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Sudan University of Science and Technology

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كلية الدراسات العليا

Identifying the Radioactive Substances in Sample and Determining their Activities

تحديد العناصر المشعة في عينة وتحديد نشاطاتها

A thesis submitted for partial fulfillments of the requirement of the degree of science master in physics

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الايـــة

قال تعالي ﴿ فتبسم ضاحكا من قولها وقال رب أوزعني أن أشكر نعمتك التي أنعمت عليّ وعلى والدي وأن أعمل صالحاً ترضاه وأدخلني برحمتك في عبادك الصالحين﴾ الايه(19)

صدق الله العظيم

سورة.النمل

الاهــداء

الي كل من في الوجود بعد الله ورسوله

الي روح ابي ....الي روح امي

الي سندي وقوتي وملازي بعد الله

اسرتي

الي من علمونا علم الحياة

الي من اظهروا لنا ماهو اجمل من الحياة

الي من تزوقنا معهم اجمل اللحظات

الي من وقف علي المنابر واعطي من حصيلته فكره لينير دروبنا

الشكروالتقدير

"كن عالما ... فإن لم تستطع فكن متعلما ، فإن لم تستطع فأحب العلماء ، فإن لم تستطع فلا تبغضهم"

بعد رحلة بحث و جهد و اجتهاد تكللت بإنجاز هذا البحث ، نحمد الله عز وجل على نعمه التي من بها علينا فهو العلي القدير ، لا يسعنى إلا أن اخص بأسمى عبارات الشكر و التقدير للدكتورة" **راويه عبدالغني** "و الاستاذ" **علي سليمان** "لما قدماه لي من جهد و نصح و معرفة طيلة انجاز هذا البحث

كما اتقدم بالشكر الجزيل لكل من أسهم في تقديم يد العون لإنجاز هذا البحث، و اخص بالذكر الاخوه **محمد منصور ووليد وقمر**.

إلى الذين كانوا عونا لي في بحثي هذا ونورا يضيء الظلمة التي كانت تقف احيانا في طريقي ..

إلى من زرعوا التفاؤل في دربي وقدموا لي المساعدات والتسهيلات والمعلومات..

Abstract

In this study scintillation counter is used for investigating and identifying the radioactive substances in the sample and determining their activities by means of gamma ray spectroscopy, sodium chloride as an example in order to determine its activity which reveals poor activity

المستخلص

تم دراسة امكانيه استخدام الكاشف الوميضى لتحديد كمية الماده المشعه في عينه ما وتحديد نشاطها وذلك من طيف قاما الذي يصدر من العينه والماده المراد تحديدها في العينه وقد تم استخدام كلوريد الصوديوم وحُدد نسبه الصوديوم في 55جرام من كلوريد الصوديوم ووجد أن الصوديوم ذو نشاط اشعاعي ضعيف يكاد لايذكر.

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Chapter One

Introduction and Literature Review

1.1 Introduction

In radioactive processes, particles or electromagnetic radiation are emitted from the nucleus. The most common forms of radiation emitted have been traditionally classified as alpha (α), beta (β), and gamma (γ) radiation. Nuclear radiation occurs in other forms, including the emission of protons or neutrons or spontaneous fission of a massive nucleus. of the nuclei found on Earth, the vast majority is stable. This is so because almost all short-lived radioactive nuclei have decayed during the history of the Earth. There are approximately 270 stable isotopes and 50 naturally occurring radioisotopes (radioactive isotopes). Thousands of other radioisotopes have been made in the laboratory. Radioactivity is now widely used in wide variety of applications .it used in medicine in curing cancer and diagnosis .it is also utilized in oil .exploration and determine the ago of organisms and old rocks by the radioisotopes Potassium . Sodium is a chemical element with symbol Na (from Latin natrium) and atomic number 11. It is a soft, silvery-white, highly reactive metal. Sodium is an alkali metal, being in group 1 of the periodic table, because it has a single electron in its outer shell that it readily donates, creating a positively charged atom the Na^{+} cation. Its only stable isotope is Na^{23}. The free metal does not occur in nature, but must be prepared from compounds. Sodium is the sixth most abundant element in the Earth's crust, and exists in numerous minerals such as feldspars, sodalite and rock salt ($Nacl$). Many salts of sodium are highly water-soluble: sodium ions have been leached by the action of water from the Earth's minerals over eons, and thus sodium and chlorine are the most common dissolved elements by weight in the oceans.

1.2 Objectives

- Recording a γ spectrum of a weakly radioactive sample.
- Identifying the radioactive substances in the sample and determining their activities.

1.3 Statement of the problem:

The effect of daily exposure of low ionizing radiation doses in our body in the field of radiation and various nuclear sites as a result of entering by different pathway (ingestion and inhalation etc).in order to determine the of this radiation we need sum revision in this field.

1.4The Methodology:

Scintillation counter techniques adopted for detection and determine and Recording a γ spectrum for sodium chloride.

1.5 Literature Review:

Measurements of radioactivity in environment and in foodstuffs are extremely important for controlling radiation levels to which mankind is direct or indirectly exposed. Another important fact is that, importation of contaminated food from any region that suffered a nuclear accident can be indirectly affect people health around the world (F. L. Melquiades. et al., 2000).

After the reactor accident in Chernobyl in the north of Germany Identifying the radioactive substances (K-40) in the sample (KCL) and determining the activities of the pots sum (K-40).(Printed in the Federal Republic of Germany Technical alterations reserved)

1.6Research layout:

This research is consists of five chapters. Chapter one is contains an introduction and literature review while chapter tow includes the theoretical back grounds of the radioactivity. In chapter three study of interaction of gamma ray with material and chapter four constructs of experimental procedure for prepared sample activities (sodium chloride) material and the method of process. Lastly there are result and discussions on chapter five.

Chapter Two

The Radio Activity

2.1 Introduction

Radioactivity is a phenomenon that occurs naturally in a number of substances. Atoms of the substance spontaneously emit invisible but energetic radiations, which can penetrate materials that are opaque to visible light. The effects of these radiations can be harmful to living cells but, when used in the right way, they have a wide range of beneficial applications, particularly in medicine. Radioactivity has been present in natural materials on the earth since its formation (for example in potassium-40 which forms part of all our bodies). However, because its radiations cannot be detected by any of the body's five senses, the phenomenon was only discovered 100 years ago when radiation detectors were developed. Nowadays we have also found ways of creating new man made sources of radioactivity; some (like iodine-131 and molybdenum-99) are incidental waste products of the nuclear power industry which nevertheless have important medical applications, whilst others (for example fluorine-18)[1].

2.2 The discovery of radioactivity

Radioactivity was discovered in 1896 by the French physicist, Henri Becquerel working in Paris. The story of the discovery is a fascinating one which is worth telling in some detail. It gives interesting insights into how quickly and easily fundamental experiments could be done 100 years ago, compared with the lengthy processes of modern scientific research.

