KING FAHD UNIVERSITY OF PETROLEUM AND MINERALS

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DEPARTMENT OF PHYSICS

PHYS-503: GRADUATE LABORATORY (TERM 142)

ENERGY RESOLUTION MEASUREMENT OF $LaCl_3:Ce$ DETECTOR USING ACTIVATION SPECTRUM

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Abstract

Energy resolution has been measured for lanthanum chloride $LaCl_3:Ce$ detector using activation spectrum through the use of MP320 portable neutron generator based Prompt Neutron Activation Analysis (**PGNAA**) setup. The detector's energy resolution is measured for both low and high energy gamma ray resulting from neutron capture in Lanthanum (La), Chlorine (Cl) and Cesium (Ce) elements in detector material and hydrogen from the moderator. Also the detector energy resolution was measured for gamma rays from Bismuth-209, Cobalt-60 and Cesium-137 gamma ray radioisotope sources. The energy resolution of $LaCl_3:Ce$ detector over 272 to 8679 keV varies from 7.09 to 0.9 % respectively. The measured energy resolution of $LaCl_3:Ce$ detector is inversely proportional to the square root of gamma ray energy (keV).

1.0 Introduction

1.1 Energy resolution

Energy resolution of a detector is defined conventionally as full width at half maximum FWHM (the width of the distribution at a level that is just half the maximum ordinate of the peak) divided by the location of the peak pulse height H_0 (shown in Fig.1a). The energy resolution of scintillation detectors ranges between 5-10%. The smaller the energy resolution the better the detector will be able to differentiate between two radiations whose energies are very close to each other. The ability to resolve fine detail of a given measurement in the incident energy of the radiation is clearly improved as the width of the spectrum (shown in Fig.1b) become smaller and smaller [1]. The curve labeled "poor resolution" represents the response of a detector with inferior performance and the curve labeled "Good resolution" represent one with sharp distribution around an average pulse height H_0. The potential sources of poor energy resolution in the response of a given detector include electronic noise, drift in operating parameter during the course of the measurements and statistical noise arising from discrete nature of the measured signal itself [1].

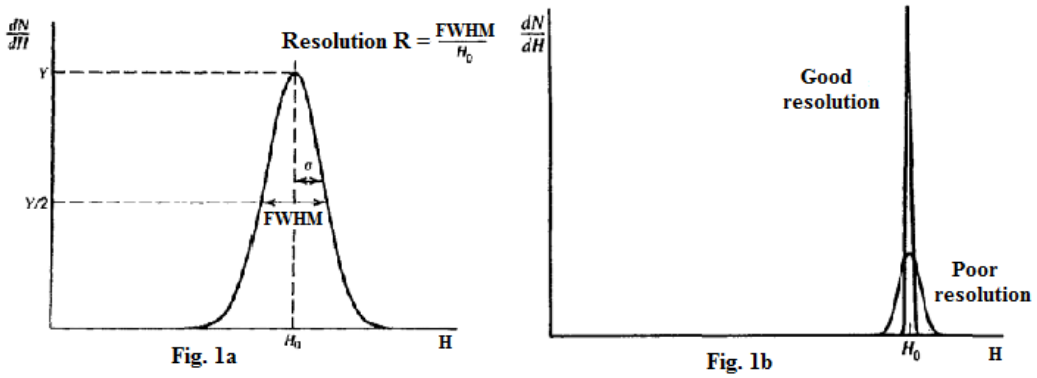

Figure 1: Shows Energy Resolution Peak and Detector Response Function

In order to measure energy resolution of a detector, one needs a monoenergetic gamma ray source. Possible sources of monoenergetic gamma rays are radioisotope gamma ray sources with their corresponding gamma ray energies listed as follow: Na-22(0.511MeV, 1.20MeV), Cs-137(0.661MeV), Co-60(1.173MeV, 1.333MeV) and Bi(0.57MeV, 1.064MeV, 1.77MeV) respectively. Nuclear reactions are also another way of generating gamma rays. For example, 14 MeV neutrons inelastic scattering from carbon gives rise to a gamma ray photon of 4.44MeV [1]. Two possible nuclear reaction studied at KFUPM are prompt gamma ray production through thermal neutron capture reaction or through inelastic scattering of 14 MeV neutrons.

