KING FAHD UNIVERSITY OF PETROLEUM AND MINERALS

DHAHRAN

DEPARTMENT OF PHYSICS

PHYS-503 GRADUATE LABORATORY (T161)

ENERGY RESOLUTION MEASUREMENT OF A CYLINDRICAL $3'' \times 3''$BGO DETECTOR

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Abstract

Energy resolution measurement of a cylindrical 3''×3'' Bismuth Germinate (BGO) detector was measured for 0.36 to 9.00 MeV gamma rays energy. These gamma rays were produced from radioactive sources (Bi-209, Cs-137 and Ba-133) and from activation spectrum of Bi (2505), hydrogen capture H (2223) from moderator and Ni (8533), Ni (8998) prompt gamma ray from $NiSO_4$-1.8mol sample. The experiment was performed using MP320 portable neutron generator based PGNAA. In order to calculate energy resolution (i.e. FWHM/E), Gaussian peak was fitted to the gamma ray spectra of known energy and energy resolution was calculated from subsequent data. The energy resolution of the 3''×3'' BGO detector varies from 14.2 to 1.9 % over 0.36-8.99 MeV. The energy resolution data was also fitted as a function of $1/\sqrt{E_\gamma}$ to validate the theoretical relation and a good fit was obtained.

1 Introduction

1.1 Gamma Ray Spectroscopy:

Gamma ray spectroscopy is the study of energy spectra of gamma rays coming out of different sources. Different radioactive sources emit gamma rays of different energy and intensity. When these gamma rays are detected and analyzed, they produce a spectrum. Gamma rays have the highest energy in electromagnetic spectrum which means that these photons have high energy and short wavelength. Because of this high energy, they can be analyzed individually [1]. The equipment used in gamma ray spectroscopy includes an energy sensitive radiation detector, electronics to process the signal produced by detector (i.e. multichannel buffer), associated amplifiers and data input/output units.

1.2 Prompt Gamma Ray Neutron Activation Analysis (PGNAA):

Prompt Gamma-ray Neutron Activation analysis is a method to determine the chemical composition of materials. It is mainly used to determine trace amounts of elements through activation spectrum. It is used in many scientific fields including geology, material science, archeology, physics and chemistry.

The sample under consideration is bombarded by a neutron beam. The sample then emits gamma rays of different wavelength and energies depending on the type of the element and its concentration in the sample. The detector records prompt gamma rays associated with detector material and with the sample to be analyzed [3-5].

The basic principle of the PGNAA operation is a nuclear capture reaction which works as follow. Neutron beams are incident at the sample and they react with the nucleus of the sample. On absorbing the incident neutrons, the nucleus goes into an excited state and forms a compound nucleus as shown below.

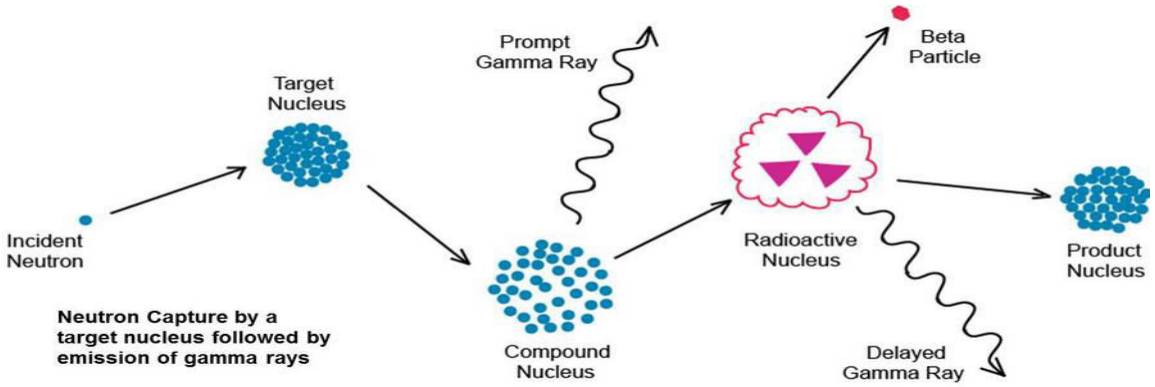

Figure 1.1: Schematic diagram describing the PGNAA process

The compound nucleus decays very quickly in the range of 10^{-14} - 10^{-9} seconds to the lowest energy state. During this transition it emits gamma rays with a very high energetic range up to about 11 MeV, a process known as prompt gamma radiation. At this stage the nucleus can either become a stable nucleus again or a radioactive one. The radioactive nucleus so formed now decays and furthers producing beta particles and a cascade of gamma rays known as delayed gamma radiation. Neutron Activation Analysis (NAA) is another elemental method which uses the delayed gamma radiation to get useful information about the

intrinsic components of the sample. It can be achieved by analyzing the energy of the resulting gamma rays that are characteristic for each element and their corresponding intensities which gives how much of a particular element is present in the sample.

Prompt Gamma ray Neutron activation Analysis PGNAA uses the prompt gamma rays emitted from the compound nucleus to get useful information about the sample chemical components. With this method, the measurements will be different from NAA because the gamma rays are detected during the nuclear radioactive decay. The advantage of this method however, is that elements that are present after the compound nucleus goes in to a stable nucleus as well as those radioactive elements that do not emit a gamma cascade can be detected.

1.3 Detector Energy Resolution:

In gamma ray spectroscopy, detectors play the vital role. Two of its most important parameters are detector efficiency and detector resolution. Not all the gamma radiations emitted by a source produce count in the detector. The probability that an emitted gamma ray will interact with the detector and produce a count is called the efficiency of the detector. High efficiency detectors produce spectra in less time. In general, larger detectors have higher efficiency than the smaller ones.

Gamma rays detected in spectroscopic system produce peaks in the spectrum. The width of these peaks is determined by the resolution of the detector. A high resolution means to separate two gamma lines that are close to each other. Gamma spectroscopy systems are designed and adjusted to produce symmetrical peaks of the best possible resolution. The peak shape is usually a Gaussian distribution.

The most common figure used to express detector resolution is full width at half maximum (FWHM). This is the width of the gamma ray peak at half of the highest point on the peak distribution. For a good energy resolution however, the distribution of the response function about an average pulse height will show a small width with a peak which approaches a sharp spike or a mathematical delta function as shown below.

