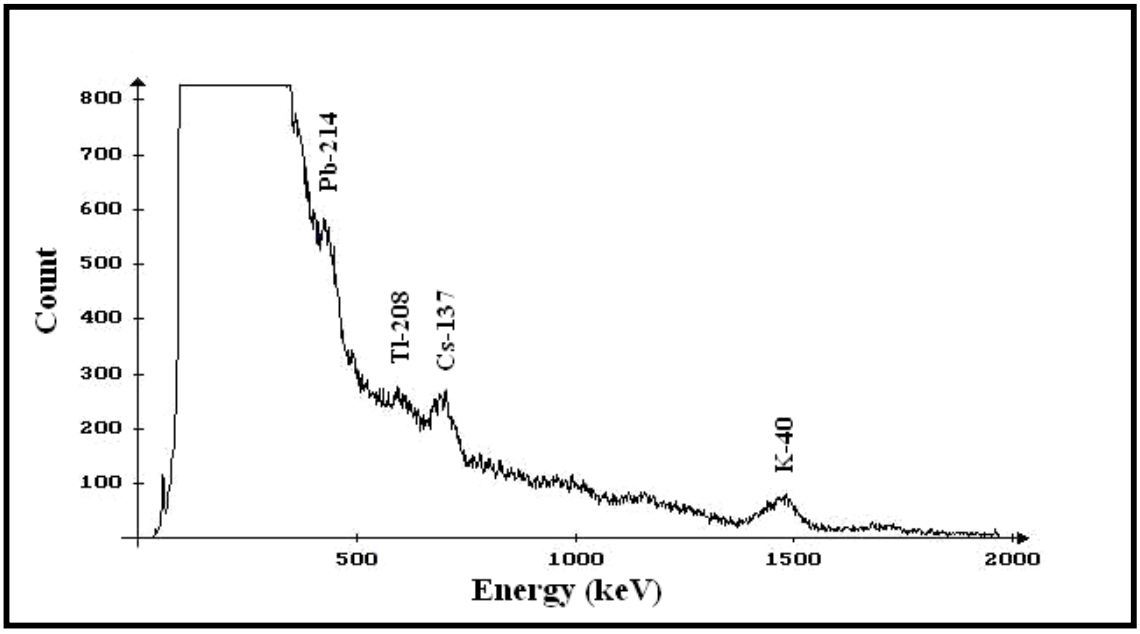

Figure (4-9) Gamma-ray spectrum for abnormal sample of colon No. 9

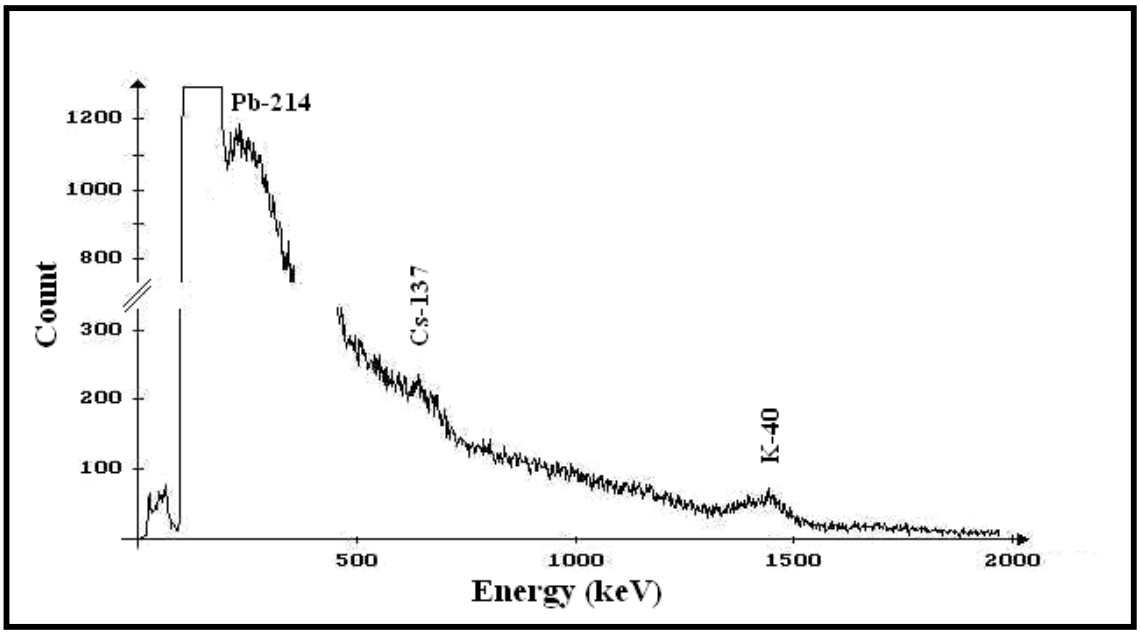

Figure (4-10) Gamma-ray spectrum for abnormal sample of colon No. 10

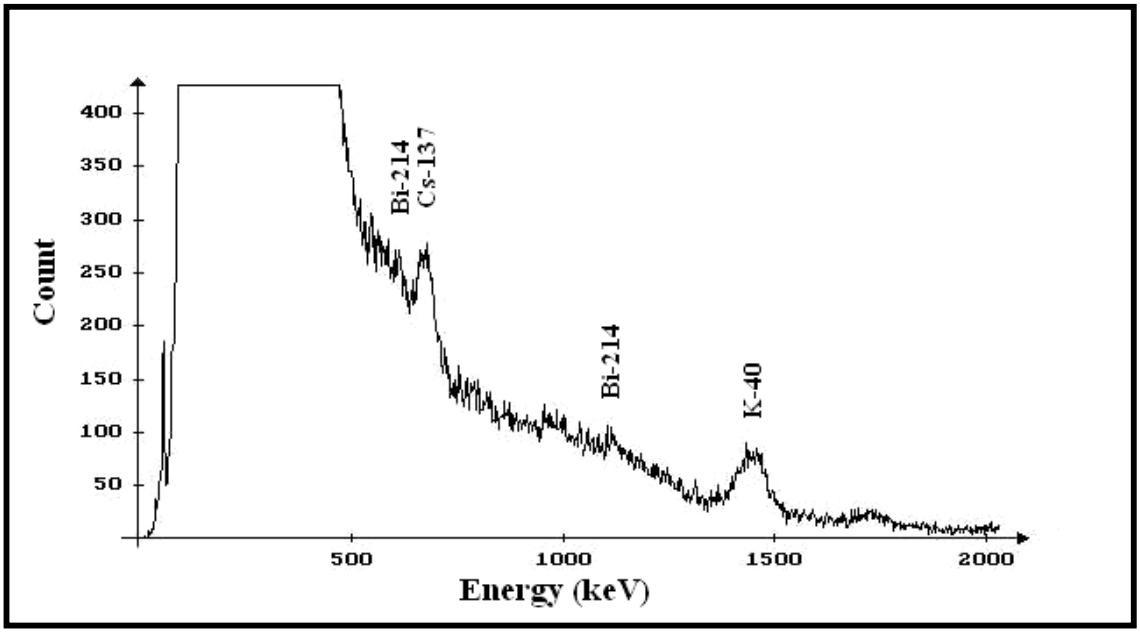

Figure (4-11) Gamma-ray spectrum for abnormal sample of colon No. 11

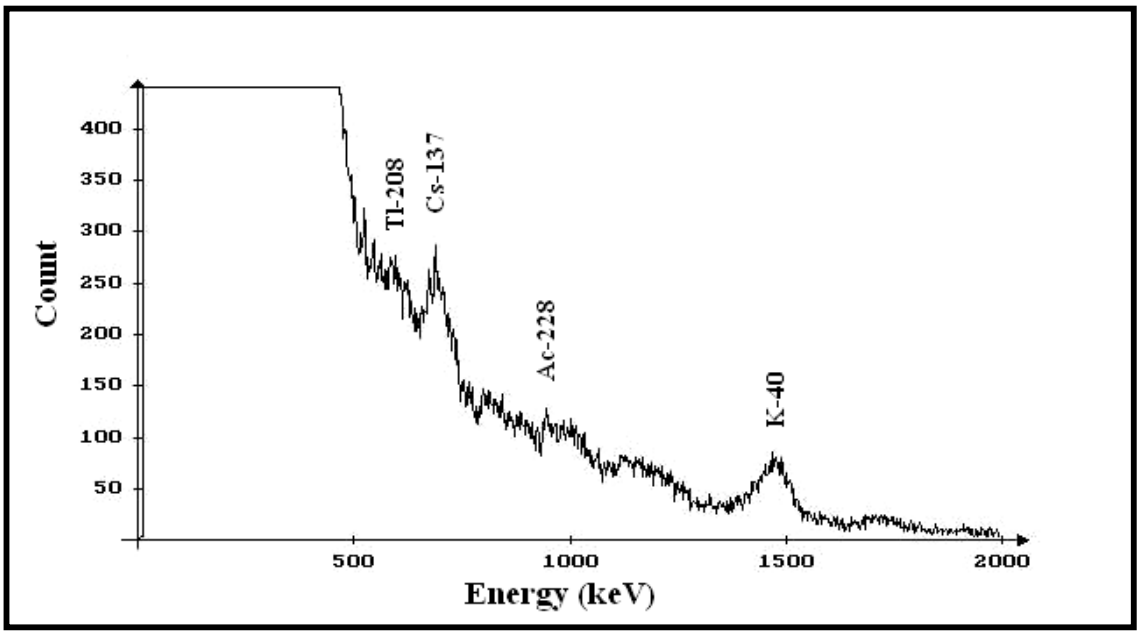

Figure (4-12) Gamma-ray spectrum for abnormal sample of colon No. 12

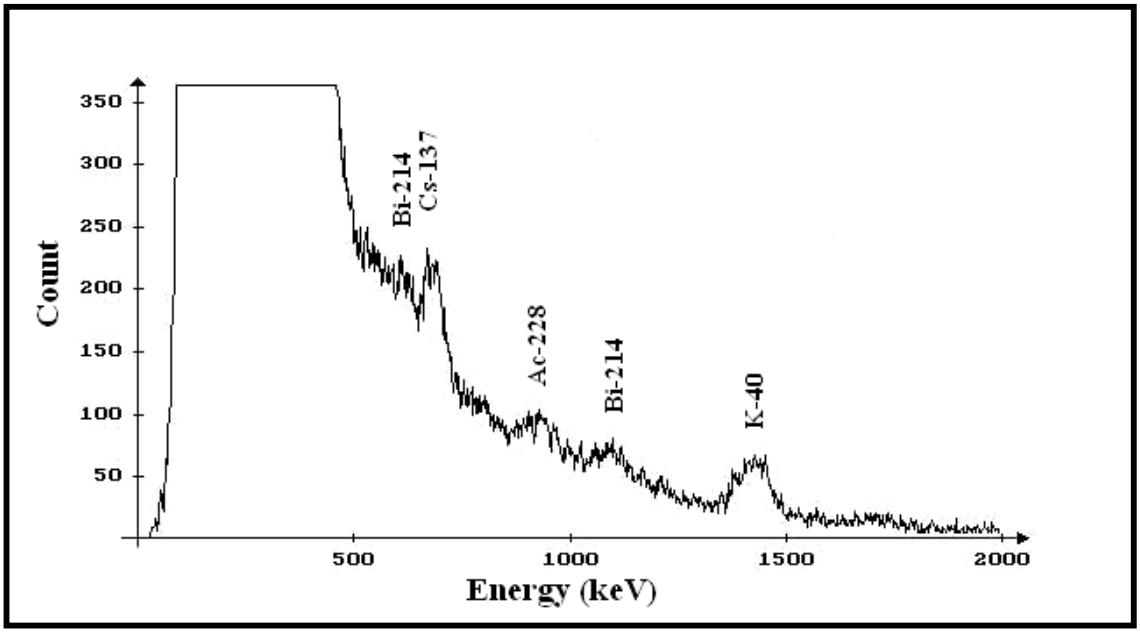

Figure (4-13) Gamma-ray spectrum for abnormal sample of colon No. 13

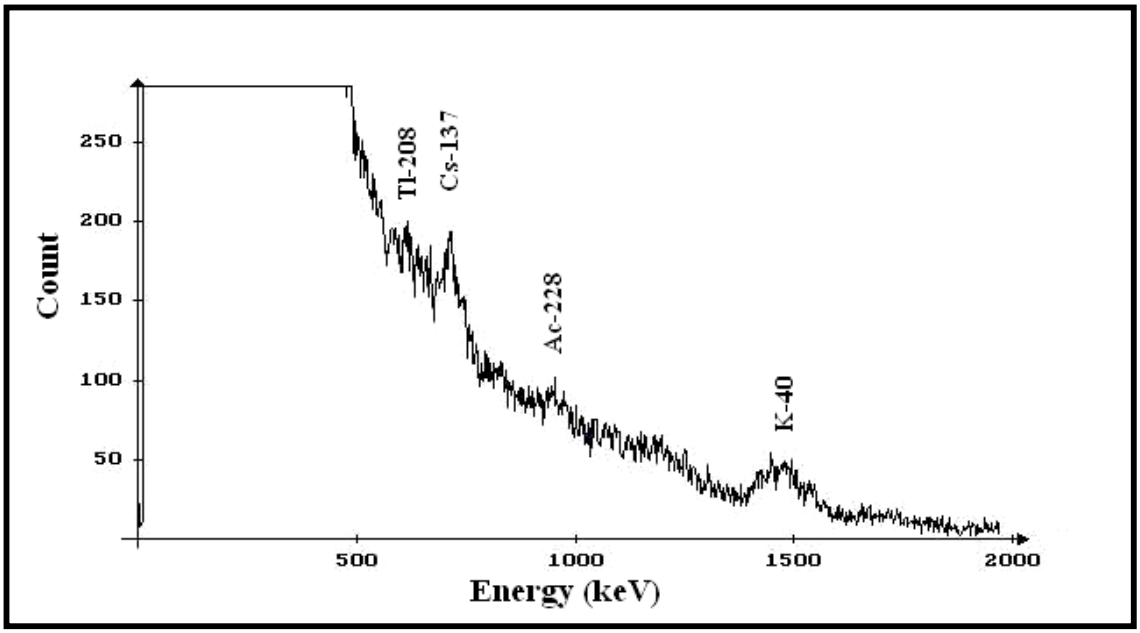

Figure (4-14) Gamma-ray spectrum for abnormal sample of colon No. 14

Table 4-3 Specific activities of radionuclides in the abnormal samples of colon

Sample No.	Energy (keV)	Nuclide	Net Area under the peak (count/energy)	Efficiency (%)	Intensity (%)	Activity (Bq/kg)