1.2 Prompt Gamma Ray Production Through Thermal Neutrons Capture Reaction

Radiactive neutron capture is the process in which neutron incident on a target nucleus to form an excited compound nucleus. The compound nucleus de-excites back to the ground state by emitting prompt and delayed gamma-rays (see Figure 2). The prompt gamma-ray intensity is proportional to the number of atoms and the energy values of the gamma –rays identify the nuclide. In Prompt Gamma Neutron Activation Analysis (PGNAA), sample material is bombarded with neutrons. Each element emits a distinctive gamma-ray signature as it returns to a stable state. To be measured, the element must have a high capture cross section of thermal neutron, and it must emit a gamma-ray within the energy window being analyzed. The amount of atoms of an element present in the sample must be enough to produce measurable intensity of gamma rays [2]. These gamma-rays are collected and measured with a high resolution gamma-ray detector. The energy resolution of the detector determines the capability of the detector to distinguish between two gamma rays with very close energy.

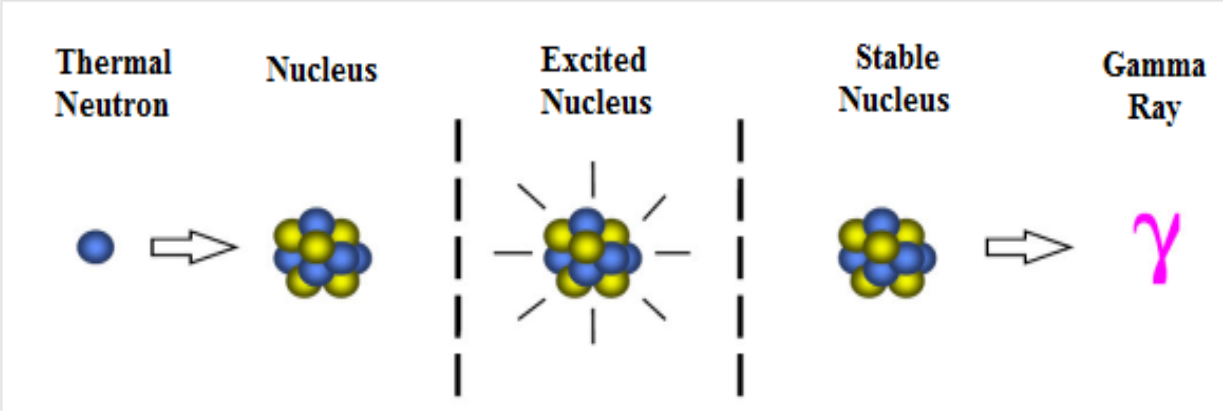

Figure 2: Schematic diagram illustrating PGNAA process at the nucleus level.

1.3 Objective of Experiment

The objective of this project is to measure the energy resolution of the ($LaCl_3$: Ce) detector for 272-8679 keV gamma ray energies.

2.0 Experimental Setup

The experimental study was carried out using KFUPM portable neutron generator based PGNAA setup using 76 mm x 76 mm (diameter x height) Lanthanum Halide ($LaCl_3:Ce$) detector for gamma-ray detection. Main sample used in this experimental exercise was the detector ($LaCl_3:Ce$) itself. Detector energy resolution was measured for the prompt gamma emitted due to thermal neutron capture in lanthanum, and chlorine in the detector and hydrogen in the moderator. Chlorine has very high thermal neutron capture cross sections and it emits several gamma rays over 517 keV to 8679 keV. Further the detector energy resolution was measured also for the gamma rays emitted from Bismuth, Cobalt and Cesium radioisotope sources.

The PGNAA setup consist of cylindrical high density moderator which is made of polyethylene, MP320 model portable neutron generator which provides a pulsed beam of 2.5Mev neutron was produced through D(d, n) reaction. 2.5 MeV neutrons were produced using 70mA beam of 70keV deuteron. The gamma rays were detected using a Lanthanum Chloride doped with cerium ($LaCl_3:Ce$) detector. The detector was shielded with 3mm thick lead and 50mm thick paraffin to prevent undesired gamma-rays and neutrons from reaching the detector. A 90 mm diameter cavity drilled through the moderator allow to irradiate a cylindrical bottle with a size of 90 mm x 140 mm (diameter x height) to be irradiated with thermal neutrons in the moderator. The ***figure 4*** below shows the schematic representation of **PGNAA** setup.

