DEVELOPING A NEW METHOD FOR GAMMA SPECTRUM STABILIZATION AND THE ALGORITHM FOR AUTOMATIC PEAKS IDENTIFICATION FOR NaI(Tl) DETECTOR

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Abstract: Environmental radiation monitoring stations using the NaI(Tl) scintillation detector have higher sensitivity and provide more accurate radiation dose values than using Geiger-Muller counters. However, when the temperature of the environment changes, the measuring data changes (due to the temperature dependence on the NaI(Tl) light yield and the quantum efficiency of the PMT). The results show that the peak positions have a relatively large shift depending on the temperature of the environment. It is necessary to correct gamma spectrum at different measured temperature to the reference temperature (e.g. 25°C). In order to analyze gamma-ray spectra, one of the important operations of the processing procedure is searching for photopeaks, determine peak shape and intensity. Environmental radiation monitoring stations using the NaI(Tl) scintillation detector have higher sensitivity and provide more accurate radiation dose values than using Geiger-Muller counters. However, when the temperature of the environment changes, the measuring data changes (due to the temperature dependence of the NaI(Tl) light yield and the quantum efficiency of the PMT). The results show that the peak positions have a relatively large shift depending on the temperature of the environment. It is necessary to correct gamma spectrum at different measured temperature to the reference temperature (e.g. 25°C). In order to analyze gamma-ray spectra, one of the important operations of the processing procedure is searching for photopeaks, determine peak shape and intensity. This study presents a new method for stabilizing gamma spectrum and automatic peaks identification-important data to calculate the radiation dose and identify isotopes. This method corrects the peak-shift according to the temperature of NaI(Tl) scintillation detector, without continuously adjusting the gain of the electronic. The relative deviation between the peak position after calibration and the peak position at the reference temperature is less than 2% in the temperature range of 0.4°C and 45°C.

Keywords: *NaI(Tl) scintillation detector; Spectrum stabilization; Peak detection; Spectrum analysis.*

1. INTRODUCTION

For spectrometer systems using scintillation detectors, the ambient temperature has a significant influence on the gamma spectrum, especially the position and shape of the peaks in the spectrum [1]. The ambient temperature affects the luminescence properties and the light pulse decay time of the scintillation crystals [2,3]; causing voltage-drift in electronic components of the spectrometer system, especially in the analog systems [4].

The environmental radiation monitoring stations are frequently operated in conditions with unstable temperature when used in an open environment. In Vietnam, the working temperature of an environmental radiation monitoring system can fluctuate between 4°Cand 45°C. For such a wide working temperature range, stabilizing gamma spectra according to the working temperature is particularly necessary.

Methods of stabilizing gamma spectrum according to temperature had been developed and applied to commercial environmental radiation monitoring systems. Some examples of these methods are as follows i) Using an electronic reference pulse corresponding to a known equivalent gamma energy [5]; ii) Using an external standard radiation sources attached into the measuring system [5]; iii) Using isotopes from natural background, e.g. ^{40}K [6]; iv) Using the temperature dependence of the light pulse decay time [6]; and v) Using light from light-emitting diodes as a reference light source [6] [7]. However, all of these methods are based on automatically adjust the gain of electronic components.

The intervention in the gain of the electronic components makes it difficult to build an automated radioactive monitoring system. Therefore, these aforementioned methods are not entirely appropriate to be used for manufacturing automatic environmental radiation monitoring systems.

In this paper, we present a completely new method for stabilizing the gamma spectrum of the NaI(Tl) scintillation detector according to the temperature. This proposed method does not adjust the gain of the electronic system; instead, algorithms are used to calibrate spectra at different temperature spectra to the reference temperature (T = 25℃). Therefore, this method can be easily embedded into the software to stabilize gamma spectrum of automatic radioactive monitoring systems.

2.THE MAIN PART OF THE REPORT

2.1. Experimental setup

In this study, the method was tested with a scintillation detector 2"x2" NaI(Tl) type 8S8/2.VD.PA.HVG from ScintiTech-USA, cylindrical shape 51 mm in diameter and 51 mm long. The detector was coupled with Hamamatsu's R6231 photomultiplier tube. Signals from the photomultiplier are amplified and shaped by the preamplifier before being analyzed by the digital multichannel analyzer (DMCA) [8]. The correction factors have been determined according to the measured temperature with a typical energy up to 1408 keV by gamma-ray emitted from radioactive sources ^{137}Cs, ^{60}Co and ^{152}Eu.

