Marine radioactive field monitoring sensor based on NaI (Tl)

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Abstract. There are many deficiencies in traditional laboratory means, which make it difficult to meet the real-time monitoring requirements of nuclear radiation on marine field. In this paper, a radioactive monitoring sensor for marine field was proposed, which is based on NaI (Tl) scintillation crystal, while energy calibration and resolution calibration are conducted by employing a standard radioactive source, and curve fitting is conducted by employing MATLAB. Through the test under seawater in Qingdao wharf, the results are in good agreement with the laboratory test results.

1. Introduction

The radioactive material leakage of Fukushima Nuclear Power Plant in Japan occurred on March 2011 which caused large-scale nuclear pollution, and the marine nuclear radiation monitoring began to draw attention. The traditional monitoring method is to bring a large number of samples back to the laboratory for processing and analysis, which includes burdensome process and waste time and energy. The test results can often not be obtained until 3-4 months later [1, 2], this non-real-time mode of work needs the skill of chemical pretreatment of the samples and is restricted by half-time of nuclide, therefore, the research and application of on-site, real-time and continuous marine radioactive monitoring technology have been highly valued [3]. In this paper, γ spectrometer detection technique based on NaI (Tl) scintillation crystal is used to realize a monitoring sensor on marine nuclear radiation field based on NaI (TI) detector, which can rely on buoy system for long-term stable operation in harsh marine environment, and can achieve real-time monitoring of marine radioactivity.

2. System implementation

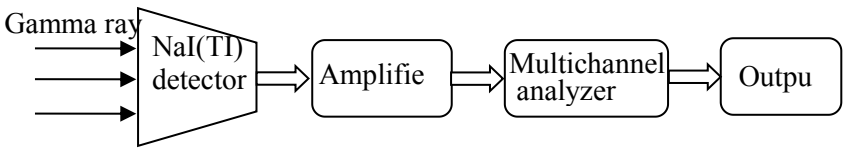

Figure 1. Radioactive detection model.

The basic principle of using NaI (Tl) scintillation crystal is the interaction between γ-ray and NaI (Tl) detector, so as to convert different energy of γ photons into electric pulse signals in different

amplitudes, collect electrical pulse signals and process data to get the energy spectrum diagram [4]. As shown in figure 1, the schematic diagram of the system implementation was given.

The system consists of NaI (Tl) detector (including NaI (Tl) crystal, photomultiplier, preamplifier), main amplifier, digital multi-channel pulse amplitude analyzer, power supply, monitoring system, data acquisition and storage system, energy spectrum analysis and application display software and other components. As shown in figure 2, the relative luminous efficiency of NaI (Tl) crystal scintillation detector is higher and is better matched with the photomultiplier, and γ photons with different energy are converted into electric pulse signals in different amplitudes for preamplifier processing; the main amplifier further amplifies and shapes voltage signals from tens mV to hundreds mV; the multi-channel analyzer is used for pulse amplitude analysis, and the count on each channel constitutes γ energy spectrum diagram; the energy spectrum analysis uses algorithm of Gaussian Fitting, which obtains the type of radionuclides and calculates the nuclide concentration automatically.

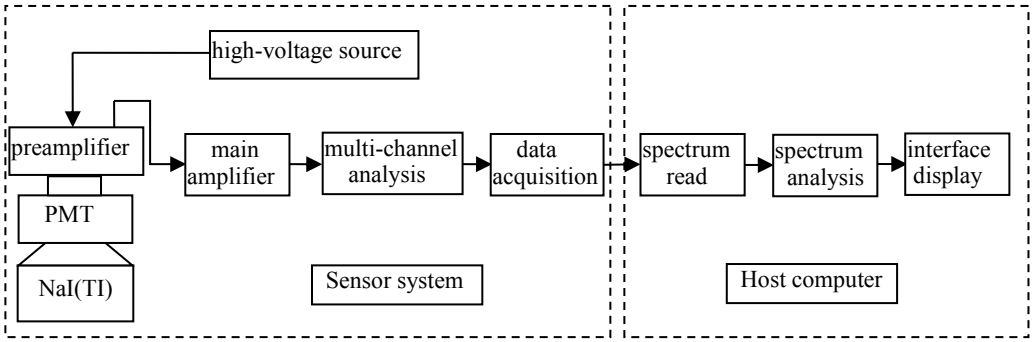

Figure 2. Block diagram of marine nuclear radiation monitoring sensor system.

