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Preliminary result of investigation of the isotope composition of archaeological objects by method of neutron resonance capture analysis

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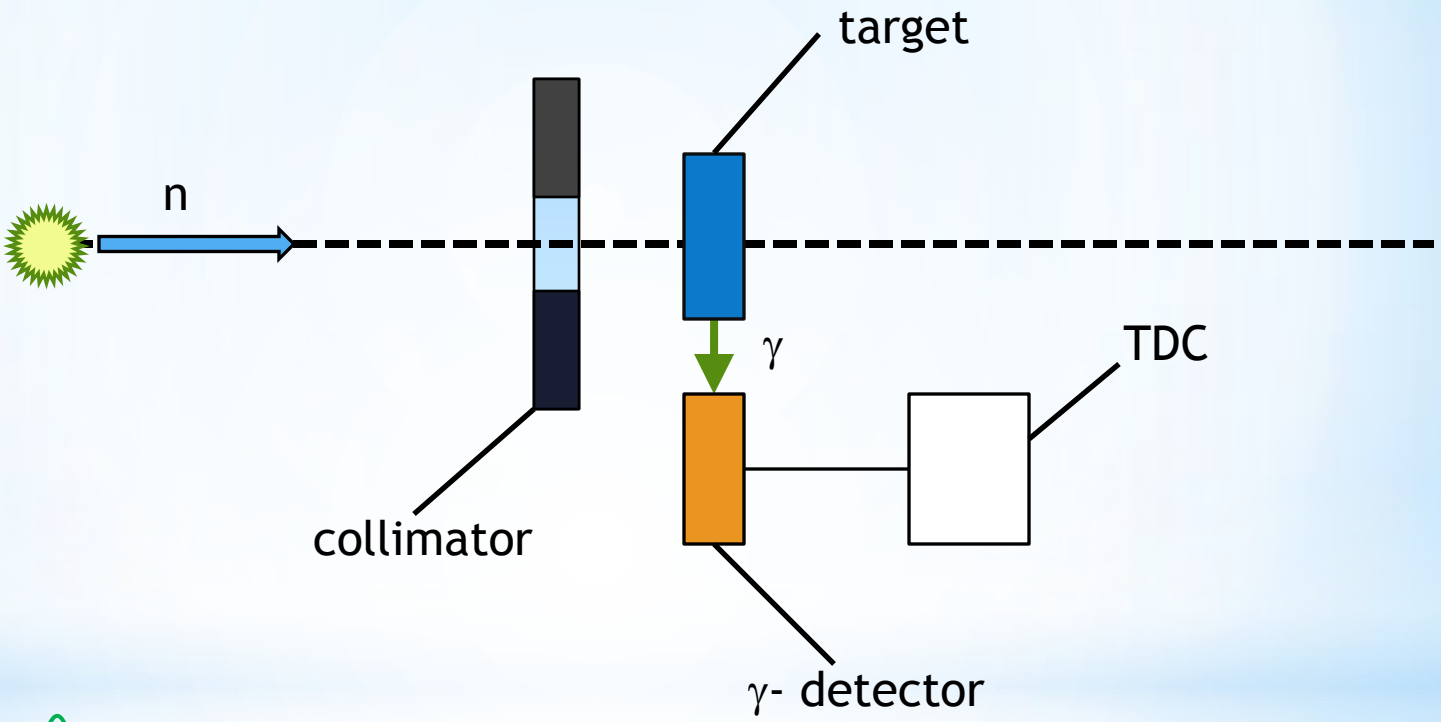
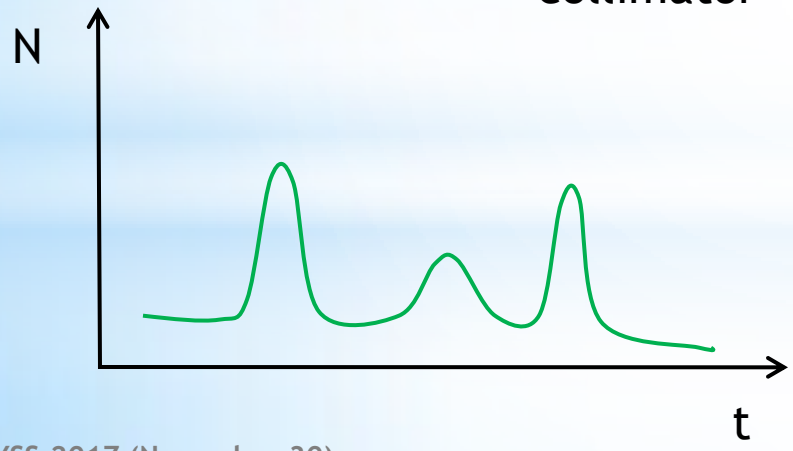
* ***Neutron Resonance Capture Analysis (NRCA)*** can be applied for nondestructive determination of the isotopic composition of samples. The method is based on the registration of neutron resonances and the measurement of the yield of reaction products in the resonances. The resonance energies are known practically for all stable nuclei and the set of energies does not coincide completely for any pair of isotopes. It allows determining the isotope composition.