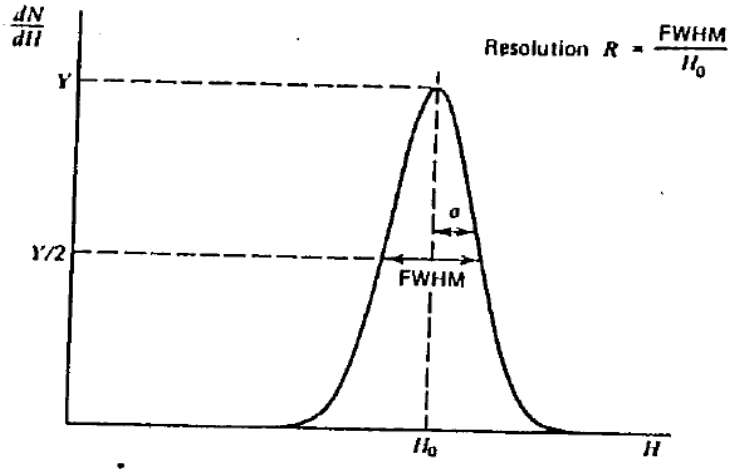

Figure 1.2: Calculation of energy resolution from Gaussian peak

The value of the calculated energy resolution is therefore a dimensionless fraction conventionally expressed as a percentage. Most detectors usually have values of energy resolution between 0 and 10%. The smaller the value of this fraction the better the resolution will be.

2 Objective of Experiment:

The main objective of this experiment is to measure the energy resolution of 3''×3'' BGO detector at KFUPM over 0.36-9.00 MeV energy range using activation samples and gamma ray radio isotope sources.

3 Experimental Setup

3.1 Description of Equipment:

The study was carried out using KFUPM portable neutron generator based PGNAA setup and the 3''×3'' BGO detector. The detector was manufactured by Saint-Gobain Company, France. The PGNAA setup consist of MP320 model portable neutron generator which provides a pulsed beam of 2.5MeV energy and a cylindrical high density moderator which is made up of polyethylene and converts the fast beam into thermal beam. The detector was shielded with 3mm thick lead and 50mm thick paraffin to prevent undesired gamma rays and neutron from reaching the detector. The main equipments used in this experiment are the BGO detector, portable neutron generator, lead shielding and moderator as shown in the figure 2.1.

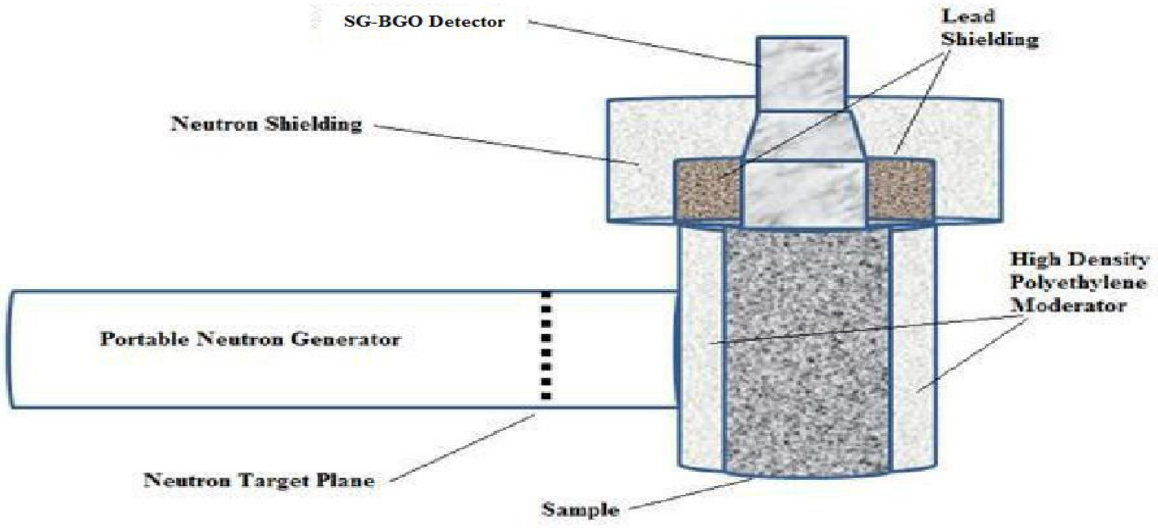

Figure 3.1: schematic diagram of MP320 portable neutron generator

Portable Neutron Generator:

A neutron generator is a device which produces neutrons by using a compact linear accelerator. Neutrons are generated by a fusion reaction of hydrogen isotopes such as deuterium or tritium or a mixture of these two isotopes into a metal hydride target. When a fusion reaction between deuterium happens then it produces ^{3}He ion and a neutron having energy approximately 2.5 MeV.

$D + D \rightarrow n + {}^{3}He$ $E_n = 2.5$ MeV

Fusion of a deuterium and a tritium atom (D + T) results in the formation of a He-4 ion and a neutron with a kinetic energy of approximately 14.1MeV

$D + T \rightarrow n + {}^{4}He$ $E_n = 14.1$ MeV

In this study we used a D+D reaction based 2.5 MeV neutron generator.

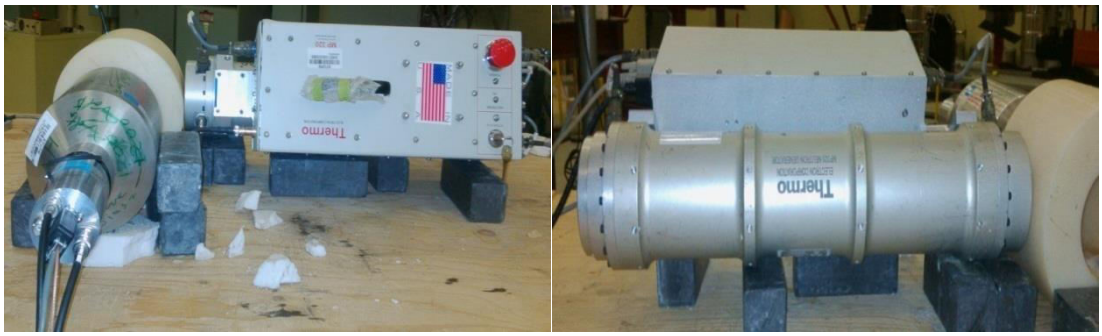

Figure 3.2: Actual PGNAA setup showing MP320 Portable Neutron Generator

Neutron Moderator:
A neutron moderator is a medium that reduces the speed of fast moving neutrons, thereby turning them into thermal neutrons by retarding their motion and converting their kinetic energy into thermal energy.

$$E = \frac{1}{2}\, mv^2 = \frac{3}{2}\, k_B T$$

Moderation however, is the process of the reduction of the initial high kinetic energy of the free neutron. Since energy is conserved, this reduction of the neutron kinetic energy takes place by transfer of energy to a material known as a moderator.

