Validation and calibration of efficiency of various standard source for radioactivity analysis of gamma soil samples

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Abstract. Gamma Spectroscopy is one of the instruments used in measuring the radioactivity of environmental components. However, an efficiency value from the gamma spectroscopy detector is needed in order to obtain an accurate measurement. Efficiency calibration of the detector can be determined from the calibration curve of the standard source used. The calibration curve of a standard source can be affected by the matrix. The study aims to examine the two of the adjacency matrixes from various standard source for radioactivity analysis of gamma soil samples. The efficiency calibration of standard matrix sand (EG-ML) and ore (IAEA-RGU-1) are $y = 3.1761 x^{0.838}$ and $y = 4.3459 x^{0.913}$ respectively. The qualitative measurement of the radioactivity analysis was not influenced by differences in the two standard sources used, where the analyzed soil samples contained K-$^{40}$, Bi-$^{212}$, Pb-$^{212}$, Bi-$^{214}$, Pb-$^{214}$, Ra-$^{226}$, and Ac-$^{228}$ which were natural radionuclides. However, the quantitative results of radioactivity values show differences with a percentage of 1.1% to 26.2% respectively. The validation of the method carried out on each EG-ML and IAEA RGU-1 standard source obtained satisfactory results with a bias value of $\leq 2\%$ is 1.2% and 4.3%, the precision value of $\leq 8\%$ is 0.6% and 1.4%, and the value of $Z \leq 2$ is 0.32 and 0.03 respectively.

1. Introduction

One of spectroscopy that is often used for radioactive sample analysis is the gamma spectrometer. High resolution gamma spectrometry is widely used for identifying and assaying gamma-emitting radionuclides in environmental samples. Gamma spectrometer usually consist of detectors, initial amplifier systems (pre-amplifiers), amplifier systems (amplifiers), single-channel analyzer circuits (SCAs), and counter circuits [1]. Each device has an important role in the gamma spectrometer. In the measurement of radioactivity for radioactive sources using a gamma spectrometer counter system there are several factors that need to be considered i.e. the type of detector, resolution of detector and detector efficiency [2,3,4].

High purity germanium detector (HPGe) is a semiconductor detector that is widely used in laboratories. HPGe detectors are very useful in determining the content of various radionuclides in radioactive waste and environmental samples i.e. soil, water, air, and living things [5,6]. Its excellent resolution and high efficiency allow HPGe detectors to be used for qualitative and quantitative analysis of various radionuclides in samples [7]. With these capabilities, various types of gamma-radionuclide transmitters in radioactive waste and environmental samples can be detected and their radioactivity could be determined.
The accuracy of the HPGe detector in quantitative analysis is largely determined by the efficiency of the detector. Detector efficiency is the ratio of the number of particles (gamma) counted by the detector to the number of particles emitted by the source. Determination of efficiency is done through direct calibration by determining the response of the detector to various gamma energies using known standard sources. Direct determination is a measurement that is often used for routine measurements such as environmental radiation monitoring and industrial samples which usually contain some radionuclides. In addition, the advantage of determining the calibration efficiency with radioisotope standards is that it is more practical, efficient, and traceable nationally or internationally than through computer simulations [8]. Efficiency is calculated on the various gamma energies then extrapolated within the detected energy range to generate an efficiency curve. The efficiency curve is used to calculate the radionuclide activity in the sample [9].

Accuracy and precision of efficiency calibration curves are very important for the quality of the detector efficiency. The quality of calibration efficiency is influenced by several factors. According to Tursinah et al. (2010), calibration efficiency is influenced by the shape and size of germanium crystals, window thickness, dead layer position, and sample matrix [7]. Likewise, according to Nurokhim (2014) the thickness of the dead layer of the HPGe detector and the geometry of the sample affect the efficiency curve [10]. According to Bahri (2007), the geometry factor and the matrix of the sample greatly affect the efficiency of the detector [11]. Also, according to Sukowati et al. (2014), besides measurement distances and geometric shapes, the most important is the proximity of the sample matrix to the standard [12]. According to Wahyudi et al. (2007) the geometry factors that affect measurements in the gamma spectrometer are the source container, source distance with the detector, matrix composition and standard density. The density of the matrix influences the counts of the gamma spectrometer [9].

