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GAMMA SPECTRUM STABILIZATION FOR ENVIRONMENTAL RADIATION MONITORING STATIONS USING NAI(TL) DETECTOR

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Gamma spectrum measured by an NaI(Tl) detector is known to be unstable with the *in situ* temperature. In the present work, an advanced method has been applied to stabilize the gamma spectrum measured by the NaI(Tl) detector at environmental radiation monitoring (ERM) stations. The method is based on experimental data obtained under controlled conditions in laboratory. In the temperature range from 4 to 45°C, the relative deviation of the peak positions within the stabilized gamma spectrum is less than 2%. To test this method in a real scenario, it has been integrated into the ERM station at the Military Institute of Chemical and Environmental Engineering in Hanoi, Vietnam. The results show that the proposed method is ready for a real application.

INTRODUCTION

NaI(Tl) detector has been widely used in environmental radiation monitoring (ERM) stations because of its high detection efficiency. However, the output signals of the NaI(Tl) detector are sensitive to the *in situ* temperature(1–3), leading to a noticeable distortion of the measured gamma spectrum, i.e. the peak shift, when the ERM station is installed at a real site with unstable temperature conditions. In Vietnam, the temperature range is from 4 to 45°C, which causes a deviation of the peak positions within the gamma spectrum up to about 15%. Therefore, in order to use the ERM stations in a real site, it is necessary to stabilize the gamma spectrum, i.e. to correct the peak shift according to the change of temperature.

In the literature, several methods have been developed for the spectrum stabilization(4–9). These methods are based on the classic principles given in Ref.(2), in which the positions of reference peaks, i.e. the well-known peaks with corresponding energies, are used to correct the distortion of the gamma spectrum. The reference peaks can be created through different techniques: using standard radiation sources (e.g. ^{40}K and ^{241}Am) attached into the measuring system(4–7), using isotopes from natural background, i.e. the naturally occurring radioactive materials (NORM)(7) and using the light from light-emitting diodes (LEDs)(4,5). These techniques have been known to be able to stabilize the measured gamma spectrum against not only the temperature variation but also other factors such as the leap of coming signals. However, these mentioned techniques require adjusting the gain of electronic components, i.e. the involved complex electronic systems. The electronic systems must be more complex when an LED is used as a reference light source because the temperature dependence between NaI(Tl) pulses and the LED's light is not the same as that between NaI(Tl) pulses and gamma radiation(5).Moreover, the use of standard radiation sources attached into the measuring system causes undesired background, leading to the decrease of the detection limit of detecting system, whereas the use of NORM isotopes may be unavailable in some places where the activities are extremely low.

Recently, Refs(7–9) proposed methods that do not need any independent source to stabilize the gamma spectrum of NaI(Tl) detectors. Instead, these methods used reference peaks in the form of a look-up table or formula, which are determined from experiments under the controlled temperature conditions. Nevertheless, the methods given in Refs(7–9) have not been tested in a real site of an open environment.

Moreover, Ref.(8) determined only six reference data within the temperature range from −27 to 50°C. These reference data are quite sparse for the wide range of temperature. In addition, the authors of Ref.(8) used a hardware to control the gain of their

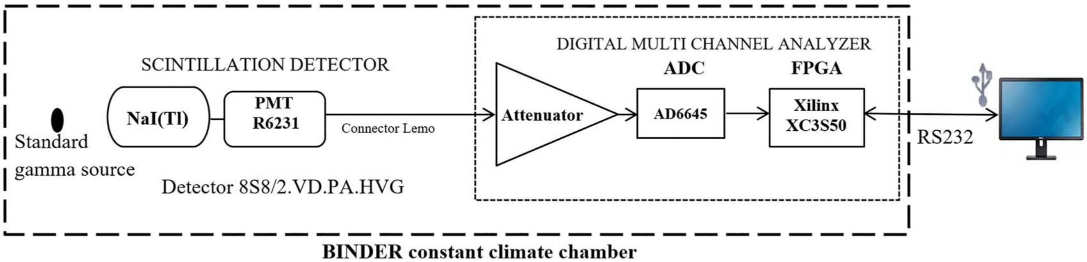

Figure 1. Schematic view of the experimental setup.

amplifier, namely the microcontroller. Meanwhile, Ref.[9] surveyed the temperature dependence from 27 to 60°C only. This temperature range is almost different from that of an open environment.