Neutron Shielding:
Undesired neutron and gamma rays are prevented from entering and interfering with the detector using 2'' x 4'' x 6'' rectangular blocks of lead shielding and 50 mm thick blocks of neutron shielding prepared by mixing paraffin with lithium carbonate around the detector.

3.2 Experimental Samples:

The samples used for this experiment are $NiSO_4$-1.8mol, lanthanum chloride detector and moderator. The radioisotopes gamma ray sources (^{209}Bi, ^{133}Ba and ^{137}Cs) were used as standards.

3.3 Experimental Procedure:

The experiment was started with the BGO detector with -968V as its operating voltage. This was done to measure the background radiations. Then different radioactive sources of known energy were placed in front of the detector to record data which was then used to make a linear fit for low energy calibration.

Then for high energy calibration, portable neutron generator was used. It was turned on without placing any sample to measure again the background radiations. The detector was exposed to fast as well as thermal neutron flux from the portable neutron generator based PGNAA set up and then the prompt gamma-ray background activation spectrum was recorded from the detector. A pulse beam of 2.5MeV neutrons was produced via D(d, n) reaction using 70 μA beam of 70 keV deuteron. The associated background spectrum was then recorded for a period of 120 min and then stored in the data acquisition computer using the electronics shown in block diagram.

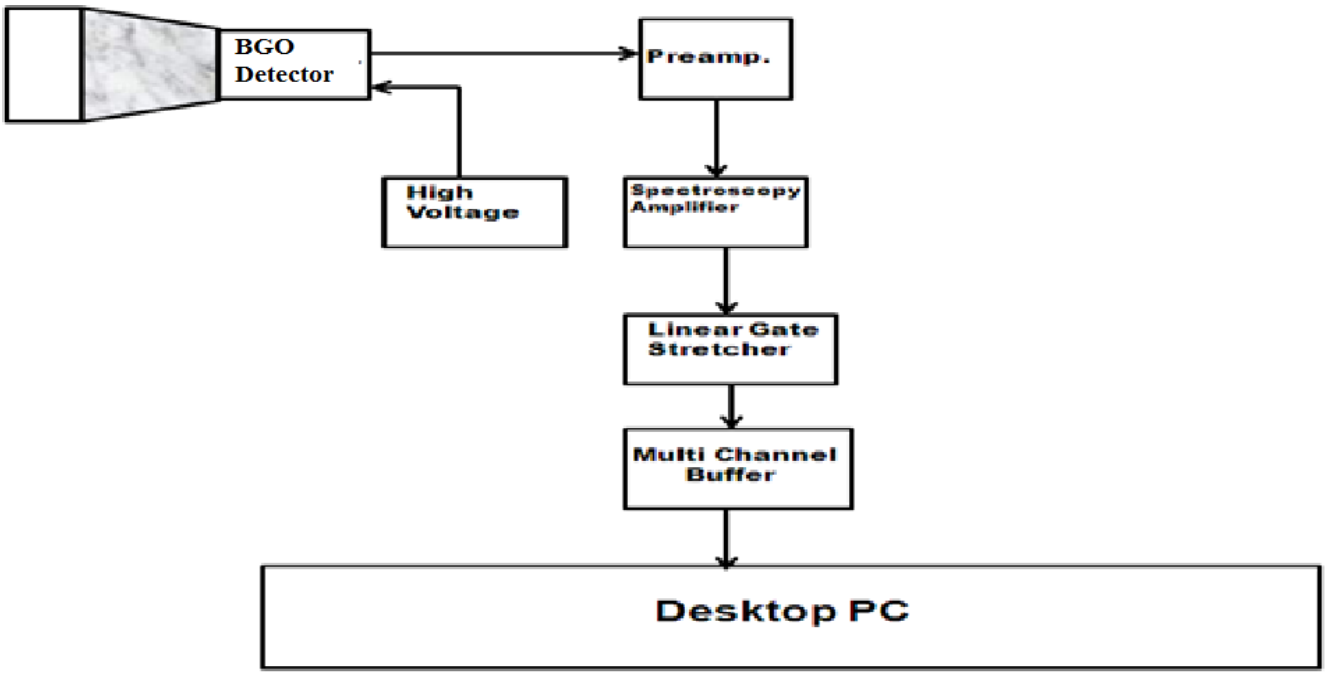

Figure 3.3: Electronic configuration diagram

After that a 1.8mol sample of $NiSO_4$ was placed in the moderator cavity and turned the neutron generator on. The peaks for Ni (8533) and Ni (8998) were recorded for 60 min and turned the generator off. The data for the resolution of BGO detector for low as well as high energy was processed and then plotted against energy.

4 Results and Discussions

4.1 Energy Resolution of BGO Detector for Radioisotope Sources:

The pulse height spectrum of the BGO detector was taken for Bi-209, Ba-133, and Cs-137. Ba spectrum shows a very sharp peak of 355 keV as shown in fig 4.1. The energy resolution was measured by fitting a peak to the selected area on the computer display screen. The area was selected by placing left and right marker on either side of the peak. From this area we get the information about FWHM and centroid of the peak. Energy resolution was calculated by dividing the FWHM with centroid. The resolution for the Ba peak corresponding to 0.36 MeV comes out to be 14.2%.