Nowadays, the constraint of the measurement of radioactivity is the limited availability of standard sources with a variety of matrices that appropriate to the samples. In addition, despite having the same species, it is possible that there are differences in the composition of the constituent elements in the sample lead differences in density. For example, differences in the composition of elements in soil samples due to differences in the characteristics of one place with another place. Therefore, testing of various standard sources that have an adjacency to the sample matrix needs to be done in order to determine the selection of appropriate standard sources so as to obtain accuracy of good measurement results.

2. Materials and Method
2.1 Materials and Apparatus
This study has been conducted with the following materials are standard source of EG-ML sand matrix radionuclides from Eckert-Ziegler, RGU-1 ore matrix radionuclides from IAEA, liquid nitrogen, Point standard of Am-241 with energy 59.6 keV, Cs-137 with energy 661.6 keV, and Co-60 with energy 1173.4 and 1332 keV from LMRI Coffret d'etalons type gamma ECGS 1, Marinelli container 500 mL, and five soil samples with code of SC-1, LSC-1, KP-1, KP-2, CL-1, and CL-2.

The equipment used is a mortar, pestle, porcelain cup, spatula, 100 mesh sieves from W.S. TYLER, the analytical balance from Mettler Toledomodel, incandescent lamp, gamma spectrometer with Canberra model HPGe type detector and integrated Genie 2000 software.

a. Method
2.2.1 Calibration of Gamma Energy and Determination of Efficiency
Calibration of gamma energy spectrometer was performed using point standard sources i.e. Am-241 with 59.6 keV energy, Cs-137 with 661.6 keV energy, and Co-60 with 1173.4 and 1332 keV energy placed above the detector at a distance of 19 cm. Adjustments conducted using Genie 2000 software to convert channel to energy in kilo-electron volts (keV) [13].

The detector efficiency calibration was performed with the EG-MLmulti-nuclide standard sand matrix and IAEA RGU-1 ore matrix in 500 mL of Marinelli geometry. Each multi-nuclide standard was
counted for 20,000 seconds to obtain the results of their net counts in counts per second (cps) from each gamma spectra arises.

Calibration efficiency was obtained from mathematical equations as follows:

\[ \varepsilon = \frac{\text{cps}}{A \cdot I \gamma \cdot m} \]  

where \( \varepsilon \) is the detection efficiency, \( \text{cps} \) is the measured count rate (counts per second) from the standard measurement, \( A \) is the certificate standard activity (Bq/kg), \( I \gamma \) is percentage of the characteristic constant of each gamma-ray with a specific energy of radionuclides (yield), and \( m \) is the mass of standard (kg) [8].

The determination of the efficiency curve is carried out in the range of low energy to high energy from various radionuclides contained in the standard until an equation can be obtained to be used in determining samples' radioactivity. The data is processed in Microsoft Excel to obtain the efficiency curves of each standard to form mathematical equations. Calibration of the efficiency of the HPGe detector through the EG-ML standard source efficiency curve is extrapolated from the energy range 122 keV to 1333 keV and the IAEA RGU-1 ore matrix standard efficiency curve from the energy range 87 keV to 1661.28 keV with the characteristics of both a decrease in efficiency exponentially as gamma energy increases.

2.2.2 Radioactivity Measurement of Soil Samples

Soil samples from various areas are cleaned from impurities then dried under incandescent lamps at temperatures of 40-50 °C for 1-2 days until dry soil is obtained. The dry soil is then ground until smooth with mortars and then sieved with a 100-mesh sieve until a smooth soil is obtained. Then each soil samples were weighed ~0.5 kg and put into 500 mL Marinelli and tightly closed. Sample geometry was made closely the same with the standard. Soil samples ready to be analyzed.

Each soil sample that was ready to be analyzed was counted with a gamma spectrometer. The counting process including counting of 6 soil samples and an empty Marinelli (background) with each counting time of 20,000 seconds. Background counting is intended as a correction factor for sample counts. The gamma spectra of radionuclides were obtained from each ground and background sample.

The radioactivity of a sample can be determined through the following equation:

\[ A = \frac{(N_t - N_b)}{\varepsilon \times I \gamma \times W} \]  

where \( A \) is the activity of radionuclide (Bq/kg), \( N_t \) is the sample count rate (cps), \( N_b \) is the background count rate (cps), \( \varepsilon \) is efficiency, \( I \gamma \) is gamma radiation emission (%), and \( W \) is the sample mass (kg) [14].

