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Application of the k_0-IAEA Software for an Instrumental Neutron Activation Analysis at the HANARO Research Reactor

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1. Introduction

The k_0-IAEA software was developed and distributed by the IAEA in 2005. This work intended to demonstrate the software with our facilities. That is, the NAA#3 irradiation hole in the HANARO research reactor and the two gamma-ray spectrometers at the NAA laboratory in KAERI were used. In addition, NIST SRM 2586-Soil was chosen as a sample to validate the analytical protocol by using the k_0-IAEA software.

2. k_0-IAEA software

The implementation of the k_0-IAEA software, from an experimental viewpoint, can be divided into four steps : (i) the first step is to edit the permanent database, input the name of detectors, irradiation facilities, sample capsules, material compositions; (ii) the second step is to calibrate the detectors; (iii) the third step is to characterize the irradiation facilities; and (iv) the fourth step is to analyze the samples and report them.

2.1 Editing a Permanent Database

To run the k_0-IAEA software, go to menu "Edit", select sub-menu "permanent Database", a window will appear as in Figure 1

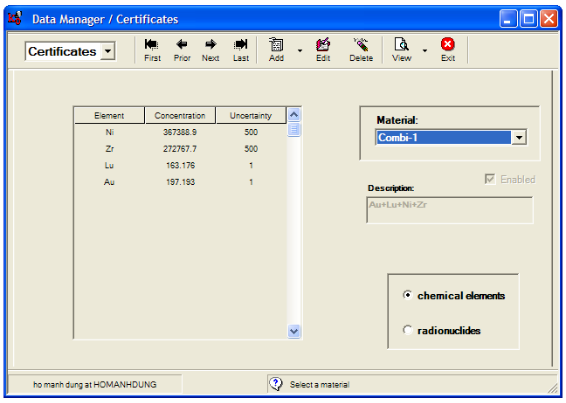

Figure 1. Window of the menu "Edit/Permanent Database

2.2 Calibration of Gamma-Ray Spectrometer

The first step is to edit the permanent database and enter the detector and its dimensions as described above. Also enter the certificates of the calibration sources. It needs two sources: A source containing only Cs-137 and a standard mixed radionuclide calibration source containing an example of the nuclides: Am-241, Co-57, Cd-109, Co-60, Cs-137 and Y-88. The two sources must be measured with the detector, long enough so that the peak statistics in each main peak of each radionuclide are better than 0.5%. The Cs-137 source should be measured at about 10 cm but the precise position is not very important. The mixed source must be counted at the precisely known distances from the detector. Figure 2 shows an example of the detector calibration result

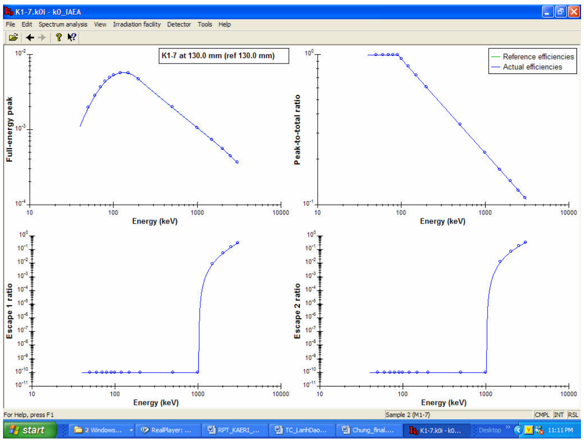

Figure 2. An example of detector calibration

2.3 Characterization of an irradiation Hole

The reactor neutron spectrum parameters considered for the corrections in the k_0-NAA method are the deviation of the epithermal neutron flux distribution from the ideal 1/E law approximated by a $1/E^{1+\alpha}$ shape (α), the ratio of the thermal-to-epithermal neutron flux (f), the ratio of the thermal-to-fast neutron flux (f_F) to evaluate the interferences by the threshold reactions, and the neutron temperature (T_n) used for the nuclides with a Westcott g-factor different from unity. These parameters change according to the reactor configuration and the position of an irradiation hole. Therefore, their determination is required when applying the k_0-NAA method. In this study, neutron spectrum parameters for the NAA #3 irradiation hole were determined by using suitable monitors such as Au, Zr, Ni and Lu.