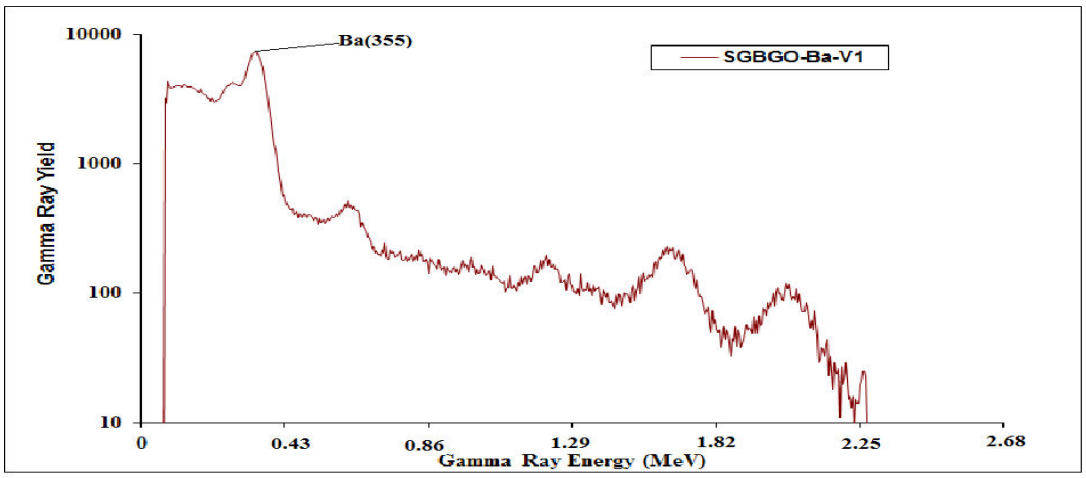

Figure 4.1: BGO detector pulse height spectrum taken with Ba-133 peak

The same procedure was repeated for Cs-137 and Bi-209 sources. Cs-137 showed a clear peak at 0.66 MeV with energy resolution of 11.1% while Bi-209 showed three distinct peaks at 0.57, 1.06 and 1.77 MeV with energy resolution of 8.4, 6.4 and 4.6% respectively as shown in figure 4.2 and 4.3.

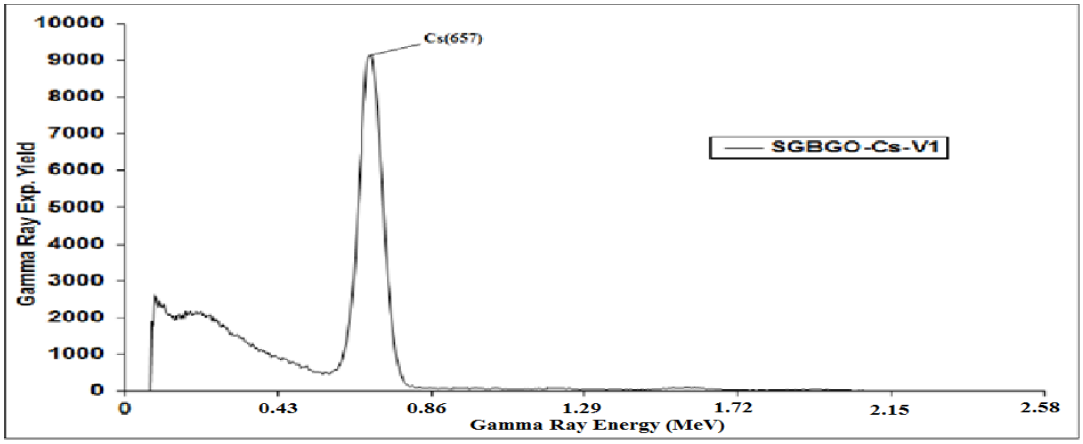

Figure 4.2: BGO detector pulse height spectrum taken with Cs-137 peak

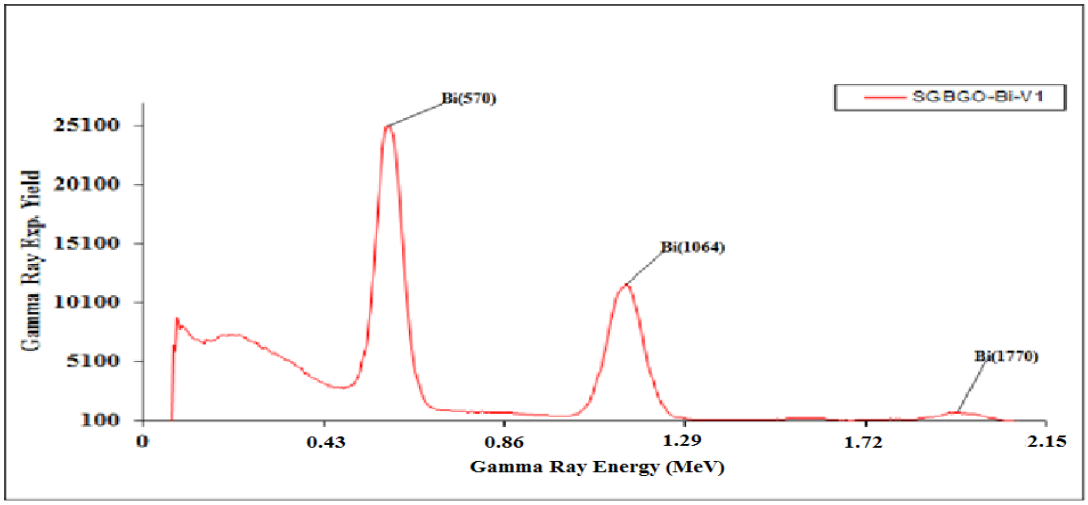

Figure 4.3: BGO detector pulse height spectrum taken with Bi-209 peaks

4.2 Energy Calibration of BGO Detector:

Low energy calibration was done by using Bismuth as gamma ray source. It shows peaks corresponding to Bi (570 keV), Bi (1064 keV) and Bi (1770 keV). By plotting these gamma ray source energies against the corresponding channel number, we obtained the low energy calibration curve for the BGO detector as shown in the figure 4.4. The fit given by relation E = 3.771x + 57.145 was used to convert the channels into gamma ray energies.

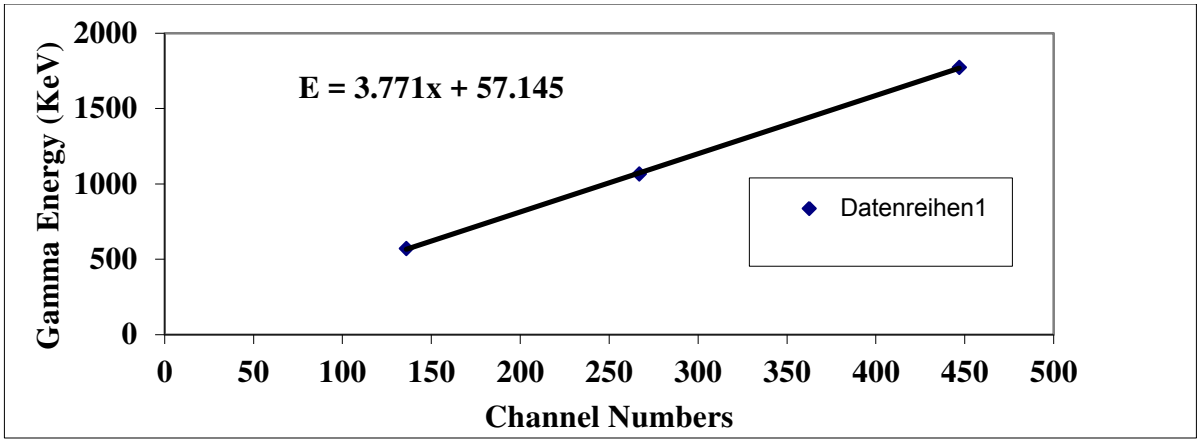

Figure 4.4: Energy calibration curve for BGO detector

4.3 Lanthanum Chloride ($LaCl_3$: Ce) detector activity measurement:

The activity of $LaCl_3$: Ce detector was measured with BGO and $CeBr_3$ detectors. Since Lanthanum is radioactive so it shows its own peaks at 789 and 1468 keV from radioactive ^{138}La. These peaks were recorded by using BGO and $CeBr_3$ detectors turn by turn for 60min each.

