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Optimization of Gamma Spectroscopy Setup for Am-Be based PGNAA Setup

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Abstract: *Gamma Spectroscopy setup is an integral part of prompt gamma activation setup. Gamma spectroscopy setup consists of a Canberra Coaxial HpGe semiconductor detector and a Canberra digital spectrum analyzer (DSA1000).The detector calibration measurement were carried out for energy range 59.5 keV to 4439.4 keV with standard gamma sources, natural background (^{40}K and ^{208}Tl) gammas and ambient gamma from of ^{241}Am-^{4}Be neutron source. Full energy peak efficiency is estimated for the energy range 59.5 keV to 1332.49 keV. Important detector performance parameter like full width at half maximum (FWHM), full width at one tenth of maximum (FWTM), peak-to-Compton ratio and gain variation of conversion factor with amplifier gain were also estimated. Optimization of digital signal processing (DSP) parameters for digital MCA were also carried out.*

Keywords: *HpGe Detector, Digital Signal Processing, Gamma Spectroscopy, High Count Rate, Radiation Detection*

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I. Introduction

In the recent past, lot of work is carried out for development of radio-isotropic neutron source based prompt gamma activation analysis (PGNAA) setup for detection and quantification of elements in sample of interest. When sample of interest are exposed to thermal neutrons, these neutrons are captured by the elements present in the sample and characteristic prompt gammas are emitted. In PGNAA setup these prompt gammas are detected online and in-situ. Such setup requires high resolution gamma spectroscopy setup and needs to be optimized for counting environment. A gamma spectroscopy setup consist of a gamma detector, Power supply for detector, pre-amplifier, amplifier, a multichannel pulse height analyzer and analogue to digital converter (ADC). Modern digital Multichannel analyzer includes amplifier, power supply, pulse height analyzer and ADC. Modern Digital MCA use digital signal processing algorithm for pulse height analysis and digitization.

High purity germanium (HpGe) detector is widely used for high resolution gamma-ray spectrometry. Detector is required to be calibrated for wide energy range and efficiency of a detector is required to be determined for the activity of unknown nuclides. Use of digital multichannel analyzer gamma-ray spectrometry also requires the optimization of digital multichannel analyzer parameter for application environment. In the present work, detector calibration measurement were carried out for energy range 59.5 keV to 4439.4 keV with standard gamma sources, natural background (^{40}K and ^{208}Tl) gammas and ambient gamma from of ^{241}Am-^{4}Be neutron source. The efficiency measurement (intrinsic efficiency and absolute efficiency) were carried out for the energy range 59.5 keV to 1332.49 keV. Important detector performance parameter like relative efficiency, Full width at half maximum (FWHM), Full width at one tenth of maximum (FWTM), Full width at one fiftieth of Maximum (FWFM), peak-to-Compton ratio and variation of conversion factor with amplifier gain were also estimated. Optimized results of digital signal processing (DSP) parameters such as rise time, flat-top time etc. were also presented.

II. Material & Methods

A gamma spectrometer with a Canberra Coaxial HPGe semiconductor detector (Model GCD1518) with relative efficiency of 15% and a Canberra digital spectrum analyzer (DSA1000) with 8192 channels working with the acquisition software Genie 2000 used for measurement. Detector is operated under a high voltage of 2.5 kV. To minimize background, detector active volume is covered with 2 cm thick lead (Pb) rings.

2.1 Detector Performance Parameter Check:

The main performance specifications of Canberra HpGe detector are as follows:
Relative efficiency = 16.4 % ,
FWHM = 1.63 keV, FWTM = 2.98 at 1332.5 keV (^{60}Co)
FWHM = 0.73 keV, FWTM = 1.35 keV at 122 keV (^{57}Co)
Peak to Compton ratio = 53.7:1 at 1332.5 keV (^{60}Co)
The crystal active diameter = 49.8 mm
The crystal active length/thickness = 37.1 mm.
The end cap to crystal distance is 4.31 mm.

The accuracy of measurement of the detector depends on many performance parameters viz Resolution, Peak Shape, Peak to Compton ratio, relative efficiency etc. In order to achieve high quality of measurements the performance of the HpGe detector shall be verified against the specifications provided by the manufacturer. For this purpose method described in germanium detector manual [10] and DSA-100 manual [9] supplied by the manufacturer were used for specification and parameter setting of DSA spectrum analyzer. Optimization method described in “Practical Gamma ray Spectrometry “ by Gilmore is [3] also used.

