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M.Sc. THESIS IN ENGINEERING PHYSICS

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DETERMINATION OF NATURAL RADIOACTIVITY OF BARAK REGION’S IN GAZİANTEP

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Determination of Natural Radioactivity of Barak Region's in Gaziantep

M.Sc. Thesis

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Supervisor

Prof. Dr. Zihni ÖZTÜRK

by

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Dilara ÇELİKTÜRK

ABSTRACT

DETERMINATION OF NATURAL RADIOACTIVITY OF BARAK REGION'S IN GAZİANTEP

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In local, regional and also global context, it has become necessary to study the environmental radioactivity and its effect on all living organisms. By monitoring the environmental radioactivity, the doze of natural radioactivity that people are exposed to and the important differences at environmental radioactivity are being identified. Performing this as a routine supports and improves our capacity for overcoming radiological emergencies and being ready for such states.

In this thesis study done in the context of environmental radioactivity monitoring program, the natural radioactivity level of soil samples collected from the Barak region in the city of Gaziantep has been determined using the gamma spectrometer system. The radioactivity concentrations of the ^{226}Ra, ^{232}Th and ^{40}K radionuclide have been determined using a well-type 3"x3" NaI(Tl) detector connected to a multichannel analyzer (MCA). Also, the dosage living things are exposed to have been calculated using a specific activity as starting point.

Key words: Gamma Spectroscopy, NaI(Tl) detector, Natural radiation,
Radioactivity.

ÖZET

GAZİANTEP-BARAK BÖLGESİ TOPRAKLARINDA DOĞAL RADYOAKTİVİTE TAYİNİ

ÇELİKTÜRK, Dilara
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Ocak 2015
63 sayfa

Çevresel radyoaktiviteyi ve bu radyoaktivitenin bölgede yaşayan canlılar üzerindeki etkilerini;yerel bölgesel ve hatta küresel düzeyde araştırma gereği doğmuştur.Çevresel radyoaktivitenin izlenmesi ile insanların maruz kaldığı doğal radyasyon seviyeleri ve çevresel radyasyon seviyesindeki önemli değişikler belirlenir.Çevre radyoaktivitesi izleme programının rutin olarak yürütülmesi,radyolajik acil durumların üstesinden gelebilmek için mevcut kapasiteyi ve bu gibi durumlara hazır olma kabiliyetini de destekler ve geliştirir.

Çevre radyoaktivitesi izleme programı kapsamında yapılan bu tez çalışmasında Gaziantep ili Barak bölgesinden alınan toprak örneklerinde,gama spektrometre sistemi kullanılarak doğal radyoaktivite seviyesi belirlendi.Toplanan 30 adet toprak numunesindeki ^{226}Ra, ^{232}Th and ^{40}K radyonüklidlerinin radyoaktivite konsantrasyonları çok kanallı analizöre (MCA) bağlı,kuyu tipi 3”x3” NaI(Tl) dedektörü kullanılarak tespit edilmiştir.Ayrıca spesifik aktiviteden yola çıkılarak canlıların maruz kaldığı dozlar hesaplanmıştır.

Anahtar Kelimeler: Gama Spektroskopi, NaI(Tl) dedektör, Doğal radyasyon, Radyoaktivite.

To my family…

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I would like to give my most sincere thanks to my Dear, who shared all my troubles like they were his own at all hours of the day and who was always as close to me as my next breath.

And you, my dear family, you most of all deserve my gratitude. My dear father, mother and sister; I give you my endless thanks for all your patience, support and love. I am lucky to have you. Yours affectionately.

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LIST OF SYMBOLS/ABBREVIATIONS

λ	Decay Constant
$t_{1/2}$	Half-life
τ	Mean Life Time
Bq	Becquerel
Ci	Curie
EC	European Commission
Gy	Gray
HpGe	High Purity Germanium
ICRP	International Commission on Radiological Protection
MDA	Minimum Detectable Activity
NaI(Tl)	Thallium Activated Sodium Iodide
OECD	Organisation for Economic Co-operation and Development
R	Rontgen
Sv	Sievert
TAEK	Turkey Atomic Energy Agency
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation

CHAPTER 1

INTRODUCTION

The main source of radiation that people are exposed to in the environment they live in is natural radiation. The effect of the doses absorbed from these sources to human life span is very important to environmental radioactivity studies. Apart from natural radiation, people are exposed to manmade radiation throughout their lives.

The main types of manmade radiation sources are methods used in medical diagnosis and treatment, industrial practices, consumer products and of course nuclear power plants which are one of the most current topics or our times. The issue of radiation has become a most controversial topic all over the world, especially after unfortunate nuclear reactor accidents and an ever increasing sensitivity and awareness has been created in people regarding this topic. Parallel to this awareness, peoples' demand for information regarding radiation has increased. As a result, in addition to manmade radiation, it is highly important for people to be informed about the natural radiation they are/will be exposed to depending on the geographic or geological characteristics of the region they live in. The most significant contribution to the average dose absorbed by the world population is (cosmic and land sourced) natural radiation. The annual average effective dose absorbed through natural radiation s reported as 2,4 mSv [1].

Land sourced natural radiation that people are exposed to is formed as a result of ^{40}K, ^{87}Rb, ^{238}U and ^{232}Th radioactive series elements and their degradation products. With regards to the determination of the concentration of radioactive elements, we have to think of the environment we live in as a whole and the activity specification of the pieces making up the whole has to done separately.

In order for the level of land sourced natural radiation to be determined; many studies have been and are being conducted all over the world using different methods, towards determining the activities of the radionuclide in the soil. While some of these studies are done towards doing measurements in regions where no measurement had been done before, some studies are done towards monitoring whether there has been a change in levels in some specific regions.

Studies to determine the radiation doses that people receive from natural sources and examine the biological effects of radiation carried out by International Commission on Radiological Protection (ICRP), United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), Turkey Atomic Energy Agency (TAEK), etc. other national and international organizations.

There are various studies conducted in different regions of the world in order to measure the radioactivity in soil and rocks and calculate the doses resulting from them. Some of these studies are as follows;

In the year 2001 N. Karunakara and his team studied the soil of the Kaiga Region in the Southwest of India and determined the radioactivity concentration in the soil using a HPGe detector. The ^{40}K activity concentration was measured between 78,3-254,8 Bq/kg, the ^{232}Th activity concentration was measured between 11,4-41,9 Bq/kg and ^{226}Rn activity concentration was measured between 15,5-61,2 Bq/kg [2].

In the year 2001 M.Brai and his team conducted studies in the Stromboli Island located off the northern coast of Siberia and determined the radioactivity concentration in the soil and rock samples collected using a HPGe detector. The ^{40}K activity concentration was measured as 340-1427 Bq/kg, the ^{214}Bi activity concentration was measured as 31-112 Bq/kg and ^{228}Ac activity concentration was measured as 30-106 Bq/kg [3].

In the year 2001 J.Yeboah and his team conducted studies in Ghana, Africa and determined the ^{40}K, ^{238}U and ^{232}Th concentration in the soil samples collected and rocks using a gamma spectrometer. In the soil samples, ^{40}K activity ranged between 91,1-1395,9 Bq/kg, ^{238}U activity ranged between 2,4-62,7 Bq/kg and ^{232}Th activity ranged between ,2-145,7 Bq/kg. While in rock samples ^{40}K activity ranged between 9,0-1510,1 Bq/kg, ^{238}U activity ranged between 0,7-40,0 Bq/kg and ^{232}Th activity ranged between 0,5-117,52 Bq/kg. ın 1 meter altitude the rate of exposure in soil was calculated as 0,9-20,6 μR/h, while in rocks it was calculated as 0,6-17,8 μR/h [4].

In a study conducted by S. Singh and his team in 2003 in India, the natural radioactivity in soils was measured using a NaI(Tl) detector and as a result, ^{40}K activity concentration was found between 143,7-228,9 Bq/kg;^{232}Th activity concentration was found between 35,2-122,8 Bq/kg and ^{226}Ra activity concentration was found between 25,1-75,7 Bq/kg. These measurements were made by weighting 250 g of each sample. Also, in this study ^{226}Rn equivalent activity was calculated to be between 90,88-275,33 Bq/kg [5].

In a study conducted by S.Saravanan and his team in 2003, the natural background radiation in the soils of Tamilnadu Region was measured using a NaI(Tl) detector. The activity levels of the soils: ^{40}K activity ranged between 73,1-120 Bq/kg and is averaged at 96,0 Bq/kg; ^{232}Th activity ranged between 21,6-69,6 Bq/kg and is averaged at 43,9 Bq/kg and ^{226}Rn activity ranged between 31,8-52,0 Bq/kg and is averaged at 42,9 Bq/kg. ^{226}Rn equivalent activity was calculated as ranging between 68,3-149,0 Bq/kg, averaged at 113 Bq/kg [6].

In a study conducted by M.K. Fasasi and his team in 2003 in Nigeria, the natural radioactivity in tar sand was measured using a Coaxial Germanium detector. ^{214}Bi (^{238}U) activity was measured as 165,64 Bq/kg and 208Tl (^{232}Th) activity was measured as 150,25 Bq/kg [7].

Malczewski and his team studied the natural and anthropogenic radioactivity in rocks and soils in Poland using gamma ray spectrometer and as a result found that the ^{40}K activity changed within the range of 320-1200 Bq/kg, ^{228}Ac (^{232}Th series) activity changed within the range of 25-62 Bq/kg and ^{226}Rn activity changed within the range of 31-122 Bq/kg [8].

In a study conducted in Mexico in 2004, the concentrations of ^{40}K, ^{238}U and ^{232}Th series for soil were determined using a high resolution gamma spectrometer. The values for ^{238}U and ^{232}Th series were about 30 Bq/kg [9].

In a study conducted in Fiji, comprising of 322 islands and located to the west of Australia in the South Pacific Ocean in the year 2002, 50 soil samples were collected and the average ^{40}K, ^{232}Th and ^{238}U activity was determined respectively as 160, 2,8 and 3,6 Bq/kg using a NaI(Tl) detector [10].

There are various studies conducted in different regions of our country whereby radioactivity measurements and dose calculations were done. Some of these studies are as follows;

In Turkey, a study conducted by Karakelle et al. natural radioactivity in soil samples of Kocaeli was determined using HPGe detector. ^{238}U activity 11-49 Bq/kg, ^{40}K activity 161-964 Bq/kg and ^{232}Th activity 11-65 Bq/kg measured [11].

In a study conducted in 2010 by Z. Korkulu, 20 pieces beach sand samples from the coast of the Black Sea region of Kocaeli Province were analyzed using HPGe detector. ^{238}U activity from 4.41 to 14.4 Bq/kg, ^{232}Th activity from 2.62 to 16.55 Bq/kg, ^{40}K activity from 11.6 to 513.3 Bq/kg and ^{137}Cs activity from 0.56 to 5.43 Bq/kg were found. Gamma dose rates calculated for all the beaches range from 4.10 to 36.80 nGy/h and the average annual effective dose rates were found to range from 5.05 to 45.25 μSv/h [12].

In a study conducted in 1999 by G. Karahan and A. Bayulken, the natural radionuclide activity concentrations in the surface soils of Istanbul, Turkey were measured using the gamma spectroscopy method. The ^{238}U, ^{232}Th and ^{40}K were measured respectively as 21, 37 and 342 Bq/kg [13].

In the study conducted by Karakelle and his team in Turkey, the natural radioactivity in soil samples from Kocaeli has been determined using a HPGe detector. ^{238}U activity was measured as 11-49 Bq/kg, ^{40}K activity was measured as 161-964 Bq/kg and ^{232}Th activity was measured as 11-65 Bq/kg [14].

Mapping the natural radioation of all the regions of our country is one of the objectives of TAEK (Turkish Atomic Energy Authority). The natural radiation levels of the soils in the city of Gaziantep and surrounding areas has not yet been studied in detail. In this study, the aim is to determine the natural radioactivity levels in the Barak region of Gaziantep using a NaI(Tl) scintillation detector in order to fill this gap in the relevant literature

CHAPTER 2

THEORY

2.1 RADIATION

Radiation is called the spread of energy from a radioactive source to another medium.[15]This transfer of energy can take the form of electromagnetic radiation (i.e., electromagnetic waves) or particulate radiation. The different forms of radiation originating from atoms are classified together under the terms "the electromagnetic spectrum" or "electromagnetic radiation". Photon is the smallest unit of electromagnetic radiation and photons have no mass. Electromagnetic radiation spreads in a straight line and move at nearly 300.000 km/s speed of light. When electromagnetic radiation passes a medium, it transfers energy. This amount of energy transferred increases with increasing frequency, decreases with decreasing wavelength of radiation. The radiation energy is reduced passing through a material, due to scattering and absorption, this decrease in energy is negatively correlated with the square of the distance traveled through the material.

There are two types of electromagnetic radiation; nonionizing and ionizing radiations. Wavelenghts of nonioznizing radiations is $\geq 10^{-7}$ m and energies of nonionizing radiations is <12 electron volts (eV). Nonionizing radiations have lowest energy in electromagnetic spectrum. Types of nonionizing electromagnetic radiation:

- Radio waves
- Microwaves
- Infrared light
- Visible light
- Ultraviolet light

2.2 IONIZING RADIATION

Ionizing radiations have highest energy in electromagnetic spectrum and they have ability to remove electrons from atoms; to ionize the atoms. Ionizing radiation can also be subdivided into electromagnetic and particulate radiations (Figure 2.1).

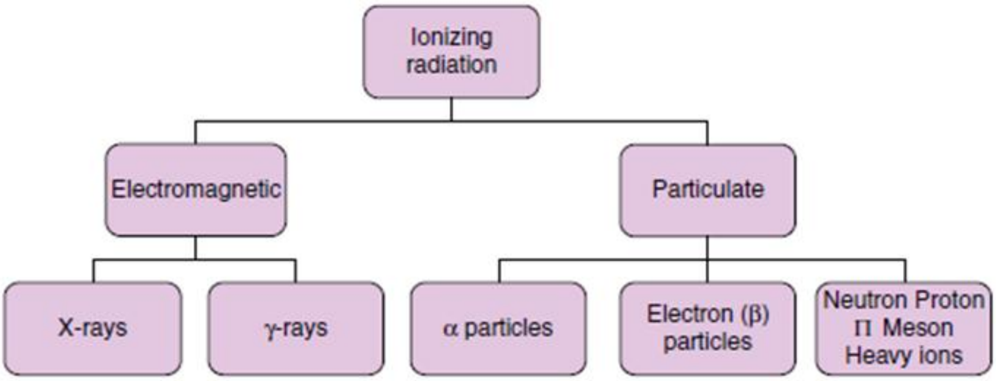

Figure 2.1 Ionizing radiations [15]

2.2.1 Ionizing Electromagnetic Radiation

The electromagnetic spectrum includes all types of electromagnetic radiation, ranging from ionizing radiations (high energy, short wavelength, high frequency) to radio waves (low energy, long wavelength, low frequency) (Figure 2.2).

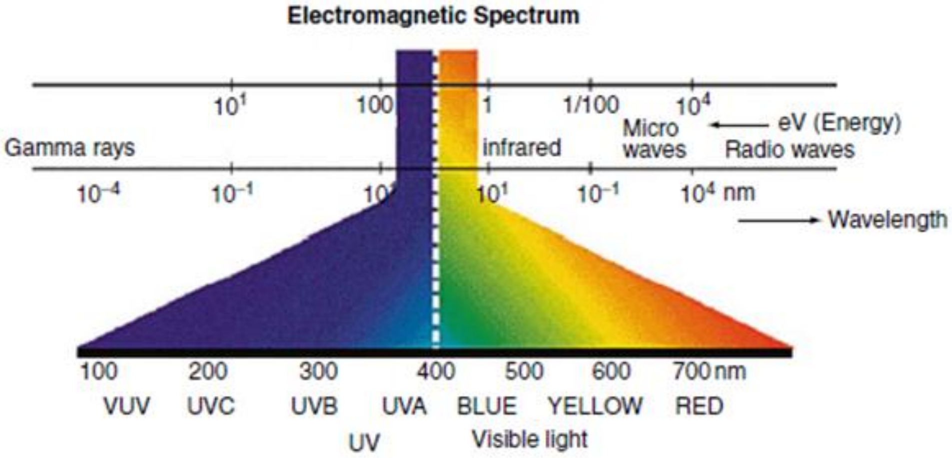

Figure 2.2 Electromagnetic spectrum [15]

When low-frequency radiation interacts with matter, electrons are separated from their atomic and molecular orbits. This process is called as ionization. Secondary electrons are produced by those electrons pending their passage through the material.

