**Energy resolution measurement of a Large La Scintillation detector using low energy prompt gamma rays.**

**Abstract.**

Energy resolution of a newly acquired large La Scintillation detector has been measured using low energy gamma rays emitted in thermal neutron capture in Boron, mercury and cadmium samples with 558keV, 478keV and 358keV respectively. The thermal neutrons capture gamma rays were produced in the KFUPM portable neutron generator based PGNAA setup. The energy resolution was calculated using the full width half maximum and energy of the gamma rays from the pulse height spectra of the samples. The measured energy resolution of the detector over 100-558 keV varies over 13-6 %. In conclusion, the Labr3 detector has good energy resolution for performing prompt gamma ray analysis (PGNAA) at lower energy range.

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**1 Introduction**

The analysis of material samples of micro and Nano-sizes using chemical analytic and laboratory sampling technique has developed tremendously over time. In the case of very large samples the search of revolutionary technique to acquire information has led to the neutron interrogation method known as Prompt Gamma-ray Neutron activation analysis (PGNAA). It is a non-destructive technique used in identifying all elements except helium (Perry et al. 2002) in bulk samples. Its nonintrusive method of probing large samples has made it to be applicable in several disciplines such as environment, homeland security and industries. It has also been proved useful for determine the presence and concentration of elements in bulk samples of narcotics, explosives and contraband material which are different from benign substances (Naqvi et al, 2013). This non-invasive method probes samples by a neutron irradiation process using a neutron source which induces a nuclear reaction to emit gamma ray photons as a result of thermal neutron capture (Favalli et al., 2007) counted by detectors as shown in figure 1.

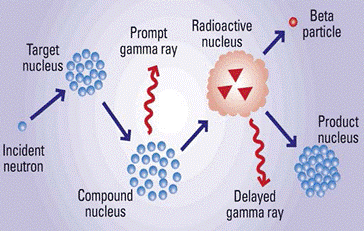


Figure 1. Schematic diagram illustrating prompt gamma ray emission due to thermal neutron captures reaction.

In the figure 1, the target nucleus absorbs the neutron then moves to an excited state with the binding energy of the added neutron. The compound nucleus goes into stability by through emission of characteristic prompt gamma rays but in most cases the product nuclei de-excites by emission of a characteristic delayed gamma ray. Gamma ray detectors, neutron source energy and intensity used for this process vary by application. Choice of a detector is important for the effectiveness of the analysis. If a detector has the following properties the uncertainty in determining gamma ray multiplicity will be minimized. i. Good energy resolution ii. Intrinsic full peak efficiency iii. Good timing resolution. The standard gamma ray detector solutions for spectroscopy are high purity germanium detectors (HPGe) and scintillation detectors (Sangsingkeow etal., 2013). La detectoris distinguished from other detectors because it has 3% resolution of 662-**k**eV peak .it has been used for in-beam spectroscopy in which decay occur to excited state in the nuclei of samples while in motion. It has been reported that in quantifying the concentration of toxic metal pollutants low energy gamma rays are useful (Naqvi et al 2012). For excellent counting of low energy prompt gamma rays scintillator detectors such Ladetector gives excellent result (Naqvi et al 2011). The accumulation of mercury, boron and cadmium in humans are life threatening and their accidental ingestion occur through plants grown in soil irrigated with cadmium or boron contaminated sewage or industrial disposals (Naqvi et al 2012). Mercury is more toxic than cadmium and boron and its ingestion has adverse effects on human life particularly development of fetus in women pregnancy. In this work, the response of newly acquired large Lascintillator detectors to low energy gamma rays emitted from samples containing Boron cadmium and mercury is investigated.

1. **Experimental**

This study was carried out using KFUPM portable neutron generator based PGNAA setup given in (Naqvi et al, 2011) using a large LaBr3: Ce detector for prompt gamma ray detection. In the following the PGNAA setup, the electronics, the detector and data taking will be described.

