ANALYSIS OF HIGH ENERGY GAMMA RAY SPECTRA USING WHOLE SPECTRUM PROCESSING

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1. Introduction

The Peak Net Area (PNA) method is the world-wide accepted technique for analysis of gamma-ray spectra [1]. It is based on the net area calculation of the full energy peak, therefore, it takes into account only a fraction of measured gamma-ray spectrum. On the other hand, the Whole Spectrum Processing (WSP) approach to the gamma analysis makes possible to use entire information being in the spectrum [2, 3, 4, 5]. This significantly raises efficiency and improves energy resolution of the analysis. A principal step for the WSP application is building up the suitable response operator. Problems are put in an appearance when suitable standard calibration sources are unavailable. It may be occurred in the case of large volume samples and/or in the analysis of high energy range. Combined experimental and mathematical calibration may be a suitable solution.

In the area of NPP, one must discriminate between two different modes of analysis of the gamma-ray fields. One is used in scheduled down time reactor phase and another is in full power reactor phase. Spectra of gamma-ray fields are different during both phases. Gamma-ray sources at the down time phase are with energy up to 2 MeV and at the full power phase are up to 10 MeV.

1.1. Whole spectrum processing

The whole spectrum processing (WSP) model is based on the response operator which is mathematically formulated by a vector model

$$d = K_c.q \tag{1}$$

where d is a column vector of the measured physical spectrum, q is a column vector of the real incident spectrum, and K_c is a matrix of the complete response operator with dimension that corresponds to the length of physical and incident spectra [6].

As an aspect of statistical fluctuation in the gamma-ray spectra, a solution of (1) cannot be found by direct computation of the vector q (for example by direct inversion of K_c), and indirect iterative computational methods must be employed [6]. These methods are based on minimizing the residuum between physical and model spectra according to the vector q. The model fitting methods can be classified into two main groups:

a) the least squares (LS) approach, and
b) the maximum likelihood (ML) approach.

Then LS and ML residual functions may be expressed as:

$$\Delta_{LS} = \left(d - K_c.q\right)^2, \text{ and } \Delta_{ML} = \log\left(d\right) - \log\left(K_c.q\right). \tag{2}$$

Using the residual function of LS or ML ($\Delta = \Delta_{LS}$ or Δ_{ML}), the gradient method yields an iteration step for q that may by formulated as $\Delta q = -w.grad(\Delta)$, where the symbol

„*grad*“ represents derivates of the residual function according to all elements in the vector of *q* (gradient) and **w** is a length of the iteration step [6].

1.2. Response matrix operator Kc

Only few components of K_c matrix could be obtained by measured. Rest of the responses cold be supplemented to the matrix using Scaling Confirmatory Factor Analysis (SCFA) or by simulation of detector response. SCFA may be used only when appropriate calibration standard sources are available. In energy range from 2 to 10 MeV are just few appropriate sources, therefore have to be used simulation.

2. Response calculations

Te goal was to create universal response matrix K_c for detector NaI(Tl) 2“ x 2“, therefore was created an model of this detector in MCNP code. Figure 1 show used model and its dimensions. Materials are described in table 1.

