Non-destructive investigation of the fragment of mirror (6th-4th centuries BCE) from the necropolis Volna 1 on the Taman Peninsula by Neutron Resonance Capture Analysis

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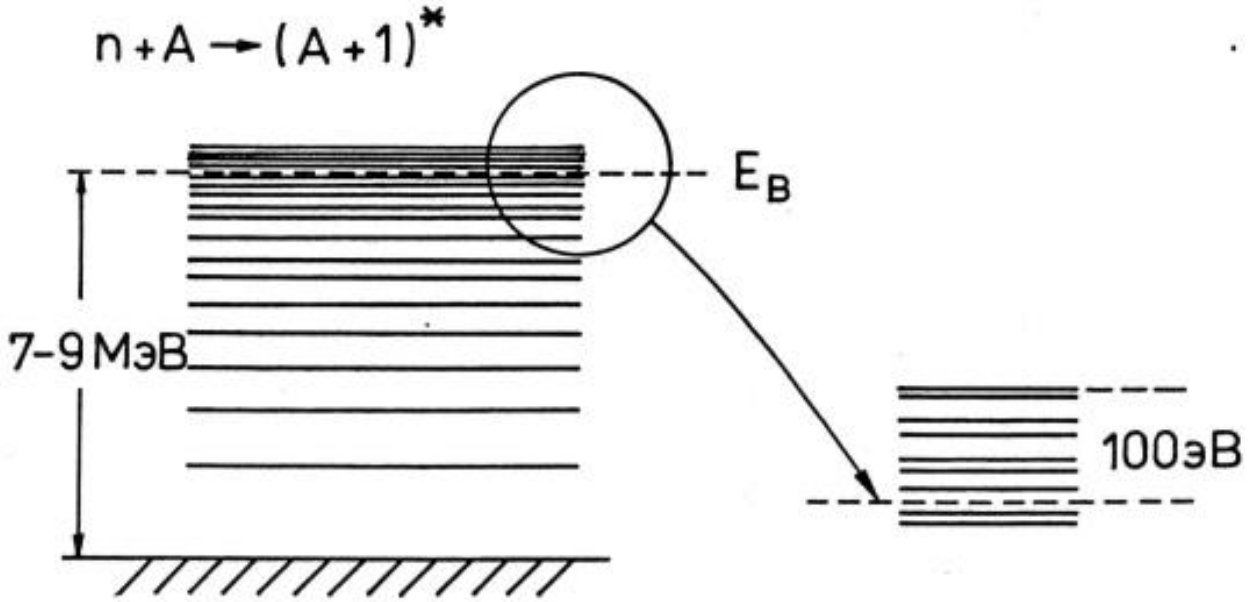
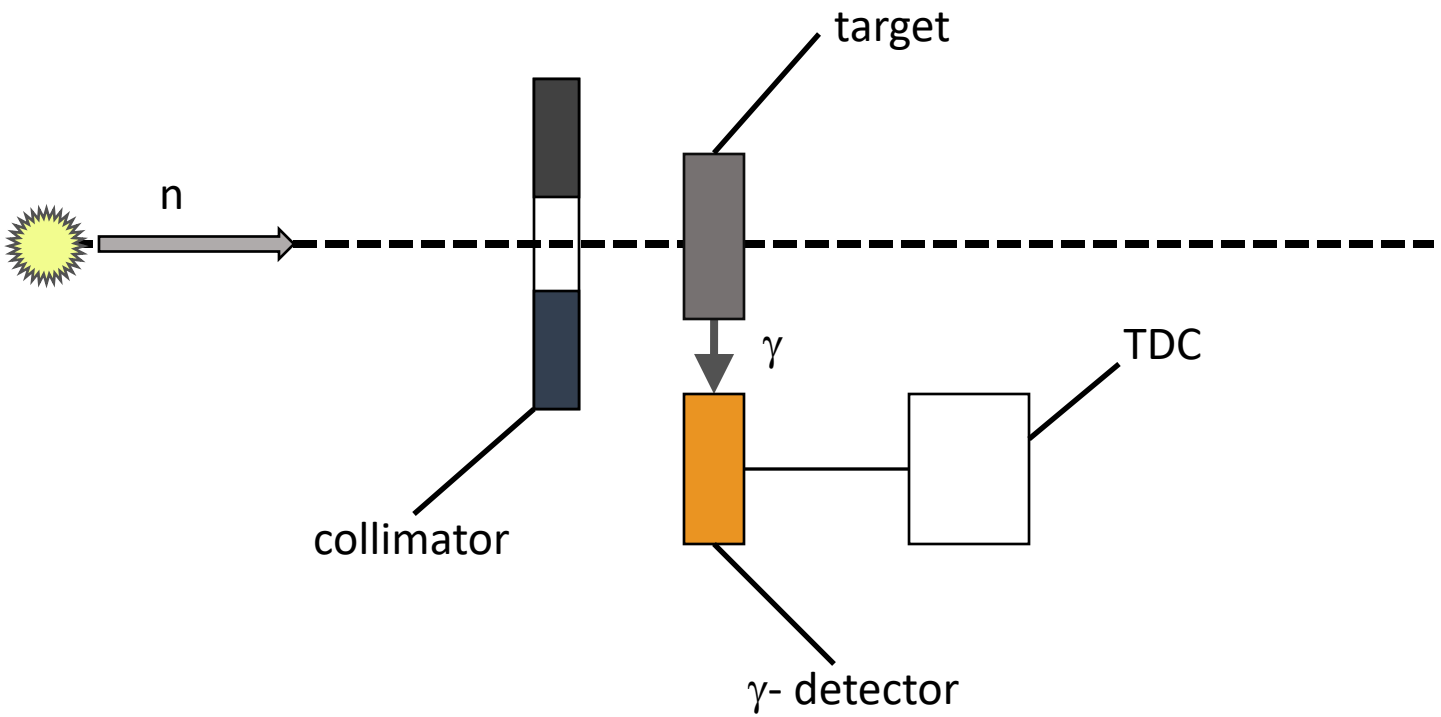
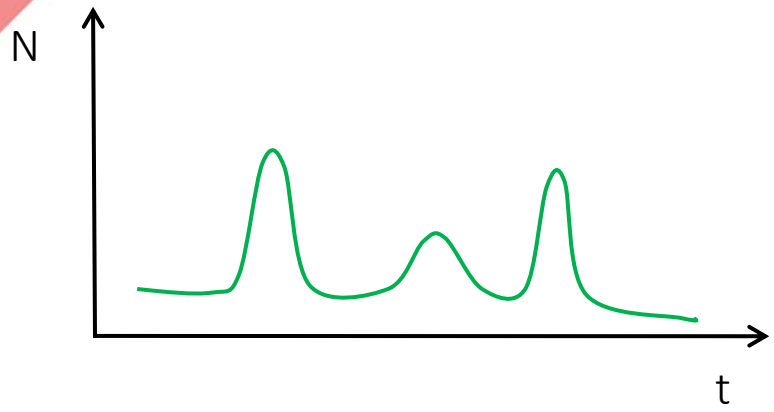
- *Neutron Resonance Capture Analysis (NRCA)* can be applied for nondestructive determination of the isotopic composition of samples. The method is based on the registration of neutron resonances and the measurement of the yield of reaction products in the resonances. The resonance energies are known 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.



