Application of Neutron Resonance Capture Analysis for Determination of Isotope Composition of Fibula from Podbolotyevsky Burial Ground (10th Century AD)

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ABSTRACT

Neutron resonance capture analysis is based on the registration of neutron resonances in radiative capture. One of the main advantages of this method is nondestructive property. The investigations were carried out at the Intense Resonance Neutron source (IREN) in Frank laboratory of Neutron Physics. The gamma-quanta liquid scintillator detector was used at this experiment. The analyzed sample, in our case it was fibula, was provided by the Institute of Archeology of the Russian Academy of Sciences. The Viking Age fibula was found in the grave of the Podbolotyevsky burial ground, which was belonged to the Finno-Ugric tribe of Murom. This burial ground dates from the VIII-IX centuries.

1. INTRODUCTION

The method of Neutron Resonance Capture Analysis (NRCA) is currently being developed in the Frank Laboratory of Neutron Physics for the purpose of the element composition determination of our samples [1]. The method is based on the use of a pulsed neutron source and time-of-flight technology [2]. Multi-sectional liquid scintillator detector (210 liters) was used for the registration prompt gamma-quanta and was created at FLNP JINR [3].

The low-lying resonance parameters were determined for almost all stable nuclei to date [4, 5]. Furthermore, the set of energies and parameters of this resonance do not completely coincide for any isotopes pair. Consequently, the elemental and isotopic composition of sample can be defined by means of energy peak position of resonances. Also, if you know area under the resonances, you can calculate the number of the element or isotope's nuclei.

This analysis was carried out for the material which was transferred by the Institute of Archeology RAS. The provided sample fibula (Fig. 1) was found during excavations in the Podbolotyevsky burial ground in the Vladimir Region. The archaeological funeral monument was found at the end of the 20th century. The experts have found nearly 7000 artifacts, from jewelry to weaponry during 3 years. There are hundreds of the Finno-Ugric tribe of Murom graves that lived downstream River Oka from the 10th century and were engaged in hunting, crafts and agriculture. Scientists have studied 181 graves over the past three years and 20 more are studied to date. Elemental and isotopic composition of fibula can be interested for the territory identification where the fibula was made.

Fig. 1. The real view of fibula.

2. EXPERIMENT

The sample was irradiated with neutrons by resonance neutron source (IREN) facility and the time-of-flight spectrum of reactions (n,γ) was registered. The main part of the IREN facility is a linear electron accelerator. The facility parameters: the average energy of electrons was ~ 40 MeV, the peak current was ~ 1.5 A, the width of electron pulse was ~ 100 ns, and the repetition rate was 25 Hz. The total neutron yield was about $3 \cdot 10^{11}$ s^{-1}. The measurements were carried out at the 58.6 meters flight path of the 3rd channel of the IREN. The big liquid scintillator detector was used for the registration of γ-quanta. The sample was placed inside the detector. The neutron flux was permanently monitored by the SNM-17 neutron counter. The signals from the detector and the monitor counter were simultaneously fed to the two independent inputs of time-to-digital converter (TDC).

The measurements with the sample lasted about 68 hours. The resonance energies were determined according to the formula:

$$E = \frac{5227L^2}{t^2}, \quad (1)$$

where, t – time of flight in microseconds, L – flight path in meters, E – kinetic energy of a particle in eV.

The resonances of gold, copper, and zinc were identified on the time-of-flight spectrum (Fig. 2). The measurements with standard samples of gold, zinc and copper were made in addition to the measurement with the investigated sample (Fig. 3, 4, 5).

