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A comparative study of NaI (TI) and HPGe Detectors with Respect to Detectors in Terms of Detection Efficiency and Energy Resolution

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دراسة مقارنة بين كاشف NaI(Tl) وكاشف HPGe من حيث كفاءة الاشعاع ودقة تمييز الطاقه لكل كاشف

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Abstract:
The main aim of this search is to compare between a sodium iodide (NaI) detector (scintillator), which is thallium (TI) doped coupled to photomultiplier and a hyper pure germanium detector (semiconductor)(HPGe) in terms of efficiency and energy resolution. Both were used to measure the energy sensitive of Gamma ray in which the gamma ray is analyzed using scintillation and a multichannel analyzer. In addition, hyper pure germanium was used in this experiment to identify the known source.

In term of energy resolution, HPGe detector found to have superiority of energy resolution over NaI detector. This can be seen in Cs-137 at 661KeV where the full width of half maximum (FWHM) was 42.8KeV with using NaI detector and 10.17 KeV with using HPGe.

In term of efficiency, it is clear that NaI detector has much more efficiency than HPGe detector. For example, the intrinsic photopeak efficiency of Na-22 at 511 keV was 12.75% with using NaI detector and 5.11% with using HPGe .

Keywords: sodium iodide detector(NaI), Hyper pure germanium detector (HPGe).

الملخص :
الهدف من هذا البحث مقارنه كاشف الاشعاع يوديد الصوديوم المشوب بالثاليوم Nal(TI) مع كاشف الجرمانيوم عالي النقاء HPGe , وذلك من حيث كفاءه الكشف ودقه قياس الطاقة. استخدم الكاشفان لقياس طاقه أشعه جاما ,حيت تم تحليل الاشارات الناتجة باستخدام تقنيه الوميض الضوئي ومحلل متعدد القنوات. أظهرت النتائج أن كاشف الجرمانيوم عالي النقاء يتميز بدقه طاقه أعلي من كاشف يوديد الصوديوم, ويتضح ذلك عند قياس طاقه أشعه جاما الصادرة من مصدر السيزيوم -137 عند Kev661 حيت كانت قيمه العرض الكامل عند نصف القمه (FWHM) اقل عند استخدام كاشف HPGe مقارنه بكاشف NaI مما يدل علي دقه افضل . في المقابل يتميز كاشف يوديد الصوديوم بكفاءة كشف أعلي من كاشف الجرمانيوم, فعند قياس كفاءه قمه الامتصاص الضوئي لمصدر الصوديوم -22 عند طاقه Kev 511 كانت 12.75% بينما كانت كفاءه كاشف HPGe هي 5.11%.

الكلمات المفتاحية: كاشف يوديد الصوديوم NaI (Tl) ، كاشف جرمانيوم عالي الدقة HPGe، الكفاءة ، التبيين الطاقي.

Introduction:
Gamma rays are a form of electromagnetic radiation with high frequency and therefore, high energy. They carry no electric charge and may be produced as a by-product of alpha and beta decay processes [1]. When alpha or beta emissions excite a nucleus, it can return to its ground state through the emissions of gamma rays [2]. The gamma –ray spectrum is characteristic of each radionuclide and is determined by the discrete energies of the emitted of radionuclides in a given sample, the photo intensities at different gamma- ray energies can be measured [2].

In this paper gamma ray is being detected by two detectors HPGe semiconductor and NaI scintillator **.**gamma ray is emitted by excited nuclei in their transition to lower lying nuclear levels (energy from 10 KeV to 5 keV). In both detectors γ ray detection is achieved only if part or all of the incident photon energy is initially transferred to an electron in the detector material**.** The original γ ray may be absorbed in NaI in three processes which are photoelectric effect, Compton scattering and pair production.

This research provides the theory and methods used in demonstrating the gamma ray spectroscopy using semiconductor HPGe detector and NaI scintillation detector.in addition to that results and discussion also presented in this report.

Methods and Theory

The penetrating radiation given in the radioactive decay of uranium was discovered in 1896 by Henri Becquerel [3] and first came to existence when an image was notched on a film using piece of uranium[1,3]

In 1909, Soddy and Russell found that gamma-ray attenuation followed an exponential law and that the ratio of the attenuation coefficient to the density of the attenuating material was nearly constant for all materials[4].