In the present work, we focus on developing an advanced method for gamma spectrum stabilization under the unstable temperature conditions, and applying it in an ERM station using the NaI(Tl) detector. The method is based on the obtained data via a controlled temperature experiment and a software solution. In the following sections, we successively describe the experimental set-up, the stabilization algorithms, the results obtained and discussion and conclusions.

EXPERIMENTAL ASPECTS

Experimental set-up

Figure 1 shows the experimental set-up. The NaI(Tl) detector of type 8S8/2.VD.PA.HVG produced by ScintiTech-USA has been used. The detector is in a cylindrical shape with diameter and length of 51 mm. The output signal is connected to a photomultiplier tube of type R6231 produced by Hamamatsu[10]. The output signal from the photomultiplier is then digitized and treated by a digital multi-channel analyzer (DMCA)[11] whose main components are an analog-to-digital converter AD6645[12] and a Field Programmable Gate Array (FPGA) Xilinx XC3S50[13]. The data acquisition and storage are controlled by an in-house software installed on a personal computer (PC). The latter is connected to the DMCA using an RS232 cable. In order to control the temperature, all the components except the PC are put in a BINDER constant climate chamber[14].

Three standard radioactive sources (^{137}Cs, ^{60}Co and ^{152}Eu) have been used to collect the experimental data. These sources emit gamma rays within the energy range from 344 to 1408 keV. Two sets of gamma spectra have been collected with the temperature range from 0.4 to 45°C. The first one is obtained using a combination of the ^{137}Cs and ^{60}Co radioactive sources, while the second one was obtained using the ^{152}Eu source. Each set contains 38 spectra corresponding to 38 successive temperature values (the temperature mesh is 2.5°C).

Stabilization algorithms

At different working temperatures, the peak positions of the gamma spectrum are accordingly shifted. It is assumed that

$$\mathrm{C_{i,0} = a_k.C_{i,k} + b_k} \tag{1}$$

where $C_{\mathrm{i,0}}$ and $C_{\mathrm{i,k}}$ are the channels of the ith peak at the corresponding T_0 and T_{k} temperatures, respectively. In the present study, $T_0 = 25$°C is chosen because it is the average value of the temperature. The assumption of Equation (1) is validated, since the linear relationship between $C_{\mathrm{i,0}}$ and $C_{\mathrm{i,k}}$ is clearly shown in Figure 2.

For every surveyed temperature, T_{k}, it is able to determine $\mathrm{a_k}$ and $\mathrm{b_k}$ by fitting Equation (1) to the corresponding experimental data ($C_{\mathrm{i,0}}$, $C_{\mathrm{i,k}}$). The peak positions within the measured gamma spectra, namely $C_{\mathrm{i,0}}$ and $C_{\mathrm{i,k}}$, have been determined by fitting to a Gaussian distribution using the Origin software[15]. Eight peaks whose energies are listed in Figure 3 have been used for the fitting process. Finally, we obtained 38 sets of ($\mathrm{a_k}$, $\mathrm{b_k}$) within the temperature range from 0.4 to 45°C. In order to stabilize the gamma spectrum, we convert all the spectra measured at different temperatures to those measured at $T_0 = 25$°C.

In reality, a spectrum measured at a given temperature, T, can be corrected as follows:

$$\mathrm{C^{corrected}} = a\,(\mathrm{T})\,.\mathrm{C^{uncorrected}} + b\,(\mathrm{T}) \tag{2}$$

where a(T) and b(T) are determined by interpolating the 38 sets of $\mathrm{a_k}$ and $\mathrm{b_k}$ obtained from the experiment under controlled conditions.