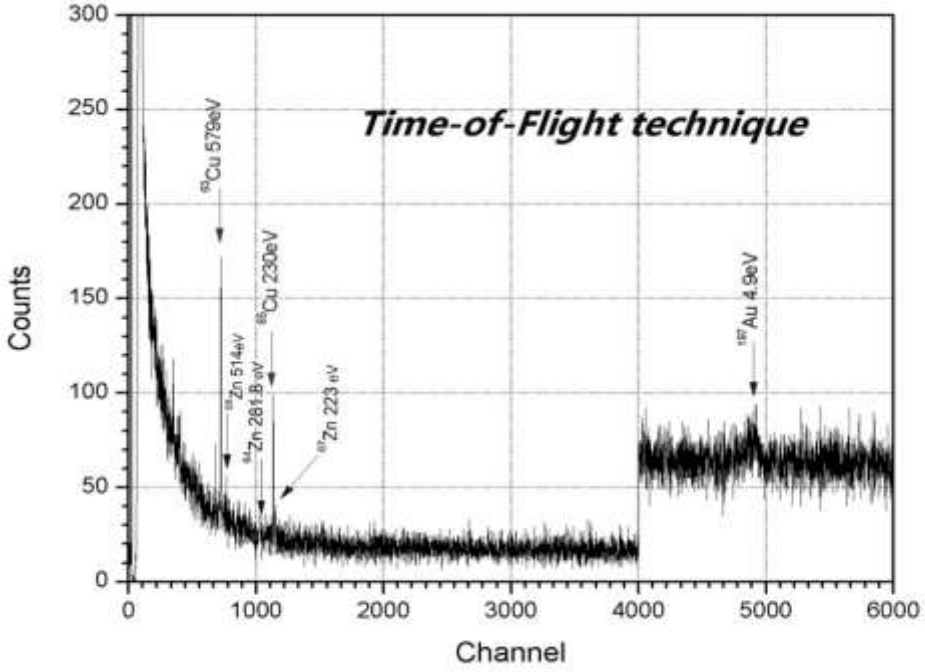

Fig. 2. The time-of-flight spectrum of reactions (n,γ) on the fibula material. The width of the time channel from 0 to 4000 channels is 0.25 μs; from 4000 to 6000 – 1 μs.

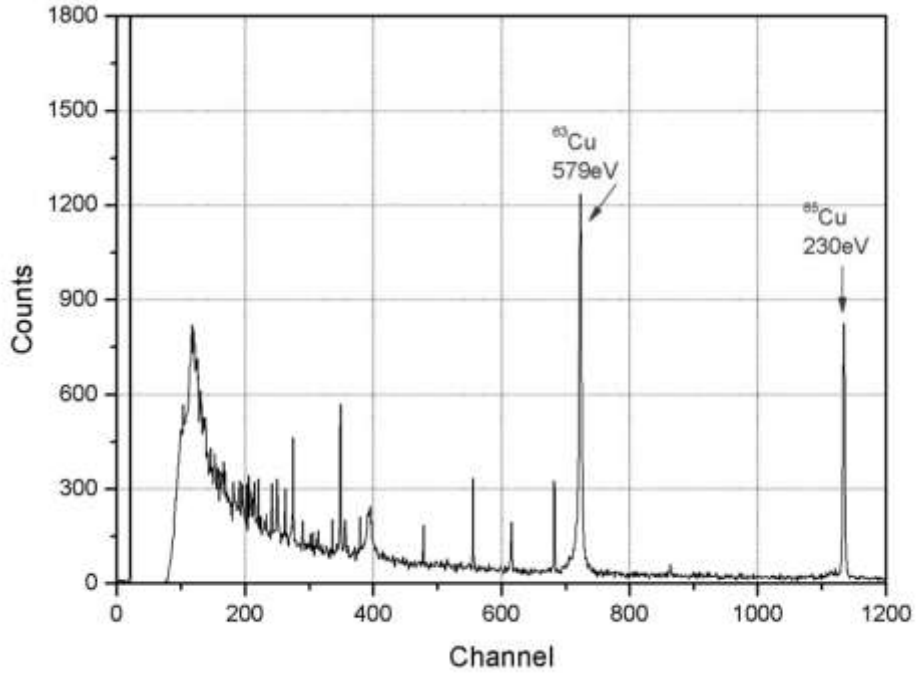

Fig. 3. The time-of-flight spectrum of reactions (n,γ) of a standard copper sample.