9	351.9 583.1 661.6 1460.7	Pb-214 Tl-208 Cs-137 K-40	1326 1288 3697 2496	53 30.8 27 11	38.9 85.7 85.2 10.7	1.79 1.36 4.46 58.91
10	295.2 661.6 1460.7	Pb-214 Cs-137 K-40	1605 1730 2738	63 27 11	19.7 85.2 10.7	3.65 2.09 64.61
11	609.3 661.6 1120.2 1460.7	Bi-214 Cs-137 Bi-214 K-40	1026 3455 656 3155	29 27 15.8 11	43.3 85.2 15.7 10.7	2.27 4.17 7.35 74.46
12	583.1 661.6 911 1460.7	Tl-208 Cs-137 Ac-228 K-40	1510 5321 759 3057	30.8 27 21.3 11	85.7 85.2 27.7 10.7	1.58 6.46 3.57 72.15
13	609.3 661.6 911 1120.2 1460.7	Bi-214 Cs-137 Ac-228 Bi-214 K-40	1117 3308 778 504 3615	29 27 21.3 15.8 11	43.3 85.2 27.7 15.7 10.7	2.47 3.99 3.66 5.64 85.36
14	583.1 661.6 911 1460.7	Tl-208 Cs-137 Ac-228 K-40	613 2056 500 1872	30.8 27 21.3 11	85.7 85.2 27.7 10.7	0.65 2.48 2.35 44.18