Some radionuclides were categorized into natural radionuclides. Natural radionuclide identification could be determined by seeing decay (daughter nuclides) from the U-238 series (Figure 1) and Th-232 series (Figure 2).

\[
\begin{align*}
^{238}_{92}U &\to ^{234}_{90}Th \to ^{234}_{91}Pa \to ^{234}_{92}U \to ^{230}_{90}Th \to ^{226}_{88}Ra \to ^{222}_{86}Rn \to ^{218}_{84}Po \to ^{214}_{82}Pb \to ^{214}_{83}Bi \\
&\to ^{214}_{84}Po \to ^{210}_{82}Pb \to ^{210}_{83}Bi \to ^{210}_{84}Po \to ^{206}_{82}Pb
\end{align*}
\]

Figure 1. Scheme of U-238 decay
\[
{^{232}Th \rightarrow ^{228}Ra}^{\alpha} \rightarrow ^{228}Ac \rightarrow ^{224}Ra \rightarrow ^{220}Rn \rightarrow ^{216}Po \rightarrow ^{212}Pb \rightarrow ^{212}Bi
\]

**Figure 2.** Scheme of Th-232 decay

2.2.3 *Estimation of Uncertainty Value*

Determination of the uncertainty of radioactivity value using the following equation as follows:

\[
\mu A = A \times \sqrt{\left(\frac{\mu_{\text{net peak}}}{\text{net peak}}\right)^2 + \left(\frac{\mu_I}{I}\right)^2 + \left(\frac{\mu_W}{W}\right)^2}
\]  

(3)

where \(\mu A\) is uncertainty of activity, \(A\) is activity (Bq/kg), \(\mu_{\text{net peak}}\) is uncertainty of peak area, net peak is area of peak, \(\mu_I\) is uncertainty of gamma intensity, \(I\) is gamma intensity (%), \(\mu_W\) is uncertainty of sample weight, and \(W\) is sample weight (kg) [15].

2.2.4 *Validation of Method*

Method validation determines the percentage bias value, which compares the results of measurement of activity on certain radionuclides against the value listed on the certificate (each standard), the percentage of precision, and the value of \(Z\) (Z-score). The difference in the results of the two standards can be written with the following equation:

\[
\frac{\% \text{Bias}}{A_{\text{spl}} - A_{\text{std}}} \times 100
\]

(4)

where \% bias is the difference in the value of sample and standard activity (%), \(A_{\text{spl}}\) is the value of sample activity (Bq/kg), and \(A_{\text{std}}\) is the value of standard activity (Bq/kg). The value of acceptable standard source validation is \(\leq 5\%\) [16]. Evaluation of the test is also done by calculating the value of precision (\(P\)) in the criteria for acceptance of test results. The precision value that meets the criteria is \(P \leq 8\%\), the value of \(P\) is determined through the following equation:

\[
P = \sqrt{\left(\frac{\mu_{A_{\text{std}}}}{A_{\text{std}}}\right)^2 + \left(\frac{\mu_{A_{\text{test}}}}{A_{\text{test}}}\right)^2} \times 100\%
\]

(5)

where \(P\) is the value of precision (%), \(\mu_{A_{\text{std}}}\) is the uncertainty of the standard activity, \(A_{\text{std}}\) is the standard activity (Bq/kg), \(\mu_{A_{\text{test}}}\) is the uncertainty of the sample activity from the laboratory, \(A_{\text{test}}\) is the laboratory test activity (Bq/kg) [17]. The value of \(Z\) determined through the equation is presented below:

\[
|Z| = \frac{\% \text{Bias} \sqrt{\mu_{A_{\text{std}}}}}{\sqrt{\mu_{A_{\text{std}}}^2 + \mu_{A_{\text{test}}}^2}}
\]