Becquerel had succeeded his father as Professor of Physics at the Museum of Natural History in Paris. There he continued his father's investigations into the phenomenon of phosphorescence; the emission of visible light by certain substances when they are activated by exposure to a bright light source. He had assisted his father with many experiments on phosphorescence and knew that a

preparation containing crystals of uranium and potassium would glow when exposed to sunlight and that this stopped quickly when it was taken into the dark. On 20 January 1896 Becquerel attended a lecture at the French Academy of Science in Paris at which he heard Henri Poincare describe the recent discovery of X-rays by Wilhelm Rontgen. Poincare menstruated how, when a beam of electrons was accelerated across a vacuum tube, visible light was emitted from the spot where the electron beam hit the glass wall (just like in a modern TV tube). This was another example of phosphorescence (although nowadays we would call it fluorescence) which others had observed before. The new discovery which Rontgen had made in 1895 was that some hitherto unknown invisible radiation was also emitted from the same spot. These became known as X-rays (X standing for the unknown). Rontgen had found that they were able to penetrate solid material and cast shadows of metal objects on photographic paper. Hearing this description, Becquerel presumed that the X-rays were associated with the phosphorescence and he wondered whether his phosphorescent crystals might also emit X-rays. He therefore conducted several experiments to check this. In each experiment he wrapped a photographic plate in light tight paper and placed some of his crystals on the outside of the paper. This was then exposed to sunlight for several hours. Sure enough, when the plate was developed it had become blackened where the crystals had been. He found that if a thin piece of metal was placed between the crystals and the plate then this cast a shadow. These results seemed to confirm his assumption that X-rays were part of phosphorescence and he reported these results to the French Academy of Science on 24 February1896. Continuing his experiments, Becquerel prepared some more samples on 26 and 27 February but the weather was poor and there was insufficient sunlight to activate his crystals, so did not use them. Instead he left the crystals lying on the wrapped photographic plate but in a dark drawer. By Sunday 1 March the sun still had not shown in Paris, but

Becquerel decided to develop his plates anyway, expecting to find only very weak images. Instead he was amazed to find an image just as intense as when the crystal has been exposed to bright sunlight. He immediately did further experiments which confirmed that the crystals could blacken a photographic plate whether or not they were made to phosphoresce. He realized that he had accidentally discovered an entirely new phenomenon which he attributed to some form of long lasting phosphorescence emitting invisible radiation. He presented his findings to a meeting of the French Academy of Sciences the very next day on 2 March 1896 and a written version of this was published within 10 days. By the end of the year he had published six more papers on his further investigations into these 'Becquerel rays' confirming that they derived from the uranium in his crystals and that they did not noticeably diminish in intensity even after several months. It is interesting to speculate what might have happened if Becquerel had chosen a different phosphorescent crystal for his experiments. He could just as easily have chosen zinc sulphate from his father's large collection of phosphorescent materials, and then he would not have found any effect on the photographic plate because zinc is not radioactive like uranium. In that case the discovery of radioactivity might well have been left to an Englishman. On 23 February 1896 Silvanus Thompson, in London, had independently performed the same experiment as Becquerel, exposing uranium crystals to sunlight whilst placed on a wrapped photographic plate. By the time that Thompson wrote to the president of the Royal Society in London to describe his results, Becquerel's initial findings had already been reported to the French Academy of Sciences. Hearing this, Thompson did no further work on the subject and thus missed the opportunity to beat Becquerel to his fortuitous discovery of 1 March. That is why we now measure radioactivity in units of megabecquerels rather than megathompsons.

By the end of 1896 Becquerel's interest in his new discovery seems to have waned as he could see little more of interest to do and Rontgen's X-rays seemed to have many more applications. However in 1897 he was joined by a young research student, Marie Curie, who wished to study for her doctorate.

Marie soon discovered that another element, thorium, also exhibited the same emission of Becquerel rays as uranium and she suggested the term 'radioactivity' for the phenomenon. She also discovered the important fact that the radioactivity was a property of the atoms themselves and it was not changed by any physical or chemical processes through which the material went. She was later joined by her husband, Pierre, and together they discovered that the mineral pitchblende contained two even stronger radioactive substances, which they called polonium and radium. After years of painstaking purification they were able to separate sufficient polonium and radium to demonstrate that these were both previously unknown elements. In 1903 Henri Becquerel, Marie Curie and Pierre Curie were jointly awarded the Nobel prize in physics for their work on radioactivity. Later Marie Curie was also awarded the 1911 Nobel prize in Chemistry for her discovery of radium.

Radioactivity had also captured the interest of another student, Ernest Rutherford, who was then studying in Cambridge under professor J J Thomson. He continued this interest after he moved to McGill University in Montreal, where he discovered that the Becquerel rays contained two different components which he simply called alpha and beta. The alpha rays were easily stopped by thin card whereas the beta rays would pass through card but were stopped by sheets of metal. Becquerel and the Curies showed that the beta rays were identical to electrons (newly discovered by J J Thomson).

Subsequently a third, even more penetrating, component of the radiation was discovered by Paul Villard in Paris and these were naturally called gamma rays. Further investigations by Rutherford, working with the chemist Frederick Soddy,

showed that the intensity of radioactive emission of many materials reduced exponentially with time, but that they sometimes converted into other materials which were themselves radioactive. By 1902 Rutherford had concluded that the atom, previously thought to be indestructible, was spontaneously disintegrating and changing from one element into another. This heretical idea was not readily accepted by many scientists who though that it sounded too much like alchemy. However, by 1907 Rutherford and Soddy had identified several separate series of naturally occurring radioactive transformations in which each element successively changed into the next one down the chain, until they eventually ended up as non-active lead.

In 1907 Rutherford moved to Manchester where he was appoints professor of physics, and in 1908 he proved that alpha rays were in fact ionized helium atoms. In 1911 two of his researchers, Hans Geiger and Ernest Marsden, performed a classic experiment in which they allowed alpha particles to scatter off a gold foil and found that some of them bounced straight back. The results of this experiment led Rutherford to deduce that there was a small nucleus at the centre of each atom. Our modern understanding of the nature of the atom and the process of radioactive decay stem largely from the theories developed by Ernest Rutherford and Niles Bohr during this period in Manchester [1].

2.3 The Radioactive Decay Law

The radioactive atoms in a radioactive substance decay according to a random process. The Probability of a nucleus decaying in a time interval is independent of time. It was noted three years after the discovery of radioactivity that decay rate of a pure radioactive substance decreases in time according to an exponential law which is called the Radioactive Decay law [2] if no new nuclei are introduced into a given radioactive substance, this law predicts how the number of radioactive nuclei which are present at time *t* decreases with:

$$\lambda = -\frac{(dN/dt)}{N} \qquad (2.1)$$

Where λ is the decay (disintegration) constant which equals the probability per unit time for the decay of an atom (the right side of equation (2.1)). Regardless of the age of the atoms, this probability is a constant. The exponential law of radioactive decay which is shown below is the solution to the differential equation (2.1) above; i.e.

$$N(t) = N_0 e^{-t\lambda} \qquad (2.2)$$

Where N_0 represents the original number of nuclei present at $t = 0$. The half-life is the time required for one half of the original nuclei to decay, denoted by the symbol $t_{1/2}$. Putting $N = N_0/2$, it follows that:

$$t_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda} = \tau_0 \ln 2 \qquad (2.3)$$

where the mean lifetime is the average time that a nucleus is likely to survive before it decays and equals $1/\lambda$. i.e., the reciprocal of the decay constant the activity, A, is the rate at which decays occur in a sample and can be obtained by differentiating Equation[2](2.2), if the time interval dt over which the decays take place is much smaller than λ-1 ($t_1/2$).i.e.,

$$A = \left|\frac{dN}{dt}\right| = \lambda N_0 e^{-\lambda t} \qquad (2.4)$$

$$A(t) \equiv \lambda N(t) = A_0 e^{-\lambda t} \qquad (2.5)$$

Where $A_0 = \lambda N_0$, and is the initial activity at $t \to 0$. The number of decays of the sample per unit time (decays/s) is a convenient unit to measure the radioactivity of a sample. Another unit for measuring the activity is the *Curie* (ci) this unit was originally indicated the activity of one gram of radium but later is defined simply as:

$ci = 3.7 \times 10^5 decay$ (B*ecquerel*) / s 10[2, 3]. Figure (2.1) shows how schematically the activity decays exponentially with time.