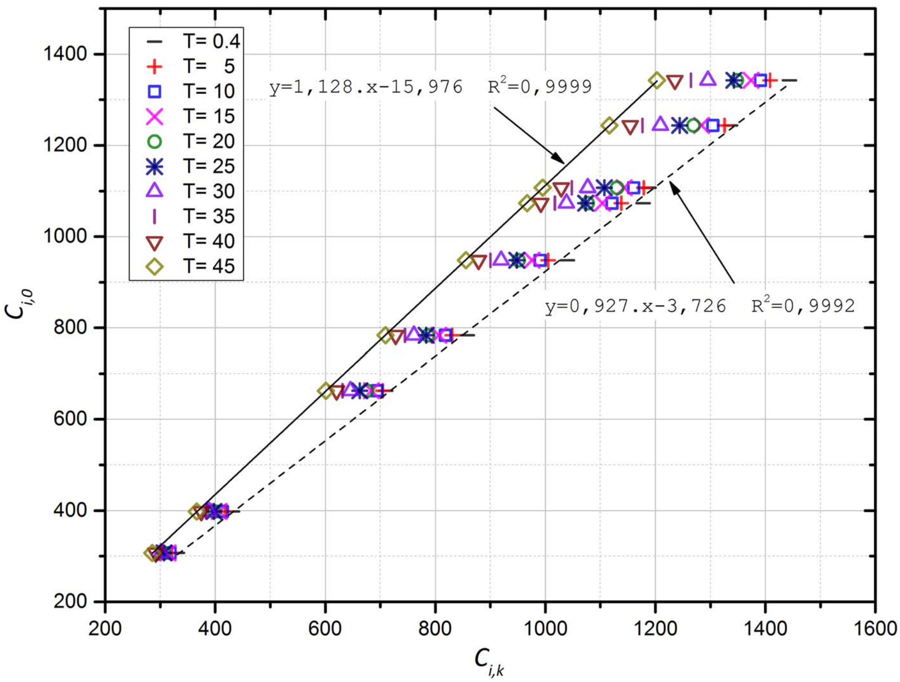

Figure 2. (color online) The relationship between $C_{i,0}$ and $C_{i,k}$ where $C_{i,0}$ and $C_{i,k}$ are the channels of the ith peak at T_0 and T_k temperatures, respectively. The solid and dash lines show the linear relationships between $C_{i,0}$ and $C_{i,k}$ when $T = 0.4$ and 45°C, respectively.