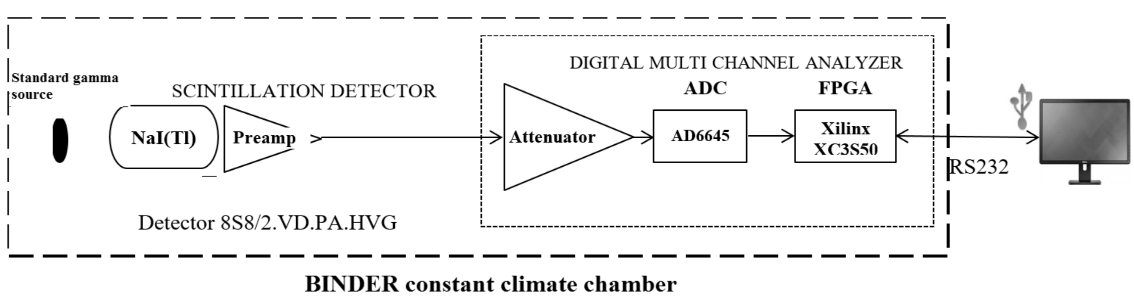

Figure 1. *Schematic view of experimental setup*

To validate the methods, we collected 38 spectra in approximate temperature range from 0.4℃ to 45℃. After thermal stability (at least 30 minutes for each temperature), two spectra were collected, the first was measured by using the combination of two radioactive sources ^{60}Co and ^{137}Cs, the second spectrum measured by using ^{152}Eu source.

2.2. Method description

2.1.1. Spectrum stabilization algorithm

When the detector's working environment temperature changes, the position of the energy peaks in the spectrum will shift accordingly. In the case of the integral nonlinear coefficient <0.1%, the relationship between the channel and the corresponding energy value is determined by equation (1).

$$E(C_{i,k}) = a_k * C_{i,k} + b_k \tag{1}$$

a_k, b_k are coefficient that depend on the temperature; $E(C_{i,k})$is the gamma energy corresponding to the channel $C_{i,k}$ at temperature T_k

When the system operates stably, at the reference temperature T_0 (e.g. T_0 = 25℃), the channel position $C_{i,0}$ corresponds to the energy peak E_i is constant. When temperature changes $T_0 \rightarrow T_k$, the channel position corresponding to the energy peak will shift $C_{i,0} \rightarrow C_{i,k}$. With fixed gamma energy E_i, we can establish the relationship between $C_{i,k}$ and $C_{i,0}$:

$$a_k * C_{i,k} + b_k = a_0 * C_{i,0} + b_0 \tag{2}$$

From Equation (2) the relationship between the channel position at the reference temperature $C_{i,0}$ and the channel position at T_k temperature $C_{i,k}$ is obtained as:

$$C_{i,0} = \frac{a_k * C_{i,\mathrm{k}} + b_k - b_0}{a_0} = \frac{a_k}{a_0} C_{i,\mathrm{k}} + \frac{b_k - b_0}{a_0} \tag{3}$$

Defining $\frac{a_k}{a_0} = \alpha_k$ and $\frac{b_k - b_0}{a_0} = \beta_k$, Equation (3) becomes:

$$C_{i,0} = \alpha_k . C_{i,\mathrm{k}} + \beta_k \tag{4}$$

α_k and β_k coefficients are determined by Least square method according to Equation (4):

$$\alpha_k = \frac{(n\sum C_{i,k}.C_{i,0}) - (\sum C_{i,k})(\sum C_{i,0})}{(n\sum C_{i,k}{}^2) - (\sum C_{i,k})^2} \tag{5}$$

$$\beta_k = \frac{(\sum C_{i,k}{}^2)(\sum C_{i,0}) - (\sum C_{i,k})(\sum C_{i,k}.C_{i,0})}{(n\sum C_{i,k}{}^2) - (\sum C_{i,k})^2} \tag{6}$$

where *i* is the number of photopeak under consideration.