2.1.1 ADC Conversion Factor

To determine the conversion factor (the energy per channel) , ratio of difference in keV between the two peaks of ^{60}Co (1173.2 keV and 1332.5 keV) and difference between the numbers of channels of two peaks were calculated for different amplifier overall gain values. Variation of conversion factor with amplifier overall gain are shown in Fig.1

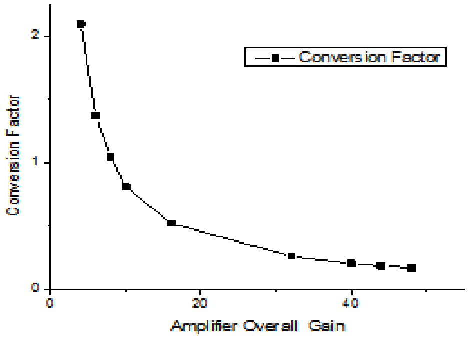

Figure 1: Amplifier overall gain vs. Conversion Gain

2.1.2 Estimation of Peak Width

In a spectrometry system, if peak areas are derived from manually selected regions-of-interest (RoI) then there is no need for a peak width calibration. However, if the computer is used for calibration or analysis then pulse shape must be known to the software to be able to deduce the width (by convention, the full width at half maximum, FWHM) of a peak as a function of energy. FWHM and FWTM for ^{60}Co 1173.2 keV and 1332.49 keV peak were estimated, Fig. 2(A) and Fig. 2(B) shows the linear variation of FWHM and FWTM with amplifier overall gain respectively.

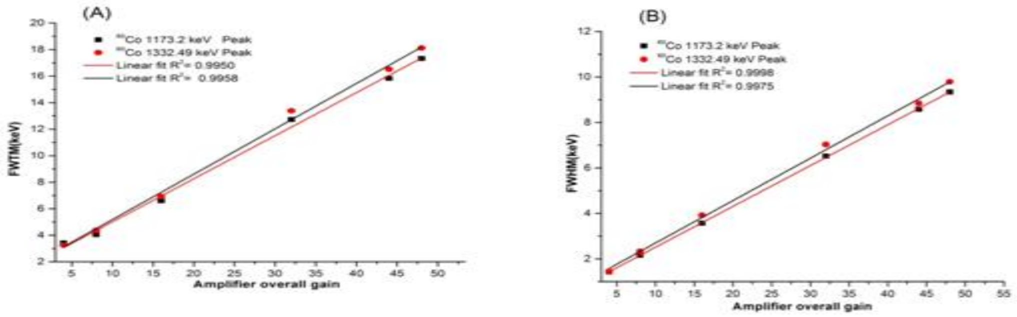

Figure 2: (A) Amplifier overall gain vs. FWHM
(B) Amplifier overall gain vs. FWTM

2.1.3 Peak Shape

Apart from peak resolution another important parameter is peak shape. Ideally, peak in the spectrum is approximated to a Gaussian distribution. For a ideal Gaussian distribution FWTM/FWHM ratio and FWFM/FWFM ratio are 1.823 and 2.376 respectively. The acceptable limit of FWTM/FWHM ratio is < 1.9. Departure from this value indicates tail in the spectrum. Most of the detector manufactures warrant a ratio better than 1.9. FWTM/FWHM ratio for ^{60}Co 1332.49 keV peak are estimated (Fig. 3(A)).

Acceptable limit of FWFM/FWHM ratio is < 2.5. Manufactures warrant a ratio better than 3.0. FWFM/FWHM ratio for ^{60}Co 1332.49 keV peak are estimated (Fig. 3(B)).