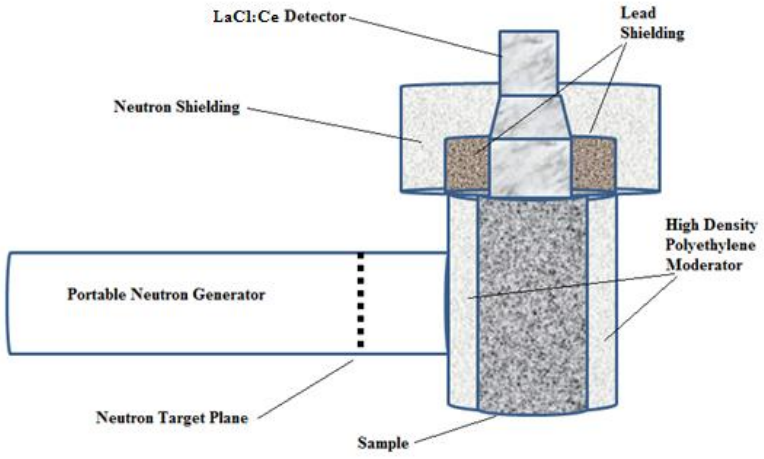

Figure 3: schematic diagram of the MP320 portable neutron generator

2.1 Lanthanum-Halide ($LaCl_3:Ce$) Detector and its Intrinsic Spectrum

Lanthanum-halide ($LaCl_3:Ce$) doped with Cerium have been developed with excellent energy resolution and efficiency. Prompt Gamma Neutron Activation Analysis (**PGNAA**) employing

these detectors because they require no cooling during operation and are expected to have a better performance compared to sodium iodide (NaI) and bismuth germinate (BGO) detectors. These have been extensively studied and found to have very good luminescence scintillation properties compare to those aforementioned NaI and BGO detectors [3]. The disadvantage of lanthanum-halide scintillators is their intrinsic activity lines, which appear as background spectral lines in their pulse height spectra and this is due to the activity of contaminated unstable lanthanum isotopes present in the detector. This intrinsic activity may limit the use of the detector especially in low level counting [4]. The complexity of the pulse height spectra for high energy gamma-ray is due to associated single escape and double escape peaks due to small size of lanthanum halide detectors crystal. According to (Naqvi et al. 2012), the lanthanum chloride ($LaCl_3:Ce$) detector has an excellent response for low energy prompt gamma-rays from boron and cadmium contaminated water samples [5].

However, $LaCl_3:Ce$ detector contains Lanthanum (radioactive isotope) and the intrinsic activity pulse spectrum of the ($LaCl_3:Ce$) detector shown in figure 4 below. The 1436 keV gamma spectrum which appears as 1468 keV gamma ray peak is the sum of 1436 keV gamma ray peak and 32 keV fluorescence peak. The 32 keV X-ray fluorescence of Barium produced due to electron capture of lanthanum [6]. The anomalous width of the sum of 32 keV X-ray fluorescence peak line and 1436 keV gamma line may be as a result of overlapping of 1460 keV line of potassium-40 with 1436 keV gamma line from Lanthanum, originating from the glass of the photomultiplier tube [7].

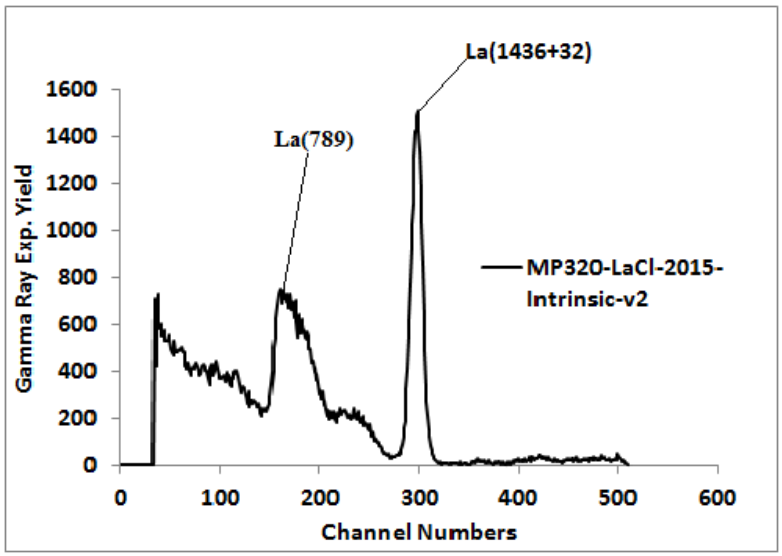

Figure 4: Intrinsic pulse height spectrum of $LaCl_3:Ce$ detector

2.2 Experimental Samples

The samples used for this experiment are lanthanum chloride detector itself, moderator . The radioisotopes gamma ray sources (bismuth, cobalt and cesium) were used as standards.