(6)

where \(|Z|\) is the quantitative value of the proficiency test results. If the value of \(Z \leq 2\) then the results of the proficiency test are satisfactory, if \(2 < |Z| < 3\) is considered, and if the value of \(Z \geq 3\) is unsatisfactory [18].
3. Results
3.1. Determination of Efficiency Calibration Curves
The results of the counting of the two standard sources of EG-ML and IAEA RGU-1 multi-nuclides obtained net peak area, uncertainty of net peak area, yield, and gamma energy which then made the efficiency curve using equation 1. Mathematics equations were obtained on the source efficiency curve of the sand matrix EG-ML standard and the IAEA RGU-1 ore matrix standard respectively, successively are presented as follows:

\[ y = 3.7352x^{-0.838} \text{ with } R^2 = 0.989 \]  

(7)

and

\[ y = 4.3459x^{-0.913} \text{ with } R^2 = 0.997 \]  

(8)

where the y-axis is the measurement efficiency value at a certain energy and the x-axis is the gamma energy in keV which can be seen in Figure 3 as follows:

\[ \text{Figure 3. Efficiency calibration curve on A), EG-ML sand matrix standard; B), IAEA RGU-1 ore matrix standard} \]
Each efficiency curve has a value of $R^2$ close to 1 that the equation above has good linearity to the true value. The determination of the energy range on the efficiency curve is determined because it is estimated that the radionuclide content in the soil sample is natural radionuclide which has a gamma energy of more than 100 keV. Determination of radionuclides in samples that have a certain gamma energy range, an efficiency curve is needed with the gamma energy range from the appropriate standard source.

Two standard source efficiency curves were used to measure radioactivity in the samples with conditions close to the standard matrix composition. Sand and ore matrix have a proximity to the soil matrix in the sample, the researchers conducted a test of the proximity of the measurement results of radionuclides activity in the sample. In measuring of soil samples, the geometry of the sample is made closely to the two standard sources using a 500 mL Marinelli container made from polyethylene.

3.2. Radionuclide Identification in Samples

Radionuclides can be identified using a gamma spectrometer with the Genie 2000 software integrated in it. Qualitative analysis was carried out to analyze the type of radionuclides contained in the sample by determining the energy spectrum produced from the results of the counted spectrometer which was compared with the gamma energy table in the literature. Quantitative analysis was carried out to determine the radionuclide activity in the sample through the calculation of the detector efficiency curve using the standard EG-ML sand matrix and the IAEA RGU-1 ore matrix standard. The equation obtained is used as an efficiency for radionuclide measurements to be used to determine the value of radionuclide activity in samples in units of becquerel per kilogram (Bq/kg).

The results of the qualitative analysis of the samples were obtained from the counting results using a gamma spectrometer in the energy peak spectrum as shown in figure 4 which shows the six soil samples containing radionuclides i.e. K-40, Bi-212, Bi-214, Pb-212, Pb-214, Ra -226, and Ac-228 which is a natural radionuclide.

U-238 and Th-232 series are primordial radionuclides that have formed long ago in the earth. The decay of U-238 and Th-232 in nature over millions of years emits radiation in various types of energy, one of which is gamma energy together with the release of its daughter nuclides. Determination of radionuclide activity of U-238 and Th-232 from several methods carried out can be determined from the descendants of each of Ra-226 and Ac-228 respectively. Radionuclide Ra-226 decays to produce Pb-214 and Bi-214 while Ac-228 decays to produce Pb-212 and Bi-212. While the K-40 radionuclide is a self-made radionuclide not included in the U-238 and Th-232 series. Radionuclide K-40 is found in nature and is contained in almost every component of the environment such as soil, air, sediments, and plants [19, 20, 21].
3.3. Analysis of Radionuclide Activity in Samples

Quantitative analysis was carried out to measure the radionuclide activity in the sample using the efficiency curves from the two standard sources used EG-ML sand matrix and IAEA RGU-1 ore matrix to see the performance of the obtained efficiency curve. In addition, a comparison of the value of the measurement results of the radionuclide activity of the sample analysis results based on the two efficiency curves to be able to see the extent of the difference in value indicated.