2.4 Analysis of samples

NIST SRM 2586-Soil was analyzed under the analytical conditions in Table 1. The samples were prepared by weighing three replicates in highly pure polyethylene vials. Although the vials used for the samples are very high purity ones, this experiment was carried out by transferring the samples to new vials after an irradiation.

Table 1. Analytical condition of NIST SRM 2586-Soil

Irradiation time (sample weight)	Decay time	Counting time
1 second (50 ~ 100mg)	15min	300s
	~ 1h	1800s
1min (100 ~ 200mg)	~ 2d	6,000s
	~ 5d	40,000s

The analytical results were evaluated by a comparison of the experimental to the certified values with the experimental results obtained from three independent measurements. In addition, the U-score [1] by taking into account the uncertainties is calculated to assess and validate the analytical protocol. Analytical results are summarized in Table 2 and Figure 3.

Table 2. Analytical results of NIST SRM 2586-Soil

Element	Certified Value			K_0-IAEA			U-score
Al	66520	±	760	66053	±	261	0.58
As	8.7	±	1.5	9.0	±	0.2	0.18
Ba	413	±	18	428	±	32	0.42
Ca	22180	±	540	21137	±	192	0.91
Ce	58	±	8	56	±	1	0.25
Co	(35)	±	1.6	33	±	0.2	1.37
Cr	301	±	45	296	±	2	0.10
Dy	(5.4)	±	0.3	6.0	±	0.2	1.73
Eu	(1.5)	±	0.03	1.4	±	0.1	1.43
Fe	51610	±	890	50323	±	859	1.04
Ho	(1.1)	±	0.02	1.0	±	0.1	0.51
K	9760	±	180	9135	±	155	2.63
La	29.7	±	4.8	29.1	±	0.5	0.12
Mg	17070	±	840	17245	±	662	0.16
Mn	1000	±	18	973	±	2	1.49
Na	4680	±	730	4630	±	5	0.07
Sc	(24)	±	1.2	23.2	±	0.03	0.67
Sm	(6.1)	±	0.1	6.0	±	0.1	0.68
Tb	(0.9)	±	0.02	0.9	±	0.04	0.64
Th	(7)	±	0.1	7	±	0.1	0.64
Ti	6050	±	660	6431	±	384	0.50
V	(160)	±	1.5	158	±	3	0.50
Yb	2.64	±	0.51	2.61	±	0.12	0.05
Zn	352	±	16	362	±	5	0.58

In the case of the non-certified values in the NIST-SRM-2586, the uncertainties were estimated by the modified Horwitz function [2] which is defined as follows ;

$$\sigma = \begin{cases} 0.22c & \text{if } c < 1.2 \times 10^{-7} \\ 0.02c^{0.8495} & \text{if } 1.2 \times 10^{-7} \le c \le 0.138 \\ 0.01c^{0.5} & \text{if } c > 0.138 \end{cases}$$

Where, c indicates the dimensionless mass ratio (for an example, 1 mg/kg = 10^{-6}).

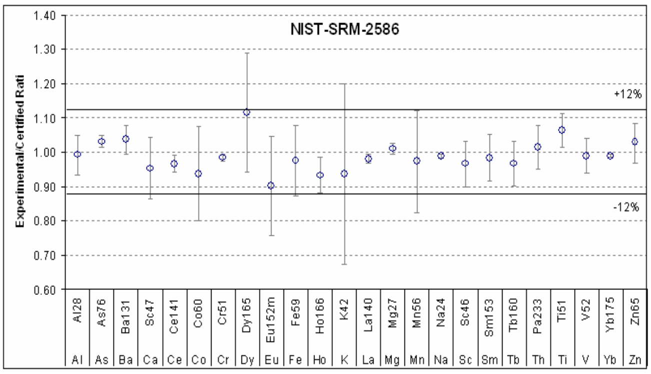

Figure 3. Summary of the analytical results of NIST SRM 2586-soil

4. Conclusion

Multi-element analysis by using the k_0-NAA method [3, 4] in the NAA#3 irradiation hole of the HANARO research reactor, by using the k_0-IAEA software was conducted. The analytical quality was very good for NIST SRM 2585-Soil when considering that the u-score values were all lower than 2 and that the deviations between the experimental results and the certified values were all within 12% except for K with the u-score of 2.63.

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