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Determination of Cu-Zn Fraction of an Ancient Brass Pipe by Prompt Gamma-ray Activation Analysis

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1. Introduction

Prompt Gamma Activation Analysis (PGAA) has an advantage over most other methods in the investigation of archeological and cultural objects which must be dealt with a non-destructive method. In this study, we study about how to determine the copper-zinc fraction in archeological objects such as a smoking pipe made from brass, where the proportions of copper and zinc can be varied to create a range of brasses with varying properties. In this study, a Japanese smoking pipe was analyzed to determine the copper-zinc fraction at the KAERI-SNU PGAA facility.[1)]

2. Experimental

2.1 PGAA at HANARO Research Reactor

A SNU-KAERI PGAA facility at the HANARO research reactor has been utilized for various applications including production of thermal neutron cross sections, analysis of chemical compositions in geological, biological and environmental samples, but has not been for archeological objects in Korea. This study is the first approach of domestic PGAA in archeology. The details of characteristic of the facility and its associated gamma-ray spectrometer are given in another article.[2,3)]

2.2 Sample preparation

Mixture samples of copper and zinc, which were used for plotting calibration curve, were prepared from zinc powder of 99.995% purity (Aldrich #324930) and copper powder of 99.999% purity (Aldrich #203122), respectively. The sample is encapsulated into a Teflon vial with 13 mm inner diameter and mounted on a Teflon mount which is hung by Teflon wire in the center of neutron beam. Mass and mass ratio of sample is listed in Table 1. An ancient smoking pipe was prepared by Dr. Kawabata of Kyoto University Research Reactor in Japan. From the elemental analysis, we already know that this smoking pipe was composed of copper, zinc and tin.

2.3 Calibration plot

Mixture samples were irradiated by a thermal neutron beam. The prompt gamma-ray spectra obtained by varying the sample masses are partially shown around two principal peaks of a 7863.55 keV line from the Zn-64(n,γ) reaction and a 7915.62 keV line from the Cu-63(n,γ) reaction. Peak analyses were carried out using a HYPERGAM code.[4)]

Table 1. Mass ratio of copper and zinc in mixture samples.

	Mass in mg		Mass ratio	
#	m_{Cu}	m_{Zn}	f_{cu}	f_{Zn}
S1	501.8	0.0	0.00	1.00
S2	433.3	106.8	0.20	0.80
S3	400.7	165.7	0.29	0.71
S4	389.4	238.6	0.38	0.62
S5	400.1	366.0	0.48	0.52
S6	194.6	295.9	0.60	0.40
S7	165.5	367.7	0.69	0.31
S8	119.9	397.9	0.77	0.23
S9	61.7	456.3	0.88	0.12
S10	0.0	447.9	1.00	0.00

The count rate $\boldsymbol{C}$ for each peak is theoretically given by using eq. (1).

$$C_x = A_0 \frac{m_x}{M_x} \sigma_x^{\gamma} \phi \varepsilon_x / t_x \tag{1}$$

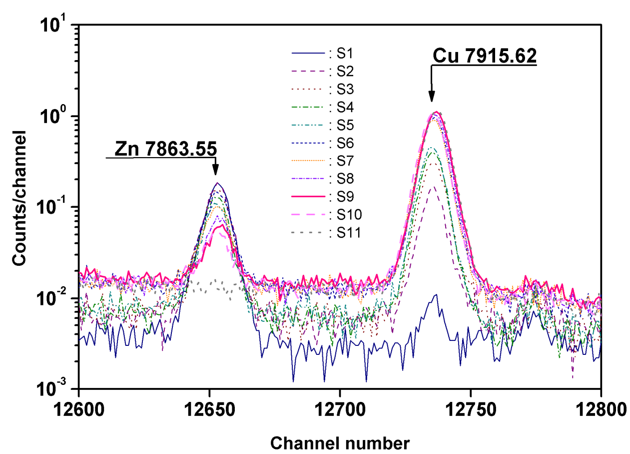

Fig. 1. Partial spectra around Zn 7863.55 keV and Cu 7915.62 keV peaks.

