**Nuclear physics in the bioarchaeological study of the Bronze Age in European Russia**

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Bioarchaeology means contextual research of animal and human bones from archaeological excavations. A broad variety of methods of the discipline gives evidence for health conditions, lifestyle, diet, mortality and physique of the past populations.  The application of nuclear physics methods in this field has so far been represented by pilot studies.

The Bronze Age is an important period in human history, approximately from 3300 BC to 1200 BC, characterized by production of bronze by smelting its own copper and alloying it with tin, arsenic, or other metals. It was aggressive period of long-distant migrations, rich by military conflicts with use of lethal weapon. The bioarchaeological approach makes it possible to conduct a material science examination of such weapons along with an examination of human skeletal remains from archaeological excavations.

A massive bronze battle axe from the Abashevo archaeological culture was studied using neutron tomography and manufacturing modeling from the production molds. Detailed structural data was attracted to simulate and model possible injuries and wounds caused by this battle axe. We report the results of neutron tomography experiments on the bronze battle axe, as well as a manufactured plastic and virtual model of the traumas of human skulls obtained at different strike angles from this axe. The reconstructed 3D models of the battle axe, the plastic imprints model, the real wound and trauma traces on the bones of the ancient peoples of the Abashevo archaeological culture were obtained. Skulls with traces of injuries originate from archaeological excavations of the Pepkino burial mound of the Abashevo culture in Volga region. The reconstruction and identification of the injuries and type of weapon on the restored skull was performed. The complementary use of 3D visualization methods allowed us to make some assumptions on cause of the death of the people of the Abashevo culture and possible intra-tribal conflict in this cultural society. The obtained structural and anthropological data can be used to develop new concepts and methods of the archaeology of conflict.

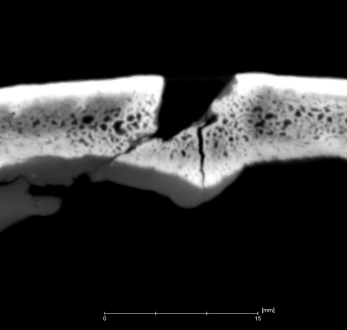
The bronze battle axes of the Abashevo archaeological culture are heavy and lethal weapons. For our studies, we selected a real bronze battle axe of the Abashevo culture from the ancient settlement Malo-Kizilsky, Russian Federation.

The weight of the studied axe is 953 g. Its blade length is 209 mm, blade width is 50 mm, and the width of hitting edge was about 6 mm and 0.3 mm of the sharp part (Figure 1). This axe could inflict deep lethal head traumas, including the penetrating wounds.



**Figure 1.** a) 3D model of the bronze axe after tomographic reconstruction from neutron data. b) Longitudinal virtual slice of the 3D model of the bronze battle axe. The inner voids and cavities are visible. The bottom large void is a manufacturing defect. The rainbow-like coloring shows neutron absorption degree from low (blue) to high (red). с) Transparent virtual model of the bronze battle axe with contrasting internal voids.

Experimental imprints of the several hits by the battle axe from the Malo-Kysilski site were made using plasticine. The obtained plastic model was converted into a 3D virtual copy using X-Ray microtomography methods (Figure 2). The shapes and cutting angles of the hitting edge of the recovered model of the bronze battle axe were used for modeling of the caused traumas on the bones. This model can also be used to identify shallow or superficial wounds that are characteristic of fighting or defending warriors. The shape of cranial wounds from excavations of the burial mound of this culture looks similar to the shape of the reconstructed plasticine model, where the edge hit angle was close to 45°.

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**Figure 2**. Virtual reconstructed model: (a) 3D virtual model of hits tracks in the plasticine obtained by the battle-axe from the Malo-Kizylski site, resolution 180; (b) virtual transverse slice of the battle axe imprint; (c) virtual longitudinal slice of the battle axe imprint, resolution is 70 µm. (d) Vertical transverse slice of cranial vault reflected the shape of weapon. Resolution is 190 µm.

The last point of our presentation proposes to use the NAA method in the study of bone remains of the Bronze Age casters. The occupational intra-vital contamination of bone tissue by chemical compounds was evaluated. Our data reveals occupational risks of early metallurgists; gives independent evidence for the assumption of arsenic bronze casting by some representatives of the Abashevo archaeological culture of the Middle Volga region and provides some information about the sources of the metal.