2.2.1.1 X-Ray

The German physicist Wilhelm Conrad Roentgen discovered X-rays in 1895. William David Coolidge developed the hot cathode Rontgen tube in 1913. The hot cathode Rontgen tube is a pressured (to 10^{-3} mmHg) glass tube consisting of anode and cathode layers between which a high-energy (10^{6} -10^{8} V) potential is applied (Figure 2.3). The potential accelarate electrons produced by thermoionic emission in the cathode towards the anode. They thus hit the anode, which is a metal with high melting temperature. The sudden deceleration of these electrons produce X-ray due to Coulomb interactions with nuclei in the anode (this sudden deceleration of fast-moving electrons is known as bremsstrahlung; (Figure 2.4). The energy and the wavelength of the X-rays depend on the atomic number of the target (anode) metal, as well as the velocity and the kinetic energy of the electrons.

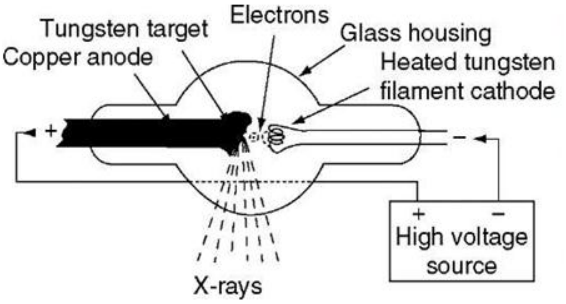

Figure 2.3 Schematic representation of an X-ray tube [15]

X-rays are produced by extranuclear procedures. Two kinds of X-rays are created by X-ray tubes. The first type corresponds to the bremsstrahlung X-rays mentioned above. The second type occurs because an electron in an inner atomic orbital is knocked out by an incoming electron, and the resulting space in the orbital is filled by other electron that moves from an outer atomic orbital (Figure 2.5). This electron must shed energy to move in this manner, and the energy released is radiated as characteristic X-rays. They are characteristic due to the fact that their energy depends on the target metal onto which the electrons are accelerated.

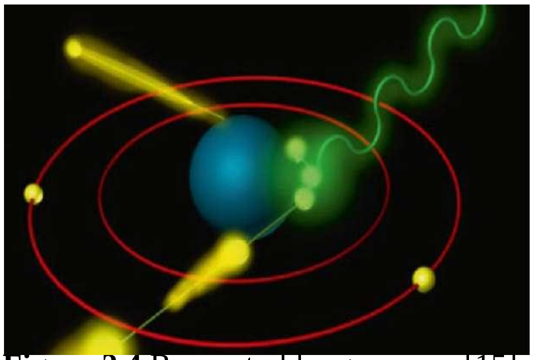

Figure 2.4 Bremsstrahlung process [15]

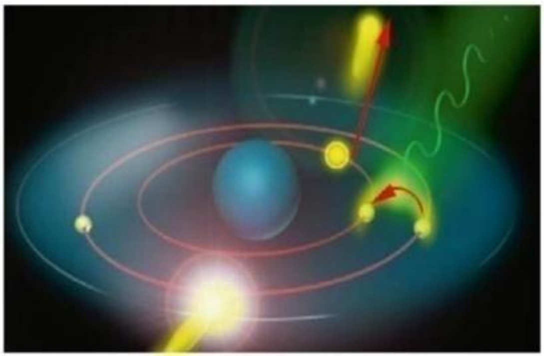

Figure2.5 Characteristic X-ray generation

X-rays produced by bremsstrahlung have a broad energy spectrum (→ heterogeneous), while characteristic X-rays are monoenergetic beams.

2.2.1.2 Gamma (γ) Rays

Gamma rays are physically identical to X-rays, but they are emitted from atomic nuclei (intranuclearly). An unstable atomic nucleus sheds its excess energy in the form of either an intranuclear electron (e^-) (beta particle) or a helium nucleus (an "alpha particle") (Figure 2.6). If it still possesses excess energy after that, gamma rays are emitted in order to reach its steady state (Figure 1.7).

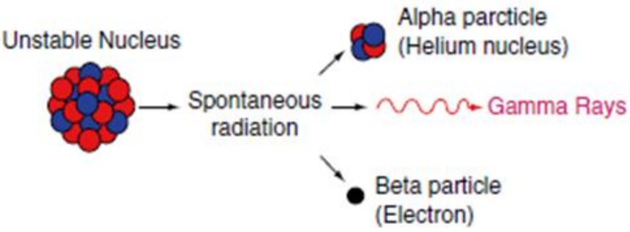

Figure 2.6 Alpha particle generation [15]

The decay of a radioactive nucleus is a spontaneous process. There are three forms of radioactive decay. Alpha or beta particles are emitted during the alpha and beta decays of an unstable nucleus in order to reach a stable nucleus. A gamma decay occurs without any change in the form of the nucleus.

Gamma Emission: A nucleus is not always fully stable (i.e., at its basal energy level) just after it decays; sometimes, the nucleus will be in a semi-stable state instead (Figure 2.11). The excess energy carried by the nucleus is then emitted as gamma radiation. There is no change in the atomic or mass number of the nucleus after this decay, so it is termed an "isomeric" decay. The half-lives of gamma radiation sources are much shorter than sources of other types of decay, and are generally less than 10^{-9} s. However, there are some gamma radiation sources with half-lives of hours or even years. Gamma energy spectra are not continuous.

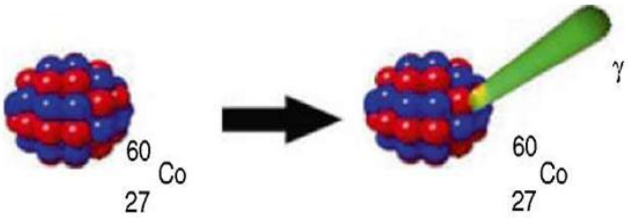

Figure 2.7 Gamma emission [15]

Isotope: Atoms with the same atomic number but different mass numbers are called isotopes (e.g., ${}^{11}_{6}C$, ${}^{12}_{6}C$, ${}^{13}_{6}C$).

Isotone: Atoms with the same number of neutrons, but different numbers of protons are called isotones (e.g., ${}^{9}_{3}Li$, ${}^{10}_{4}Be$, ${}^{10}_{5}B$, ${}^{12}_{6}C$).

Isobar: Atoms with the same number of nucleons but different numbers of protons are called isobars (e.g., ${}^{12}_{5}B$, ${}^{12}_{6}C$, ${}^{12}_{7}N$).

Isomer: Atoms with the same atomic and mass numbers but which are in different energy states are called nuclear isomers (Tc^{99m})

2.2.2 Ionizing Particulate Radiation

Electrons, protons, alpha particles, neutrons, pi mesons and heavy ions are all forms of ionizing particulate radiation.

Electrons, due to their negative charge and low mass, can be accelerated to high energies in linacs or betatrons. The mass of an electron is 9.109 3826(16) x 10^{-31} kg. The electrical charge of an electron is -1.6x10^{-19} C. Electrons are normally bound to a (positively charged) nucleus. The number of electrons is equal to the number of protons in a neutral atom. However, an atom can contain more or less electrons than protons, in which case it is known as a negatively or positively charged ion, respectively. Electrons that are not bound to an atom are called free electrons; free electrons can be produced during nuclear decay processes, in which case they are called beta particles. Electrons have much smaller ranges (i.e., they travel smaller distances) in matter than gamma and X-rays, and can be absorbed by plastics, glass or metal layers (Figure 2.12).

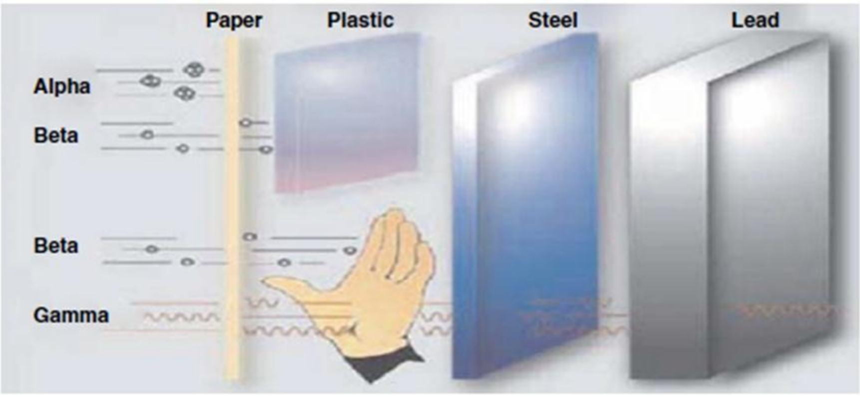

Figure 2.8 Penetration ranges of various ionizing radiations [15]

Neutrons are the neutrally charged particles that enable the formation of stable large atomic nuclei (Figure 2.9) by decreasing the repulsion between the protons in the nucleus. However, neutrons, like protons, actually consist of particles called quarks; a neutron is one up quark and two down quarks, while a proton (Figure 2.10) is two up quarks and one down quark.

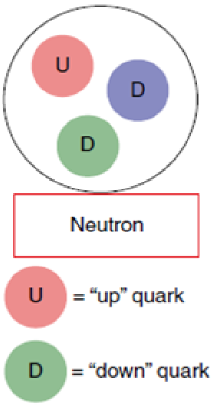

Figure 2.9 Neutron [15]

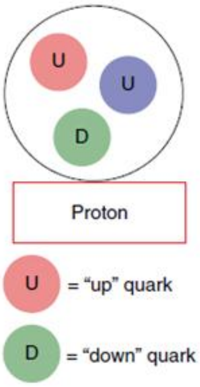

Figure 2.10 Proton [15]

Alpha Decay: An alpha particle consisting of two protons and two neutrons is emitted if a nucleus is unstable because it has an excessive number of both protons and neutrons (Figure 2.11). After alpha decay, the alpha particle possesses most of the energy, due to the conservation of momentum and the fact that the alpha particle is much less massive than the residual nucleus. Although the $^{4}_{2}He$ nucleus is very energetic, does not travel very far compared to most forms of radiation, due to its relatively heavy mass. Alpha decay is usually observed in nuclei with mass numbers of more than 190. The energy spectrum of alpha decay is not continuous, and varies between 4 and 10 MeV. Alpha particles strongly interact with the electrons of the matter through which they pass, since they are charged particles.

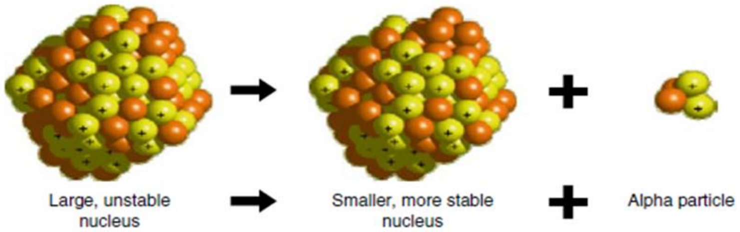

Figure 2.11 Alpha decay [15]

Beta Decay: There are three types of beta decay. If a radionuclide is unstable because it has an excess number of neutrons in its nucleus, it transforms one of the neutrons into a proton and an electron in order to reduce the amount of energy in its nucleus (Figure 2.12). The electron is rapidly propelled out of the nucleus, while the proton remains. This high-speed electron called a β^- particle or negatron, and the process is termed β^- *decay*. The atomic number of the radionuclide increases by one, and thus it changes into the next element in the periodic table. Note that the mass number does not change (it is an "isobaric" decay).

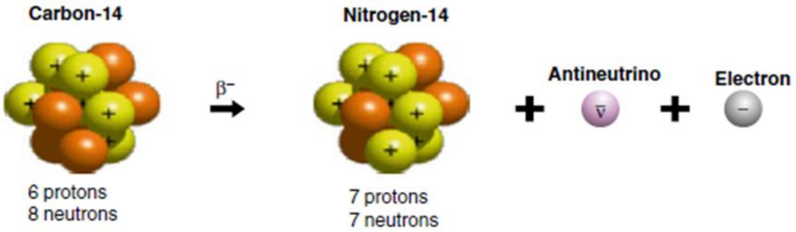

Figure 2.12 β^- decay [15]

If a radionuclide is unstable due to an excess amount of protons or a lack of neutrons, one of the protons transforms into a neutron and a small positively charged particle called a positron in a process termed β^+ *decay*. The neutron stays in the nucleus while the positron is propelled out of it (Figure 2.13). The atomic number of the radionuclide that emits the positron decreases by one, and thus it changes into the preceding element in the periodic table. Again, note that the mass number does not change.

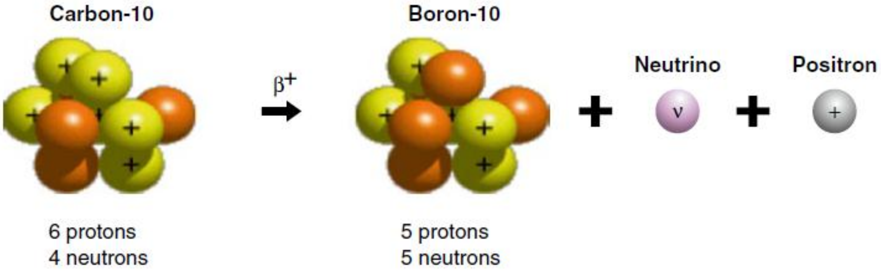

Figure 2.13 β^+ decay [15]

If the nucleus is unstable due an excess amount of protons, one of the electrons close to the atomic nucleus, such as an electron in a K and L orbital, is captured by the nucleus (Figure 2.14). This electron then combines with a proton, yielding a neutron and a neutrino. This process is called *electron capture*. Note that no particle is emitted from the nucleus, but the atomic number decreases by one, as in positron decay. Yet again, the mass number does not change. The space in the inner orbital is filled by an electron from an outer orbital, resulting in the emission of characteristic X-rays.

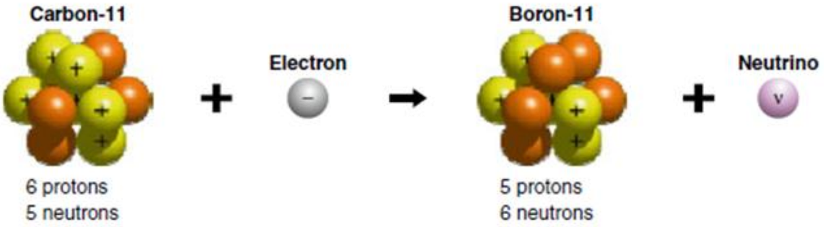

Figure 2.14 Electron capture phenomenon [15]

In all three types of beta decay, the mass number of the nucleus remains constant during the decay, while the numbers of protons and neutrons change by one unit. Furthermore, the emission of some massless, uncharged particles called neutrinos and antineutrinos is observed during each beta decay process. The existence of these particles was first suggested by Pauli in 1930, although it was Fermi that provided the name "neutrino".

2.3 RADIOACTIVITY

2.3.1 Radioactivity and Radioactive Decay Law

Nuclei, with the same atomic number (Z) and different mass number (A) or neutron number (N) are called isotope [16]. Stable isotopes are nuclei that do not change spontaneously over time. In contrast, the unstable radioactive nuclei are isotopes that change over time.

Nuclei with small atomic number tend to have equal number of neutrons and protons (N=Z). If atomic number is increased, neutron number is increased faster than atomic number (N>Z). Figure 2.15 shows neighboring nuclei to stability bar. According to the figure 2.15, N is approximately equal to Z ($N \cong Z$) for small Z values and $N \cong 1.6 \cdot Z$ for larger values.

There are approximately 250 stable isotopes. The numbers of stable isotopes vary with atomic number and neutron count is odd or even. In approximately 60% of stable isotopes, both atomic number and neutron count is even; in 20% of them, atomic number is even and neutron count is odd; in the other 20% of stable isotopes both atomic number and neutron count is odd. In only 5 stable isotopes, both atomic number and neutron count is odd.

