Elemental Analysis of Wepal Sample Using INAA In The Framework of The 2017 IAEA Proficiency Test Program

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Abstract. The 2017 IAEA Proficiency Test Program has been carried out to improve the performance of the Neutron Activation Analysis (NAA) laboratory. This activity has been organized by the International Atomic Energy Agency (IAEA) cooperated with Wageningen Evaluating programs for Analytical Laboratory (Wepal). Eight samples of ISE (soil samples) and IPE (plant samples) obtained from Wepal under the 2017 Proficiency Test program. Moisture content has been determined using a gravimetric method at 105-110°C and 100-105°C for ISE and IPE samples respectively. Target irradiation was carried out for long, medium, and short irradiation using a thermal neutron flux of about 2.3x10^13 n.cm^-2.s^-1 at the rabbit facility of GA Siwabessy reactor. Elemental analysis has been done using kay zero (k0) and comparative method of Instrumental Neutron Activation Analysis (INAA). On the kay zero-INAA method, the Al-0.1%Au alloy of IRMM-530R has been used as a flux monitor. Short half-life radionuclide was calculated using an Excel program for the comparative method and correction for a dead and counting time was applied. Quantitative determination has been carried out on a dry weight basis. The water content of the IPE sample was higher than that of the ISE sample. The result of the moist content of the IPE sample was in the range of 8% to 10%; meanwhile the moist content of the ISE sample was 2% to 6%. The elements detected on the IPE samples were less than that on the ISE sample. The elements of Na, Mn, V, Cl, Sc, Fe, Co, Zn, As, Br, Rb, Zr, Sb, Cs, Ba, La, Ce, U, and Th have been determined. In the meantime, for IPE sample, the elements of K, Na, Mn, Cl, Mg, Al, Ca, Cr, Fe, Co, Zn, Br, Rb, Sr, Sb, Cs, La, and Th can be evaluated quantitatively. Most of the elements evaluated have Z-score and Zeta-score of -3 to +3, which indicate good analytical performance for some elements, but for the element, some of them are out layer.

1. Introduction

Improvement of research reactor utilization (RRU) is often followed by increasing the nuclear analytical technique (NAT) activities. This NAT, in principle, is available in more than half of operational RRU worldwide [1]. The INAA, one of NAT, is it still suitable as an analytical tool for multielement quantification [2][3][4]. It has a high capability on elemental quantification; meanwhile, the markets for NAA laboratories may have also been founded and identified. The utilization of k. INAA method on the NAA laboratory is currently a trend towards increasing compared to a comparative method [5][6][7][8]. However, a problem remains are still obtained on the implementation of quality control and quality assurance (QA/QC) in the NAA laboratory. The QA/QC has an essential role in the NAA laboratory[9]. Whereas the markets for NAA laboratories may have been founded and identified, a problem remains
on QA/QC. In this context, a study to evaluate the level of performance of NAA laboratories has been conducted by the IAEA since 2010.

Regarding to the above problem, the proficiency test program was carried out under coordination of IAEA who cooperate with an accredited company of Wageningen Evaluating Programs for Analytical Laboratories (WEPAL) of Wageningen University, Netherlands, prepared and distributed the samples as part of their International Soil-analytical Exchange (ISE) and International Plant-analytical Exchange (IPE) programs [1]. The IAEA has responsible for data evaluation and reporting [1].

The objectives of this inter-comparison study were to evaluate the performance of the neutron activation analysis laboratory through the Proficiency Test Program under the coordination of the IAEA, to identify significant problems encountered and to discuss potential solutions for laboratory improvement. A particular goal was given to QA/QC in the elemental quantification of different samples. In this case, a Z-score, Zeta-score, relative bias, and U-test will be used as a parameter to evaluate the performance of the analytical result.

