Assessment of aluminum concentration in fe-Al Alloy sheets using (662, 1173 and 1332 keV) gamma energies

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ABSTRACT

In this research work, a nuclear gauge, based on single energy gamma ray transmissions, has been developed and used to determine the concentrations of the aluminum in iron-aluminum alloy. The sample sheets of thicknesses ranging from 0.30 to 1.308 cm have been prepared from the Fe-Al alloy to be used as targets. The concentration of Al for thickness 0.30cm of alloy is 95.5% at 662 keV, and the concentration of Al for other energies 1173keV and 1332keV are 85% and 82% respectively. Similarly, for the other thickness, observed that the concentration of Al is reliable at low energy. According to the result, the best choice of the suitable energy for single energy gamma ray transmissions have been investigated.

Keywords: Nuclear Gauge, Concentration of Alloy, Gamma ray transmission Method

Introduction

An alloy is a mixture of two or more elements in solid solution in which the major component is a metal. Most pure metals are either too soft, brittle or chemically reactive for practical use. Combining different ratios of metals as alloys modifies the properties of pure metals to produce desirable characteristics. The aim of making alloys is generally to make them less brittle, harder, resistant to corrosion, or have a more desirable color and luster. Of all the metallic alloys in use today, the alloys of iron (steel, stainless steel, cast iron, tool steel, alloy steel) make up the largest proportion both by quantity and by commercial value.

Other significant metallic alloys are those aluminum, titanium, copper and magnesium. Copper alloys have been known since prehistory bronze give the Bronze Age its name and have many applications today, most importantly in electrical wiring. The alloys of the other three metals have been developed relatively recently; due to their chemical reactivity they require electrolytic extraction processes. The alloys of aluminum, titanium and magnesium are valued for their high strength- to – weight ratios; magnesium can also provide electromagnetic shielding. These materials are ideal for situations where high strength - to-weight ratio is more important than material cost, such as in aerospace and some automotive applications.

Application of Alloys

The components of various alloys contain metallic and non-metallic elements. There are a large number of possible combinations of different metals and each has its own specific set of properties. The alloys and the metals are covered by standards. The applications for

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alloys are limitless depending on the materials involved and the complexity of the alloy. The alloys are used in an extensive range of aircrafts, military, commercial, industrial, medical, residential and manufacturing applications. Alloys like Aluminum, Copper, Nickel, Stainless steel, Titanium have different uses in various applications.

Metals are good conductors, making them valuable in electrical appliances and arrying an electric current over a distance with little energy lost. Electrical power grids rely on metal cables to distribute electricity. Home electrical systems, the most part, are wired with copper wire for its good conducting properties.

The thermal conductivity of metal is useful for containers to heat materials over a flame. Metal is also used for heat sinks to protect sensitive equipment from overheating.

Aluminum

Aluminum is a chemical element with symbol Al and atomic number 13. It is silvery white, and it is not soluble in water under normal circumstances.

Aluminum is the third most abundant element (after oxygen and silicon), and the most abundant metal, in the Earth’s crust. It makes up about 8% by weight of the Earth’s solid surface. Aluminum is remarkable for the metal’s low density and for its ability to resist corrosion due to the phenomenon of passivation. Structural components made from aluminum and its alloys are vital to the aerospace industry and are important in other areas of transportation and structural materials. The most useful compounds of aluminum, at least on a weight basis, are the oxides and sulfates. Aluminum is a good thermal and electrical conductor, having 59% the conductivity of copper, both thermal and electrical, while having only 30% of copper’s density.

Uses of Aluminum Alloy

Aluminum when combined with other metals gives strength and specific characteristics for a particular use. Aluminum alloys in which aluminum (Al) is the predominant metal. Aluminum alloys are extensively used in the production of automotive engine parts. The huge array of quality aluminum is used in various applications like transport, packaging, electrical application, medicine, and construction of homes and furniture. The high-altitude flying is not possible without the huge pressures and stresses involved in the strong aluminum alloys.

