Academic Journal of Engineering and Technology Science
ISSN 2616-5767 Vol.3, Issue 4: 170-178, DOI: 10.25236/AJETS.2020.030416

The Overview of $LaBr_3$:Ce Detector Application

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ABSTRACT. *$LaBr_3$:Ce detector is widely used in the field of radiation detection due to its many advantages. This article summarizes the relevant achievements of researchers at home and abroad on the application of $LaBr_3$:Ce detector, and summarizes the application of $LaBr_3$:Ce detector from the aspects: radioactivity measurement, nuclear safety and nuclear accident monitoring, and particle detection. On this basis, the research trend and development direction of $LaBr_3$:Ce detector in airborne gamma spectrometry measurement are proposed.*

KEYWORDS: *$LaBr_3$:Ce detector, radioactivity measurement, nuclear safety and nuclear accident monitoring, particle detection*

1. Introduction

Since Van Loef EVD and others first launched $LaBr_3$:Ce crystals in the world in 2001 [1], $LaBr_3$:Ce crystals have been widely used in the field of radiation detection after research by many scholars. Various types of $LaBr_3$:Ce detectors have been successively produced. $LaBr_3$:Ce detector has higher energy resolution (662KeV for ^{137}Cs, <3%); light output is high and stable (~ 61000 photons/MeV for 662KeV γ rays) [2]; The decay time is short (~20ns), showing good time characteristics; great linear response capability (non-linearity < 7% in the range of 60-1300KeV) [3]. These unique advantages make the $LaBr_3$:Ce detector widely used in environmental radiation monitoring, mineral exploration, low energy physics, medical imaging, etc.

However, due to the presence of the radionuclides ^{138}La and ^{227}Ac and their progeny in the detection crystal, the inherent background of the $LaBr_3$:Ce detector has increased. ^{138}La spontaneously emits X-rays, γ-rays and β-rays, forming individual energy peaks or superimposed peaks in the background gamma energy spectrum of the $LaBr_3$:Ce detector. Due to the manufacturing process, ^{227}Ac will produce a series of α decay, forming a continuous spectrum between 1.6MeV-2.8MeV in its background gamma energy spectrum [4-6]. The inherent background not only increases the difficulty of the spectral decomposition of the $LaBr_3$:Ce detector gamma spectrum, but also limits its application in low-activity environments. In this paper, novel applications about $LaBr_3$:Ce detector in the world are investigated and reviewed from three aspects: radioactivity measurement, nuclear safety and nuclear accident monitoring, and particle detection.

2. Environmental radioaction monitoring

2.1 Terrestrial radioactivity

In the natural, there are many natural radionuclides in the lithosphere, such as ^{40}K, ^{238}U, ^{232}Th, ^{222}Rn, ^{208}Tl and other radionuclides. Monitoring these radionuclides is helpful for grasping significant information such as mineral distribution and soil composition. $LaBr_3$:Ce detector is favored in ground radioactivity measurement because of its high energy resolution, detection efficiency and portability.

The relevant researchers of Chengdu University of Technology in China measured the gamma energy of each model on the saturation reference model (standard K model, U model, Th model, Mixed model, Background model, etc.) composed of special ores using $LaBr_3$:Ce detector Spectrum. First, they contrastive analyse the energy window analysis method and full spectrum analysis method on the energy spectrum obtained by the $LaBr_3$:Ce detector [5], and discuss the effect of the center of gravity method and the least squares fitting method on the spectral line smoothing [6]. Finally, the effect of the straight line background method, the stepped background method, the parabolic background method, the SNIP method [8] and the Fourier background deduction method [9] are compared to the $LaBr_3$:Ce detector. These researches[7] provides a data reference for the application of $LaBr_3$:Ce detector in the measurement of soil or ground gamma spectrometry. University of Rapai, Nigeria uses an array detection system composed of multiple $LaBr_3$:Ce detectors, combined with γ-γ coincidence detection technology to obtain a better minimum detectable activities(MDAs) for the entire system. The ^{235}U and ^{232}Th in the soil samples were qualitatively and quantitatively analyzed [10]. Belgian Nuclear Research Center applied the $LaBr_3$:Ce detector to the treatment of uranium ore. It used the isotope ratio method to measure the uranium enrichment under the empirical efficiency model with the $LaBr_3$:Ce detector, combining artificial intelligence algorithms with $LaBr_3$: Ce detection system, proposed a cluster analysis method for uranium enrichment determination [11-13].