2.2.2. Peak detection algorithm

Assuming that the photopeaks on the spectrum can be described by the Gaussian distribution function and the background below the photopeaks is approximately described by a linear function. Thus, the number of counts at channel number *x* in the peak region can be described:

$$N(x) = A.\frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(x-x_0)^2}{2\sigma^2}\right) + B.x + C \tag{7}$$

where *A*, *B* and *C* are constants describing the photopeak intensity and the background. If the counts number distribution function - *N(x)* is a continuous function, the second derivative – *N''(x)* becomes independent of the underlying background [9,10]. Therefore *N''(x)=0* for regions without peaks and *N''(x)* ≠ 0 for regions with photopeaks.

However, in practice, the counts number at the *i* channel - N_i are discrete values. Thus, the second derivative is replaced by the second difference:

$$S_i = N_{i+1} - 2N_i + N_{i-1} \tag{8}$$

Similar to the second derivative, the second difference only different from zero in regions with appearance of photopeaks. However, because N_i values fluctuate due to its statistical errors, the second difference values also fluctuate around the expected value, and if at the peak centroid $i = i_0$, the S_i value is equivalent to its standard deviation, it will not be possible to distinguish the peak region automatically. The value of S_i at the peak region depends on the amplitude, width of the peak and the intensity of the underlying background.

In order to automatically detect peaks with small intensity, it is necessary to apply average method with second difference value S_i [9]:

$$S_i(\omega) = \sum_{j=i-m}^{j=i+m} S_j \tag{9}$$

With $\omega=2.m+1$ is the window width. In order to optimize peak detection sensitivity, we used Weighted Average method:

$$S_i = \sum_{j=i-k}^{j=i+k} C_j.S_j \tag{10}$$

Weight coefficient C_j are defined as:

$$C_j = \frac{100(j^2 - \sigma^2)}{\sigma^2}.\mathrm{e}^{-\frac{j^2}{2.\sigma^2}} \tag{11}$$

where σ is Gaussian width σ = FWHM/2.355 The first coefficient C_0 is always equal to –100, and the set of coefficients is terminated at *k*, where the absolute value of C_k less than one. Second, the set of coefficients is then adjusted so that the sum of the coefficients is zero.

From Equation (10), the modified second derivative's standard deviation is defined as:

$$F_i = \sqrt{\sum_{j=i-k}^{j=i+k} C_j^{\,2}.S_j} \tag{12}$$

The photopeak regions are automatically detected by considering the "Significance Value" - $SS_i = \frac{S_i}{F_i}$. The absolute value of the significance value must be above a threshold value to confirm that the peaks are existent

2.3. Results and discussion

2.3.1. Dependence on temperature of photopeak shape and positions

The ratio of the photopeak position at different temperatures to the position at the reference temperature (T_0 = 25 ℃) is shown in Figure 2. From Figure 2, it can be seen that the higher the temperature difference, the stronger displacement of the photopeaks. Relative peak position displacement according to the measured temperature is up to ~ 12%. The results in Figure 2 show that the relative position of the peak correlates linearly with the measured temperature.

The peak positions are normalized to unity at reference temperature (T_0=25°C). Figure 3a and 3b show the gamma spectra obtained from 0.4°C to 45°C for ^{152}Eu (a) and ^{60}Co, ^{137}Cs composed source. At temperatures lower than the reference temperature, the spectrum is shifted to the right of the reference spectrum - the amplitude of the signal increases. Conversely, at temperatures higher than the reference temperature, the spectrum is shifted to the left of the reference spectrum - the amplitude of the signal is reduced. It is clear that without correction, from the data sets on obtained gamma spectra, it is not possible to give good results about gamma dose rate and nuclides identification if using energy calibration curve at reference temperature. From the marked photopeaks, the coefficient α_k, β_k calculated by Equation (5) and (6).