Aluminum alloy surfaces will keep their apparent shine in a dry environment due to the formation of a clear, protective layer of aluminum oxide. In a wet environment, galvanic corrosion can occur when an aluminum alloy is placed in electrical contact with other metals with more negative corrosion potentials than aluminum.

Material and Method

Total Photon Attenuation Coefficient

When a photon travels through matter, it may interact through any of the three major ways. There are other interactions, but they are not mentioned here because they are not important in the detection of gammas.

The total probability of interaction μ, called the total linear attenuation coefficient, is equal to the sum of the three probabilities.

$$\mu = \tau + \sigma + K \quad (1)$$

where; μ = the probability of interaction per unit distance

τ = the probability of photoelectric effect

σ = the probability of Compton scattering

K = the probability of pair production

There are tables that give μ for all the elements, for many photon energies. If μ is given in m^2/kg (or cm^2/g), it is called the total mass attenuation coefficient. The mass attenuation coefficient μ_m is the linear attenuation coefficient divided by the density of the absorber material

$$\mu_m = \frac{\mu}{\rho} \quad (2)$$

where; μ_m = the mass attenuation coefficient

μ = the total linear attenuation coefficient

ρ = the density of the absorber material

The basic property of the absorber material of γ-rays is the exponential decrease in the intensity of radiation as a homogenous beam γ-rays pass through a thin slab of matter. The intensity I_0 of a collimated γ-rays beam will be attenuated to an intensity I after it has passing through an absorbing material mixture of mass thickness x according to the following general absorption law. It is shown in Figure(1).

$$I = I_0 e^{-\mu_t x} \quad (3)$$

where; I = the intensity after passing through a thickness x

I_0 = the intensity without absorber

μ_t = the total mass attenuation coefficient

x = the thickness of absorber

$$\mu_t = \Sigma_i \mu_i C_i \quad (4)$$

$$\Sigma_i C_i = 1 \quad (5)$$

Where μ_i and C_i are the mass absorption coefficient and the weight fraction of the i^{th} component in the material mixture, respectively.

In the energy gamma ray transmission technique, an unknown concentration of a material component is determined by measuring the intensities of a narrow beam of low or high-energy γ-ray that is transmitted through an absorbing material of mass thickness x. In the case the absorbing material is a binary alloy such as Fe-Al alloy [4].

By equation (4),

$$\mu_t = \ln\left(\frac{I_0}{I}\right)/x$$

$$\mu_{Al} C_{Al} + \mu_{Fe} C_{Fe} = \ln\left(\frac{I_0}{I}\right)/x$$

By equation (5),

$$C_{Al} + C_{Fe} = 1$$

$$C_{Fe} = 1 - C_{Al}$$

$$C_{Al}\,\mu_{Al} + (1 - C_{Al})\,\mu_{Fe} = \ln\left(\frac{I_0}{I}\right)/x$$

$$C_{Al}\,\mu_{Al} + \mu_{Fe} - C_{Al}\,\mu_{Fe} = \ln\left(\frac{I_0}{I}\right)/x$$

$$C_{Al}(\mu_{Al} - \mu_{Fe}) = \left\{\ln\left(\frac{I_0}{I}\right)/x\right\} - \mu_{Fe}$$

$$C_{Al} = \left\{\ln\left(\frac{I_0}{I}\right)/x - \mu_{Fe}\right\}/(\mu_{Al} - \mu_{Fe}) \qquad (6)$$