The gamma rays interact with detectors and absorbers by three major processes: photoelectric absorption, Compton scattering, and pair production. In the photoelectric absorption process, the gamma ray loses all of its energy in one interaction. The probability for this process depends very strongly on gamma-ray energy E-y and atomic number [3].

In Compton scattering, the gamma ray loses only part of its energy in one interaction.

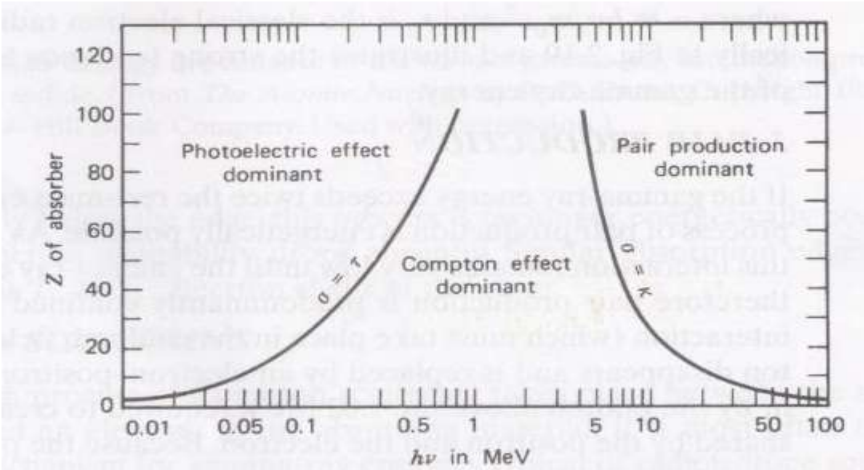

Figure 1-shows the relative contribution by absorber Vs. photon energy.

The probability for this process is weakly dependent on E and Z. Gamma ray can lose all of its energy in one pair-production interaction. However, this process is relatively unimportant for fissile material assay since it has a threshold above 1 Me [5].

The superiority in energy resolution of the HPGe detector lead to make the suitable apparatus for measuring gamma rays. The main two disadvantages of HPGe is that the efficiency is lower than that in NaI detector because of their smaller size and lower Z. the second disadvantage is that HPGe needs to be cooled at low temperature by nitrogen liquid which lead to make it expensive in purchase and maintenance.

Experimental arrangement and apparatus:

An electronic system is used to collect the charge which also, measures the amount of that charge and store the information. When we position a source the the detector collects the charges which then produce electrical current proportional to the amount of gamma absorbed by the detector. For both detectors HPGe and NaI positive high voltage was used 3.5 kV and .5kV respectively. The second component of electronic system is preamplifier which provides optimized coupling between the output of detector and the rest of the system as this reduces noise from any other sources.3rd component is the amplifier which transfer the weak signal to a suitable signal for measurement. The 4th component is multichannel analyzer (MCA) which stores and record pulses according to height. The height of the pulses are proportional to energy of gamma ray that enters to detector. After obtaining the spectrum, it will displayed on the screen.

Metodology and results:

1-Callibration:

The calibration for 300sec time was done for the system by using Cs-137 source and Co-60. The spectrum were obtained for both detectors, but unfortunately the spectrum copy is not available and could not attach it here. On the other hand, table-1 represents the FWHM corresponding to the photo peak channel. Usually, the calibration is necessary to prepare and set the system.

table-1 The FWHM corresponding to the photo peak channel.

Source	Energy (Kev)	Channel	FWHM (Kev)
Cs-137	663.07	3222.33	10.17
C0-60 1st peak	1173.20	5665.73	2.98
Co-60 2nd peak	1332.50	6434.59	2.96

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2-**gamma ray spectroscopy using NaI:**

a-**Energy resolution:**

energy resolution defined by the ability of the detector to distinguish between two very close photo peaks. It is calculated by this equation:

$$R=K/\sqrt{E}$$

To study the energy resolution of NaI three sources was used as stated in table-2.

Table-2 shows the calculated energy resolution for NaI detector.

source	Peak H	FWHM	Resolution%	E(Kev)/error
Cs-137	275.77	42.87	6.48	661.66
Na-22 1st peak	214.33	33.85	6.6	511
Na-22 2nd peak	527.45	55.15	4.327	1274.53
Ba-133 1st peak	36.77	23.58	7.79	302.85
Ba-1332nd peak	150.11	5.54	1.56	356.02
Ba-133 3rd peak	80.99	8.94	11.04	81

The graph below is representing the relation between resolution% Vs. the gamma ray of sources.