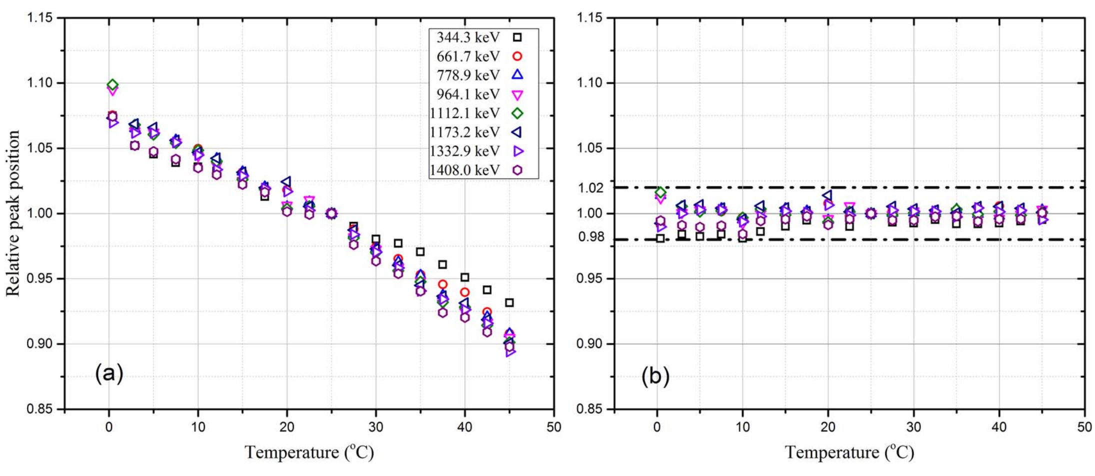

Figure 3. (color online) Relative peak positions with (b) and without (a) using the spectrum stabilization. The relative peak positions are calculated by $C_{i,k}/C_{i,0}$.

RESULTS AND DISCUSSION

Figure 3 shows the relative peak positions with (Figure 3(b)) and without (Figure 3(a)) the proposed spectrum stabilization procedure. It can be seen that without the spectrum stabilization, the relative peak positions fall into a range from 0.90 to 1.10. By using the proposed method, the relative peak positions fall into a much narrower range, i.e. from 0.98 to 1.02. The obtained results in Figure 4 clearly show the fluctuation of the corrected peak positions with respect to the reference positions. In this figure, it

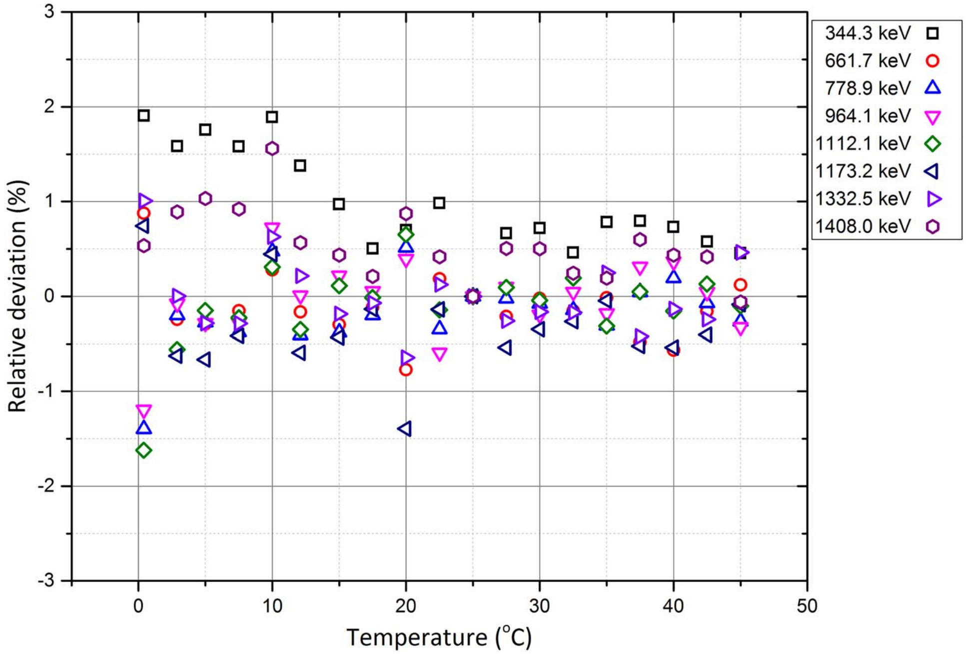

Figure 4. (color online) Relative deviation between peak positions after the correction with peak positions at reference temperature (RD(%) = 100% ($C_{i,k} - C_{i,0}$)).

visually seems that the relative values are more and larger to the positive side. In fact, the number of positive relative deviation is almost similar with that of the negative one (i.e. 69 and 75, respectively). The average value of the relative deviation on the positive side is 0.56% whereas that on the negative side is −0.33%. This small bias to the positive side is because of the large positive values of the relative deviations corresponding to 344.3-keV peaks. Thus, there might be a certain systematic uncertainty within the determination of the position of 344.3-keV peaks. The latter are taken from the ^{152}Eu gamma spectra, in which the number of gamma rays contributed is extensive, especially in the energy region from 100 to 500 keV[16].

