A generic isotope identification approach for nuclear instrumentation

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***Abstract*— Isotope identification is generally done from spectra from high intrinsic resolution such as germanium. A lot of approaches are proposed in the literature. Most of them are not efficient with poor energy resolution detectors such as non-loaded scintillators. The proposed approach is a new isotope identification principle to deal with the overall range of nuclear detectors. The proposed method allows the identification of isotopes using detectors with poor intrinsic resolution and lower counting than the existing techniques.**

***Index Terms*— Nuclear measurements, Nuclear electronics, gamma rays, Spectroscopy, System identification, Energy resolution**

I. Introduction

THE technic is presented here for the detector which has the worthiest energy spectra resolution, the plastic scintillator

The non-loaded plastic scintillators are not usually used to perform isotope identification due to the lack of photopeaks effect. This paper presents a new method to identify an isotope with the poor energy spectrum provided from a plastic scintillator. This method, based on a vectors distance analysis, implemented on RPM (Radioactive Portal Monitor) and gives promising results. Section 0 presents the related works on isotope identification with plastic scintillators. In section **Error! Reference source not found.**, a new method to identify isotope is described and results are discussed in section IV. The section V concludes the paper

II. Related Works

The conventional methods of treatment for isotope identification do not provide satisfying results using information contained in poor resolution energy spectra. However, several techniques have been developed to solve this issue. The most widely used technique is to divide the spectrum into multiple windows of interest. This technique is commonly known as "energy windowing". The Compton edge in the energy spectrum is relatively large and does not allow deducing the energy of the incident gamma. Using window may allow implementing discrimination criteria. The discrimination process defines a set of windows in the spectrum, then calculates the ratio between the different windows of the spectrum to classify and identify isotope [1]. However, these techniques are relatively limited and do not allow to identifying the sources.

Another set of methods is based on the deconvolution of the spectrum [2], [3]. Deconvolution allows considering the shortage of the detectors and canceling their effects to produce a spectrum close to an incident energy spectrum. To categorize or identify an isotope, the isotope must be present in an identification library. This library contains the names and information of all the isotopes to be identified. Description of an isotope generally includes the components of energy, their proportions and their resolutions for a kind of detector. There are as many sensors as libraries. The parameters for the implementation of the identification and categorization are determined based on the list of a gamma emitting isotope peaks weighted by the detector efficiency of the energy peaks. The peak broadening is simulated by a Gaussian for each gamma emission depends on the energy resolution of the detector and peaks. If no match is found after spread spectrum, peaks are combined according to their percentage transmission. The peaks with a percentage of less than 1% are removed as their influence is limited. The combination process is an iterative process; priority is always given to the two closest peaks for given spectrum lines. In this way, several lines from the same region will be combined. The process also compensates the effect of the Compton scattering taking account Compton edge when they appear in the same area that the energy of low-energy photopeak. This allows predicting recovery between photopeaks and the Compton edge. The result provides a small relevant library for plastic scintillators taking into account their poor energy resolution and the recovery of photo-peaks with the front Compton. The main drawback of this method is that ghost peaks may appear in the deconvolution spectrum that do not correspond to any physical issue. In this case, the identification process must be performed manually by the operator who must remove ghost peaks which do not correspond to physical. Moreover, the counting statistics in the spectrum must be high before obtaining an effective identification.

The last group of methods uses neural networks to realize a learning sample spectrum given and the network can then match a current spectrum to a spectrum from its base and learning and identify isotopes [4], [5], [6]. These techniques are based on learning a system to recognize a spectrum as a known spectrum or as a spectrum which is not yet been processed. They are based on a set of known and accurate

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spectrum. When the learning phase is complete, the system can analyze new spectra by determining whether it contains predefined patterns and if it can be classified in relation to already known spectra. The system is easily integrated and relatively efficient. However, to obtain the correct results, you must perform a large number of reference spectra in the learning phase. Neural networks are also strongly dependent on simulated during the learning phase models. In addition, a spectrum with an unknown shape cannot be classified, that can be the case when the sources are shielded or masked.