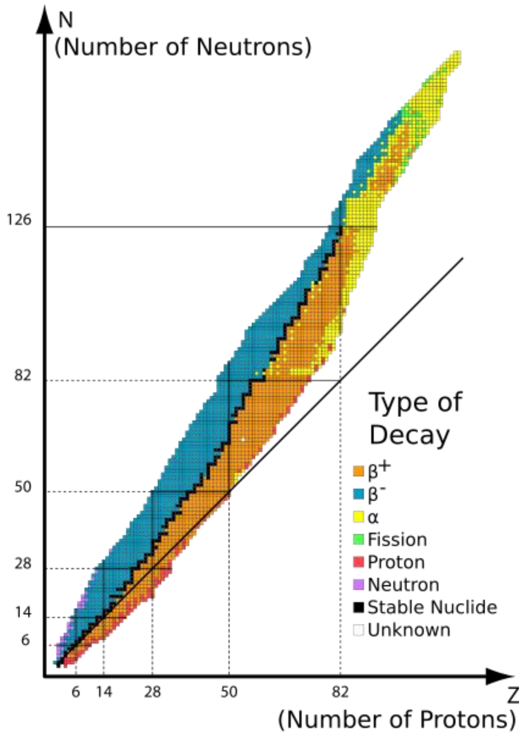

Figure 2.15 Graph of number of neutron versus to number of proton [17]

Unstable nuclei fling off excess energy carried by their by emitting particle or radiation. This event making conversion itself or emitting radiation is called radioactivity. Transformed into a nucleus to another isotope particle self-releasing or even the same isotope turned into another state is called radioactive decay.

Radioactive decay of radioactive atoms of a radioisotope is time-independent and represents completely a coincidental character. Number of fragments is proportional to only the current number of atoms and refers to number of decay per unit of time. Experimental results show that the properties of radioactive decays are exponential. In a radioactive disintegration, if decay constant λ indicates the decay probability per unit time, decay probability of any nucleus is λdt for a dt time. If there are N radioactive nuclei at t moment, decayed number of nuclei in time $t+dt$ is

$$dN = -\lambda N dt \qquad (2.1)$$

The minus sign on the left side of the equation shows that the number of radioactive atoms decreases (inversely proportional) with increasing over time. Assuming that number of radioactive nuclei is N_0 at $t=0$ and if either side of Eq.(2.1) divided by N, then the equation is integrated with substituting boundary conditions;

$$N = N_0 e^{-\lambda t} \tag{2.2}$$

Eq.(2.2) is found. Where, N is the number of radioactive nuclei at any t time. This law, according to Eq.(2.2), the number of radioactive nuclei varies over time, is radioactive decay law. According to the time derivate of both side of Eq.(2.2);

$$\begin{aligned} A &= -\frac{dN}{dt} \\ A &= \lambda N \end{aligned} \tag{2.3}$$

where A is the activity. Another important characteristic value of radioactive substances is the half-life. Half-life, abbreviated $t_{1/2}$, is the period of time it takes for the amount of a substance undergoing decay to decrease by half. To determine the half-life, in Eq.(2.2) if t equal to $t_{1/2}$ and N equal to $N_0/2$, correlation between half-life and decay constant is

$$t_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}. \tag{2.4}$$

The average time that has undergone until decaying of a nucleus is called mean lifetime (τ). N is the number of nuclei remaining intact in time t and t and t + dt ranges the number of decay nuclei is $|dN/dt|\,dt$. In this case, the mean lifetime,

$$\tau = \frac{\int_0^\infty t\,|dN/dt|\,dt}{\int_0^\infty |dN/dt|\,dt} \tag{2.5}$$

equation is written. Term at denominator is the total number of nuclear decays. The integral is taken,

$$\tau = \frac{1}{\lambda} \tag{2.6}$$

is found. Mean lifetime, simply, is the opposite of decay constant.

2.3.2 Sequential Decay Law

Radioactive isotopes decay may occur in case of successive ruptures [18]. The main radioactive element to another product, the product of radioactive decay is another element. This decay ends up the product being a decisive element. A radioactive decay, such as N1, N2, N3, ..., Ni-1, Ni the actual process resulted in the radioactive product. This process is continued until the latest stable isotope.

$$N_1 \xrightarrow{\lambda_1} N_2 \xrightarrow{\lambda_2} N_3 \xrightarrow{\lambda_3} .... \xrightarrow{\lambda_{i\text{-}2}} N_{i\text{-}1} \xrightarrow{\lambda_{i\text{-}1}} N_i \quad \text{stable} \qquad (\text{i}=1,2.........\text{n})$$

Here, $\mathrm{N_1, N_2, N_3......, N_{i\text{-}1}, N_i}$ ($\mathrm{N_i}$ stable nucleus) members of any series of degradation at time t and λ_1, indicate decay constants of these radioactive nuclei. At any t time the number of nuclei, description of the activity, the number of decay per unit of time, given to the following differential equations:

$$\begin{aligned} \frac{dN_1}{dt} &= -\lambda_1 N_1 \\ \frac{dN_2}{dt} &= \lambda_1 N_1 - \lambda_2 N_2 \\ \frac{dN_i}{dt} &= \lambda_{i-1} N_{i-1} - \lambda_i N_i \end{aligned} \tag{2.7}$$

Solutions of these equations depend on the initial conditions. For the initial time t = 0 there is only the main nucleus, if we accept that daugther and grandchildren are not available nuclei : $\mathrm{N_1{=}N_{10}}$ and $\mathrm{N_2{=}N_3{=}N_4{=}..........{=}N_i{=}0}$ .Thus,

$$\begin{aligned} N_1 &= N_{10} e^{-\lambda t} \\ N_1 &= N_{10} \lambda_1 \left[\frac{e^{-\lambda_1 t}}{(\lambda_2 - \lambda_1)} + \frac{e^{-\lambda_2 t}}{(\lambda_2 - \lambda_1)} \right] \end{aligned} \tag{2.8}$$

the complete solution:

$$N_i = N_{10} \prod_{j=1}^{j=i-1} j \sum_{j=1}^{j=i} \frac{e^{-\lambda_j t}}{\prod\limits_{\substack{k=1 \\ k \neq j}}^{k=i} \left(\lambda_i - \lambda_j\right)} \tag{2.9}$$

are obtained in the form. In sequential decay change the number of nuclei over time is shown in Figure 2.16 .

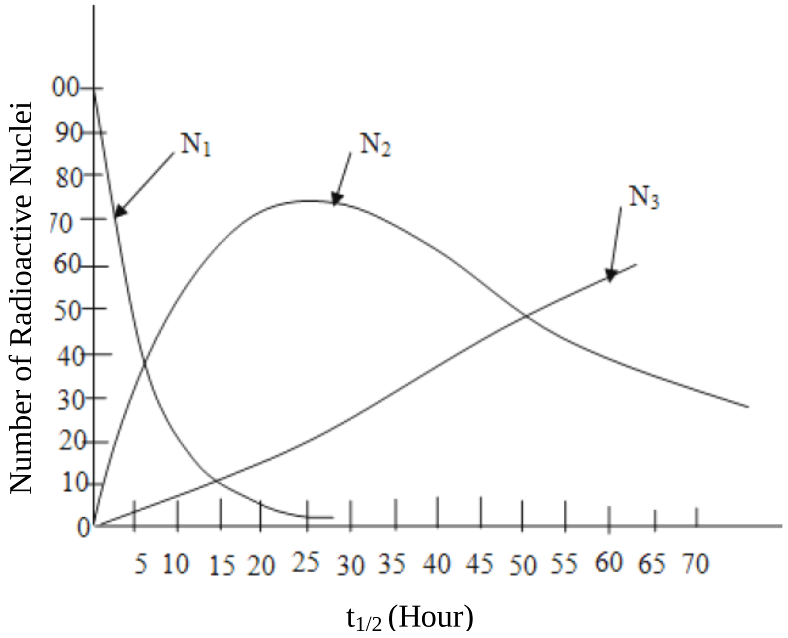

Figure 2.16 Graph of Sequential Decay [16]

2.3.3 Radioactive Equilibrium

When we apply some special cases to the decay chain equations, the two equilibrium occur. First of these special cases occurs when $\lambda_1 \cong \lambda_2$, this case is temporary equilibrium. Second case occurs when $\lambda_1 < \lambda_2$, this case is stable equilibrium.

2.3.3.1 Transient Equilibrium

Consider that λ_1 is the decay constant of one main nucleus and λ_2 is decay constant of its product. Suppose that the same extent to the average life of these two types nucleus and thus $\lambda_1 \cong \lambda_2$**.** In this case,

$$N_2 = \frac{\lambda_1}{(\lambda_2 - \lambda_1)} N_{10}(e^{-\lambda_1 t} - e^{-\lambda_2 t}) \tag{2.10}$$

at this equation if take derivative according to t and and set equal to zero, find t_m which N_2 reaches maximum value. After t_m time, λ_1 and λ_2 whichever is smaller will be effective on decay rate. Here it is;

i) if $\lambda_1 < \lambda_2$, at Eq.(2.10) $e^{-\lambda_2 t}$ term quickly reach zero, and therefore the term can be omitted. So,

$$N_2 = \frac{\lambda_1}{(\lambda_2 - \lambda_1)}(N_{10}e^{-\lambda_1 t}) \tag{2.11}$$

$$N_2 = \frac{\lambda_1}{(\lambda_2 - \lambda_1)} N_1 \tag{2.12}$$

Eq.(2.12) shows that first product decay with decay constant of main nucleus.

ii) if $\lambda_2 < \lambda_1$,

$$N_2 = \frac{\lambda_1}{\left(\lambda_2 - \lambda_1\right)}\left(-N_{10}e^{-\lambda_2 t}\right) \tag{2.13}$$

This equation shows that after a certain time first product decay with itself decay constant λ_2.

2.3.3.2 Secular Equilibrium

Let us consider the status of the $\lambda_2 \gg \lambda_1$ at Eq.,(2.10). In this instance, it will be $\lambda_2 - \lambda_1 \cong \lambda_2$ and $e^{-\lambda_1 t} \cong 1$

$$N_2 = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_{10}(1 - e^{-\lambda_2 t}) \tag{2.14}$$

Moreover, if t is greater than the mean lifetime of the product element ($t \gg 1/\lambda_2$), $e^{-\lambda_2 t}$ term goes to zero.

$$N_2 = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_{10} \tag{2.15}$$

This expression shows that N_2 is fixed. In this expression, activity has stopped and there is a continuous equilibrium between the main element and first product element. The main element is a huge amount of half-life is almost constant ($N_{10} = N_1$). Because of

$$\lambda_1 N_1 = \lambda_2 N_2 \tag{2.16}$$

continuous equilibrium condition is obtained.

2.3.4 Natural Radioactive Series

Natural radioactive series consisted of three groups as Thorium, Uranium and Actinium. Natural radioactive series and features are given Table 2.1.

Table 2.1 Natural Radioactive Series

	The longest life member		
Name of Serie	**Nucleus**	**Half-life (year)**	**Last Product (Stable)**
Uranium	^{238}U	$4{,}47x10^{9}$	^{206}Pb
Thorium	^{232}Th	$1{,}41x10^{10}$	^{208}Pb
Actinium	^{235}U	$7{,}04x10^{8}$	^{207}Pb

2.3.4.1 Uranium Series

Features given in the table 2.2 with three isotopes of uranium is a naturally occuring element in nature. There are lower amounts of uranium in layers of rock and soil that produce building materials. Uranium decay chain is seen Figure 2.17.

Table 2.2 Isotopes of Natural Uranium

Isotope	**Half-life (year)**	**Natural Abundance**
^{238}U	$4{,}47x10^{9}$	%99,29
^{235}U	$7{,}04x10^{8}$	%0,71
^{234}U	$2{,}45x10^{5}$	%0,006

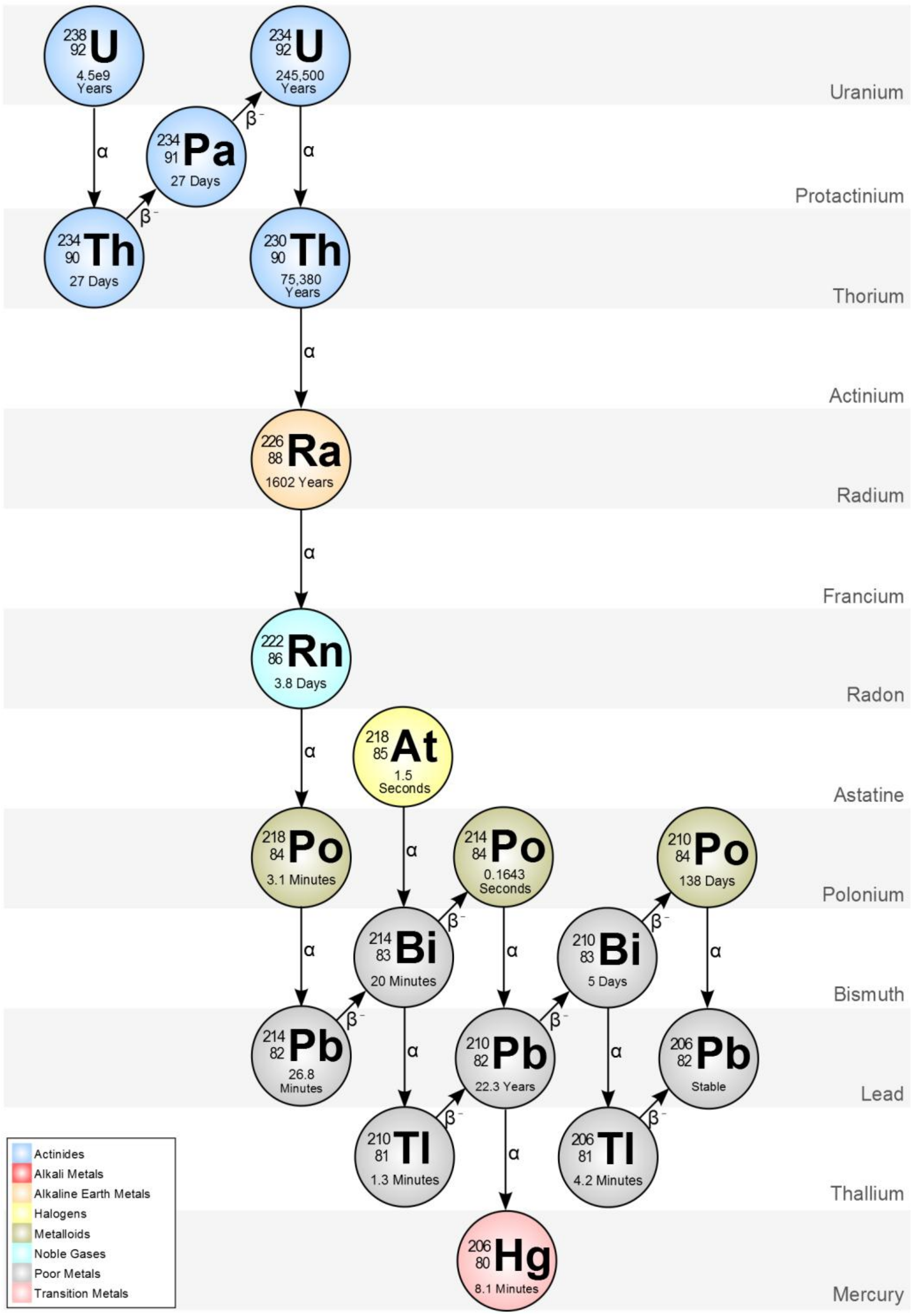

Figure 2.17 ^{238}U series decay chain [19]

^{238}U emits 8 α and 6β and decays until it turns to last non-radioactive daughter ^{206}Pb. Situated among the first products consisting and especially in indoor environments ^{222}Rn gas is very important for human health.

Uranium series gamma spectrum is very complex, so there is no peak characteristic to make quantitative measurements. Uranium spectrum has many gamma peaks and 1760 keV peak of ^{214}Bi is used to make quantitative analysis.

2.3.4.2 Thorium Series

Nuclides of thorium series contain 11 products. There is a complex spectrum of thorium series and almost all of them are always unstable. Thorium decay chain is given in Figure 2.18. The appropriate gamma peak of thorium series used in analysis is 2615 keV energy peak of ^{208}Tl.