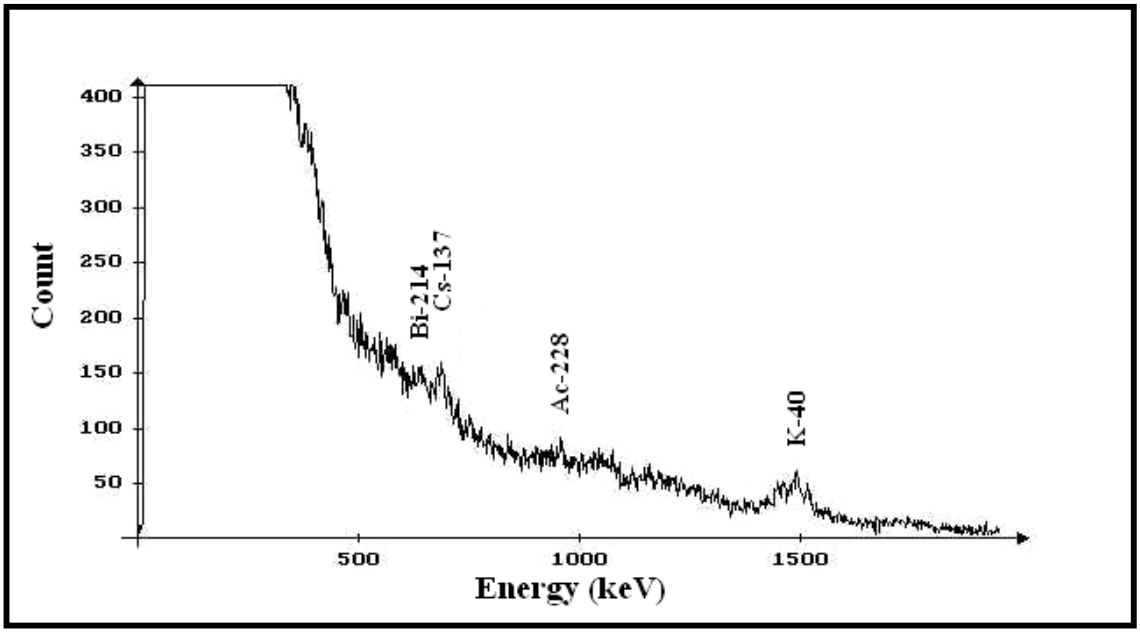

Figure (4-15) Gamma-ray spectrum for normal sample of colon No. 15

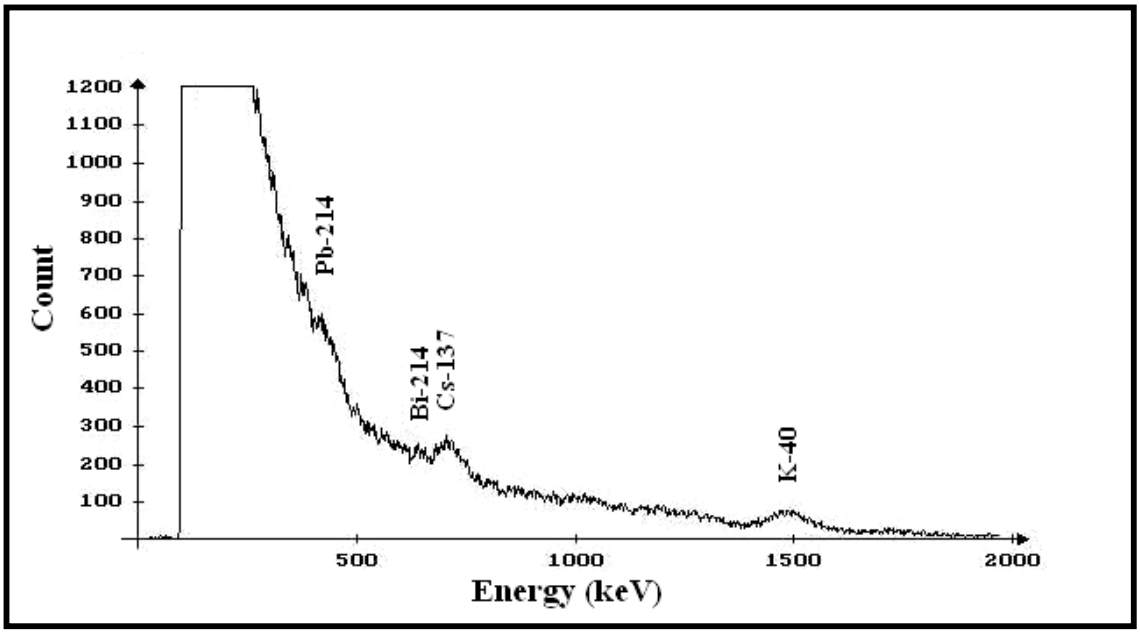

Figure (4-16) Gamma-ray spectrum for normal sample of colon No. 16

Table 4-4 Specific activities of radionuclides in the normal samples of colon

Sample No.	Energy (keV)	Nuclide	Net Area under the peak (count/energy)	Efficiency (%)	Intensity (%)	Activity (Bq/kg)
15	609.3	Bi-214	578	29	43.3	1.28
	661.6	Cs-137	770	27	85.2	0.93
	911	Ac-228	414	21.3	27.7	1.95
	1460.7	K-40	2179	11	10.7	51.43
16	351.9	Pb-214	656	53	38.9	0.88
	609.3	Bi-214	705	29	43.3	1.56
	661.6	Cs-137	2864	27	85.2	3.46
	1460.7	K-40	2413	11	10.7	56.95

From table (4-3), six radionuclides (Bi-214, Pb-214, Ac-228, Tl-208, Cs-137 and K-40) had been detected in the abnormal samples of colon where distributed between (3 - 5) radionuclides in the selected samples.

The appearance of the Bi-214 radionuclide in sample No. 11 (excised from female, 45 years in age) and sample No.13 (excised from female, 69 years in age) with two energy lines (609.3 and 1120.2 keV) shows the high existence of the U-238 radionuclide in these samples compared with others, and the appearance of the Ac-228 and Tl-208 radionuclides in sample No. 12 (excised from male, 63 years in age) and sample No. 14 (excised from male, 55 years in age) shows the high existence of the Th-232 radionuclide in these samples compared with others.

All abnormal samples of colon contained Cs-137 and K-40 radionuclides with ranges (2.09 - 6.46 Bq/kg) and (44.18 - 85.36 Bq/kg) respectively, where the last radionuclide had the largest specific activity compared with other radionuclides.

Same radionuclides (Bi-214, Pb-214, Ac-228, Cs-137, and K-40) are often detected in the normal samples of colon (4 radionuclides in each sample) as shown in table (4-4), but these radionuclides are often appeared with least specific activities compared with the abnormal samples.

One can conclude that diverse radionuclides appeared in the colon tissue because this organ is directly exposed to all the radionuclides that may be reach it by ingestion (food, water, etc.) which differ from person to another.

4-2-3 Breast Samples

Gamma-ray spectra for abnormal and normal samples of breast are shown in figures (4-17 to 4-22) and (4-23 and 4-24) respectively. The specific activities for each detected radionuclide in both samples are shown in tables (4-5) and (4-6) respectively.

