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High-energy ion beam analysis: the study of raw materials and manufacturing techniques for cultural heritage objects.

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Ion beam analysis has been developed at ARRONAX cyclotron in Nantes [1]. Light ions including H^+ and He^{2+} are accelerated to reach the required energy for the analyses before being extracted in-air. We use a fixe 68MeV α beam and several proton beams at 17MeV to 70MeV. We will explore the specific interest concerning material analysis by beam irradiation. Interaction between ions and target atoms produced X-rays and γ-rays by electronic collision and nuclei activation which are characteristic of the nature of the target material. It is the basis of two analytical techniques: HE-PIXE (High-energy particle induced X-rays interaction) and PAA (Proton activation analysis). High energy is used to probe material in depth through a few µm to several mm depending on the nature of the material and the beam. The K X-rays production cross-section is high for heavy elements, it increases the probing depth compared to less energetics L and M lines that are much more attenuated at the target surface. Even so, HE-PIXE analysis remains dependent on X-rays attenuation in the target. For thicker targets (>1mm), we use PAA to detect energetic γ-rays emitted by the target after irradiation by radioactive decay.

The non-destructive analysis of art and archaeological objects is central to heritage studies, enabling us to trace societies' cultural evolution and technical history. The presentation will focus on two applications of ion beam analysis looking at raw material supply in silver coins and the manufacturing technique used on a medieval lead pipe.

The first study was carried out on silver coins minted in Nantes in the late 16th century. The South American mine at Potosi, in present-day Bolivia, has been in production since 1548. Nantes' trade with Spain favoured the use of potosian silver to mint French coins from 1575 onwards. Previous studies using the thermal neutron activation technique have highlighted indium as a trace element specific to Potosí silver [2]. A new look into the activity of the Nantes mint during the Wars of Religion is provided by this study. We seek to identify coins containing a high concentration of indium in order to trace exchanges between Nantes and Potosi silver. For this purpose, we use HE-PIXE with 68MeV α beam.

The second study focused on a set of lead pipes discovered during the excavation of the water supply system of a medieval castle (13th - 14th centuries). PAA is performed to characterize the composition of the metals used. Regarding the pipe solder joints, we look if the tin-lead concentration profile is homogeneous in all the solder joints to characterize the quality of the soldering technique [3]. The analysis is based on the differential gamma ray attenuation of the Sn and Pb radioisotopes probed for several beam energies (17,34,45 and 68MeV).

[1] C. Koumeir, F. Haddad, V. Metivier, N. Servagent, et N. Michel, « A new facility for High energy PIXE at the ARRONAX Facility », p. 9.

[2] M. F. Guerra, Éd., « The mines of Potosi: A silver Eldorado for the European economy », présenté à Ion beam study of art and archaeological objects: a contribution by members of the COST G1 Action, Luxembourg: Office for the Official Publications of the European Communities, 2000, p. 88.

[3] E. Paparazzo, « Surface and interface analysis of a Roman lead pipe "fistula": microchemistry of the soldering at the join, as seen by scanning Auger microscopy and X-ray photoelectron spectroscopy », Appl. Surf. Sci., vol. 74, no 1, p. 61-72, janv. 1994, doi: 10.1016/0169-4332(94)90100-7.

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