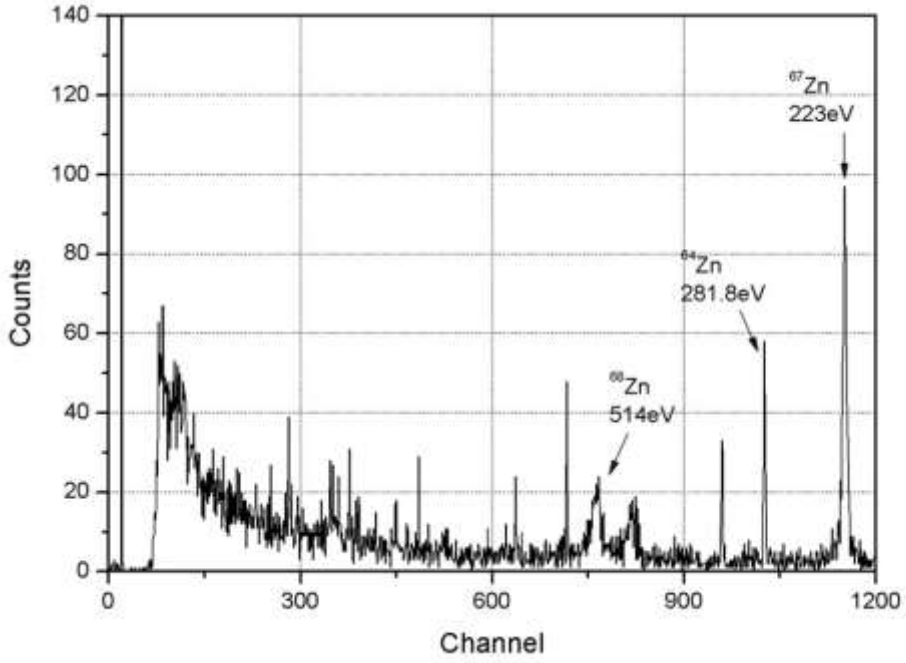

Fig. 4. The time-of-flight spectrum of reactions (n,γ) of a standard zinc sample.

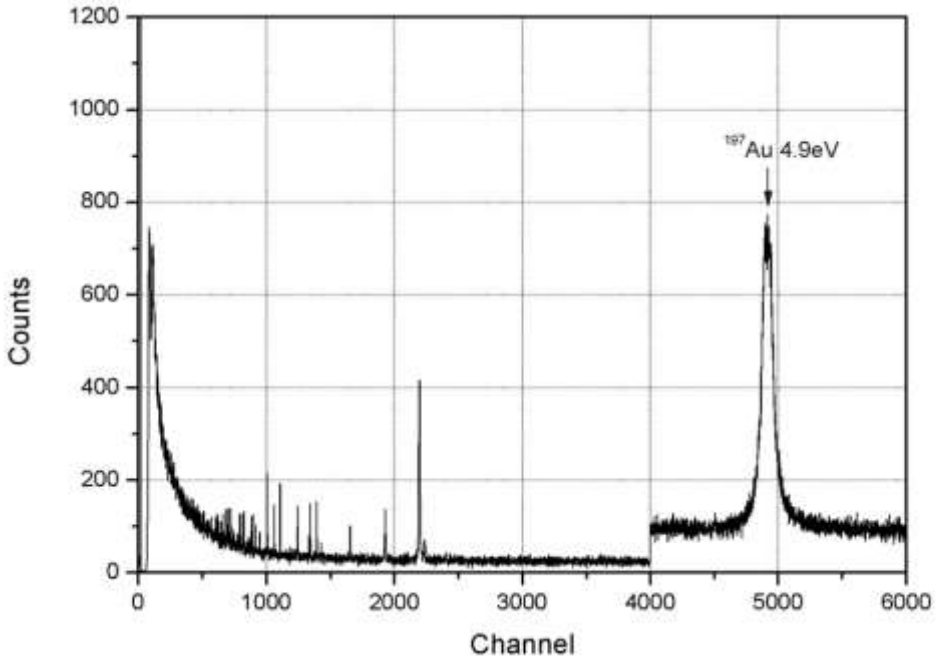

Fig. 5. The time-of-flight spectrum of reactions (n,γ) of a standard gold sample.