where; C_{Al} = concentration of aluminum in alloy

I_0 = net count without absorber

μ_{Al} = linear attenuation coefficient of aluminum

μ_{Fe} = linear attenuation coefficient of iron

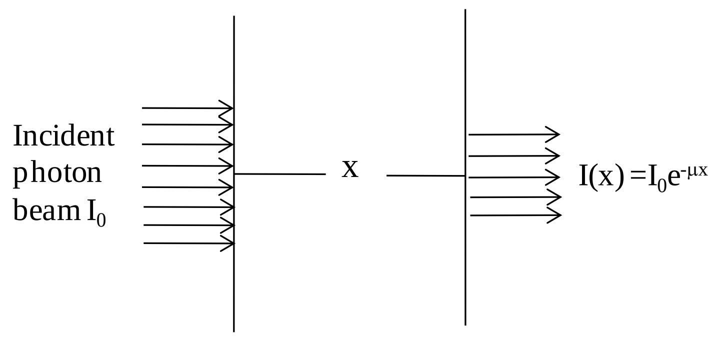

Figure (1) The intensity of the transmitted beam decreases exponentially with material thickness

Target Sheets

The sample sheets of thickness ranging from 0.3cm to 1.07cm have been prepared from the Fe-Al alloy to be used as targets for the gamma energies (662 keV, 1173 keV and 1332 keV). Moreover pure aluminum sheets of thickness ranging from 0.61 cm to 1.51 cm and iron sheets of thickness ranging from 0.38cm to 1.9 cm have been also prepared to find linear attenuation coefficient of Al and Fe separately.

Experimental Procedure

The standard radioactive sources of known energies were used to calibrate the spectrometer. Therefore, energy calibration was first made for 300 seconds by using Ba-133(81 keV and 356 keV), Na-22(511 keV and 1274 keV), Co-60 (1173.23 keV and 1332.49 keV) and Cs-137 (661.65 keV) sources. In this work, conversion gain is set at 2048. First the Cs-137 standard source without absorber (sample) was placed in front of NaI (T*l*) detector. The detector was placed horizontally and the distance between the source and the detector was 5cm. The Cs-137 source was fixed in the lead shield. The detector was located forward direction of gamma beam. A spectrum was accumulated for a period long enough to determine the peak position. The amplifier gain and shaping time were adjusted until peaks were obtained at the desired energy.

The experimental set up is systematically made. Then the emitted-radiations from the source were detected by the NaI(T*l*) detector and a spectrum collection time was 600 seconds. The sample was positioned between source collimator and detector collimator.

The pure aluminium sample of thickness 0.61 cm was placed between source and detector and the spectrum was collected again. Samples with different thickness (0.84 cm, 1.04 cm, 1.23 cm, 1.39 cm and 1.51 cm) were placed between source and detector and spectra for the same period were collected.

Then the iron sample of thickness 0.38 cm was placed between source and detector and the spectrum was collected again. Samples with different thickness (0.76 cm, 1.14 cm, 1.52 cm and 1.9 cm) were put between source and detector and spectra for the same period were also collected.

Finally the Alloy sample of thickness 0.30 cm was placed between source and detector and the spectrum was collected again. Samples with different thickness (0.53 cm, 0.70 cm, 0.84 cm, 0.96 cm and 1.07cm) were set between source and detector and spectra for the same period were collected.

The spectra were stored in PC with MCA and analyzed by the Gamma Vision 32 software. The net counts of radioactive elements from the spectra in samples were obtained by subtracting the background area from gross area. From these data, the graphs using thickness and net area were drawn and linear attenuation coefficients ($\mu(cm^{-1})$) was calculated. Experimental set up of gamma transmission measurement was shown in Figure (2).
The procedure in measurement was taken using in.

Detector biasing voltage = + 1000 V

Amplifier coarse gain = 10

Amplifier fine gain setting = 2.7

Shaping time = 0.1 μs

Four radioactive sources provided seven peaks of known energy: 511 keV and 1274 keV for the ^{22}Na, 81 and 356 keV for the ^{133}Ba, 1173 and 1332 keV for the ^{60}Co and 662 keV for the ^{137}Cs.