NaI energy resolution.

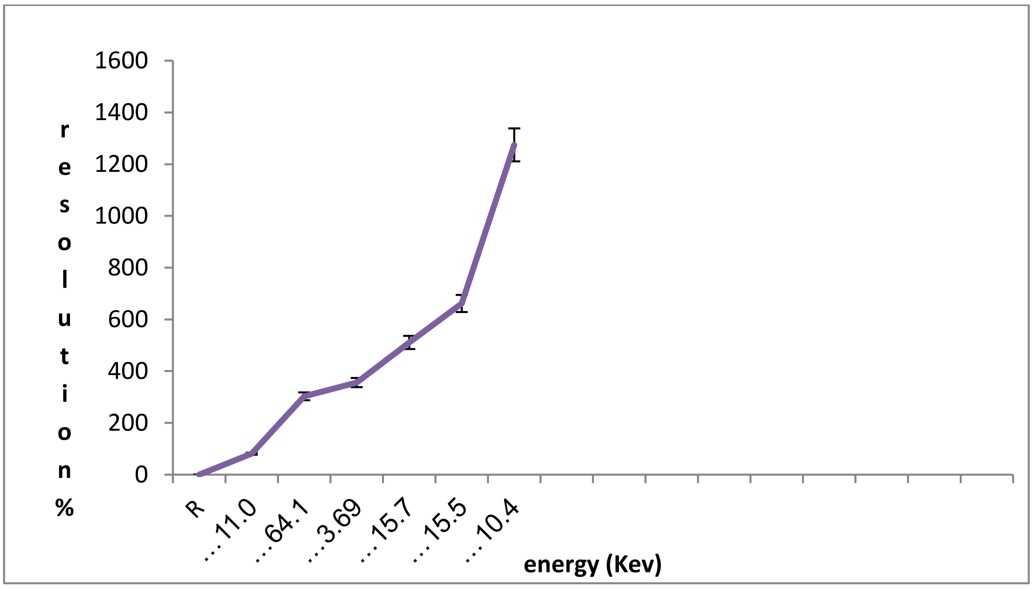

Figure-2:shows energy resolution vs. gamma energy

b-Detection efficiency of NaI:

Efficiency is defined by the amount of radiation that the detector can measure it. It is calculated by measuring the fraction of particles being detected and depends on density and size of the material, type and energy of radiation and electronics. It is divided into three types which are absolute efficiency(Ɛa), internist efficiency(Ɛi),intrinsic photo peak efficiency(Ɛp), all will be calculated later.

1-Absolute efficiency(Ɛa), is measured by the ratio of number of the photons recorded over number of photons emitted by source.

It is calculated by: $(\varepsilon a)=C_t / N_\gamma *100\%$

$N_\gamma = AI_\gamma$

C_t is the number of counts recorded/unit time integrated over the record spectrum, N_γ is number of gamma photons emitted per unit time.

A is the relative activity of the source

I_γ number of gamma photons emitted per disintegration.

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2-Intrinsic efficiency is the ratio of number of photons recorded over the number of number of incident on to detector.

It is calculated by: $\mathcal{E}i=C_t /N_\gamma'$

Where $N_\gamma' = \Omega N_\gamma/ 4\pi$

Therefore $\mathcal{E}_{i} = 4\pi\mathcal{E}a / \Omega$

N_γ' is the total number of gamma rays incident to the detector and Ω is the solid angle from source to detector window. Where Ω is calculated by:

$$\Omega = 2\pi/[1-d/\sqrt{(d^2+a^2)}]$$

Ω for NaI detector is = .094rad

2-Intrinsic efficiency:Ɛa is defined by the ratio of the number of photons recorded in photo peak over number of photons incident to the detector.

It is calculated by: $\mathcal{E}i=C_t/N_\gamma'$

$N_\gamma'= \Omega N_\gamma/4$

Therefore $\mathcal{E}i=4\pi\mathcal{E}a/\Omega$

N_γ' is the total gamma rays incident to detector.

3-Intrinsic photopeak efficiency:$\mathcal{E}_p$ is defined as the ratio of the number of photons recorded in the photo peak over number of photons incident to the detector.