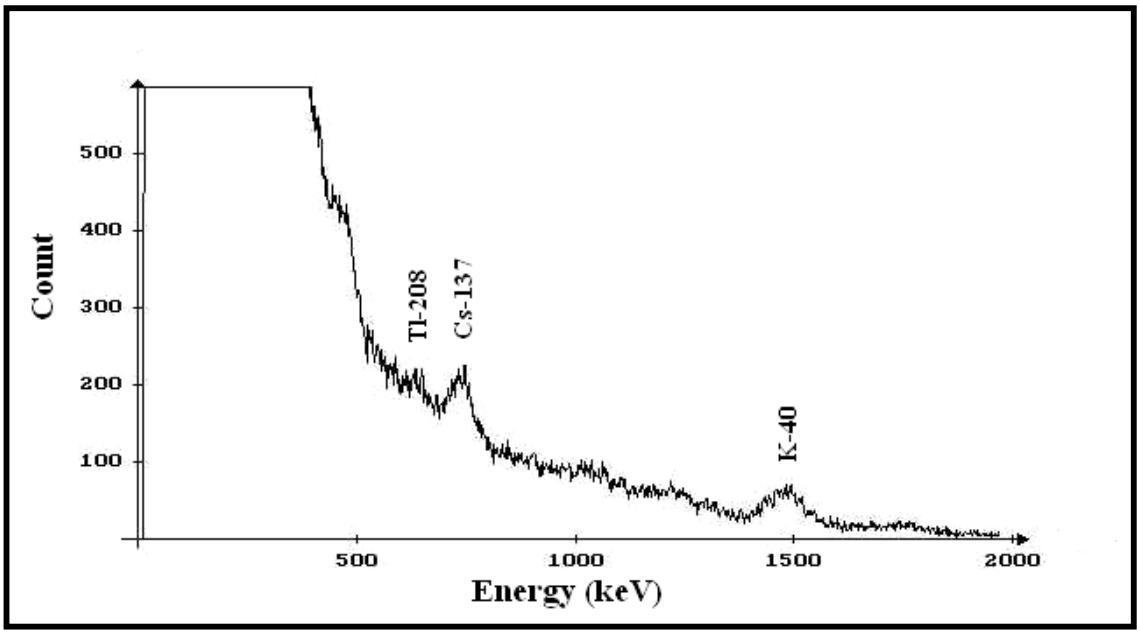

Figure (4-17) Gamma-ray spectrum for abnormal sample of breast No. 17

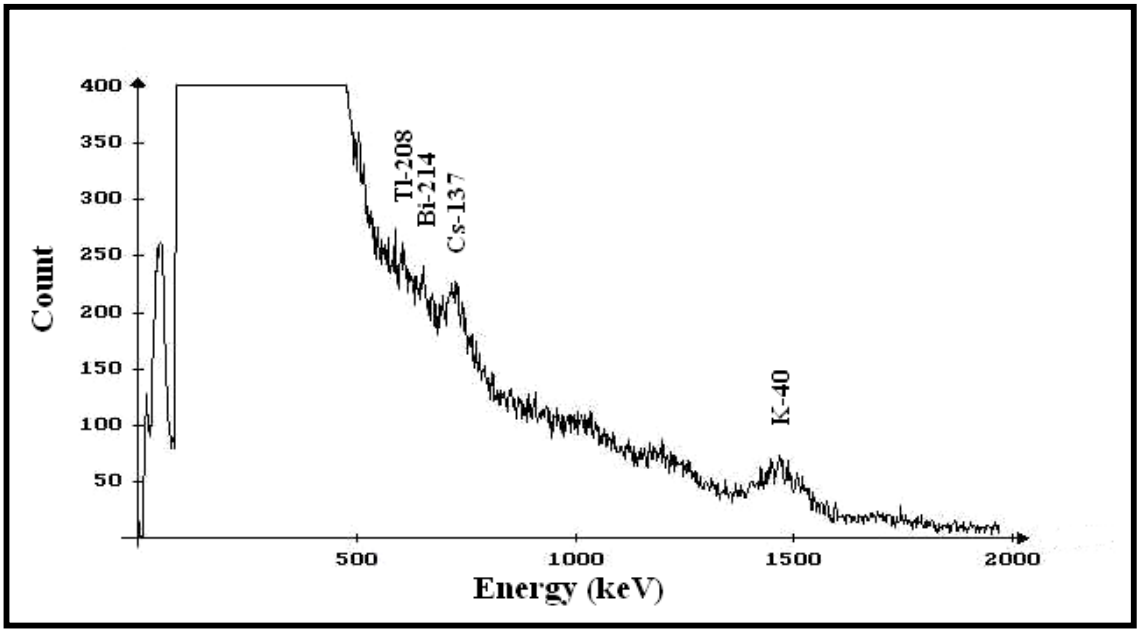

Figure (4-18) Gamma-ray spectrum for abnormal sample of breast No. 18

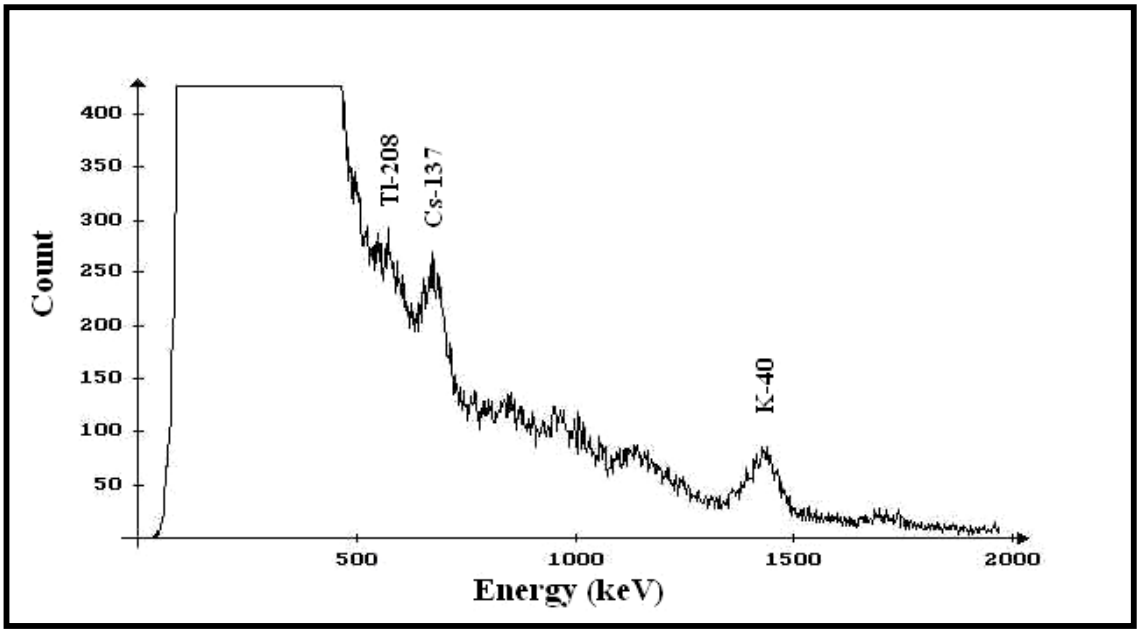

Figure (4-19) Gamma-ray spectrum for abnormal sample of breast No. 19

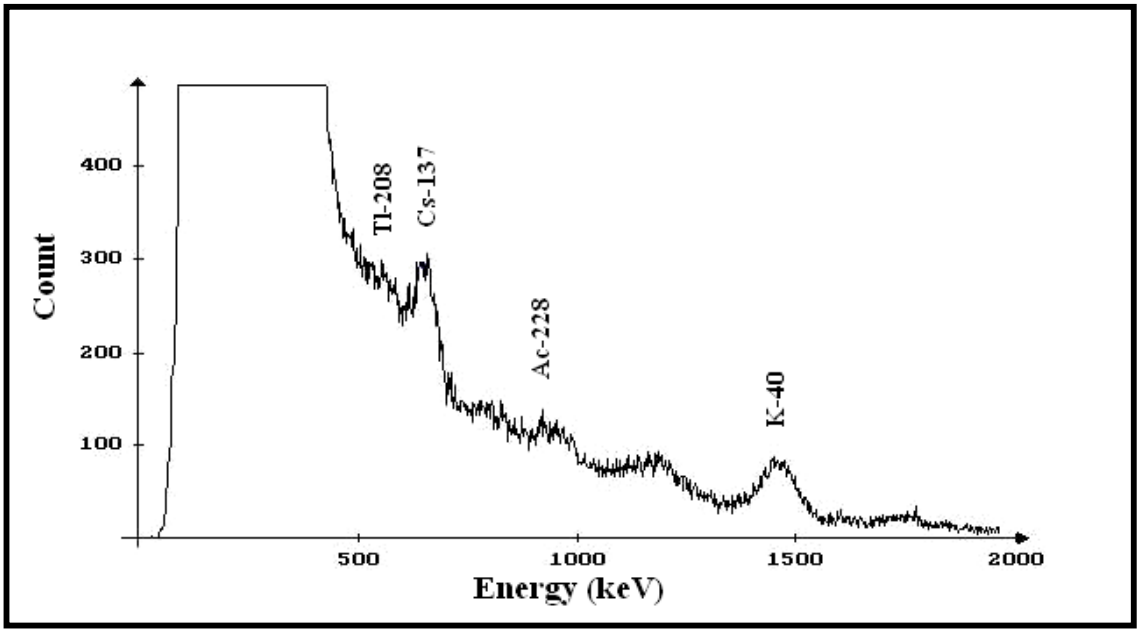

Figure (4-20) Gamma-ray spectrum for abnormal sample of breast No. 20

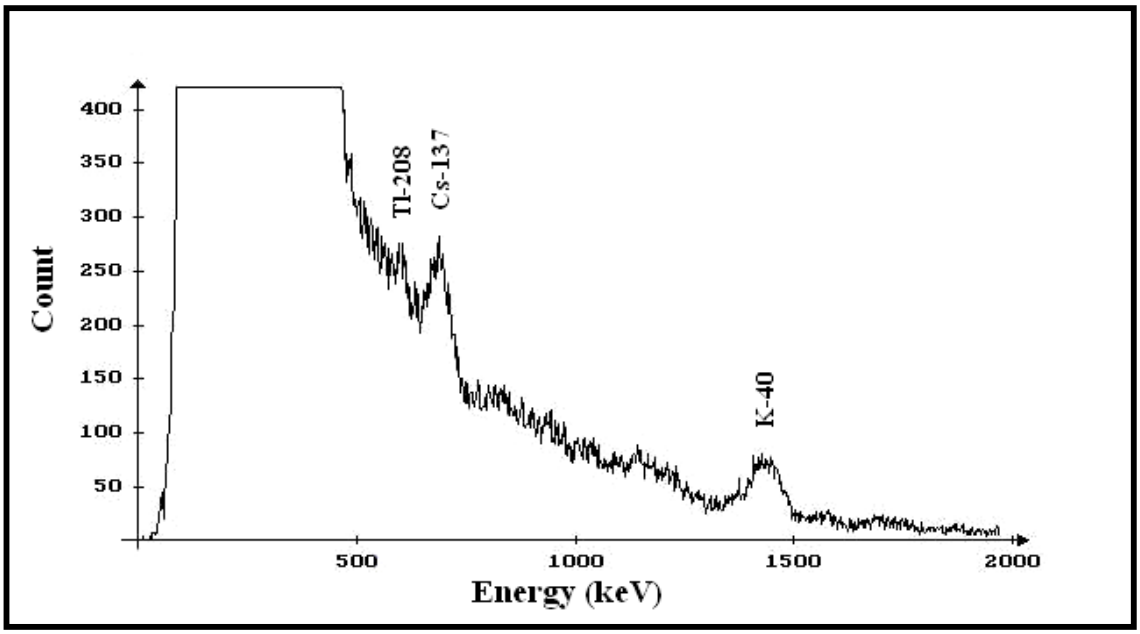

Figure (4-21) Gamma-ray spectrum for abnormal sample of breast No. 21

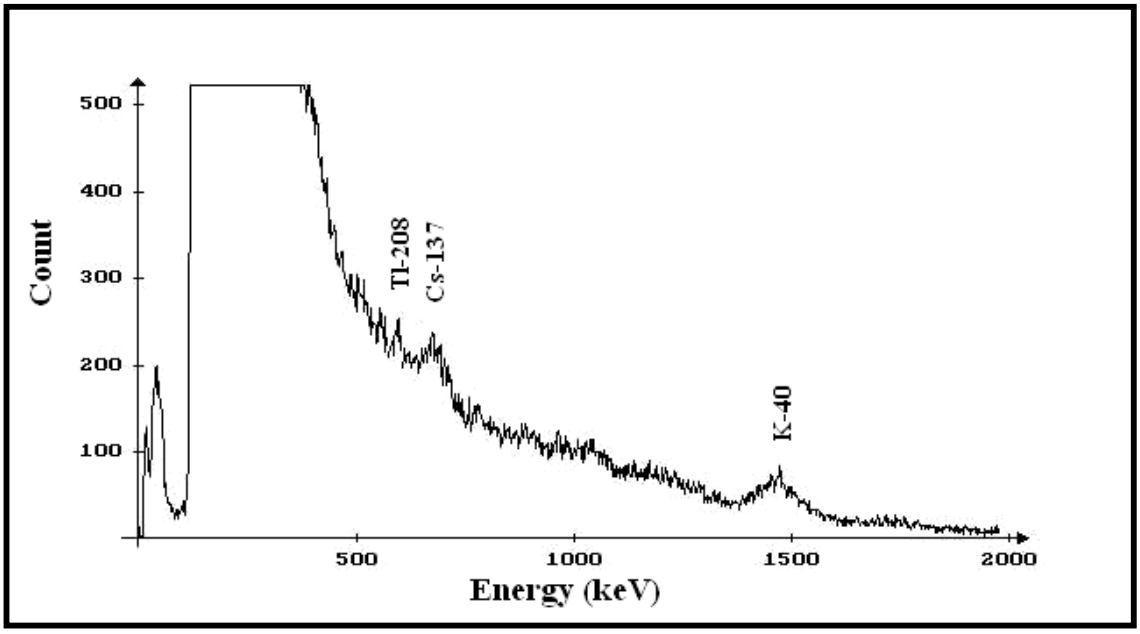

Figure (4-22) Gamma-ray spectrum for abnormal sample of breast No. 22

Table 4-5 Specific activities of radionuclides in the abnormal samples of breast

Sample No.	Energy (keV)	Nuclide	Net Area under the peak (count/energy)	Efficiency (%)	Intensity (%)	Activity (Bq/kg)
17	583.1 661.6 1460.7	Tl-208 Cs-137 K-40	693 3378 2971	30.8 27 11	85.7 85.2 10.7	1.01 4.08 70.12
18	583.1 609.3 661.6 1460.7	Tl-208 Bi-214 Cs-137 K-40	1116 634 3092 2392	30.8 29 27 11	85.7 43.3 85.2 10.7	1.17 1.4 3.73 56.45
19	583.1 661.6 1460.7	Tl-208 Cs-137 K-40	564 2740 2704	30.8 27 11	85.7 85.2 10.7	0.59 3.31 63.86

20	583.1 661.6 911 1460.7	Tl-208 Cs-137 Ac-228 K-40	1714 3448 1027 2958	30.8 27 21.3 11	85.7 85.2 27.7 10.7	1.8 4.16 4.84 69.81
21	583.1 661.6 1460.7	Tl-208 Cs-137 K-40	1224 4849 2384	30.8 27 11	85.7 85.2 10.7	1.29 5.86 56.26
22	583.1 661.6 1460.7	Tl-208 Cs-137 K-40	1145 542 2637	30.8 27 11	85.7 85.2 10.7	1.21 0.65 62.23