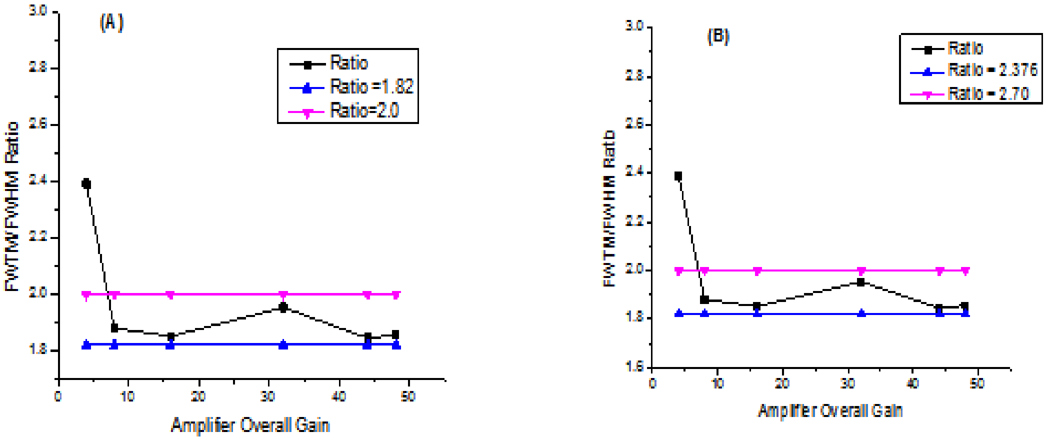

Figure 3: (A) Amplifier overall gain vs. FWTM/FWHM ratio
(B) Amplifier overall gain vs. FWFM/FWHM ratio

2.1.4 Peak to Compton

Compton continuum affects both detector resolution and full energy peak efficiency. The big size detector has greater probability of absorption in comparison to small size detector. Thus in case of big detector, there will be more counts in the full energy peak rather than the Compton continuum and peaks will be narrower Generally, Peak to Compton ratio is inversely proportional to resolution and proportional to efficiency. In the ANSI/IEEE standard [4] the peak to Compton ratio is defined as the ratio of the number of counts in the highest channel of the 1332.5 keV ^{60}Co peak to the average channel count in the Compton continuum between 1040 and 1096 keV in that same spectrum . i.e

$$\frac{P}{C} = \frac{\text{Number of Counts at peak of 1332.5 keV(60Co)}}{\text{Average count per channel from 1040 to 1096 keV}}$$

Peak to Compton ratio were calculated for different amplifier overall gain are as shown in Fig.4.

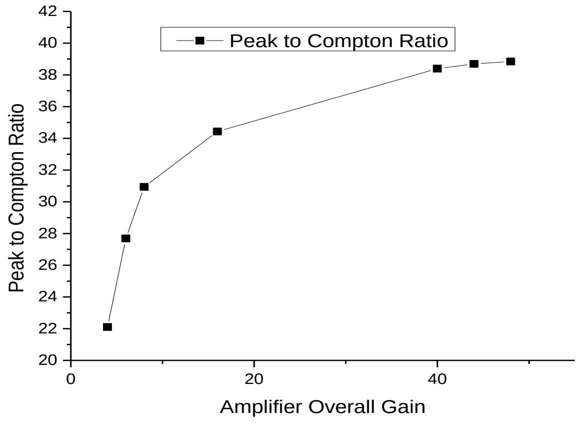

Figure 4: Amplifier overall gain vs. Peak to Compton Ratio

2.2 Optimization of Digital Signal Processing Parameters

For different type of detectors, the DSP parameters of digital multichannel analyzer are provided by the manufacturer .One need to optimize DSP parameters for their counting environment.

2.2.1 Pole /Zero Matching

For detectors with RC preamps, Pole/zero compensation is extremely required and ideally must be set to zero to achieving good performance at high counting rates. Digital Multichannel analyzer provide graphical interface for adjusting Pole/Zero matching manually. In Canberra DSA-100 multichannel analyzer Pole/Zero matching is adjusted manually by using slider bar located on the Pole zero adjust screen. For Pole/Zero adjustment a ^{60}Co radioactive source is kept in-front of the detector to achieve incoming count rate (ICR) 20 K counts/sec. The adjustment were done by grabbing and moving the Pole/Zero slider bar tab with mouse pointer to place pointer near centerline null point. DSA-1000 provides a four digit value (reference umber) for pole/zero adjustment range in our case reference number value is 3100. The precision is also verified by observing the trailing edge of the trapezoid waveforms as it returns to the baseline using the inbuilt digital oscilloscope. No over and undershoot were observed.