BGO Detector Measurements:

First the background spectrum was measured by keeping the BGO detector on for 60min. Then $LaCl_3$ detector was placed near BGO to detect the counts of Lanthanum. The spectrum is shown in figure 4.5.

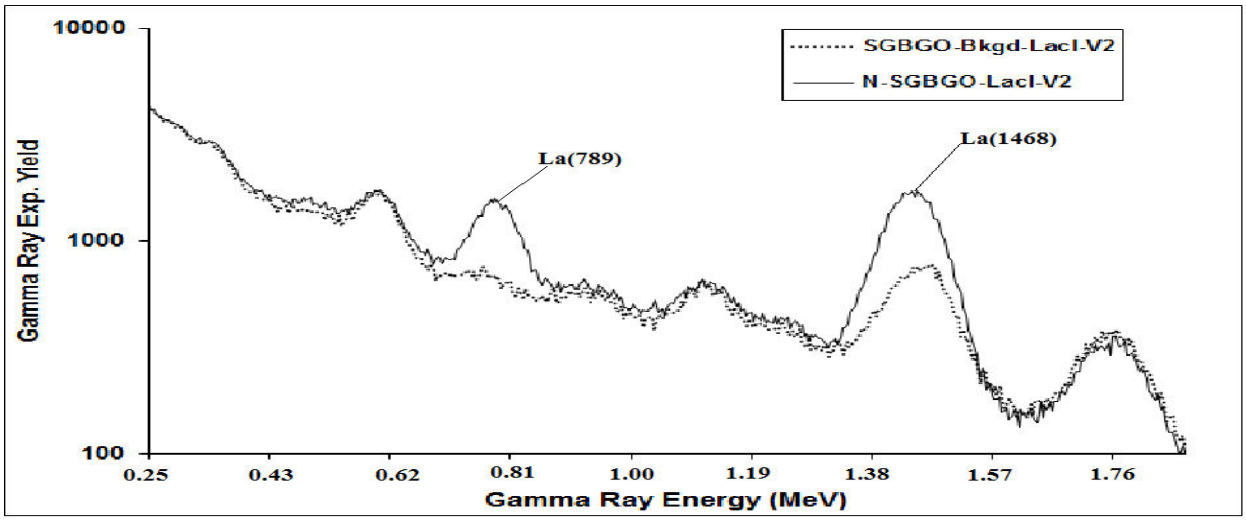

Fig 4.5: Activity spectrum of $LaCl_3$ detector superimposed upon background spectrum for BGO detector

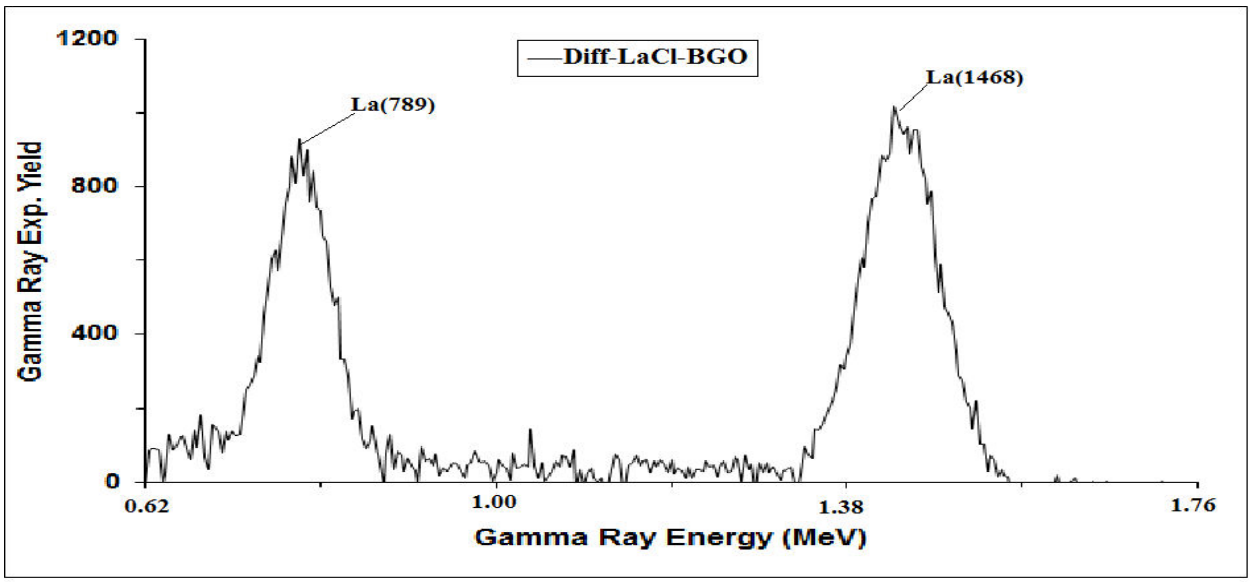

Figure 4.6: Difference spectrum of $LaCl_3$ exhibiting 789 keV and 1468 keV peaks for BGO detector

$CeBr_3$ Detector Measurements:

First the background spectrum was measured by keeping the $CeBe_3$ detector on for 60min. Then $LaCl_3$ detector was placed near $CeBr_3$ to detect the counts of Lanthanum for 60mins again. The spectrum shows the Lanthanum peaks at 789keV and 1468keV. The spectrum obtained as shown in figure 4.7.