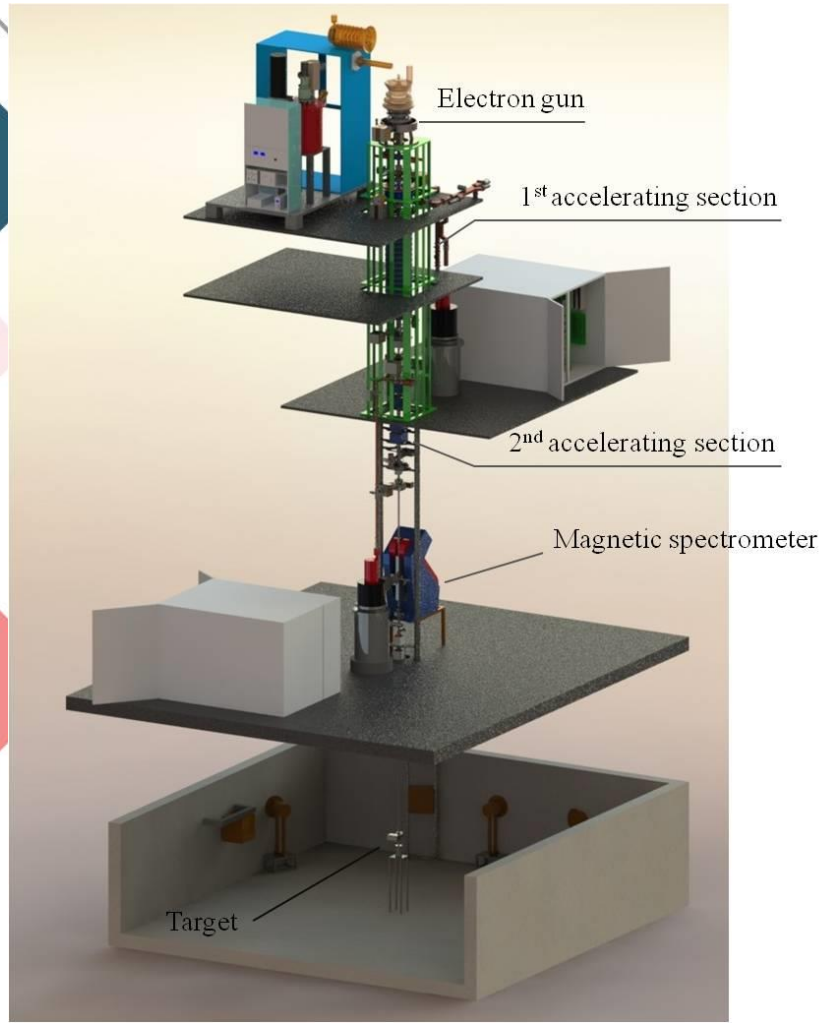
Neutron resonance capture analysis (NRCA) is based on use of the pulsed neutron source and time-of-flight method (TOF)