2.2 Marine radioactivity

In addition to the small amount of radionuclides that exist in the ocean, there are artificial radionuclides that exist due to human activities, such as ^{137}Cs and ^{131}I. The detection of radionuclides in seawater is very important for researcher to master the marine ecological status. The application of NaI(Tl) in marine radioactivity monitoring has been very common. During the application process, it was found that the energy spectrum drift caused by seawater temperature and the instrument's efficiency calibration are two unresolved issues in marine radioactivity monitoring.

In 2011, the Key Laboratory of Particle and Radiography at Tsinghua University in China verified the feasibility of $LaBr_3$:Ce crystals for monitoring artificial radionuclides in seawater through MCNP simulation [14]. Subsequently, the laboratory developed a $LaBr_3$:Ce in-situ gamma spectrometer for marine radioactivity monitoring [15]. They used three known peaks in the $LaBr_3$:Ce detector's inherent background spectrum to overcome the energy spectrum drift problem caused by temperature changes, and used MCNP simulation and two water tank dilute standard sources (^{137}Cs and U_3O_8) to solve the instrument's efficiency calibration. Greatly improved the stability and accuracy of the in-situ gamma spectrometer [16].

2.3 Air radioactivity

Except the large amount of natural radionuclides that already exist in the air, there are artificial radionuclides formed by human activities such as nuclear experiments, nuclear accident leaks, and industrial emissions. The monitoring of related natural radioactive elements in the air can be used to find related minerals, such as the airbrone gamma spectrometry technology. The monitoring of artificial radioactivity can be helpful for early warning of nuclear accidents. The $LaBr_3$:Ce detector is rarely reported because of its high inherent background in airbrone gamma spectroscopy measurement, but because of its high energy resolution and portability, it is very suitable for the field of artificial radionuclides identification.

Around two nuclear power plants in Catalonia, Spain, a gamma-ray scintillation spectrometer based on NaI(Tl) and $LaBr_3$:Ce detectors was used to detect changes in the radioactivity of the air around the nuclear power plant. In 2017, University of Virginie proposed a new energy window technology to improve the influence of ^{222}Rn and its progeny on the energy spectrum of the monitor in the air, and tested it with $LaBr_3$:Ce detector. The reliability of the technology enables the monitor to achieve real-time monitoring of artificial radionuclides ^{131}I and ^{137}Cs in the air [17]. In the same year, Extremadura University replaced the ZnS:Ag scintillation crystals in the LB-BAT9850 monitoring system with $LaBr_3$:Ce crystals and developed a set based on NaI(Tl) and $LaBr_3$: Ce detector has an advanced radioactive air particle monitoring system with two functions —— radioactive warning and monitoring, and it is installed around the Almaraz nuclear power plant, and has achieved great effect[18].

3. Nuclear safety and nuclear emergency monitoring

3.1 Nuclear safety

Nuclear safety includes ensuring the safe operation of nuclear reactors and proper disposal of spent fuel. Due to the high radioactivity of both nuclear reactors and spent fuel, the detectors used must be able to be used normally under the conditions of higher count rates. The researchers have verified the good characteristics of $LaBr_3$:Ce detector under the condition of higher count rate through experiments [19]. According to this result, nuclear engineering teaching at the University of Texas at Austin, USA Laboratory analyzed the changes of $LaBr_3$:Ce detector's timing performance, detection efficiency, energy resolution, signal-to-noise ratio and other parameters under high count rate conditions, indicating that $LaBr_3$:Ce detector can work under the condition of counting rate above 400KHz and is successfully used in the treatment of spent fuel [20]. These provides data for the application of $LaBr_3$:Ce in nuclear safety.

China Naval Engineering University developed a multi-channel gamma spectrometer based on $LaBr_3$:Ce detector for on-site identification and activity monitoring of radionuclides in the reactor and tested the activity monitoring ability of the instrument with ^{137}Cs solution of different concentrations[21]. Idaho National Laboratory and Space Nuclear Research Center combined the deconvolution method to measure the nuclear reactor fuel burn depth with $LaBr_3$:Ce detector[22] to ensure the safe operation of the reactor.

3.2 Emergency monitoring of nuclear accidents

In a nuclear accident, the artificial radionuclides such as ^{131}I, ^{137}Cs, and ^{134}Cs will be emitted in large quantities. Monitoring these artificial radionuclides will help researchers predict and evaluate nuclear accidents.

In 2016, China Nanjing University of Aeronautics and Astronautics made rapid identification of radionuclides in the emergency detection of NH-UVA airborne radioactive detection system composed of $LaBr_3$:Ce detector and HPGe detector in nuclear accident emergency detection Related research, and tested the feasibility of a new energy spectrum correction algorithm through MCNP simulation in different stages of the Chernobyl nuclear accident and the Fukushima nuclear accident, different flight altitudes, different detection positions, different source item sizes. It also pointed out the effect of the radiation source term size and radioactive intensity on the system MDAs [23-25].