Neutron resonance capture analysis (NRCA) is based on use of the pulsed neutron source and time-of-flight method (TOF)





$$E\ (eV) = \frac{\left(72{,}3 \cdot L\ (м)\right)^2}{t\ (\mu s)^2}$$

The archaeological objects

We received an application from Institute of Archaeology Russian Academy of Sciences to make the analysis for:

- ***Ancient coins from Phanagoria's treasure (3th century AD)***
- ***Fibula from Podbolotyevsky burial ground (10th century AD) in the Vladimir Region***

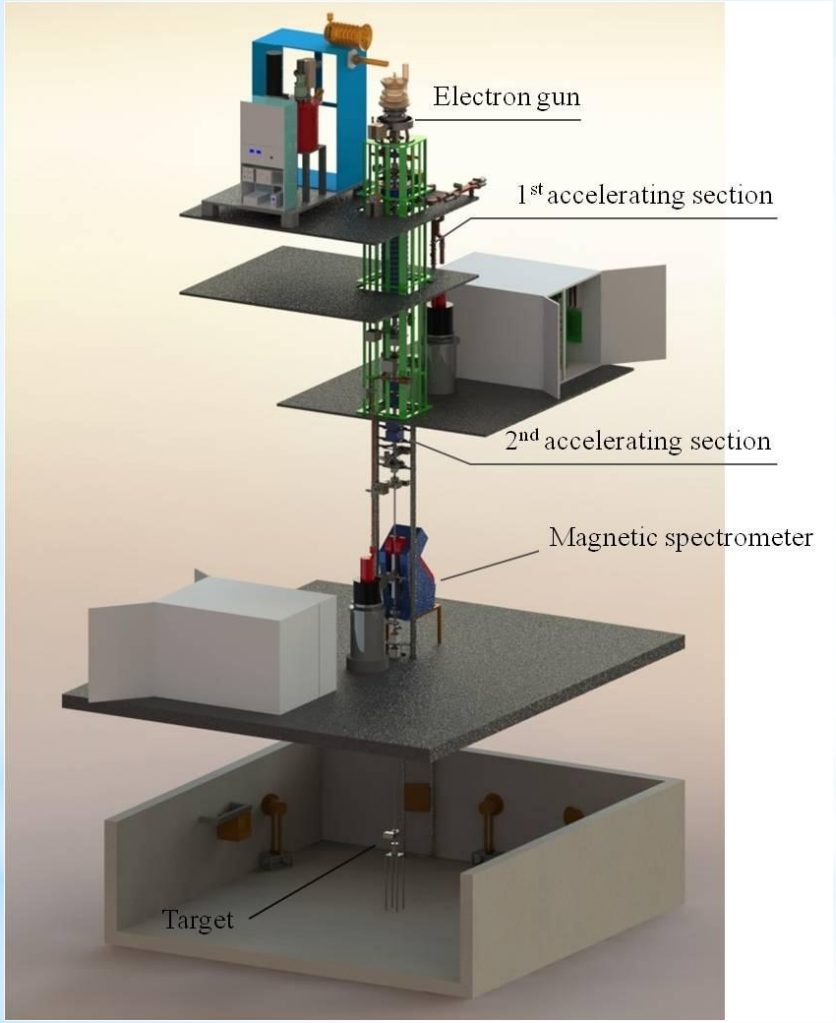
Parameters of samples

	Sample	Area, cm^2	Weight, g	Measurement time, h
Standard	Zinc	142.8	103.57	5.78
	Silver	38.46	3.55	7.88
	Copper	162.8	216	6.13
	Gold	31.79	3.049	11.11
Investigated	Fibula	17.01	19.98	67.75
	Coins (10 pieces)	26.95	73.03	13.3

The ancient coins from Phanagoria's treasure

The aim of research is determination of the elemental composition of coins and the tracking of the dynamics of the decrease of the silver content in the alloy. The one more task is to find out the peaks of the alloy degradation and their correlation with the dates of barbarians march to Bospor. It is known that Bosporan government looked for finances to fight against barbarians. That time correlates with inflationary processes which are followed by degradation of coinage alloy of staters.

