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Gradient Shielding for Scintillation Detector NaI(TI) Using multiple Materials

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Abstract

In this research, we studied the graded shielding using one of gamma-ray spectroscopy techniques, which consists of a scintillation detector sodium iodide activated by thallium NaI (Tl) with dimensions of 3"×3" and its electronic accessories .Shielding is fundamentally necessary to minimize the influence of ambient radiation, which consists of single or multiple layers of different materials, such as copper, aluminum and fiberglass, in addition to the lead shield manufactured with a thickness 3cm and through this work it led to reducing the values of the Compton edge and background scattering using industrial source of Cs-137. This method works to attenuate unwanted complications, which leads to reducing the count rates in some channels. These new layers should not contain any materials that would add new contributions to the radiation background, ultimately eliminating the complications resulting from the use of the lead shield.Theexperimental results and theoretical conclusion show consistent.

Keywords: Layers shielding, NaI(Tl) detector, Stander source, Backscattering, gamma ray spectroscopy.

1.Introduction

One of the most hazardous forms of environmental pollution is radioactive

contamination, which poses a threat to human cells.

Particularly dangerous form of physical pollution, radioactive contamination refers to the leakage of radioactive material into a component environment, such as water, soil and the atmosphere. There are two primary categories of radioactive materials, the first category includes electromagnetic radiation such as gamma rays and x-rays, which are frequently scientific using. For this category of material radioactive substances have a high ability to penetrate biological tissues over a long distance. The second type is particle radiation such as alpha and beta rays. This form of radioactive material has a lower capacity to the earliest kind of penetration into the human body [1]. Radioactive contamination, it may occur from natural sources such as radiation from space external, radioactive gases rising from the earth's crust or from man-made sources of radiation [2]. Three basic methods used to reduce the external radiation hazard are time, distance, and shielding. Good radiation protection practices require optimization of these fundamental. When reducing the time or increasing the distance may not be possible, one can choose shielding material to reduce the external radiation hazard. The proper material to use depends on the type of radiation and its energy [3]. Shielding is the third method for reducing the risk from external radiation. In general, this approach is recommended because it produces working circumstances that are inherently safe, as opposed to approaches that rely on exposure time or distance, which may necessitate ongoing administrative control over employees. The required level of shielding is determined by the type of radiation, the source's activity, and the permissible dose rate outside the shielding material [4]. Shielding of gamma radiation is an important component of radiation safety programs aiming to reduce personnel exposure to ionizing radiation. Selecting the most appropriate shielding material for a given source of ionizing radiation will require knowledge of the source of radiation, understanding of the basic principles gamma ray interactions with matter, other factors, such as cost and chemical compatibility [5].

Gamma radiation shielding is the absorption and attenuation of gamma energy in shielding material. Most materials absorb the energy of gamma rays to some extent. The extent of attenuation depends on the density and thickness of the shielding material. A useful measure of shielding property is the mass per unit area of material. Hence a thick layer of a lighter material will have the same effect as a thin layer of a denser material [6]. There are two different types of shielding: composite and multilayer. An additive-mixed base material makes up a composite shield. This may enhance the material's ability to shield. For instance, the density of a material can be enhanced by adjusting the amount of additives in concrete, leading to higher performance [7]. Two or more layers of various materials make up a multilayer shield. In this configuration, the shield will have a greater probability of scattering and absorbing the incoming radiation. For the Chicago graphite-moderated reactor, which was one of the first to use multilayer shield, concrete and paraffin zed wood were used in 1943. In order to protect against mixed radiation [8]. A shield is made from the combinations of composite and multilayer configurations which can be observed later in this review. This is because each of the materials has different shielding properties that they can be mixed and matched to solve a particular problem depending on the application [9]. Gamma radiation interaction with the medium can occur in one of three ways: photoelectric absorption, Compton scattering, and pair production [10]. The interaction of gamma radiation with matter results in shielding, or the attenuation of gamma radiation. The energy of the incident gamma radiation, the atomic number and density of the elements in the shielding material, and the thickness of the shielding all affect how much gamma radiation is reduced. Additional advantages in chemical resistance, physical durability, and portability may be provided by composite materials [11]. Any detector's setup involves selecting detector shielding to lessen background radiation's influence. Consider the shielding materials made of lead (Pb) Due to its high density (11340 kg/m3) and high atomic number (Z = 82) [12]. Which can change depending on the source to detector distance and geometry, radiation energy, attenuation layers around the detector [13]. One of the most popular gamma spectrometry materials is NaI(Tl), and its effectiveness is closely correlated with its detection efficiency [14]. When the thickness of the target material increases, the number of scattered photons will increase, the intensity of the scattered photons depends on the thickness and atomic number of the materials [15]. The photon can scatter by a free electron and transfer an amount of energy that depends on the scattering angle. The maximum energy given to an electron in Compton scattering occurs for a scattering angle of 180°, and the energy distribution is continuous up to that point this energy known as the Compton edge

The backscattered peak occurs when the gamma scatters without being detected and then scatters again until it is fully absorbed. In fact the energy value of the backscattered peak equals the energy of the Compton edge subtracted from the energy value of the photo peak [16].