Within the temperature range from 0.4 to 45°C, the relative discrepancy between the corrected peak positions and the reference peak positions are less than 2% as shown in Figures 3(b) and 4. It is the normal operating temperature range for a normal ERM station. Figure 5 shows a comparison between uncorrected spectra and the corrected ones. It can be seen that the corrected spectra are more constant with temperature variations than the uncorrected ones. The results shown in Figures 3–5 validate the proposed method for the temperature range from 0.4 to 45°C under controlled conditions in laboratory.

Particularly, the proposed method has also been tested by implementing it into an ERM station working in an open environment. Figure 6 (right panel) shows the ERM station manufactured and installed in Military Institute of Chemical and Environmental Engineering (MICEE), Hanoi, Vietnam. The stabilization spectrum algorithms have been integrated into the control software of the ERM station. The temperature of the environment, which is continuously sent to the control software, is measured by using a temperature probe.

With the present test, the stabilization spectrum algorithms have not integrated into the FPGA yet. Therefore, the correction must be performed after the spectrum acquisition. Typical ERM systems allow us to freely set the acquisition time. This time should be short (i.e. about 10 minutes to an hour) in order to warn the prompt change of radiation dose rate in the environment, but it should be long (e.g. few hours to few days) in order to reliably and accurately determine low-activity radiation background. Thus, it is impossible to select an appropriate temperature value for the correction process. In order to ensure the validity of the method, we have separated a given spectrum acquisition into short integration (e.g. 10 minutes) and correct the spectra after each integration. The temperature value used for correcting the spectrum (each integration) is the average temperature