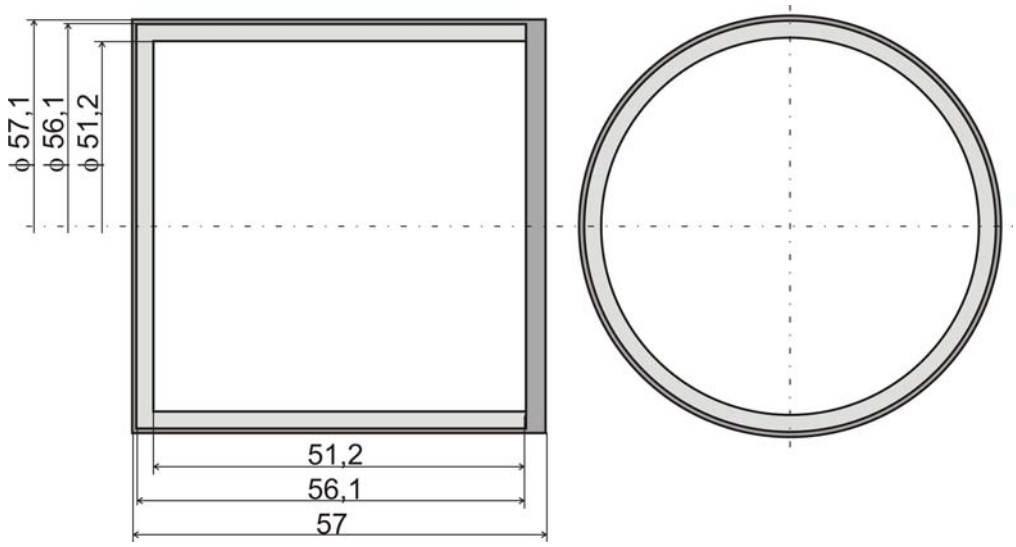

Fig. 1 *Model of detector.*

Tab. 1. *Material of detector model***.**

component	material	composition	density [g cm^{-3}]
scintillation crystal	NaI	Na:I (1:1)	3,67
reflector	MgO	Mg:O (1:1)	0,338
vessel	aluminium	Al	2,7
surround	air	N:O (4:1)	0,0129

Response of the detector to a mono-energetic source 10 cm from the detector at his axis was calculated. It was calculated for energies from 10 keV to 10 MeV with step 1 keV. The model was analogue. Tally F8 (detector tally) was used to calculate detector response in active area and it was divided in to energetic intervals with width 1 keV. Figure 2 shows the columns of matrix simulated in MCNP code (K_{MCNP}) with step 1 MeV. As we can see there, the calculation considers only interaction of the gamma rays with matter of detector. Peak energy broadening caused by flash collection and amplification in photo-multiplier tube wasn’t considered.

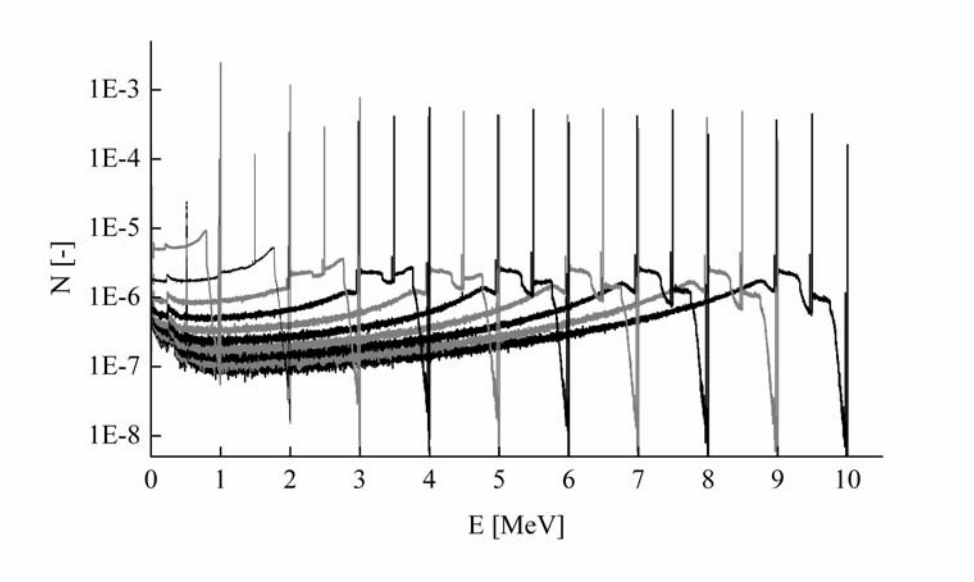

Fig. 2. *Response operator matrix calculated by MCNP code*.

Complete response operator matrix K_c could be obtained by multiplication of the K_{MCNP} matrix with matrix of peak broadening M_{FWHM}.

$$K_c = M_{FWHM} * K_{MCNP} \tag{3}$$

Rows of M_{FWHM} are Gaussian peaks with unit surface under the curve while the position is corresponding to the row ergo energy and the width of peak is corresponding to *FWHM=f(E)* function. This function could by little bit different for different detectors, therefore was made calibration measurements. Figure 3 shows FWHM at measured sources and curve fitted to these points.