Energy Calibration

The standard radioactive sources of known energies were used to calibrate the spectrometer. The gamma rays' spectra of three standard sources ^{133}Ba (81.65 keV and 356.02 keV),^{137}Cs (661.66 keV) and ^{60}Co (1173.24 keV and 1332 keV) were measured for 300 seconds by using NaI (Tl) scintillation detector in Table (1) and the energy calibration curve is shown in Figure (3). Establishing a direct relationship between photo peak energy and multi-channel number could do the energy calibration process. The amplifier gain was adjusted until peaks were obtained at the desired channel numbers. In doing so, the energy calibration curve was obtained.

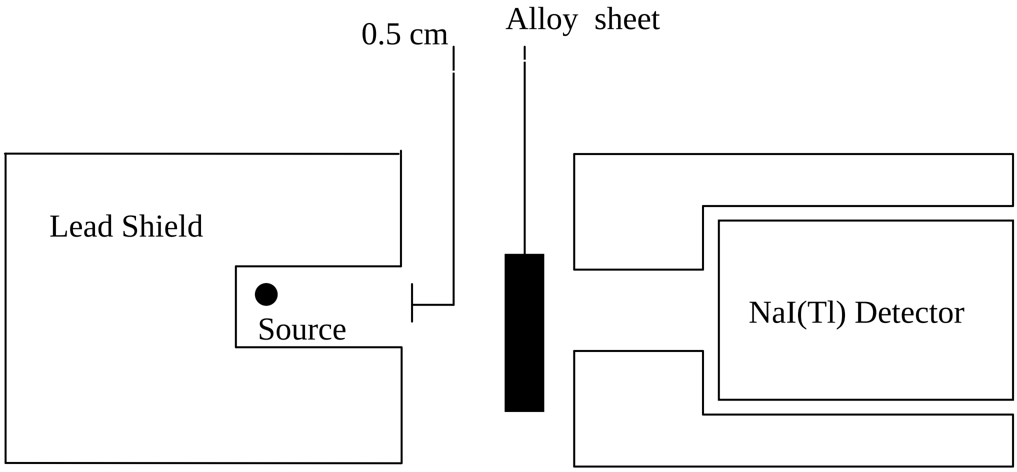

Figure (2) Experimental set up and arrangement

Table (1) Energy calibration data using standard gamma sources

Source	Energy (keV)	Channel	Gamma Emission Probability %
^{133}Ba	81.65	91	34.06
^{133}Ba	356.02	366	62.05
^{137}Cs	661.65	666	85.10
^{60}Co	1173.23	1155	99.97
^{60}Co	1332.5	1310	99.98