In 2018, the Fukushima Remote Monitoring Group of the Japan Atomic Energy Agency Fukushima Environmental Safety Center adopted the URM radiation measurement system composed of three $LaBr_3$: Ce detectors produced by the Japanese Radiation Engineering Company’s factory to carry out an air radioaction monitoring after the nuclear accident in some areas, and evaluate the impact of the radionuclides emitted by the Fukushima Daiichi Nuclear Power Plant accident on the entire Japanese territory [26]. In 2019, to enhance the ability of the $LaBr_3$:Ce detector-based environmental radiation monitoring system (ERM) to recognize artificial radionuclides ^{131}I, ^{137}Cs, and ^{134}Cs produced by nuclear accidents. the Korea Atomic Energy Research Institute first used the $LaBr_3$:Ce detector to obtain the dose rate spectrum of the radionuclide at a distance of 1 meter from the ground, by subtracting the contribution of natural radionuclides such as ^{214}Pb, ^{214}Bi, ^{228}Ac, ^{212}Pb, ^{208}Tl, etc. in the region of interest subtracted from ^{131}I, ^{137}Cs, ^{134}Cs. According to these results, the scholar researched the deposition of artificial radionuclides Cs on the Fukushima nuclear accident contaminated soil [27-29].

4. Particle measurement

4.1 Identification of α and γ particles

$LaBr_3$:Ce scintillation crystal ^{227}Ac will produce a series of alpha decay to enhance its inherent background, which limits the application of $LaBr_3$:Ce detector in the measurement of low activity gamma spectroscopy. Reducing the inherent background of the detector by discerning the α and γ events in the scintillation crystal is expected to improve this limitation.

Many researchers have done a lot of research on the discrimination of α and γ events in $LaBr_3$:Ce scintillation crystals based on pulse discrimination technology (PSD) [30]. Scholars from the University of Milan, Italy, Fika and Tsinghua University, China, have enhanced the difference between α and γ pulses by charge comparison method(CCM) [31-32], and some scholars have added other nuclides to $LaBr_3$:Ce crystals, such as Ca and Sr to enhance the difference between α and γ pulses [33]. Either way, it makes the α and γ events in $LaBr_3$:Ce scintillation crystals easier to distinguish, and then reduce the inherent background.

4.2 Neutron and electronic measurement

The excellent characteristics of $LaBr_3$:Ce crystals make it used to measure neutrons and electrons in nuclear physics experiments and high-energy physics experiments. The researchers analyzed the interaction between neutrons and $LaBr_3$:Ce crystals [34-35], using the $LaBr_3$:Ce detector to successively determine the neutron energy spectra of different neutron sources [36-37], and analyzed the detection efficiency and detection sensitivity of $LaBr_3$:Ce for different energy neutrous[37-39]. For electronic measurement , scholars of the University of Novi Sad in Serbia used the $LaBr_3$:Ce detector to accurately measure the energy of the LINAC-200 fast electrons and calibrated the $LaBr_3$:Ce detector with 1.17MeV-25MeV electrons [40].

4.3 Lifetime measurement of nuclide

The good light output and fast decay time of $LaBr_3$:Ce scintillation crystal make it possible to make accurate measurements on the nanosecond scale, so it is often used for the lifetime estimation of nuclear energy states. University of Brighton in the United Kingdom used a hybrid gamma sphere array coupled with 25 $LaBr_3$:Ce detectors to measure the lifetime of the three energy levels in ^{114}Pd [41]. The

American Superconducting Cyclotron Laboratory used an array detection system consisting of 16 $LaBr_3$:Ce detectors to measure the excited state lifetime of ^{152}Sm and ^{152}Gd [42]. Relevant personnel from the University of Dar es Salaam in the United Republic of Tanzania measured the life of the first excited state of ^{133}Cs using the $LaBr_3$:Ce detector [43].

5. Conclusion

$LaBr_3$:Ce detector has been widely used in many fields because of its advantages. Based on the research of scholars at home and abroad, this paper summarizes the application results of $LaBr_3$:Ce detector in several main fields. In the future, the $LaBr_3$:Ce detector will be used more in environmental radiation monitoring and rapid identification of on-site nuclides, and overcoming its inherent background limitations will become the main problem solved in the application. With this problem be solved, the $LaBr_3$:Ce detector will be used in low-activity scenes such as airborne gamma spectrometry.

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