



LPNPE Lab's energy calibration method for gamma spectrometry using detector CZT-500s & MCA-166

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Abstract: In this paper the developed method for energy calibration of the LPNPE Lab's gamma spectrometry is described. In LPNPE Laboratory, two spectra are measured (spectra of Cs-137 and I-131). From known values of gamma-ray energies, a calibration curve is plotted. The best fit line on the calibration curve matched the data with a least squares fit of $R^2 \approx 1$. The spectra are measured using the CZT-500s detector coupled with the MCA-166. For the analysis, only full-energy peak is identified.

Keywords: gamma spectrometry, energy calibration, CZT-500s

I. Introduction

The “Laboratoire de Physique Nucléaire et Physique de l'Environnement” (LPNPE) is the nuclear physics laboratory of the physics Department of the University of Antananarivo. This laboratory is created on April 2013 and received its first equipments on March 2014. These equipments include some dose rate meters and a complete gamma spectrometry chain, which are donated by the “International Atomic Energy Agency” (IAEA). The gamma spectrometry chain includes a CZT-500s detector coupled with a multi channel analyzer MCA-166. The first work to be done in a Laboratory with such gamma spectrometry equipment is to set up properly the whole chain. That means definition of: detector response, detector efficiency, spectral resolution, energy calibration, etc. The present work aims to set up an energy calibration method for the gamma spectrometry. This work is performed at LPNPE Laboratory and in the frame of the collaboration with “Laboratoire des Radioisotopes” (LRI) of the University of Antananarivo-Madagascar. While a Geiger counter determines only count rates for radiation, gamma spectrometry has the ability to determine both the count rate and the energy of the radiation. This is important as different radioactive nuclides emit many gamma rays of different energies. A gamma spectrum is created by taking measurements of emitted gamma rays and processing them. Energy calibration is then needed to interpret a spectrum in terms of energy (to identify radioactive nuclides). A detector coupled with an MCA can identify unknown radioactive nuclides by identifying features on the gamma spectrum and comparing them to known spectra. The implications of this are quite wide. In the field of environmental pollution study, for example, a detector could collect information from a sediment sample. In the LPNPE Laboratory, for energy calibration of the gamma spectrometry, the spectra of two different sources are measured. These sources are Cs-137 (the LPNPE available source) and I-131 (the LRI source).

II. Methodology: Steps in the Energy Calibration Process

As having sufficient counts ensure good peak shape and an accurate determination of the channel for the peak centroid, the total count time for all measurements is taken equal to 300s which is enough for getting sufficient counts and the distance source-detector is taken such as dead times are less than 5%.



Fig.1 The gamma spectrometry chain



Cs-137



I-131

For the analysis, only full-energy peak is identified. The channel containing the peak centroid is used by the software WinSPECi to determine the curve for energy vs channel (keV/channel). The energy calibration is then performed with independent sources (Cs-137 and I-131) that have different gamma ray emitters. The software WinSPECi offers the three calibration methods as follows:

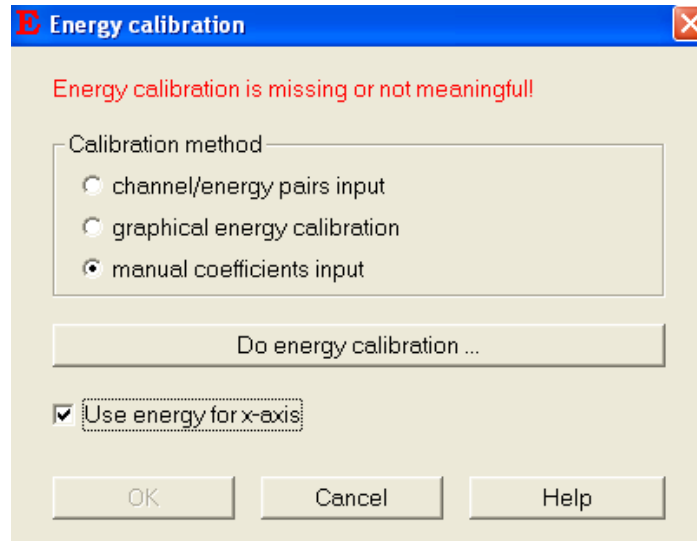


Fig. 2 Calibration method

First method: *channel/energy pairs input*. When peak positions are known, this first method can be used. The disadvantage of this method is that the number of channel/energy pairs to be used for the calibration is limited by three pairs.