IREN parameters



The main part of the IREN facility is a linear electron accelerator. The bunched electron beam generates bremstruhlung in the tungsten target and it produces the neutron pulses via (γ,n)-reaction in the same target.

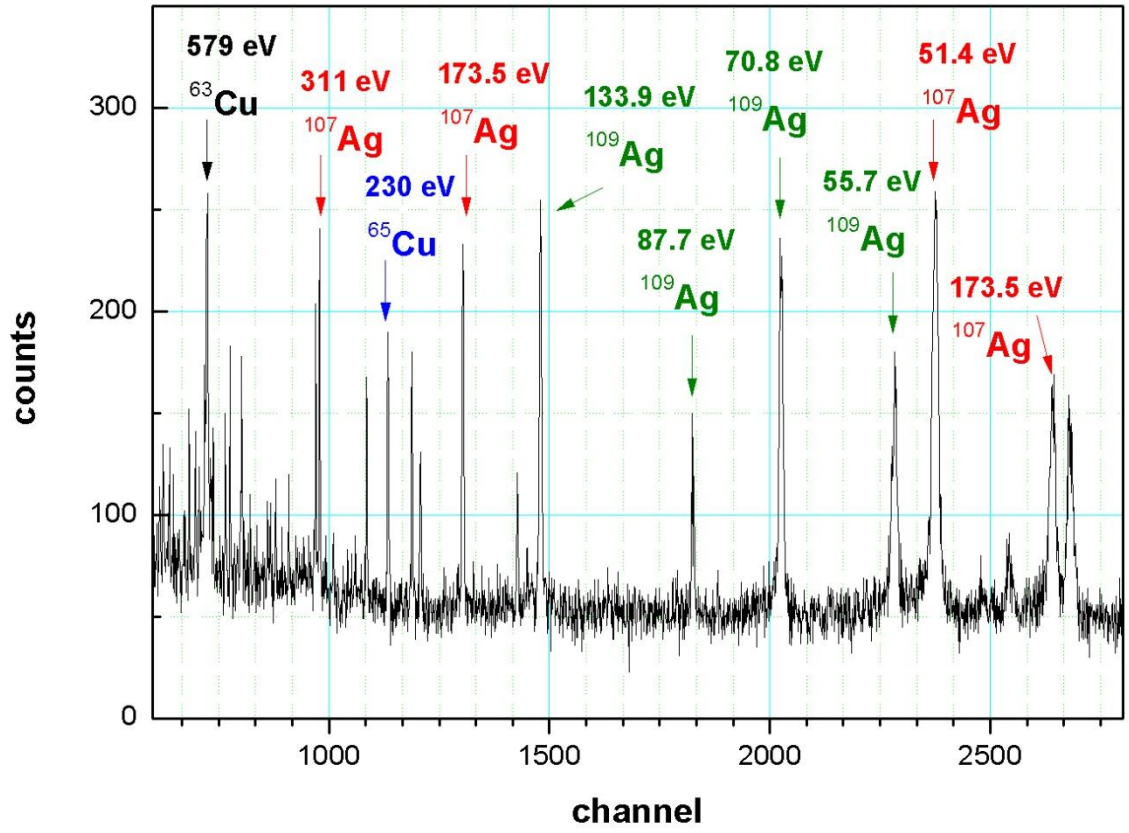
Peak current, A	3
Repetition rate, Hz	50
Electron pulse duration, ns	100
Electron energy, MeV	60
Neutron intensity, n/s	$4 \cdot 10^{11}$

