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FLNP

Non-destructive investigation of fragment of leggings (4th centuries BCE) using Neutron Resonance Capture Analysis

N. Simbirtseva[1], S. Mazhen[1,2], A. Yergashov[1,2,3], P.V. Sedyshev[1], I.A. Saprykina[1,4],E. I. Savchenko [4]

[1] *Frank Laboratory of Neutron Physics, Joint Institute for Nuclear Research, Dubna, Russia*

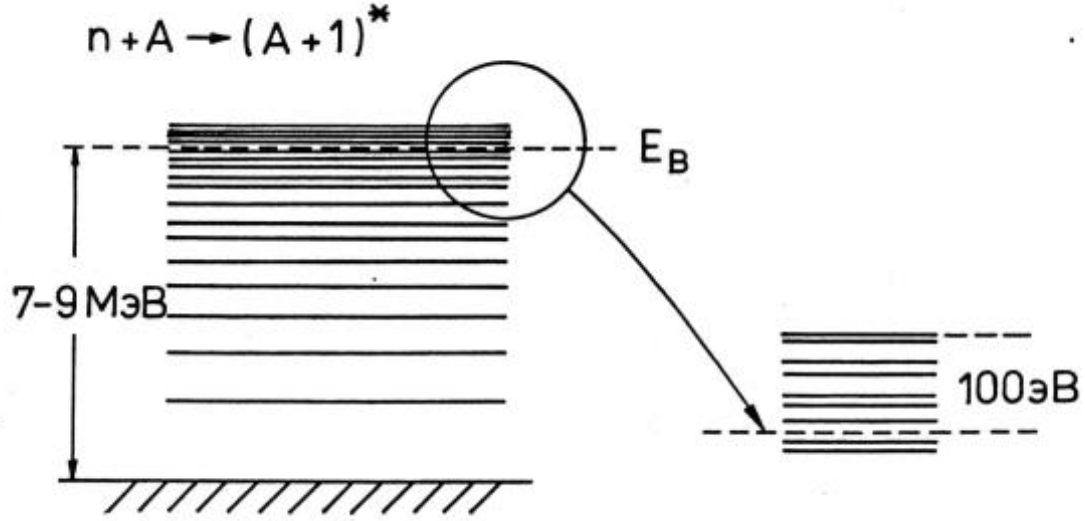
[2] *Institute of Nuclear Physics, Almaty, 050032, the Republic of Kazakhstan*

[3] *L.N. Gumilyov Eurasian National University, 010008 Nur-Sultan, Kazakhstan*

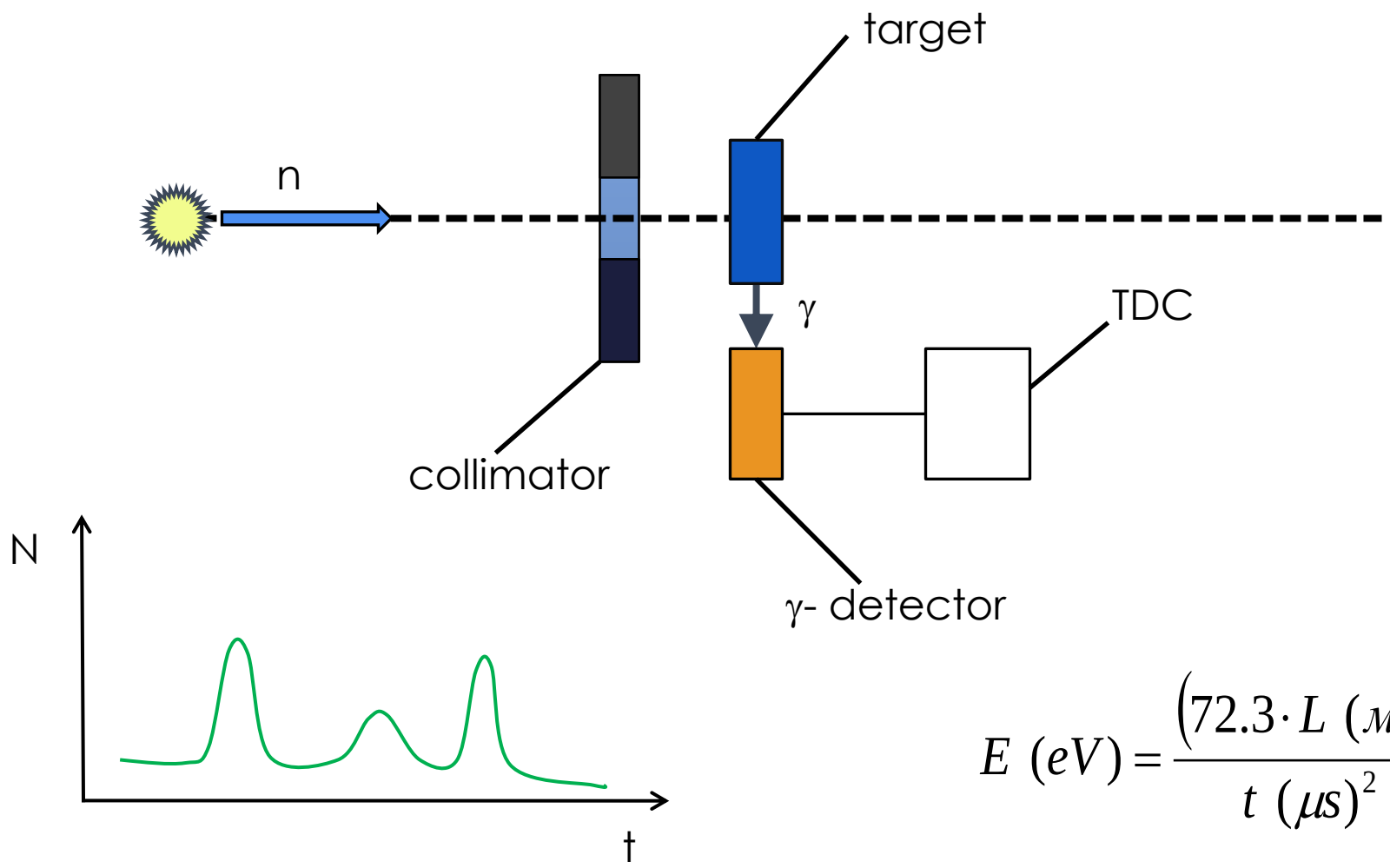
[4] *Institute of Archaeology of the Russian Academy of Sciences, Moscow, Russia*