$$E\ (eV) = \frac{\left(72.3 \cdot L\ (м)\right)^2}{t\ (\mu s)^2}$$

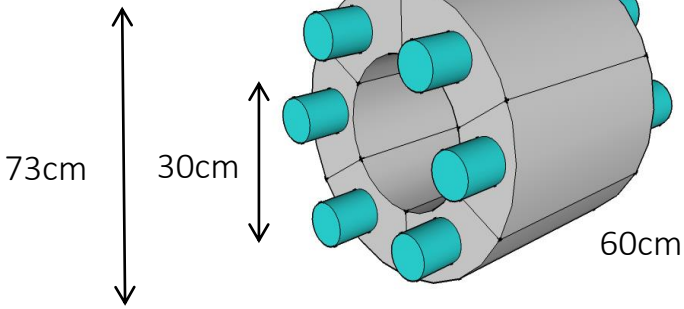
Intense Resonance Neutron Source (IREN) parameters



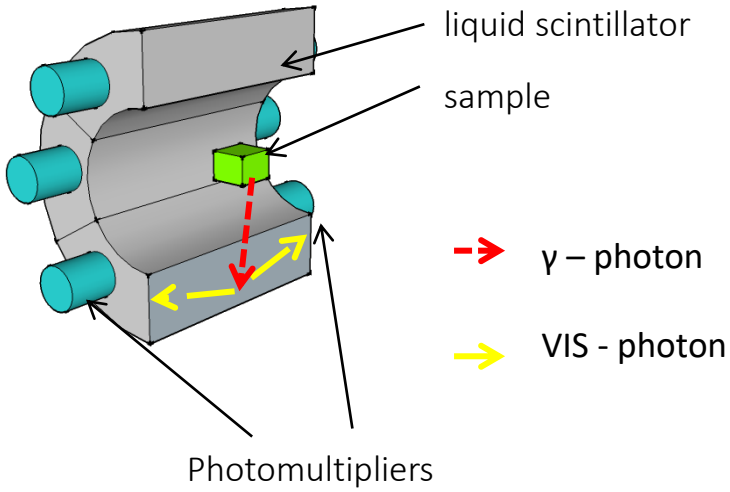
The main part of the IREN facility is a linear electron accelerator. The bunched electron beam generates bremstruhlung in the tungsten target and it produces the neutron pulses via (γ,n)-reaction in the same target.