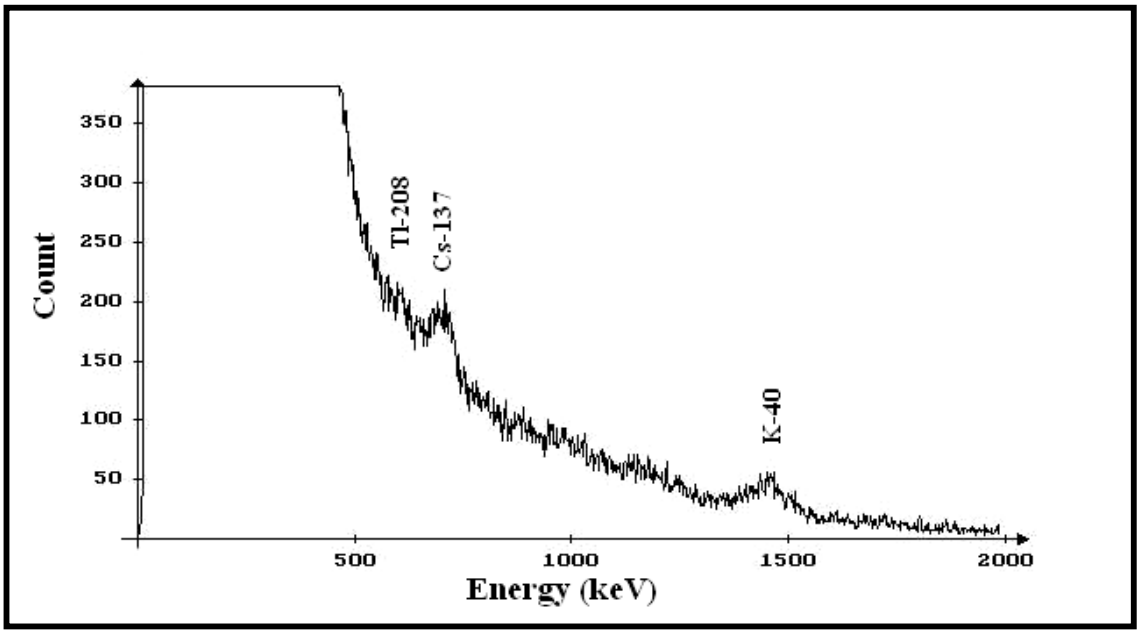

Figure (4-23) Gamma-ray spectrum for normal sample of breast No. 23

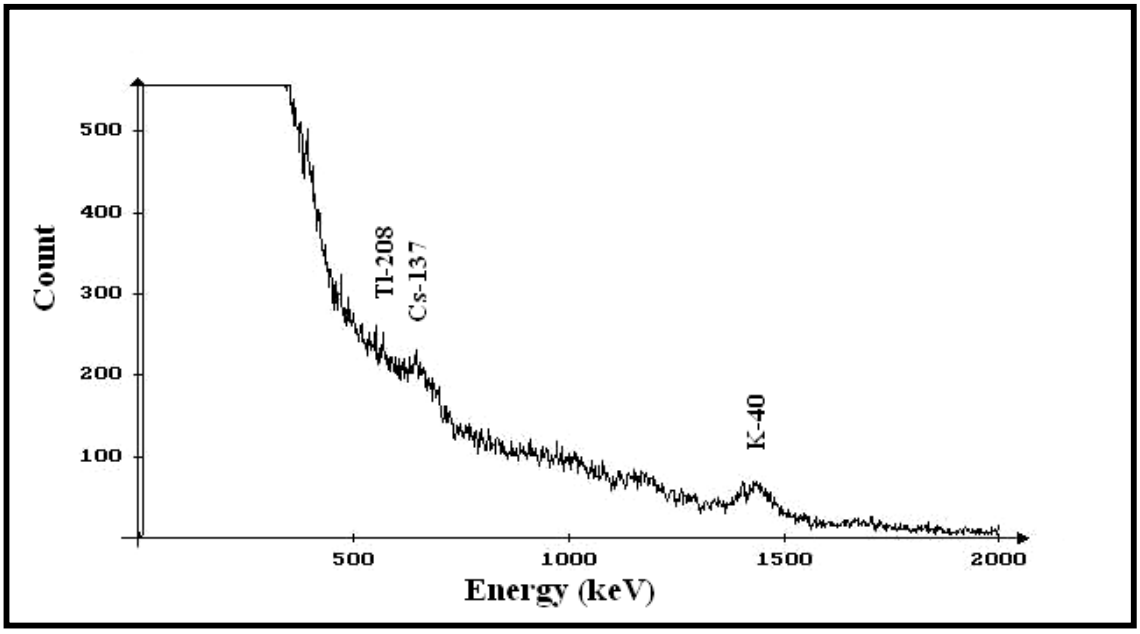

Figure (4-24) Gamma-ray spectrum for normal sample of breast No. 24

Table 4-6 Specific activities of radionuclides in the normal samples of breast

Sample No.	Energy (keV)	Nuclide	Net Area under the peak (count/energy)	Efficiency (%)	Intensity (%)	Activity (Bq/kg)
23	583.1 661.6 1460.7	Tl-208 Cs-137 K-40	465 2387 1995	30.8 27 11	85.7 85.2 10.7	0.49 2.88 47.08
24	583.1 661.6 1460.7	Tl-208 Cs-137 K-40	589 1081 2325	30.8 27 11	85.7 85.2 10.7	0.62 1.31 54.87

From table (4-5), five radionuclides (Bi-214, Ac-228, Tl-208, Cs-137 and K-40) had been detected in the abnormal samples of breast where distributed between (3 - 4) radionuclides in the selected samples.

Just one sample (sample No.18 that excised from female, 48 years in age) contained Bi-214 radionuclide while the Tl-208 radionuclide detected in all samples with range (0.59 -1.8 Bq/kg) where it had maximum specific activity in sample No.20 (excised from oldest female, 72 years in age) which contained Ac-228 radionuclide, this result indicates that breast tissue is most susceptible to Th-232 radionuclide because it has long biological half-life (about 73000 days) compared with U-238 radionuclide which has (15 days) [41].

The largest specific activity was for K-40 radionuclide compared with other radionuclides where it detected in all samples with range (56.26 - 70.12 Bq/kg). Also, the Cs-137 radionuclide detected in all samples too with range (0.65 - 5.86 Bq/kg).

Three radionuclides (Tl-208, Cs-137, and K-40) had been detected in each sample of normal breast as shown in table (4-6), but these radionuclides are often appeared with least specific activities compared with the abnormal samples.

One can conclude that breast tissue is highly susceptible to the radionuclides because it contains much lymphatic vessels and Lymphocytes [40, 63].

4-2-4 Uterus Samples

Gamma-ray spectra for abnormal and normal samples of uterus are shown in figures (4-25 to 4-30) and (4-31 and 4-32) respectively. The specific activities for each detected radionuclide in both samples are shown in tables (4-7) and (4-8) respectively.