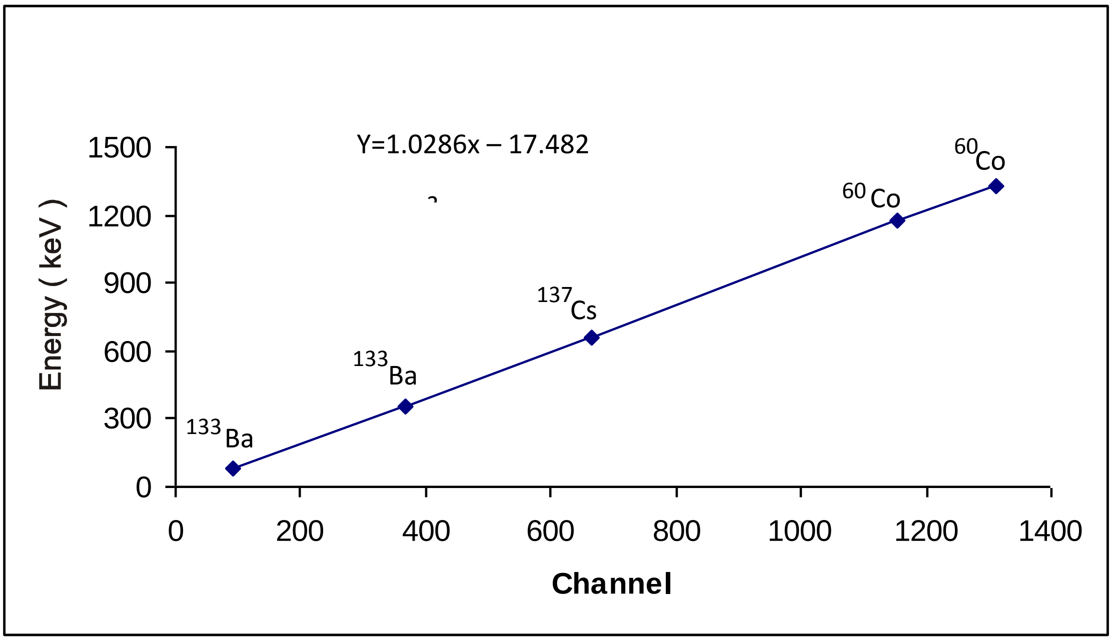

Figure (3) Energy calibration curve

Result and Discussions

Results

The values of different thickness with error of Al, Fe and Alloy and their results are described in Table (2), (3) and (4). The spectra without absorber and Alloy absorber were shown in Figure (4) and (5). The region of interest (ROI) of suitable channels both left and right of photo peak is marked. When the $\ln(I/I_0)$ is plotted against the absorber thickness, the slope of the straight line gives the linear attenuation coefficient (μ) of Al and Fe. Determination of linear attenuation coefficient of Al and Fe was shown in Figure (6) to (7). Comparison of linear attenuation coefficients for Al and Fe was shown in Table (5). Aluminum concentration in Alloy was determined by using the following equation,

$$C_{Al} = \left\{ \ln\left(\frac{I_0}{I}\right) / x - \mu_{Fe} \right\} / \left(\mu_{Al} - \mu_{Fe}\right)$$

Where C_{Al} = concentration of aluminum in alloy

I_0 = net count without absorber

μ_{Al} = linear attenuation coefficient of aluminum

μ_{Fe} = linear attenuation coefficient of iron

The calculated results are shown in Table (6).

Table (2) The measurement results of Al with various thickness

No	Thickness (cm)	Net Area (662keV)	Net Area (1173keV)	Net Area (1332keV)
1	0	88614	22058	18274
2	0.61±0.000045	82252	20950	17286
3	0.84±0.000077	79374	20384	16781
4	1.04±0.000089	76736	20100	16593
5	1.23±0.000099	74471	19579	16213
6	1.39±0.000113	72222	19207	15977

Table (3) The measurement results of Fe with various thickness

No	Thickness (cm)	Net Area (662keV)	Net Area (1173keV)	Net Area (1332keV)
1	0	95273	25435	20281
2	0.38±0.000013	79575	21709	17637
3	0.76±0.000022	66419	18383	15624
4	1.14±0.000028	55823	15813	13584
5	1.52±0.000036	46093	13402	11744
6	1.90±0.000043	38392	11835	10394

Table (4) The measurement results of Alloy with various thickness

No	Thickness (cm)	Net Area (662keV)	Net Area (1173keV)	Net Area (1332keV)
1	0	93634	24688	20830
2	0.30±0.000067	87372	23618	19938
3	0.53±0.000071	83195	22967	18999
4	0.74±0.000084	80811	22547	18510
5	0.84±0.000087	78951	21997	18328
6	0.96±0.000096	76619	21677	17846