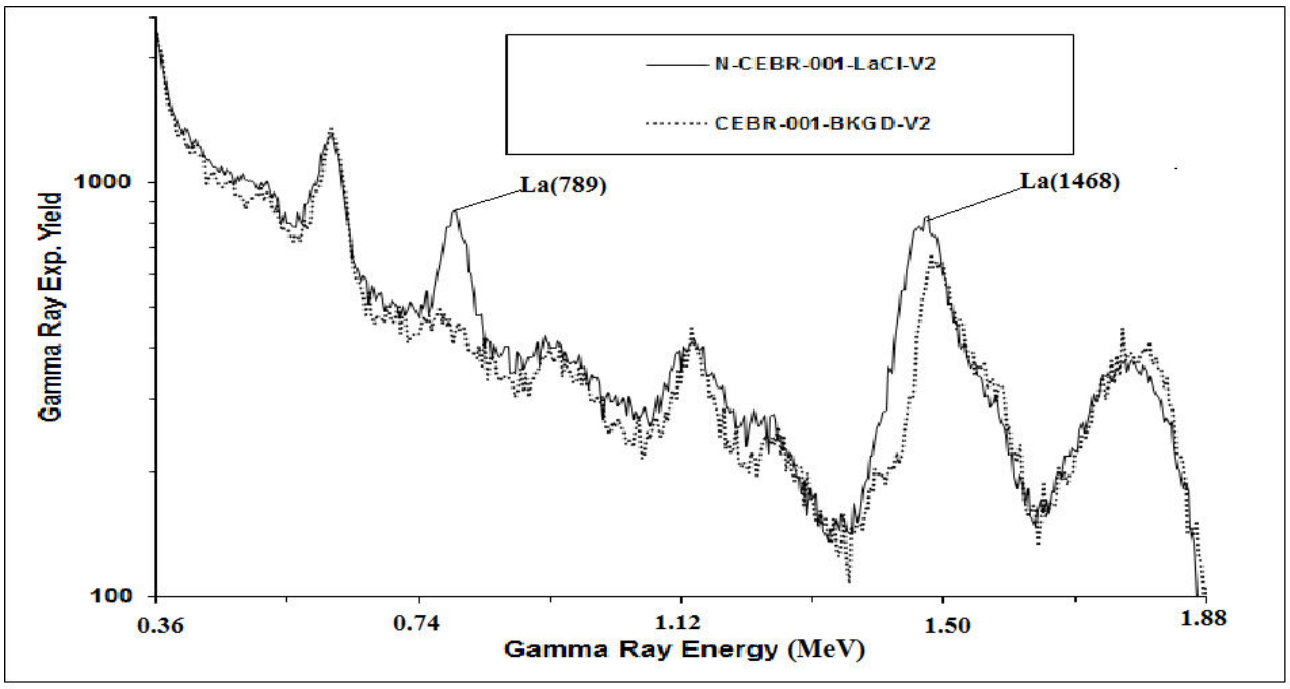

Figure 4.7: Activity spectrum of $LaCl_3$ detector superimposed upon background spectrum for $CeBr_3$ detector

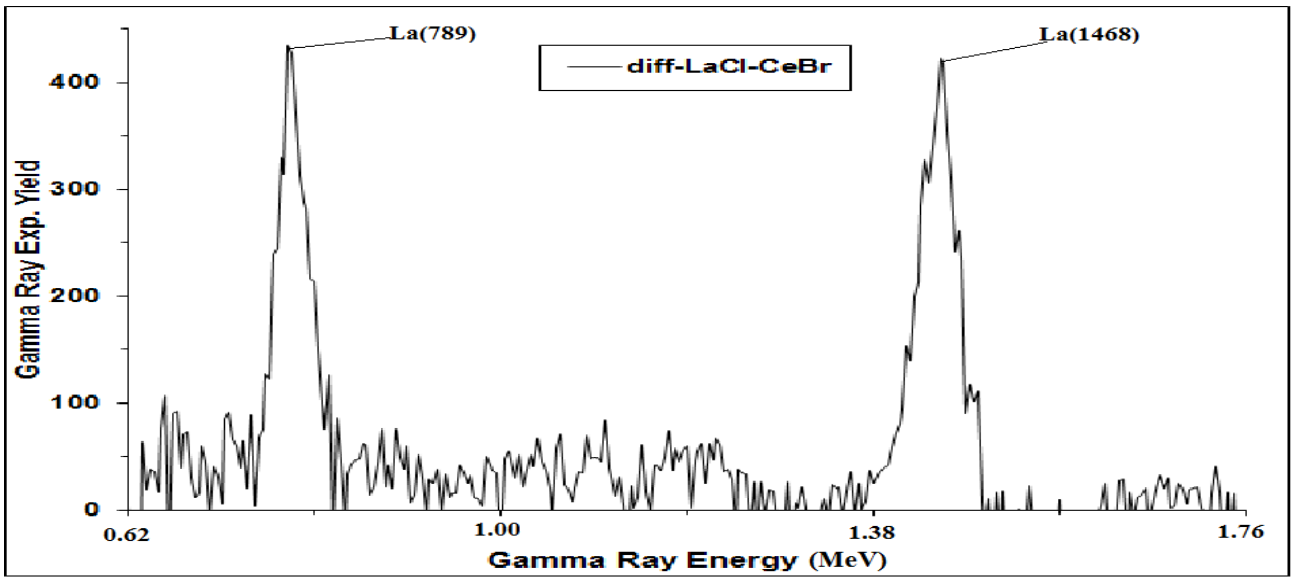

Figure 4.8: Difference spectrum of $LaCl_3$ exhibiting 789 keV and 1468 keV peaks for $CeBr_3$ detector

4.4 Activation Measurement for Nickel ($NiSO_4$-1.8mol) Sample Using BGO Detector:

The portable KFUPM neutron generator based PGNAA setup was used to measure the activation spectrum of Nickel ($NiSO_4$-1.8mol) using the BGO detector. The spectrum shows peaks at 2223keV (i.e. for hydrogen from the moderator) and for Ni at 8533keV and 8998keV as shown in fig 3.6. The spectrum also shows Bismuth peaks at 2505keV, 2828keV and a range of energy from4054 to 4256keV from the activation of Bi in BGO detector as shown in figure 4.9.

