Analysis of energy-peaks characteristic in NaI(Tl) spectrometer for radionuclide identification in environmental radiation monitoring device

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Abstract. The development of nuclear facilities has been emerging rapidly in this century, it’s causing the development of technology which concerns the quality of the environment is a must. Because this condition is related to the polluted nuclear radiation in the environment, especially in urban, and nuclear facilities. This causes an environmental radiation monitoring device is needed to determine abnormalities. Currently, the environmental radiation monitoring devices in the station only could monitors gross gamma radiation. The device cannot distinguish whether the increase in dose rate is due to abnormal events, or due to natural radiation. Therefore, we need a device that can have the ability of spectroscopy, thus it can distinguish the radionuclide source that causes an increase in the dose rate like NaI(Tl) gamma spectrometer. The device has been configured using a NaI(Tl) detector with a peak characteristic observation method with various conditions of acquisition time and dose rate. This was tested in laboratories using Cs-137 as a sample. Tests have been done by varying the value of time and dose rate when measure. Time used varies, 1 minute, 5 minutes, 10 minutes, 30 minutes, 60 minutes, 90 minutes and 120 minutes with a varying dose rate of 0.1479, 0.1115, 0.0956 and 0.0802 µSv/h. Data has been analyzed using the high summing ratio method to be able to distinguish measurement values using sample and background measurements. The result shows that the detector has stable when measuring for 30 minutes with FWHM value 60, and the dose rate is not less than 0.0802 µSv/h, and it was able to distinguish background and source value from 1-minute acquisition using a high summing ratio method.

1. Introduction
The significant increase in nuclear facilities for a fast time, make us should develop technology which concerns the quality of environmental, and consequently, the quality of life. Because it is related to the polluted nuclear radiation in the environment, especially in the urban, nuclear facilities, and contaminated area [1]. To maintain the quality of the environment, we need a device that can monitor in the field which is commonly called an environmental radiation monitoring device [2,3]. This tool monitors the radiation changes that occur in the environment, if there are significant changes that exceed a predetermined threshold, then this tool will act as an early information during emergency like...
nuclear facility accident. Thus, if we have early information, we could make recommendation for decision of PAZ and UPZ areas and zones [4–7].

Currently, environmental radiation monitoring device that it can only monitor changes in gross radiation in the environment. The radiation in the environment increases at certain situations such as when it rains. The special natural sources that usually increase when rain is the $^{222}\text{Rn}$ as progeny from $^{214}\text{Pb}$ and $^{214}\text{Bi}$, and it will be scavenged in the cloud then will be deposited on the ground during rain. This naturally source $^{222}\text{Rn}$ is the product of naturally source $^{238}\text{U}$ which have a long half-life (for 4.468 billion years) [8]. This situation will cause the radiation reading value on the monitor device to go up and make it possible to cause false warnings. This is because the environmental radiation monitoring equipment used has not been able to separate the radiation that is released naturally (natural phenomena) or releases that occur due to artificial processes. To be able to separate between natural radiation or from facility radiation, a gamma spectrometry facility is needed.

Radiation in the air whether it is a result of the release of nuclear facilities or natural radiation, is greatly influenced by weather factors [9]. In addition to the foregoing, radiation in the environment is affected by rain, radiation is also influenced by the movement of wind, humidity and environmental temperature. These parameters cause rapid changes that can cause measurements made by the detector to be less good. Therefore, we need a method that can quickly detect radionuclides in the environment and find out the types of radionuclide sources. To overcome this, we tried the high summing ratio method to detect the presence of radionuclides and their types of elements in the environment quickly.

2. Material and method

Data was taken using All in One Gamma Spectrometer based on NaI(Tl) crystal detector by Baltic Scientific Instruments (BSI) which use a USB cable as an interface communication with GammaPro desktop application in the computer [10]. GammaPro desktop application is an application provided by BSI which support NaI(Tl) detector via USB communication, this application has functions to plot the spectrum, FWHM (Full Width at Half Maximum) calculation, and save raw data in excel format or other [11]. Calibrated Inspector survey meter also used to get dose rate value from each varies distance. In this test, we are using Cs-$^{137}$ radionuclide source as a sample. This all devices and setup are shown in Figure 1.

