The development of $LaBr_3$ detection system which can realize rapid identification and analysis of radionuclides

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1. Background and overview of the research work

It is a coordinated research project called advancing radiation detection equipment for detecting nuclear and other radioactive material out of regulatory control.

This paper gives an overview of the development of $LaBr_3$ detection system which can realize rapid identification and analysis of radionuclides under simplified user conditions.

The analysis method in the rapid identification of radionuclides is highlighted.

2. Research objectives and key technologies

2.1. Research objective

Regarding the application scene of repaid measurement and analysis of nuclear and other radioactive materials out of regulatory control, a set of compact portable $LaBr_3$ detection system is established. With the function of showing result, storing the data, transmitting and sharing data. It integrates the gamma spectrum analysis and nuclide identification algorithm to achieve the rapid identification of radionuclides. For some industrial radioactive sources, such as ^{60}Co and ^{137}Cs, the recognition time is less than one minute when the radiation dose of radioactive sources exceeds the background level by two times.

2.2. Key technologies

2.2.1 Specific analysis algorithm of γ spectrum for $LaBr_3$ detector

The energy self-calibration technology is developed which is based on $LaBr_3$ self-emission characteristic γ rays. The algorithm to identify and separate the overlapped peak is also researched. By the method of efficiency calibration without source and built-in parameters with typical structure, the system can quickly calculate the volume source efficiency achieving semi-quantitative analysis of radioactivity.

2.2.2 Rapid identification of radionuclide technology

Based on the special spectrum analysis, the sequential Bayesian method is used to analyse the characteristic gamma rays and identify the nuclide, which improves rate and speed of the identification.

3. Technical approach

3.1. The $LaBr_3$ scintillator detector

The $LaBr_3$ scintillator detector is a device that uses $LaBr_3$ crystal to generate fluorescence after ionization and excitation when it acts on nuclear radiation, and the fluorescence is collected and analysed for nuclear radiation detection. The scintillator detector is generally composed of a scintillator, a photomultiplier tube and a preamplifier. It also includes detector housing, optical cable, and an optical coupling device.

The ideal radiation detection performance of $LaBr_3$ scintillator is due to its good physical properties including high material density, higher light yield under the same radiation conditions, and light die-away time of only 35 ns. Its luminosity fluctuation in the range of 0-50 °C is less than 1%. The physical parameters of $LaBr_3$ and other scintillating materials are shown in the table below, and the data in the table can reflect its performance advantages.

Physical characteristic table of scintillate materials used to detect gamma Ray at room temperature

Materials	density/g.cm^{-3}	Light production /n·keV^{-1}	Decaying time/ns	Maximum wavelength of emission /nm
$LaBr_3$(Ce)	5.1	65	35	380
NaI(Tl)	3.7	39	250	415
CsI(Tl)	4.5	60	800	550
LYSO(Ce)	7.1	30	42	420
BGO	7.1	9	300	480

3.2. Optimized design of $LaBr_3$ Detector structure

The integrated $LaBr_3$ detector uses a scintillator material with a size of Φ5cm×7.5cm. It is coupled with a photomultiplier tube and encapsulated in a metal cavity with both electromagnetic shielding and collimator functions. The system integrates a handheld computer (PDA) as a data collection and processing unit. It also integrated wireless communication and 4G digital communication module for data remote transmission and sharing management. Users can synchronize, view, and check the data in the application software (APP) supported by mobile phones or other intelligent terminals.

Design of $LaBr_3$ detector

The system operation and control software has the added function of spectrum stabilization, which can automatically adjust the amplification gain of the electronic within a certain range, which can effectively prevent the drift of the spectrum characteristics of the $LaBr_3$ detector with the change of the ambient temperature. The main technical indicators of the products are shown in the table below.

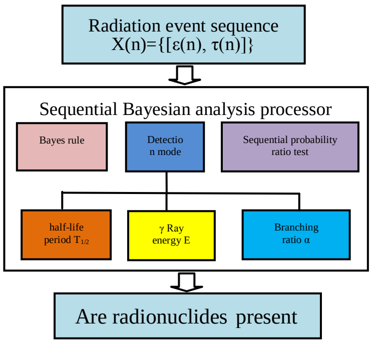
The Parameters of $LaBr_3$ (Ce) detector

Size	D50mm×75mm	Photon conversion efficiency	~62000 photon / MeV
Energy resolution	2.89%@662keV	Energy nonlinearity	<1.0%@60keV~1.3MeV
Output Range	0.01-2.0V	Output Temperature Coefficient	<0.1% / ℃(-10~50℃)
Output signal waveform		Positive exponential Pulse, back edge time constant ζ=1μs	

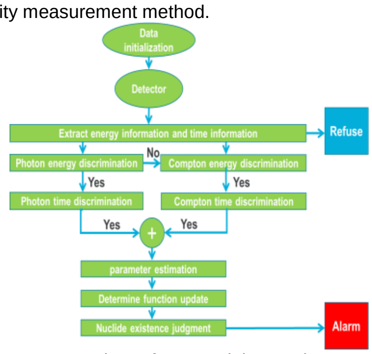
4. Analysis method

4.1. Sequential Bayesian analysis method

Sequential Bayesian analysis method is a new method of radiation information processing and analysis, which provides a rapid and reliable detection and identification of radioactive materials, and can greatly improve the practicability of existing detection systems. This method combines the Bayesian rule and the sequential probability ratio test theory, and uses the information of half-life, characteristic Gamma Ray Energy and branch ratio of the radionuclide to determine the existence of radionuclide. In signal processing mode, it uses single event parallel / distributed processing mode to sort, evaluate and judge the received data one by one, and make the best use of the useful information received. It breaks through the technical bottleneck of low lower limit and long time consuming of traditional radioactivity measurement method.



The problem of interest

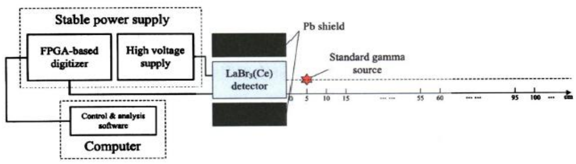


Procedure of sequential Bayesian analysis approach

4.2. Experimental study of sequential Bayesian analysis method

The technical specifications of Bayesian data acquisition system are summarized as follows:

- 1 GHz sampling rate, 12 bits sampling accuracy,
- input signal range of ±5V, input impedance 50Ω,
- Real-time acquisition of amplitude and time information of signal.



Experimental set-up Configuration of the sequential Bayesian analysis system

The maximum detection distance (MDD) of the $LaBr_3$ detection system for ^{137}Cs, ^{60}Co, ^{133}Ba and ^{152}Eu four radioactive sources is measured through experiments, and the equivalent minimum detectable activity (EMDA) of the detection system for the four radionuclides is evaluated. The results are as follows:

Evaluation on detection limitation of system

Radionuclides	Activity	Detection time/s	MDD/cm	EMDA/Bq
^{137}Cs	1.592×10^5	0.071-0.476	125	15.9
^{60}Co	1.857×10^4	0.163-1.653	78	4.76
^{133}Ba	6.871×10^4	0.158-1.231	100	10.73
^{152}Eu	9.719×10^4	0.151-0.991	79	24.31

5. Conclusions and Acknowledgements

In summary, the sequential Bayesian analysis approach for rapid detection and identification of radionuclides was systematically studied, and its feasibility was completely verified according to the experiments.