Based on the calculation results obtained by the comparison of the activity data of each sample from the two efficiency curves can be seen in Table 1-6 as follows:

| Nuclide    | $A_{\text{std. EG-ML}}$ (Bq/kg) | $A_{\text{std. RGU-1}}$ (Bq/kg) | %|Bias |
|------------|---------------------------------|---------------------------------|---|------|
| K-40       | 96.12 ± 1.06                    | 121.33 ± 1.34                   | 26.23 |
| Bi-212     | 9.71 ± 0.11                     | 12.03 ± 0.13                    | 23.81 |
| Pb-212     | 13.36 ± 0.13                    | 14.00 ± 0.13                    | 1.10  |
| Bi-214     | 9.58 ± 0.11                     | 11.74 ± 0.13                    | 22.55 |
| Pb-214     | 9.19 ± 0.10                     | 10.35 ± 0.11                    | 12.71 |
Table 2. Comparison of radionuclide activity on sample code CL-2

| Nuclide | $A_{\text{std. EG-ML}}$ (Bq/kg) | $A_{\text{std. RGU-1}}$ (Bq/kg) | %|Bias |
|---------|---------------------------------|---------------------------------|--------|
| K-40    | 115.95 ± 1.27                   | 146.36 ± 1.61                   | 26.23  |
| Bi-212  | 13.82 ± 0.15                    | 17.17 ± 0.19                    | 24.26  |
| Pb-212  | 9.15 ± 0.10                     | 9.66 ± 0.11                     | 5.61   |
| Bi-214  | 8.60 ± 0.09                     | 10.54 ± 0.12                    | 22.49  |
| Pb-214  | 6.69 ± 0.07                     | 7.54 ± 0.08                     | 12.65  |

Table 3. Comparison of radionuclide activity on sample code SC-1

| Nuclide | $A_{\text{std. EG-ML}}$ (Bq/kg) | $A_{\text{std. RGU-1}}$ (Bq/kg) | %|Bias |
|---------|---------------------------------|---------------------------------|--------|
| K-40    | 51.48 ± 0.51                    | 64.98 ± 0.64                    | 26.23  |
| Bi-212  | 8.00 ± 0.08                     | 9.23 ± 0.09                     | 15.33  |
| Pb-212  | 15.28 ± 0.15                    | 16.02 ± 0.16                    | 4.79   |
| Bi-214  | 6.42 ± 0.06                     | 7.83 ± 0.08                     | 22.03  |
| Pb-214  | 9.23 ± 0.09                     | 10.40 ± 0.10                    | 12.71  |

Table 4. Comparison of radionuclide activity on sample code KP-1

| Nuclide | $A_{\text{std. EG-ML}}$ (Bq/kg) | $A_{\text{std. RGU-1}}$ (Bq/kg) | %|Bias |
|---------|---------------------------------|---------------------------------|--------|
| K-40    | 54.76 ± 0.63                    | 69.12 ± 0.79                    | 26.23  |
| Bi-212  | 24.79 ± 0.28                    | 29.80 ± 0.34                    | 20.20  |
| Pb-212  | 32.82 ± 0.38                    | 34.29 ± 0.39                    | 4.48   |
| Bi-214  | 18.83 ± 0.22                    | 23.04 ± 0.26                    | 22.37  |
| Pb-214  | 18.68 ± 0.21                    | 21.06 ± 0.24                    | 12.74  |

Table 5. Comparison of radionuclide activity on sample code KP-2

| Nuclide | $A_{\text{std. EG-ML}}$ (Bq/kg) | $A_{\text{std. RGU-1}}$ (Bq/kg) | %|Bias |
|---------|---------------------------------|---------------------------------|--------|
| K-40    | 39.21 ± 0.44                    | 49.49 ± 0.56                    | 26.23  |
| Bi-212  | 22.34 ± 0.25                    | 27.61 ± 0.31                    | 23.59  |
| Pb-212  | 45.73 ± 0.52                    | 47.56 ± 0.54                    | 3.98   |
| Bi-214  | 18.58 ± 0.21                    | 22.80 ± 0.26                    | 22.69  |
Table 6. Comparison of radionuclide activity on sample code LSC-1

| Nuclide | $A_{\text{std. EG-ML}}$ (Bq/kg) | $A_{\text{std. RGU-1}}$ (Bq/kg) | %|Bias| |
|----------|----------------------------------|----------------------------------|----------------|--------|
| K-40     | 51.51 ± 0.58                     | 65.03 ± 0.73                     | 26.23          |
| Bi-212   | 12.44 ± 0.14                     | 14.81 ± 0.17                     | 19.01          |
| Pb-212   | 20.53 ± 0.23                     | 21.42 ± 0.24                     | 4.33           |
| Bi-214   | 12.19 ± 0.14                     | 14.89 ± 0.17                     | 22.17          |
| Pb-214   | 11.97 ± 0.13                     | 13.50 ± 0.15                     | 12.75          |