2.3 Electronic Diagram

A preamplifier and photomultiplier is connected to the detector to minimize the source of noise transmitted with the signal and to convert the photon to electrical signal for further processing. However, amplifier increases the power of the signal and an analogue to digital converter (ADC) convert the signal to digital number that represents the quantity's amplitude and linear gate stretcher was used to stretch a gated fast pulse to slow pulse by using a shaping time of $1.0\mu s$. This figure below shows the electronic configuration diagram.

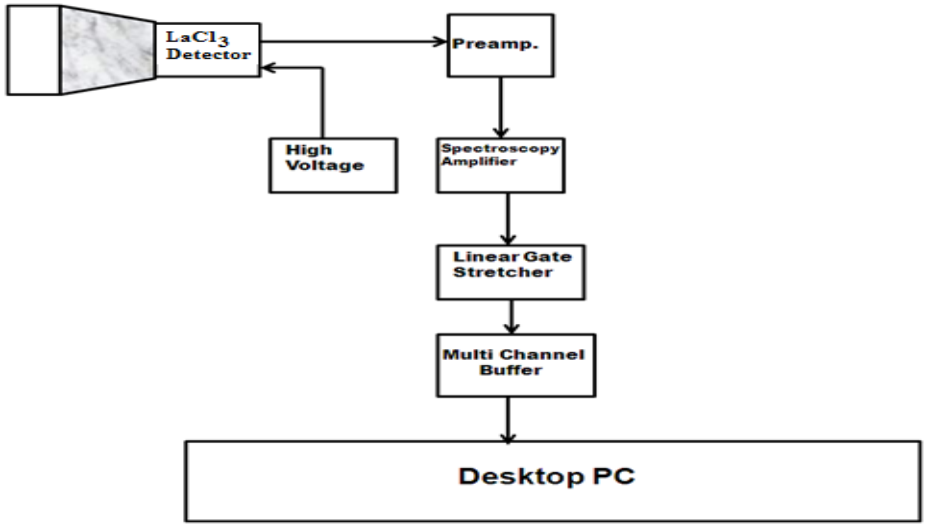

Figure 5: Electronic configuration diagram

2.4 Experimental Procedure

Throughout the experimental run, +724V bias voltage was applied to the $LaCl_3{:}Ce$ detector. Then the neutron beam generator was put on without placing any sample in the moderator cavity. Meanwhile the Radiation laboratory was always locked for proper safety before putting on neutron beam generator. So the detector was exposed to moderated thermal neutron and then the prompt gamma ray yield intrinsic activation spectrum was recorded from the detector activation spectrum. The system was left to run for approximately 10 minutes and data was stored in the created directory. This spectrum gave peaks as a result of lanthanum, chlorine and hydrogen built in with detector and moderator and the corresponding channel number location, real time and full width at half maximum (FWHM) were recorded. The experiment was carried out for both high

energy run and low energy run using different setting of the coarse gain of the detector pulse height amplifier. For each energy run different energy calibration curve of the detector was used. This was done due to detection of capture gamma ray with varying energies

The neutron generator was switch off and gamma ray radioactive sources were placed in the moderator cavity to measure detector energy resolution of the gamma rays from the radioisotope source. The peaks came up again and channel number, real time and FWHM were recorded and data was saved in the folder of the hard drive (disk). These procedures were repeated throughout the experiment for radioisotope source spectra. The data of radioisotope source was taken over period varying from 7-20 minutes.

3.0 Results and Discussion

3.1 Energy Resolution of $LaCl_3:Ce$ Detector for Radioisotope sources

The pulse height spectrum of the lanthanum halide ($LaCl_3:Ce$) detector taken with Cesiun-137,Cobalt-60 and Bismuth-209 sources are shown in figure 6,7 and 8 below. The Cesium-137 spectrum shows prominent peak with gamma ray energy of 661 keV. The energy resolution was calculated by fitting a peak to the selected area on the computer display screen. The area was selected by placing left and right maker on either side of the peak. Computer calculated the FWHM and centroid of the peak. Energy resolution was calculated by dividing FWHM of the peak by the peak centroid. Energy resolution of the detector for Cesium-137 source was calculated to be 4.3%. The gamma ray analysis of Cobalt-60 and Bismuth-209 sources produces multiple peaks with different gamma ray energies and different irradiation times. The Bismuth-209 gave three peaks with gamma ray energies of 570 keV, 1064 keV, and 1770 keV. The energy resolutions of the detector for bismuth source were calculated as 4.9%, 3.6%, and 2.8% respectively. Cobalt-60 also gave two peaks with energy 1173 keV and 1333 keV . The energy resolutions of the detector due to gamma ray from Cobalt-60 were calculated to be 3.27% and 3.25% respectively. The energy resolution of the detector for radioisotope source is also listed in Table 1.

