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# Quality Assessment of the $k_0$-NAA Method by the Analysis of Biological and Environmental Certified Reference Materials

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## 1. Introduction

In the $k_0$-based neutron activation analysis method ($k_0$-NAA), the normalization of the analytical result is based on so-called $k_0$-factors that are associated with each gamma line in the activation spectrum. These factors replace a series of nuclear constants, such as cross-sections and gamma-emission probabilities, and are determined in specialized NAA laboratories. This method enhances the accuracy of the results by avoiding the unnecessary build-up of uncertainties on the underlying physical constants. The $k_0$-factors are reactor and detector independent, and their values are agreed upon and used by an increasing number of $k_0$ users all over the world [1]. The $k_0$-NAA method is at present capable of tackling a large variety of analytical problems when it comes to the multi-element determination in many practical sample objects [2].

The objectives of the present work were to assess the applicability of the $k_0$-NAA method using the HANARO research reactor experimental system and irradiation protocol [3].

## 2. Experimental

Analyses of some certified reference materials (CRMs) were performed for three types of biological objects, i.e. Leaves of Spinach NIST-SRM-1570a, Citrus NIST-SRM-1572, and Tomato NIST-SRM-1573a, and three types of environmental objects, i.e. Coal NIST-SRM-1632c, Soil NIST-SRM-2586, and Industrial Sludge NIST-SRM-2782.

Sample conditions of the biological CRMs were obtained after a drying at 60$^{o}$C for 1 hour with the moistures of 4.60% for SRM-1570a, 3.80% for SRM-1572, and 3.85% for SRM-1573a. The environmental CRMs were dried at 100$^{o}$C for 2 hours with the moistures of 2.42% for SRM-1632c, 1.95% for SRM-2586, and 2.91% for SRM-2782.

## 3. Results and Discussion

The analytical results were evaluated by the ratio of the experimental results to the certified values and the standard deviations (SD) from three independent determinations. Figures 1 to 6 show the comparison of the experimental results with the certified values expressed in the vertical axis; the horizontal axis indicates the determined elements along with the corresponding nuclides. The Y-error bar indicates the SD normalized in a relative arbitrary unit. The elements in the circles are non-certified.

The results of NIST-SRM-1570a (Spinach Leaves) displayed in Fig. 1, indicate that two of the elements, Sr and Th, have large SD values because: a) The $^{85}$Sr nuclide with a gamma line at 514 keV is overlapped with the 511 keV line, and b) Th using the $^{233}$Pa nuclide has too low a concentration in the certificate (0.048ppm). The remaining elements have a good agreement with the certificate.

The results of NIST-SRM-1572 (Citrus Leaves) displayed in Fig. 2, indicate that most elements agreed with the certified values where the deviations between the experiment and the certificate were generally within 12%, except for I & Sc (16-20%).

The results of NIST-SRM-1573a (Tomato Leaves) displayed in Fig. 3, indicate that most elements have a good agreement with the certified values, except for Sr which has the same problem mentioned above.

The results of NIST-SRM-1632c (Coal) displayed in Fig. 4, indicate that most elements were agreed with the certified values where U using the $^{239}$U nuclide with a gamma line at 74.7 keV gives an acceptable result. It was found that, as for $^{153}$Sm, using the average result of two gamma lines at 69.7 keV and 103.2 keV is better than using only the 103.2 keV line. Also, as for $^{134}$Cs, the average result of the two gamma lines at 604.7 keV and 795.8 keV is better than the result from only one gamma line. It was found that the deviation between the experimental and the certified value for Ca (18%) using the $^{49}$Ca nuclide with a gamma line at 3085 keV was caused by an efficiency problem in high energy region.

The results of NIST-SRM-2586 (Soil) displayed in Fig. 5, indicate that most elements were in agreement with the certificate where the deviations between the experimental and the certified value were generally within 12%. It was found that the determination of Ca using the $^{47}$Sc nuclide produced by the $^{46}$Ca(n, $\gamma$)$^{47}$Ca/$^{47}$Sc reaction is more accurate than that using the $^{49}$Ca nuclide although the detection limit of the latter case is better.

The results of NIST-SRM-2782 (Industrial Sludge) displayed in Fig. 6, indicate that most elements were in agreement with the certified where the deviations between the experimental and the certified generally were within 12%, except for Eu (19%) with too low a concentration of 0.34ppm and Sc (24%) because Sc is a non-certified element.