In the present work, the experimental study of various detector shielding materials with different thicknesses to determine the Compton edge location and back scattering of gamma-ray photons using Cs-137 gamma sources is described. We used different materials such as lead, multiple layers of aluminum, copper and fiberglass. The lowest Compton edge and backscatter values were obtained with a suitably shielded NaI(Tl) scintillation detector 3" x 3" while keeping the distance between the radiation source and the detector constant.

2. Experimental part

2.1 The NaI(Tl) detector setup

The NaI (Tl) detector that was used in this study is situated inside at the laboratory of environmental and radiation pollution research in the department of physics, college of science, university of Thi- Qar. The setup consists of a NaI detector (with an attached MCA) situated inside a lead shield and connected to a laptop as shown in Figure 2.1 below.

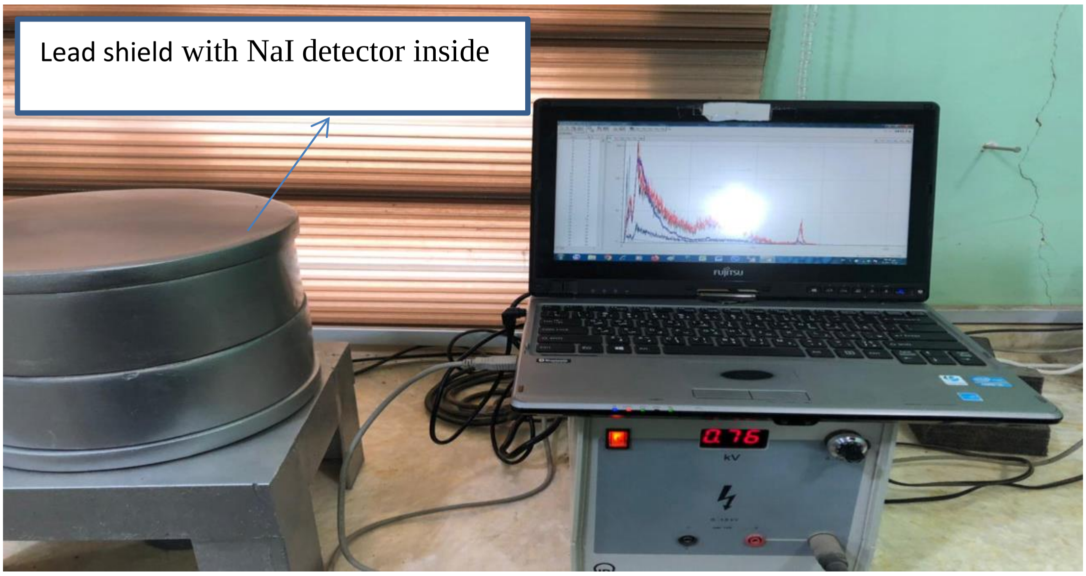


Figure 2.1: A picture of the detection setup that was used showing a lead shield and its stand housing a NaI detector which is connected to a laptop.

Table 2.1: Types of shields

Shield ID	Types of shields
L3Cu1	Lead shield with one layer of copper
L3Cu1Al1	Lead shield with one layer of copper and one layer of aluminum
L3Cu2Al1	Lead shield with two layers of copper and one layer of aluminum
L3Cu2Al2	Lead shield with two layers of copper and aluminum
L3Cu2Al1FIG	Lead shield with two layers of copper, aluminum and fiber glass
L3Cu2	Lead shield with two layers of copper

In the current work, the Teledyne Isotope scintillation detector of an American origin was used, its crystal size 3"x 3". This detector mainly consists of a transparent solid inorganic scintillation crystal of sodium iodide doped with thallium (TI), and attached to this crystal a high-efficiency photomultiplier tube whose function is to convert the light flash into an electrical signal proportional to the energy of the gamma-ray photons falling on detector. This detector is characterized by a good energy analysis ability close to (7.5%) at a power line (661.7 KeV) which is one of the energies of gamma rays emitted from the standard source of the radioactive cesium-137 (Cs137) isotope and operates at operating voltage (733 Volt) gamma rays emitted from the standard source of the cesium isotope - 137 radioactive surrounded by a lead shield lined from the inside with a copper plate in the form of a cylinder, cut into pieces and assembled on each other to form a cylinder thick (3 cm). Its height is (20 cm) and its inner diameter is (20 cm) to reduce the radiation background to a minimum. The lead shield which houses the detector and the source, materials with a low atomic number, such as copper layer at thick (0.5cm), were used as an inner lining for a shield for materials with a high atomic number, such as lead shield (3cm).

Layers of materials with a low atomic number, such as two layers of aluminum at (0.2cm) and one layer of copper at (0.5cm), were used as an inner lining for materials with a high atomic number, such as the lead shield, with a thickness of (3cm) to reduce the radiation backscattering and the Compton edge. In the current work, we made many shields with different materials with different thicknesses, and we made shields from more than one material. In this type, we put two layers of copper (1cm), two layers of aluminum (0.2cm), and a shield made of fiberglass, and these materials form an inner lining for the lead shield with thickness (3cm).

The laptop which has the cassy lab software for spectrum analysis are the most important components of this setup.

Spectrometer includes built-in electronic units such as a preamplifier, a secondary amplifier, a multi-channel analyzer (MCA), and other accessories show as in Figure (2.2) shows a diagram of the most important parts of the measurement system used.