3. DATA ANALYSIS AND RESULTS

Three resonances of zinc, two resonances of copper and one resonance of gold were selected during the analysis of the experimental data. The sum of the detector counts in resonance is expressed by the formula:

$$\sum N = f(E_0) \cdot S \cdot t \cdot \varepsilon_\gamma \cdot \frac{\Gamma_\gamma}{\Gamma} A. \quad (2)$$

Here, $f(E_0)$ is the neutron flux density at the resonance energy E_0, S – the sample area, t – measuring time, ε_γ – the detection efficiency of the detector radiative capture, Γγ, Γ – the radiative and total resonance widths.

$$A = \int_{-\infty}^{+\infty} [1 - T(E)]\, \mathrm{dE} \quad (3)$$

is resonance area on the transmission curve.

$$T(E) = e^{-n\sigma(E)} \quad (4)$$

is the energy dependence of the neutron transmission by the sample; σ(E) – the total cross section at this energy with Doppler broadening, n – the number of isotope nuclei per unit area. The value A was determined from experimental data for investigated sample by the formula:

$$A_x = \frac{\sum N_x \cdot M_S \cdot S_S}{\sum N_S \cdot M_x \cdot S_x} \cdot A_s. \quad (5)$$

Here, $\sum N_x$, $\sum N_s$ are counts under the resonance peak of the investigated and standard samples, S_x, S_s – the areas of the investigated and standard samples. M_x, M_s – the numbers of monitor counts during the measurement of the investigated and of standard samples.

The value A_s was calculated by means of well-known parameters of resonances for the standard sample, the value n_x was determined from the value of A_x for the investigated sample. The values of σ (E) and A were numerically determined by using the algorithm which was described in [6]. This procedure is schematically shown in (Fig. 6). The analysis results are presented in the Table 1.

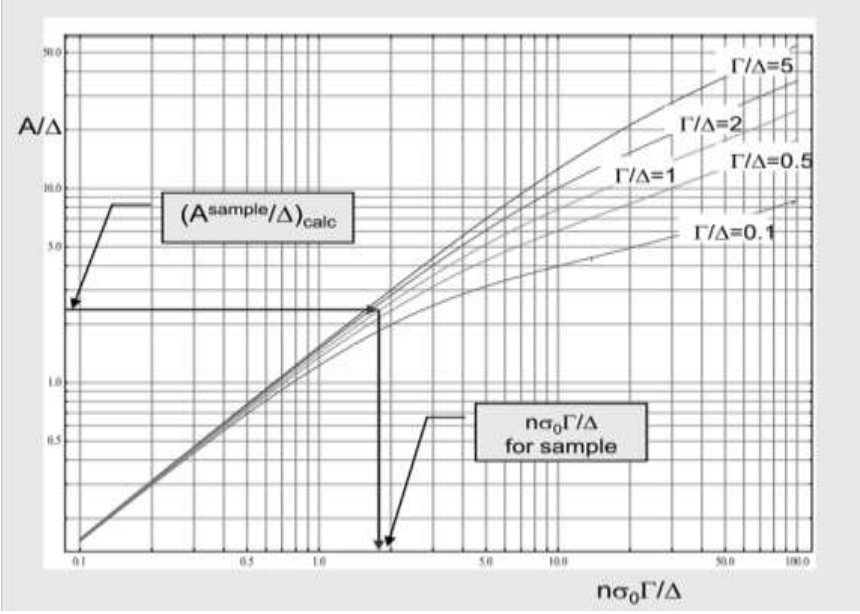

Fig. 6. The dependence of A value on number of nuclei and resonance parameters [6].

Table 1. The results of measurements with the fibula

№	Element	Mass, g	Weight, %
1	Au	0.0171±0.0027	0.85±0.14
2	Cu	13.5±1.5	67.8±7.5
3	Zn	1.06±0.39	5.3±2.0

4. CONCLUSION

This paper presents the results of investigation of the fibula which was found in the Podbolotyevsky burial ground (VIII-IX centuries). The elemental and isotopic composition of the sample was determined by the neutron resonance analysis method. The mass of fibula was 19.9 g. The mass of zinc, determined by resonances is equal to 1.06 ± 0.39 g. The fibula was probably made on the Old Russian territory by the assumption of experts from the Institute of Archeology of the Russian Academy of Sciences. These conclusions are based on following fact: these kinds of artifacts usually have a small zinc portion in the composition - no more than 10%. However, 27% of the fibula material remains unidentified. We think that it might be lead. The detection efficiency of a gamma-ray detector in radiative capture of neutrons by lead isotopes is rather low, and during such short time of statistics collection, lead resonances still do not exceed the background.

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