Based on table 1-6, the value of sample radionuclide activity measured using the efficiency curve of EG-ML sand matrix standard source was smaller than the value of sample radionuclide activity using the curve of RGU-1 ore matrix standard source. Radionuclide K-40 activity showed the highest value in each sample. The highest of K-40 radioactivity were found in sample of CL-2 i.e. 115.95 ± 1.27 Bq/kg (EG-ML) and 146.36 ± 1.61 Bq/kg (RGU-1). The highest of Bi-212 showed in sample of KP-1 that were 24.79 ± 0.28 Bq/kg (EG-ML) and 29.80 ± 0.34 Bq/kg (RGU-1). The highest of Pb-212 radioactivity showed in sample of KP-2 that were 45.73 ± 0.52 Bq/kg (EG-ML) and 47.56 ± 0.54 Bq/kg (RGU-1). The highest of Bi-214 radioactivity showed in sample of KP-1 that were 18.83 ± 0.22 Bq/kg (EG-ML) and 23.04 ± 0.26 Bq/kg (RGU-1). The highest of Pb-214 radioactivity showed in sample of KP-1 that were 18.68 ± 0.21 Bq/kg (EG-ML) and 21.06 ± 0.24 Bq/kg (RGU-1). The differences of the radioactivity value in each sample indicate that the difference of the nuclide composition in each sample that does not rule out the differences in the composition of the elements. In addition, the difference of the radioactivity percentage value on the sample measurements using efficiency curve of the EG-ML sand matrix standard and efficiency curve of the IAEA RGU-1 ore matrix standard have the highest percentage difference obtained from the K-40 radioactivity at 26.23% while the lowest percentage difference obtained from Pb-212 radioactivity at 3.98%.

These results show that it has differences value in measurement of radioactivity of the soil samples using the EG-ML sand matrix standard and IAEA RGU-1 ore matrix standard. The difference of matrix has a big effect on the measurement results despite having the proximity of the matrix type. Thus, the method of measuring radioactivity in soil samples using both standard sources could be conducted but it was to be refined approach.

3.4. Validation of Method

Calculations used in the standard source of EG-ML sand matrix were carried out on the activity of one of the radionuclides, namely Cs-137 with a half-life of 30.17 years.

Table 7. Validation of Standard EG-ML Sand and IAEA RGU-1 Ore.

| Radioactivity on February 6, 2019 | Radioactivity on February 7, 2019 |
|----------------------------------|----------------------------------|
| $A_{\text{Cs-137}}$ (Bq/kg)      | $A_{\text{U-238}}$ (Bq/kg)       |
| $A_{\text{laboratory}}$          | 2189.276 ± 13,942                |
| $A_{\text{certificate EG-ML sand}}$ | 1783.265 ± 0,031                 |
| Bias (%)                         | 4.390                            |
| Precision (%)                    | 0.637                            |
| $Z$-score                        | 0.315                            |
|                                  | 5031.306 ± 71,349                |
|                                  | 4940.000 ± 0,006                 |
|                                  | 1.848                            |
|                                  | 1.418                            |
|                                  | 0.026                            |
Whereas at the IAEA standard source RGU-1 the ore matrix was carried out on one of the radionuclides namely U-238 with a half-life of $4.4689 \times 10^9$ years. The results of validation were presented in the Table 7.

Based on table 7, it is found that the percentage of bias obtained from the EG-ML standard was 4.39%, the precision percentage was 0.637%, and the Z score was 0.315. Whereas the percentage of bias obtained from IAEA RGU-1 standard was 1.848%, the precision percentage was 1.418%, and the Z score was 0.026. From these results show that the radioactivity analysis using gamma spectrometer at the Environmental Radioactivity Analysis Laboratory, PSTNT BATAN Bandung was satisfactory where the percentage of bias values was ≤ 5%, i.e. 4.39% (EG-ML) and 1.85% (RGU-1), the percentage of precision was ≤ 8%, i.e. 0.64% (EG-ML) and 1.42% (RGU-1), and the Z score ≤ 2 i.e. 0.32 (EG-ML) and 0.03 (RGU-1).