2.2.2 Pileup Rejection

Pulse-pileup losses are also called random summing losses. Depending upon the counting environment significant events may be lost in the gamma-ray spectrometer system. Counting system component like the detector, pre-amplifier, amplifier, ADC, and MCA or computer have finite response time and slowest un-buffered units are detector, amplifier and ADC. Finite response time of these components of counting system is main source of count lost. When two or more unrelated gamma rays arrive at detector within the short time compared to detector/ADC response time and/or amplifier shaping time then a pulse of whose height is sum of events occurs. Thus, genuine signal counts are lost from the low energy part of the spectrum and one sum up high energy count is added in the high energy part of the spectrum. These losses may or may not be compensated and uncompensated losses are main source of inaccuracy in measurement. [8]

Modern multichannel analyzers compensate for ADC dead time by gating the live time clock off during the conversion. Pile up rejecter monitors the signal processing activities of the fast discriminator and digital filtered signal and allows only signals resulting from a single event. The fast discriminator detects the arrival of input events and discriminate multiple pulses arriving less than 500 ns time period. If the fast discriminator detects two or more pulses within the processing time of digital filtered signal then events are considered as contaminated by pile up and rejected.[9]

For pileup rejection with live source ADC gain is so adjusted to get 122 keV ^{57}Co peak in channel 3500 channel and distance of the source is adjusted to achieve incoming count rate (ICR) for 50 kcps. Spectrums were recorded for 60 Sec with LTC OFF and LTC ON features of DSA-1000.Comparison of LTC OFF and LTC ON spectra is shown in Fig. 5 (A) & (B)

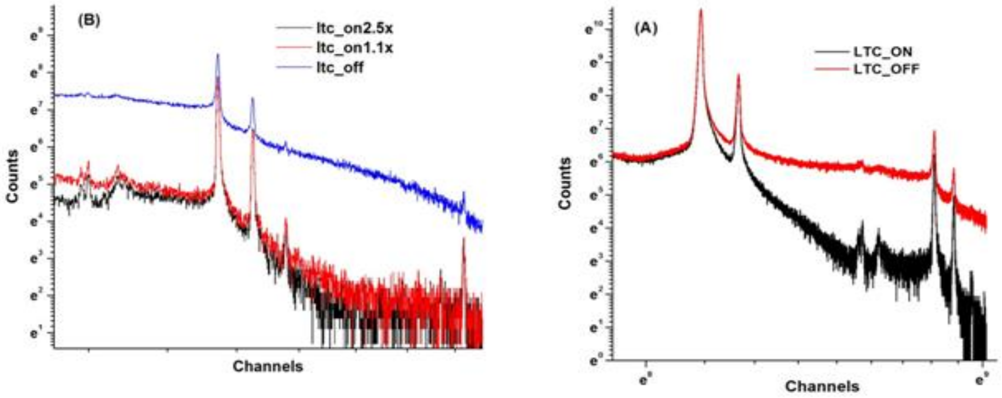

Figure 5: (A) ^{57}Co Spectra with LTC on and LTC off
(B) ^{57}Co Spectra with LTC off and LTC on with PUR guard 1.1X and 2.5 X

2.2.3 Live time Correction

Events rejected due to pileup and processing time should be compensated. Digital multichannel analyzer derive dead time by live time correction function. The dead time signal controls the MCA "Live Time" clock which extends the acquisition time by appropriate time. Digital Multichannel analyzers provides LT TRIM function which allows minor adjustment of pulse evolution time or dead time of the digital trapezoid signal to normalize the fast and slow energy thresholds without affecting the spectral low energy cutoff threshold. [9]

Detector system is calibrated using two source method and performance is optimized by choosing suitable LT Trim value (Fig. 6).

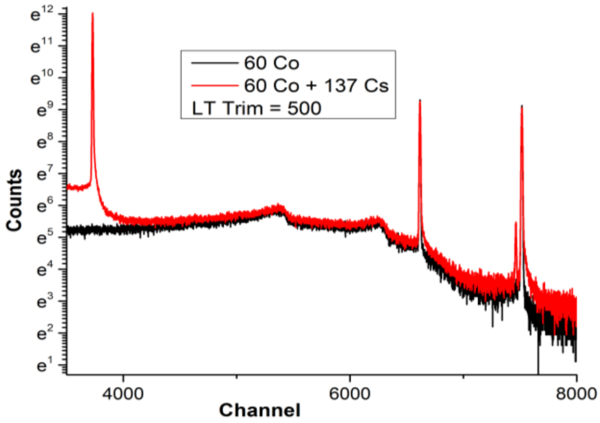

Figure 6: ^{60}Co and 60Co+137Cs Spectra (two source method) LT Trim =500

2.2.4 Filter Setting

Digital multichannel analyzer uses digital filters to analyze pulses. The digital filter has a triangular/Trapezoidal shaping function. The pulse processing time is set by the selection of optimum rise time and flattop time. [9] Digital multichannel analyzers provides a wide range of selection of shaping time by choosing different rise time and flat top time. Detector resolution depends on the shaping time. Short shaping time does not include all of the pre-amplifier pulses while longer shaping time includes noise pulses also. Best resolution may be obtained by the longer shaping time but increases the processing time thus increases the dead time of the detector [11]. Thus optimization of shaping time is essential for gamma spectroscopy application environment. Canberra recommended values for rise time and flat top time are 5.6 □ s and 0.8 □ s respectively. For Rise time = 5.6□ □ s^{60}Co spectra were recorded for Flat Top Time 0, 0.4□ □ s, 0.8□ □ s, 1.2□ □ s and 1.6□ □ s (Fig. 7A & 7B).