2. Methodology

The detail method of the NAA utilization for quantitative analysis have been reported and published [3][4][5]. Four plan sample and four soil samples have been obtained from WEPAL under IAEA coordination. The sample obtained is IPE-238 Banana Leaf, IPE-159 Lucerne, IPE-215 Pepper fruit, IPE-203 Cabbage and four soil sample ISE-874 Sandy Soil, ISE-876 Clay, ISE-863 Clay Soil, ISE-866 Loess. All plan sample has been dried at 100°C for 3 hours until constant weight obtained; in the meantime, the soil sample has been dried at 110°C hours.

About 50 mg to 100 mg of dry sample was weighted on cleaned 0.7 mL micro Vial (Cole Parmer, Polyethylene, 983 mg/L) and was sealed using a hot glass rod. Alloy Al-0.1%Au has been used as a comparator to determine a thermal neutron flux at the same position of the sample. Than target placed on rabbit capsule for medium irradiation and aluminum capsule for long irradiation [Figure 1]. Irradiations have been carried out at the irradiation channel of rabbit system for 30 minutes and 4 hours respectively at a reactor power of 15 MW. Water content has been calculated using equation (1) below,

\[ W_C = \frac{(W_{\text{wet}} - W_{\text{dry}})}{W_{\text{dry}}} \cdot 100 \]  

Where \( W_C \) is Water Content, \( W_{\text{wet}} \) and \( W_{\text{dry}} \) are wet weight and dry weight, respectively. Moreover, a corrected concentration of elements have been calculated using equation (2),

\[ [C]_{\text{corr}} = \frac{x}{(1 - W_C)} = \frac{x}{1 - W_C} \]  

\( [C]_{\text{corr}} \) is corrected analytical result, and CF is a correction factor applied. The result of induced nuclear reaction was measured using a high-resolution HPGe detector (Canberra, Coaxial type, Resolution of 1.99 keV at 1332.4 keV of \( ^{57}\)Co, P/C=40) after three days decay for medium half-life, and 1 – 2 weeks for long half-Life radionuclides, respectively. The gamma-ray spectrum obtained was analyzed using Hyperlab software.
Figure 1. Target irradiation for medium and long irradiation at the rabbit system of the GA Siwabessy Multipurpose reactor at Serpong.

Quantitative analysis has been carried out using k method using k-IAEA software [6][7]. The parameter Z-score [10], Zeta (ξ)-score[11], relative bias [10], and U-test [10] have been used to evaluate the analytical result. The Z-score and Zeta(ξ)-score were calculated using Equation (3) and (4), meanwhile U-test, equation (5), used for an acceptance criteria determination for analytical result[10]. Table 1 of the U-test has been used to determine acceptance criteria.

\[
Z_{score} = \frac{X - X_{ref}}{\sigma_R}
\]

and

\[
\xi = \frac{X - X_{ref}}{\sqrt{X^2 + X^2_{ref}}}
\]

\[
U - test = \frac{|X - X_{ref}|}{\sqrt{U^2 + Unc^2_{ref}}}
\]

Table 1. The acceptance criteria for U-test [10]

| U      | Acceptance Criteria                                      |
|--------|----------------------------------------------------------|
| U ≤ 1.64 | The reported result does not differ from the assigned values |
| 1.64 ≤ U ≤ 1.95 | The reported result probably does not differ from an assigned value |
| 1.95 ≤ U ≤ 2.58 | It is not clear whether the reported value and assigned value differ. |
| 2.58 ≤ U ≤ 3.29 | The reported result probably different from an assigned value |
| 3.29 ≤ U | The reported result differs from the assigned values |
3. Result and Discussion

Various methods of determining the moisture content have been published [12][13][14]. However, the application of drying temperature significantly affects the release of water content in the sample, and this depends on the sample type. For plant samples the temperature range is used around 90 - 100 °C, while for soil and sediment samples, generally a little higher, i.e., in the range 105-110 °C. The content of water in soil samples has considerable variation, ranging from 1.32% for ISE 874 Sandy soil to 6.02 for ISE 863 Clay soil. Water content in plant samples has a narrow range with a range of values of 9% to 11% and is relatively higher than with water content in soil samples. The value of water content in the can is then used to correct the concentration of the elements obtained using Correction Factor (CF), so that the final value of the concentration is expressed as dry weight.