General view of the detector

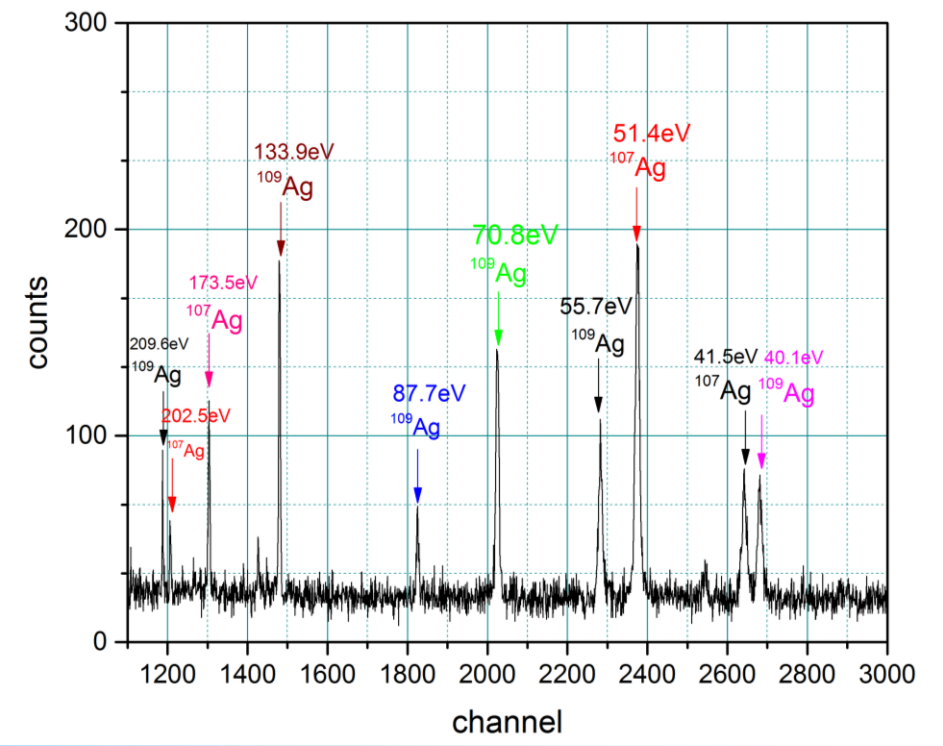
Detector contains 6 sections forming together the cylinder with the channel along the neutron beam direction. Diameter of the channel is 300 mm, external diameter of the detector is 730 mm, length 600 mm. Total volume of liquid scintillator is 250 liters. There are photomultipliers in both ends of each section. The signals from two photomultipliers of each section are summarized on output load resistor.

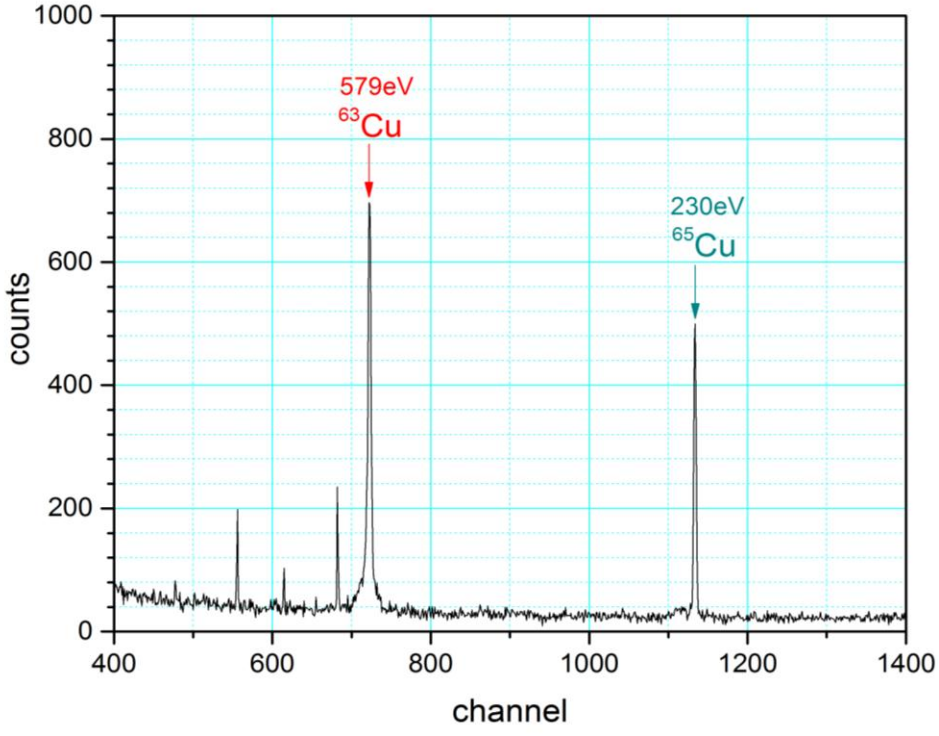
Then after amplification and shaping they go to the majority coincidence circuit.
The majority coincidence circuit is applied to observe radiative capture of a neutron. Various combinations of coincidence of pulses in different sections are possible.