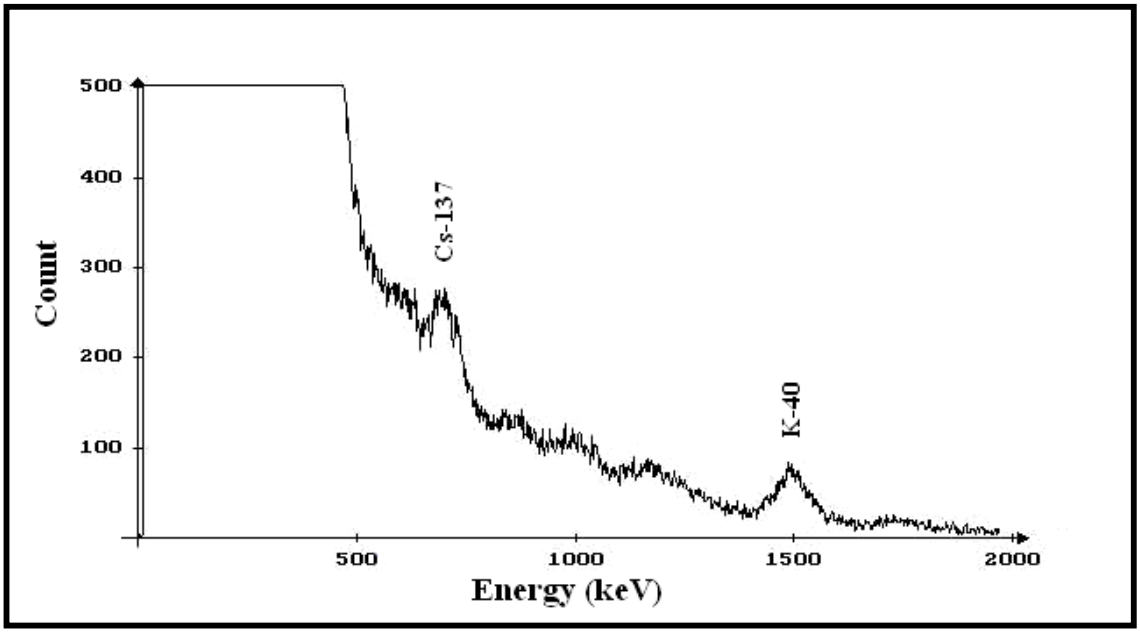

Figure (4-25) Gamma-ray spectrum for abnormal sample of uterus No. 25

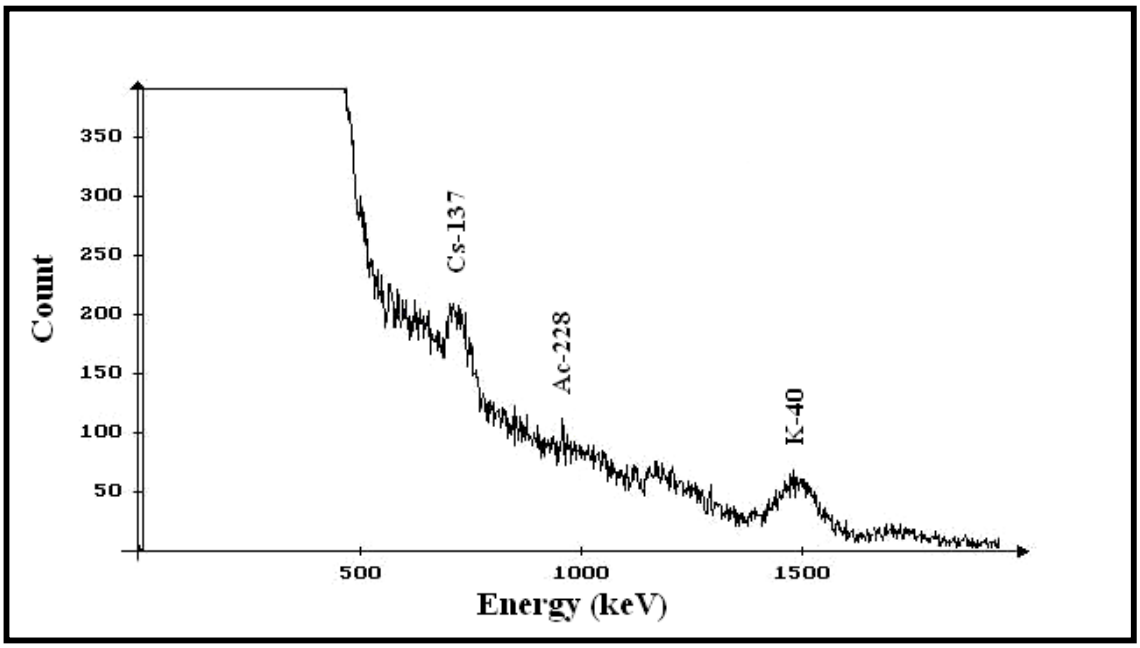

Figure (4-26) Gamma-ray spectrum for abnormal sample of uterus No. 26

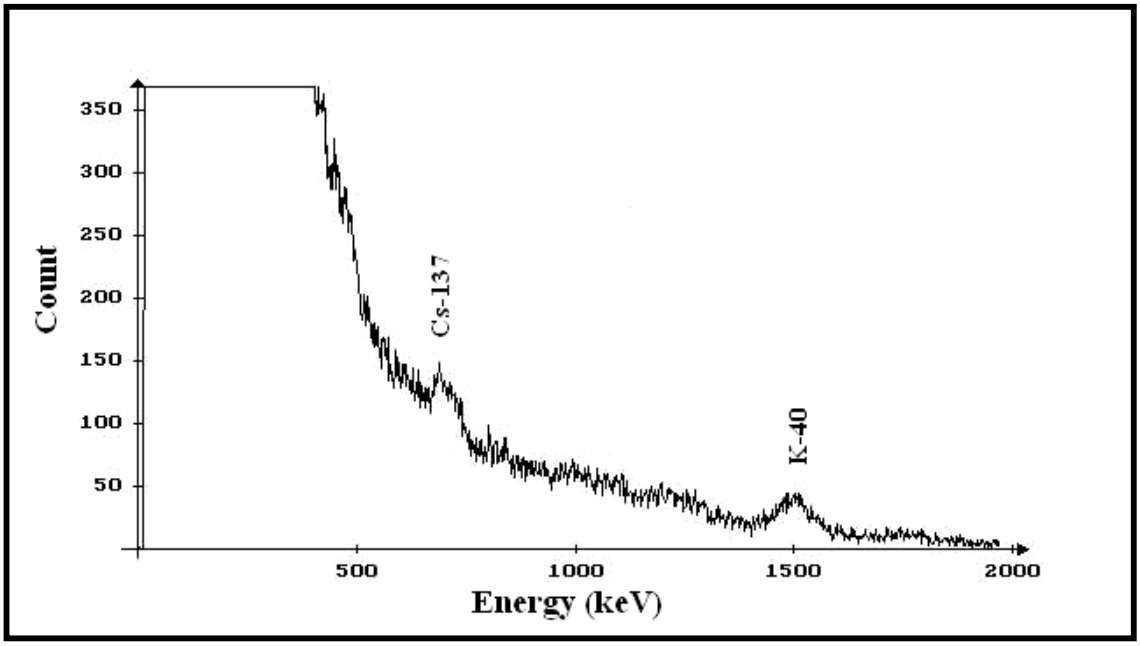

Figure (4-27) Gamma-ray spectrum for abnormal sample of uterus No. 27

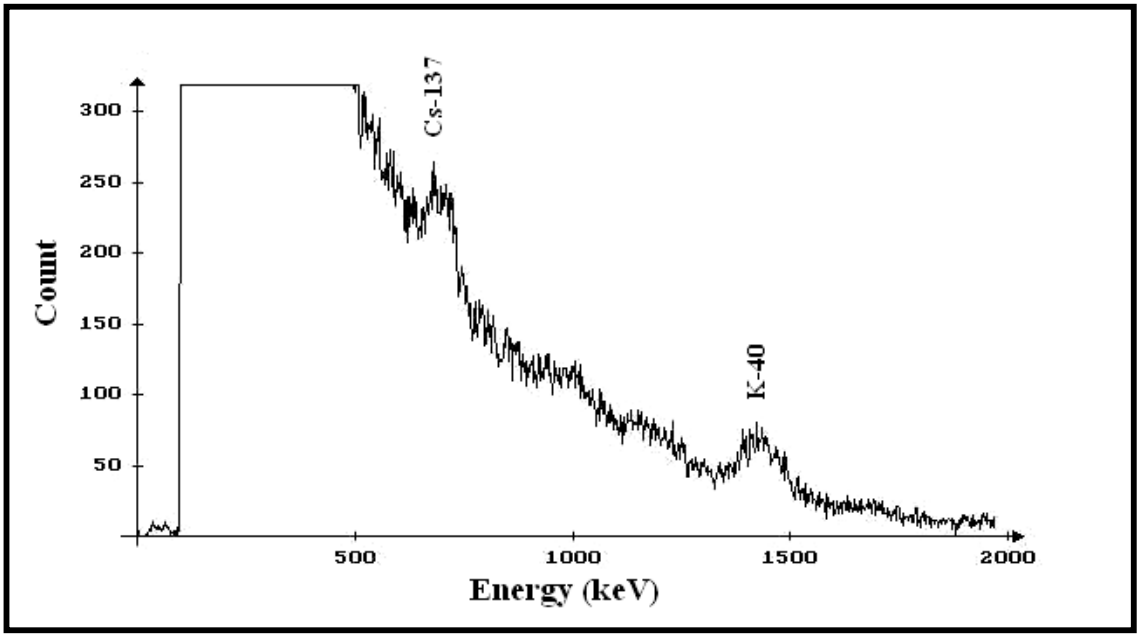

Figure (4-28) Gamma-ray spectrum for abnormal sample of uterus No. 28

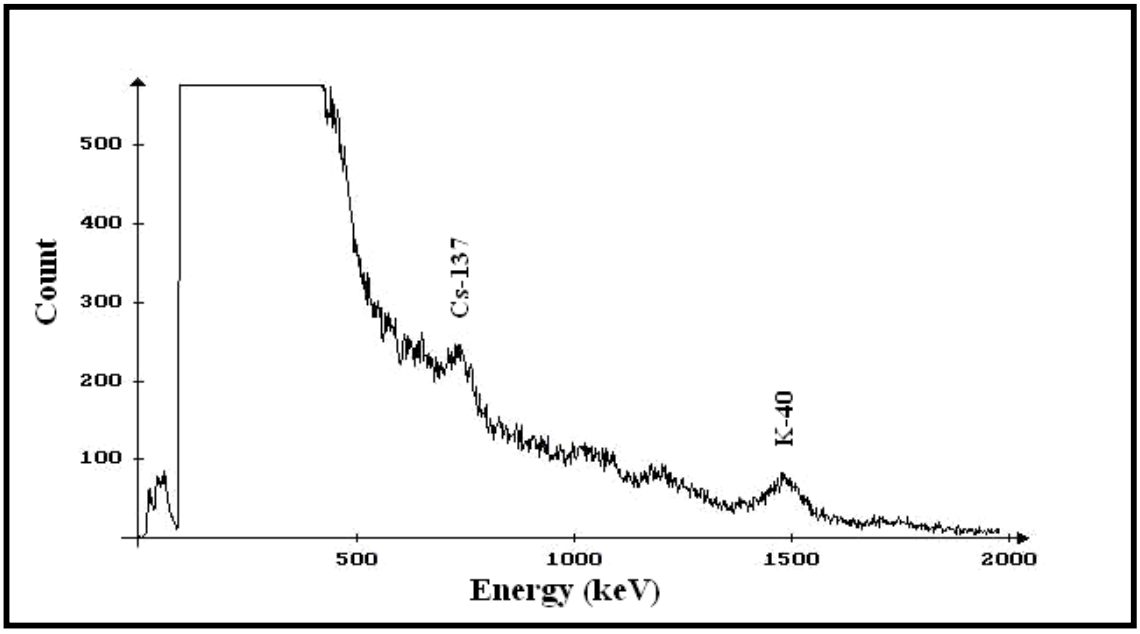

Figure (4-29) Gamma-ray spectrum for abnormal sample of uterus No. 29

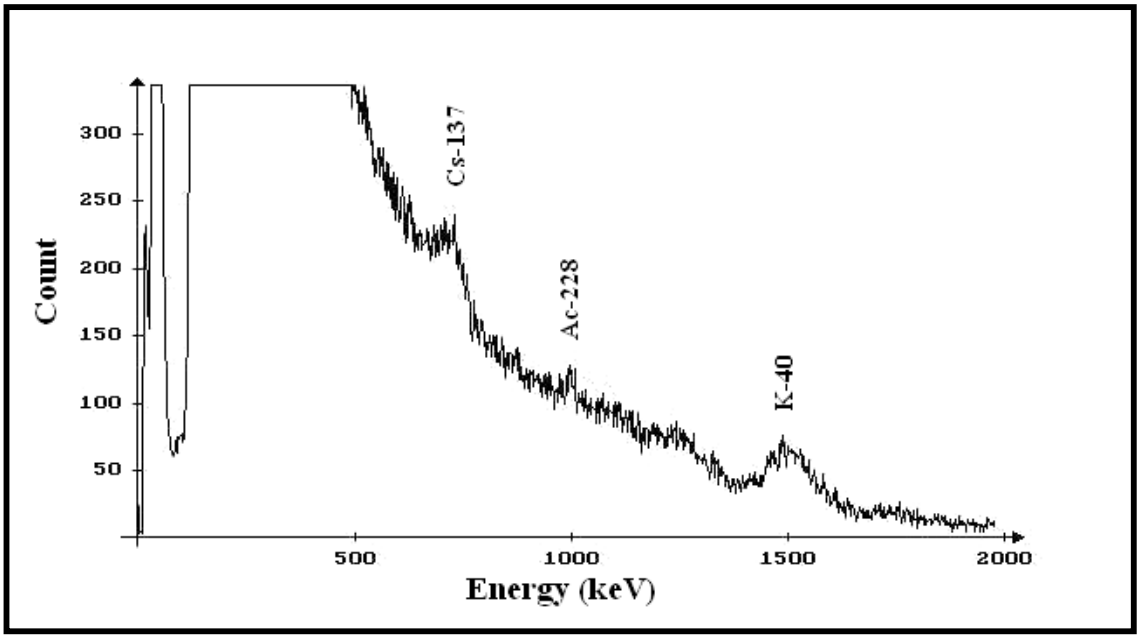

Figure (4-30) Gamma-ray spectrum for abnormal sample of uterus No. 30

Table 4-7 Specific activities of radionuclides in the abnormal samples of uterus

Sample No.	Energy (keV)	Nuclide	Net Area under the peak (count/energy)	Efficiency (%)	Intensity (%)	Activity (Bq/kg)
25	661.6 1460.7	Cs-137 K-40	3092 2577	27 11	85.2 10.7	3.73 60.82
26	661.6 911 1460.7	Cs-137 Ac-228 K-40	2160 459 2197	27 21.3 11	85.2 27.7 10.7	2.61 2.16 51.85
27	661.6 1460.7	Cs-137 K-40	2236 1977	27 11	85.2 10.7	2.7 46.66
28	661.6 1460.7	Cs-137 K-40	2395 2378	27 11	85.2 10.7	2.89 56.12
29	661.6 1460.7	Cs-137 K-40	2473 2289	27 11	85.2 10.7	2.99 54.02
30	661.6 911 1460.7	Cs-137 Ac-228 K-40	528 902 2516	27 21.3 11	85.2 27.7 10.7	0.64 4.25 59.38

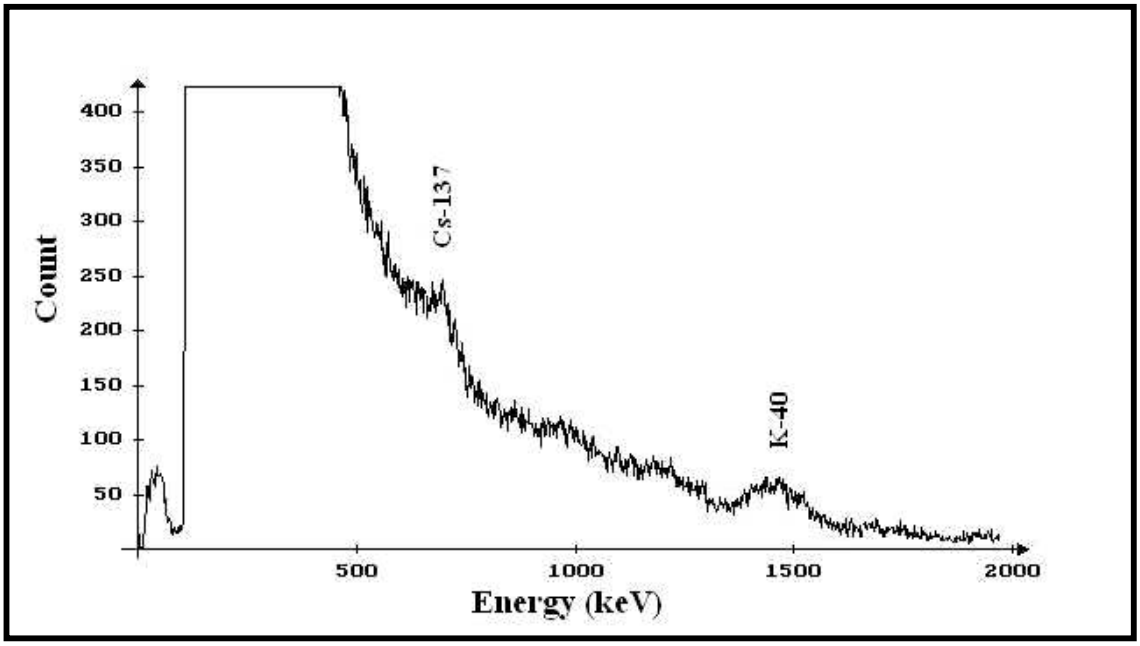

Figure (4-31) Gamma-ray spectrum for normal sample of uterus No. 31

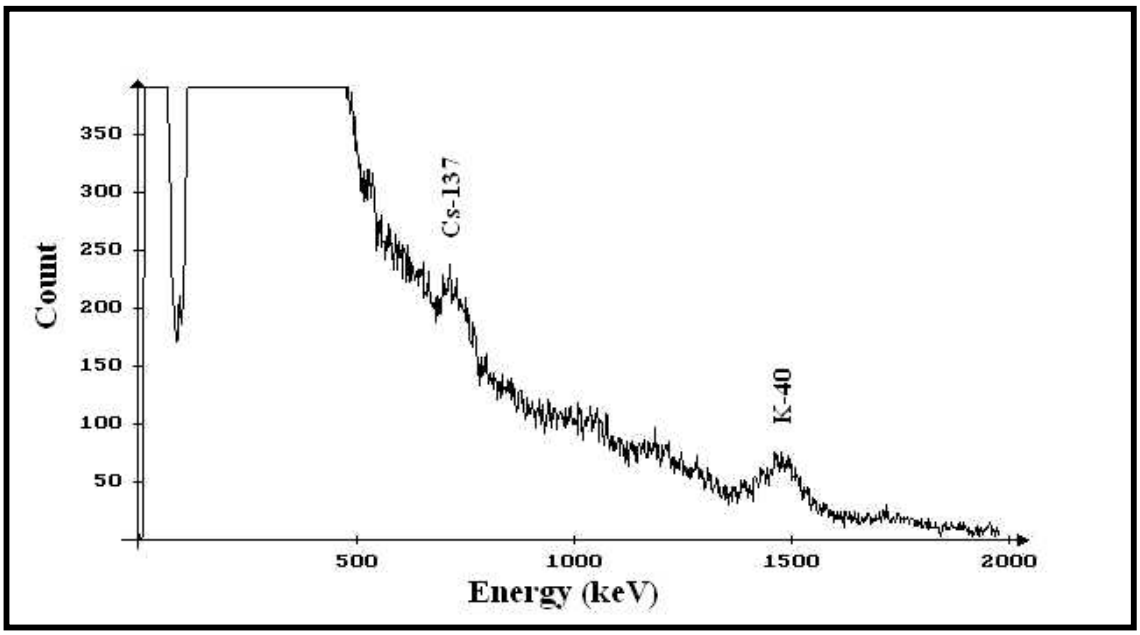

Figure (4-32) Gamma-ray spectrum for normal sample of uterus No. 32

Table 4-8 Specific activities of radionuclides in the normal samples of uterus

Sample No.	Energy (keV)	Nuclide	Net Area under the peak (count/energy)	Efficiency (%)	Intensity (%)	Activity (Bq/kg)
31	661.6 1460.7	Cs-137 K-40	1981 2172	27 11	85.2 10.7	2.39 51.26