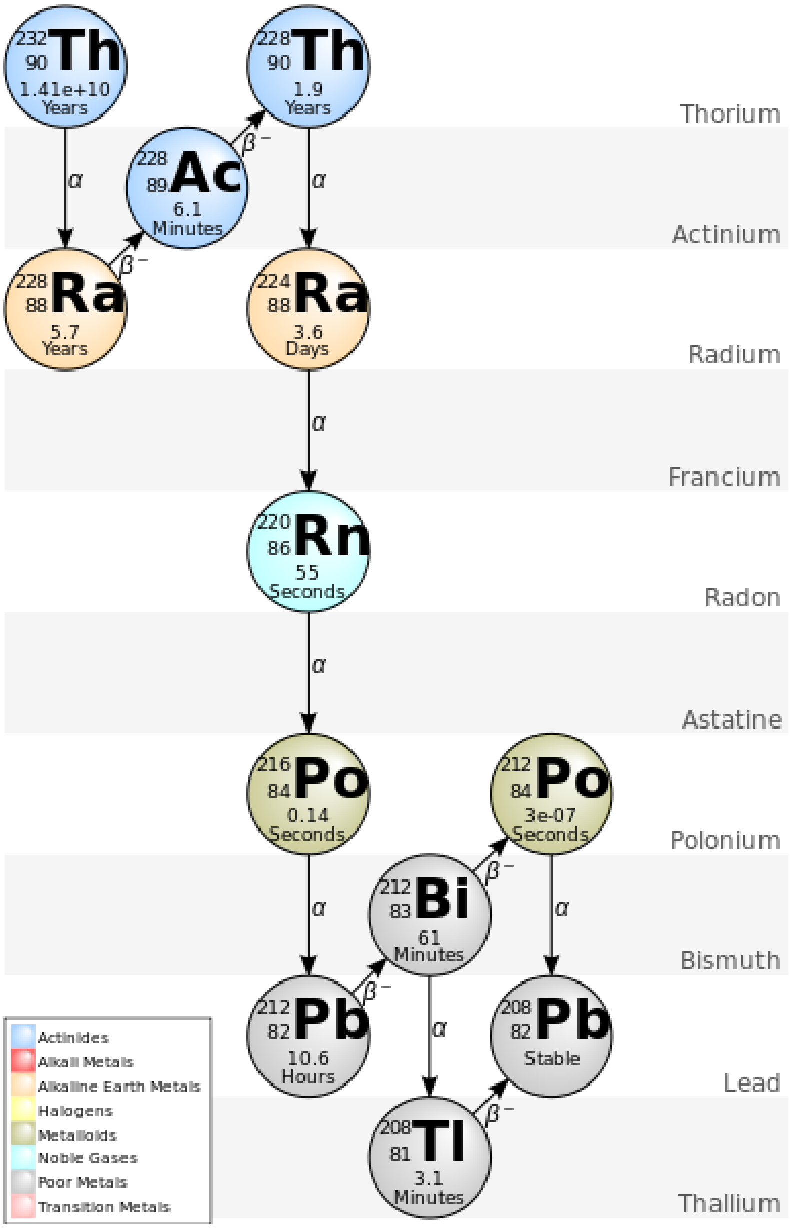

Figure 2.18 ^{232}Th series decay chain [19]

2.3.4.3 Actinium Series

^{235}U is the main element of the series and natural abundance of ^{235}U is %0.72. Ending with ^{207}Pb isotope. Actinium series decay chain is given in Figure 2.19.

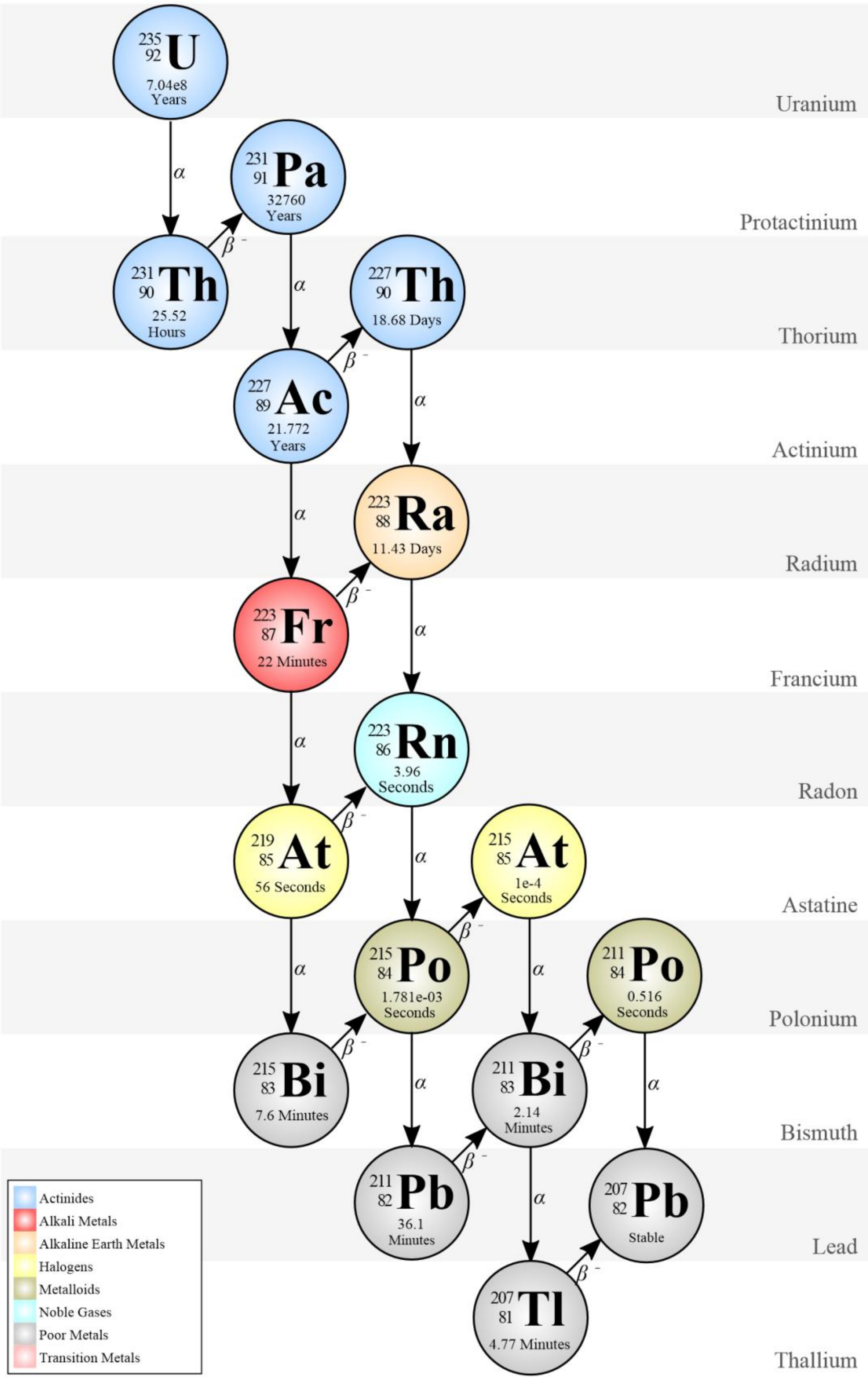

Figure 2.19 Actinium series [19]

2.3.5 Potassium 40

Potassium in the crust which is equal to 2.6% is an important element. Small amount of natural potassium (%0.12) is radioactive ^{40}K. Gamma ray energy of 1.461 MeV is released as a result of decay of ^{40}K. After the decay, nucleus produced is stable. Abundance of radioactive potassium is approximate 0,012 and half-life is 1.26x10^9 year and specific activity is 3.3 Bq/g.

2.4 IONIZING RADIATION UNITS

The amount of radiation delivered needs to be known in order to determine possible harmful biological effects and to reach definite conclusions in studies that use ionizing radiation. Specific units are required for radiation measurement. The measured quantities associated with ionizing radiation can be briefly summarized as follows (Figure 2.20):

Source → activity units

The first interaction point → kinetic energy released in matter (kerma)

Matter → absorbed dose

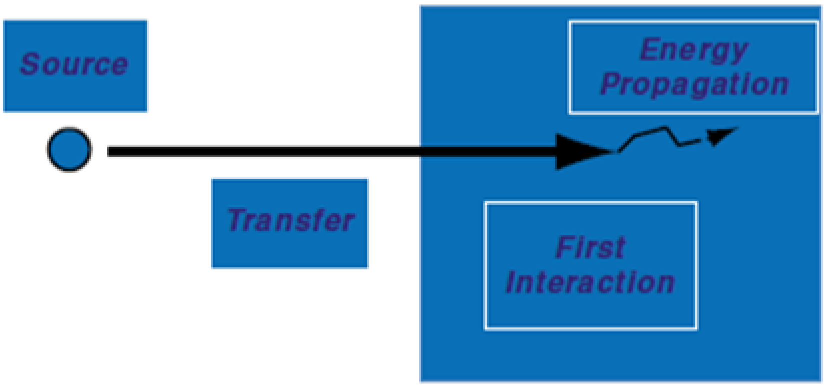

Figure 2.20 Three points of associated with ionizing radiation measurement

Activity unit. This is the number of spontaneous nuclear disintegrations *(N)* per unit time (t) (A = N/t), as measured in becquerels (Bq). Note that an older system of units, the curie (Ci), is also often encountered.

Radioactivity: This is the transition of an unstable nucleus to a steady state through the emission of particulate or electromagnetic radiation from the nucleus.

Curie (Ci): This is an activity of 3.7 x 10^{10} disintegrations per second.

Becquerel (Bq): This is an activity of one disintegration per second and 1 Bq=2.7 x 10^{-11} Ci or 1 Ci = 3.7 x 10^{10} Bq.

Kerma (kinetic energy released in the medium): This is the sum of the initial kinetic energies of all of the charged particles liberated by uncharged ionizing radiation (neutrons, protons) in a sample of matter divided by the mass of the sample. The kerma is measured in the same units as absorbed dose (Gy).

The *reference air kerma* is used to define the visible activity. It is the dose delivered in one hour to air one meter away from a source with an activity of 1 MBq. Its units are 1 μGy^{-1}. m^2 = 1 cGy. h^{-1}. cm^2.

Absorbed dose: The basic quantity associated with radiation measurement in radiotherapy is the absorbed dose. This defines the amount of energy absorbed from a radiation beam per unit mass of absorbent material. It is measured in grays (Gy), although an older unit, the rad, is also still used.

Rad. This is the amount of radiation that causes one erg (of energy) to be absorbed per gram of irradiated material (rad=radiation absorbed dose).

1 rad = 100 erg/g.

Gray (Gy). This is the amount of radiation that causes one joule to be absorbed per kilogram of irradiated material.

1 Gy = 1 J/kg.

1 Gy = 100 cGy = 100 Rad.

Exposure: This is the amount of ionization produced by photons in air. Since it is impossible to directly measure the absorbed dose in tissue, the measurement of radiation is performed in air. The exposure is the amount of radiation required to liberate a positive or negative charge of one electrostatic unit of charge (esu) in 1 cm^3 of dry air at standard temperature and pressure (this corresponds to the generation of approximately 2.08 x 10^9 ion pairs). It is measured in coulombs per kilogram (C/kg), although the old unit of the roentgen (R) is also commonly encountered.

Roentgen (R): In normal air conditions (0°C and 760 mmHg pressure), this is the amount of X-radiation or gamma radiation that produces 2.58×10^{-4} coulombs of electrical charge (in the form of ions) in one kilogram of air.

C/kg: In normal air conditions, this is the amount of radiation that produces one coulomb of electrical charge (in the form of ions) in one kilogram of air.

Integral dose: This is the total energy absorbed in the treated volume (in J=kg x Gy).

Equivalent dose: Since different radiations have different harmful effects on human tissues, the basic dosimetric unit of absorbed dose (Gy) is not sufficient for studies of radiation protection. Thus, the absorbed dose in tissue must be multiplied by a radiation- weighting factor that depends on the type of radiation employed. The resulting dose is called the equivalent dose, and it is measured in sieverts (Sv), although an older unit, the rem (roentgen equivalent man), is often used too.

$$H = D \times W_R \tag{2.17}$$

H = equivalent dose (Sv)
W_R = radiation-weighting factor (no unit)
D = dose (Gy)
1 Sv = 1 J/kg = 100 rem

The roentgen and C/kg are only used for photonic radiation (X-rays and gamma rays), not for particulate radiation. The energies of therapeutic or diagnostic gamma rays and X-rays are in the kilovolt (kV) or megavolt (MV) range, while the energies of therapeutic electrons are in the megaelectronvolt (MeV) range. The most important radiation quantities and their units are listed in Table 1.1. Also listed are the definitions of the various quantities and the relationships between the old and the SI units for these quantities [20].

Table 2.3 Radiation quantities, units and conversion between old and SI units

Quantitiy	Definition	SI unit	Old unit	Conversion
Exposure (X)	$X=\frac{\Delta Q}{\Delta m_{air}}$	$2.58\times\frac{10^{-4}C}{\text{kg air}}$	$\text{R}=\frac{1\text{esu}}{\text{cm}^3\text{air}_{\text{STP}}}$	$1\text{R}=2.58\times\frac{10^{-4}\text{C}}{\text{kg air}}$
Dose (D)	$D=\frac{\Delta E_{ab}}{\Delta m}$	$1\text{Gy}=1\frac{\text{J}}{\text{kg}}$	$1\text{ rad}=100\frac{\text{erg}}{\text{g}}$	1Gy=100rad
Equivalent dose (H)	$H=Dw_R$	1 Sv	1 Rem	1 Sv=100 rem
Activity (A)	$A=\lambda N$	1 Bq=1 s^{-1}	1 Ci=$3.7\times10^{10}\text{s}^{-1}$	$1\text{ Bq}=\frac{1\text{ Ci}}{3.7\times10^{10}}$

ΔQ is the charge of either sign collected;
Δm_{air} is the mass of air;
ΔE_{ab} is the absorbed energy;
Δm is the mass of medium;
w_R is the radiation weighing factor;
λ is the decay constant;
N is the number of radiactive atoms;
R stands for roentgen;
Gy stands for gray
Sv stands for sievert
Bq stands for becquerel
Ci stands for curie;
STP stands for standart temperature (273.2 K) and standart pressure (101.3 kPa).

2.5 RADIATION SOURCES

2.5.1 Natural Sources

There are three types of natural sources of radiation: cosmic, terrestrial, and internal [21]. Exposure from most of these sources is very minimal and therefore does not cause any measurable damage to our bodies. However, as it will be seen later in this section, there are some potentially hazardous materials, such as radon in our surroundings, which indeed are a cause of concern since they are capable to delivering high integrated doses.

2.5.1.1 Cosmic Radiation Sources

The outer space is filled with radiation that comes from a variety of sources such as burning (for example, our Sun) and exploding (for example, Supernovae) stars. These bodies produce immense amounts of radiation, some of which reach earth. Fortunately the earth's atmosphere acts as a shield to the worst of these radiations, such as ultraviolet rays from the Sun are blocked by the ozone layer. However not all of the harmful radiation is blocked and some reach the surface of earth causing skin burns and cancer in people who remain exposed to sun light for extended periods of time. The situation is even worse in places where the ozone layer has depleted due to some reasons.

On top of these localized sources of radiation there is also a background radiation of low energy photons. It is known as cosmic microwave background radiation since the photon spectrum peaks in the microwave region of the electromagnetic spectrum. Although these photons reach the earth's surface but due to their low energies, they are not deemed harmful.

Apart from photons, there are other particles as well that are constantly being produced in the outer space. Most of them, however, never reach the earth either due to magnetic deflection or the earth's upper protective atmosphere. Some of the particles, like muons, electrons, and neutrinos, are produced when other cosmic particles interact with atoms in the upper atmosphere. Shower of these particles reach earth's surface time but due to their low energies and low interaction probabilities, they do not pose any significant health hazard.

Muons and neutrinos directly produced by luminous objects in space also manage to reach earth due to their low interaction capabilities but are not considered hazardous to health due to their extremely low interaction cross sections.

2.5.1.2 Terrestrial Radiation Sources

This type of radiation is present in small quantities all around us and is more or less inescapable. Our surroundings, the water was drunk, the air was breathed in, and the food was consumed, all are contaminated with minute quantities of radiation emitting isotopes. Although these isotopes, in general, are extremely hazardous, they are not supposed to cause any appreciable harm to our bodies except when they are present in higher than normal concentrations.