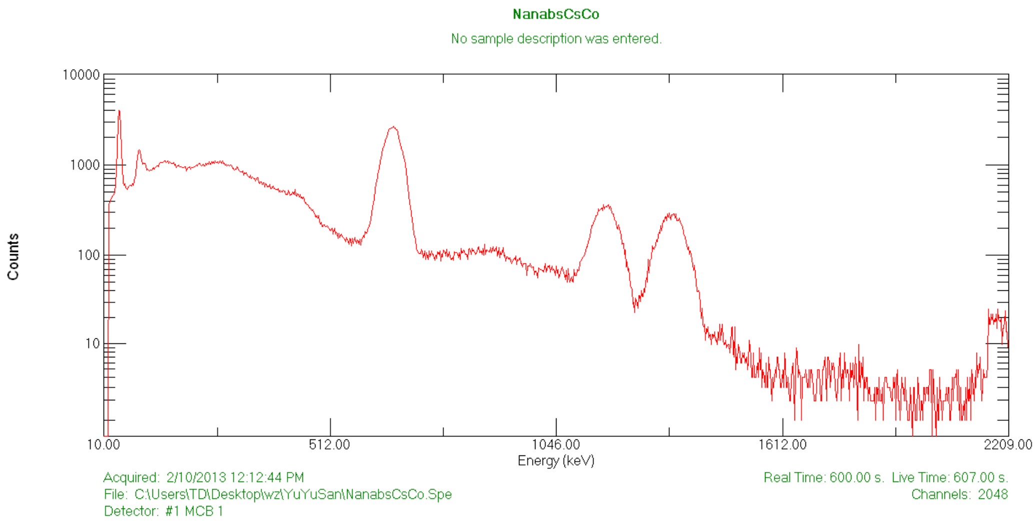

Figure (4) Spectrum of non-absorber for Cs and Co Gamma sources

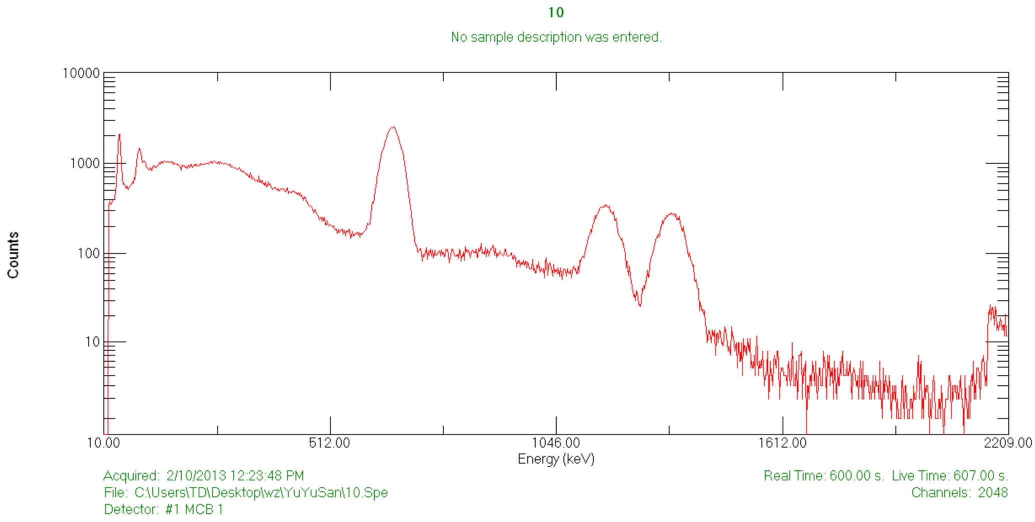

Figure (5) Energy Spectrum of Alloy (0.30 cm)