The analytical results of the element in the IPE sample, shown in Table 2, while for the ISE sample shown in Table 3. The distribution of the elements is heavily dependent on the sample type; plant samples have relatively few elements in comparison with the elements in soil samples. For plant samples, the distribution of elements can be divided into two group, i.e. major elements i.e. Al, Ca, Fe, K, and Na while the other elements are the minor group, i.e., Cl, Cr, Co, Mn, Mg, Zn, Ba, Br, Rb, Sr, Mo, Sb, Cs, La, and Th. For soil samples, the major elements are Al, Ca and K, while the other elements Mn, Na, Ti, V, Cl, Sc, Fe, Co, Zn, As, Br, Rb, Zr, Sb, Cs, Ba, La, Ce, Sm, Eu, Tb, Yb, Lu, Th, and U are minor elements.

**Table 2a. Analytical Result of IPE 2017 3 Wepal Sample (Result given on the basis of Dray Weight)**

| Element | Unit | IPE-238 Banana leaf | IPE-159 Lucerne |
|---------|------|----------------------|------------------|
|         |      | This work | Unc | Assigned value | Unc | This work | Unc | Assigned value | Unc |
| Ba      | mg/kg | 25.4    | 4.6 | 24.8           | 2.2 | -        |      |                  |      |
| Br      | mg/kg | 18.1    | 6.6 | 17.5           | 1.9 | 32.0     | 12.8 | 30.3            | 1.6 |
| Ca      | g/kg  | -   | -   | -              | -   | 17.5     | 0.3  | 16.5            | 0.9 |
| Cl      | mg/kg | 8.6    | 0.3 | 9.8            | 0.6 | 5.9      | 0.7  | 5.5            | 0.7 |
| Cs      | mg/kg | 36.6   | 5   | 41.6           | 8.2 | 204      | 21   | 195            | 40  |
| Fe      | mg/kg | 114    | 5.2 | 94             | 9   | 1468     | 130  | 923            | 149 |
| K       | g/kg  | 40.9   | 7.0 | 39.0           | 2.7 | 24.6     | 0.6  | 21.8           | 1.5 |
| Mg      | mg/kg | -     | -   | -              | -   | 1.8      | 0.1  | 1.8            | 0.1 |
| Mn      | mg/kg | 962    | 75  | 916            | 72  | 41.9     | 2.9  | 34.7           | 3.5 |
| Na      | mg/kg | 94     | 15  | 95             | 17  | 1198     | 100  | 1043           | 107 |
| Rb      | mg/kg | 1.3    | 0.1 | 1.2            | 0.1 | 13.5     | 0.5  | 11.6           | 1.4 |
| Sr      | mg/kg | 23.3   | 3.0 | 20.2           | 2.4 | -        | -    | -              | -   |
| Zn      | mg/kg | 26.2   | 5.0 | 22.0           | 1.6 | 27.4     | 5.1  | 19.7           | 1.7 |
Table 2b. Analytical Result of IPE 2017 3 Wepal Sample (Result given on the basis of Dray Weight), unit on mg/kh, otherwise noted.