![Laboratorium Test Setup](image1)

**Figure 1.** Lab test Setup.

![Blok diagram of Lab Test Step](image2)

**Figure 2.** Blok diagram of Lab Test Step.
Figure 2 shows block diagram test steps. In the First step, we get data from the detector using GammaPro via USB communication and save it to excel format, then we find FWHM value using Peak List feature in GammaPro application. To get dose rate value, we write the data from the calibrated survey meter and averaging the value for each varies distance. We are varying distance from 50 cm, 70 cm, 100 cm, 200 cm, and 300 cm that represented as 0.1479, 0.1115, 0.0956, and 0.0802 μSv/h. After the acquisition of all data, we process the data using high summing ratio method, this method following the equation (1) below.

\[ S_H(n_R) = \sum_{n=1}^{n_{max}} C_n \]  

Where \( SH \) is represented high energy sum value, \( nR \) is reference energy when the calculation was doing, \( n_{max} \) is the maximum energy value (this detector using 12-bit value which is mean maximum value at channel number 4095) and \( C_n \) is nth channel intensity count. This method is used to identify the difference between background value and peak count value through cross value, thus we can identify the kind of radionuclide source which detected [12]. After using high summing ratio method, then we continue to normalize the value. Normalization is important to make the trend looks smooth and easy to be identified, this process following the equation (2).

\[ \text{Norm}_n = \frac{S_H(n_R)}{\max(S_H(n_{R-4096}))} \]  

After this normalization step we can plot it to the chart and compare between background count and radionuclide source count. It will be showing the different patterns and will make a cross line between both. The cross line means the characteristic energy from each radionuclide source, so through this method we can identify a single radionuclide source.

3. Result and analysis

3.1. Gamma Spectrometry

The result of the test was shown in Figure 3. It is describing the spectrum of background acquisition for 1-minute measurement time in the frame (a) and Cs-137 radionuclide source for 1-minute measurement time in the frame (b). In background acquisition, nothing photopeak spectrum was found, only the effect of gamma rays in a matter like photoelectric, Compton edge or the other, and background value [13,14].

![Figure 3. Result of spectrum from GammaPro for (a) Background with 1 minute measurement time, and (b) Cs-137 at 50 cm with 1 minute measurement time.](image)

Different from background acquisition, radionuclide sample source acquisition has a photopeak spectrum, we can see that in the frame (b) it has peaked at around channel number 1003.9. The channel number 1003.9 was described as the energy of the Cs-137 sample source at 661.64 keV. Table 1 shows data results for each distance and measurement time photopeak from the GammaPro raw data. Table 2 shows that the photopeak has fluctuation value with 2.9 until a 3.787 deviation standard.
Table 1. The raw data of Photopeak channel number value from GammaPro Application.

| Distance (cm) | Dose rate Value (µSv/h) | Deviation (σ) | Channel number of peak at certain measurement time |
|--------------|--------------------------|---------------|---------------------------------------------------|
| 50           | 0.1479                   | 0.025         | 1003.900, 1010.600, 1008.400, 1004.000, 1004.600, 1001.900, 1003.250, 1002.575, 1002.913 |
| 70           | 0.1115                   | 0.028         | 1002.900, 997.110, 995.890, 996.500, 994.590, 995.190, 996.195, 991.170, 995.235 |
| 100          | 0.0956                   | 0.019         | 992.580, 988.830, 997.780, 999.040, 998.710, 1000.700, 996.273, 999.273, 998.273 |
| 200          | 0.0802                   | 0.022         | 1000.413, 1000.413, 1008.200, 1000.413, 1000.600, 1000.410, 1000.410, 1000.830, 1000.388 |

Table 2. The result of photopeak channel number fluctuation

| Distance (cm) | Dose rate Value (µSv/h) | Deviation (σ) | Channel Number of Photopeak |
|--------------|--------------------------|---------------|------------------------------|
| 50           | 0.1479                   | 0.025         | 1004.682, 1001.900, 1003.250, 1002.575, 1002.913 |
| 70           | 0.1115                   | 0.028         | 996.087, 996.500, 994.590, 995.190, 996.195, 991.170, 995.235 |
| 100          | 0.0956                   | 0.019         | 996.829, 997.780, 999.040, 998.710, 1000.700, 996.273, 999.273, 998.273 |
| 200          | 0.0802                   | 0.022         | 1000.409, 1000.413, 1000.600, 1000.410, 1000.830, 1000.388 |

From the result, we also can find FWHM value, FWHM is a method used to describe the resolution of the detector in separating between 2 closes energy photopeak [15]. Figure 3 frame (b) shows the facility from GammaPro to find FWHM value using peak list feature, for Cs-137 measurement at 50 cm for 1 minute measurement time, the FWHM value is 41.921.