Peak current, A	2
Repetition rate, Hz	50
Electron pulse duration, ns	100
Electron energy, MeV	70
Neutron intensity, n/s	~10^{11}

Experimental setup



6 Liquid scintillator (210 liters)
12 Photomultipliers



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 210 liters. There are photomultipliers in both ends of each section. The signals from two photomultipliers of each section are summarized on output load resistor.

General view of the detector

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.

Necropolis Volna 1

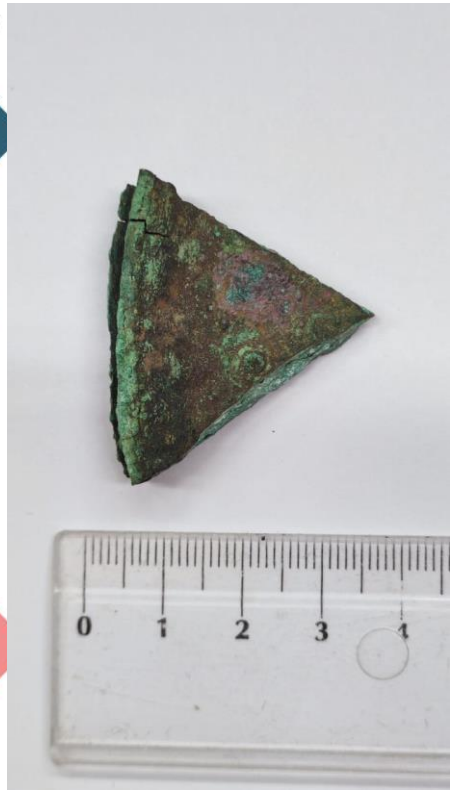
- Necropolis Volna 1

In 2016-2018 a Sochi Expedition group of Institute of Archaeology of the Russian Academy of Sciences under the leadership Roman A. Mimokhod conducted excavations of an antique town soil necropolis Volna 1 on the Taman Peninsula.

The burial ground Volna-1 is an important monument for studying of a problem of Greek-Barbarian relations on the territory of the borderland - the Northern Black Sea region, the clash and interaction of two different ethnocultural layers of the population.

During the excavation of the burial ground, a representative collection of archaeological material was obtained, dated within the 6th-4th centuries BCE. Rather rare objects were found in the burials: an artificial limb, musical instruments (cithara, harp), a bronze Corinthian helmet, and fragments of mirrors.