Experimental spectrum, obtained from measurement with ancient coins from the Phanagoria's treasure



Time-of-flight spectrum of standard samples



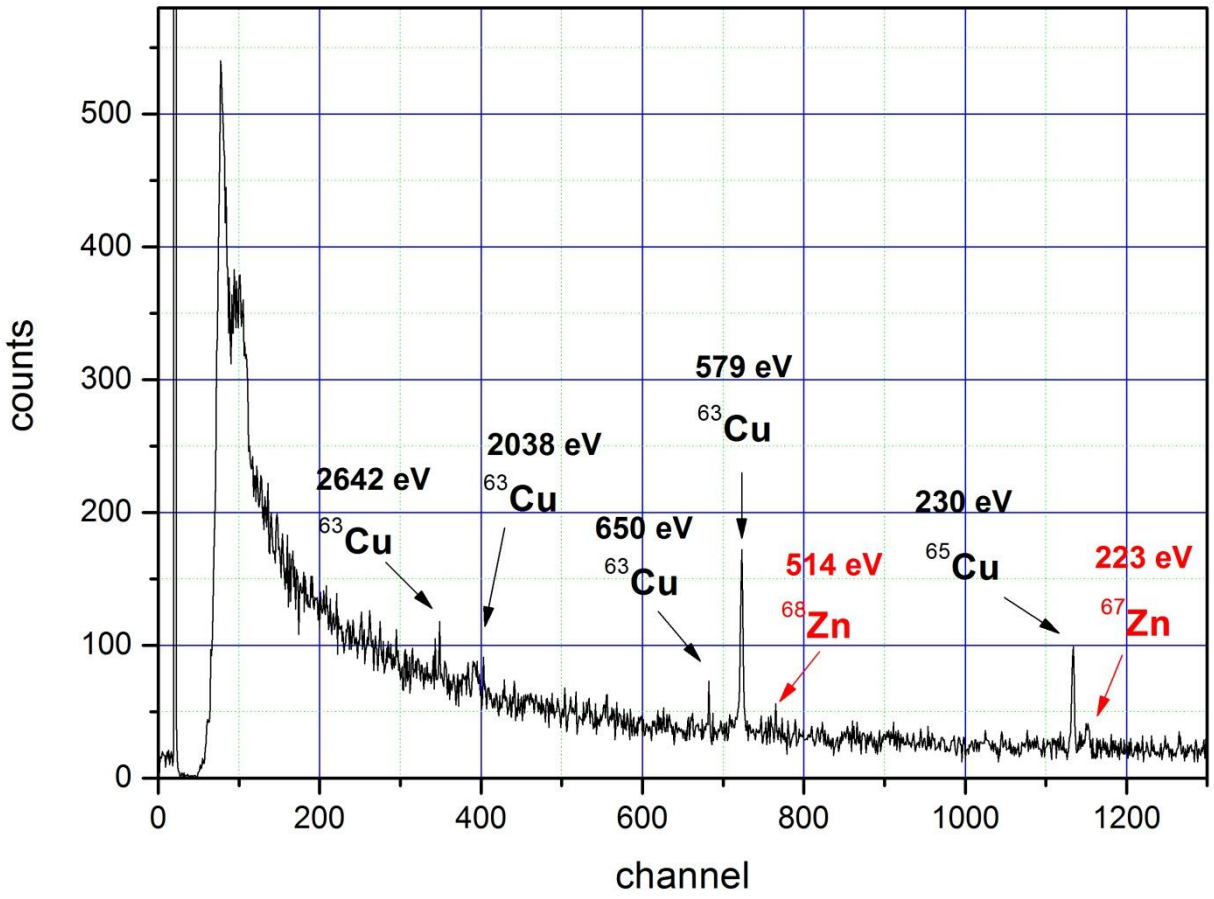


Fibula from Podbolotyevsky burial ground (10th century AD)