III. Identification Approach

In the proposed approach, the identification is performed on a distance from current measured isotope with a set of isotope reference sored in a database. Each spectrum is shown as a vector in the multidimensional space with a number of dimensions equal to the number of channels in the spectrum. The coordinates of a vector is the number of counts in each channel. As the statistics of each spectrum may be different according to their conditions of acquisition, all spectra should be standardized so that the ends of all the vectors are on a multidimensional sphere as shown in Fig. 1. The normalization of the spectrum is based on the formula described in Equation 1

$$c'(n) = \frac{c(n)}{\sqrt{\sum_{i=0}^{N} c(i)^2}} \qquad (1)$$

- C (n) - the number of strokes in the channels for the n input spectrum,
- C '(n), the new number of counts in the standard spectrum,
- N - the number of channels in the spectrum,

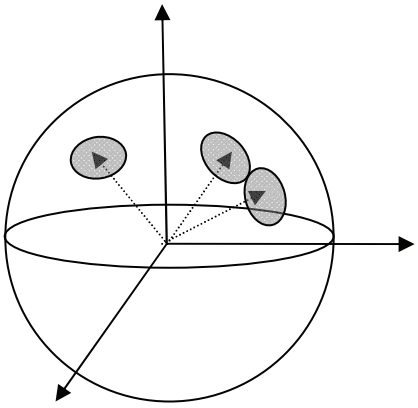

Fig. 1. Vectors normalization of energy spectra.

Statistical fluctuation of each embodiment of spectrum for the same isotope has an influence on the direction of the vector. This effect is modeled by an ellipse at the end of each vector that corresponds to changes of direction of the vectors due to statistical fluctuations.

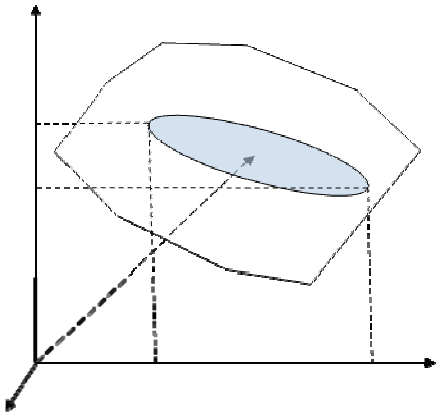

Fig. 2. Statistical effect on vector.

Thus the distance between the ends of the vectors can be used to characterize the proximity of the spectra from each other. The width of the Compton edge, appears in the spectrum depends on the energy of the isotope. This ridge is wider for higher energies than at low energies. The coordinates of the vectors in the high-energy zone are more volatile than the low energy, the surface of the ellipses will, in this case, more important.

Covering areas of statistical fluctuations in the area of high energy may be offset by additional measures to increase the statistics. Another process has been implemented to avoid or reduce the effects of bad statistic for the unknown being analyzed spectra. The peak position of the Compton spectra is different for each of the main isotope depends and energies emitted. To reduce the fluctuation of the vector coordinates for axes corresponding to high energies (high number of channels) must use the average count in a window. The width of this window should be equal to the width of the main peak of the Compton energy in the spectrum.

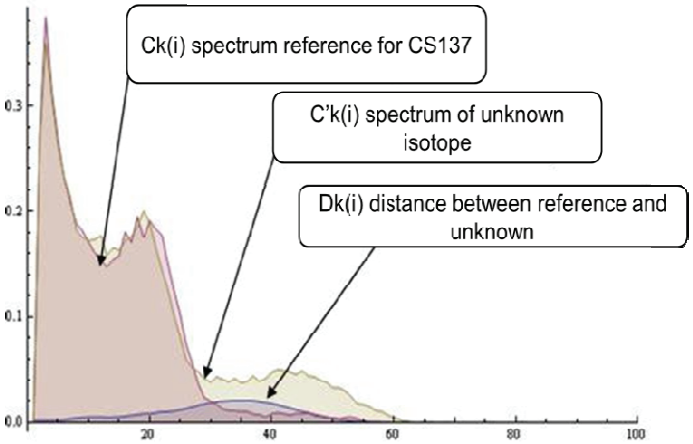

Fig. 3. Distance from a unknown isotope to a ^{137}Cs source, spectral representation.