Second method: *graphical energy calibration*. This method is used when peak positions are to be determined by looking at the spectrum and placing the cursor at the peak position. The disadvantage of this method is that the number of peak positions is limited by the existing peaks in the spectrum.

Third method: *manual coefficients input*. If the equation of the energy calibration is pre-defined, the coefficients are just to be entered for the calibration. This method is flexible since it allows using as many peaks as wanted. The higher the number of peak positions is chosen, the best the fitting is obtained. Therefore, this method is chosen and the pre-defined energy calibration equation calculation is computerized.

III. Spectrum of Cs-137 and I-131 for peaks localization

As reference for gamma energy emission, the data from the report of the French atomic energy commission "Commissariat à l'Energie Atomique" (CEA) year 2008 (CEA-R-6201) have been taken. From this document, the most important gamma energies emitted by these two elements are listed below:

Cs-137: 661.657keV, emission percentage: 84.99%.

I-131: 284.305keV, emission percentage: 6.06%

364.489keV, emission percentage: 81.2%

636.989keV, emission percentage: 7.26%

The following figures show the spectrum of Cs-137 and I-131 from which four peaks could be localized.

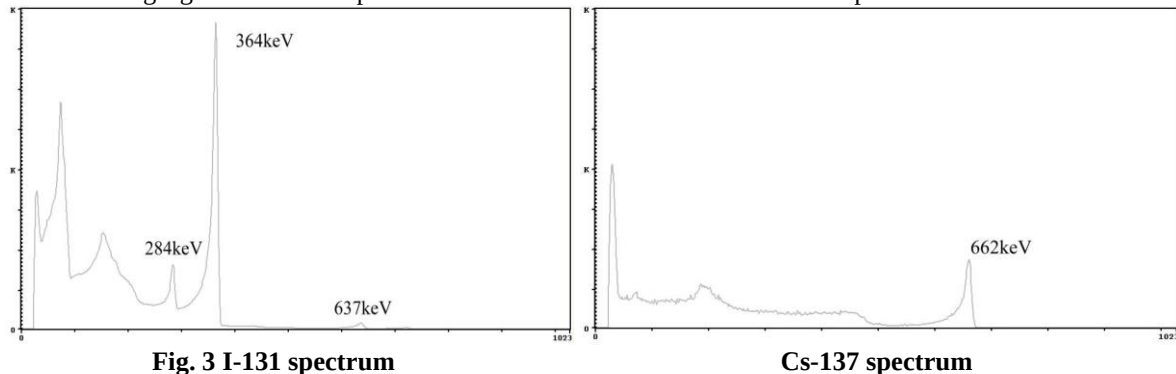


Fig. 3 I-131 spectrum

Cs-137 spectrum

IV. Energy calibration method for Peak Identification (Energy vs. Channel Number)

The recommended high voltage for the detector CZT-500s by the manufacturer which is +1400V is applied. Two radioactive sources (Cs-137 and I-131) whose gamma rays span the energy range from 284keV to 662keV are used to set the energy calibration range. This function is performed by starting counting and adjusting the gain on the systems amplifier until the gamma ray peak of known energy is in the channel that corresponds to the pre-selected value of keV/channel. This value is chosen around 1keV per channel. This calibration is

supposed to be linear. For different measurements with same setup parameters, the exact position of a gamma ray peak is supposed to be in the same channel. However due to variation in line voltage, humidity, resistance variation of the connections, room temperature and other indeterminate environmental variations, the peak position is slightly shifting. The energy calibration is performed in different positions relative to the detector and it is verified that the gamma ray position in the spectrum is only dependent on the detector setup parameters. Indeed, it should not be important how many events occur to perform the energy calibration.