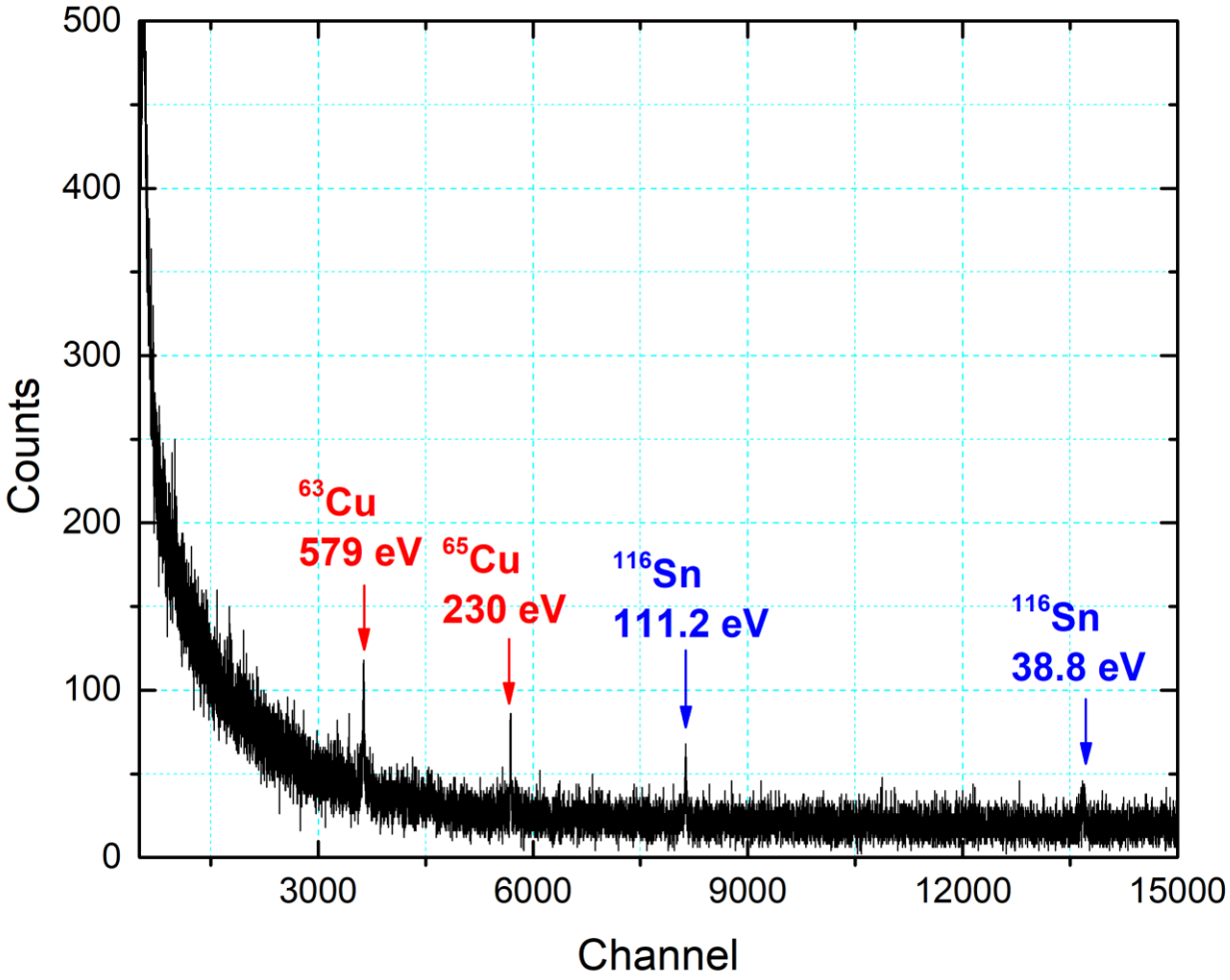
Fragment of mirror



We have applied the method for the analysis of several archeological objects from the necropolis Volna 1. In this work, we concentrate on a study of fragment of mirror.