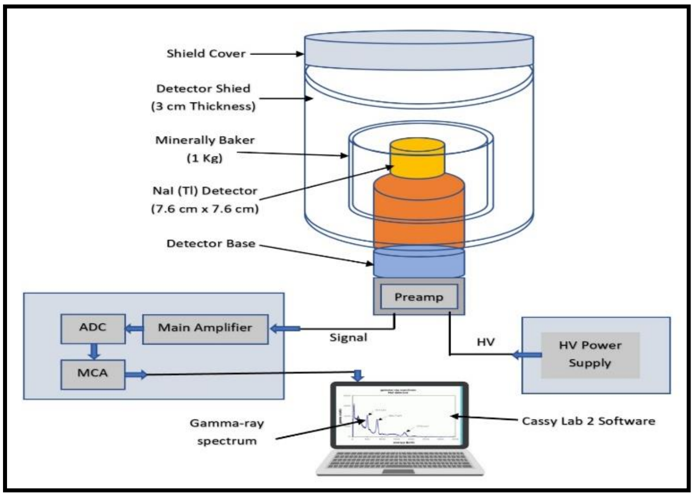


Figure 2.2: Scheme of the most important parts of the measurement system used in the current study.

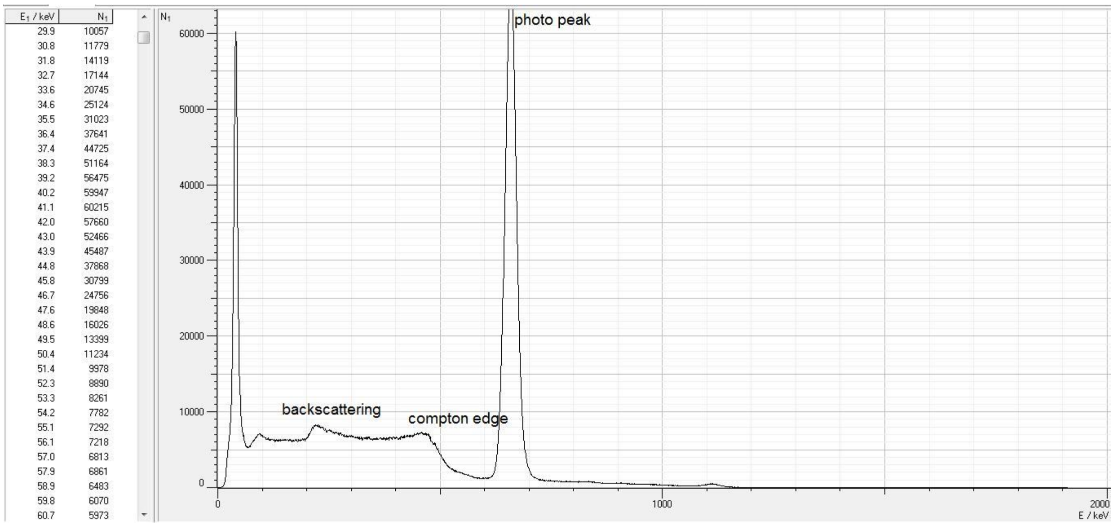
3. Results and Discussion

Backscattering and Compton edge measurements were calculated using the passive shielding method for one or more materials (compound materials) for many of the shields used in this work by standard industrial source such as CS-137.This study came to reduce energy interference in the spectrum of this type of detector by reducing Compton edge and backscattering by using combinations of different materials to shield the detector as in the tables 3.1and 3.2. Its shows count rates in the gradient shielding layers in a number of energy peaks of importance in gamma ray spectroscopy. From the experimental side, it is possible to reduce the contributions of beta particles(β) from the material used in shielding, the characteristic X- rays from lead or the sources used, and the events related to Compton scattering of gamma ray photons (where the graded shielding method is used), in which materials with a small atomic number are used as an internal lining for the materials With a large atomic number, like the lead shield in our current work, these materials interact with the characteristic x-rays of lead, beta particles, and background radiation, cosmic rays, and work to attenuate unwanted complications which leads to reducing the count rates

in some channels.

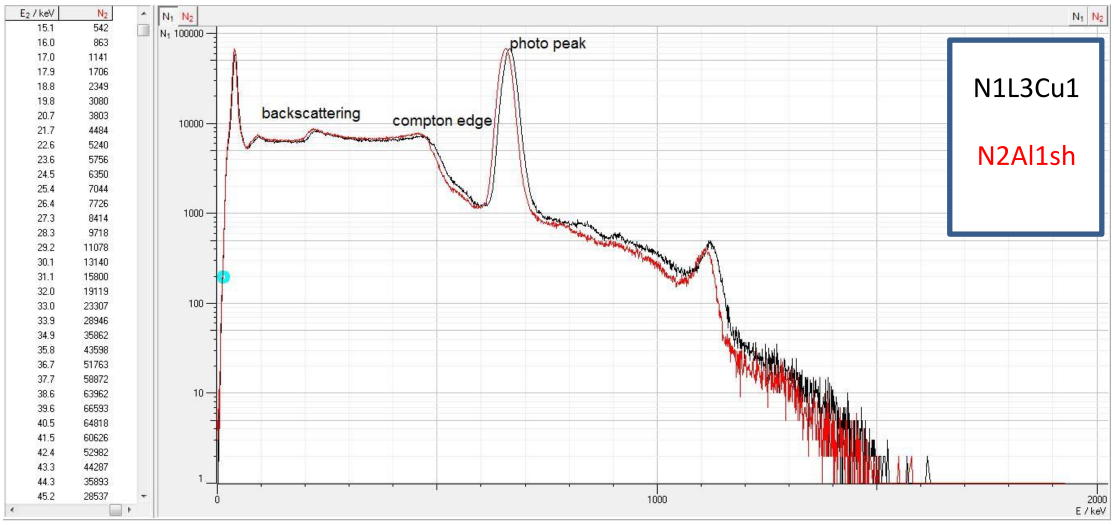
Table 3.1: The backscattering and Compton edge of the standard source of CS-137 for the scintillation detector type $3'' \times 3''$.