4. Conclusion

Radioactivity in the soil matrix sample of environmental components analyzed by the calibration curve of the efficiency of the sand matrix and ore matrix shows varying values that depending on the composition of the nuclides contains. Comparison of the efficiency calibration curve at the standard source of sand and ore matrix multi-nuclides shows different results, where the activity value of radionuclide measured using the efficiency curve of sand matrix standard is smaller than using the efficiency curve of ore matrix standard. Sand and ore matrix standard sources could be used as a reference for radioactivity analysis of environmental components in the soil matrix, although improvements are still needed. The performance of the calibration efficiency curve of each sand and ore matrix standard source used for radioactivity analysis of environmental components in the soil matrix samples has shown results including qualitative and quantitative analysis of various radionuclides contained in soil samples have satisfactory results with validation of bias value was ≤ 2% i.e. 1.2% and 4.3%, precision values was ≤ 8% i.e. 0.6% and 1.4%, and Z score was ≤ 2 i.e. 0.32 and 0.03 respectively.

References
[1] Sari, H.L. & Budi, W.S., (2017). *J. Young. Phys* 6 151-56
[2] Candra, H., Pujadi, & Wurdiyanto. G. (2010). *Prosiding Pertemuan Ilmiah XXIV HFI Jateng dan DIY* Semarang 258-64
[3] Alauddin, A.B., Wicaksono A.S., and Sunardi, J., (2012). *J. Forum Nuklir* 6 11-7
[4] Aziz, M., Hidayanto, E., & Lestari, D.D., (2015). *Young. Phys. J.* 4 89-96
[5] Khandaker, M.U., (2011). *International J. Fundamental Physic Science.* 1 42-6
[6] Syahputra, A.Y., Sasongko, D.P., Arifin, Z., and Sukimo, (2017). *Young Physic Journal.* 6 315-22
[7] Tursinah, R., Santoso, M., & Suherman, A., (2010). *Prosiding Seminar Nasional Keselamatan dan Lingkungan (VI)* Jakarta 79-85
[8] Wahyudi, Iskandar, D. & Marjanto, D., (2007). *J. Forum Nuklir* 1 65-78
[9] Sudiyati, (2005). *Buletin Limbah* 9 21-7
[10] Nurokhim, (2014). *J. Tekn. Pengolahan Limbah.* 17 21-30
[11] Bahri, S., (2007). *J. Gradien* 3 204-9
[12] Sukowati, K., Sujiyanto, G.S., & Muharini, A., (2014). *TEKNOFISIKA.* 3 28-34
[13] Luhur, N. & Subiharto, K., (2013). *Buletin Pengelolaan Reaktor Nuklir.* 10 22-30
[14] Susetyo, W., (1988). *Gamma Spectrometric and Its Applied for NAA.* (Yogyakarta-Gadjah Mada University Press)
[15] Tsoulfsnidis, N., (1995). *Measurement and Detection of Radiation* (NY-Hemisphere Pub.)
[16] Sunardi, S.T., (2006). *Validation of Method of AANC with Neutron Generator for Implementation of the Quality Assurance Testing Program* (Yogyakarta-PTAPB-BATAN)
[17] IAEA (2005). Environmental Radiation Monitoring and Regional Data Base: Final Report *Proficiency Test on the Determination of Alpha, Beta, and Gamma-emitting Radionuclides* (Seibersdorf-IAEA). TC Project RAS/9/2004

[18] ISO 1997 ISO/IEC GUIDE 43-1: Proficiency Testing by Interlaboratory Comparation. Part 1 Second Edition (*Geneva-Development and Operation of Proficiency Testing Schemes*)

[19] Desideri, D., Battisti, P., Giardina, I., Roselli, C., Feduzzi, L., Gorietti, D., & Meli, M.A., (2019). *Food Chemistry*. 279 408-15

[20] Konya, J. & Nagy, N.M., (2018). Chapter 13 - *Environmental Radioactivity, Nuclear and Radiochemistry* 2nd Ed. 339-419

[21] Lely N, Yulianti, N.&Hindarto,(2012)*Unnes Phys.*1 1-7