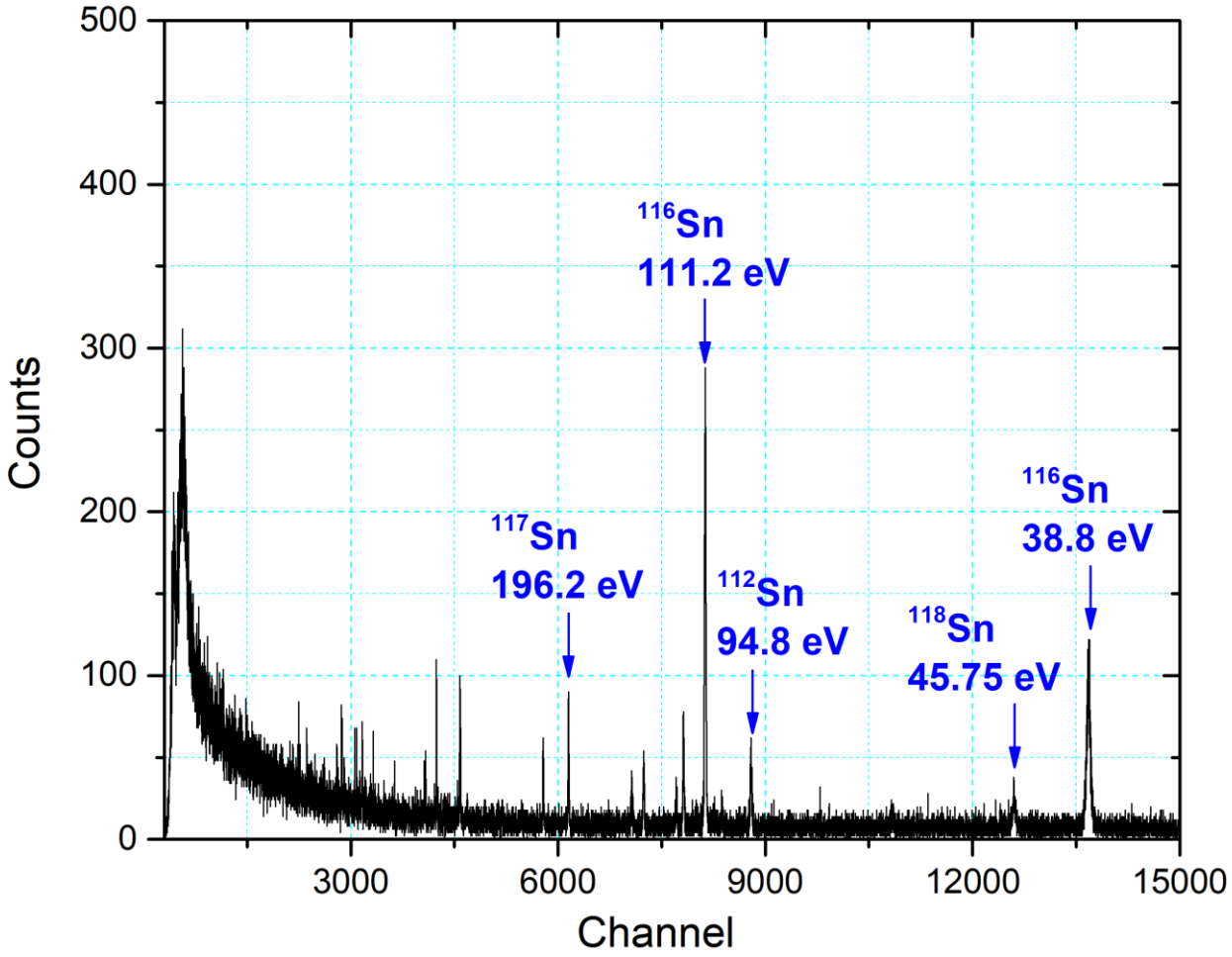
The mirror has high vertical ledges, presumably belong to the Borysthenitic type of mirrors. The handle is lost, the remains of the fastening are preserved on the mirror. The metal of the mirror is degraded to a large extent, it is not possible to restore the height of the side and the design of the fastening. Analysis of the elemental composition by the XRF method is difficult. In this regard, data on the elemental composition obtained by the NRCA method are of great importance.