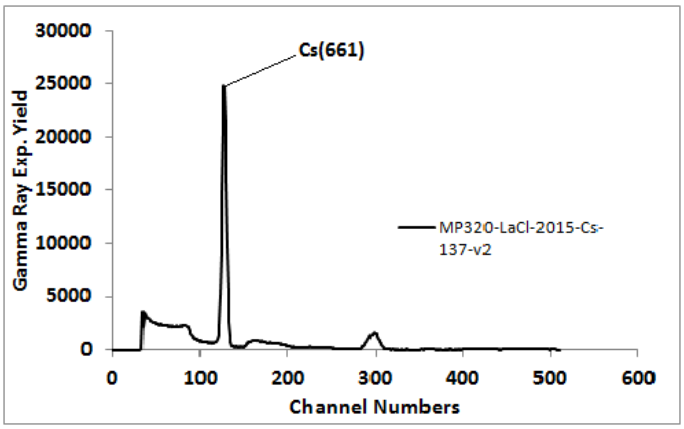

Figure 6: $LaCl_3:Ce$ detector pulse height spectrum taken with Cesium-137 peak

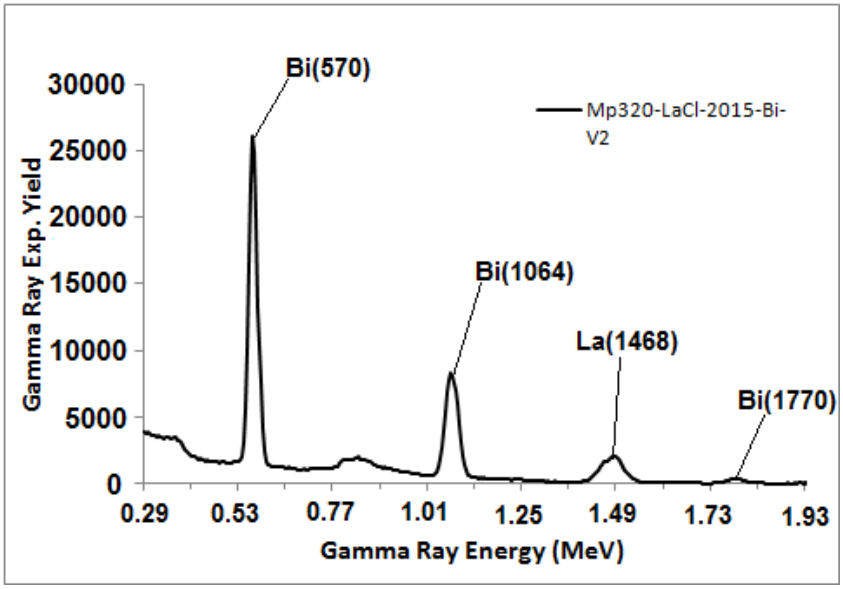

Figure 7: $LaCl_3:Ce$ detector pulse height spectrum taken with Bismuth-209 peaks along with intrinsic peak due to La

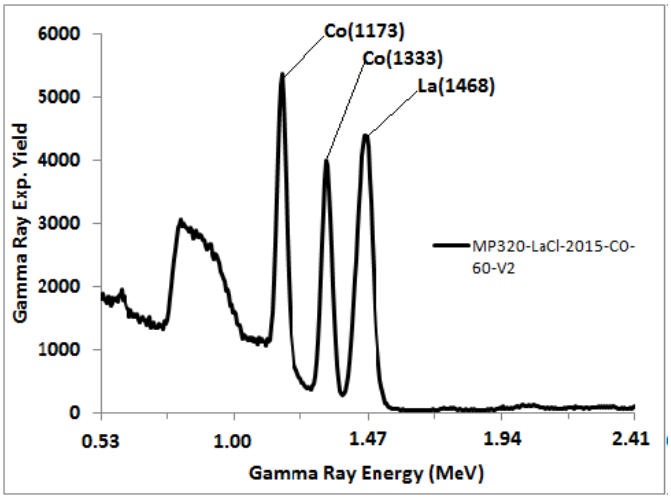

Figure 8: $LaCl_3:Ce$ detector pulse height spectrum taken with Cobalt-60 peaks along with intrinsic peak due to La

3.2 Activation Spectrum of $LaCl_3:Ce$ Detector

3.2.1 Low Energy Activation Measurement of $LaCl_3:Ce$ Detector

The low energy activation measurement of the detector was acquired with high coarse gain 50 of the amplifier.