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.

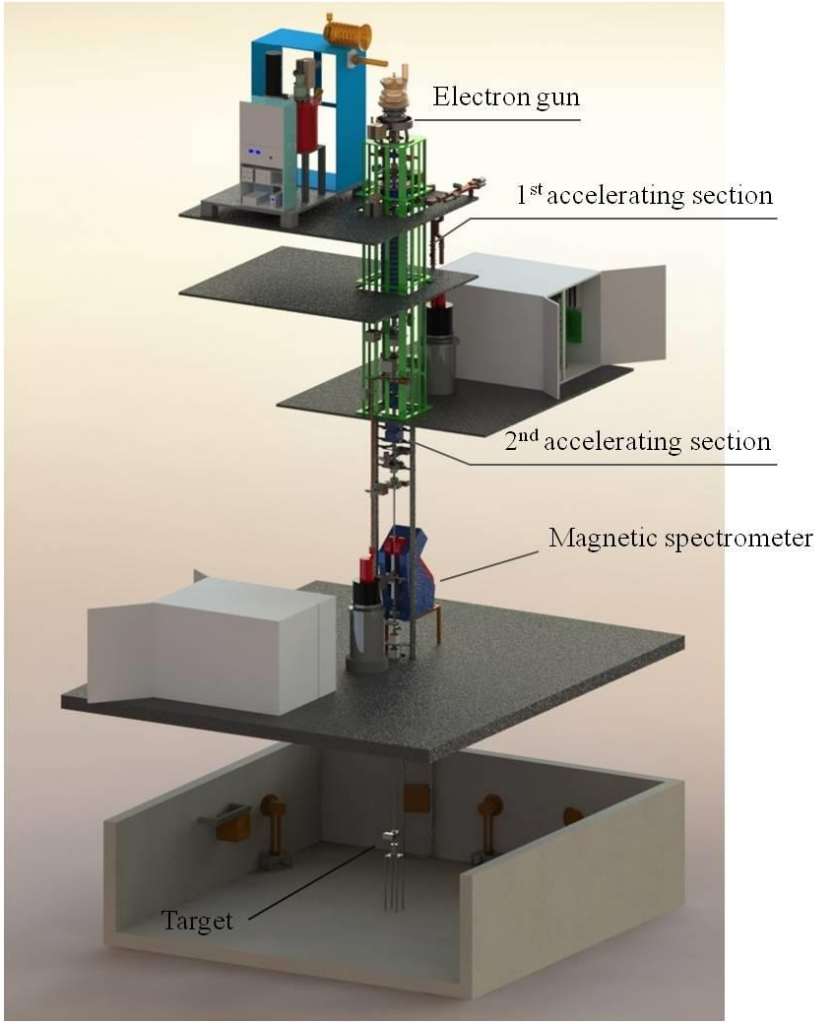


Neutron resonance capture analysis (NRCA) is based on use of the pulsed neutron source and time-of-flight method (TOF)