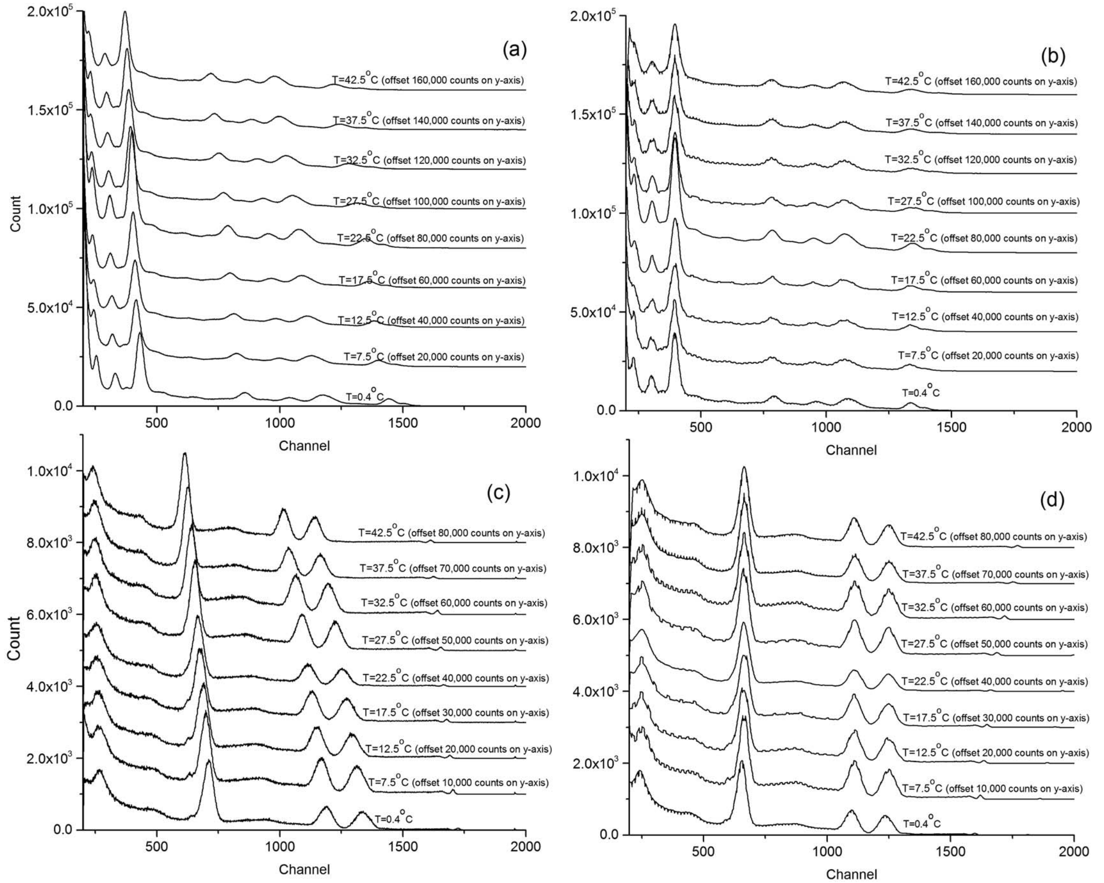

Figure 5. The ^{60}Co and ^{137}Cs gamma spectra as a function of temperature without (a) and with (c) using our stabilization procedure. The ^{152}Eu gamma spectra as a function of temperature without (b) and with (d) using our stabilization procedure.

during the integration. Figure 7 compares the spectra taken from the tested ERM station in two cases: with and without the stabilization spectrum process. This test is performed in 24 hours. During this time period, the environmental temperature varies from 30 to 42°C (Figure 8). The existence of some gamma peaks corresponding to a few naturally occurring radionuclides on the measured spectra is marked. It can be seen that, without the use of the spectrum stabilization procedure, the measured spectrum is almost impractical. For example, the peak corresponding to the gamma ray of 1460.8 keV of ^{40}K is found as a doublet within the destabilized spectrum. With the stabilized one, this peak is well resolved. Our spectrum stabilization method works very well for a real ERM, and therefore, it is ready for the real applications.

The obtained results prove that the spectrum stabilization method is accurate, practical and simple since it is performed by software, and therefore, it does not require changing the gain of hardware components such as the amplifier. However, this method also has two limitations. The first one is the requirement of measurements under controlled temperature conditions, which are perhaps specific to each detector. The second one is that our method may fail if the *in situ* temperature promptly changes (e.g. more than 10°C in 10 minutes). However, in real application, these limitations do not raise crucial problems. First, the NaI(Tl) detector is rather durable. Therefore, it is not necessary to regularly replace NaI(Tl) detector for an ERM station. Additionally, while in principle, the temperature dependence parameters should be determined for each ERM system (via the measurements under controlled temperature conditions), the primary sources of the temperature dependence are intrinsic to the NaI(Tl) detector and the Photomultiplier tube (PMT) thus, a set of calibration parameters could be used for different ERM systems as long as these systems use the same type of NaI(Tl) detector and PMT. Second, the environmental temperature normally changes