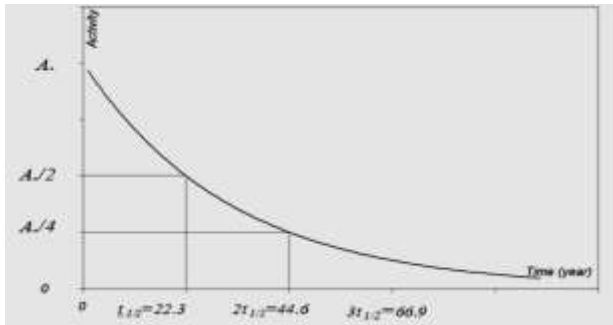

Figure 2.1: Schematic of the exponential decay of activity for 210Pb which has (half-life 22.3 years)

2.4 Radioactive equilibrium

In a radioactive decay the produced nuclei are often radioactive themselves. Such continued radioactive transformation processes lead to whole decay chains. The genetically following nuclides are called mother and daughter nuclides etc. Radioactive nuclides in genetic connection do not follow any longer the simple exponential transformation law for the temporal reduction of the activity. In a radioactive chain the number Ni of the ith nuclide depends on its proper decay ($-\lambda_i N_i$) and on the production coming from its mother nuclide. The production can be described by a function $q_i(t)$ the temporal variation of the atomic number $N_i(t)$ is given by equation [4].

$$\frac{dN_i(t)}{dt} = q_i(t) - \lambda_i N_i \qquad (2.6)$$

Integration of (2.6) leads to

$$N_i(t) = \left[N_i(0) + \int_0^t q_i(t) e^{\lambda_i t} dt \right] e^{-\lambda_i t} \qquad (2.7)$$

In the same way one can calculate the number of the next species of nuclide if $N_i(t)$ of equation (2.7) is known. With $q_{i+1}(t) = \lambda_i N_i(t)$ the solution for the number $N_{i+1}(t)$ is:

$$N_{i+1}(t) = \left[N_{i+1}(0) + \int_0^t \lambda_i N_i(t) e^{-\lambda_{i+1} t} dt \right] e^{-\lambda_{i+1} t} \qquad (2.8)$$

The simple exponential law (2.1) for radioactive decay is a consequence of (2.7) if one sets q_i (t) = 0.

Secular equilibrium: the case of the transformation of a very long-lived parent nuclideT1/2(1) into a short-lived daughter nuclide T1/2(2) with T1/2(1) ≫T1/2(2). The activity of the mother nuclide does not change consequently and guarantees a constant production of its daughter nuclide during a long time. With equation (2.7) one calculates the number of atoms of the daughter nuclide

$$q_2(t) = \lambda_1 N_1 = A_1 \qquad (2.9)$$

$$N_2(t) = \frac{A_1}{\lambda_2} + \left[N_2(0) - \frac{A_1}{\lambda_2} \right] e^{-\lambda_2 t} \qquad (2.10)$$

The activity of the daughter nuclide increases exponentially in time and for $t \to \infty$ Equilibrium is reached.

$$N_2(\infty) = \frac{A_1}{\lambda_2}; A_2(\infty) = A_1 = A_1(0)e^{-\lambda t} \qquad (2.11)$$

In practice equilibrium is already reached after 6 half-life of the daughter nuclide. In radioactive equilibrium the activities of mother and daughter nuclide are equal, not to confound with the number of atoms. As an example: The isotope Rn^{222} of the noble gas radon (T1/2 = 3.825d) is a daughter nuclide of Ra^{226} (T1/2 = 1600y) and secular equilibrium is reached after 23 days.[4]

Current equilibrium if the half-life of mother nuclide is shorter than the one of its daughter nuclide one cannot neglect the decreasing activity of the mother nuclide.

The production of the daughter nuclide follows the exponentially decreasing mother nuclide. With the initial condition $N_2(0) = 0$ equation (2.7) leads to the general solution

$$q_2(t) = \lambda_1 N_1(0) e^{-\lambda_1 t} \qquad (2.12)$$

$$N_2(t) = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_1(o)\left[e^{-\lambda_1 t} - e^{-\lambda_2 t}\right] \qquad (2.13)$$

For the case of a short lived mother nuclide in comparison to a longer lived daughter nuclide, i.e. T1/2(1) $\ll$ T1/2(2), the mother nuclide will disappear long before its daughter nuclide as $e^{-\lambda_1 t} \to 0$ equation(2.13) reduces to

$$N_2(t) = \frac{\lambda_1}{\lambda_1 - \lambda_2} N_1(0) e^{-\lambda_2 t} \qquad (2.14)$$

In order to get the respective activities, we need to multiply both sides by λ_1 and λ_2 and take into account, that $\lambda_1 \gg \lambda_2$ to get the final result [4].

$$A_2(t) \cong A_1(0) \frac{\lambda_2}{\lambda_1} e^{-\lambda_2 t} \qquad (2.15)$$

2.5 Decay modes

2.5.1 Alpha decay

In alpha decay an unstable nucleus disintegrates into a lighter nucleus and an alpha particle. An alpha particle consists of two protons and two neutrons and is therefore the same as a stable helium nucleus 4He. For energetic reasons α-decay happens only for heavy nuclides with A> 170 and Z > 70 according to

$$ {}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}X' + {}^{4}_{2}He \qquad (2.16)$$

Where X and X' are different elements. Decay processes of this kind liberate energy, since the decay products are more tightly bound than the initial nucleus. The liberated energy which appears as the kinetic energy of the alpha particle and the daughter nucleus

X' Can be found from the masses of the nuclei involve:

$$Q = \left[m(X) - m(X') - m({}^{4}_{2}He)\right]c^2 \qquad (2.17)$$

Typical alpha decay energies are a few MeV; thus the kinetic energies of the alpha particle and the nucleus are much smaller than their corresponding rest energies, and so we can use nonrelativistic mechanics to find the energy of the alpha particle:

$$K_\alpha \cong \frac{A-4}{A} Q \qquad (2.18)$$

The alpha decay is a proof of quantum tunneling: The Coulomb barrier of the nucleus would be too high for the alpha particle to escape if it couldn't borrow a necessary amount of energy ΔE out of the uncertainty relationship $\Delta E \cdot \Delta t \approx h$ for an infinitesimal time Δt where h is Planck's constant[5].

2.5.2 Beta Decay

Beta particles were discovered by Henri Becquerel in 1900. In beta decay the atomic number (Z) and the neutron number (N) of a nucleus each change by one unit, but the total mass number, $A=N+Z$, remains constant [6]. Therefore, β decay provides a convenient decay mode for an unstable nucleus to increment

down a mass parabola of constant A to approach the stable isobar. There are three processes by which nuclei may undergo radioactive beta decay: β^- decay, β^+ decay and electron capture. A β particle is much lighter than an α-particle which means that for a given energy, β^- particle is much more penetrating [6]

1. Negative β-decay

The first process is negative beta or β- decay. It can occur only if the daughter nucleus is more energetically stable than the parent; where a neutron converts directly to a proton, electron and an anti-neutrino [7]. The formed proton remains in the nucleus and the electron is ejected as a β^- particle. This process occurs when the ratio of neutrons to protons is larger than the stable ratio for that particular isobaric chain. This process decreases the number of neutrons by one and increases the number of protons by one [6]. The following

example represents a β^- decay process:

$$pb^{210}_{82} \rightarrow bi^{210}_{83} + e^- + \upsilon^- \qquad (2.19)$$

$\beta-$Particles have a continuous distribution of energies, from 0 up to an upper limit which is called the endpoint. This point is equal to the difference in the energy between the initial and final states in the mother and daughter nucleus respectively Since β^- decay is a three-body process (in contrast to α-decay which is a two-body process), in which the kinetic energy released is shared between the β^- particle and the antineutrino [6], the emitted β-particles have a continuous distribution of kinetic energies, ranging from 0 to the maximum allowed by the Qβ- value (the beta 'end point' energy).