**2.1 KFUPM Portable Neutron Generator Based PGNAA Setup**

Samples used in this experiment include Boron, Cadmium acetate, mercury nitrate which are stored in plastic cylindrical containers .The sample to be analysed is placed inside a cylindrical high density polyethylene moderator aligned to a cylindrical 3 in.by 3 in. (diameter length) Lagamma-ray detector exposed to fast as well as thermal neutron flux but at right angle to a portable neutron beam generator (MP 320 model) which provides a pulsed beam of 2.5MeV neutrons was produced via D(d, n) reaction using 70 mA beam of 70keVdeuteron. The deuteron pulse had a width of 5ns and a frequency of 250Hz. For effective irradiation process proper shielding is required which prevent undesired gamma-rays and neutrons from reaching the detector. Hence, 3 mm thick lead shielding and 50 mm thick paraffin shielding were provided around the gamma-ray detector. The neutron shielding is made of a mixture of paraffin and lithium carbonate mixed in equal weight proportion.

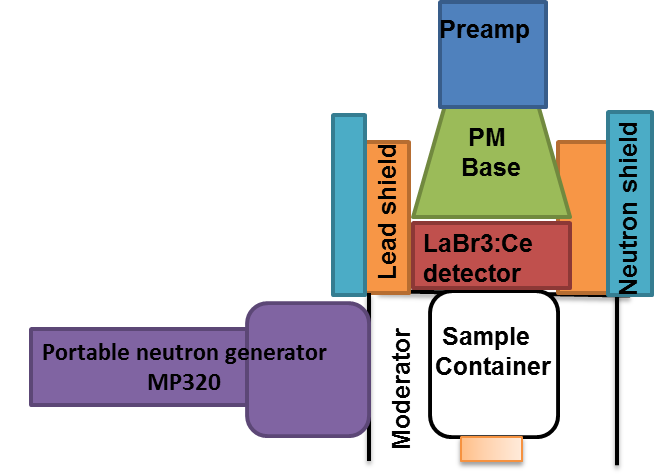
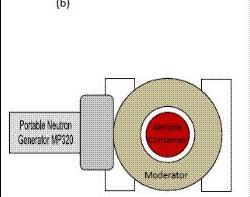
 

Figure 2. PGNAA technique setup (a) top view (b) front view.

**2.2 Block Diagram of the Electronics of the PGNAA setup**

The characteristic gamma rays emitted by the samples after irradiation serve as fingerprints which is measured and counted with a specific energy to deduce the chemical element of the sample. Hence series of electronic components shown in figure 3 are connected to the detector. A photomultiplier and preamplifier are coupled to the detector to convert the photon to electrical signal and minimize the source of noise transmitted with the signal respectively. Other components include: An amplifier which increase the amplitude of the signal, an analogue-to-digital converter (ADC) that digitizes the input pulse height and assigns it to a specific channel, a linear gate stretcher which is to gate a signal prior to its pulse-height analysis when necessary. The prompt gamma ray data from the samples were therefore collected in a personal computer. In other to get alow energy region with maximum energy peak of 800keV with 500 channel the coarse and fine gain is adjusted to 10 and 20 on the amplifier of the electronic setup.

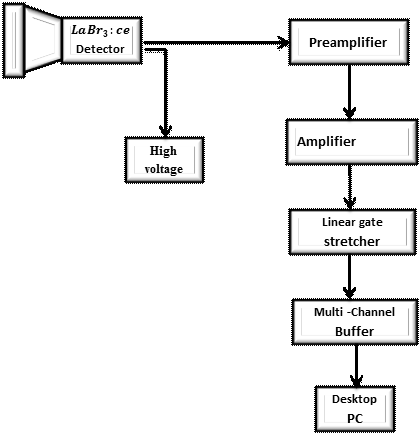


Figure 3. The electronic component for processing signals produced by the detector