, where subscript x is element of interest, A_0 Avogadro number, m sample mass, M atomic weight, σ^{γ} partial capture cross section, ϕ thermal neutron flux, ε detection efficiency and t irradiation time. From eq. (1), f_{Cu} ,which is mass ratio of copper in copper and zinc matrix, is given in eq. (2). Because the difference of two energies for Zn 7863.55 keV and Cu 7915.62 keV is small, the detection efficiency for two energies can be assumed to be almost same. And Avogadro number and thermal neutron flux can be also canceled. The value for zinc f_{Zn} is also determined in same way.

$$f_{Cu} = \frac{m_{Cu}}{m_{Cu} + m_{Zn}} = \frac{1}{1 + \dfrac{C_{Zn}}{C_{Cu}} \dfrac{M_{Zn}}{M_{Cu}} \dfrac{\sigma^{\gamma}_{Cu}}{\sigma^{\gamma}_{Zn}}} \qquad (2)$$

Fig. 2 shows a calibration curve of f_{Cu} experimentally determined from the peak count rates of copper and zinc gamma lines according to the mass fraction of copper in the copper and zinc mixture samples.

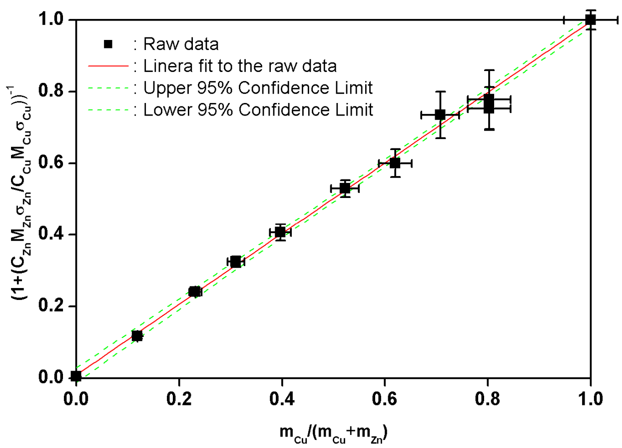

Fig. 2. Calibration plot of f_{Cu} according to the mass fraction of copper in the copper and zinc mixture samples.

2.4 Mass ratio of Cu-Zn in a smoking pipe

Fig. 3 shows a prompt gamma-ray spectrum in full energy range measured for Japanese smoking pipe and a red box in the figure shows a partial spectrum around the Cu 7915.62 keV and Zn 7863.55 keV peaks. From the area of the two peaks, we can obtain the Cu and Zn mass fraction in the smoking pipe sample. The count rate for Cu 7915.62 keV is 11.6 ±0.1 counts/s and that for Zn 7863.55 is 0.69 ± 0.08 counts/s. f_{Cu} : f_{Zn} was determined to be 0.726:0.274.

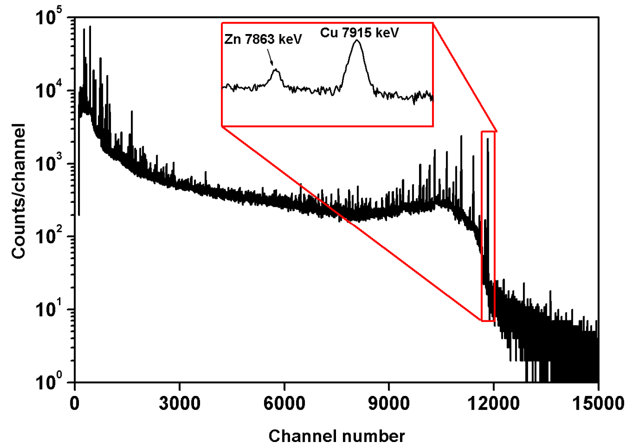

Fig. 3. Prompt gamma-ray spectrum measured for Japanese smoking pipe.

3. Conclusions

The PGAA method was applied to the archeological object to determine the copper and zinc fraction. By using the proximity of the energies of principal prompt gamma-rays from copper and zinc elements, simple equation for mass ratio of copper in a copper and zinc matrix was derived, and the mass ratio of copper and zinc was easily obtained by using peak count rates omitting the detection efficiency. This method can be also applied to the similar case for U-238 with 4060 keV line and Th-232 with 4045 keV line.

REFERENCES

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