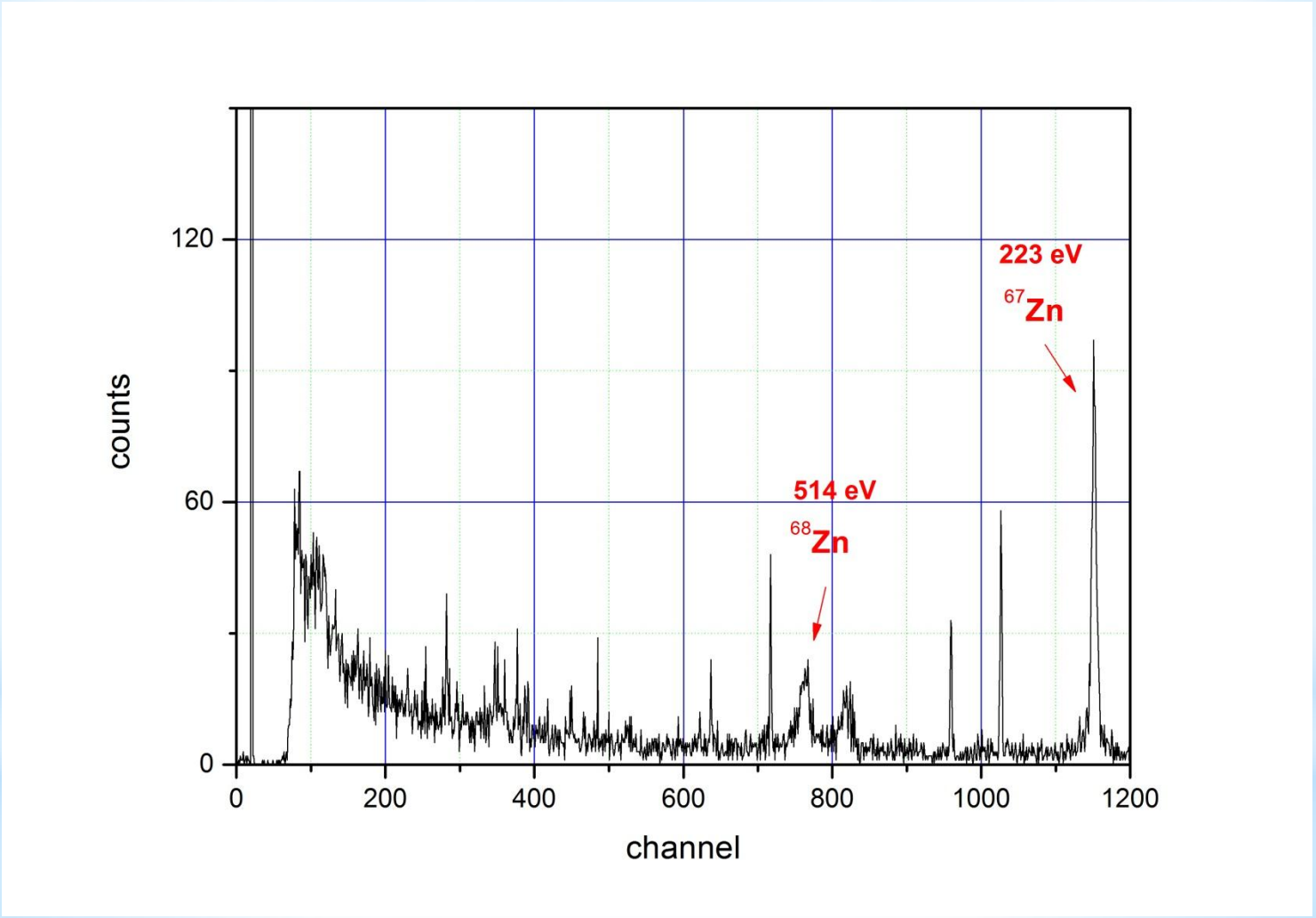
We received an application from Institute of Archaeology Russian Academy of Sciences to make the analysis for fibula from Podbolotyevsky burial ground (10th century AD) in the Vladimir Region.

The archeological funeral monument was found at the end of the 20th century. Within 3 years of excavations the experts have found nearly 7000 artifacts, from jewelry to weaponry. These are hundreds of graves of the Finno-Ugric tribe of Murom that lived downstream River Oka from the 10th century and was engaged in hunting, crafts and agriculture. For the last three years scientists examined 181 graves and 20 more are being studied at present.