| Element | Unit | IPE-215 Pepper fruit | IPE-203 Cabbage |
|---------|------|----------------------|-----------------|
|         |      | This work | Unc | Assigned value | Unc | This work | Unc | Assigned value | Unc |
| Al      | g/kg | -        | -   | -              | -   | 18.1      | 1.7 | 20.9          | 4.8 |
| Br      | mg/kg | 1.03     | 0.17 | 0.89           | 0.12 | 9.7       | 0.2 | 7.7           | 0.8 |
| Ca      | g/kg | 15.2     | 2.8  | 14.4           | 0.83 | 19.1      | 0.3 | 17.9          | 1.0 |
| Cl      | mg/kg | 0.7      | 0.1  | 0.7            | 0.2  | 2.1       | 0.5 | 2.0           | 0.2 |
| Cr      | mg/kg | -        | -    | -              | -    | 2447      | 85  | 2760          | 408 |
| Cs      | mg/kg | -        | -    | -              | -    | 65.8      | 8.3 | 79.1          | 13.2 |
| Fe      | mg/kg | 120      | 6    | 89             | 8    | 93.7      | 6.0 | 67.0          | 7.0 |
| K       | g/kg | 49.8     | 2.8  | 48.8           | 8.1  | 55.7      | 0.5 | 47.7          | 3.5 |
| Mg      | mg/kg | 4.5      | 0.7  | 3.4            | 0.3  | -         | -   | -             | -   |
| Mn      | mg/kg | 149      | 15   | 141            | 11   | 77.8      | 5.0 | 66.2          | 3.7 |
| Na      | mg/kg | 25.9     | 4.0  | 24.9           | 11.9 | 934       | 100 | 1016          | 78  |
| Rb      | mg/kg | 3.7      | 0.5  | 38.3           | 4.0  | 38.9      | 12.3|
| Sb      | mg/kg | -        | -    | -              | -    | 38.3      | 4.0 | 38.9          | 12.3 |
| Zn      | mg/kg | 58       | 1    | 54             | 4    | 65        | 2   | 51            | 4   |
### Table 3a. Analytical Result of ISE 2017 3 Wepal Sample (Result given on the basis of Dry Weight)

| Elements | Unit   | ISE-874-Sandy Soil | ISE-876-Clay |
|----------|--------|---------------------|--------------|
|          |        | This work | Unc | Assigned value | Unc | This work | Unc | Assigned value | Unc |
| Al       | g/kg   | 18.8      | 1.9 | 18.4         | 1.3 |
| As       | mg/kg  | 3.8       | 0.5 | 2.9          | 0.3 | 9.5       | 0.7 | 8.8          | 0.8 |
| Ba       | mg/kg  | 244       | 49  | 244          | 21  | -         | -   | -            | -   |
| Br       | mg/kg  | 15.4      | 1.2 | 13.0         | 1.0 | 9.1       | 0.5 | 7.9          | 0.5 |
| Ca       | g/kg   | 65        | 6   | 71.4         | 5.2 | -         | -   | -            | -   |
| Ce       | mg/kg  | 20.2      | 0.8 | 20.5         | 0.6 | 68.5      | 3.4 | 63.9         | 2.9 |
| Co       | mg/kg  | 5.3       | 0.3 | 4.9          | 0.6 | 18.0      | 1.8 | 17.2         | 1.3 |
| Cr       | mg/kg  | 159       | 10  | 129          | 24  | 200       | 17  | 185.8        | 15.6 |
| Cs       | mg/kg  |           |     |              |     |           |     |              |     |
| Fe       | g/kg   | 10.1      | 0.5 | 9.9          | 0.7 | 33.8      | 1.9 | 33.3         | 1.4 |
| K        | g/kg   | 8.3       | 0.8 | 8.0          | 0.5 | 17.8      | 0.9 | 16.7         | 0.7 |
| La       | mg/kg  | 14.2      | 0.9 | 10.5         | 1.3 | 31.9      | 1.6 | 32.1         | 2.7 |
| Mg       | g/kg   | 8.8       | 1.7 | 9.0          | 0.8 | -         | -   | -            | -   |
| Mn       | mg/kg  | 224       | 11  | 210          | 18  | 740       | 37  | 730          | 46  |
| Na       | mg/kg  | 2370      | 95  | 2379         | 180 | 10710     | 590 | 10721        | 484 |
| Rb       | mg/kg  | 30.0      | 3.3 | 25.6         | 2.5 | -         | -   | -            | -   |
| Sc       | mg/kg  | 4.1       | 0.1 | 3.8          | 0.5 |           |     |              |     |
| Sr       | mg/kg  | 415       | 21  | 312          | 34  | 340       | 15  | 311          | 34  |
| Th       | mg/kg  | 3.7       | 0.4 | 3.6          | 0.9 |           |     |              |     |
| V        | mg/kg  | 38.5      | 1.9 | 36.4         | 3.6 | 32.1      | 1.6 | 36.4         | 3.6 |
| Zn       | mg/kg  | 50.1      | 6.1 |              |     |           |     |              |     |
Table 3b. Analytical Result of ISE 2017 3 Wepal Sample (Result given on the basis of Dry Weight)