The main source of terrestrial radiation is the element uranium and its decay products such as thorium, radium, and radon. Although the overall natural concentration of these radioactive materials is within the tolerable range of humans, some parts of the world have been identified where higher levels of uranium and thorium in surface soil have increased the radiation to dangerous levels. Unfortunately man has also contributed to this dilemma by carrying out nuclear explosions and by dumping nuclear waste.

The two isotopes of radon, ^{222}Rn and ^{220}Rn, and their daughter products are the most commonly found hazardous radioactive elements in our surroundings. The main cause of concern with respect to these α-emitting isotopes is their inhalation or digestion, in which case the short range α-particles continue to cause damage to internal organs that can lead to cancer.

2.5.1.3 Internal Radiation Sources

Human bodies contain some traces of radioactive elements that expose our tissues to continuous low level radiation. This internal radiation primarily comes from Potassium-40 and Carbon-40 isotopes. However the absorbed dose and the damage to tissues due to this radiation is minimal.

2.5.2 Man-Made Sources

Right after the discovery of radiation and realization of its potentials, scientists started working on developing sources that can be used to produce radiation in controlled laboratory environments. These sources are made for specific purposes and generally give off one type of radiation. Common examples of such sources are

- medical x-ray machines,
- airport x-ray scanners,
- nuclear medicines,
- particle accelerators, and
- lasers.

Out of all these sources, the ones used in medical diagnostics and therapy expose the public to the most significant amounts of radiation. For example a single chest x-ray exposes the patient to about 20 mrem of radiation, which is a significant fraction of about 360 mrem of total radiation exposure to general public due to all types of radiation. Repeated x-rays of patients are therefore discouraged unless there is absolute medical necessity.

There are also some consumer products that give off radiation although they have been made for some other purpose. Examples of such sources are

- television,
- smoke detectors, and
- building materials.

The down chart is taken from the National Council on Radiation Protection and Measurements (NCRP) Report No. 160.

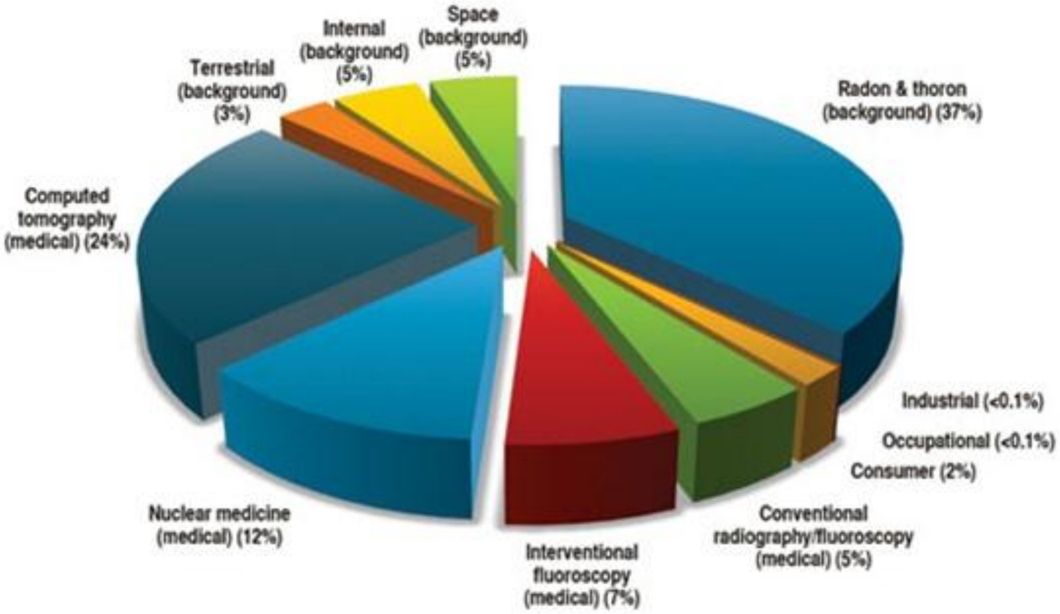

Figure 2.21 Exposure sources for collective effective dose of the Population of the United States, 2006 [22].

CHAPTER 3

MATERIAL AND METHOD

3.1 GAMMA SPECTROMETRY SYSTEM

Gamma spectrometry is a system that detects whether a material is radioactive or not and if it is radioactive it enables us to discover this radioactivity stems from which radioisotope and separate gamma rays released by these radioactive elements according to their energies [23].

The radiation emitted from a particular source generates a current pulse is proportional to the absorbed energy interacting with detector. This pulse is translated to voltage pulse with the help of amplifiers, amplified, shaped and come in multi-channel analyzer (MCA). Information translated and digitized in analyzer is observed on the spectrum. Information on this spectrum is taken out for consideration by an appropriate input/output (I/O) connected to MCA. A gamma spectrometer is made up of NaI(Tl) detector, high voltage unit (HV), preamplifier, amplifier, multi-channel analyzer (MCA) and computer (PC).

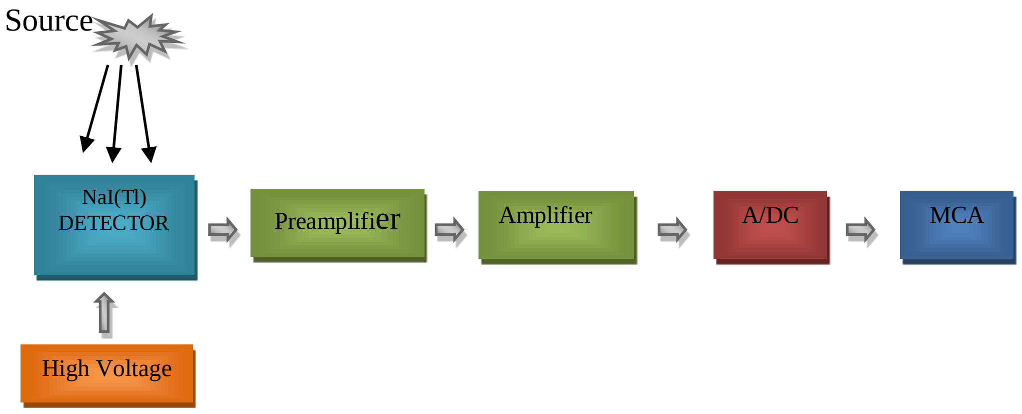

Figure 3.1. NaI(Tl) gamma spectroscopy system

3.1.1 NaI(Tl) Detector

Scintillation detectors consists a substance used as a scintillator and a photomultiplier tube connected directly behind it. Ionization and excitation occurs as a result of ionizing radiation interacting with solid, liquid or gaseous of certain substances called scintillator. When supplied energy to the electron is not enough to break the electron orbit, visible light (about wavelength between 3300 A^0 and 5000 A^0) is emitted with the induced electron returning to its previous state (Figure 3.2). Light emitted by the scintillator is converted into voltage pulse collected by photomultiplier tubes. Occurring pulse amplitude is proportional to the radiation energy. These detectors are used for counts, as well as energy separation.

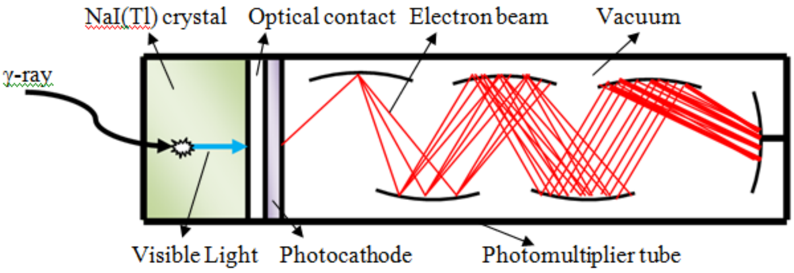

Figure 3.2 Schematic representation of the scintillation detector

As result of the absorption of γ-rays falling on the crystal consists of crystal light gleams. Passing through photomultiplier tube glitters cause removing electrons from the surface of the photocathode. These removed electrons drifting towards enhancements voltage will be placed one after the other way 800 to 1500 volts applied potential of many metals replicator. Each of these electrons drifting electron multiplier replicator transformed into more electrons allows the formation of large quantities of electrons at the replicator end of the tube. All of these events are speeded up less than a microsecond. Here, these electrons are converted to a load pulses. Height of this pulse is proportional to the energy of the photons. These pulses are amplified and counted with a counter.

Iodine`s atomic number in NaI scintillator is higher which makes it possible to obtain high yields of gamma rays detection. Generally the crystal is activated by adding a small amount of Thallium. Composed of this structure is called as NaI(Tl).

Figure 3.3 Ortec digiBASE and 3’’x3” NaI(Tl) detector [24]

The above figure shows the used detector (Ortec 3"x3" NaI(Tl)) and digiBASE tube base in this study for the measurements. The digiBASE is a 14-pin photomultiplier tube base for gamma-ray spectroscopy applications with NaI(Tl) scintillation detectors. The digiBASE combines a miniaturized preamplifier and detector high voltage (0 to +1200 V bias) with digital signal processing, multichannel analyzer, tube base with a USB connection.

3.1.2 High Voltage Unit

High voltage unit provides supply voltage (800V-1200V for NaI(Tl) detector) to detector. There are voltage units to create the electric field necessary for charge buildup [25].

3.1.3 Preamplifier

Preamplifier is used to enlarge the small signal coming from the detector, to adjust the level of resistance detector and subsequent components, to adjust the signal shape and to format.

3.1.4 Amplifier

Amplifier amplifies signals coming from preamplifier to able to analyze the signals and makes forming allowing the separation of energy.

3.1.5 Analog to Digital Converter (ADC)

Amplified and adjusted analog signal coming to analog to digital converter is converted to digital signal proportional to its amplitude.

3.1.6 Multi-Channel Analyzer

Multi-channel analyzer (MCA) places each digital signal coming to MCA to a memory channel proportional to its amplitude. Each channel corresponds to a specific energy in MCA and peak occurs by accumulation of the signals during the counting. The resulting peaks’ spectrum is monitored on the computer screen.

3.2 COLLECTION OF SAMPLES AND PREPARATION TO COUNTING

Location selection, method of taking soil samples and the method for preparing samples for testing are very important for gamma spectroscopy analysis. A soil sample not collected with due regard for method may lead to wrong results even if analyzed with the most advanced equipment and using the most sensitive methods, as well as lead to waste of money, effort and time [28]. The location of sample collection should have a diameter of about 10 m, the land should be clear and level, the water permeability good, the surface not entirely covered with vegetation or under the shade of high plants and their branches and leaves, far from buildings and trees, not recently cultivated or planted. The surface of the soil shall be unharmed with flood or excessive rain fall and under no danger of harm from these in the future, if possible, the land should be away from skirts of valleys. Also, rodents and worms which cause the layers of soil to mix together should be few. As much as possible, the diversity of vegetation should be minimal. The locations where the samples are taken from are determined using GPS. These locations should remain within 50 m of the previous sample location. The coordinates are noted on the soil sample information form.

When we take a soil sample from a big farm, the sample taken is very little compared to the soil on the farm. Thus it is evident how important the method to choose a sample location is, as it will represent the whole. A method to gather samples fit for the purpose must be determined when there is no method to gather a soil sample that is fulfilling in every way which fits all differing conditions and is generally accepted.

Radionuclides generally gather on the top layers of the soil; thus in non-agricultural locations the sample should be collected from a depth of 0-10 cm, while in agricultural areas the samples should be collected from a depth of 0-20 cm, which is the plough depth. Samples from at least three different points from around the sample collection location are mixed together. Samples are collected beginning from one end of the field or farm, and the other end of the field is reached by collecting samples. However, these samples shall be collected from holes dug in a zigzagged pattern shown in Figure 3.4 along a straight line drawn from one end of the farm to the other.

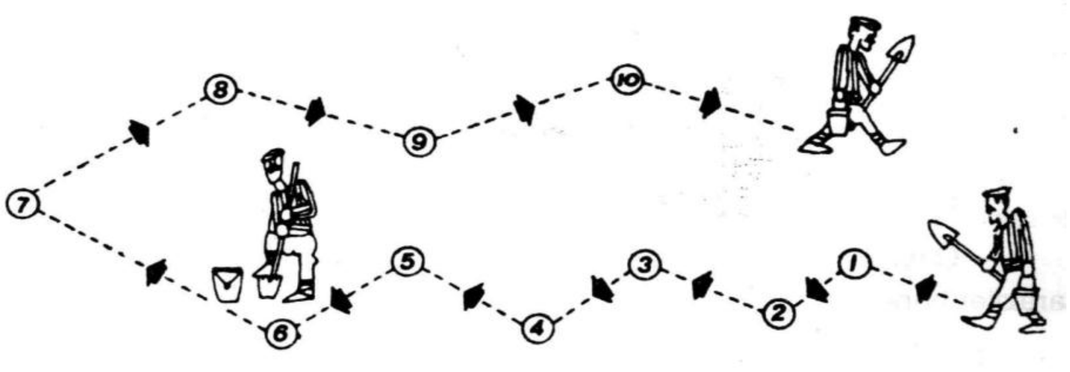

Figure 3.4 The schematic representation of the collection of soil samples. [26].

The other end of the field or farm is reached thusly by putting each sample in bucket as they are collected and moving along to the next hole. Samples collected and placed in the bucket one on top of the other are thoroughly mixed together. About 2 kg of this mixture is put in a paper, nylon or clothe bag.

Collected soil samples are dried at room temperature and in way that avoids dust gathering on them. The decision of sieving the organic residue from these dried soil samples or preserving them as is depends entirely on the purpose of the study. Rock pieces are weeded out and thrown away. After being sterilized of the foreign matter and made into the size and homogeneity desired, the soil samples; are fragmentized and powdered and put into sample containers with labels and delivered to the laboratory for testing. 30 different soil samples were brought in, preserving bags weighting 2 kg. All these powdered samples were dried at 105C for 24 hours. After drying, each sample was placed into plastic containers of 100ml sieving by sieve of 0.1mm thick. Cover is closed and edges of cover are wrapped up with parafilm to prevent gas output. The prepared samples were stored to equilibrate radionuclides with their decay products for 40 days.

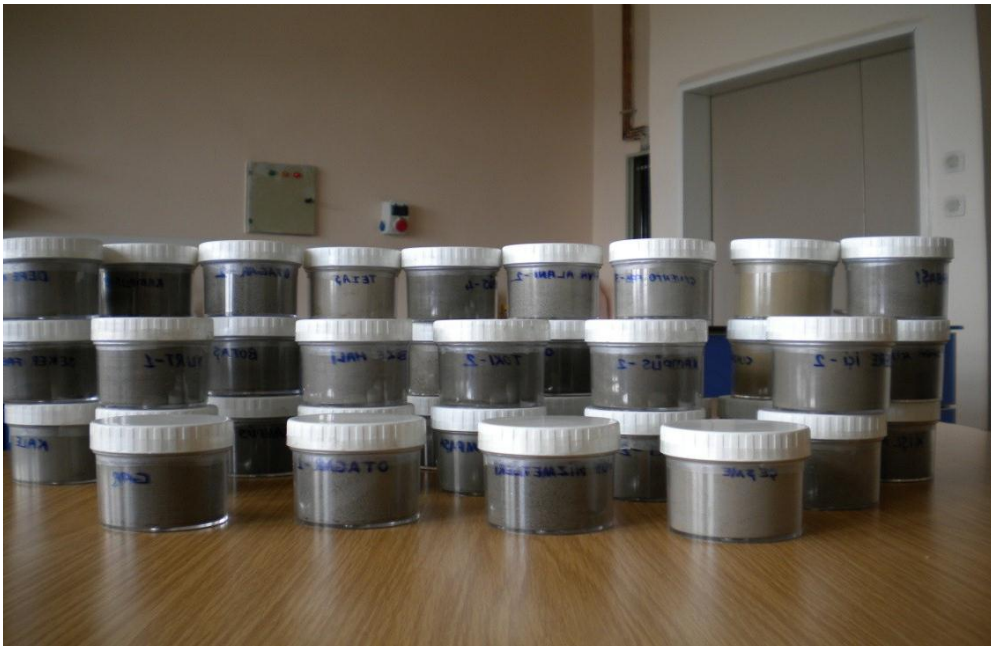

Figure 3.5 Soil Samples

3.2.1 Measurement Field

In this study, the barak regions of the Gaziantep city have been chosen as the measurement field and the natural radioactivity concentrations of the points shown with flags in Figure 3.2 (from where the soil samples were collected) were determined experimentally. Sample collection points have been determined using GPS (Garmin 12 XL).