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

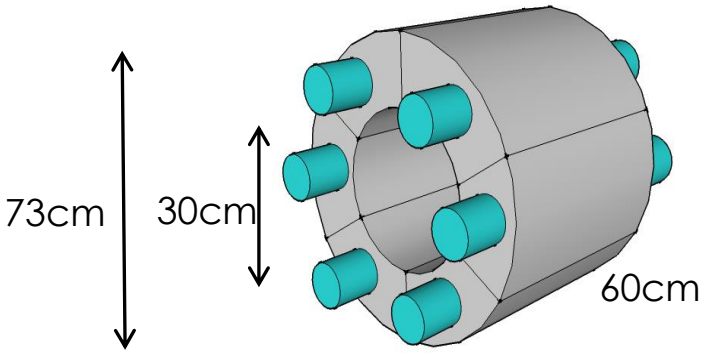
Intense Resonance Neutron Source (IREN) parameters



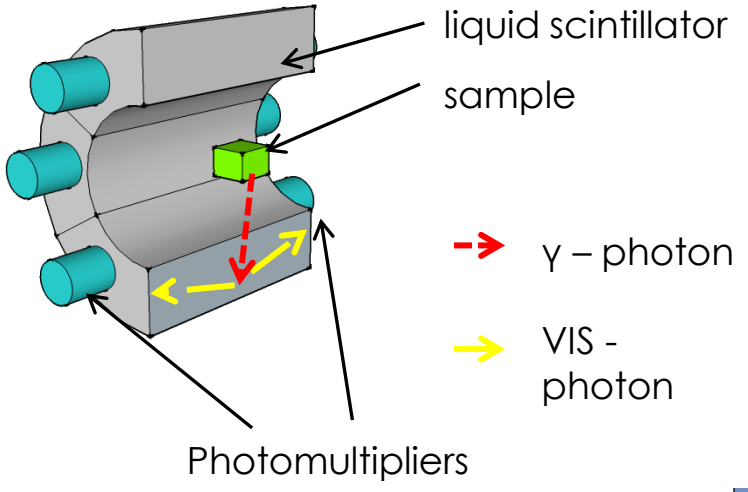
The main part of the IREN facility is a linear electron accelerator. The bunched electron beam generates bremstruhlung in the tungsten target and it produces the neutron pulses via (γ,n)-reaction in the same target.

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

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.