**2.3 La detector and its intrinsic Spectrum**

The LaBr3:Ce detector contains radioactive La isotope The La-138 isotope is present in the natural lanthanum with an abundance of 0.09% and its lifetime is of the order of years (Nicolini et al., 2007)and it has intrinsic radioactivity spectrum. The intrinsic activity pulse height spectrum of the detector measured over a period of 151s is shown in figure 4. The spectrum shows 1468(1436+32) keV gamma ray peak resulting from 1436 keV gamma due to beta decay of La isotope and 32keV x-ray fluorescence of Ba produced in the electron capture by La (Naqvi et al 2012) though another 789 gamma peak appears which is of lower pulse height. These peaks are the fingerprints generated due to 138La nuclide decay during its intrinsic activity in the Ladetector. These gamma rays are evident in the background spectrum of the detector and do not produce a significant interference in the active interrogation application (Seabury etal 2006) because it has fast response time~~.~~

Figure 4. Intrinsic Spectrum of the Large LaBr3 detector.

For detector energy calibration, Cs-137 and Na-22 were attached to the lead shield of La detector operating at voltage of -960V. In this process a radioactive source of known energy is hooked to the detector. From the energy spectrum of this radionuclide channel number of the full energy peak and corresponding full width at half maximum was determined from the multichannel analyser program. A graph of energy against channel was plotted in order to determine the energy calibration of the detector.

**2.4 Energy calibration of the Labr3:Ce Detector**

The spectrum acquired by attaching the Na-22 and Cs-137 radionuclides to the detector for calibration without providing neutron source is shown in figure 5. The pulse height spectrum shows the superimposition of the two spectra obtained from the individual calibration source with the Cs-137 having the most prominent peak.

Figure 5. La detector calibration spectrum obtained from sodium and caesium radionuclide

The energy channel relation acquired which gives a linear function of E= 2.0377c + 14.789 for the calibration of the LaBr3 detector is shown in figure 6. As it can be seen from the graph the large La detector exhibits an outstanding linear response which would make it easy to fit in the channel number of a peak into the function to obtain the corresponding energy .the element that has the energy is determined by comparing the values with those elements in table 1.

Figure 6. Plot of Resolution against prompt gamma ray energy.

Table 1: Energies and partial element cross section of prominent capture gamma rays of some selected elements(Choi et al., 2006)

|  |  |  |
| --- | --- | --- |
| **Element** | **Gamma ray Energy (keV)** | **Cross section** |
| **B(n,α)** | **478** | **716** |
| **Br** | **195** | **0.434** |
|  | **276** | **0.158** |
|  | **367** | **0.233** |
| **Cd** | **558** | **1860** |
| **Ce** | **475** | **0.082** |
| **La** | **163** | **0.489** |
| **Hg** | **368** | **251** |

**2.5 Prompt gamma Ray Measurement**

Samples used in this experiment include Boron, Cadmium acetate, mercury nitrate which are stored in plastic cylindrical containers .The sample to be analysed was placed inside the moderator of the KFUPM portable neutron generator based PGNAA setup. The portable neutron beam generator (MP 320 model) which provided a pulsed beam of 2.5MeV neutrons via D(d, n) reaction , was operated with 70 mA beam of 70keVdeuteron. The deuteron pulse had a width of 5ns and a frequency of 250Hz. The background spectrum for low energy gamma rays detected is shown in figure 7. The pulse height appears due to the material component of the detector such as Bromine Cerium, and Lanthanum.

**2.5.1 Background spectrum**

The beam associated background spectrum of the LaBr3:Ce detector taken during 15 min of run is shown in figure 7.the pulse height spectra shows peaks of La-163,Br-195, Br-276, Br-367 and a broad peak which indicates that more than one peak is present. These peaks appear due to the intrinsic activity undergone by La, Br and Ce elements in the detector. The hydrogen peak which is reported appear in the background spectrum due to the polyethylene material of the moderator has is not seen in this spectrum because it doesn’t belong to the low energy region The lanthanum, cerium and bromine listed in table 1 is identified in figure 7.

Figure 7. LaBr3: Ce detector background spectrum for low energy gamma rays.