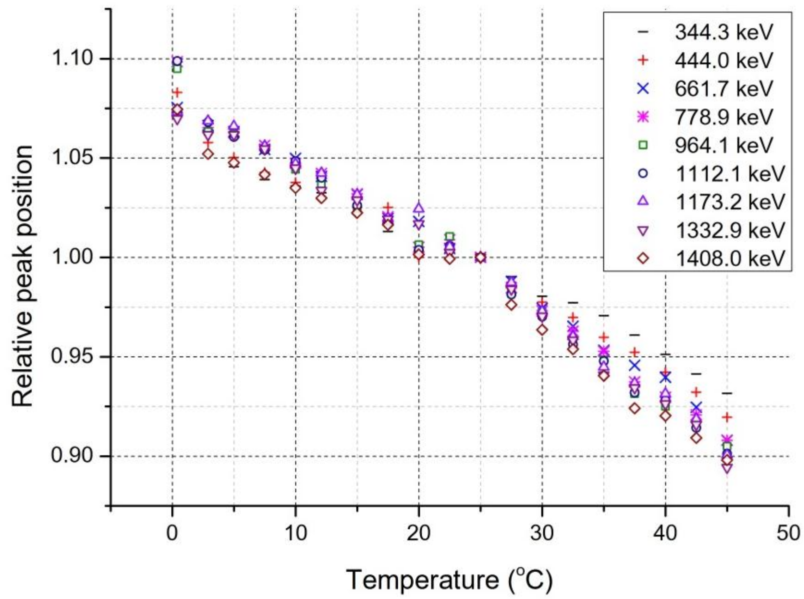

***Figure 2**. Relative peak-shift position according to measured temperature.*

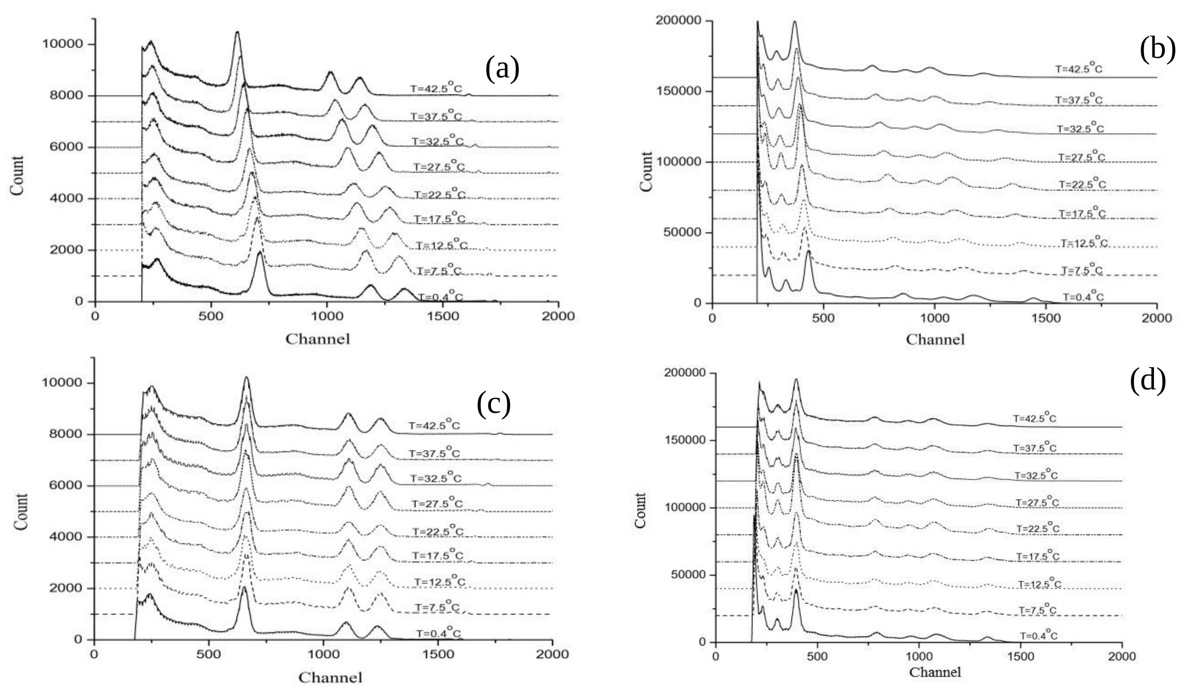

***Figure 3**. ^{60}Co+ ^{137}Cs composed source gamma spectra before (a) and after (c) correction; ^{152}Eu gamma spectra before (b) and after (d) correction*

From the α_k, β_k coefficients, gamma spectra are calibrated directly by the software. The results show that the photopeaks displace strongly according to changing temperature. In addition, the spectrum is also significantly distorted. Figure 4 shows the corrected spectra after adjustment.

All relative deviation values (%) below 2% (in absolute value). Figure 4 shows that for the most of the investigated energies, considering the entire temperature range, the peak position after correction fluctuate around the reference peak position, relative displacement bouncing on both sides around the value 0 is within the statistical error of the photopeak.