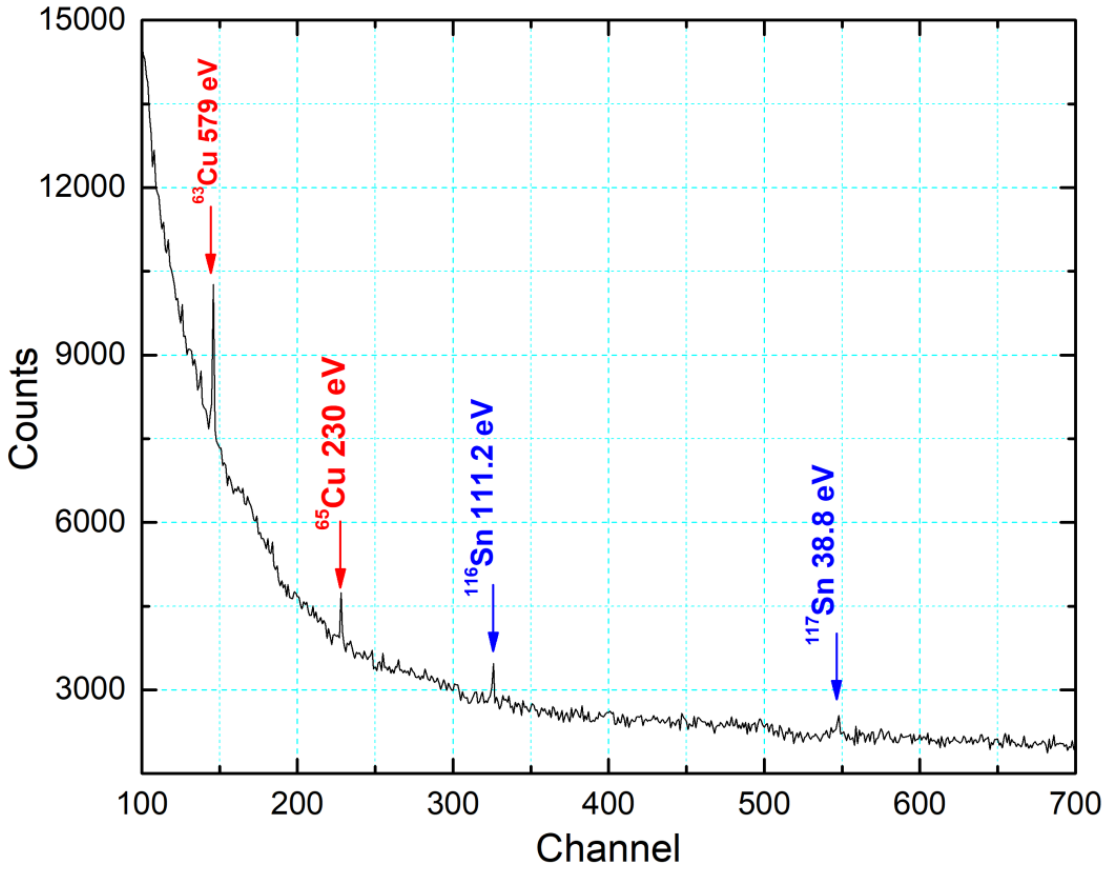
General view of the detector

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.

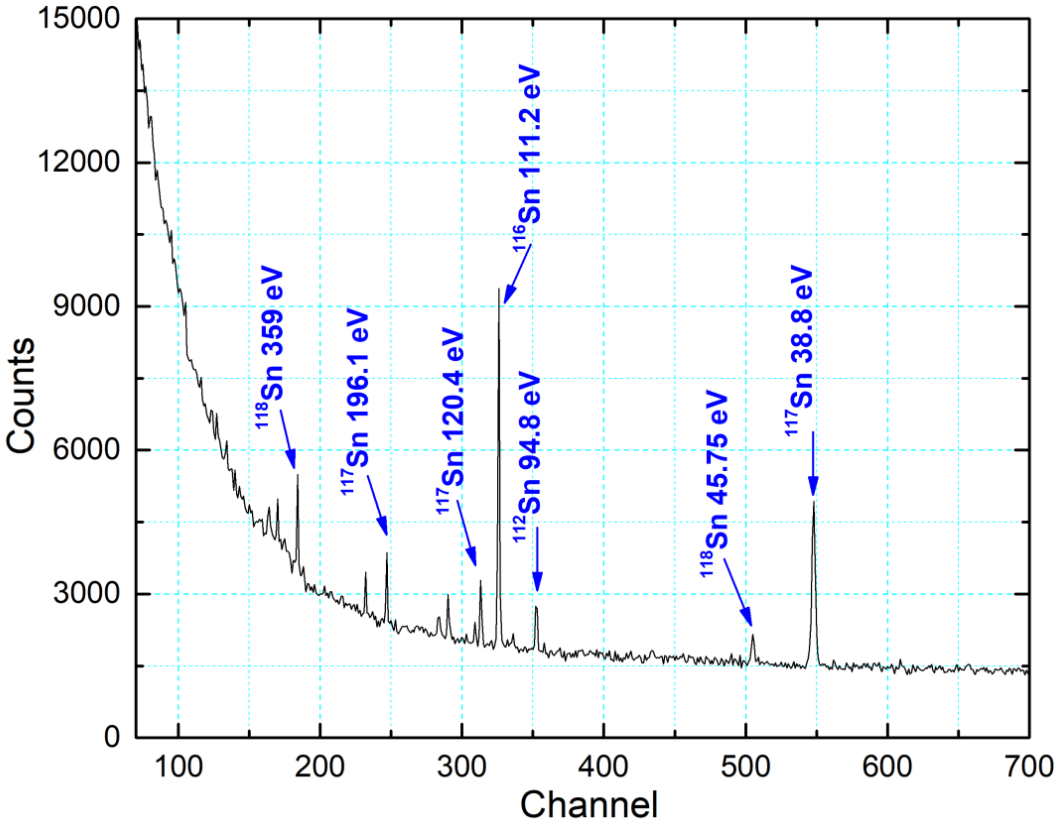
Fragment of leggings (4th centuries BCE)

- As part of this direction, joint work is being carried out with the Institute of Archeology of the Russian Academy of Sciences (RAS) for various samples. One of these samples is a fragment of leggings. This archeological object was found during excavations of the Scythian mound Gorki-I, carried out by senior researcher at the Institute of Archeology of RAS Savchenko E.I. in 2003. The burial mound was located in the Krasnyansky district of the Belgorod region, in the burial mound No. 13, dating from the mid-second half of the 4th century BCE. A pair of bronze leggings was found there, one of which was so poorly preserved that only one could be reconstructed.
- The bronze leggings, which are leg armor that protects not only the shin, but also the knee, are extremely rare in the burials of the Scythian nobility; they are found only in the richest (royal) Scythian burial mounds. In view of such rarity fragility of the artifact, the determination of element and isotope composition by non-destructive Neutron Resonance Capture Analysis is particularly relevant.