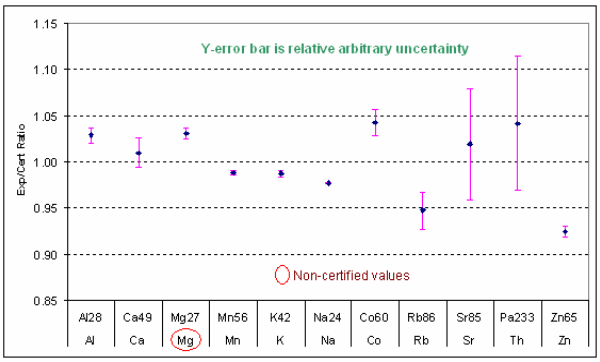


**Fig. 1.** Comparison of experimental results with certified values of NIST-SRM-1570a

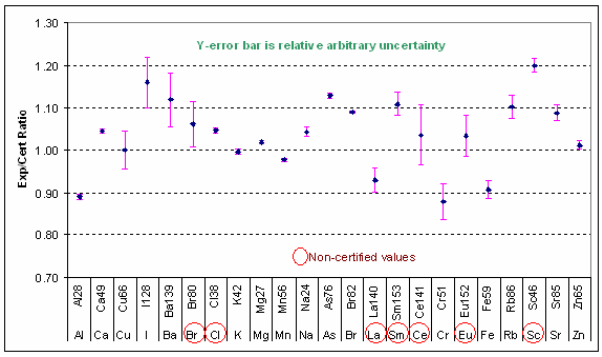


**Fig. 2.** Comparison of experimental results with certified values of NIST-SRM-1572

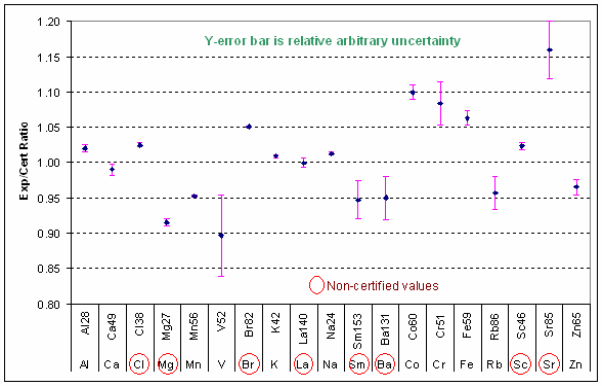


**Fig. 3.** Comparison of experimental results with certified values of NIST-SRM-1573a

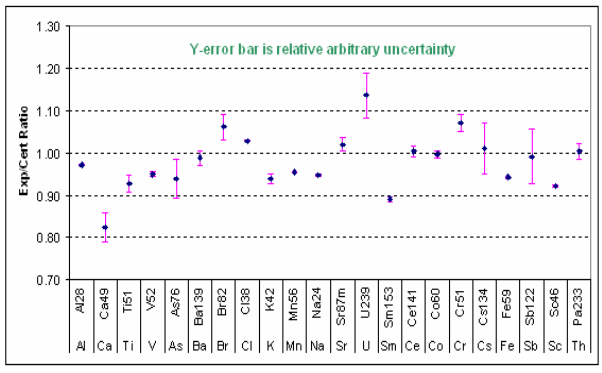


**Fig. 4.** Comparison of experimental results with certified values of NIST-SRM-1632c

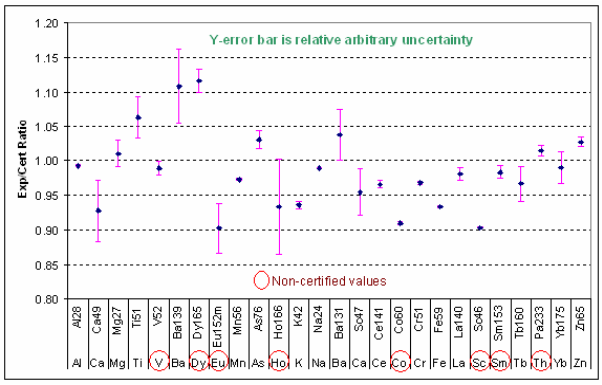


**Fig. 5.** Comparison of experimental results with certified values of NIST-SRM-2586

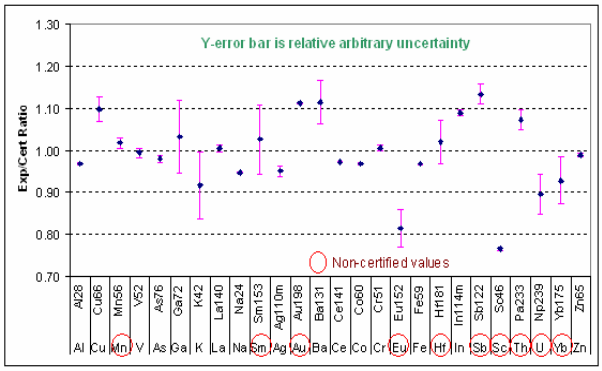


**Fig. 6.** Comparison of experimental results with certified values of NIST-SRM-2782

## 4. Conclusions

A multi-element analysis using the $k_0$-NAA method at the NAA#3 irradiation hole of the HANARO reactor allows the user to simultaneously determine concentrations in biological samples of leaf types for 25 elements and in environmental samples of coal, soil and sludge types for 35 elements.

The analytical quality was rather good with the deviations between the experimental results and the certified values generally within 12%. It can be concluded that practical applications of the $k_0$-NAA method at the NAA#3 irradiation hole of the HANARO reactor is reasonable.

## REFERENCES

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