It is calculated by: $\mathcal{E}_p=C_p/ N_\gamma''*100\%$

Where $N_\gamma''=\Omega/4\pi*A*I_\gamma(E_\gamma)$

C_P is the number of counts in photo peak corresponding to energy E_γ

N_γ'' is total number of gamma photons energy

$I_\gamma E_\gamma$ is the fractional numbers of photons of energy E_γ emitted per disintegration

Table3-represtns the results of calculated efficiencies for NaI detector:

Source	Activity	$E_\gamma I_\gamma$	I_γ	$\mathcal{E}_t$	$\%\mathcal{E}_I$	$\%\mathcal{E}_p$
Na^{22}	0.8937066	2198.8	2	14.41 3.67	1.4 .88	41.6 10.6
Cs^{137}	19.088	661.66	1	15.25	3.4	24.4
Ba^{133}	5.386	304	3	7.72 7.72 10.74	2 2.3 .95	8.2 4.9 13.4

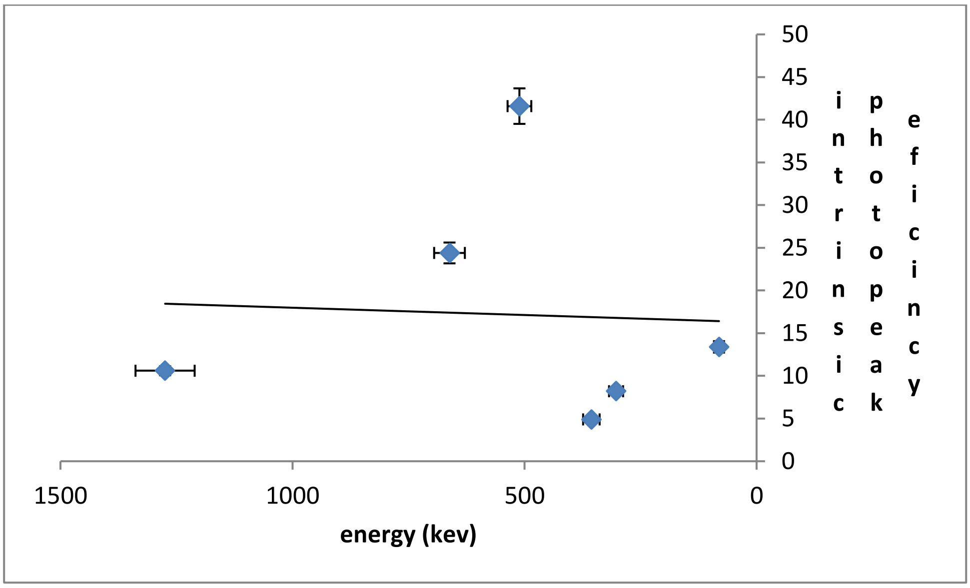

Figure 3- shows the intrinsic photo peak efficiency.

2-Gamma ray spectroscopy using HPGe:

Same procedure was used to study the energy resolution and detection efficiency but with using HPGe to detect gamma rays and same equations were used to calculate them.

a-Energy resolution:

Three sources were used to study energy resolution of HPGe which are Cs^{137}, Co^{60} and Na^{22}.

Table 4- represents energy resolution

Source	FWHM	E	R % error
Na^{22}	4.6 2.6	511 1273.32	0.9 ±..948 0.204 ±.451.
Co^{60}	2.98 2.96	1173.2 1332.5	0.254 ±.5 0.222 ±.471
Cs^{137}	10.17	663.07	.0153 ±.124

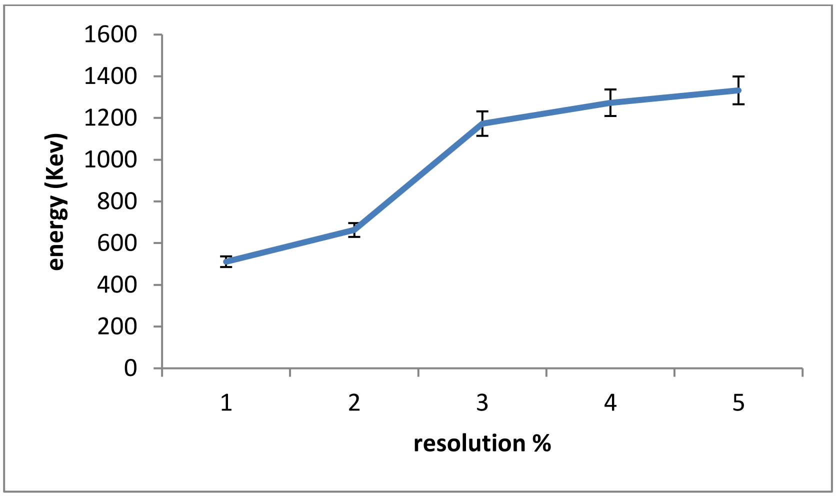

Figure 4- represents the energy resolution of HPGe.

b-Detection efficiency of HPGe:

For HPGe the three types of efficiencies will be calculated using same equations that were used for NaI and three sources were used to study it as listed in the table-5.wher Ω for HPGe was calculated and was 2.576rad.

