

PGAA and subsequent INAA for Archaeometry

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PGAA and INAA are ideally suited for a panoramic analysis of the elemental composition in different materials. In the end the bundle of different advantages make these two methods attractive for archaeometry and cultural heritage – this includes e.g. low-destructiveness, straightforward sample preparation and proper detection limits for many elements.

Due to the fact that PGAA and INAA are complementary for several elements, a combination of both makes sense for certain applications like provenance studies. At the PGAA-facility of the FRM II additional INAA measurements can be performed subsequently after the PGAA irradiation. Short-lived activation products can be determined directly in the PGAA chamber. A separate low background chamber is available for long-term measurements.

The PGAA facility at the FRM II

The PGAA facility was one of the first instruments which were installed at the FRM II and has now been successfully in operation for a decade. A cold neutron beam with an average energy of 1.82 meV is used. Conventional PGAA can be operated in two different modes: The collimated beam size is 20×30 mm² with a max. flux of 2·10⁹ cm⁻²s⁻¹ (thermal neutron equivalent) and with the elliptical guide 11×16 mm² / 5·10¹⁰ cm⁻²s⁻¹. Further information of the facility is described in [1] and [2].

Some recent improvements are particularly useful for measurements of archaeological objects. Archaeometrical projects often come along with high amounts of individual samples. Since 2016 a new sample changer (Fig. 1) with complete new control software helps to handle this issue.

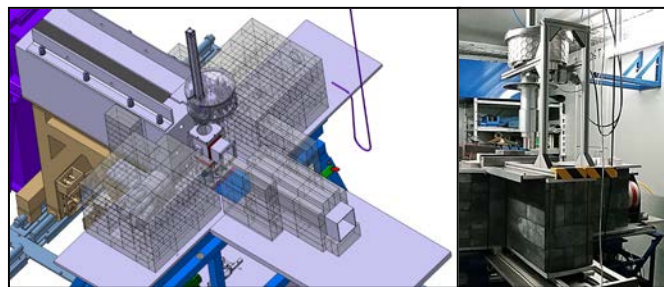


Figure 1: The new sample changer was constructed at the Institute of Nuclear Physics (IKP), University of Cologne.

In addition, it is now possible to use another sample setup – a moveable table which allows the positioning in three directions and to set the angular orientation. Larger objects can be scanned with a spatial resolution of a few millimeters (prompt gamma activation imaging, PGAI [3]). This setup was tested again and will be available in an automatized operation mode in the near future.

The low background chamber for INAA was refitted last year and will be equipped with an automatic sample changer in 2017.

Archaeometry and cultural heritage applications

A few examples of present user projects in the context of archaeometry and cultural heritage are given below.

Corrosion of iron objects like ancient swords is a major problem from a conservator-restorer's point of view. Chlorine plays a key role in this context. The reduction grade of the chlorine content by using different techniques can be determined well with PGAA or INAA.

It is of the essence for many provenance studies to measure a high amount of different elements – especially if a multivariate analysis is foreseen. Subsequent INAA after the PGAA measurement delivers notable amounts of additional elements in many cases. At our facility this was e.g. recently used for pottery. The overlap of some elements between the both methods can also be useful for intercomparison [4].

Sinter from old Roman aqueducts and other water installations often contains annual layers, which can contain information about certain events (e.g. extreme weather, earthquakes, rebuilding of aqueduct parts etc.). The investigation of isotope ratios as well as trace element concentrations helps to identify such events. Beside the possible use as a climate archive, the sinters may deliver data for geo-archaeology in the context of Roman culture – for further information see the works of *Sürmelihindi* and *Passchier*, e.g. [5]. The PGAA measurements will be done in early 2017 at the FRM II.

Archaeometry remains an important part of the research at the PGAA facility of the FRM II. Continuous improvements allow a wide range of applications.

- [1] P. Kudejova, G. Meierhofer, K. Zeitelhack, J. Jolie, R. Schulze, A. Türler, T. Materna, *The new PGAA and PGAI facility at the research reactor FRM II in Garching near Munich*, J Radioanal Nucl Chem. (2008) Vol. 278, Iss. 3, pp. 691–695
- [2] Zs. Révay, *PGAA: Prompt gamma and in-beam neutron activation analysis facility*. Heinz Maier-Leibnitz Zentrum, Journal of large-scale research facilities (2015), 1, A20. doi:10.17815/jlsrf-1-46
- [3] S. Söllradl, M.J. Mühlbauer, P. Kudejova, A. Türler, Development and Test of a Neutron Imaging Setup at the PGAA Instrument at FRM II, *Physics Procedia* (2015), Volume 69, pp. 130–137
- [4] C. Stieghorst, *Neutronenaktivierungsanalyse in Archäometrie und Solarenergieforschung*, Dissertation, Johannes Gutenberg-Universität Mainz, 2016
- [5] G. Sürmelihindi, C. Passchier, (2016, April). *Reading carbonate deposits from ancient water installations: why are they useful for geoarchaeology?*. In EGU General Assembly Conference Abstracts (Vol. 18, p. 8349).