Figure. 2.2 show continuous distribution of energy from 0 up to $1.16 MeV$ from β^- particles emitted from Bi^{210} .

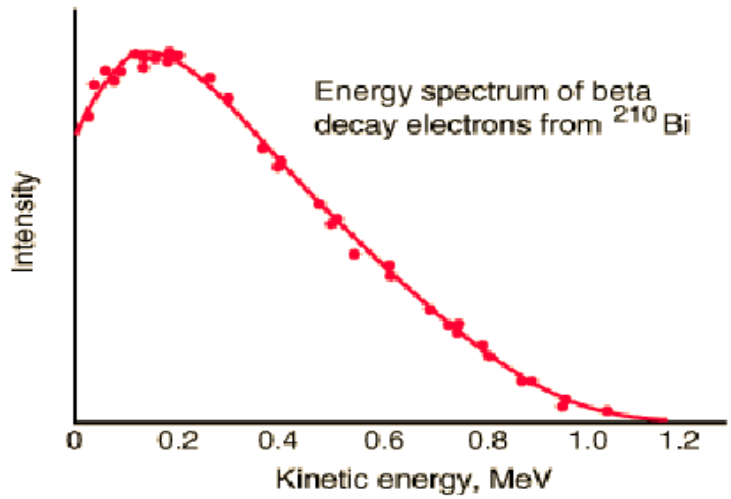

Figure 2.2: β^- energy spectrum from the decay of Bi^{210} (taken from [8]).

In β decay, the Q-value can be defined as, the difference between the initial and final nuclear mass energies .If the differences in electron binding energy and electron masses are neglected, the $Q\beta^-$ value can be determined from the following equation [6]:

$$Q_{\beta-} = [m(x) _ m('x)]c^2 \qquad (2.20)$$

where the masses are neutral atomic masses. The Q value represents the energy shared by the electron and neutrino, i.e.,

$$Q_{\beta-} = T_e + E_{\bar{\upsilon}>} \qquad (2.21)$$

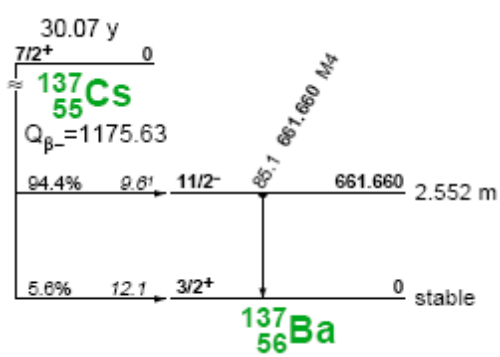

Figure 2.3: Schematic decay scheme of Cs^{136}showing two different decay modes, β^- decay, followed by electromagnetic decays (figure taken from reference [8]).

2. Positive β-decay

The second weak interaction decay process is positive, β^+ decay or 'positron decay'. It occurs when the ratio of protons to neutrons is higher than that for the most stable isobar of that particular A chain (i.e., for 'proton-rich' nuclei). In this process, a proton is transformed into a neutron, a positron and a neutrino. As a result, the nuclear charge is decreased by one unit. As in β^- decay, this decay is a three-body process and the positrons are emitted with a continuous range of energies .The following example represents β^- decay process:

$$Al_{13}^{25} \rightarrow Mg_{12}^{25} + e^+ + \upsilon \qquad (2.22)$$

The Q-value must be greater than 0 for this process to be able to occur .The Q value of

β^+ decay is given by

$$Q_{\beta+} = [m(x) - m(x') - 2m_e]c^2 \qquad (2.23)$$

2.5.3 Electron capture ECA

Nuclear decay process that competes with positron emission is electron capture. It can also be considered as beta decay if the available energy is too small for β^+. The basic electron capture process is:

$$p + e^- \rightarrow n + \upsilon \qquad (2.24)$$

In which a proton captures an electron from its orbit and converts into a neutron plus a neutrino. The electron necessary for this process is one of the innermost K-shell electrons in an atom. The electron capture process does not occur for free protons, but in nuclei the process is [5].

$$^{A}_{Z}X + e^- \rightarrow {}_{Z-1}^{A}\grave{X} + v \qquad (2.25)$$

2.5.4 Gamma transition

Following alpha or beta decay, the final nucleus may be left in an excited state. Just as an atom does, the nucleus will reach its ground state after emitting one or more photons, known as nuclear gamma rays. The energy of each photon or the sum of the energies in gamma-cascades is the energy difference between the initial and final nuclear states, less a negligibly small correction for the recoil kinetic energy of the nucleus. These energies are typically in the range of 100 K_eV to a few M_eV and are thus highly ionizing radiations. [5]

2.6 Natural Radioactivity

All of the elements beyond the very lightest hydrogen were produced by nuclear reactions in the interiors of stars. These reactions produce not only stable elements, but radioactive Ones as well. Above lead ($pbZ = 82$) no more stable isotopes do exist. Most of the radioactive elements have half-life of the order of days or years, much smaller than the age of the Earth (about $4.5 \cdot 10^9$ y). Therefore, most of the radioactive elements that may have been present when stars and the Earth were formed have decayed to stable elements. However a few of them have half-life of the order as the age of the Earth, and so are still present. Those radioisotopes represent the natural radioactivity. Artificial radioactivity consists of manmade radioactive isotopes these are especially the fission products of heavier nuclei produced in atomic bombs, nuclear power plants and particle accelerators.

Radioactive material is found throughout nature. It occurs naturally in the soil, rocks, water, air, and vegetation. 76 different natural radioactive isotopes are known today, the largest part of it lies in the 4 natural decay series. These are the thorium series, uranium series, neptunium series and actinium series (or uranium-235 series). The neptunium series, starting with Np^{273}, does not exist anymore because of the shorter half-life of $2.1 \cdot 10^6$ Years of Neptunium compared to the age of the earth all the isotopes in this series have decayed[5].

Table (2.1): Thorium series A= written isotopes are the ones measured by gamma spectrometry in our experiments source 4n. The three bold [9]

Nuclide	Decay	$T_{1/2}$	MeV	Product
^{232}Th	α	1,405·1010 a	4,083	^{228}Ra
^{228}Ra	β^-	6,7 a	1,325	^{228}Ac
^{228}Ac	β^-	6,15 h	2,127	^{228}Th
^{228}Th	α	1,9131 a	5,520	^{224}Ra
^{224}Ra	α	3,66 d	5,789	^{220}Rn
^{220}Rn	α	55,6 s	6,405	^{216}Po
^{216}Po	α	0,145 s	6,906	^{212}Pb
^{212}Pb	β^-	10,64 h	0,574	^{212}Bi
^{212}Bi	β^- 64,06 % α 35,94 %	60,55 min	2,254 6,207	^{212}Po ^{208}Tl
^{212}Po	α	2,99·10-7s	8,954	^{208}Pb
^{208}Tl	β^-	3,083 min	5,001	^{208}Pb
^{208}Pb	.	stable	.	