Figure 4 shows the relative deviation (%) of the photopeak position after adjusting to the measured temperature.

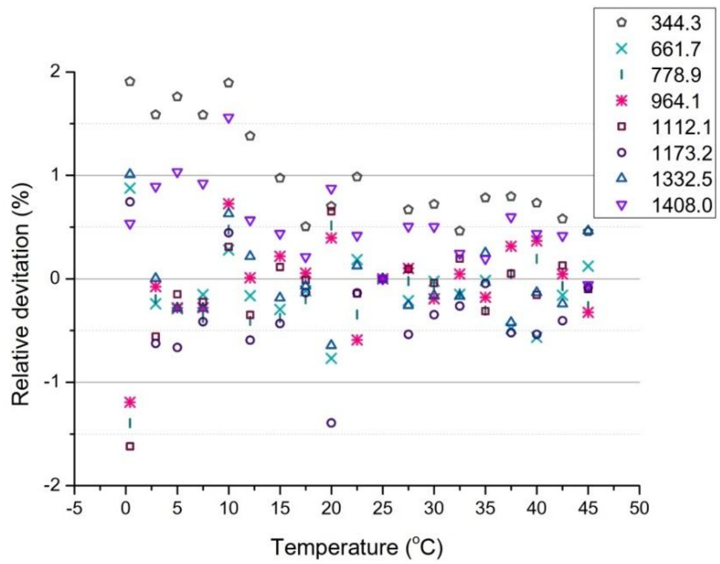

Figure 4. *Relative deviation between peak position after correction with peak position at reference temperature. (RD (%) =* $(C^{*}_{i,k} - C_{i,0}) / C_{i,0}.100\%$ *)*

2.3.2. Photopeaks detection

Weighted coefficient C_j defined in Equation (11) are used to calculate the second derivative, second derivative's standard deviation and the significance value. From Cj coefficients, we calculate the values of second derivative S_j according to formula (10) for a recorded background gamma spectrum. The background spectra and the S_j value are shown in the Figure 5.

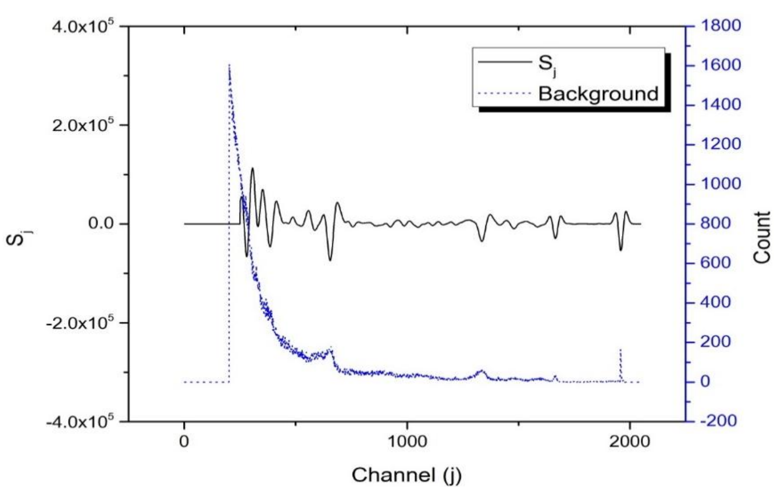

Figure 5. *The recorded background spectra and the corresponding* S_j *values*

The spectrum analysis algorithm has been integrated into the central control software. The analytical results are displayed, including: Peak position, energy (used to identify nuclides in the spectra), peak area, background area, count rate, and relative error. Figure 6 shows the analytical results with standard source ^{137}Cs spectra by automatic peak detection algorithm implemented in central control software.