To make the identification, the unknown spectrum being acquired is represented in normalized vector form and is then compared with standard spectra of isotopes of reference vectors. Each pair of spectra (the unknown spectrum test and the reference spectrum), the window used to calculate the

average count value must be adjusted to match the width of the Compton peak for primary energy in the reference spectrum. Then the comparison of the spectra is to calculate the geometric distance between the spectrum (vector) and the normalized unknown spectrum (vector) of the reference standard by applying specific window corresponding to the width of each reference spectrum. The geometric distance is calculated by the formula described in Equation (2).

$$D_k(n) = \sum_{i=n}^{n+L(k)} (C'(i) - C'_k(i))^2 \qquad (2)$$

- C'(i) : the number of shots into the unknown normalized spectrum,
- $C'_k(i)$: the number of counts in the spectrum of standard reference,
- L(k) : the width of the window for the reference spectrum,
- k : the number of the reference spectrum,
- $D_k(n)$: the distance between the vectors (spectra) in the n-channel.

$D_k(n)$ is an array containing the values in the window distances L(k) between the unknown spectrum and the reference spectrum k. The same procedure must be used for all reference spectra k taking into account the width of the windows L (k). Figure 3 shows the comparison of the unknown spectrum with the reference spectrum of ^{137}Cs.

Calculated for each one Dk(n) seeks the maximum value MaxDk. These values represent the degree of remoteness of the unknown spectrum compared to reference spectra. So the higher the MaxDk value is, the greater the unknown spectrum is different from the reference spectrum. The calculated values MaxDk can serve as a measure of the combining of an unknown spectrum and a reference spectrum. The conditions for acquiring spectra (gain of the measurement chain) must be the same for all reference spectra and for the spectrum to be tested. The quality detection of the isotopes depends on the statistics in the spectrum. Also, the increase of statistical improves identification process of isotopes. Consider a ^{137}Cs source; its vector is compared to the reference vectors that are:

- background noted BckGd,
- ^{137}Cs,
- ^{60}Co,
- ^{22}Na,

The distance between measured vectors and ^{137}Cs reference vector is the smallest. The suspected isotope is ^{137}Cs in the example presents in Table I.

TABLE I. MAX DK FOR A ^{137}CS ISOTOPE

Set of reference vectors	Max Dk value between reference vectors and vector from measured ^{137}Cs isotope
BckGd	0.2
^{137}Cs	0.02
^{60}Co	0.042
^{22}Na	0.084

One may use more complicated tests to perform the choice of isotope detected. For example, based on the value chart MDL_k values can be created as described in equation (3).

$$MDL_k = \frac{1}{0.001 + MaxD_k} \qquad (3)$$

The values in this array can be compared to a TD threshold above which it is consider that the isotope is present, this threshold may be determined by the equation (4).

$$TD = \frac{Max(MDL_k)}{2} \qquad (4)$$

Consider the same experimental conditions as above, with this criterion, the representation change as shown in table II.

TABLE II. MDL_k FOR A 137CS ISOTOPE

Set of reference vectors	MDL_k value between reference vectors and vector from measured 137Cs isotope
BckGd	4.97
^{137}Cs	47.6
^{60}Co	23.25
^{22}Na	11.76

IV. RESULTS

The following configuration is used to perform spectra acquisition. A set of four EJ 200 plastic scintillators and the DAQs system as described in **Error! Reference source not found.** are used. This setting answers to sensitivity of RMP applications. The acquisition system digitizes the signal provided by photomultipliers . A Graphical Unit Interface, Fig. 5, has been developed to show the identification result. The user can select a list of isotope references that can be compared to the unknown source to identify.