Type of shield	Photo peak(kev)	Compton edge(kev) Experimental	Backscattering(kev) experimental
L3Cu 1	662	474.1	221
L3Cu1Al1	661	472	218.1
L3Cu2Al1	661.3	474.8	216
L3Cu2Al2	664.1	476.9	218
L3Cu2Al1FIG	657.6	471	215
L3Cu2	660.4	474.8	215.7



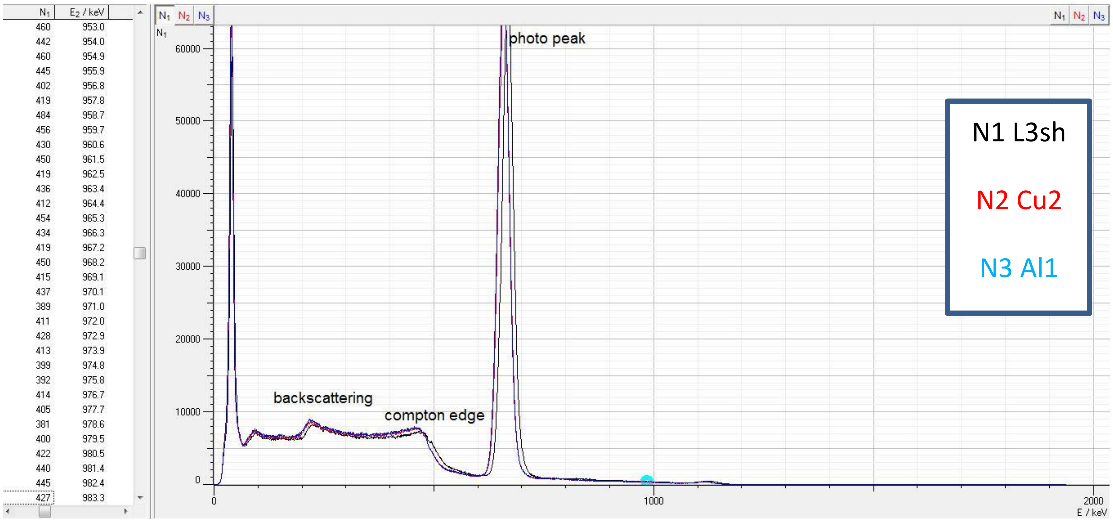
E_1 / keV	N_1
29.9	10057
30.8	11779
31.8	14119
32.7	17144
33.6	20745
34.6	25124
35.5	31023
36.4	37641
37.4	44725
38.3	51164
39.2	56475
40.2	59947
41.1	60215
42.0	57660
43.0	52466
43.9	45487
44.8	37868
45.8	30799
46.7	24756
47.6	19848
48.6	16026
49.5	13399
50.4	11234
51.4	9978
52.3	8890
53.3	8261
54.2	7782
55.1	7292
56.1	7218
57.0	6813
57.9	6861
58.9	6483
59.8	6070
60.7	5973

Figure 3.1: Cs-137spectrum measured using NaI (Tl) detector for many shields (L3Cu 1).