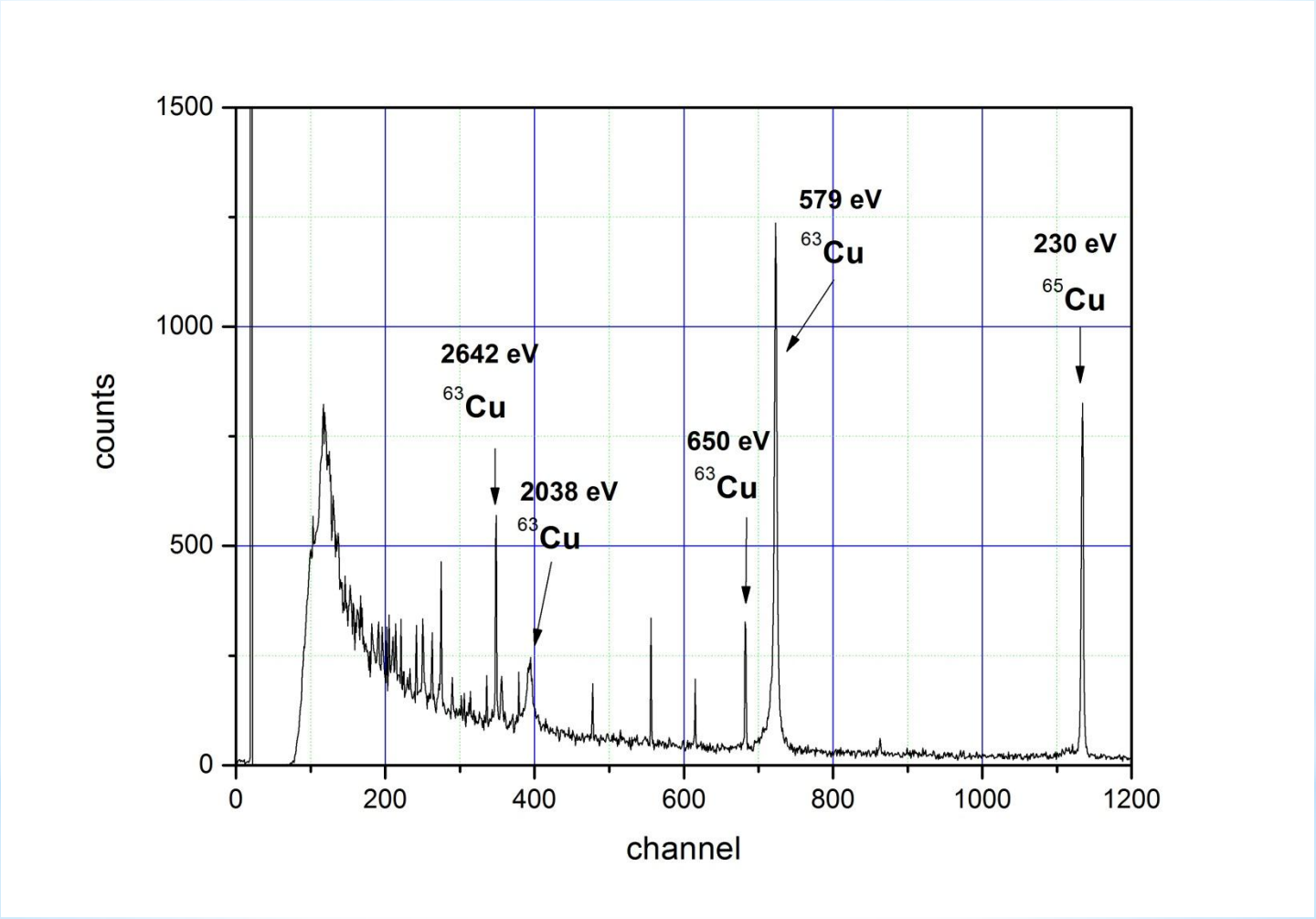
Time-of-flight spectrum from the fibula



Time-of-flight spectrum from Zn standard sample



Time-of-flight spectrum from Cu standard sample



Amount of the element is determined by an intensity of the resonance area

$$\sum N = \Pi(E_0)\varepsilon_\gamma \frac{\Gamma_\gamma}{\Gamma} A$$

$\Pi(E)$ - total neutron number have been falling on the sample during the measurement time per unit of energy