3.2.2 Low Energy Calibration of $LaCl_3:Ce$ Detector

Low energy calibration was done using radioisotope gamma ray source Bi(570 keV),Cs(661 keV), Bi(1064 keV), Co(1173 keV), Co(1333 keV) and Bi(1770 keV). By plotting these gamma ray source energies against the corresponding channel number, we obtained the energy calibration curve for $LaCl_3:Ce$ detector as shown below.

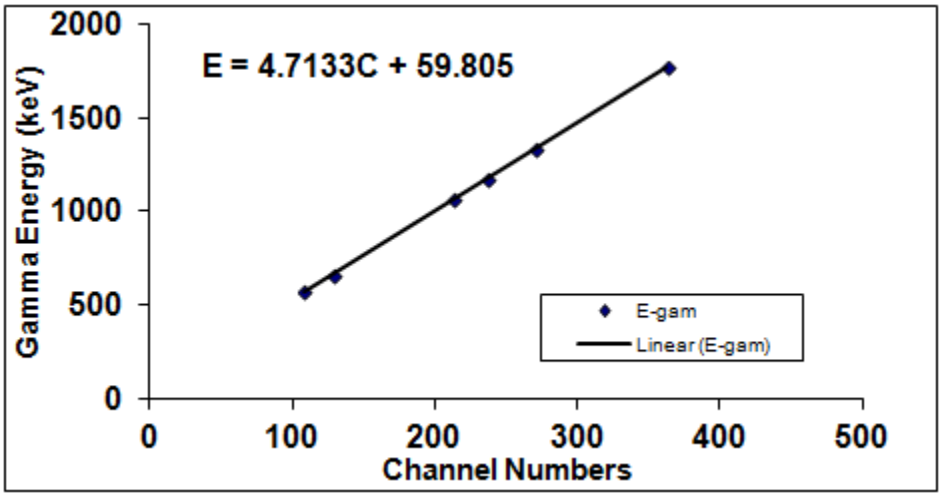

Figure 9: Low energy calibration curve of $LaCl_3:Ce$ detector

Figure 7 shows low energy calibration curve of $LaCl_3:Ce$ detector with a slope of 4.71 keV/channel.

3.2.3 Low Energy Activation Spectrum of $LaCl_3:Ce$ Detector

The portable KFUPM neutron generator based PGNAA setup has been used to measured activation spectrum of $LaCl_3:Ce$ detector. In the low energy activation spectrums of $LaCl_3:Ce$ detector, as shown in Fig 10, well resolved prompt ray peaks due to thermal neutron capture in lanthanum, Chlorine and Hydrogen (moderator) are observed at La(272 keV), Cl(517 keV), Cl(1165 keV), Cl(1951 + 1959 keV) and H(2223 keV) respectively. Low energy activation spectrum of $LaCl_3:Ce$ detector was recorded for 71 minutes run. From the low energy activation spectrum, energy resolution of the detector was calculated for La(272 keV), Cl(1165 keV), and H(2223 keV) peaks and are listed in Table 1.