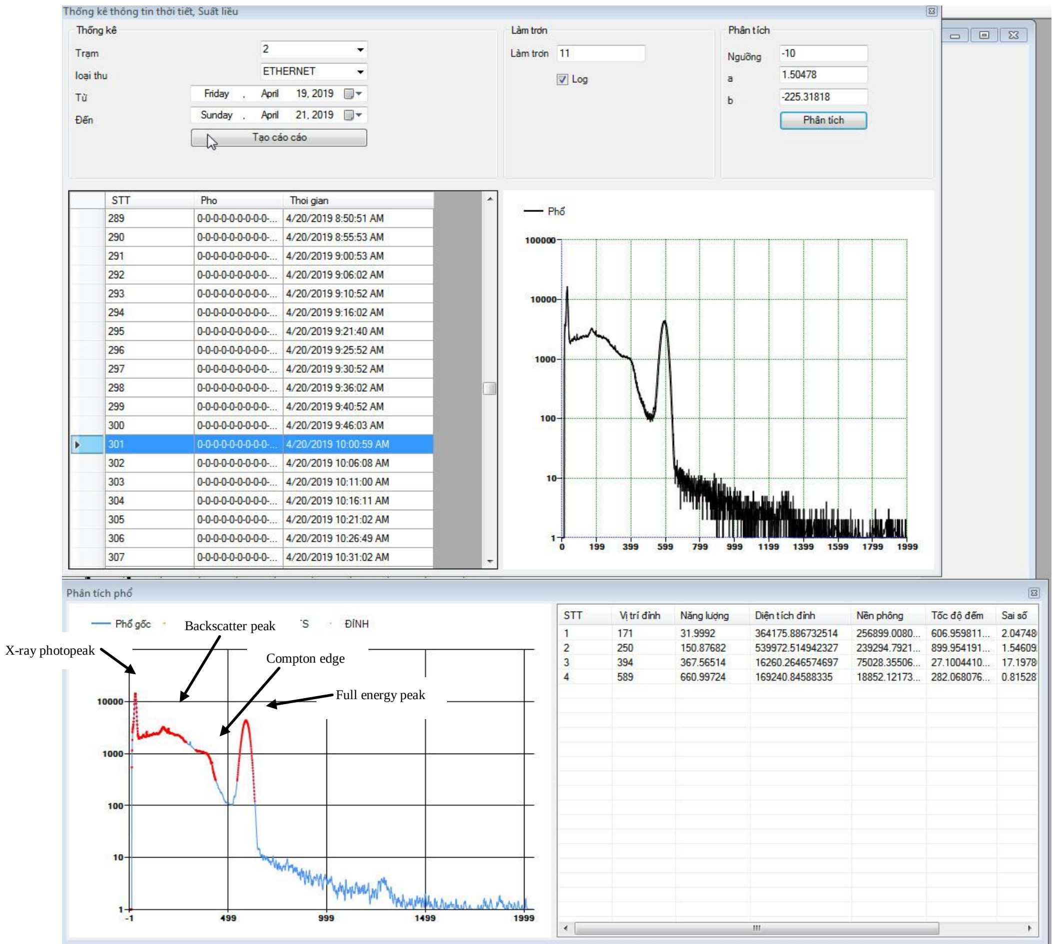

Figure 6. *Analytical result displayed for ^{137}Cs gamma spectra in the Central control software GUI*

3. CONCLUSION

The study confirmed the temperature dependence of gamma spectra collected by the NaI (Tl) scintillation detector. The new spectrum stabilization method allows adjusting the peak positions of the measured spectra at different temperatures in the range of 0.4℃ to 45℃ to reference peak positions measured at T = 25℃, with a relative deviation less than 2%. With this accuracy, our spectrum stabilization method can be used to stabilize the spectrum for automatic environmental monitoring stations.

However, it is necessary to have experimental studies in the practical environments with strong and unusual temperature fluctuation before applying this method to a radioactive monitoring systems environment in practice.

The method of gamma spectrum stabilization and photopeaks detection has been successfully applied to central control software in several environmental monitoring stations, allowing to identify radionuclides in local area.