32	661.6 1460.7	Cs-137 K-40	997 1721	27 11	85.2 10.7	1.2 40.62

From table (4-7), three radionuclides (Ac-228, Cs-137 and K-40) had been detected in the abnormal samples of uterus where distributed between (2 - 3) radionuclides in the selected samples.

Just one radionuclide (Ac-228) belonging to thorium series had been observed in the abnormal samples of uterus (sample No.26 that excised from female, 74 years in age and sample No.30 that excised from female, 68 years in age), because this radionuclide and its origin (Th-232) have long biological half-lives (about 73000 days for each) [41].

All samples contained Cs-137 and K-40 radionuclides with ranges (0.64 - 3.73 Bq/kg) and (46.66 - 60.82 Bq/kg) respectively, where the last radionuclide had the largest specific activity compared with other radionuclides.

Same radionuclides (Cs-137 and K-40) are often appeared in the normal samples of uterus as shown in table (4-8), but usually with least specific activities compared with the abnormal samples.

One can conclude that uterus tissue contained few radionuclides compared with other tissues because this organ consists of

reborn cells (that is, they have short age), so it removes the radionuclides by decaying the cells, in addition to the biological elimination process.

From tables (4-1 to 4-8) it can be seen that, for each tissue, same radionuclides are often appeared in both normal and abnormal samples because the sensitivity of each tissue is from some limiting radionuclides depending on the exposure pathway and the biological half-lives for these radionuclides.

Also, it can be seen that all tissues were containing Cs-137 radionuclide because it can be deposited in total body [41].

To compare the results, the radionuclides and their specific activities in the selected samples of tissues are shown in table (4-9).