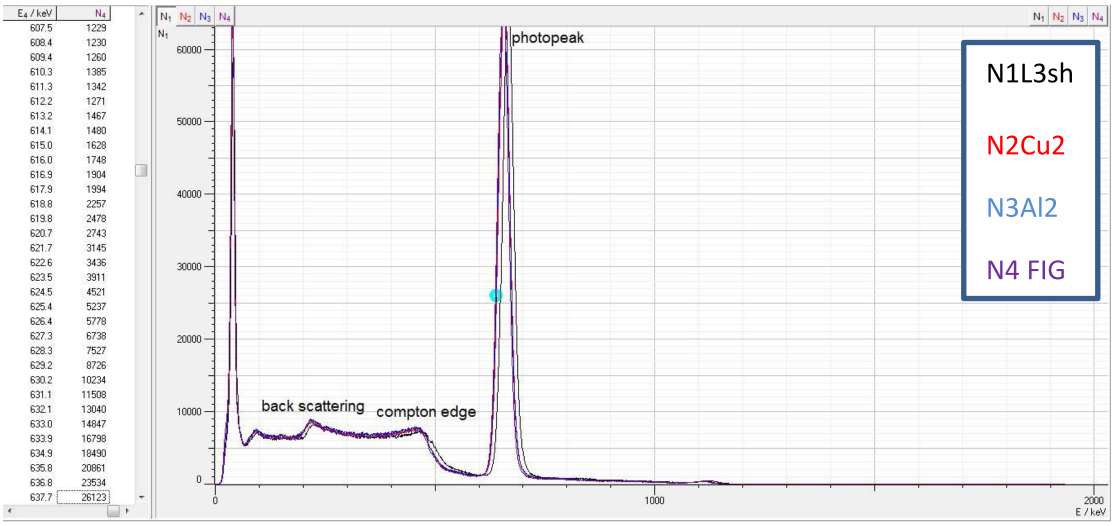
E_2 / keV	N_2
15.1	542
16.0	863
17.0	1141
17.9	1706
18.8	2349
19.8	3080
20.7	3803
21.7	4484
22.6	5240
23.6	5756
24.5	6350
25.4	7044
26.4	7726
27.3	8414
28.3	9718
29.2	11078
30.1	13140
31.1	15800
32.0	19119
33.0	23307
33.9	28946
34.9	35862
35.8	43598
36.7	51763
37.7	58872
38.6	63962
39.6	66593
40.5	64818
41.5	60626
42.4	52982
43.3	44287
44.3	35893
45.2	28537

Figure 3.2: Cs-137spectrum measured using NaI (Tl) detector for many shields (L3Cu1Al1).



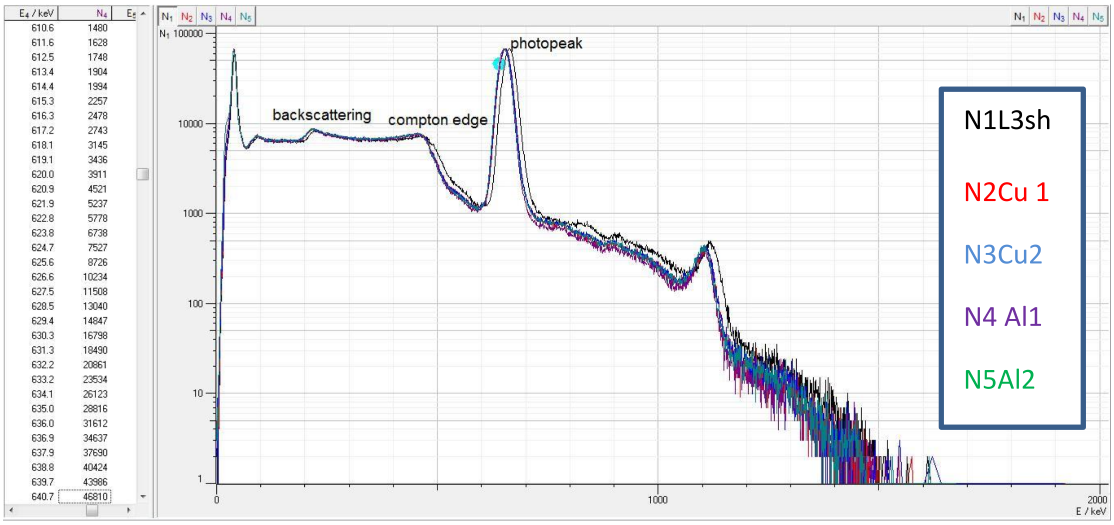
N_1	E_2 / keV
460	953.0
442	954.0
460	954.9
445	955.9
402	956.8
419	957.8
484	958.7
456	959.7
430	960.6
450	961.5
419	962.5
436	963.4
412	964.4
454	965.3
434	966.3
419	967.2
450	968.2
415	969.1
437	970.1
389	971.0
411	972.0
428	972.9
413	973.9
399	974.8
392	975.8
414	976.7
405	977.7
381	978.6
400	979.5
422	980.5
440	981.4
445	982.4
427	983.3

Figure 3.3: Cs-137spectrum measured using NaI (Tl) detector for many shields (L3Cu2Al1).



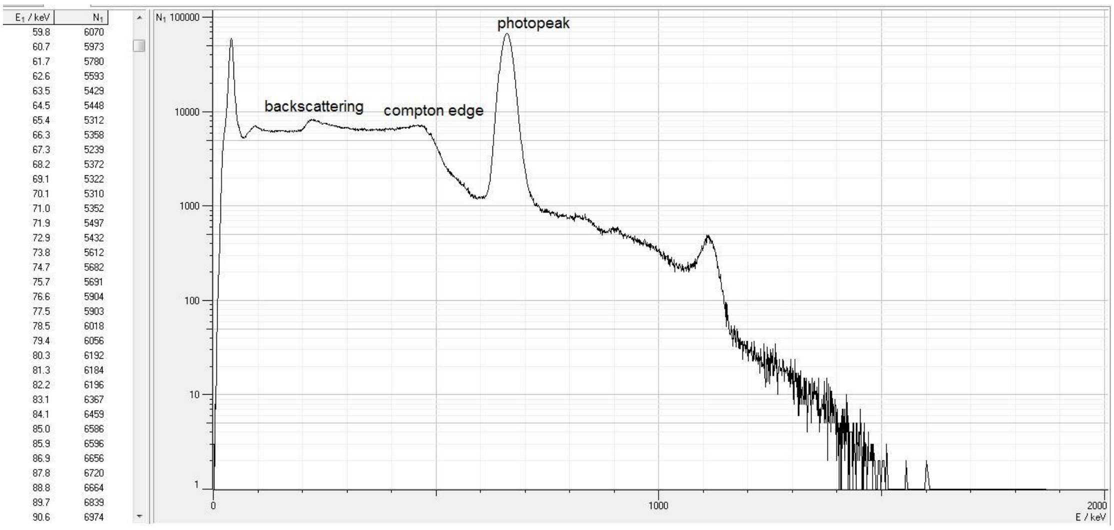
E_4 / keV	N_4
607.5	1229
608.4	1230
609.4	1260
610.3	1385
611.3	1342
612.2	1271
613.2	1467
614.1	1480
615.0	1628
616.0	1748
616.9	1904
617.9	1994
618.8	2257
619.8	2478
620.7	2743
621.7	3145
622.6	3436
623.5	3911
624.5	4521
625.4	5237
626.4	5778
627.3	6738
628.3	7527
629.2	8726
630.2	10234
631.1	11508
632.1	13040
633.0	14847
633.9	16798
634.9	18490
635.8	20861
636.8	23534
637.7	26123