| Elements | Unit   | ISE-863-Clay Soil | ISE-866 Loess |
|----------|--------|------------------|--------------|
|          |        | This work | Unc | Assigned value | Unc | This work | Unc | Assigned value | Unc |
| Al       | g/kg   | 51.2     | 2   |                |     | 36.5     | 5.0 | 41.0           | 1.9 |
| As       | mg/kg  | 32.1     | 9.5 |                |     | 10.2     | 0.5 | 9.1            | 0.6 |
| Ba       | mg/kg  | 488      | 30  |                |     | 361      | 36  | 370            | 31  |
| Br       | mg/kg  | 10.6     | 0.5 |                |     | 5.7      | 0.8 | 4.5            | 0.5 |
| Ca       | g/kg   | 8.2      | 1.6 |                |     | 4.6      | 0.4 | 3.9            | 0.3 |
| Ce       | mg/kg  | 109      | 14  | 97.5           | 7.6 | 68.6     | 6.9 | 69.3           | 5.1 |
| Co       | mg/kg  | 19.0     | 0.5 | 17.5           | 1.3 | 9.0      | 0.3 | 8.9            | 0.5 |
| Cr       | mg/kg  | 151      | 18  | 126.3          | 8.9 | 98       | 5   |                |     |
| Cs       | mg/kg  | 12.9     | 0.4 | 11.2           | 0.8 | 3.4      | 0.2 |                |     |
| Fe       | g/kg   | 55.2     | 2.8 | 52.9           | 2.1 | 19.9     | 0.6 | 19.7           | 0.7 |
| K        | g/kg   | 20.7     | 2.6 | 20.5           | 0.9 | 16.5     | 3.3 | 16.3           | 0.6 |
| La       | mg/kg  | 52.1     | 2.3 | 49.1           | 2.3 | 31.1     | 1.2 | 32.5           | 1.9 |
| Mg       | g/kg   | 8.4      | 0.7 | 7.6            | 0.6 | 2.5      | 0.6 | 3.3            | 0.5 |
| Mn       | mg/kg  | 478      | 35  | 456            | 26  | 577      | 50  | 601            | 26  |
| Na       | mg/kg  | 3150     | 158 | 3042           | 305 | 6660     | 366 | 7975           | 364 |
| Rb       | mg/kg  | 180      | 9   |                |     | 83       | 5   | 72             | 4.5 |
| Sc       | mg/kg  | 19.5     | 1.0 | 18.2           | 0.9 | 7.2      | 0.4 | 7.3            | 0.4 |
| Th       | mg/kg  | 16.7     | 1.5 | 13.9           | 0.8 | 10.9     | 1.3 | 10.1           | 0.5 |
| Ti       | mg/kg  | 5282     | 300 | 4900           | 245 | -        | -   | -              | -   |
| V        | mg/kg  | 150      | 9   | 146.8          | 7.4 | 41.4     | 3.0 | 51.7           | 2.9 |
| Zn       | mg/kg  | 225      | 15  | 228            | 10  | 130      | 18  | 104            | 7   |
| Zr       | mg/kg  |          |     |                |     |          |     |                |     |

Various indicators have been used by the laboratory to determine the performance of an analytical method, e.g., using Z-score, Zeta-score, or E parameters. In this study, we used the Z-score, $\xi$-score, relative bias, and U-test parameter to evaluate the performance of the analytical result for elements of interest. All parameters have been done using assign value given by Wepal. However, not all elements can be evaluated for the Z score because of no data provided by Wepal.