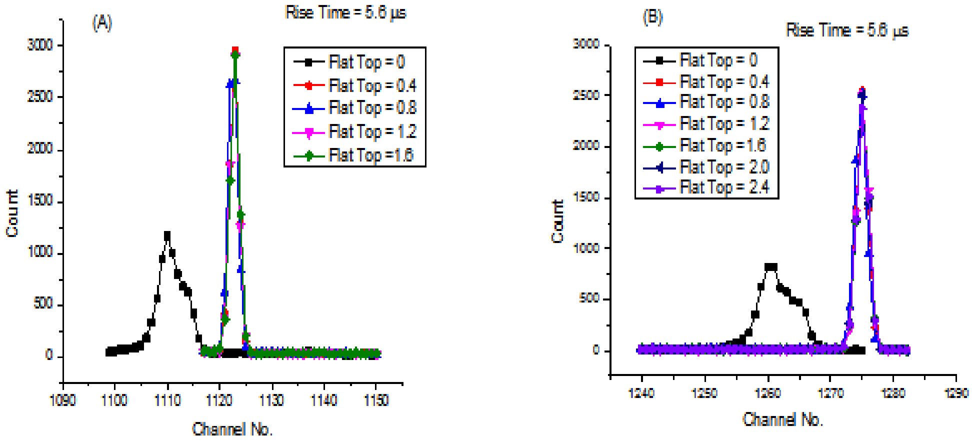

Figure 7: (A) ^{60}Co 1173.23 keV peak for different flat top time
(B) ^{60}Co 1332.49 keV peak for different flat top time

2.3 Detector Calibration

Disk type standard Gamma reference sources (^{133}Ba, ^{137}Cs, ^{22}Na, ^{60}Co, ^{57}Co, ^{241}Am) were used for detector calibration. Beside these reference sources , 2223 keV Gamma rays from thermal neutron captured by ^{1}H, 4438 keV gamma-rays from ^{9}Be(α,n)^{12}C reaction in ^{241}Am-^{9}Be neutron source, 1460 keV and 2614 keV gamma from natural background were also used for detector calibration. Detector Calibration is based on the method described in IEEE standard 325-1996 test procedure [4]. For detector calibration spectrum were recorded for 3600 Sec for each source with amplifier overall gain 8.

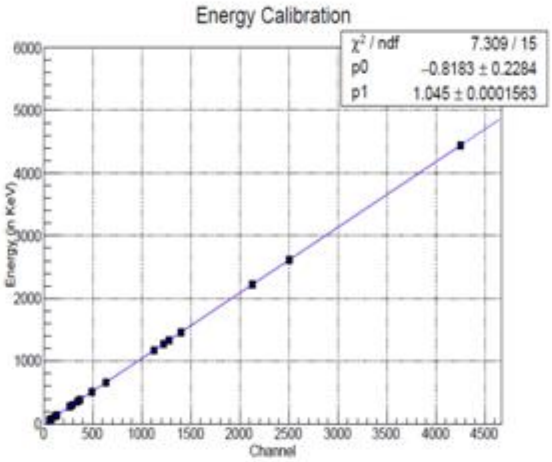

Figure 8: The energy calibration curve Energy calibration linear fit equation -

$$\mathrm{E\ (keV)} = -8.07\mathrm{x}10^{-1}\ \mathrm{(keV)} + 1.045\ \mathrm{x\ C\ (Channel)} \qquad (1)$$

2.4 Detector Energy Resolution

Energy resolution of a gamma ray spectrometer is the ability to separating two adjacent energy peaks with slightly different energy. The energy resolution is the ratio of the full width at half maximum of a given energy peak to the peak height.

$$\mathrm{R} = \frac{\mathrm{FWHM}}{\mathrm{Peak\ Height\ Channel}}\ \mathrm{x}\ 100\ \%$$

Where, R is the resolution in percent.