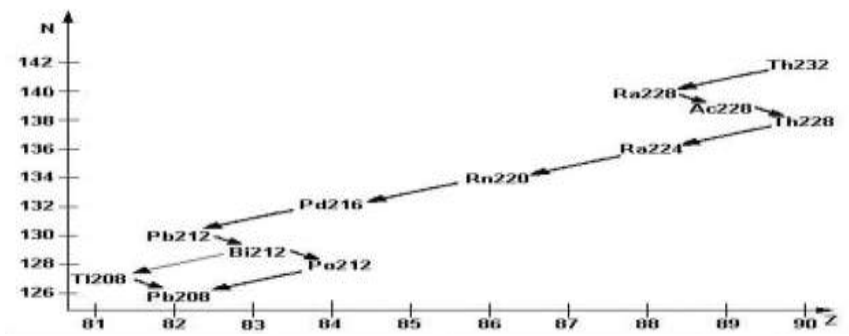

Figure (2.4): Thorium series. Left arrows represent *a*-decay and right arrows β^- decay source [9].

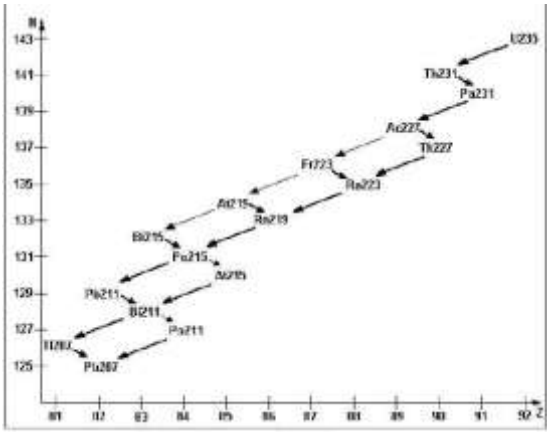

Figure (2.5) Uranium-235 series, Left arrows represent a-decay and right arrows β-decay

Chapter Three

Gamma Spectrometry

3.1 Introduction

Gamma ray spectrometry is an analytical method that allows the identification and quantification of gamma emitting isotopes in a variety of matrices. In one single measurement and with little sample preparation, gamma ray spectrometry allows you to detect several gammas emitting radio nuclei in the sample. The measurement gives a spectrum of lines, the amplitude of which is proportional to the activity of the radionuclide and its position on the horizontal axis gives an idea on its energy

3.2 Gamma Rays with Material

Understanding the γ -ray interactions with a detector is an important issue in order to know how γ -rays photons are detected and attenuated. From the number of possible interactions processes for γ -ray in the matter, three mechanisms play the most significant roles in interactions with γ -ray detectors to transfer their energy partially or completely to the detection medium [10].

3.2.1 Photoelectric Effect

In this mechanism, a photon undergoes an interaction with the detector medium atoms. As a result, the photon completely disappears and a photoelectron is ejected by the atom in its place. If the energy is sufficient, the photoelectron will be produced from the most tightly bound (K) shell. The energy of the ejected photoelectron can be expressed as follows:

$$E_{e-} = h\upsilon - E_b \qquad (3.1)$$

where E_{e-} represents the kinetic energy lunatic of the photoelectron, and *Eb* is the binding energy of the photoelectron's original shell.

Accordingly, this interaction creates an ionized absorber atom with a vacancy in one of the bound electron shells. A free electron can then be captured from the

medium or a rearrangement of electrons from outer shell orbits of the atom then fills this vacancy. Therefore, characteristic X-ray photons are also produced. These may be reabsorbed through photoelectric absorption involving electrons from less tightly bound shell, Auger electrons may also be generated following this type of interaction [10].

3.2.2 Compton Scattering

This process is a collision between the incident gamma photons and an electron in the absorber. Unlike the photoelectric effect, the γ-ray photon is deflected through an angle θ with respect to its original direction. A portion of the photon energy is transferred to a recoil electron [10]. This energy may vary from zero to a significant large fraction of the original γ-ray energy depending on the scattering angle. The energy transfer and scattering angle for any given interaction can be derived by solving simultaneous equations assuming conservation of total mass-energy and linear momentum [10]. The solution for the scattered energy, as a function of scattering angle, can be written as follows:

$$h\upsilon' = \frac{h\upsilon}{1 + \frac{h\upsilon}{m_0 c^2}(1 - \cos\theta)} \qquad (2.2)$$

where $m_0 c^2$ is the rest-mass energy of the ejected electron (0.511MeV). From this, the kinetic energy of the recoil electron can be expressed as:

$$E_{e-} = h\upsilon - h\upsilon' \qquad (2.3)$$

$$E_{e-} = h\upsilon[\frac{(h\upsilon/m_0 c^2)(1 - \cos\theta)}{1 + (h\upsilon/m_0 c^2)(1 - \cos\theta)}] \qquad (2.4)$$

In the case where $\theta \approx 0$, the recoil electron carries away very little energy and the scattered γ ray has almost the same energy as the incident γ ray. Equations (3.2) and (3.3) show that in this extreme case that $h\upsilon \approx h\upsilon'$ ´, and $E_{e-} \approx 0$. However, by contrast, if a head-on collision occurs, (i.e., one in which $\pi \approx 0$) and the incident gamma-ray is scattered toward its direction of origin, the energy

transferred to an electron in a single Compton interaction reaches a maximum value, resulting in a spectral feature known as the 'Compton Edge'. In normal situations, all scattering angles can occur in a finite sized gamma-ray detector volume. Therefore, a continuum of energies can be transferred to the recoil Compton electron, ranging from zero up to maximum predicted by Eq (3.3) for θ=π. The energy difference or 'gap' between the maximum Compton recoil electron energy and the incident gamma-ray energy is given by:

$$E_e = h\upsilon - E_{e-}[\frac{h\upsilon}{1+2h\upsilon/m_0c^2}] \qquad (2.5)$$

In the cases where $h\upsilon >> mc^2/2$, this energy difference tends toward a constant value of:

$$E_c = \frac{m_0c^2}{2} = 0.256MeV \qquad (2.6)$$

3.2.3 Pair Production

The third important process for photon interactions in matter is Pair Production. This process occurs close to the nuclei of the absorbing material due to the high electric field at this point. The incident γ -ray photon disappears and an electron-positron pair produced in

Its place [10]. An energy of $2m_0c^2$ is required to create an electron-positron pair and therefore a minimum γ -ray energy of $1.022MeV$ is required for any incident photon to undergo this process. Any excess energy above this value is transferred into kinetic energy which is shared by the electron-positron pair. The total kinetic energy of the electron positron pair will then be:

$$E_{e-} + E_{e+} = h\upsilon - 2m_0c^2 \qquad (3.7)$$

The electron and positron typically travel a few millimeters in the material before losing their energy in the absorbing medium. As the positron slows down due to collisions within the medium, the positron can combine with another electron from the absorbing medium.

This is followed by the annihilation of both particles, which are replaced by two Annihilation photons, each of energy m_0c^2 (i.e., 0.511MeV) which are emitted back-to-back (to conserve linear momentum).