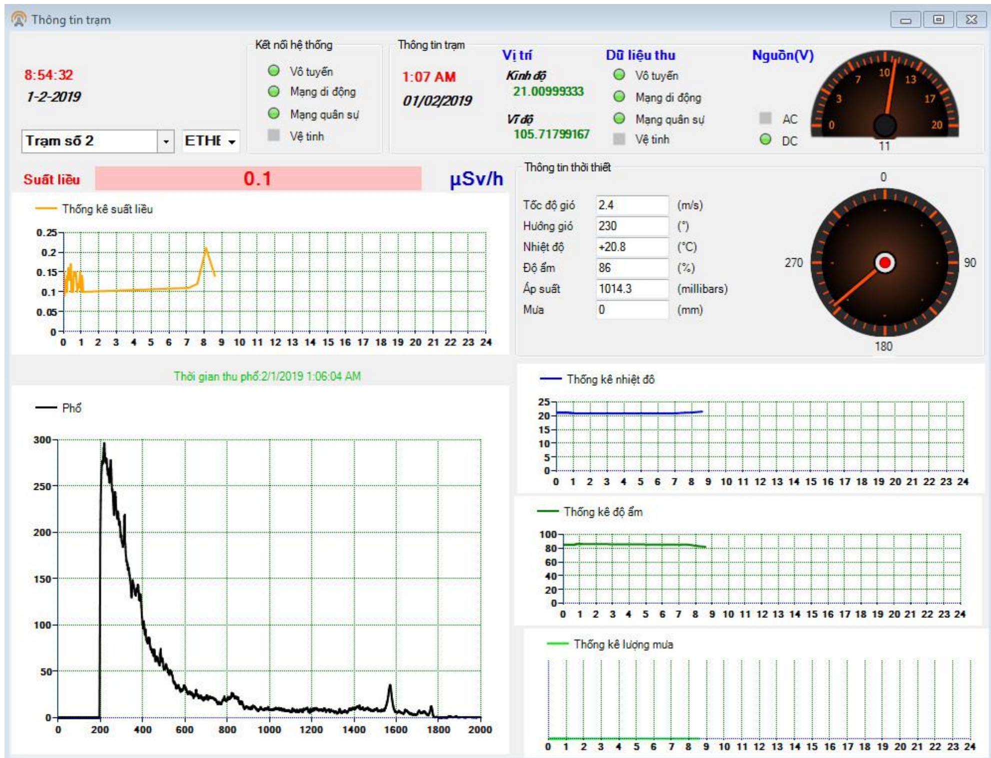

Figure 7. *The interface window of control software; where the dose rate, gamma spectrum, wind speed and direction, amount of rain, humidity, temperature, … are collected and displayed*

4. ACKNOWLEDGMENT

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XÂY DỰNG PHƯƠNG PHÁP ỔN ĐỊNH PHỔ VÀ THUẬT TOÁN NHẬN DIỆN ĐỈNH NĂNG LƯỢNG ĐỐI VỚI DETECTOR NHẤP NHÁY NaI(Tl)

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Tóm tắt: Các trạm quan trắc môi trường phóng xạ sử dụng detector nhấp nháy NaI(Tl) có độ nhạy cao hơn và cung cấp giá trị liều bức xạ chính xác hơn so với việc sử dụng các ống đếm Geiger-Muller. Tuy nhiên, khi nhiệt độ môi trường vùng đặt trạm quan trắc thay đổi thì số liệu hệ đo lại thay đổi (do độ ra sáng của tinh thể và hiệu suất lượng tử của ống nhân quang điện thay đổi mạnh theo nhiệt độ). Kếtquả nghiên cứu chỉ ra rằng vị trí đỉnh phổ có sự dịch chuyển tương đối lớn phụ thuộc vào nhiệt độ môi trường đo đạc. Do vậy, rất cần thiết hiệu chỉnh các phổ ở các nhiệt độ khác nhau về phổ đo ở điều kiện chuẩn (25℃). Ngoài ra, để phân tích phổ gamma thu nhận, một thao tác quan trọng trong quá trình xử lý phổ là tự động nhận diện vị trí đỉnh cũng như hình dạng và cường độ đỉnh năng lượng. Báo cáo này trình bày một phương pháp mới để ổn định phổ gamma và tự động nhận diện đỉnh phổ - dữ liệu quan trọng để tính liều bức xạ và xác định thành phần các đồng vị tạo nên trường gamma - theo nhiệt độ đối vớidetector NaI(Tl). Phương pháp này sử dụng thuật toán hiệu chỉnh phổ theo nhiệt độ của detector mà không cần thay đổi hệ số khuếch đại của hệ thống điện tử đi kèm.Việc sử dụng phương pháp ổn định phổ do nhóm nghiên cứu đề xuất cho sai số tương đối giữa vị trí đỉnh sau khi hiệu chỉnh và vị trí đỉnh tại nhiệt độ tham chiếu là nhỏ hơn2% trong toàn bộ dải nhiệt độ khảo sát từ 0.4℃ đến 45℃.

Keywords: *Detector nhấp nháy NaI(Tl); ổn định phổ; nhận diện đỉnh; phân tích phổ.*