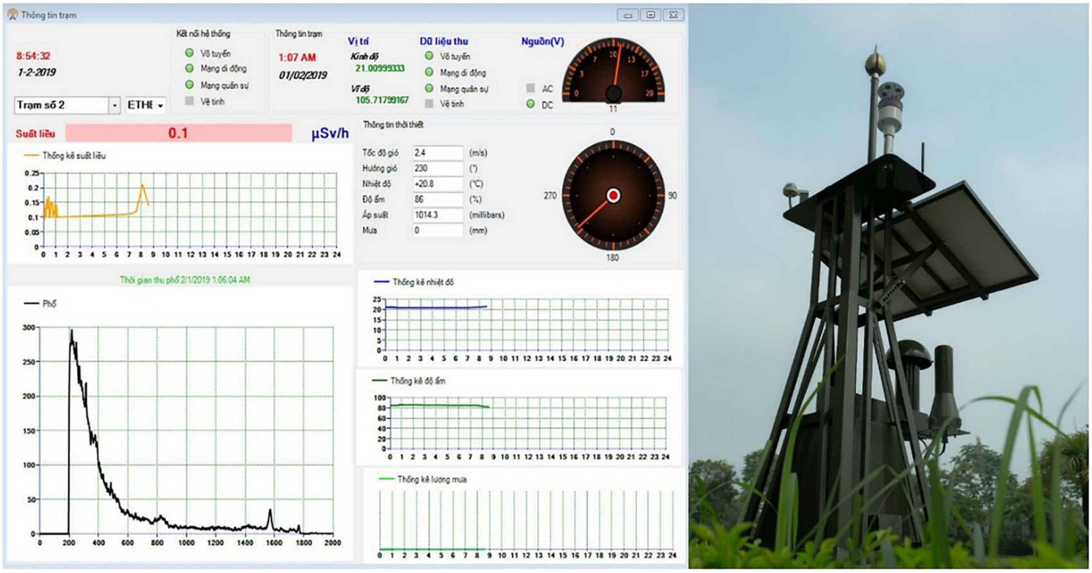

Figure 6. (color online) An ERM station installed at MICEE (right panel) and its graphics user interface (left panel).

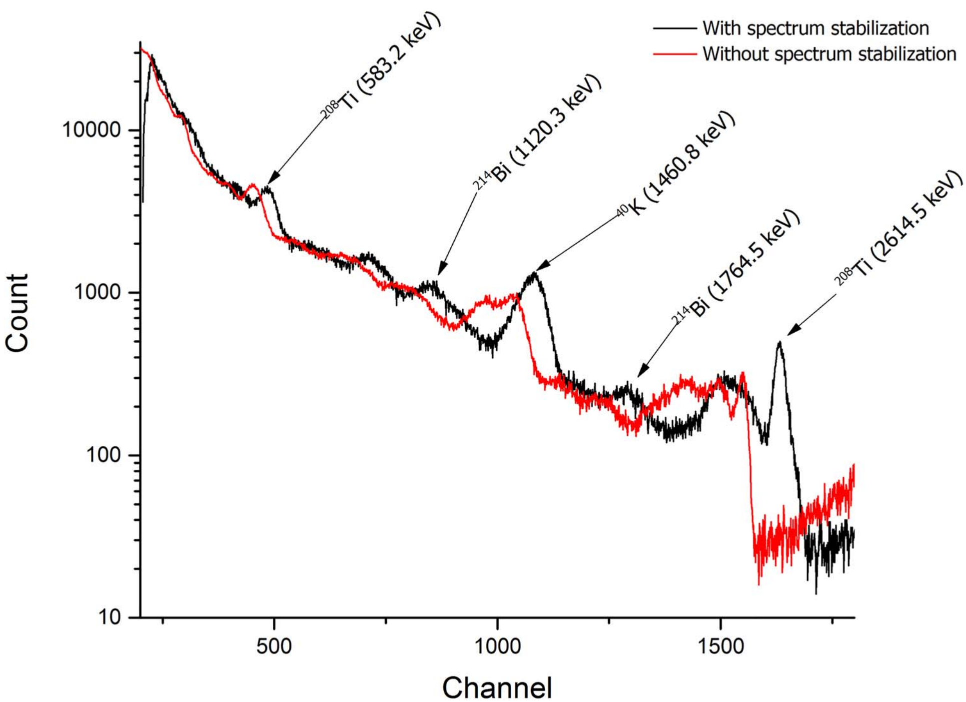

Figure 7. (color online) The gamma spectra measured by our ERM station with and without using the spectrum stabilization procedure.