3. Energy calibration

The corresponding energy peak position is detected by using the known energy γ radiation source to to obtain the relation curve between energy and peak position (channel) [5]. The correspondence between the peak position and the energy is the energy calibration, and the curve determined by the relationship between the peak and the energy is the energy calibration curve. Through the energy calibration curve, the energy of the characteristic peak can be determined by the peak position (channel), and then the nuclide matched with it can be found in the nuclide library to identify the nuclide type. Therefore, the energy calibration is crucial in the qualitative identification of nuclides. The energy resolution characterizes the resolution ability of the detector on different nuclides, whose value is the ratio of the full width at half maximum of the characteristic peak to the peak position [6-8]. The functional relationship curve between the energy resolution and energy is the energy resolution curve.

The sensor uses the radiation standard source: ^{241}Am, ^{133}Ba, ^{60}Co, ^{137}Cs, ^{152}Eu for energy calibration and resolution calibration [9], the detector uses NaI crystal with the size of 3 * 3 inches, the point source is 25 cm from the detector's front end, and the multi-channel energy spectrum analysis meter is 1024 channel, with the energy range of 0-2000 keV.

The energy calibration curve with confidence ratio of 95% is calculated by matlab fitting:

$$y = 1.891x - 10.4$$

In the formula, x is the peak position, y is the energy of the nuclide characteristic peak [10], in keV. The standard deviation of fitting is 0.9999. The energy calibration curve is shown in figure 3, and it can be seen that the curve is well linear.

The parabola fitting is made to data on the rectangular coordinate paper with characteristic γ ray energy and the corresponding full-energy peak position track address, and the energy resolution curve calculated with matlab fitting when the fiducial probability is 95%:

$$Y = 0.008453 + 0.06973 * \sqrt{x + 0.009146x^2}$$

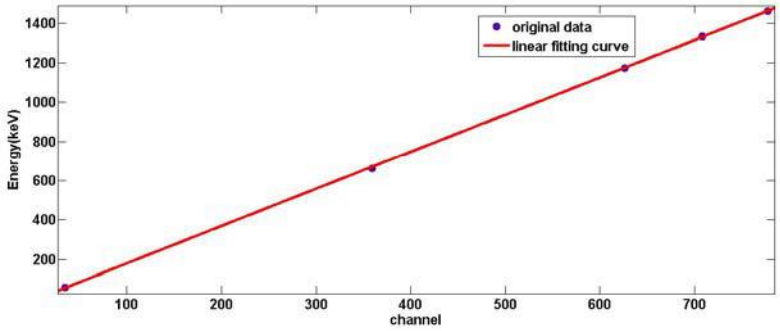

Figure 3. Energy calibration curve.

In the formula, x is Energy, in MeV, Y is half width FWHM, in MeV. The fitting standard deviation is 0.9941. The energy resolution curve is shown in figure 4. It could be seen from the experimental data in table 1 that when the voltage is as high as 800v, FWHM of ^{137}Cs is 45.3 keV when the energy is 661.6 keV, and the energy resolution is 6.8%.

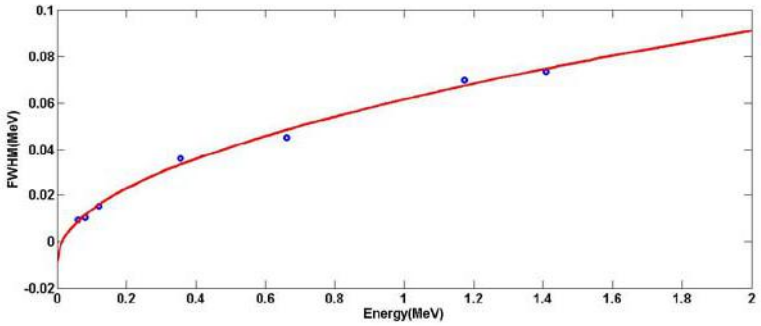

Figure 4. Energy resolution curve.

Table 1. Source characteristics used in energy calibration.

No.	Nuclide	Major γ ray energy (keV)
1	241Am	59.54
2	133Ba	81.0,302.85,356.02
3	137Cs	661.662
4	60Co	1173.24,1332.5
5	152Eu	121.782,344.29,778.2,964.11,1085.89,112.08,1408.0

4. Experimental results and analysis

Figure 5 shows that the sensor is connected to the upper computer in the laboratory to test the copying machine. The sensor is experimented in the Eight Great Passes in Qingdao, the water at the wharf is about 8 m deep, in order to eliminate the interference of cosmic rays and submarine material, the sensor is suspended 3 meters below the water surface by crane, and the cumulative time is 24 hours, as shown in figure 6. The spectrum at 19:00 on April 19, 2015 is shown in figure 7, from which the 40 K characteristic peak can be clearly identified.