Figure 3.6. Map

3.3 MEASUREMENT

The measurements were taken 55000 seconds by the NaI(Tl) gamma spectrometer for each sample. Detector shielded with 3 cm thick layer of lead in order to prevent external background radiation from the environment is shown in figure 3.7. ^{40}K activity from its gamma peak, ^{226}Ra and ^{232}Th activities from daughter radionuclides' peaks in constantly equilibrium with themselves is determined by spectrums taken from NaI(Tl) detector gamma spectrometry system.

Figure 3.7 Gama spectrometer system

3.4 ENERGY CALIBRATION

For the correct radioactivity analysis of the collected samples, the energy calibration should be performed before experimental measurements with known radioisotopes [26]. Then the spectra in the computer memory will be compared with the measured spectras of collected samples. In order to energy calibration, the energy of the gamma rays emitted by the radioactive sources must be known and therefore the standard radioactive sources whose energies are known were first used in this study. Table 3.2 provides information on standard radioactive sources (^{137}Cs (661,6 keV) and ^{60}Co (1173 keV-1332,5 keV)) used for calibration of NaI(Tl) detector systems in this study and the decay scheme of these sources is shown in figure 3.8 The standard source first was placed in front of the detector and then its spectrum was recorded by the computer. The recorded spectrums of ^{137}Cs and ^{60}Co are shown in figures 3.9 and the energy according to the channel is shown in the figure 3.10.

Table 3.4 Features of Calibration Sources

Radionuclide	Energy (keV)	Ratio of γ-rays to disintegrations
^{137}Cs	661,6	85,2%
^{60}Co	1173	99,9%
^{60}Co	1332,5	100%

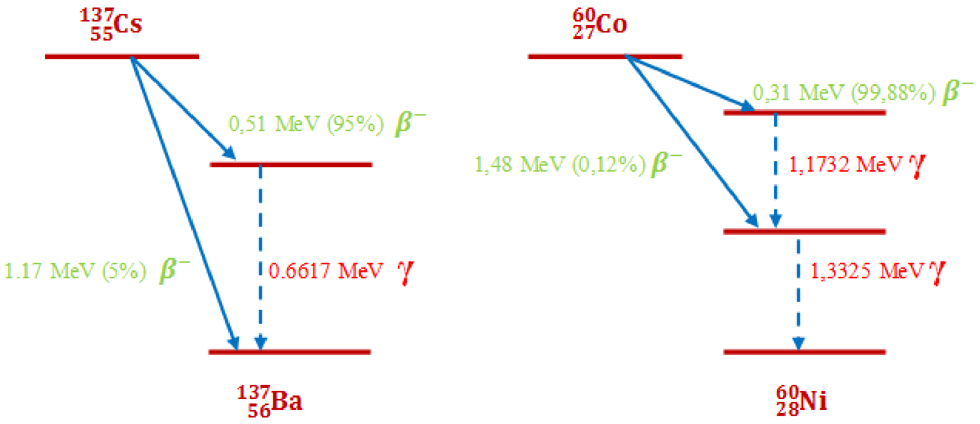

Figure 3.8 ^{137}Cs and ^{60}Co decay scheme

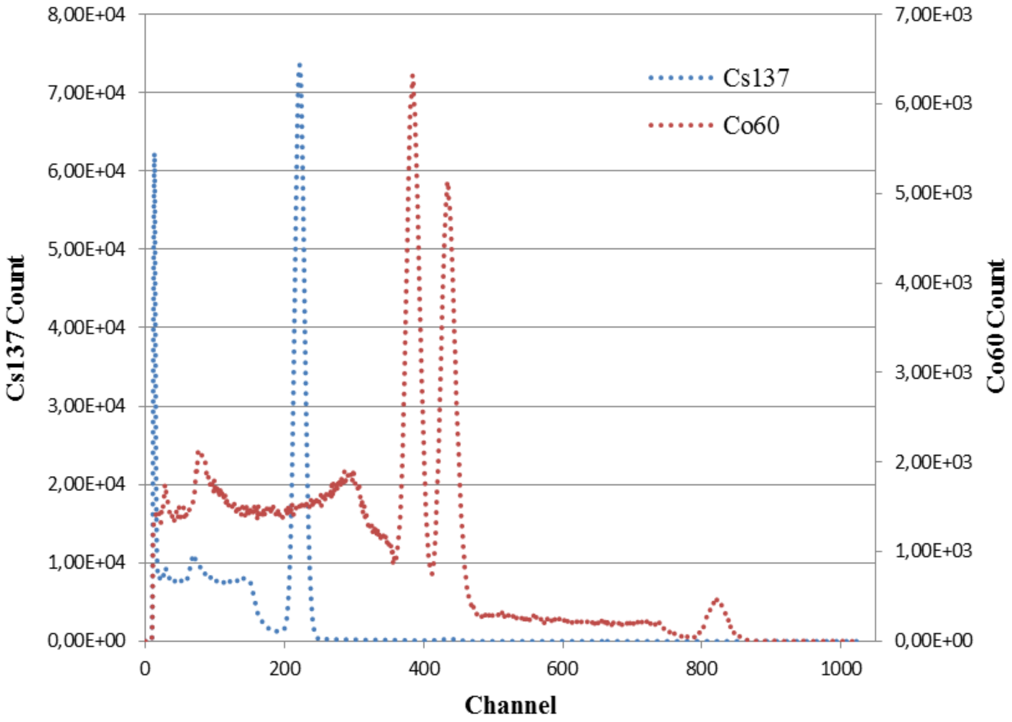

Figure 3.9 The gamma spectrum of ^{137}Cs and ^{60}Co.

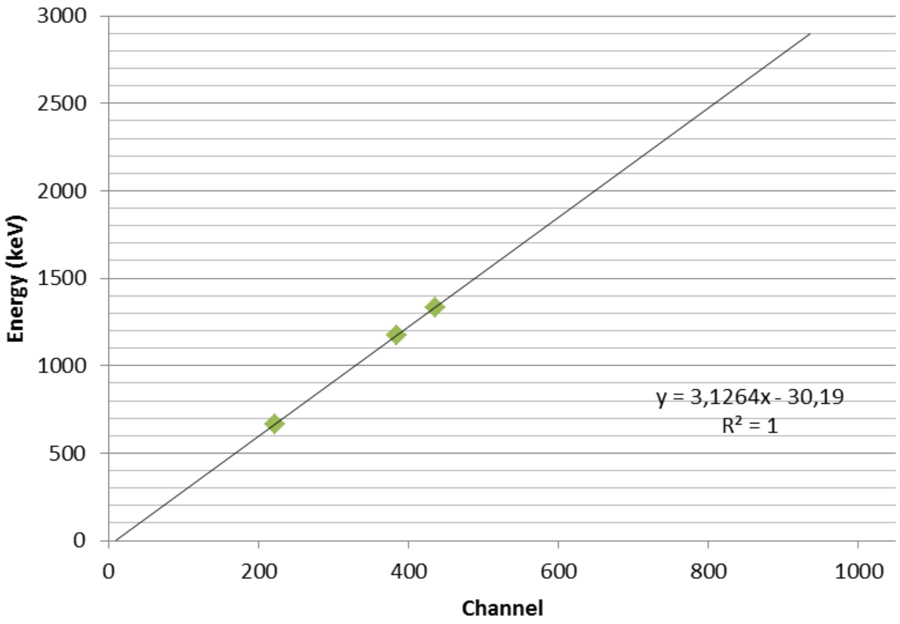

Figure 3.10 Energy calibration graph

3.5 CALCULATION OF ACTIVITY USING METHOD OF COMPARISON WITH THE STANDARD

3.5.1 Peak Info Calculation

After the samples were counted with detector, the net area under interested peak in the measured spectrum should be calculated to obtain the activity of the samples [27]. In this study; a commercial Ortec ScintiVision software program was used for calculation of peak area. This program is commonly used to calculate the area of a single peak. ScintiVision peak area calculation is based on Covel Method. The method is explained in below and another peak does not contribute to interested peak as shown in figure.

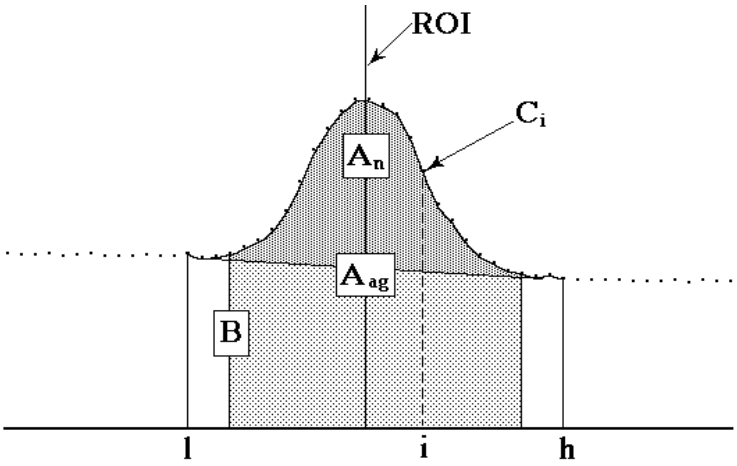

Figure 3.11 The detail background calculation.

The background is given by:

$$B=\left(\sum_{i=l}^{l+2}C_i+\sum_{i=h-2}^{h}C_i\right)\frac{h-l+1}{6} \tag{3.1}$$

where:

B = the background area

l = the region of interest (ROI) low limit

h = the ROI high limit

C_i = the contents of channel i

6 = the number of data channels used (three on each end)

The gross area is the sum of all the channels marked by the ROI according to following:

$$A_g=\sum_{i=l}^{h}C_i \tag{3.2}$$

where:

A_g = the gross count

l = the ROI low limit

h = the ROI high limit

C_i = the contents of channel i

The adjusted gross area is the sum of all the channels marked by the ROI but not used in the background, calculated as follows:

$$A_{ag} = \sum_{i=l+3}^{h-3} C_i \tag{3.3}$$

where:

A_{ag} = the adjusted gross counts in the ROI

l = the ROI low limit

h = the ROI high limit

C_i = the contents of channel i

The net area is the adjusted gross area minus the adjusted calculated background, as follows:

$$A_n = A_{ag} - \frac{B(h-l-5)}{(h-l+1)} \tag{3.4}$$

The uncertainty in the net area is the square root of the sum of the squares of the uncertainty in the adjusted gross area and the weighted error of the adjusted background. The background uncertainty is weighted by the ratio of the adjusted peak width to the number of channels used to calculate the adjusted background. Therefore, the net peak-area uncertainty is given by:

$$\sigma_{A_n} = \sqrt{A_{ag} + B\left(\frac{h-l-5}{6}\right)\left(\frac{h-l-5}{h-l+1}\right)} \tag{3.5}$$

where:

A_{ag} = the adjusted gross area

A_n = the net area

B = the background area

l = the ROI low limit

h = the ROI high limit

3.5.2 Efficiency

In gamma spectroscopy, the area under the interested peak represents the amount of radioactivity. Therefore, peak area and efficiency are needed to determine the radioactivity. Efficiency establishes a relationship between number of gamma rays emitted from sources and the number of counts counted in spectrum. Efficiency of the detector system depends on the effects of arising from the detector itself, the effects of the source-detector geometry, the impact of substances, the materials around the detector and the effect of self-absorption in source material. Peak efficiency is determined using activity of certainly known standard sources. Standard sources and samples must have the same geometry and density to obtain correct results. Peak efficiency is determined by the equation for required gamma energies.

$$\varepsilon_\gamma = \frac{N_{net}}{AI_\gamma t} \tag{3. 6}$$

wherein ε_γ counting efficiency for energy E_γ, N_{net} peak area formed by the photon energy E_γ, t counting time of standard source in detector, A radionuclides known activity in the gamma standard source, I_γ ratio of γ-rays emission by radionuclide to disintegrations.

3.5.3 Activity

Activity is defined as number of decayed nuclei per unit of time, can be determined by Eq.(3.7).

$$A = \frac{N_{net}}{\varepsilon t I_\gamma} \tag{3.7}$$

where, calculated activity A, ε detector photo peak efficiency, t counting time, I_γ gamma emission probability per decay. The specific activity of samples SA (Bq/kg) can be calculated as follows.

$$SA = \frac{A}{m} \tag{3.8}$$

where, m is the mass of sample. Net peak area of interest in spectrum obtained after counting is calculated by background radiation correction.

$$SA_{sample} = \frac{CPS_{sample} - CPS_{background}}{\varepsilon I_\gamma m_{sample}} \tag{3.9}$$

where; CPS is count rate proportion of N_{net}/t . Activity of the sample, were to compare the activity of the reference material;

$$SA_{sample} = \frac{SA_{reference}\left(CPS_{sample} - CPS_{background}\right)m_{reference}}{\left(CPS_{reference} - CPS_{background}\right)m_{sample}} \qquad (3.10)$$

3.5.4 Uncertinity in Activity

Magnitudes in exprimental measurements always contain a specific error (uncertainity) [12]. Many times a magnitude is function of several other magnitude and statiscal error can be calculated by measured values and their errors. If variables of f function $f=(x_1,x_2,\ldots\ldots,x_n)$ is x_i and their errors is Δx_i, error of measurement of f function Δf:

$$\Delta f = \sqrt{\sum_{i=1}^{n}\left(\frac{\partial f}{\partial x_i}\Delta x_i\right)^2} \qquad (3.11)$$

According to Eq.(3.11), uncertinity in specific activity ΔSA_{sample} is equal to Eq.(3.11).

$$\Delta SA_{sample} = \sqrt{\begin{array}{l}\left(\frac{\partial SA_{sample}}{\partial SA_{reference}}\Delta SA_{reference}\right)^2 + \left(\frac{\partial SA_{sample}}{\partial CPS_{sample}}\Delta CPS_{sample}\right)^2 + \\ \left(\frac{\partial SA_{sample}}{\partial CPS_{background}}\Delta CPS_{background}\right)^2 + \left(\frac{\partial SA_{sample}}{\partial m_{reference}}\Delta m_{reference}\right)^2 + \\ \left(\frac{\partial SA_{sample}}{\partial CPS_{reference}}\Delta CPS_{reference}\right)^2 + \left(\frac{\partial SA_{sample}}{\partial m_{sample}}\Delta m_{sample}\right)^2\end{array}} \qquad (3.12)$$

3.5.5 MDA (Minimum Detectable Activity)

The MDA is then given as the following formula:

$$MDA = \frac{2.71 + 3.29\sqrt{2 \times \sum_{i=l}^{h} C_i}}{\varepsilon \times T \times \gamma_d} \qquad (3.13)$$

where

C_i = the channel contents of background channel I

l = the peak lower limit

h = the peak higher limit

ε = the efficiency at the peak energy

T = the live time of the acquisition

γ_d = the branching ratio

It should be noted that the MDA value will not always represent the maximum activity of a particular nuclide that might be present in a sample. Rather, it measures the limit of dedection for that particular nuclide. Theoretically, if a nuclide activity exceeds the dedection limit, the peak will be calculated.

For peaks of ^{214}Bi (609keV), ^{40}K (1460keV) and ^{218}Tl (2614keV), MDA values in used dedector are 9 Bq/kg, 47 Bq/kg and 15 Bq/kg, respectively.