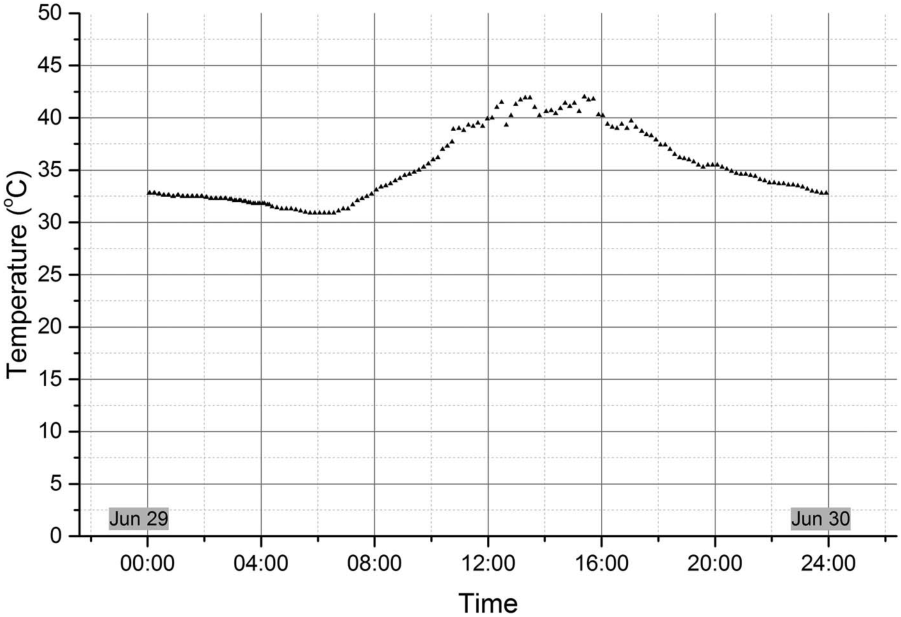

Figure 8. Temperature variation during 24 hours of testing under open environment. Experimental points correspond to the average temperature at every 10 minutes.

slightly over time. Moreover, even if the temperature changes rapidly, one is still able to deal with it by separating the acquisition time into shorter integration (i.e. 2 minutes instead of 10 minutes as used in the test).

Recently, Ref.[17] proposed $LaBr_3$, $CeBr_3$ and SrI_2 scintillator as promising candidates for ERM instead of the conventional NaI(Tl) scintillator because these state-of-the-art scintillators provide a much better energy resolution and higher sensitive to gamma-rays. However, the pulse shape of these scintillators still depends on the temperature. In this case, we believe that the proposed temperature stabilization method is not limited to the NaI(Tl) detectors. In fact, we expect that our method is able to apply to the other types of scintillator, since the principle of the temperature stabilization is the same for the scintillator mentioned above.

On the other hand, we should note that there are two effects of temperature on the NaI(Tl) light output: the decreases of pulse height with increasing temperature and the increases of light scintillation decay time with decreasing temperature[18]. The latter effect may be stronger than the former in the systems whose detector pulses are treated with analogue technique. Nevertheless, our method is able to correct the spectrum distortion caused by both of these two effects since it directly adjusts the output from the MCA, which are influenced by these effects mentioned above.

CONCLUSION

An advanced method to stabilize the spectrum measured using NaI(Tl) detectors has been developed. This method does not require adjusting gains of electric components as the conventional methods. Therefore, it is simpler and more practical, although it also has a small inconvenience, as the parameters for the temperature stabilization process must be redetermined whenever the detector or the PMT of ERM systems are replaced. Under the controlled temperature conditions, the present method provides relative deviations of the corrected peak positions with respect to the reference ones of less than 2% within the temperature range from 0.4 to 45°C.

To prove the validation of this method in a real application, we have tested it with the real scenarios by integrating the spectrum stabilization method proposed into the software of an ERM station into an ERM station. The serviceability is well recognized when two spectra (with and without applying the method) are compared. For the future works, we will integrate the spectrum stabilization method into the DMCA (i.e. the FPGA components) to event-by-event (online) stabilize the spectra measured by ERM stations.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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