ε_γ - detection efficiency

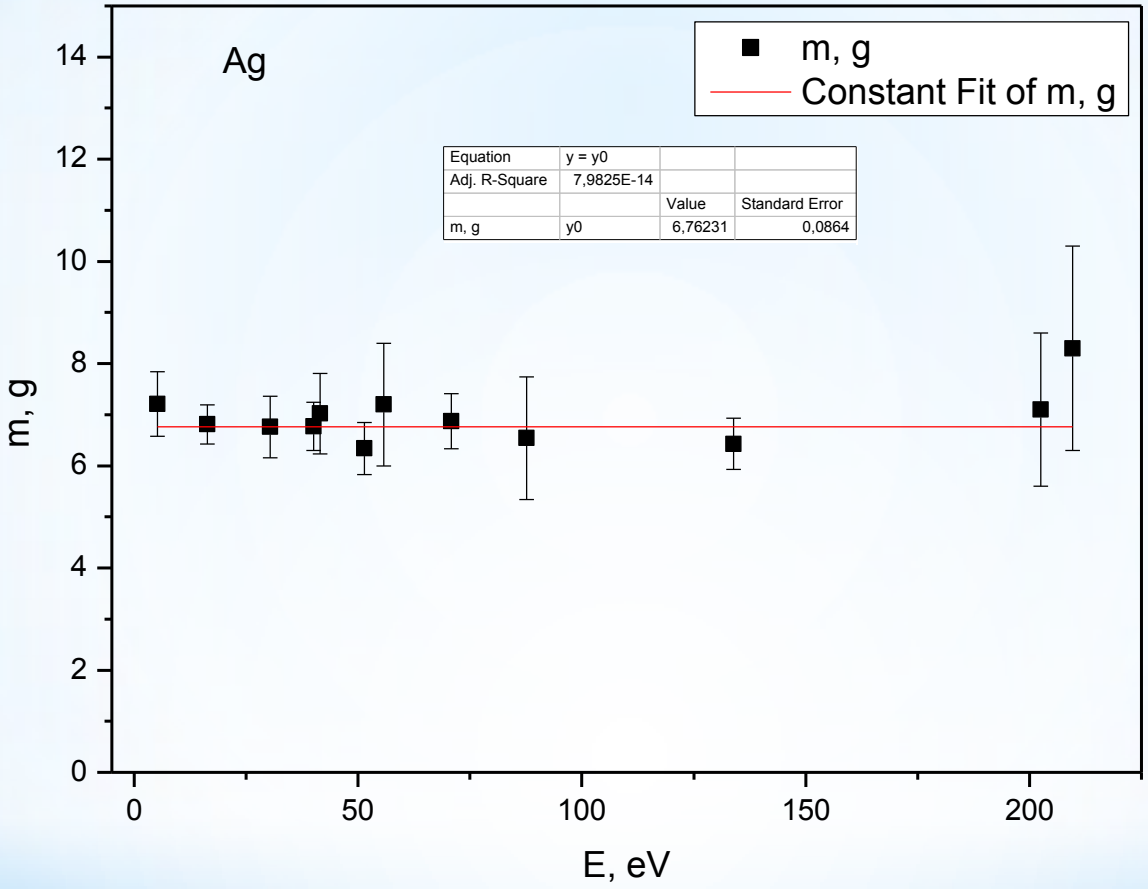
Γ_γ - radiation width of the resonance

Γ - total width of the resonance

A - resonance area on the transmission curve, $A = \int_{-\infty}^{\infty} [1 - T(E)]dE$

where $T(E)=e^{-n\sigma(E)}$ is defined as function of the resonance parameters and the sample thickness (nuclei/cm^2).

Results of the analysis



E, eV	**Isotope**	*σ_0, b*	*n, number of nuclei for the isotope, cm^2*	*m, g*
230	^{65}Cu	493.9	$6.9 \cdot 10^{21}$	62.0 ± 3.1

Preliminary result

№	Element	Mass, g
1	Au	0,0171±0,0027
2	Cu	13,5±1,5
3	Zn	1,06±0,39

Conclusion

- The weighted-average value of silver content in the samples was 6.76± 0.09 g. The copper content was estimated only for one resonance of ^{65}Cu 230 eV. The result is 62.0 ± 3.1.The total mass of the elements in coins, determined from the resonances, is 68.76 ± 3.1. The mass of coins determined by weighing 73.033 g. The difference does not exceed two standard deviations, so the result can be considered satisfactory.
- It would be more interesting to measure each coin separately and for this case we can make preliminary estimation of the error. The weighted-average value of silver content in ten coins is 6.76± 0.09 g. The error is 1 %. In the case when each coin is measured separately, the statistics will be in 10 times less during the same measurement time and the error will increase by 3 times (up to 4 %). In that way if the difference in the silver content in coins is more than 12 % we will define it with good accuracy.
- The weight of fibula equal to 19.9 g. The mass of zinc determined from the resonances is 1.06±0.39 g. Most probably the fibula was made in Old Russian territory because such kinds of artifacts from this area typically had small portion of Zn (not more than 10%).

NRCA allows not only to identify with high accuracy the elemental and isotopic composition of the sample, but also makes it possible to determine the amounts of elements and isotopes in the sample.
The method is non-destructive, the induced activity of the sample is practically absent. All this makes it promising for research of archaeological artifacts and objects of cultural heritage.

Thanks for your attention !