Figure 3.4: Cs-137spectrum measured using NaI (Tl) detector for many shields. (L3Cu2Al1FIG).



E_4 / keV	N_4	E_5
610.6	1480	
611.6	1628	
612.5	1748	
613.4	1904	
614.4	1994	
615.3	2257	
616.3	2478	
617.2	2743	
618.1	3145	
619.1	3436	
620.0	3911	
620.9	4521	
621.9	5237	
622.8	5778	
623.8	6738	
624.7	7527	
625.6	8726	
626.6	10234	
627.5	11508	
628.5	13040	
629.4	14847	
630.3	16798	
631.3	18490	
632.2	20861	
633.2	23534	
634.1	26123	
635.0	28816	
636.0	31612	
636.9	34637	
637.9	37690	
638.8	40424	
639.7	43986	
640.7	46810	

Figure 3.5: Cs-137spectrum measured using NaI (Tl) detector for many shields (L3Cu2Al2).



E_1 / keV	N_1
59.8	6070
60.7	5973
61.7	5780
62.6	5593
63.5	5429
64.5	5448
65.4	5312
66.3	5358
67.3	5239
68.2	5372
69.1	5322
70.1	5310
71.0	5352
71.9	5497
72.9	5432
73.8	5612
74.7	5682
75.7	5691
76.6	5904
77.5	5903
78.5	6018
79.4	6056
80.3	6192
81.3	6184
82.2	6196
83.1	6367
84.1	6459
85.0	6586
85.9	6596
86.9	6656
87.8	6720
88.8	6664
89.7	6839
90.6	6974

Figure 3.6: Cs-137spectrum measured using NaI (Tl) detector for many shields (L3Cu2).

Each interaction mechanism creates features within the observed pulse height spectrum: Photoelectric interactions give rise to a full-energy peak. Compton scattering events can occur where the scattered photon escapes the detector without further interaction. This gives rise to the Compton distribution. Compton scattering events can occur where the scattered photon itself undergoes Compton scattering and then escapes the detector. This gives rise to energy deposition in the detector, higher in energy than the Compton edge, but lower than the full-energy peak. Finally, the scattered photon can also be completely absorbed, which gives a full-energy peak event, Figures (3.1-3.6).