V. Least squares fitting of data to a curve

For N pairs of data (C_i, E_i) , $i=1, \dots, N$, where C_i is the channel number corresponding to the gamma energy E_i , a good fit to the data is to calculate the coefficients a and b such that $E=F(C)=aC+b$.

The difference between the given E_i value and the fit function evaluated at C_i is

$$r_i = E_i - F(C_i) \\ = E_i - (aC_i + b)$$

For statistical and computational reasons, the criterion for choosing the “best” fit is to minimize

$$\rho = \sum_{i=1}^N r_i^2 = \sum_{i=1}^N [E_i - (aC_i + b)]^2$$

The best fit is then obtained by the values of a and b that minimize ρ .

The minimum requires :

$$\left(\frac{\partial \rho}{\partial a} \right)_{b=\text{constant}} = 0 \quad (1)$$

and

$$\left(\frac{\partial \rho}{\partial b} \right)_{a=\text{constant}} = 0 \quad (2)$$

Carrying out the differentiation and solving equations (1) and (2) for a and b yields:

$$a = \frac{\sum_{i=1}^N C_i \sum_{i=1}^N E_i - N \sum_{i=1}^N C_i E_i}{(\sum_{i=1}^N C_i)^2 - N \sum_{i=1}^N C_i^2}$$

$$b = \frac{\sum_{i=1}^N C_i \sum_{i=1}^N C_i E_i - \sum_{i=1}^N C_i^2 \sum_{i=1}^N E_i}{(\sum_{i=1}^N C_i)^2 - N \sum_{i=1}^N C_i^2}$$

R^2 Statistic

R^2 is a measure of how well the fit function follows the trend in the data. $0 \leq R^2 \leq 1$.

$$R^2 = 1 - \frac{\sum_{i=1}^N (E_i - F(C_i))^2}{\sum_{i=1}^N (E_i - E_m)^2}$$

E_m is the average of the E_i values

When $R^2 \approx 1$ the fit function follows the trend of the data.

Calculations of a , b and R^2 are computerized by a program written in QBasic language.

VI. Energy calibration for energy full range of 1MeV

The energy calibration is performed with independent sources (I-131 then Cs-137) that have different gamma ray emitters. As the most important peaks of these two sources should appear at respectively 284.305keV; 364.489keV; 636.989keV for I-131 and 661.657keV for Cs-137, these two sources are better for energy calibration at full range of 1MeV. The following figure shows the setup relating to the energy full range of about 1MeV and the different peak positions of I-131 and Cs-137 relatively. Five spectra series are measured for each source and mean values are used for energy calibration.

Σ Setup summary			
MCA		Detector high voltage	
Channels:	1024	High voltage (Volt):	+ 1400
Energy threshold (%):	2	HV inhibit mode:	unused
LLD:	0	Preamplifier power supply	
ULD:	991	+12 V:	on
ADC input:	Amplifier	-12 V:	on
Amplifier		+24 V:	on
Coarse gain:	200	-24 V:	on
Fine gain:	1.0655	Stabilization	
Shaping time (μsec):	low	Stabilization off	
Input polarity:	pos	Presets	
Pile up rejection:	on	Choice:	Live Time (sec)
PZC:	360	Value:	300
		ROI	

Fig.4 Setup summary of all measured spectra

The channel containing the peak centroid is used by the software WinSPECi to determine the curve for keV/channel (energy calibration). The peak centroid is the geometric centre of a peak calculated as follows:

$$Centroid = \frac{\sum C_i * i}{\sum C_i}$$

Where C_i is the content of the channel i

Five spectra of I-131 are measured and the mean values as well as the standard deviations of peak centroid positions are shown in the table below.

	channel centroid ROI=264-292	channel centroid ROI=302-378	channel centroid ROI=614-650
Mean values	282.533	362.11	633.0
Standard deviation	0.007	0.01	0.2

Table 1. Identification of I-131 peaks positions for energy calibration

The same spectra measurement process for Cs-137: Five spectra are measured and the mean values as well as the standard deviations of peak centroid positions are shown in the table below.