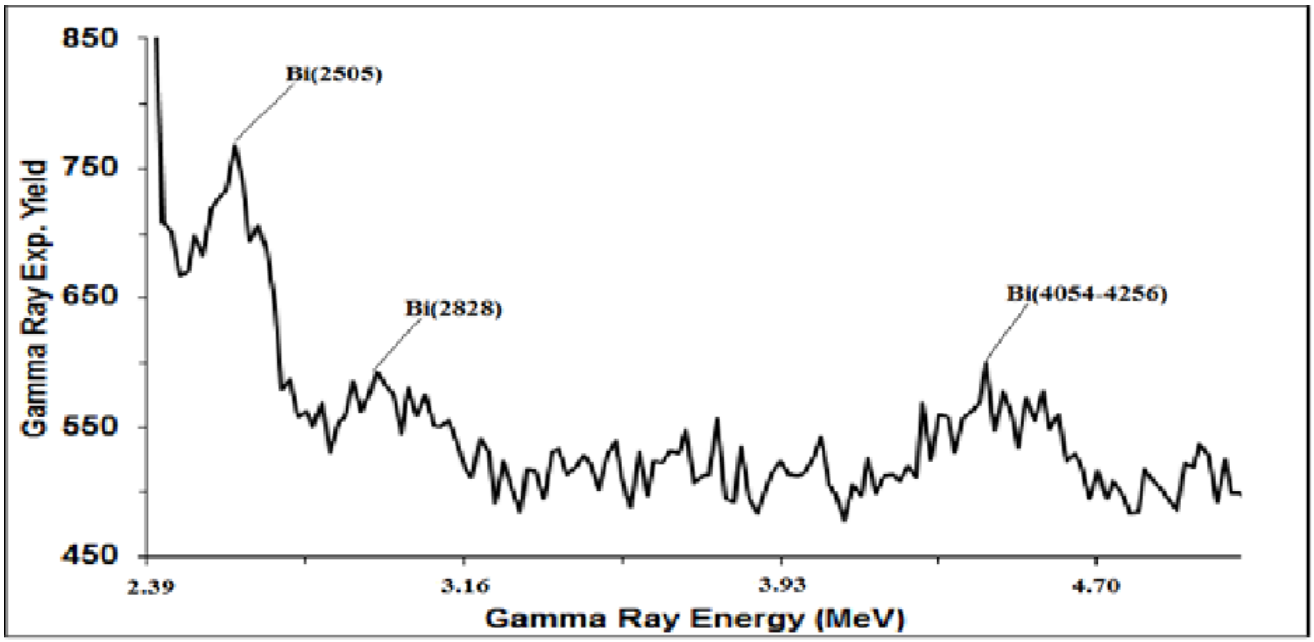

Figure 4.9: Enlarged prompt gamma ray spectrum of BGO detector background spectrum having Bi (2505), Bi (2828), Bi (4054-4256) energy coming from BGO detector

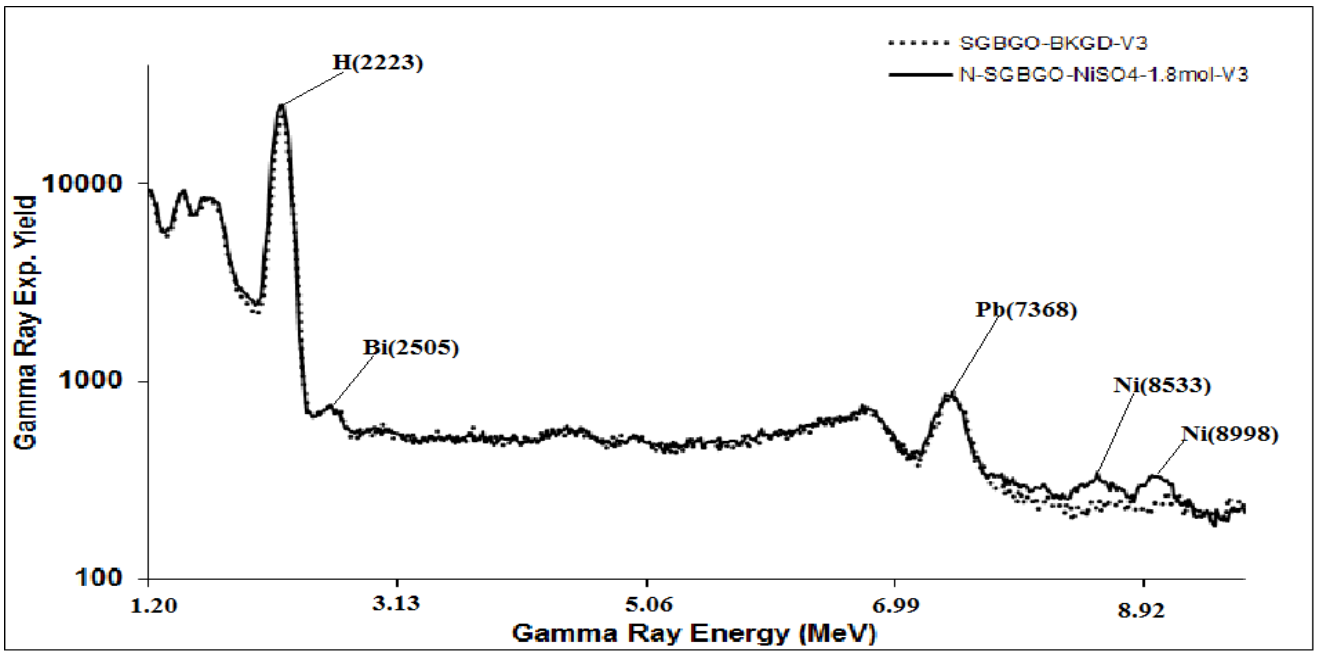

Figure 4.10: Activation spectrum of BGO detector showing distinct Ni (8533) and Ni (8998) peaks over background spectrum

4.4 Energy Resolution Measurement:

The energy resolution of the BGO detector was calculated for prompt gamma rays coming out of moderator and Nickel ($NiSO_4$-1.8mol) sample. The energy resolution was also calculated for radioactive sources like Ba (356keV), Bi (570keV), Cs (661keV), Bi (1064keV) and Bi (1770keV). The energy resolution data is listed in Table 1 and then plotted against energies. The data with fitted curve is shown in figure 4.11.