3.2. FWHM value

Table 3 is the results of FWHM value from the GammaPro application, this result has been plotted in a chart shown in Figure 4.

Table 3. The result of FWHM value from GammaPro Application.

| Distance (cm) | Dose rate Value (µSv/h) | Deviation (σ) | FWHM value at certain measurement time |
|--------------|--------------------------|---------------|----------------------------------------|
| 50           | 0.1479                   | 0.025         | 41.921, 47.511, 44.716, 46.189, 47.661, 49.834, 49.044, 49.439 |
| 70           | 0.1115                   | 0.028         | 35.919, 51.840, 44.133, 46.230, 48.326, 48.740, 48.533, 48.637, 48.585 |
| 100          | 0.0956                   | 0.019         | 24.334, 46.580, 31.681, 37.698, 40.476, 41.386, 40.931, 41.159, 41.045 |
| 200          | 0.0802                   | 0.022         | 14.313, 19.056, 23.798, 28.541, 33.283, 35.263, 37.179, 38.136, 39.094 |

The lowest dose rate with the lowest FWHM value has a logarithmic fitting value in equation (3). Using this equation, we search the stable FWHM value using percentage method, we make a threshold value for the difference value between the current FWHM and the last before is not more than 1%. The result was described that the stable FWHM value is found at 15 minutes measurement value. It also means that if we use the energy point from the high energy sum graph as identifying radionuclide method, it has to more than 15 minutes measuring time be set up to get a stable result, and it is not enough as the radiation environment monitoring device specs.

\[ y = 12.338 \ln(x) + 12.301 \]
Figure 4. FWHM VS Measurement Time with Varies Dose Rate.

Table 3 was also described that the photopeak channel number fluctuation value from Table 2 with 2.9 until 3.787 deviations standard value is still inside the lowest FWHM value with 14.313 FWHM value, so the detector is still good for used as photopeak identifier.

3.3. High summing ratio method result

To get a faster method for identifying radionuclide sources in the radiation environment monitoring device, we use the high summing ratio as a method. Figure 5 shows us the result of the high summing ratio method and normalization from background and radionuclide source measurement. In the results, we can see that using a high summing ratio method and normalization, we have a similar pattern for each varies measurement time, and they have an identically cross value at the same number channel value which means they have the same energy. The result also shows that we can identify the radionuclide source from the fastest measurement time, as from 1-minute measurement time. This result shows us that the high summing ratio method is more suitable as an identifier radionuclide source method than identify radionuclide using the energy point from the high energy sum graph.

Besides we analyze the high summing ratio method with various measurement times, we also analyze how the high summing ratio method characteristics in any various dose rates. We got from 2 samples various time, 1-minute measurement time as fastest measurement time, and 30 minutes measurement time as the stable FWHM values measurement time. The result was shown in Figure 6 and Figure 7.

The results showed that each dose rate value has a different high summing ratio value, the greatest dose rates have the most clearly pattern to distinguish background pattern and radionuclide source pattern. Figure 7 shows that varying measurement time value did not change the pattern for significant and cross value channel numbers, but this varying measurement time will make a little bit different in chart pattern that is closer to the background because of the lowest counting value from the acquisition.
Figure 5. High Summing Ratio Method with 0.1115 μSv/h Dose Rates with Various Measurement Time.

Figure 6. High Summing Ratio Method with Various dose rates for 30 minutes measurement time.

Figure 7. High Summing Ratio Method with Various dose rates for 1 minute measurement time.
4. Conclusion
All in one NaI(Tl) gamma spectrometer can be used to be a radiation environmental monitoring device using a high summing ratio method to identify a single radionuclide source. This device has a stable ability to distinguish between background and radionuclide source or between one radionuclide and the other when we set measurement time for 15 minutes or more. The high summing ratio method can distinguish between background and radionuclide source within 1-minute measurement time, and it also not influenced by various measurement times. The device and method also can distinguish between background and radionuclide source with dose rates value 0.1479, 0.1115, 0.0956 and 0.0802 μSv/h, but the different pattern between background and radionuclide source depends on dose rates value, the lowest dose rate value will have less clearly different with the background pattern. This result shows that this configuration device, using All in one NaI(Tl) gamma spectrometer with a high summing ratio method has been suitable to applied in radiation monitoring devices based on spectroscopy.

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