	channel centroid ROI=642-672
Mean values	658.1
Standard deviation	0.3

Table 2. Identification of Cs-137 peak position for energy calibration

The linear fitting curve coefficients a and b as well as the R^2 are obtained by least squares fit method and using the mean values of peak centroid positions as follows:

I-131: 284.305keV / 282.533 Ch

364.489keV / 362.110 Ch

636.989keV / 633.000 Ch

Cs-137: 661.657keV / 658.100 Ch

This gives:

$a = 1.005\text{keV/Ch}$, $b = 0.381\text{keV}$, and $R^2 = 0.999$

$R^2 \approx 1$ means that the fit function follows the trend of the data.

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C:\ Invite de commandes - qbasic/QBASIC.EXE
Energy calibration calculation for gamma spectra by LPNPE Lab.
-----
How many peaks to use for fitting? 4
Input channel N°
C< 1 >=? 282.533
C< 2 >=? 362.11
C< 3 >=? 633
C< 4 >=? 658.1
Input Energy (keV)
E< 1 >=? 284.305
E< 2 >=? 364.489
E< 3 >=? 636.989
E< 4 >=? 661.657

Results:
-----
a= 1.005256
b= .3805585
R2= .9999993

Energy calibration equation: \ E(keV)= 1.005256 (keV/Ch)*C + .3805585 (keV)\
Good result!
Appuyez sur une touche pour continuer
  
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Fig. 5 Computerized energy calibration equation

The energy calibration curve is shown in the following figure.

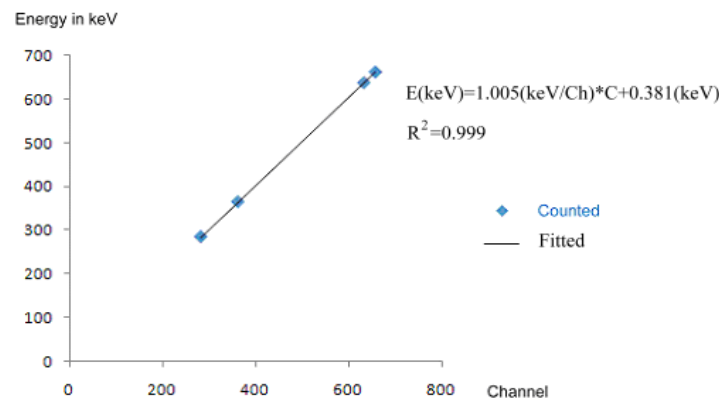


Fig. 6 Energy calibration curve

VII. Test of the energy calibration equation on a sources mixture

Cs-137 and I-131 are placed side by side and in front of the detector. The corresponding spectra are shown in the following figures. These figures present one spectrum from the five spectra of the series of measurements: the first one shows one example of peak position (364keV peak where the cursor is placed) of the I-131 after energy calibration while the second one shows the positions of the four peaks of I-131 and Cs-137 together.