**2.5.2 Cadmium Sample Spectra**

Figure 8 shows the pulse height spectra of prompt gamma rays from cadmium acetate sample containing with background spectrum taken without sample. Since the cadmium peak contains the contribution of Ce (475) peak, the difference spectra of cadmium peak were generated by subtracting the background spectrum which is shown in figure 9.

Figure 8 Prompt gamma-rays pulse height spectra of Cadmium acetate sample with background spectrum

Figure 9 Enlarged prompt gamma-ray experimental pulse height spectra after background subtraction from Cadmium acetate samples.

**2.5.3 Boron Sample spectra**

Figure 10 shows pulse height spectra of prompt gamma-rays from Boron samples with background spectrum taken without sample. Since boron peaks appears very close to Ce (475) peak, difference spectra of boron peaks were generated by subtracting the background spectrum which is shown in figure 11.

Figure 10 Prompt gamma-rays pulse height spectra of Boron sample with background spectrum

Figure 11. Enlarged prompt gamma-ray experimental pulse height spectra after background subtraction from Boron samples.

**2.5.4 Mercury Sample spectra**

The pulse height spectra of prompt gamma rays from Mercury nitrate sample containing with background spectrum taken without sample is shown in Figure 12. Since the cadmium peak contains the contribution of Br (367) peak, the difference spectrum of Mercury peak was generated by subtracting the background spectrum from the spectrum which is shown in figure 13.

Figure 12 Prompt gamma-rays pulse height spectra of Mercury sample with background spectrum.

Figure 13 Enlarged prompt gamma-ray experimental pulse height spectra after background subtraction from Mercury samples

**3 Energy Resolution of the LaBr3: Ce Detector**

Table 2 shows the resolution obtained from pulse height of the calibration spectrum peaks, background peaks due to detector material and the samples. Figure 5 shows is the relationship between the between the prompt gamma ray energy and the resolution obtain from the peaks with an uncertainty of 5%.The minimum resolution is 6% for a prompt gamma ray energy of 661keVand the maximum resolution obtained is approximately 10% equivalent to 163 keV of the background spectrum . An average estimated error of ± 0.1 is obtained in all the measurement. Since the LaBr3:ce detector is reported to have a resolution of 3% with 662keV prompt gamma ray energy then the actual error of the measurement is .This amount of error might be due to insufficient counting time which is averagely 1000 seconds. The largest error was also noticed in the resolution calculated from the peaks of the background spectrum a delineation occur in the error towards the calibration peaks and sample peaks after background subtraction. The resolution also follows the expected E-1/2 dependence as shown by the least-squares fit through the data points.

Table 2. Energy and Resolution of the background peaks, calibration source and samples.

|  |  |  |
| --- | --- | --- |
| **Elements** | **Energy Gamma Ray (keV)** | **Resolution (%)** |
| **Lanthanum(La)** | **163** | **10.3±0.10** |
| **Bromine(Br)** | **195** | **12.6±0.13** |
| **Bromine** | **276** | **10.6±0.11** |
| **Mercury(Hg)** | **358** | **9.3±0.09** |
| **Bromine** | **367** | **8.8±0.09** |
| **Boron(B)** | **478** | **8.4±0.08** |
| **Sodium(Na-22)** | **511** | **6.4±0.06** |
| **Cadmium** | **558** | **5.9±0.06** |
| **Caesium(Cs-137)** | **661** | **5.8±0.06** |

Figure 14. Plot of Resolution against prompt gamma ray energy.

**4. Conclusion.**

The performance of newly acquired large Ladetectors has been successfully tested by using it to detect low energy prompt gamma rays from samples containing boron, cadmium and mercury using a portable 2.5 MeV neutron–based PGNAA setup. The measured energy resolution of the detector over 100-558 keV varies over 13-6 % which is almost equivalent to the 3% resolution reported for LaBr3:Ce detector .The result obtained from the resolution-energy relation graph shows it has a good resolution with a minimised error for low energy gamma ray analysis.

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