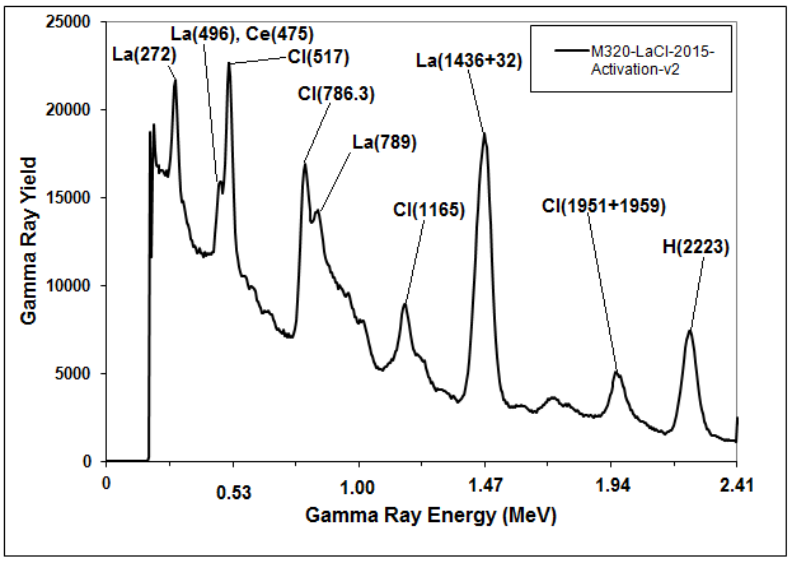

Figure 10: Low energy prompt gamma ray spectrum due to activation of $LaCl_3:Ce$ detector caused by capture of thermal neutrons in La, Cl and Ce elements present in $LaCl_3:Ce$ detector.

3.2.4 High Energy Activation Measurement of $LaCl_3:Ce$ Detector

The high energy activation measurement of the detector was taken with low coarse gain 5 of the amplifier.

3.2.5 High Energy Calibration of $LaCl_3:Ce$ Detector

Different calibration was done for higher energy run by shifting down low energy through adjusting of coarse gain and fine gain in the spectroscopy amplifier. This figure below depicts higher energy run calibration curve of the detector.

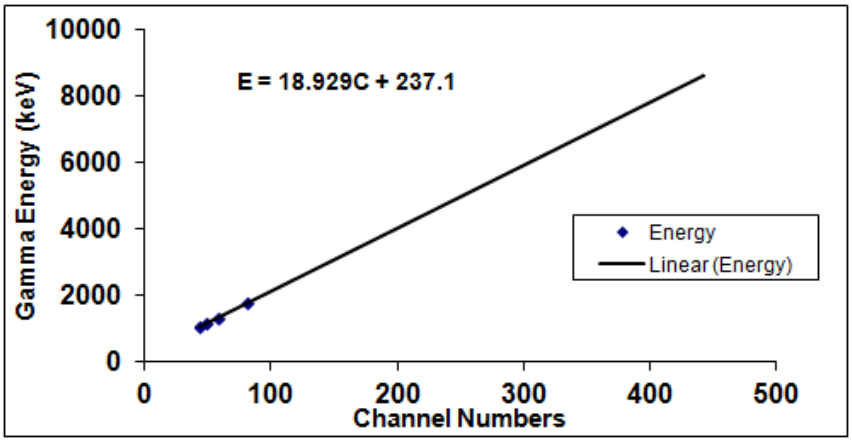

Figure 11: High energy calibration curve of $LaCl_3:Ce$ detector

Figure 11 shows energy calibration curve taken with known peaks of radioisotopes source Bismuth and Cobalt. The slope of calibration curve shown in Fig.11 is 18.93 keV/channel.

3.2.6 High Energy Activation Spectrum of $LaCl_3:Ce$ Detector

In the high energy activation spectrums of $LaCl_3:Ce$ detector, as shown in Fig.12, well resolved prompt gamma ray peaks due to thermal neutron captured in Lanthanum and Chlorine elements present in the detector are observed at La(4502 keV), Cl(2470 keV), Cl(2864 keV), Cl(6111 keV), Cl(6620 keV), Cl(6978 keV), Cl(7790 keV) and Cl(8679 keV) respectively. High energy activation spectrum of detector was also run for 78 minutes. The energy resolution of the detector was calculated for Cl(2470 keV), Cl(2864 keV), Cl(6111 keV), Cl(6620 keV), Cl(6978 keV), Cl(7790 keV) and Cl(8679 keV) respectively. The calculated energy resolution of the detector for high energy gamma ray is listed in Table 1.

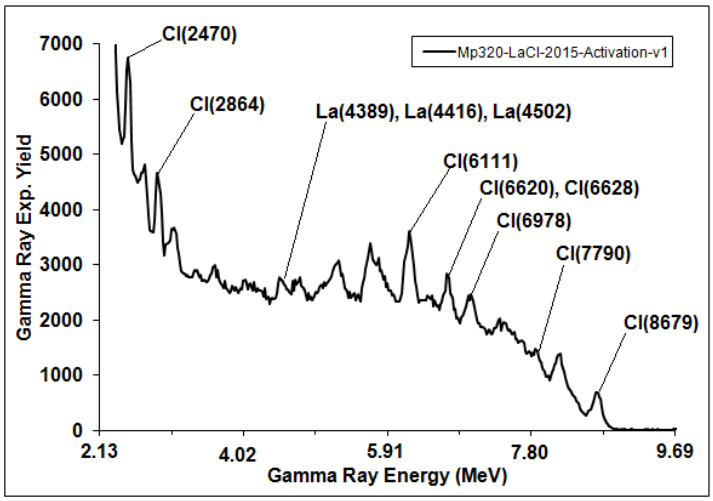

Figure 12: High energy prompt gamma ray spectrum due to activation of $LaCl_3:Ce$ detector caused by capture of thermal neutrons in La, Cl and Ce elements present in $LaCl_3:Ce$ detector.