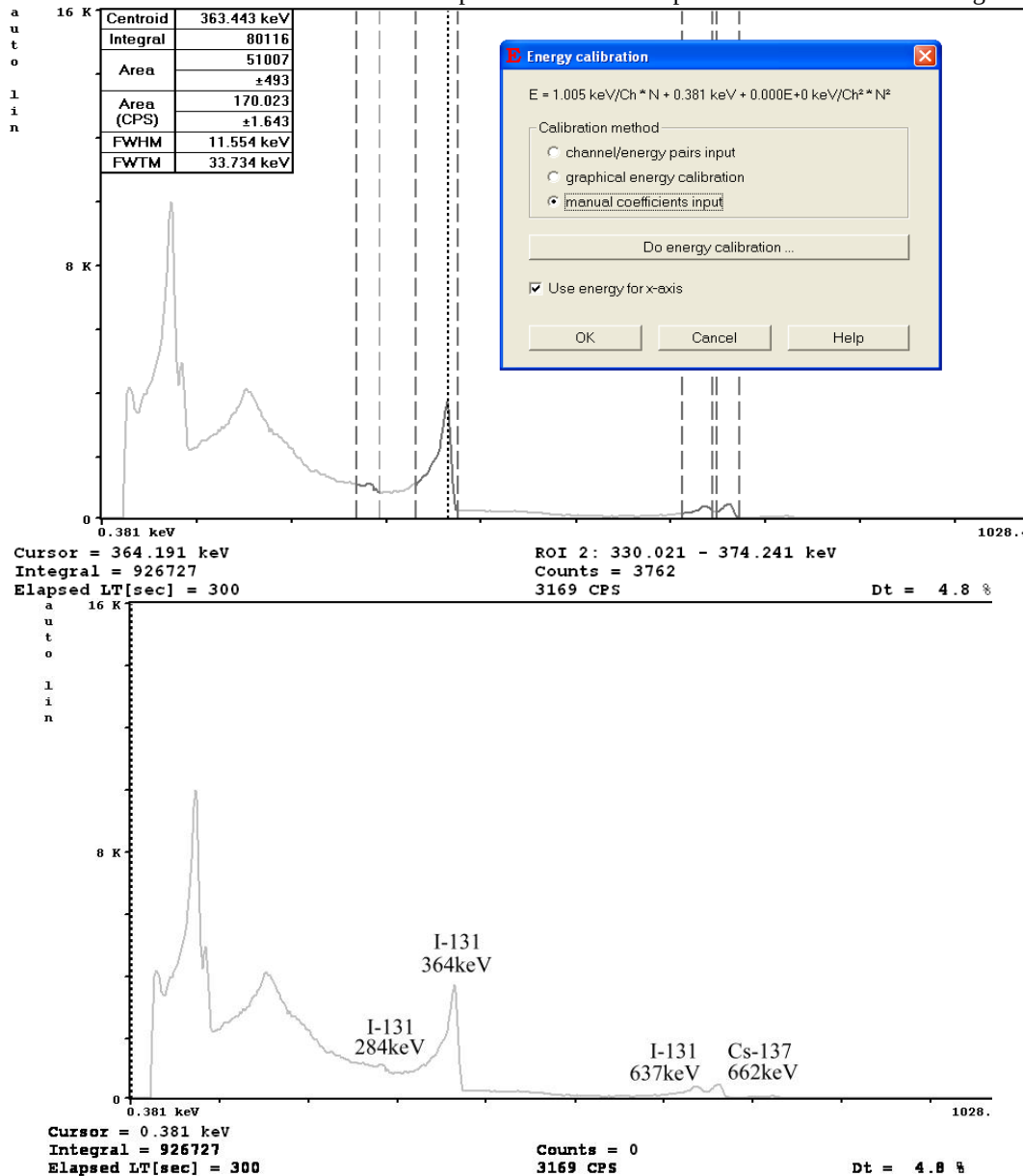


Fig.7 I-131+Cs137 spectrum

IX. Interpretations

- All measurements are performed with the same parameters (detector high voltage, number of channels, Live Time, coarse gain, fine gain, etc.) so that spectra could be compared each other.
- Cs-137 and I-131 spectra are measured separately for peak centroid positions identification and energy calibration. Results (tables 1 and 2) show that peaks are placed around expected positions: indeed, the energy full range is pre-defined as to be equal to about 1MeV for the chosen parameters setup, therefore the channel number which is quite close to the energy value is in accordance with the slope of the energy calibration curve which is close to 1keV/channel. Besides, tables 1 and 2 show that the variation of peaks positions values (from five series of spectra measurements) from one spectrum to another is not meaningful (low values of standard deviation).
- For testing the method, the energy calibration equation is used for the energy calibration of spectra from Cs-137 and I-131 placed side by side and all the four peaks are placed around the expected channels (Fig.7).
- $R^2 = 0.999 \approx 1$ means that the fit function follows the trend of the data.

X. Conclusion

It is verified that the energy calibration is accurate over the energy full range and for values interpolated from the curve. The energy calibration method is satisfying and will be used in the LPNPE Lab. As the Lab has not yet a standard source with known activity for efficiency calibration, the procurement of such standard is imperative for the interpretation of spectrum in terms of activity (quantify radioactive nuclide).

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