The number of elements evaluated for Z-score and $\xi$-score parameters, based on Wepal assigned value, varies depending on the sample type. The Z-score and $\xi$-score profile on the plant sample differ from the Z-score profile on the soil sample. However, the Z score and $\xi$-score range used remains at -3 to +3. Figure 2 shows the results of the Z score and $\xi$-score evaluation for four plant samples, while Figure 3 shows the Z score and $\xi$-score for four soil samples.

The Z score for plant samples yields an out layer value (Z-score> + 3) for elements Fe and Zn while other elements are in the range of -3 < Z <+3. Meanwhile the evaluation using $\xi$-score, almost all
elements selected in the range of \(-3 < \xi < +3\). The results of the analysis of short-lived partial elements, generally give meaningless results, so it needs to be done in the improvement of the analysis. This condition is equal to the \(Z\)-score value obtained on soil samples.

The graph in Figure 3 shows the zeta-score and \(\xi\)-score results for the elements in the ISE sample. The \(\xi\)-score are relatively lower compared to the \(z\)-score results, as in the example IPE described earlier. A total of 22 elements including Al, As, Ba, Br, Ca, Ce, Cs, Co, Fe, K, La, Mg, Mn, Na, Rb, Sb, Sc, Th, U, V, Zn, and Zr have zeta-score values in the range of \(-3 < \xi < +3\). That means all analytical results are accepted. However, if the \(Z\)-score criterion is used, then U, Th, V, Zn, and Zr are outliers, although not systematically for all samples.

**Figure 2.** Comparison \(Z\)-Score and Zeta-score of IPE sample for selected elements.
Several implementing institutions for proficiency test programs use relative bias as one indicator of acceptance of the test results. The IAEA sets the acceptability of the results, define as Maximum Acceptable Bias (MAB), of the analysis if the relative bias for the related element is below 20%, the analytical result is satisfactory, while if the result higher than 20%, the analytical result is unsatisfactory. The relative bias was applied to IAEA-Wepal Proficiency Test Program since 2010 [1].

The graph in Figure 4 shows a relative bias for IPE and ISE samples. Most of the elements analyzed have a bias below 20%, except for Fe, Mg, and Zn in the IPE and Rb samples in the ISE 876 Clay and ISE 866 Loess samples. As, La and Sr in the Sandy Soil sample, the outer layer is around 30%. From the results obtained, there is no indication of systematic error. Elements obtained through short irradiation, for example, $^{27}$Al($n, \gamma$) $^{28}$Al, $^{51}$V ($n, \gamma$) $^{52}$V and $^{26}$Mg($n, \gamma$) $^{27}$Mg need attention because they are still out layer.
Figure 4. Profile of relative Bias of element selected for all IPE samples.
The ISO 13852 standard provides guidance and acceptance criteria of the analytical results through U-test parameters to compare two analytical results. The acceptance result is grouped into several criteria based on the U-test value obtained for each element, as showed in Table 1. The results of the U-test, for IPE and ISE sample shown in Table 5 and Table 5 below.