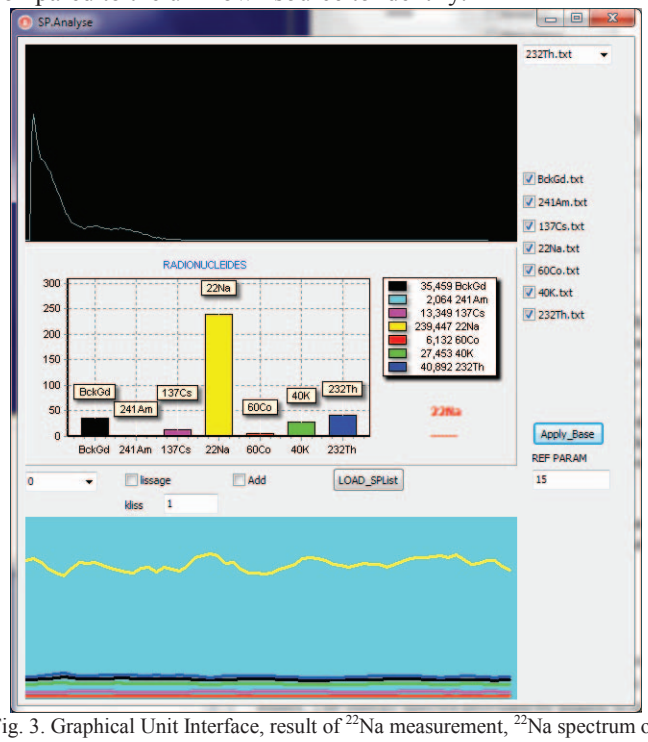

Fig. 3. Graphical Unit Interface, result of ^{22}Na measurement, ^{22}Na spectrum on the top window, and representation of identification analysis on the middle and bottom windows, ^{22}Na in yellow

A. *Static sources identification*

To validate the approach, a record data base of background and 6 isotopes, ^{241}Am, ^{132}Cs, ^{22}Na, ^{60}Co, ^{232}Th, ^{40}K. All spectra are defined into normalized vectors. First test sets are done to evaluate the sensitivity of the new approach with different kinds of energy emission. The tests are realized in laboratory condition.

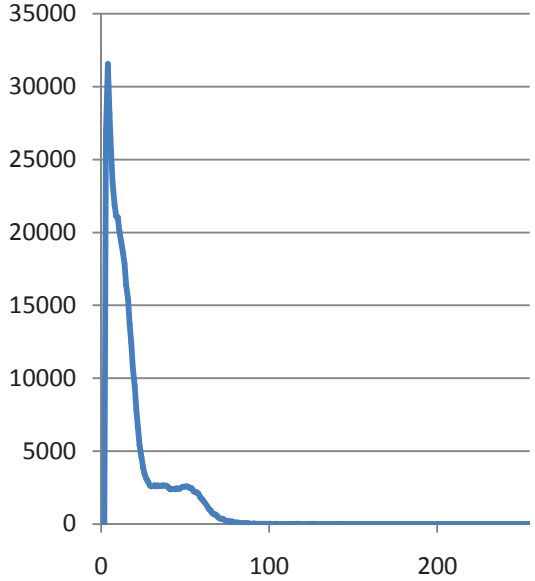

Fig. 5. Energy spectrum for 22Na.

The background counting rate measured during the test campaign is around 3600 cps. The Table III gives the lower limit of the counting rate that enable the system to identify an isotope.

TABLE III STATIC RESULTS

Unknown isotope	Isotope counting rate (cps)	Isotope/background Counting ratio
^{241}Am	4611	1.28
^{137}Cs	11167	3.1
^{22}Na	10389	2.9
^{60}Co	12147	3.4
^{40}K	--	--
^{232}Th	11534	3.2

Results show that the system is able to identify an isotope from a #1.3 source/background ratio for low energy emission isotope such as ^{241}Am to a 3 source/background ratio for high energy emission isotope like ^{137} Cs. The available quantity of ^{40}K creates only 10000 cps, the system cannot identify it. The activity identification limit depends of the background counting rate. The system can be easily improved by reducing the background counting.

B. *Identification of unknown isotope in movement*

To evaluate the dynamic response of the system, an experimental setting is created to move the source in front of the scintillator with a constant speed. Results described in table II shows the ability to identify a mobile isotope. Speeds 1.2 and 2.2 correspond to RPM standard for pedestrian and vehicle [8] and [9]. The dynamic limit is around 2.5 m/s and depends of the activity vs solid angle.

V. CONCLUSION

The proposed method allows the identification of isotopes using poor resolution detectors and a low statistical count. This method can be used to identify mobile sources. The next step is to extend the limits of mixed sources that the method is able to identify. This method can be used in a large amount of applications that use different kind of sensors like CzT, LaBr and others detectors. Promising results for a usage case with CzT are described in [10]. It adds spectroscopy and identification solutions to complete many existing systems that achieve only detection.

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