Time-of-flight spectrum from the fragment of mirror



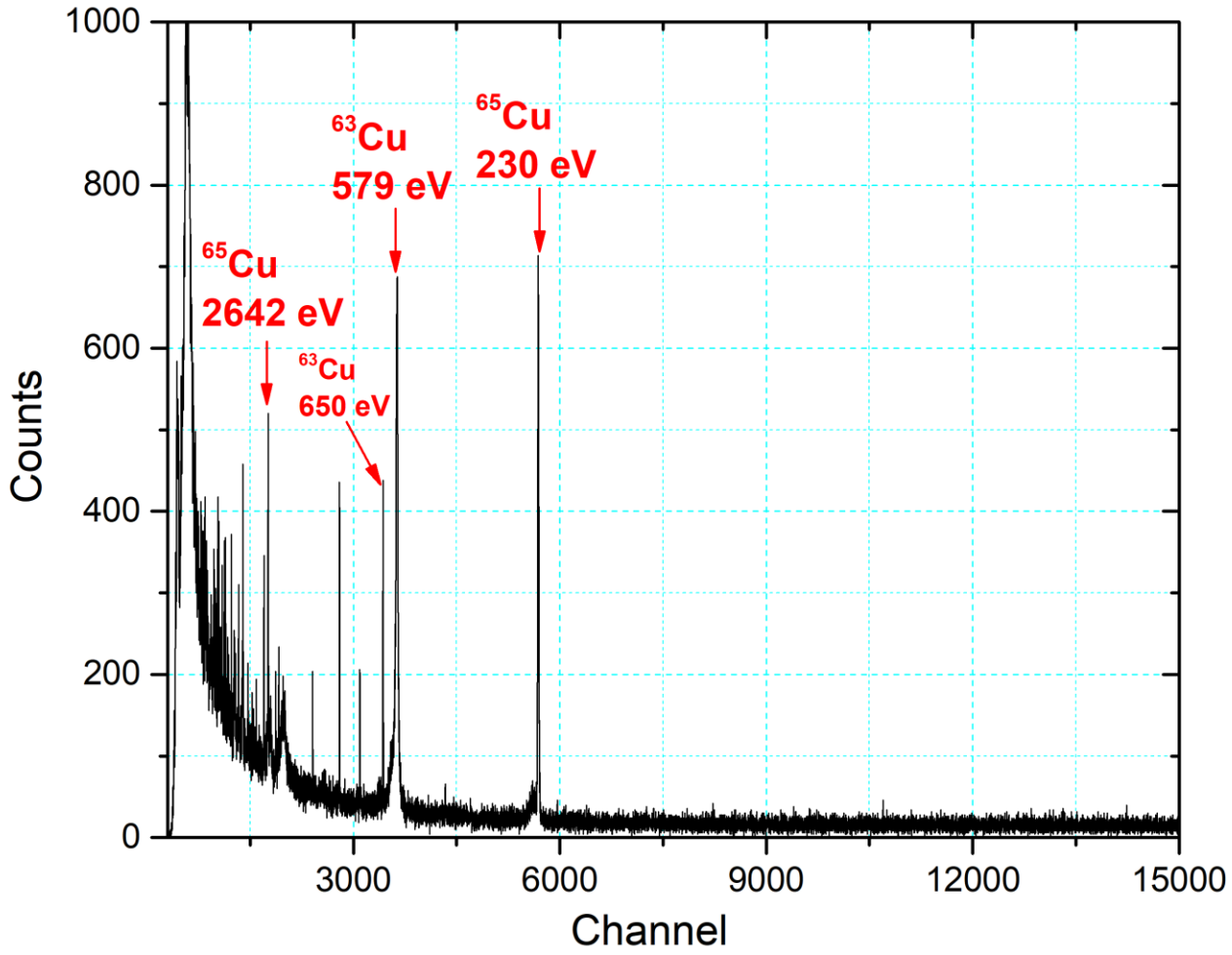
The width of the time channel is 0.05 μs

Time-of-flight spectrum from the standard tin sample



The width of the time channel is 0.05 μs.

Time-of-flight spectrum from the standard copper sample



The width of the time channel is 0.05 μs.

Parameters of samples

Sample	Area, cm^2	Weight, g	Measurement time, h
Copper	101.7	305.28	22.89
Tin	100	34.07	15.33
Mirror	6.48	18.83	37.17

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).

Result for **fragment of mirror**

№	Element	Mass, g	Weight, %
1	Cu	16.76±0.98	89±5
2	Sn	1.98±0.10	10.51±0.53

Conclusion

The fragment of the mirror was found in the necropolis Volna 1 on the Taman Peninsula. The elemental and isotopic composition of the sample was determined by NRCA. The mass of the fragment of the mirror is 18.83 g. According the result of analysis the value of determine total elements mass coincides with the artifact mass within the margin of error.

The result obtained allows us to be sure that during the manufacture of this mirror in the 6th-4th centuries BC. tin bronze was used with a tin content of up to 10%. These data are well extrapolated to the results of studies of Greek and Etruscan bronze mirrors, carried out by various methods of analysis. In this case, the NRCA method showed good results in the analysis of completely corroded objects, on which it is difficult to study the composition of the metal by other standard analysis methods.

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 !