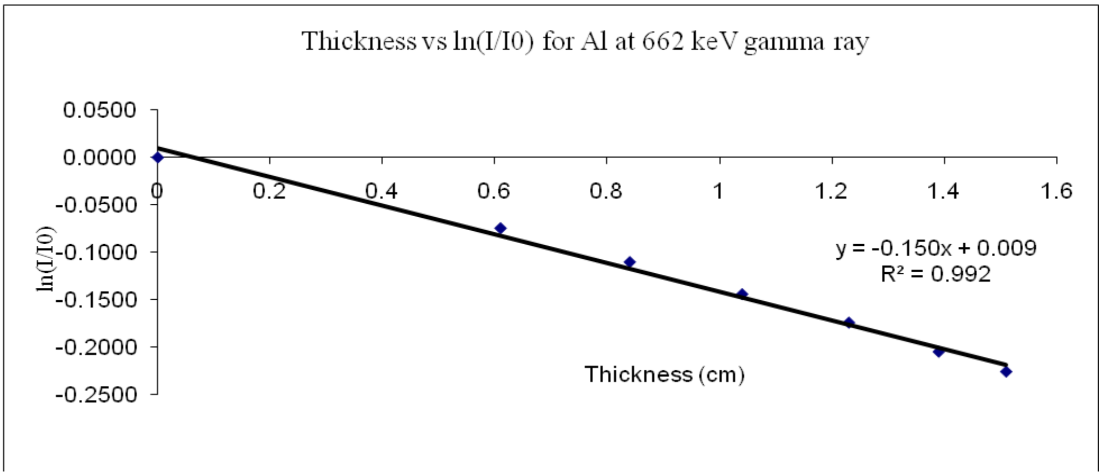

Figure (6) Determination of linear attenuation coefficient of Al at 662 keV

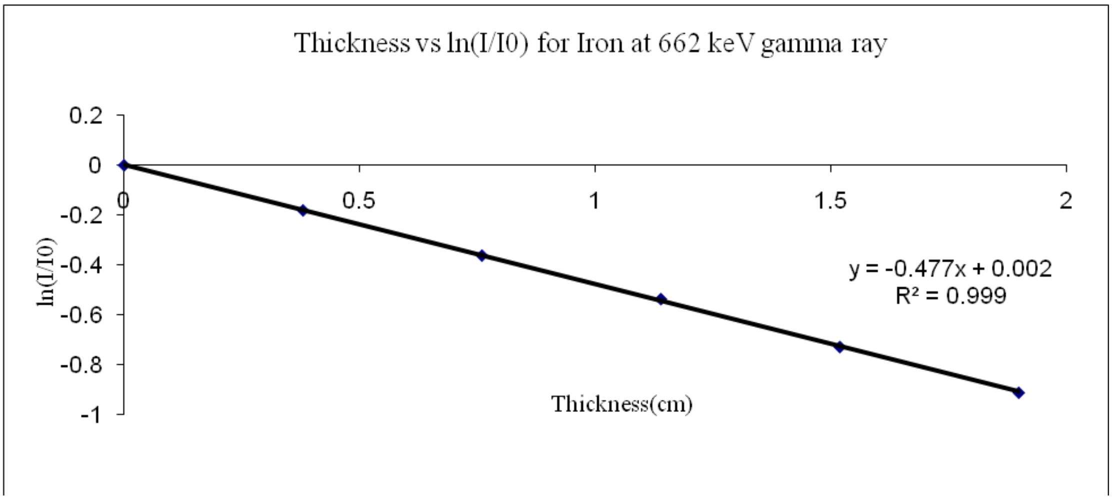

Figure (7) Determination of linear attenuation coefficient of Fe at 662keV

Table (5) The measurement results of Linear Attenuation Coefficient (μ) of Al and Fe

No.	Energy (keV)	Linear Attenuation Coefficient (μ) of Al	Linear Attenuation Coefficient (μ) of Fe
1	662	0.1506	0.4772
2	1173	0.1007	0.4077
3	1332	0.0997	0.3535

Table (6) The Concentration of Al in alloys with (662, 1173 and 1332 keV) Gamma energies

No.	Thickness (cm)	662keV	1173keV	1332keV
1	0.30	0.9552	0.8469	0.8180
2	0.53	0.9547	0.8839	0.7088
3	0.70	0.9673	0.9059	0.7282
4	0.84	0.9597	0.8805	0.7926
5	0.96	0.9517	0.8867	0.7582

Discussions

In this research, the concentrations of Al component in iron-aluminum alloy with 662, 1173 and 1332 keV gamma energies were calculated by using equation (6). Criteria for the best choice of the suitable photon energies for single energy gamma ray transmission have been investigated. According to Table (6), the concentration of Al for thickness 0.30cm of alloy is 95.5% at 662 keV, and the concentration of Al for other energies 1173keV and 1332keV is 85% and 82% respectively. Similarly to the other thickness, the concentration of Al is reliable at low energy.

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