Table 1: Energy resolution of BGO detector:

Element	E_γ (keV)	Centroid (Channel)	FWHM (Channel)	E-Resolution (%)
Ba	356	81	11.5	14.2
Bi	570	136	16.6	12.2
Cs	661	160	17.7	11.1
Bi	1064	267	22.6	8.4
Bi	1770	453	28.9	6.4
Bi	2505	124	5.7	4.6
Bi	2828	143	7.0	4.9
La	789	192	15.5	8.1
La	1468	367	28.2	7.7
H	2223	104	6.9	6.6
Pb	7368	373	13	3.5
Ni	8998	456	11	2.4
Ni	8533	431	8.2	1.9

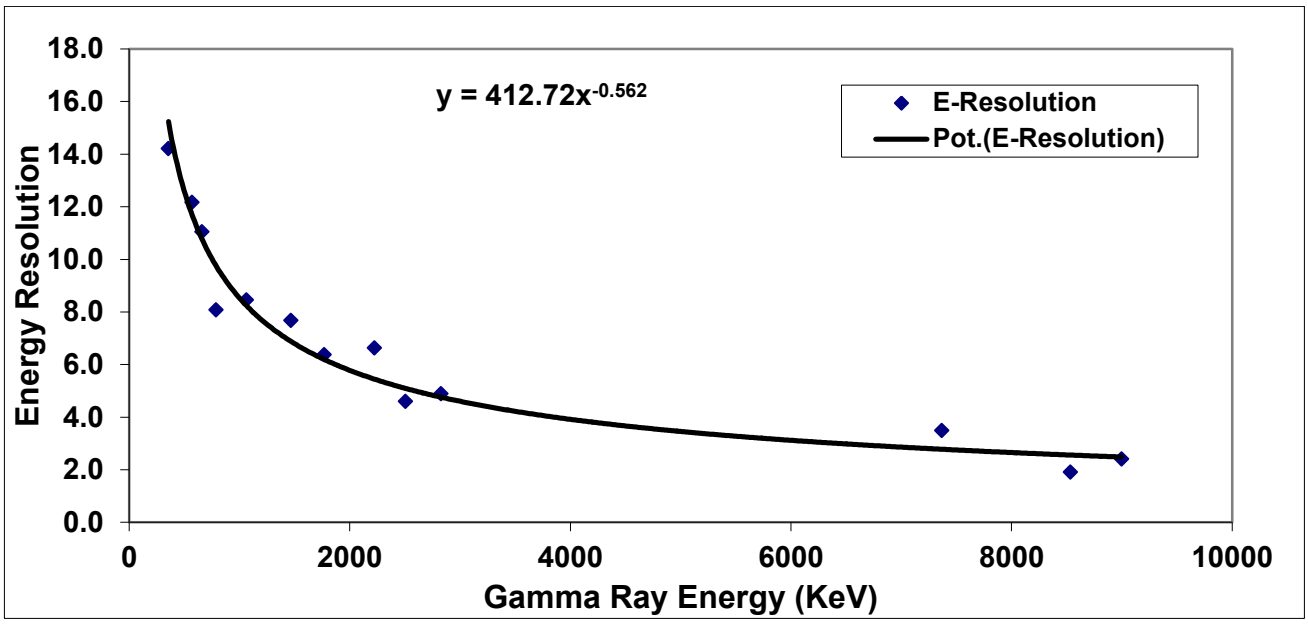

Figure 4.11: Energy resolution curve for BGO detector

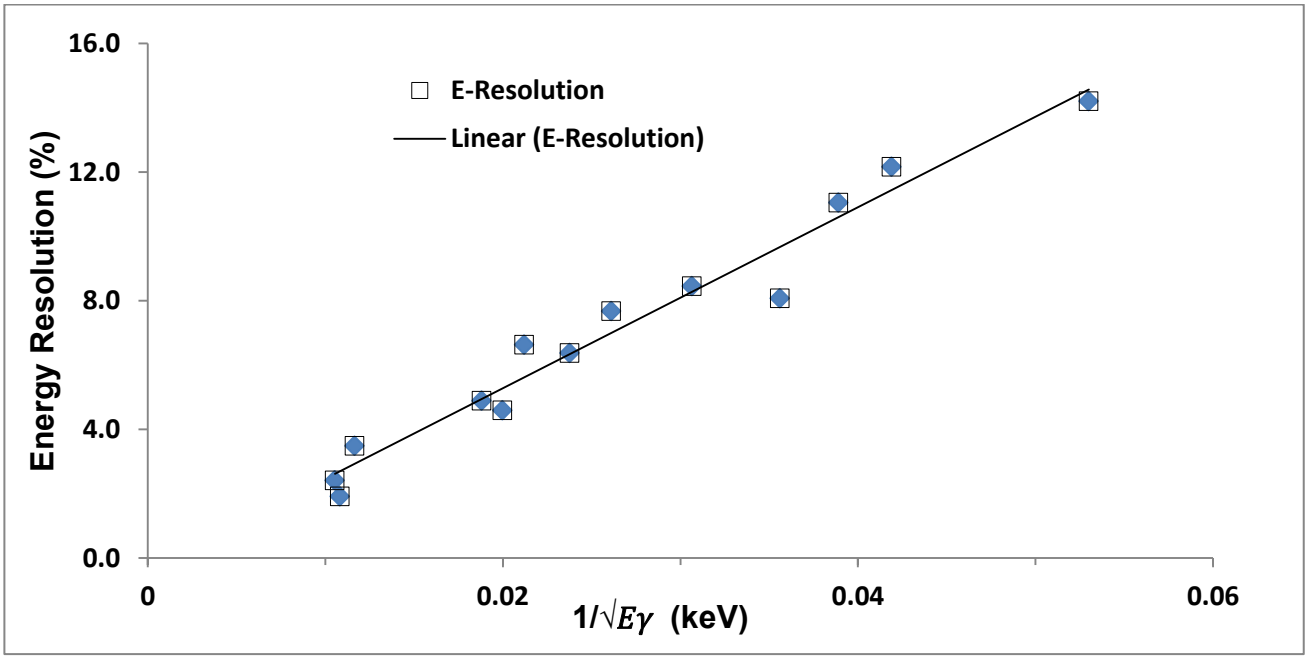

Figure 4.12: Energy resolution (%) of 3×3 inch SG-BGO detector plotted as a function of 1/√$E\gamma$

5 Conclusion:

In this experiment PGNAA technique was utilized to test the energy resolution of the BGO detector using high energy prompt gamma rays from Nickel ($NiSO_4$-1.8mol) sample. Two peaks were observed for nickel at Ni-8533 and Ni-8998 with corresponding energy resolution of 1.9% and 2.4% respectively. Energy resolution is also measured for radioactive sources at low energies. The resolution of the detector was not very good at low energies but improved at higher energies. The energy resolution of BGO detector is inversely proportional to square root of gamma ray energy.

6 Acknowledgement

In particular, I would like to thank my experiment supervisor Dr. Akhtar Abbas Naqvi for dedicating most of his time to make me understand the basic principles behind the PGNAA set up and also for his methods of correcting mistakes with sublime encouragement. I also want to extend my gratitude to King Fahd University of Petroleum for giving me the privilege and opportunity to be exposed to such high standard of experimental physics.

7 References:

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