3.6 CALCULATED PARAMETERS ON THE BASIS OF ACTIVITY

3.6.1 Absorbed Dose Rate

Absorbed dose in indoor air and appropriate annual effective dose due to gamma ray emission from radioactive nuclei (^{226}Ra, ^{232}Th and ^{40}K) in construction material are calculated by formula and information provided by UNSCEAR (2000) and EC (1999) [28-29]. Dose conversion coefficients have been calculated for a standard room in reports of EC and UNSCEAR. The room size is 4m x 5m x 2,8m. Thickness of the walls is 20 cm and wall, floor and ceiling density is 2350 kg/m^3 for concrete. These conversion coefficients are 0.08 nGy/h per Bq/kg for ^{40}K, 1.1nGy/h per Bq/kg for ^{232}Th and 0.92nGy/h per Bq/kg for ^{226}Ra.

$$D_{indoor}(nGy/h) = 0,92 \times A_{Ra} + 1,1 \times A_{Th} + 0,08 \times A_K \qquad (3.14)$$

where, A_{Ra}, A_{Th} and A_K are specific activity of ^{226}Ra, ^{232}Th and ^{40}K, respectively. Dose conversion coefficients for outdoors are 0.46 nGy/h per Bq/kg for ^{226}Ra, 0.62 nGy/h for ^{232}Th and 0.041 nGy/h per Bq/kg for ^{40}K.

$$D_{outdoors}(nGy/h) = 0,46 \times A_{Ra} + 0,62 \times A_{Th} + 0,041 \times A_K \qquad (3.15)$$

3.6.2 Annual Effective Dose

The indoor occupancy factor and conversion coefficient are taken into account to calculate annual effective dose. According to UNSCEAR (2000) reports, in recent times worldwide the average time spent indoors was determined to be 80% so indoor occupancy factor determined as 0.8 and exposure by adults absorbed dose in air to effective dose conservation factor of 0.7 Sv/Gy value was used.

$$AED(mSv/y) = D(nGy/h) \times 8760(h/y) \times 0,8 \times 0,7(Sv/Gy) \times 10^{-6} \qquad (3.16)$$

where, *D* is the value of the absorbed gamma dose rate

3.6.3 Radium Equivalent Activity

The distributions of natural radionuclides are not homogeneous in the samples under analysis. So it is a common radiological index is introduced to assess radiation damages on radioactive nuclei and actual level of ^{40}K, ^{232}Th and ^{226}Ra activity in samples. This index is generally known as radium equivalent activity and Beretka and Mathew (1985) determined by the expression,

$$Ra_{eq} = A_{Ra} + 1.43 A_{Th} + 0.077 A_K \qquad (3.17)$$

where, A_{Ra}, A_{Th} and A_K are specific activity of ^{226}Ra, ^{232}Th and ^{40}K, respectively [30]. In the definition of Ra_{eq} is assumed that 10 Bq/kg of ^{226}Ra, 130 Bq/kg of ^{40}K and 7 Bq/kg of ^{232}Th have the same gamma dose.

3.6.4 Hazard index

Krieger (1981) and Amrani and Tahtat (2001), in their studies, made a modeling of the risk of radiation exposure from building materials in areas that come into contact with the open air without doors and windows with thick walls [31-33]. This modeling is called as external hazard index (H_{ex}) and is calculated using the following formula.

$$H_{ex} = A_{Ra}/370 + A_{Th}/259 + A_K/4810 \leq 1 \tag{3.18}$$

H_{ex} value recognized in the world, in materials made of building blocks containing natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K should be less than 1. One of the most dangerous gases that can damage the internal organs is ^{222}Rn product of ^{226}Ra with very short half life. Krieger (1981) and Beretka and Matthew estimated acceptable concentration limits of ^{226}Ra for indoor environments. This criterion is called as the internal hazard index (H_{in}).

$$H_{in} = A_{Ra}/185 + A_{Th}/259 + A_K/4810 \leq 1 \tag{3.19}$$

For living beings, H_{in} value universally accepted should be less than 1 for residences made of building blocks that contain ^{226}Ra, ^{232}Th and ^{40}K.

3.6.5 Gamma Index

EU countries do not allow construction materials can cause containing amounts of radioactivity over annual effective dose of 1 mSv. Gamma index corresponds to the dose; A_{Ra}, A_{Th} and A_K are specific activity of ^{226}Ra, ^{232}Th and ^{40}K, respectively, to be calculated by the formula (EUROPEAN COMMISSION REPORT, 1999):

$$I_\gamma = \frac{A_{Ra}}{200} + \frac{A_{Th}}{300} + \frac{A_K}{3000} \tag{3.20}$$

According to the materials used, gamma index (I_γ) should not exceed the following values.

Table 3.6.5 Gamma Index Limits

Material	**I_γ**
Materials used for construction of building (concrete, etc.)	1
Surface materials (tile, ceramic, etc.)	6

The value of $I_\gamma \leq 0,5$ is equal or less than annual effective dose of 0.3 mSv and value of $I_\gamma \leq 1$ is equal or less than annual effective dose of 1 mSv [34].

3.7 RESULTS

Gamma spectra of all samples studied in this thesis was obtained after energy and efficiency calibration of the detector using standard calibration sources. The specific activities of all samples were calculated on the basis of gamma spectra of calibration samples. All radiation parameters were calculated on the basis of the specific activities obtained from the samples. Figure 3.7.1 shows a typical gamma spectrum obtained from sample of Soil1.

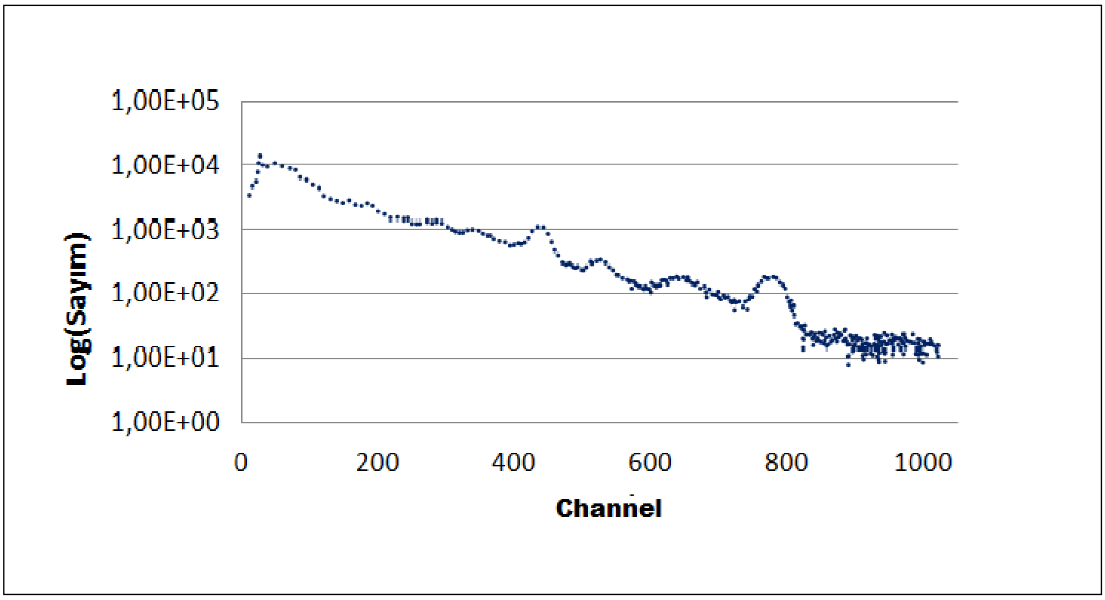

Figure 3.7.1 A typical gamma spectrum from sample of soil

3.7.1 Specific Activity

According to the analysed results obtained from the counted gamma spectra, the activity concentration of ^{40}K is ranged. The calculated specific activities and uncertainties of measured samples are given in table 3.7.1.For example 159,6±30,56 Bq/kg (Bağlarbaşı Ayrımı) to 139,72±32,83 Bq/kg (Oğuzeli Mezarlık Yanı). The activity concentration of ^{226}Ra is ranged from 61,473±7,102 Bq/kg (Soylu Köyü) to 32,40±4,95 Bq/kg (Barak Caddesi).The activity concentration of ^{232}Th is ranged from 44,741±13,021 Bq/kg (Karkamış) to 61,396±12,493 Bq/kg (Sazgın Köyü). The activity graphics of ^{40}K, ^{226}Ra and ^{232}Th are shown in figures 3.7.1.

Table 3.7.1.1 Spesific activities and uncertinities of measured samples

No	Sample	Activity ^{40}K (Bq/kg)	Error	Activity ^{238}Ra (Bq/kg)	Error	Activity ^{232}Th (Bq/kg)	Error
1	Havaalanı Yolu	356,906	43,389	17,914	4,776	53,139	11,701
2	Karkamış	218,042	45,276	25,396	6,019	44,741	13,021
3	Oğuzeli Merkez 6	198,809	49,192	31,156	7,922	44,742	13,311
4	Oğuzeli Merkez 7	213,38	37,547	29,39	5,727	39,773	11,048
5	Oğuzeli Merkez 8	176,653	38,331	28,83	6,788	45,98	10,292
6	Oğuzeli Merkez 9	225,663	44,411	28,598	7,147	55,2	11,624
7	Oğuzeli Merkez 10	117,734	36,496	18,79	6,257	40,911	10,531
8	Sazgın Köyü	353,923	45,175	43,118	7,907	61,396	12,493
9	Soylu Köyü	250,955	45,871	61,473	7,102	48,291	10,974
10	Dönüş	266,64	44,372	33,476	5,277	38,972	11,811
11	Altınyurt Karpuz Atan	246,043	44,59	12,64	5,61	54,72	12,66
12	Barak Caddesi	406,974	40,31	32,40	4,95	62,38	10,07
13	Biyolojik Atık Su Arıtma	413,612	51,44	16,2	5,06	95,28	11,39
14	Cansunar Süt Fabrikası	252,080	45,5	9,54	6,26	42,269	13,05
15	Direkli Köyü Dönüş	103,466	45,74	12,83	4,84	37,04	9,58
16	Direkli Köyü Gidiş (Keçisuyu)	310,605	42,49	19,19	5,27	42,99	11,74
17	İlçe Hastanesi Yanı	403,149	39,03	14,78	5,1	57,398	10,89
18	Karkamış Yolu Üzeri	220,999	38,25	21,770	5,14	39,232	8,86
19	Oğuzeli MYO	211,05	35,49	55,906	6,21	39,363	9,96
20	Oğuzeli Mezarlık Yanı	139,721	32,83	22,540	5,27	28,12	9,92
21	Suriye Kabul Konakları İnsaatı	466,839	41,49	33,82	5,17	72,246	11,29
22	Yeşildere 2	274,31	36,31	18,847	5,14	65,44	9,64
23	Yeşildere 1	325,747	30,67	20,698	5,77	76,92	9,17
24	Bağlarbaşı Ayrımı	159,601	30,56	19,867	5,38	19,415	9,19
25	G.Antep Kilis Yolu Üzeri	88,55	43,10	9,804	6,08	2,457	11,99
26	Havaalanı Ayrımı 1	314,995	44,59	25,293	6,19	33,376	11,51
27	Havaalanı Ayrımı 2	238,984	40,07	44,427	6,94	27,597	10,17
28	Kavşak Havaalanı	138,196	39,84	10,208	6,76	3,490	12,04
29	Şahinbey Anıtı	347,453	38,90	14,577	6,11	36,243	11,68
30	Toplu Konutlar Yanı	452,266	45,33	7,717	5,86	18,332	11,01

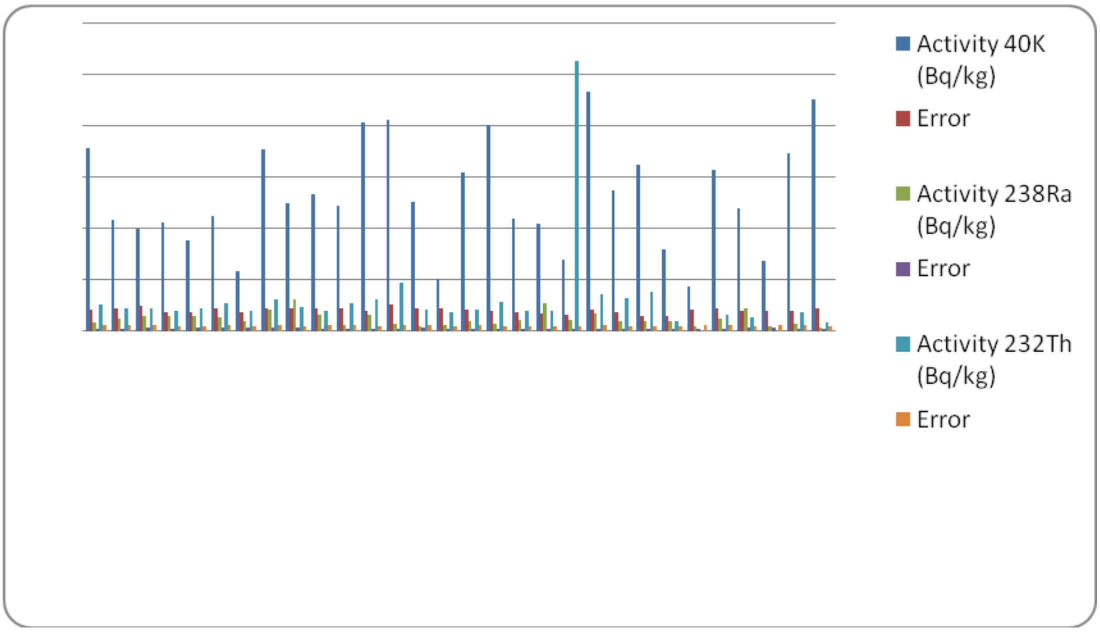

Figure 3.7.1.2 Spesific activities of measured samples

3.7.2 ^{40}K in the Activity Concentration in Soil Samples

^{40}K there is not a single task in the nature of decay series. Half-life of 1.26x10^9 years.1460 keV there is a peak of %11 in abundance. ^{40}K are in huge concentrations in soil.

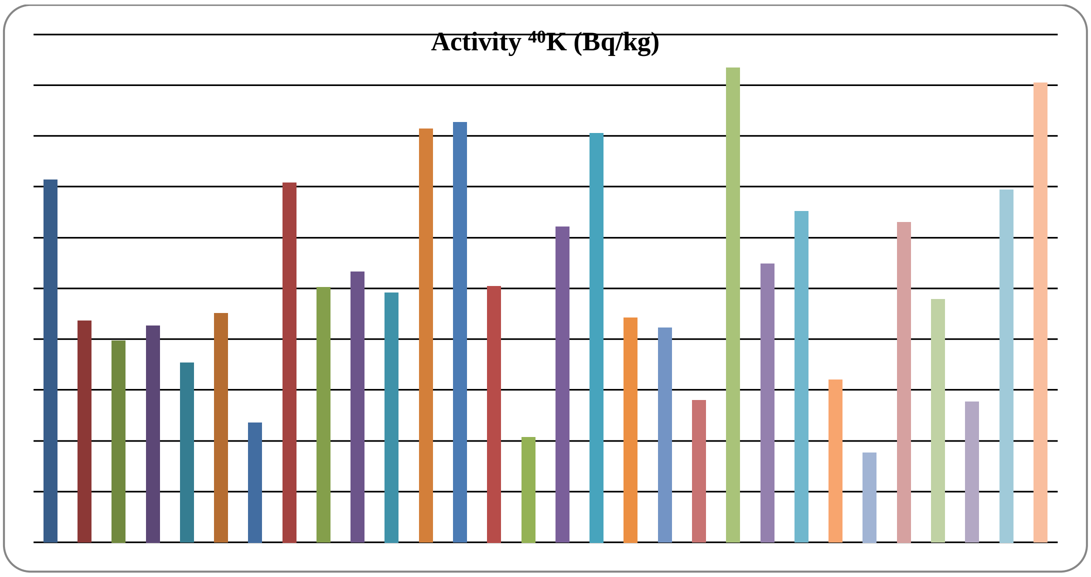

Figure 3.7.2.1 ^{40}K The Distribution of the soil sample from Barak region

3.7.3 ^{226}Ra (^{238}U) in the Activity Concentration in Soil Samples

^{226}Ra the concentration of radioactivity was found in the decay series; ^{214}Pb (352 and 295 keV the peak) and ^{214}Bi of (609 and 1764 keV the peak) was taken as the average of the activity concentration.In ideally ^{226}Ra with the product ^{220}Rn and ^{220}Rn with the girls ^{214}Bi and ^{214}Pb in that balance 295,352,609 and 1764.Best of the average of the activity of the peak ^{226}Ra (238) were calculated activity.