3.3 Interaction with the detector

The interaction is always transferring of the gamma-ray energy to electrons or in pair production to electrons and positrons. The energy of these individual particles can range from near zero to the full energy of the gamma-ray. As already mentioned gamma-rays cover an energy range from a few KeV to many MeV. Comparing this energy to the energy of $2.96eV$ necessary to create an ion pair in sodium it is obvious that one gamma-ray will produce many electron-hole pairs. The expected number of ion pairs is thus

$$n = \frac{E_e}{\varepsilon} \qquad (3.6)$$

Where E_e the energy of the primary electron is excited by the gamma-ray and ε is the needed to create the ion pair. These generated secondary electrons and their associated positively charged holes must be collected in order to produce the electrical signal from the detector.

3.3.1 The large detector

Consider an infinitely large detector as drawn in figure (3.3) which is bombarded with gamma-rays of energy above $1022KeV$. Because the detector is large we can assume that every gamma-ray will have an opportunity to interact by one or other of the three main processes mentioned before. Every gamma-ray will thus deliver its total energy to the detector, nothing is lost. Many Compton scatterings and many pair productions will occur until all the initial energy is transferred to the detector.

3.3.2 The small detector

This detector shall be defined so small that only one interaction can take place within it. In this case only photoelectric interactions will produce full-energy absorption and contribute to the full-energy peak. Because of the small size of the detector all Compton scattering events will produce only a single recoil electron carrying only a portion of the whole gamma energy. The scattered photon will escape from the detector as one can see in figure (3.3) and this energy will be lost to counting leading to so call single or double escape peaks. The energy absorbed by pair production events is limited to the energy excess of the electron-positron rest masses. It can be assumed that both will transfer their kinetic energy to the detector but the two annihilation gamma-rays will escape from the detector which leads to the double escape peak. Where one finds a peak $1022 KeV$ below the full energy peak see figure (3.5).

3.3.3 The real detector

Any real detector represents a case between these two extremes figure (3.4). There will be many Compton scatterings and pair productions leaving all the energy in the detector and thus contributing to the full-energy peak. But there will also be some

Compton scattering events followed by others, each absorbing a little bit more of the initial energy, before the scattered gamma-ray escapes from the detector. Such events are referred to as multiple Compton events. For pair production there is the possibility that after annihilation only one photon escapes leading to a single escape peak $511 KeV$ below the full energy peak.

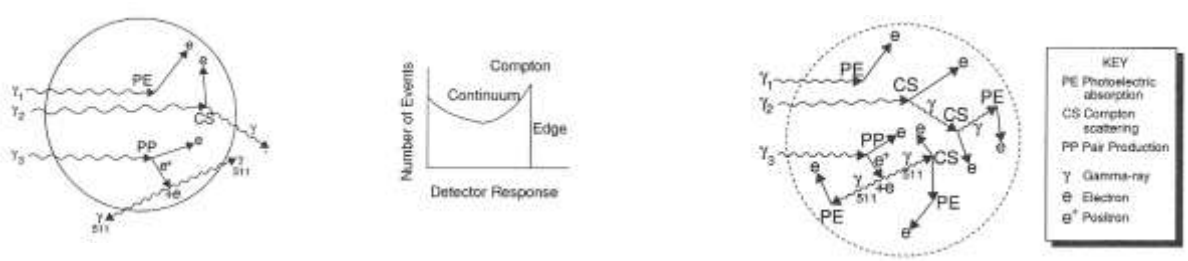

Figure (3.1): Interactions within a large detector on the left and within a small detector on the right [11]

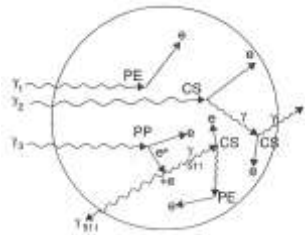

Figure (3.2): Interactions within a real detector, something between the large and the Small detector Spectra [11]

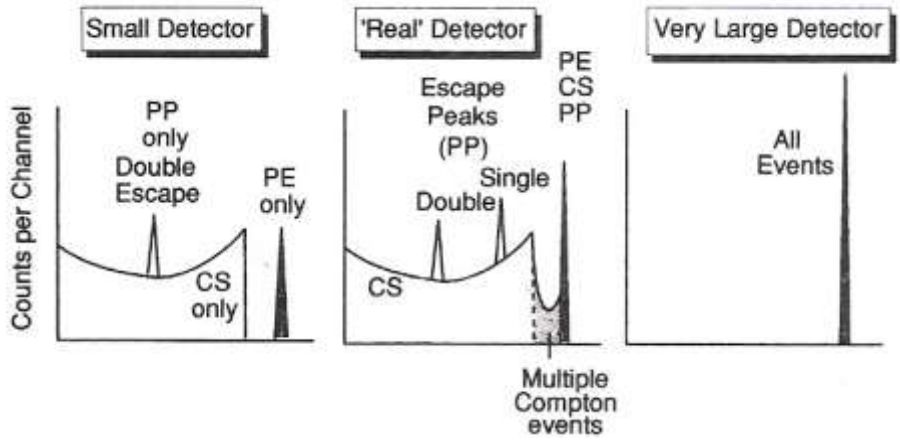

Figure (3.3): The three different approaches to detectors would lead to those three different Spectra [11]

3.4 Calibration of the Multi Channel Analyzer MCA

The produced current in the detector is analyzed through a large setup of electronics.

First the signal is amplified then digitalized and finally gets into a multi channel analyzer where each channel represents a certain energy range. The relationship between the absorbed energy and the channel number is almost linear. Before doing precise measurements the MCA has to be calibrated. Doing this one uses

standardized radioactive samples with known energies and activities of the nuclides.

3.4.1 Energy calibration

During the energy calibration primarily the emitted gamma energies are assigned to the appropriate channel numbers of the multichannel analyzer. For the calibration a preparation is needed, which exhibits at least two gamma lines in the energy region which can be measured. Still it is better to use a radioactive preparation with 3-5 lines distributed over the whole measured energy range. The activity of the preparation does not play a substantial role; it should however be in the size that one gets to a reasonable counting statistics in finite time after taking up the spectrum a 2 point calibration is accomplished with the energetically lowest and the energetically highest photo peak in the spectrum. For an exact energy calibration however if possible all lines existing in the spectrum should be considered.

For energy calibration in the measuring range $50KeV$ to $2MeV$ the nuclide mixture given in table 3.1 is suitable: The relation between channel number and energy is almost

Table3.1: Mixture of 3 nuclides used for energy calibration [12]

Nuclide	γ-ray Energy [keV]
^{241}Am	59.54
^{137}Cs	661.66
^{60}Co	1173.24
^{60}Co	1332.50

Linear However it is best described by a square function, whereby the square term is very small and refers to quasi linearity.

Chapter Four

Experimental

4.1 Material and Apparatus

For determining the activity of a weakly radioactive sodium chloride, the sodium chloride is often put into a beaker (see Fig4.1). The beaker encloses the scintillation crystal almost completely and ensures a well defined geometry of the measurement.

By comparison with the γ spectrum of a calibration preparation which has the same geometry, the activity of the potassium chloride can be calculated immediately. One should bear in mind that the detection probability of the scintillation counter depends on the γ energy.

When the γ spectra are recorded, a background interferes, which is reduced by a lead screening around the measuring arrangement.