The data of 24 hours from it for analysis were detected. The device of the upper computer of the sensor configures software to automatically find the peak, use Gaussian fitting method to fit the 40 k spectral line curve, as shown in figure 8:

Figure 5. The sensor is connected to the upper computer in the laboratory.

Figure 6. Field measurement of detector ready to be immersed into seawater.

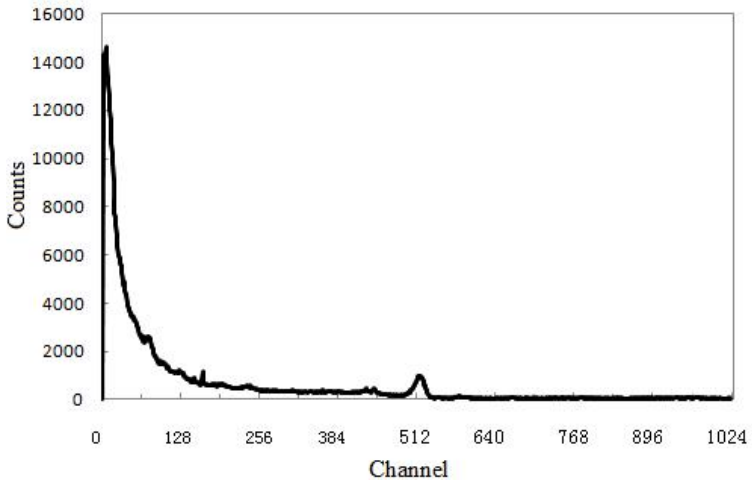

Figure 7. Spectrum below 3 meters of water on April 19, 2015.

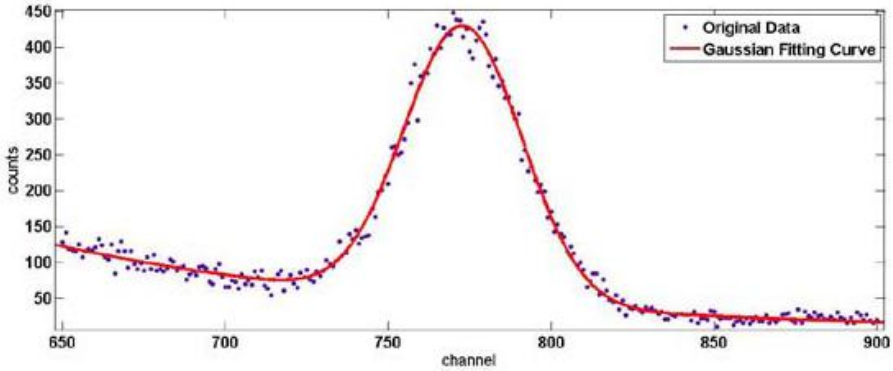

Figure 8. The instrumental spectrum and the original spectrum after seawater 40 k characteristic peak Gaussian fitting.

The fitting curve is: $f(x) = a1 * \exp(-((x-b1)/c1)^2 + a2 * \exp(-((x-b2)/c2)^2)$

The coefficient values are as follows (confidence probability: 95%):

A1 = 383.3, b1 = 772.9, c1 = 25.67, a2 = 2.811e + 015, b2 = -7191, c2 = 1414,

According to the fitting curve, the characteristic peak of 40K seawater is 18650 (24 hours), according to the formula of activity [11]

$$A = \frac{S}{T * \varepsilon * I}$$

The activity of 40k is 12.42 Bq/L. In the formula, S is the net count of nuclide characteristic peak, T is the measurement time, ε is the detection efficiency of the instrument, and I is the fractional ratio.

In order to verify the accuracy of the 40 K measurement of the sensor, the seawater is sampled in the same position at the wharf at the same time, and then the sample is taken back to the laborator, where the salinity of the seawater is measured with SYC2-2 salinity meter produced by China Ocean University to the, and then calculates the concentration of 40 K according to the proportional relationship [12], which is 12.33 Bq/L, and the comparison result shows that the measurement result of the sensor is consistent with the laboratory measurement result.

Through the experiments on the waters of the Eight Great Passes in Qingdao, it can be seen that there is a significant 40 K peak near the 526 channel, which is in line with the natural properties of seawater. The two spikes near 170-channel is caused by the noise of the circuit. The subject will study the elimination of these noises in the next work.

5. Conclusions

The sensor described in this paper will mainly be used for long-term, continuous real-time monitoring of the marine environment on marine fields, such as Marine Data Buoy and ocean station [13, 14], and can identify a variety of target radionuclides and calculate concentrations. In the next step, the energy efficiency calibration algorithm and low power consumption will be improved, to improve the sensor optimization and realize the on-line monitoring of marine radioactivity.

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