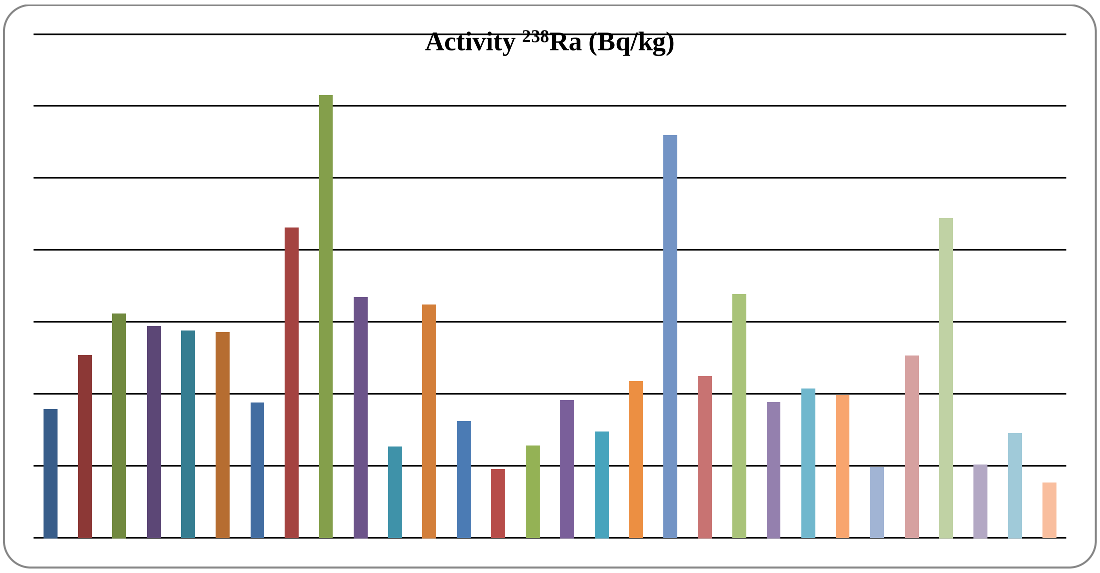

Figure 3.7.3.1 ^{226}Ra The Distribution of the soil sample from Barak

3.7.4 ^{232}Th in the Activity Concentration in Soil Samples

^{232}Th the concentration of radioactivity was found in the decay series; ^{208}Tl (583 keV of the peak) and ^{228}Ac in (338 and 911 keV of the peak) of the average activity concentrations.

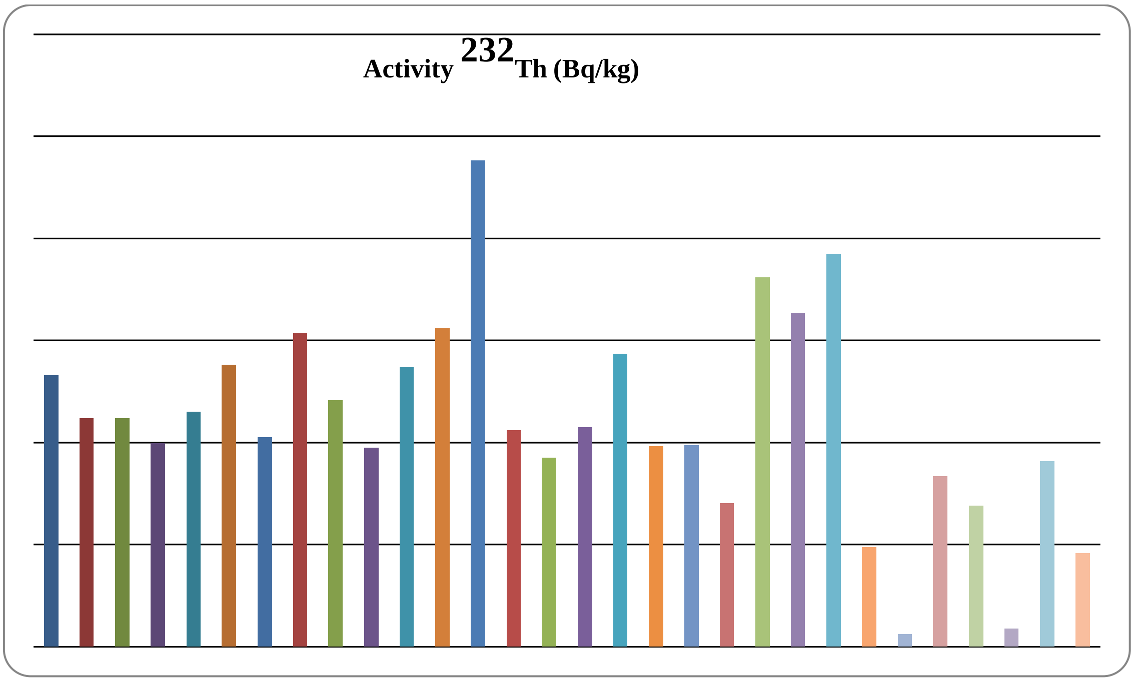

Figure 3.7.4.1 ^{232}Th Distribution of the soil sample from Barak region

CHAPTER 4

CONCLUSION

In this study, 30 soil samples taken from the region for the gamma spectrometric analysis methods are examined. Each soil sample was found to contain ^{238}U, ^{232}Th and ^{40}K with a varying concentration.

Average activity concentrations of ^{238}U is found as 10.25 Bq / kg and the maximum value of 61.47 Bq / kg was found at Soylu Köyü samples, while the minimum value was found in the samples of Toplu Konutlar Yanı as 7,717 Bq / kg.

The average activity concentration of ^{232}Th is found as 14.46 Bq / kg and the maximum value was found at the sample of Biyolojik Atık Su Arıtma as 95.28 Bq / kg, while the minimum value was found in the samples of Gaziantep Kilis Yolu Üzeri as 2,457 Bq / kg..

^{40}K average was found to be 213.68 Bq / kg and the maximum value was measured as 466.83 Bq/kg at the samples taken from Suriye Kabul Konukları İnşaatı, while the minimum value was found to be 88.55Bq/kg at the samples taken from Gaziantep Kilis Yolu Üzeri. In the UNSCEAR 2000 report, the world average activiyties of ^{238}U, ^{232}Th, and ^{40}K were published to be 35 Bq / kg, 30 Bq / kg, and 400 Bq/kg, respectively.

This study indicates that the average activities of ^{238}U, ^{232}Th are much lower than the average value of ^{40}K .The results obtained form this work for Barak region shows that the natural activities of the investigated isotopes are lower than the activity level of the world average. Further studies should be performed for different regions of Gaziantep City to get a better judgement for the natural radiactivity level.

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APPENDIX 1

IAEA-RGU-1 , Uranium Ore

Inorganic , Ores

- Unit Size: 500g
- Price per Unit: 50 EUR
- Report: IAEA/RL/148
- Date of Release: 1987-01-01
- Producing Laboratory: email

Both, IAEA-RGU-1 and IAEA-RGTh-1 reference materials were prepared on behalf of the International Atomic Energy Agency by the Canada Centre for Mineral and Energy Technology by dilution of a uranium ore BL-5 (7.09% U) and a thorium ore OKA-2 (2.89% Th, 219 µg U/g) with floated silica powder of similar grain size distribution, respectively. No evidence for between-bottles inhomogeneity was detected after mixing and bottling. BL-5 has been certified for uranium, ^{226}Ra and ^{210}Pb confirming that it is in radioactive equilibrium. The agreement between radiometric and chemical measurements of thorium and uranium in OKA-2 shows both series to be in radioactive equilibrium.

Analyte	**Value**	**Unit**	**95% C.I.**	**N**	**R/I/C**
^{232}Th	< 4$^{?}$	Bq/kg	-	None	I
^{235}U	228$^{?}$	Bq/kg	226 - 230	None	R
^{238}U	4940$^{?}$	Bq/kg	4910 - 4970	None	R
^{40}K	< 0.63$^{?}$	Bq/kg	-	None	I
K	< 20	mg/kg	-	None	I
Th	< 1	mg/kg	-	None	I
U	400	mg/kg	398 - 402	None	R

(Value) Concentration calculated as a mean of the accepted laboratory means
(N) Number of accepted laboratory means which are used to calculate the recommended or information values and their respective confidence intervals
(R/I/C) Classification assigned to the property value for analyte (Recommended/Information/Certified)
(?) Natural radionuclide activity concentrations derived from the elemental concentrations on basis of isotopic abundance and half-life data

The values listed above were established on the basis of a gravimetric dilution of materials with known uranium, thorium and potassium composition. The details concerning the criteria for qualification as a recommended or information value can be found in the respective report (attached).

IAEA-RGTh-1 , Thorium Ore

Inorganic , Ores

- Unit Size: 500g
- Price per Unit: 50 EUR
- Report: IAEA/RL/148
- Date of Release: 1987-01-01
- Producing Laboratory: email

Both, IAEA-RGU-1 and IAEA-RGTh-1 reference materials were prepared on behalf of the International Atomic Energy Agency by the Canada Centre for Mineral and Energy Technology by dilution of a uranium ore BL-5 (7.09% U) and a thorium ore OKA-2 (2.89% Th, 219 µg U/g) with floated silica powder of similar grain size distribution, respectively. No evidence for between-bottles inhomogeneity was detected after mixing and bottling. BL-5 has been certified for uranium, ^{226}Ra and ^{210}Pb confirming that it is in radioactive equilibrium. The agreement between radiometric and chemical measurements of thorium and uranium in OKA-2 shows both series to be in radioactive equilibrium.

Analyte	**Value**	**Unit**	**95% C.I.**	**N**	**R/I/C**
^{232}Th	3250$^{?}$	Bq/kg	3160 - 3340	155	R
^{235}U	3.6$^{?}$	Bq/kg	3.3 - 3.9	145	R
^{238}U	78$^{?}$	Bq/kg	72 - 84	145	R
^{40}K	6.3$^{?}$	Bq/kg	3.1 - 9.5	45	I
K	200	mg/kg	100 - 300	45	I
Th	800	mg/kg	784 - 816	155	R
U	6.3	mg/kg	5.9 - 6.7	145	R

(Value) Concentration calculated as a mean of the accepted laboratory means
(N) Number of accepted laboratory means which are used to calculate the recommended or information values and their respective confidence intervals
(R/I/C) Classification assigned to the property value for analyte (Recommended/Information/Certified)
(?) Natural radionuclide activity concentrations derived from the elemental concentrations on basis of isotopic abundance and half-life data

The values listed above were established on the basis of a gravimetric dilution of materials with known uranium, thorium and potassium composition. The details concerning the criteria for qualification as a recommended or information value can be found in the respective report (attached).

IAEA-RGK-1 , Potassium Sulfate

Inorganic , Ores

- Unit Size: 500g
- Price per Unit: 50 EUR
- Report: IAEA/AL/148
- Date of Release: 1987-01-01

- Producing Laboratory: email

The IAEA-RGK-1 material is produced from high purity (99.8%) potassium sulphate supplied by the Merck Company. The potassium property value and its uncertainty were obtained from repeated measurements performed at the IAEA Laboratories Seibersdorf and the results confirmed the value certified by Merck. The upper limits for the uranium and thorium property values were estimated by the IAEA Laboratories Seibersdorf using fluorimetry and activation analysis, respectively.

Analyte	Value	Unit	95% C.I.	N	R/I/C
^{40}K	14000?	Bq/kg	13600 - 14400	20	R
K	448000	mg/kg	445000 - 451000	20	R
Th	< 0.01	mg/kg	-	20	I
U	< 0.001	mg/kg	-	20	I

(Value) Concentration calculated as a mean of the accepted laboratory means
(N) Number of accepted laboratory means which are used to calculate the recommended or information values and their respective confidence intervals
(R/I/C) Classification assigned to the property value for analyte (Recommended/Information/Certified)
(?) Natural radionuclide activity concentrations derived from the elemental concentrations on basis of isotopic abundance and half-life data

The values listed above were established on the basis of a gravimetric dilution of materials with known uranium, thorium and potassium composition. The details concerning the criteria for qualification as a recommended or information value can be found in the respective report (attached).

APPENDIX 2

```
// Program of Radioactivity Analyses
#include <iostream>
#include <cmath>
#include <iomanip>

using namespace std;

double Ak, mk, SHn, SHb, SHk, mn;

enum { TAK=1, TMK, TSHN, TSHB, TSHK, TMN};

double An(){
return Ak*mk*(SHn-SHb)/((SHk-SHb)*mn);
}

//~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
double Turev(int k){
double h = 0.001, f1=0, f2=0;
if(k==1){
double oAk = Ak;
Ak = oAk + h; f1 = An();
Ak = oAk - h; f2 = An();
Ak = oAk;
return (f1-f2)/(2*h);
}
else if(k==2){
double omk = mk;
mk = omk + h; f1 = An();
mk = omk - h; f2 = An();
mk = omk;
return (f1-f2)/(2*h);
}
else if(k==3){
double oSHn = SHn;
SHn = oSHn + h; f1 = An();
SHn = oSHn - h; f2 = An();
SHn = oSHn;
return (f1-f2)/(2*h);
}
else if(k==4){
double oSHb = SHb;
Ak = oSHb + h; f1 = An();
Ak = oSHb - h; f2 = An();
Ak = oSHb;
return (f1-f2)/(2*h);
}
else if(k==5){
double oSHk = SHk;
SHk = oSHk + h; f1 = An();
SHk = oSHk - h; f2 = An();
```

```
SHk = oSHk;
return (f1-f2)/(2*h);
}
else if(k==6){
double omn = mn;
mn = omn + h; f1 = An();
mn = omn - h; f2 = An();
mn = omn;
return (f1-f2)/(2*h);
}
}
//~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~



//-------------------------------------------------------------------------
int main(){

cout<<"***************************************"<<endl;
cout<<"PROGRAM of RADIOACTIVITY ANALYSES"<<endl;
cout<<"***************************************"<<endl;
cout<<endl;

double  x, t, NPAn, dNPAn, NPAb, dNPAb, NPAk, dNPAk, dAn;

cout<<"Press for 40K Analyses 1, for 226Ra Analyses 2, for 232Th Analyses 3"<<endl;
cin>>x;

if(x<=1){ cout<<"*Potassium Analyses"<<endl;}

if(x==2){cout<<"**Uranium Analyses"<<endl;}

if(x>=3){cout<<"***Thorium Analyses"<<endl;}
cout<<endl;

cout<< "Counting Time = ";
cin>> t;

cout<< "Mass of Sample (Enter two digit after , )= ";
cin>> mn;

cout<< "Net Peak Area of Sample = ";
cin>> NPAn;

SHn=NPAn/t;
cout<< "Error of Net Peak Area of Sample = ";
cin>> dNPAn;

cout<< "Net Peak Area of Background = ";
cin>> NPAb;
SHb=NPAb/t;

cout<< "Error of Net Peak Area of Background = ";
cin>> dNPAb;

cout<< "Net Peak Area of Reference = ";
cin>> NPAk;
```

```
SHk=NPAk/t;


cout<< "Error Net Peak Area of Reference = ";
cin>> dNPAk;

double dAk, dmk;
if(x<=1){ Ak=14000;  dAk=400;
mk=149; dmk=0.005;}

if(x==2){Ak=4940; dAk=30;
mk=140; dmk=0.005;}

if(x>=3){Ak=3250; dAk=10;
mk=140.93; dmk=0.005;}

double dSHn=dNPAn/t;
double dSHb=dNPAb/t;
double dSHk=dNPAk/t;
double dmn=0.005;

cout<<"-------------------------"<<endl;
cout<< "AKTIVITY = "<<An()<<endl;

dAn = sqrt( Turev(TAK)*Turev(TAK)*dAk*dAk +
Turev(TMK)*Turev(TMK)*dmk*dmk +
Turev(TSHN)*Turev(TSHN)*dSHn*dSHn +
Turev(TSHB)*Turev(TSHB)*dSHb*dSHb +
Turev(TSHK)*Turev(TSHK)*dSHk*dSHk +
Turev(TMN)*Turev(TMN)*dmn*dmn );

cout<<"Error of Statistical = +-"<<setprecision(9)<<dAn<<endl;
cout<<endl;
cout<<endl;
cout<<endl;
cout<<endl;
cout<<endl;
cout<<endl;
cout<<"The program is working for reference material 149g RGK-1, 140g RGU-1 ve 140.93g RGTh-
1"<<endl;
cout<<endl;
cout<<endl;
double g;
cin>>g;
} /* main */
```