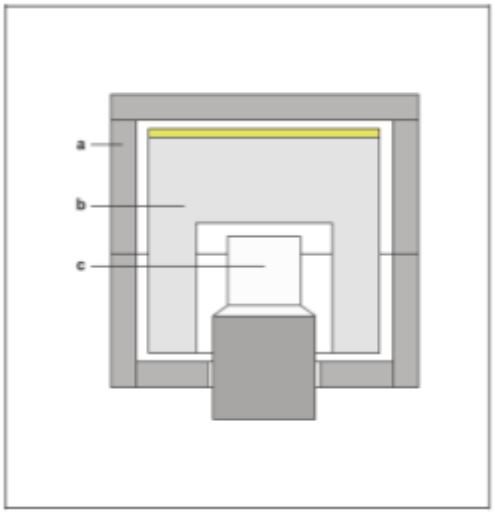

Figure (4.1): Measuring arrangement with a scintillation counter for determining the activities of weakly radioactive sodium chloride.

a. Lead screening
b. beaker with sodium chloride
c. scintillation counter

4.2 Method

a) The sodium chloride sample as a calibration preparation:

A 55 g of sodium chloride was putted into the beaker; if there are bigger salt pieces, must be crushed. The beaker putted over the scintillation counter inside the scintillation screening, and covers the screening with the cap. The program "MCA" started Then "Define settings" Choosed in the main menu: Resolution = 8 bit (256 channels) Line diagram (confirm with <CR>) Meas. time = 3600 s

"Record measurement" is Choosed in the main menu

The measurement was started in the measuring screen with <F_1>, When the detection time is over, change to "Graphical evaluation" in the main menu and switch on the graphics cursor with <F9> and the channel display with <+>.

Placed the cursor to the left of the peak of total absorption with <Shift + Tab> (cursor moved to the left) and <Tab> (cursor moved to the right), and entered the left limit of integration with <Ctrl + ← >, then moved the cursor to the right of the peak of total absorption and entered the right limit of integration with <Ctrl + >.

Displayed the range of integration with <F5> and the integrated counting rate with <Alt + F5>. Take the integrated counting rate down.

b) A weakly radioactive sample:

Replaced the filled beaker with beaker(1.289 g)the measuring time was Choosed 3600 s. and Deleted old measuring values with <Ctrl + C>, and start a new measurement with <F1>,When beaker(Na) detection time is over and determine the integrated counting rate in the peaks of total absorption.

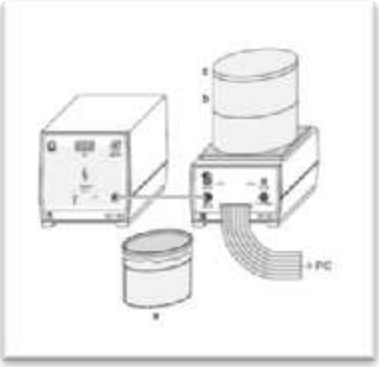

Figure (4.2): Experimental setup for determining the activity of weakly Radioactive samples

Chapter Five

The Result and Conclusion

5.1 Introduction

In this chapter, the experiment is carried out, the results and calculation has been done