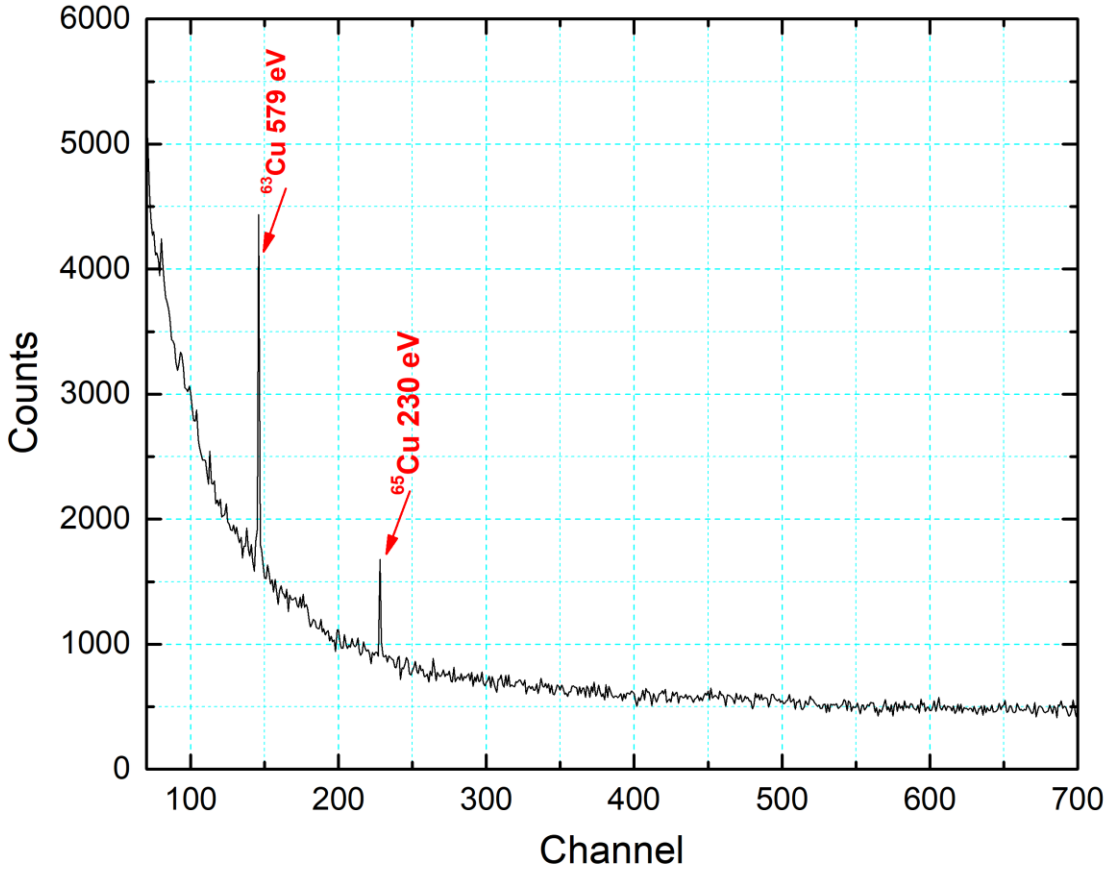
Time-of-flight spectrum from the fragment of leggings



Time-of-flight spectrum from standard tin sample



Time-of-flight spectrum from standard copper 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).

Result of investigation

Element	Mass, g	Weight, %
Cu	0.915±0.036	89±4
Sn	0.0975±0.0049	9.48±0.48

Conclusion

The elemental and isotopic composition of the sample was determined by NRCA. The mass of the leggings is 1.03 g. According the result of analysis the value of determine total elements mass coincides with the leggings mass within the margin of error.

The obtained data on the type of alloy of the leggings - tin bronze, characterized by a tin content of no more than 10%, does not stand out against the general background characteristic of both the Bosporan non-ferrous metalworking and the metalworking of Greece and its colonies of this period. Such a “hit” in the recipe of an alloy that circulated throughout ancient Greece and its most distant colonies (Bosporus), in combination with the manufacturing technique, indirectly indicates the imported nature of the studied leggings and their production, possibly in one of the workshops in the Western Black Sea region.

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 !