Table 4-9 Radionuclides and their specific activities in the selected samples of tissues

Sample					Specific activity (Bq/kg)					
Type	**Case**	**No.**	**Sex**	**Age**	**Bi-214**	**Pb-214**	**Ac-228**	**Tl-208**	**Cs-137**	**K-40**
Kidney	abnormal	1	female	34	1.4	---	---	---	2.25	49.49
		2	male	61	---	5.17	2.97	---	3.08	63.37
		3	male	67	3.13-7.46	---	3.53	0.89	4.53	66.9
		4	male	50	4.64-6.56	---	---	---	5.76	78.11
		5	female	59	2.08	2.12	3.32	---	4.12	75.31
		6	male	45	---	1.02	---	---	4.67	51.43
	normal	7	male	23	1.44	1.56	---	---	3.19	55.63
		8	male	49	2.01	---	2.71	---	0.5	48.66
Colon	abnormal	9	male	53	---	1.79	---	1.36	4.46	58.91
		١٠	male	32	---	3.65	---	---	2.09	64.61
		١١	female	45	2.27-7.35	---	---	---	4.17	74.46
		١٢	male	63	---	---	3.57	1.58	6.46	72.15
		١٣	female	69	2.47-5.64	---	3.66	---	3.99	85.36
		١٤	male	55	---	---	2.35	0.65	2.48	44.18
	normal	١٥	female	57	1.28	---	1.95	---	0.93	51.43
		١٦	male	40	1.56	0.88	---	---	3.46	56.95
Breast	abnormal	١٧	female	35	---	---	---	1.01	4.08	70.12
		١٨	=	48	1.4	---	---	1.17	3.73	56.45
		١٩	=	29	---	---	---	0.59	3.31	63.86
		٢٠	=	72	---	---	4.84	1.8	4.16	69.81
		٢١	=	65	---	---	---	1.29	5.86	56.26
		٢٢	=	51	---	---	---	1.21	0.65	62.23
	normal	٢٣	=	47	---	---	---	0.49	2.88	47.08
		٢٤	=	54	---	---	---	0.62	1.31	54.87
Uterus	abnormal	٢٥	female	56	---	---	---	---	3.73	60.82
		٢٦	=	74	---	---	2.16	---	2.61	51.85
		٢٧	=	46	---	---	---	---	2.7	46.66
		٢٨	=	50	---	---	---	---	2.89	56.12
		٢٩	=	33	---	---	---	---	2.99	54.02
		٣٠	=	68	---	---	4.25	---	0.64	59.38
	normal	٣١	=	52	---	---	---	---	2.39	51.26
		٣٢	=	66	---	---	---	---	1.2	40.62

4-3 Conclusions

1. Six radionuclides had been detected in the selected samples, included: two radionuclides (Bi-214 and Pb-214) belonging to the uranium series; two radionuclides (Ac-228 and Tl-208) belonging to the thorium series; one artificial radionuclide (Cs-137) which appeared in all samples with range (0.64-6.46 Bq/kg) in the abnormal samples and (0.5-3.46 Bq/kg) in the normal samples; and the natural radionuclide (K-40) which appeared in all samples too, but with largest specific activity compared with other radionuclides where it ranged between (44.18-85.36 Bq/kg) in the abnormal samples and (40.62-56.95 Bq/kg) in the normal samples.
2. The existence of the radionuclides differ with different tissue kinds where,
   - kidney tissue has the largest content of U-238 decay products.
   - diverse radionuclides appear in the colon tissue.
   - breast tissue has the largest content of Th-232 decay products.
   - few radionuclides appear in the uterus tissue compared with other tissues.
3. For each tissue, same radionuclides are often appeared in both normal and abnormal samples but, usually, with least specific activities in the normal samples.
4. The radionuclides appear with largest specific activities (concentrations) in the samples that excised from oldest patients compared with other samples.

4-4 Future Work Suggestions

1. Gamma-rays detection of radionuclides in human tissues that excised from peoples of other Iraqi Provinces (especially, the west provinces that contain the phosphate opulent with uranium) and comparing the results with this study.
2. Determination of the distribution of alpha emitters in the human tissues by using alpha track etch method with (CR-39) detector.
3. Detection and measurement of radioactivity in human blood for both leukemia patients and healthy people by using nuclear track detector (CR-39) and comparing the results.
4. Study of human tissues with NaI(Tl) detector for different weights and periods and noting their effects on gamma-ray spectra.

Dedication

I dedicate my work to all the researchers and scientists who use the science to make the world a better place.

To all the people who sacrifice in their life for a better future for their country and for their sons.

To my country as a simple gift, and to the memory of my sweethearts (my family).

Examination Committee Certificate

We certify that we have read the thesis entitled ***"Gamma-rays Detection of Radionuclides in Human Tissues"*** and as Examining Committee, examined the student ***Mohammed Saad Ali*** in its contents and what is related to it, and that in our opinion it is adequate as standard of thesis, with ***Excellent*** standing of degree of Master of Science in Physics.

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(Dean of the college of science)
Date: / /2006

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الخلاصة

وضعت هذه الدراسة لكشف وحساب الفعالية النوعية للنويدات المشعة في الأنسجة البشرية المسرطنة التي تم استئصالها من مرضى مدينة بغداد باستخدام تقنية التحليل الطيفي لأشعة كاما بواسطة كاشف التألق ايوديد الصوديوم المطعم بالثاليوم (٢×٢ انج).

استندت الدراسة الحالية على ٢٦ عينة مصابة و٨ عينات سليمة لمقارنة النتائج وقد شملت أربعة أنواع من الأنسجة الطرية (كلية، قولون، ثدي، رحم) والتي يمكن الحصول عليها بكتل كبيرة. أما عملية جمع العينات فقد تم الحصول عليها من قسم الهستوباثولوجي التابع للمختبرات التعليمية لمستشفى مدينة الطب ومستشفى الجراحات التخصصية.

أخذت كل عينة بوزن ٢٥٠ غم، غسلت بالماء المقطر لتخليصها من سائل الفورمالين (المادة الحافظة)، قطعت ثم وضعت في وعاء مارنيلي بشكل منتظم، بعد ذلك فحصت بكاشف ايوديد الصوديوم المطعم بالثاليوم لفترة زمنية مقدارها ٤ ساعات (١٤٤٠٠ ثانية) وفولتية تشغيل مقدارها ٥٣٠ فولت.

قيست كفاءة الكاشف باستخدام مصدر (Eu-١٥٢) اما أطياف أشعة كاما لعينات النسيج فقد تم معايرتها وفقا لطيف كل من مصدر (Cs-١٣٧) و(Co-٦٠) و(Na-٢٢).

تم رصد ٦ نويدات مشعة في العينات المنتخبة حيث توزعت بين ٢ - ٥ نويدات في كل عينة وقد شملت: نويدتين (Bi-٢١٤، Pb-٢١٤) عائدتين الى سلسلة اليورانيوم؛ نويدتين (Ac-٢٢٨، Tl-٢٠٨) عائدتين الى سلسلة الثوريوم؛ نويدة صناعية واحدة (Cs-١٣٧)؛ والنويدة الطبيعة (K-٤٠).

تراوحت الفعالية النوعية لليورانيوم الملاحظ (نواتج انحلال U-٢٣٨) في العينات المصابة بين (١,٠٢-٧,٤٦ بكرل/كغم) أما العينات السليمة فقد تراوحت بين (٠,٨٨-٢,٠٢ بكرل/كغم) وقد تراوحت الفعالية النوعية للثوريوم الملاحظ (نواتج انحلال Th-٢٣٢) في العينات المصابة بين (٠,٥٩-٤,٨٤ بكرل/كغم) أما العينات السليمة فقد تراوحت بين (٠,٤٩-٢,٧١ بكرل/كغم).

رصدت نويدة (Cs-١٣٧) في جميع العينات المنتخبة بفعالية نوعية تراوحت بين (٠,٦٤-٦,٤٦ بكرل/كغم) في العينات المصابة أما العينات السليمة فقد تراوحت بين (٠,٥-٣,٤٦ بكرل/كغم)، أما نويدة (K-٤٠) فقد ظهرت في جميع العينات المنتخبة أيضا لكن بفعالية نوعية اكبر مقارنة بالنويدات الأخرى حيث تراوحت بين (٤٤,١٨-٨٥,٣٦ بكرل/كغم) في العينات المصابة أما العينات السليمة فقد تراوحت بين (٤٠,٦٢-٥٦,٩٥ بكرل/كغم).

تشير النتائج الى ظهور نفس النويدات على الأغلب في كلا النماذج المصابة والسليمة لنفس النوع من النسيج لكن بفعالية نوعية أقل في النماذج السليمة.

Chapter One

Introduction

Chapter Two

Biological Effects of Radiation and NaI(Tl) Detector

Chapter Three

Experimental Details

Chapter Four

Results and Discussion

References

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة النهرين
كلية العلوم/قسم الفيزياء

كشف أشعة كاما للنويدات المشعة في أنسجة بشرية

رسالة
مقدمة إلى كلية العلوم - جامعة النهرين
وهي جزء من متطلبات نيل درجة الماجستير في علوم الفيزياء

من قبل
محمد سعد علي
(بكالوريوس/جامعة النهرين-٢٠٠٣)

رجب ١٤٢٧هـ
آب ٢٠٠٦م

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

﴿ رَبِّ أَوْزِعْنِي أَنْ أَشْكُرَ نِعْمَتَكَ الَّتِي

أَنْعَمْتَ عَلَيَّ وَعَلَى وَالِدَيَّ وَأَنْ أَعْمَلَ

صَالِحاً تَرْضَاهُ وَأَدْخِلْنِي بِرَحْمَتِكَ فِي

عِبَادِكَ الصَّالِحِينَ ﴾

صدق اللَّهُ العظيم

﴿ النمل: ١٩ ﴾