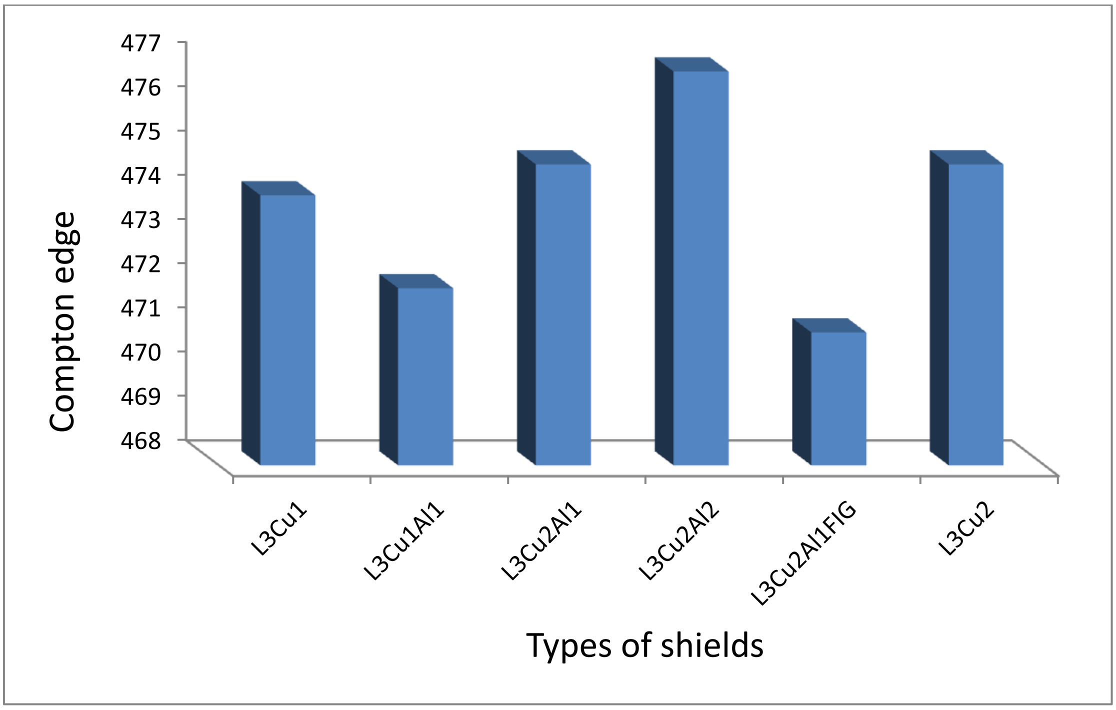


Figure 3.7: Experimental of the compton edge is function of types of shielding for stander source of Cs-137.

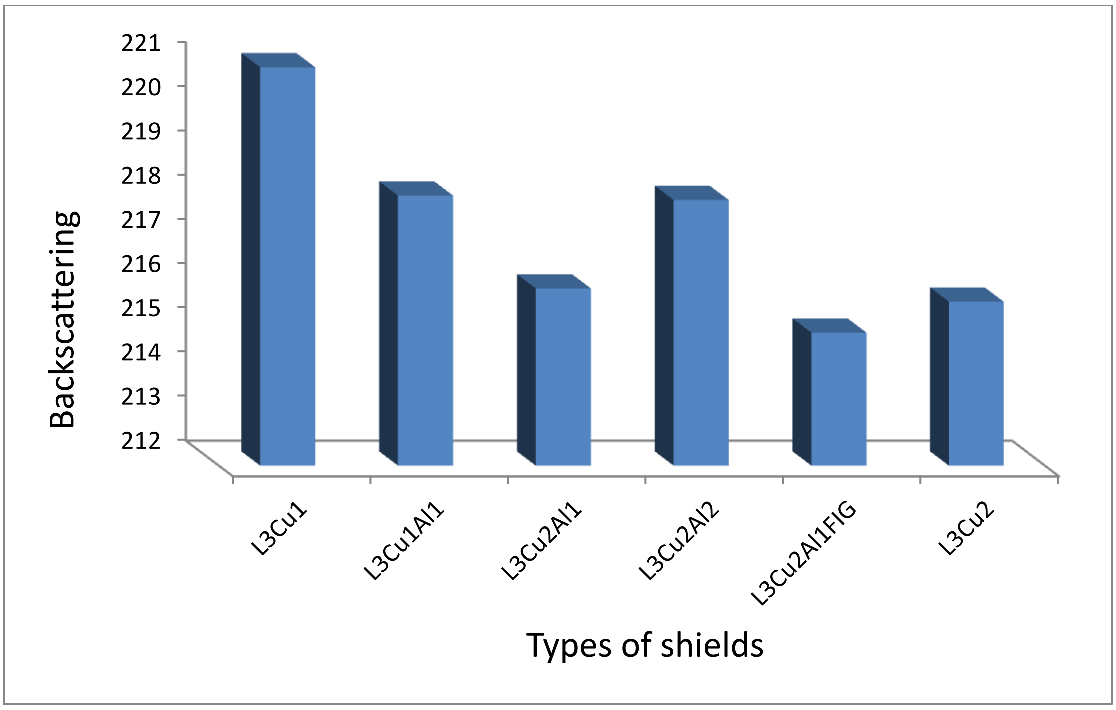


Figure 3.8: Experimental of the backscattering is function of types of shielding for stander source of Cs-137.

Type of shield	Photo peak(kev)	Compton edge(kev) Theoretical	Backscattering(kev) theoretical
L3Cu 1	662	477.65	184.35
L3Cu1Al1	661	476.73	184.27
L3Cu2Al1	661.3	477.00	184.3
L3Cu2Al2	664.1	479.59	184.51
L3Cu2Al1FIG	657.6	473.59	184.1
L3Cu2	660.4	476.17	184.23

Table 3.2: Calculation theoretically of the back scattering and Compton edge of the standard source of CS-137 for the scintillation detector type 3″ × 3″.