**Table 4.** U-test result of selected elements on IPE Sample

| Elements | U-test result |
|----------|---------------|
|          | IPE-238 Banana leaf | IPE-159 Lucerne | IPE-215 Pepper fruit | IPE-203 Cabbage leaf |
| Al       | -              | -              | -                   | 0.12                |
| Ba       | 0.07           | -              | -                   | -                   |
| Br       | 0.03           | 0.01           | 4.68                | 2.83                |
| Ca       | -              | 1.15           | 0.10                | 1.15                |
| Cl       | 3.23           | 0.58           | 1.33                | 0.42                |
| Cs       | 0.07           | 0.01           | -                   | 0.07                |
| Co       | -              | -              | -                   | 0.60                |
| Fe       | 0.25           | 0.02           | 0.40                | 0.44                |
| K        | 0.26           | 1.18           | 0.05                | 0.66                |
| Mg       | -              | 3.24           | 1.93                | -                   |
| Mn       | 0.01           | 0.48           | 0.03                | 0.41                |
| Na       | 0.01           | 0.01           | 0.01                | 0.01                |
| Rb       | 2.43           | 0.01           | -                   | 0.01                |
| Sb       | -              | -              | -                   | 0.01                |
| Sr       | 0.31           | -              | -                   | -                   |
| Zn       | 1.63           | 0.31           | 0.26                | 0.96                |

**Figure 5.** Profile of % Bias of selected element for ISE sample.
Table 5. U-test result of selected elements on ISE Sample

| Elements | ISE-874 Sandy Soil | ISE-876 Clay soil | ISE-863 Clay soil | ISE-866 Loess |
|----------|-------------------|-------------------|-------------------|--------------|
| Al       | 0.10              | -                 | -                 | 1.24         |
| As       | 3.78              | 0.89              | -                 | 2.43         |
| Ba       | 0.01              | -                 | -                 | 0.01         |
| Br       | 1.31              | 3.39              | -                 | 1.68         |
| Ca       | 0.13              | -                 | -                 | 3.45         |
| Ce       | 0.41              | 0.31              | 0.06              | 0.01         |
| Co       | 0.99              | 0.22              | 0.94              | 0.34         |
| Cr       | 0.05              | 0.04              | 0.07              | -            |
| Cs       | -                 | 0.20              | -                 | -            |
| Fe       | 0.26              | 0.13              | 0.26              | 0.26         |
| K        | 0.01              | 0.01              | 0.01              | 0.02         |
| La       | 1.91              | 0.03              | 0.39              | 0.34         |
| Mg       | 0.01              | -                 | 0.01              | 0.01         |
| Mn       | 0.04              | 0.01              | 0.02              | 0.01         |
| Na       | 0.01              | 0.01              | 0.01              | 0.01         |
| Rb       | 0.35              | -                 | -                 | 0.32         |
| Sc       | 1.48              | -                 | 0.98              | 0.49         |
| Sr       | 0.08              | 0.02              | -                 | -            |
| Th       | 0.12              | -                 | 1.19              | 0.48         |
| V        | 0.16              | 0.32              | -                 | 0.82         |
| Zr       | -                 | -                 | -                 | 0.03         |
| Zn       | -                 | -                 | -                 | 0.08         |

Br has U-test result > 2.83 at IPE 203, IPE 215 and ISE 876. It means the analytical result for Br is differ from the assigned value given. Cl on the IPE 238 Banana leaf sample has a U-test relatively high, which is 3.23, meaning that the obtained value is probably different from the assigned value given. Analytical result of Rb at IPE 238 Banana leaf is not clear compared to the assigned value given, but for the ISE sample, the Rb result is not different from the assigned value. The U-test results for other elements of interest, both in the IPE sample and the ISE sample, give the results that are not different from the assigned values.

4. Conclusion
The element determined on the IPE sample was less than that on the ISE sample. The elements of Mn, Na, Ti, V, Cl, Sc, Fe, Co, Zn, As, Br, Rb, Zr, Sb, Cs, Ba, La, Ce, Th, and U have been determined on the ISE sample. In the meantime, for the IPE sample, the elements of K, Na, Mn, Cl, Mg, Al, Ca, Cr, Fe, Co, Zn, Br, Rb, Sr, Sb, and Cs can be evaluated quantitatively. Al, Mg, and Ca were quite challenging to determine at routine reactor operation, which has the flux of about 10^13 n.cm⁻².s⁻¹. Most of the elements evaluated have Z scores in the range of -3 to +3, which indicate excellent analytical performance for some elements, but the element of unfavorable outcomes. Further studies need to be done for elements with a short half-life.
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