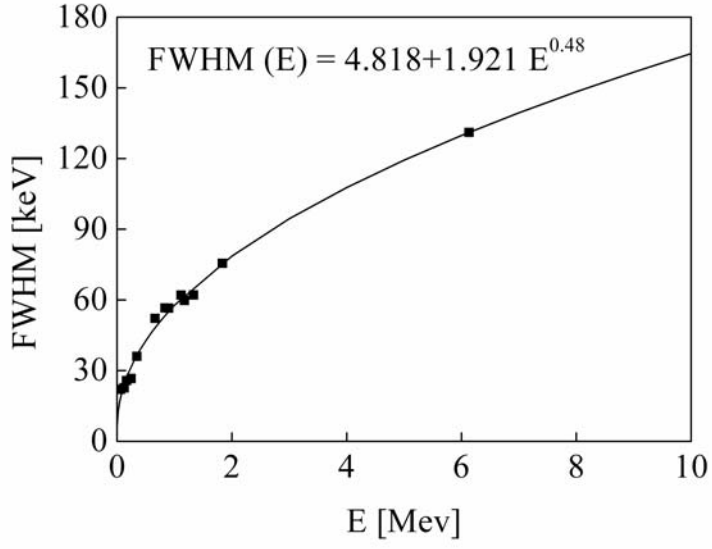

Fig. 3. *FWHM=f(E)*

Values of M_{FWHM} matrix could by formulated as follows:

$$M_{FWHM} = \frac{2.\sqrt[2]{\ln(2)}}{\sqrt[2]{\pi}FWHM(C)} e^{-\frac{4.\ln(2).(R-C)^2}{(FWHM(C))^2}} \quad (4)$$

where, R (row) and C(column) are coordinates in matrix and both ar corresponding to energy. Complete response operator matrix K_c showed figure 4.

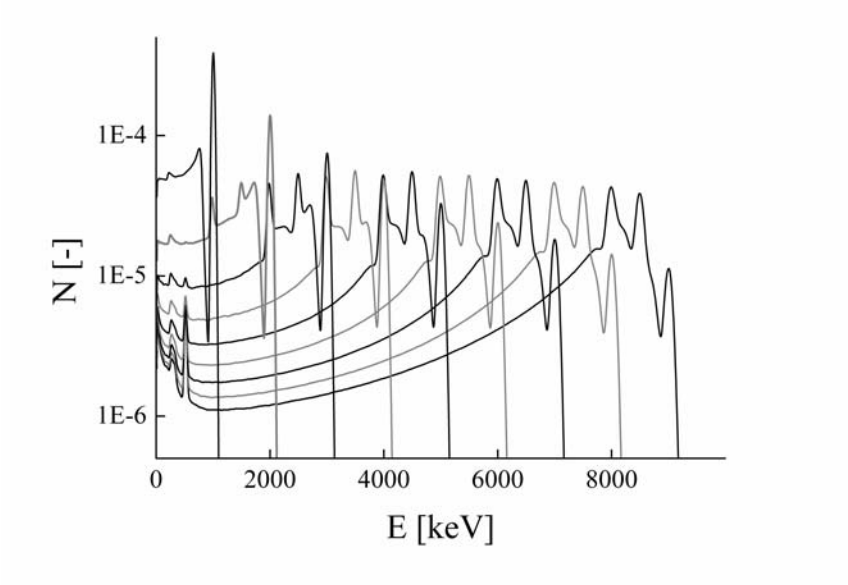

Fig. 4. *Complete response operator matrix K_c*

Conclusion

This paper described new method of gamma ray analysis using whole spectrum processing. Necessary condition for application of this method is existence of response matrix operator in appropriate energy range. Gamma rays emitted around nuclear reactor under operation could reach high energy. Therefore have to by used energy range up to 10 MeV. In this work is described method of creation such matrix for scintillation detector (NaI(Tl) 2“x2“) using simulation of responses on mono-energetic rays in MCNP code. This matrix was created and used in analyses of spectra measured in Slovak nuclear power plant Mochovce[7].

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References:

[1] K. Debertin, R. G Helmer.: Gamma- and X-Ray Spectrometry with Semiconductor Detectors. Amsterdam_ North Holond (1998).

[2] Š. Krnáč, P. Povinec.*: Journal of Radioanalytical and Nuclear Chemistry*, **204** (1) 57, (1996).

[3] Š.Krnáč, P Ragan: *Radiation Protection Dosimetry* **58** (3) 217,(1995).

[4] Š. Krnáč, P. Povinec.*: Applied Radiation and Isotopes*, **47** (9-1) 905, (1996).

[5] Š. Krnáč, P. Povinec., R P.agan: *Spectrometry. Journal of Radioanalytical and Nuclear Chemistry*, **209** (2) (1996).

[6] XXX Days of Radiation Protection., 10.-14.11.2008 Liptovský Ján, Slovak Republic, p. 103_(2008), XXXIII. dni radiačnej ochrany, 7.-11.11.2011 Vyhne Slovak Republic p. 89 (2008)