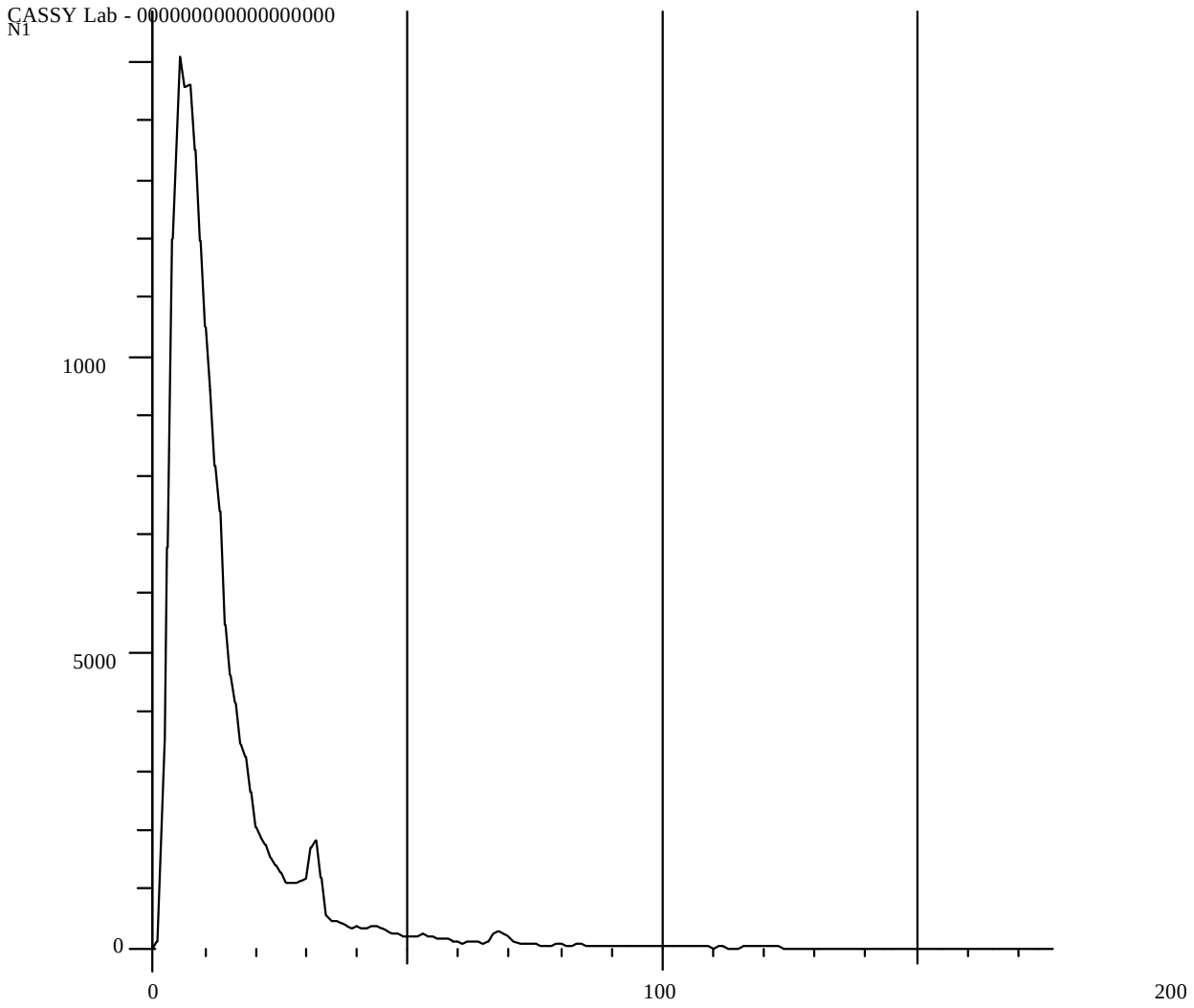

Figure5.1 spectrum of the sodium chloride sample

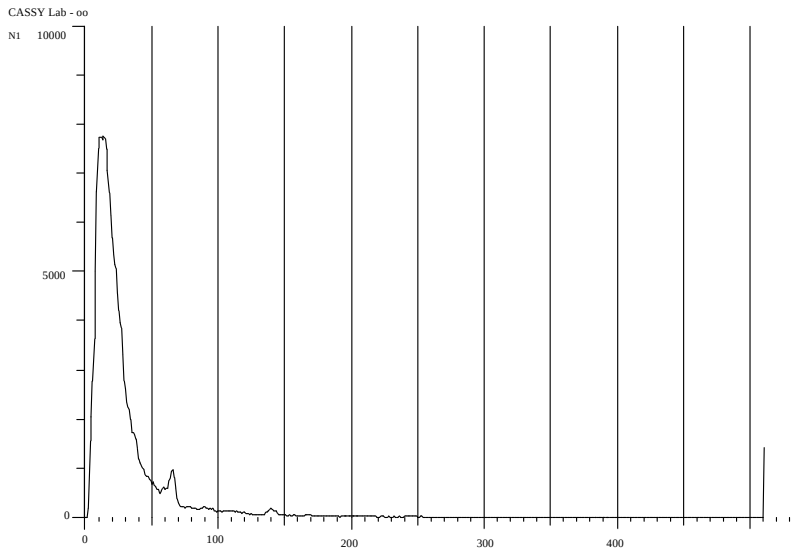

Figure. 5.2spectrum of sodium

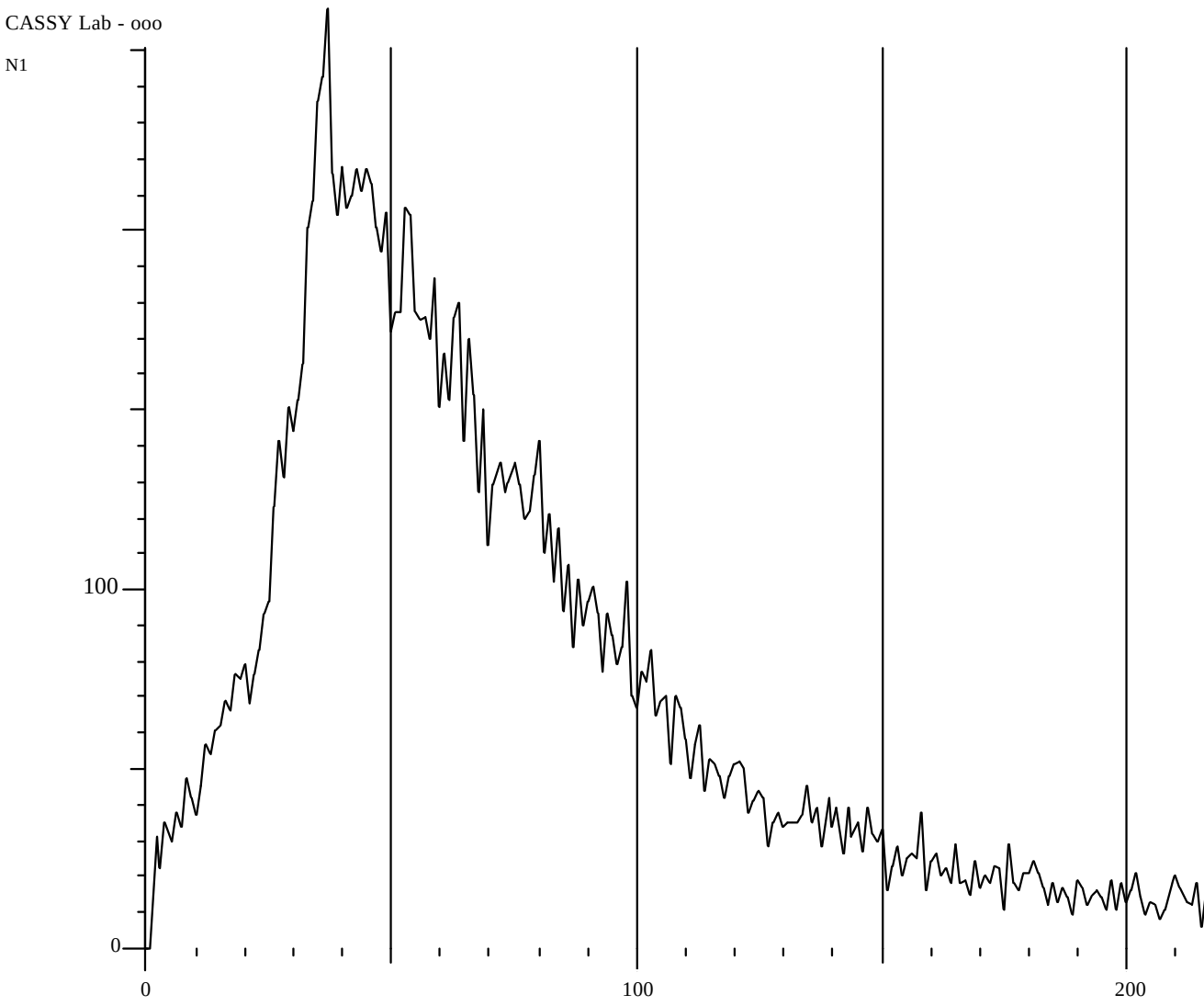

Figure5.3 spectrum of the laboratory background.

5.2 Result

Table (5.1): Integrated counting rates in the peaks of total absorption

Sample	***Measuring time***	***E*** γ
sodium chloride (m = 55 g)	*3600s*	*15929.4*
*caps * (m = 1.289 g)*	*3600s*	*8096.7*

5.3 Evaluation

Calibration of the scintillation counters:

Sodium chloride sample (55 g):

Determining the number N and the activity A of the Na atoms:

Molecular weight of Nacl: $M = 58.44 \frac{g}{mol}$

Avogadro number Na $N_A = 6.022.10^{23} \frac{1}{mol}$

Relative content of Na: $r = 0.023$

Half-life of Na: $T_{1/2} = 3.6.10^3 a$

From this we obtain:

$$N = \frac{55}{m}.N_A.r = 7.61.10^{23}, A = \frac{N.\ln 2}{t_{1/2}} = 1.85353.10^{17} KBq$$

Determining the calibration factor:

Na counting rate without background:

$$R = 8.09 s^{-2}$$

Calibration factor (at E_γ): $K_K = \frac{A}{R} = 0.22911.10^{17} \frac{Bq}{s^{-1}}$

Radionuclide Na (E_γ)

Na counting rate

Without background: $R = 7.73 s^{-1}$

Na activity of the sample: $A = R.K_k = 2.31212.10^{17} Bq$

Specific activity of Na: $\frac{A}{m} = 1.66435 \frac{Bq}{g}$

Calculating the sodium content of the sample:

Atomic weight of sodium $22.98 \frac{g}{mol}$

Portion of sodium in of 55gKacl $392 g$

Activity of Na: $1.85353.10^{17} KBq$

Specific activity of Na: $\frac{A}{m} = 5.9.10^{17} \frac{Bq}{g}$

From this we obtain:

Sodium content of the sample: $\frac{1.7373 \frac{Bq}{g}}{5.9.10^{17} \frac{Bq}{g}} = 0.295.10^{-17} g$

5.4 Dissections

From results obtained it is clear that the activity of sodium chloride

Is very poor so it reveals (Na activity of the sample) of $A = R.K_k = 2.31212.10^{17} Bq$

Also scintillation counter can be used to calculate and identify radioactive samples.

5.5 Conclusion

With a calibrated scintillation counter, it is possible to identify the radioactive admixtures of a sample and to determine their activities.

For calibrating the detection probability of the scintillation counter, a preparation which ensures a well-defined geometry of the measurement is required. The detection probability depends on the γ energy.

5.6 Recommendation

- Federal agencies should ensure and enhance monitoring and surveillance relative to sodium intake measurement, salt taste preference, and sodium content of foods, and should ensure sustained and timely release of data in user-friendly formats.
- More research should be conducted for identifying the radioactive substances.
- Physicist who works in the field of Radiation Protection (coefficient of nuclear -tab) has to be at the level of higher training and higher qualifying and distinctive in the field of radiation protection.
- Estimate the radiation dose that workers are exposed in the field of radiology to ensure they do not exceed the limits recommended dosage globally as well as ensure the safety of the system and the workplace and advice people and authorities concerned in cases of malfunction.

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