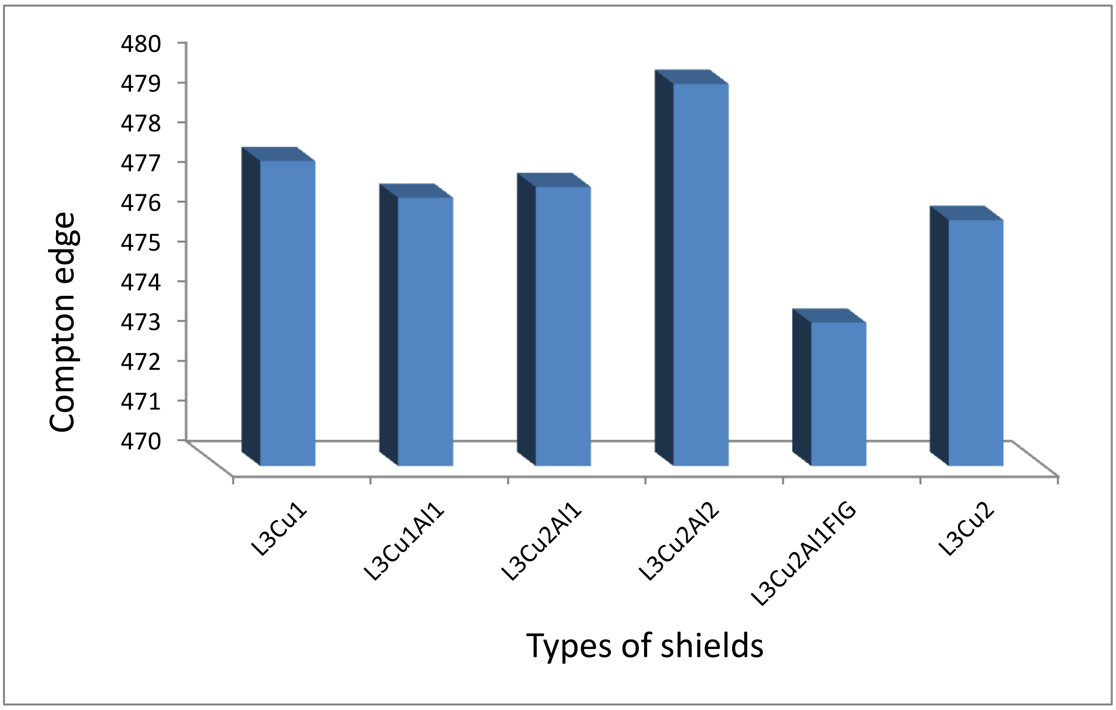


Figure 3.9: Theoretically of the Compton edge is function of types of shielding for stander source of Cs-137.

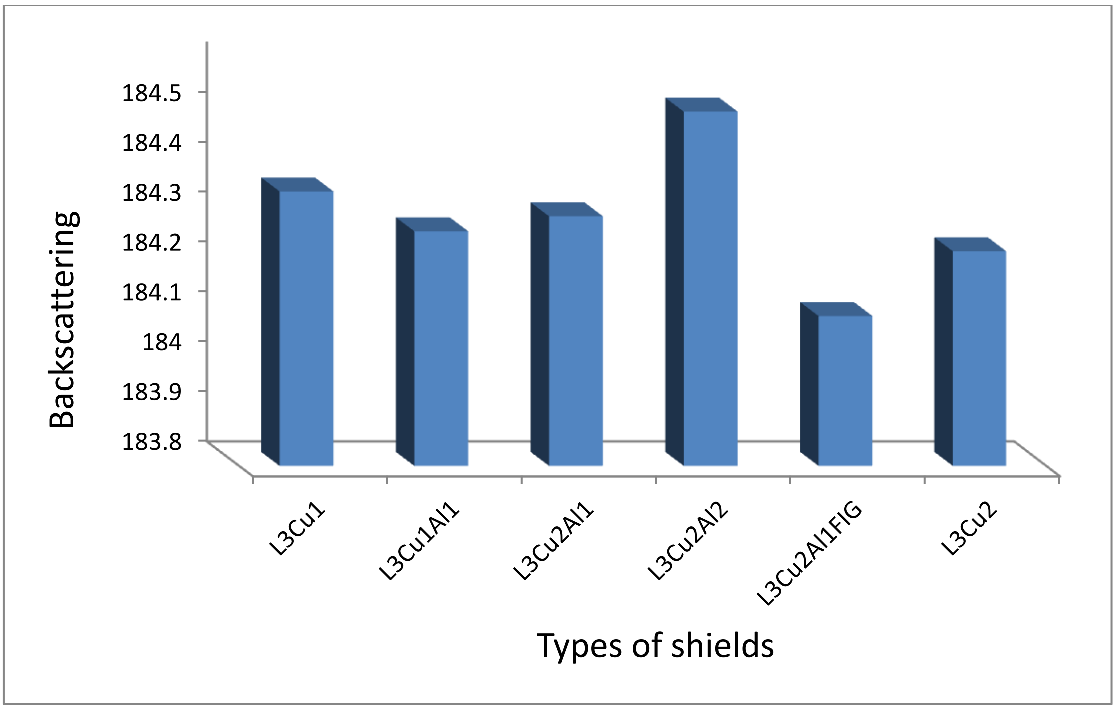


Figure 3.10: Theoretically of the backscattering is function of types of shielding for stander source of Cs-137.

4. Conclusion

Using the scintillation detector represented NaI(TI), we obtain a spectrum of gamma rays for radioactive source, one of which is stander source of CS-137 , containing continuous regions and peaks whose locations vary according to the energy of the incident photon, and thus the type of interaction between it and the detector material .This study showed us that the count rates in the gradient shielding method at a number of energy peaks are important in gamma ray spectroscopy, especially in the range (0-500) Kev, that is the region where backscattering of gamma rays occurs and the Compton edge prevails .It was also shown that the gradient shielding method is not suitable for lead shields of low thickness because the complications resulting from it are greater than the reduction that occurs as a result of it. The count rate decreases when the detector is surrounded by materials with a large atomic number, such as lead, and adding internal shielding layers, such as copper, aluminum, and fiberglass, led to a reduction in the total count rates.

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