3.3 Energy Resolution Fit

The energy resolution of the $LaCl_3:Ce$ detector has been measured for prompt gamma rays from Lanthanum, Chlorine and hydrogen capture in the moderator. Also, the energy resolution of $LaCl_3:Ce$ detector was also determined for Bismuth (570 keV), Cesium(661 keV), Bismuth(1064 keV), Cobalt (1333 keV) and Bismuth(1770 keV) radioisotope source. The energy resolutions data of the detector at sixteen different energies, as listed in Table 1**,** was fitted with a least square fit of type $\frac{\Delta E}{E}(\%) = aE^{-b}(keV)$. The data along with the fitted curve is shown in Fig.13. The value of constant **b** obtained from the fit was 0.5. This shows that energy resolution of the detector is inversely proportional to the square root of energy (keV) of the gamma ray.

Table 1: Energy Resolutions of $LaCl_3:Ce$ Detector

Elements	Energy (keV)	Energy Resolution (%)
La	272	7.09 ± 0.02
Bi	570	4.86 ± 0.01
Cs	661	4.30 ± 0.01
Bi	1064	3.58 ± 0.01
Cl	1165	3.46 ± 0.01
Co	1333	3.25 ± 0.01
Bi	1770	2.84 ± 0.01
H	2223	2.67 ± 0.01
Cl	2470	2.51 ± 0.01
Cl	2864	2.28 ± 0.01
La	4502	1.85 ± 0.01
Cl	6111	1.56 ± 0.01
Cl	6620	1.30 ± 0.01
Cl	6978	1.49 ± 0.01
Cl	7790	1.30 ± 0.01
Cl	8679	0.90 ± 0.01

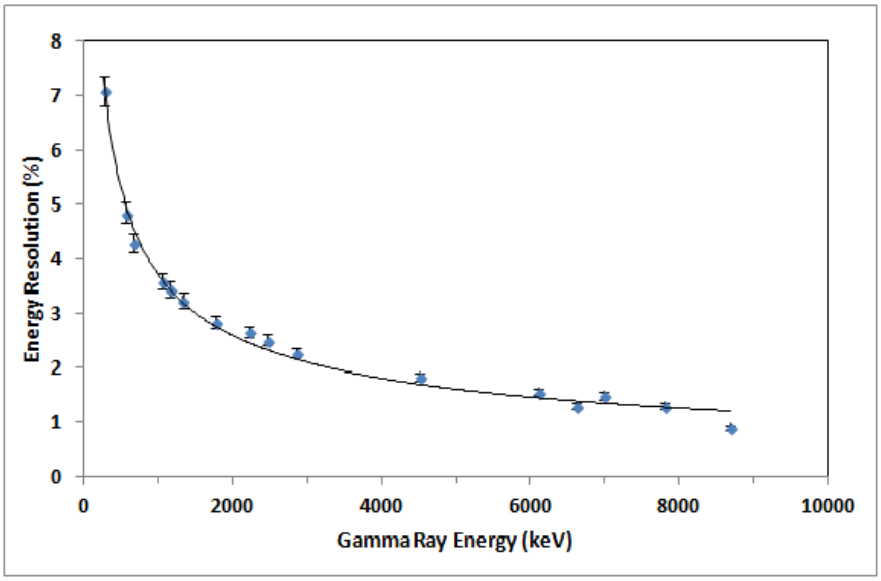

Figure 13: Energy Resolution Curve for $LaCl_3:Ce$ Detector with Power Fit

4.0 Conclusion

Prompt Gamma Neutron Activation Analysis (**PGNAA**) method has been used in this experiment to study energy resolution of $LaCl_3:Ce$ detector using activation spectrum. The energy resolution of $LaCl_3:Ce$ detector varies from 0.9% to 7.09% corresponding to 8679 keV to

272 keV gamma ray energy. The energy resolution of $LaCl_3:Ce$ detector is inversely proportional to the square root of gamma ray energy.

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