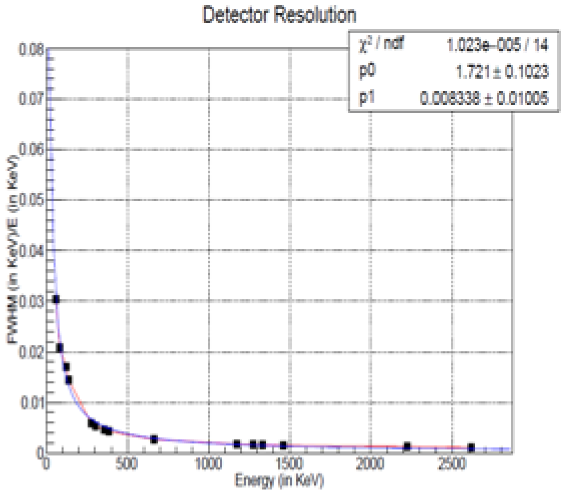

Figure 9: Energy Resolution curve

2.5 Detector Efficiency

Radiation measurement requires an accurate knowledge of the detector spectral performance. The detection efficiency depends on the volume and shape of the detector active material, absorption cross section, attenuation layers in front of the detector, and distance and position from the source to the detector. Detector efficiency is related with emitted gamma radiation quanta and radiation quanta counted by detector. Various kinds of the efficiency definitions are used and among those full energy peak absolute efficiency and full energy peak intrinsic efficiency are widely used.

2.5.1 Full Energy Peak Absolute Efficiency

FEP Absolute efficiency relates the number of pulses recorded by detector and number of radiation quanta emitted by radioactive source, i.e.

$$\varepsilon_{\text{abs}} = \frac{\text{number of pulses recorded}}{\text{number of radiation quanta emitted by source}}$$

FEP Absolute efficiency depends on detector properties and counting geometry (distance from the source to the detector). FEP Absolute efficiency formula is based on the assumption that all sources are isotropic and no attenuation takes place between the source and detector.

2.5.2 Full Energy Peak Absolute Intrinsic Efficiency

FEP Intrinsic efficiency relates the number of pulses recorded by detector and number of radiation quanta incident on detector, i.e.

$$\varepsilon_{\text{int}} = \frac{\text{number of pulses recorded}}{\text{number of radiation quanta incident on detector}}$$

FEP Intrinsic efficiency depends on the solid angle subtended by detector from point source.

Disk type calibrated sources (^{241}Am, ^{133}Ba, ^{137}Cs, ^{22}Na and ^{60}Co) were used to estimate the efficiency of the HPGe-detector. There is a certain probability of coincidence losses of cascade gamma-rays when the sources are put closer to the detector. To eliminate the coincidence loss, All sources were individually placed at 25 cm far from the surface of the detector [4]. The fifth order polynomial of the form –

$$\epsilon_\gamma = \exp\left(\sum_{i=0}^{4} a_i \left(\ln E_\gamma\right)^i\right) \qquad (2)$$

is used as fitting functions for absolute full energy peak efficiency and shown in Fig. 10

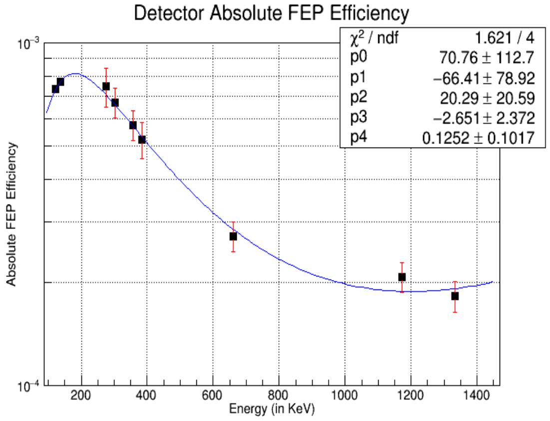

Figure 10: Absolute full energy peak efficiency variation with energy

III. Conclusion

The main performance specification of detector matches with parameter warranted by the manufacturer. Energy calibration function is linear in the energy range. The FEPE values are obtained for gamma energy range 59.5 keV to 1332.5 keV.

DSP parameters of Digital spectrum Analyzer were optimized for amplifier overall gain 8 X rise time 5.6 µs and Flat Top Time 0.4 µs for counting environment as high as 30 kcps.

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