Table 5-shows the three efficiencies of HPGe.

source	Activity(KBq)	I_γ	E_γ I_γ	$_{t}\mathcal{E}$	$_{i}\mathcal{E}$	$_{p}\mathcal{E}$
Cs^{137}	243.16	1	661.66	43.5	87.4	11.5
Co^{60}	20.523	2	2500	25.8	68.9	1.8 .196
Na^{22}	13.168	2	2198.8	24.9	12.14	19.9 2.3

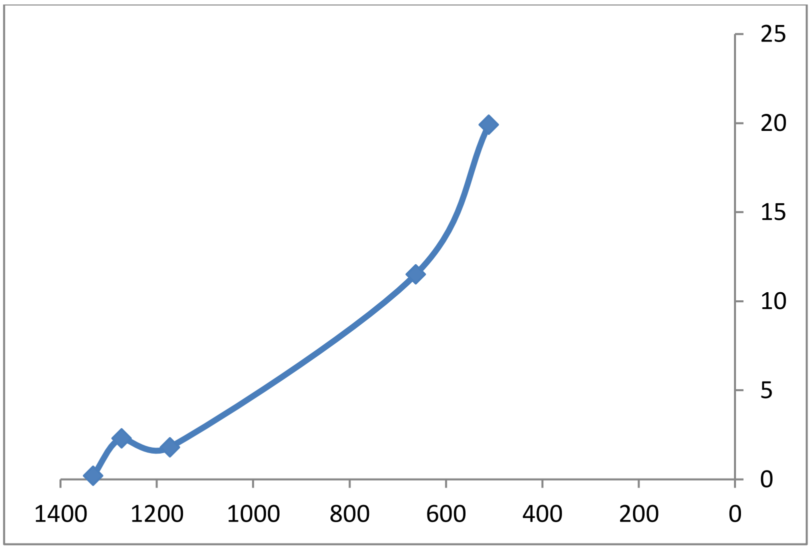

Figure 5- repents the intrinsic photo peak of HPGe.

3-**Unknown source:**

The unkown sourec was studied by using HPGe due to it is high energy resolution.

Table-6:shows the chain of some of the photopeaks of the specrum of the unknown source.

Detected peak(kev)	Probable radionuclide	Radiative chain
Bi^{214}	1656.93	U^{238}
Ba^{214}	1507	U^{238}
Ag^{110}	1384.12	U^{238}
Br^{82}	1314.93	U^{238}
Bi^{214}	1153.99	U^{238}
Bi^{214}	608.77	U^{238}
U^{235}	185.75	U^{238}

Discusion:

In this study three aspects which are energy resoltion and detection efficiency for two detectors which are HPGe and NaI Scitillator are compared .where callibration was done for of them befor obtaining spectrums.from(table 2) we can figure out that the resoltuion of NaI dectreses as the energy increase.The detection efficncy of NaI as shown in the table-3 proves that the efficieny decreses as the energy increases.

For the second part where HPGe was used ,it is obvious from table-4 that the energy resoltion of HPGe decreases with increasing the enrgy .On the other hand, from table-5 is clearly seen that efficiency of NaI is decreasing with increasing the energy.

From table -5 all elements belong to the radioactive decay of U^{238} which proves that the unkown source consists mainly of U^{238}.

Conclusion:

In this work we can comprehended the main featurs for both detectors NaI and HPGe. NaI is cheaper, and have low energy resoltion between 6-10%. HPGe better in term of energy resoltion,therefore it is preferable for studing spectrums with many peaks as what was done in this experment where it was used to identify the unkown sourceHowever it can not be used in room tepmerture must be cool down.

Compliance with ethical standards

Disclosure of conflict of interest

The author(s) declare that they have no conflict of interest.

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