PGA-Imaging and Neutron Tomography at MLZ's PGAA-facility (FRM-II). A position-sensitive spectroscopy-visualization method with neutrons.

Jan Jolie [a], Eschly Kluge [a], Zsolt Révay [b], Christian Stieghorst [b]*

[a] *University of Cologne, Institute of Nuclear Physics, Zülpicher Str. 77, 50937 Cologne, Germany;* [b] *Technical University of Munich, Maier-Leibnitz Centre (FRM-II), Lichtenbergstraße 1, D-85748 Garching, Germany; * main-author: ekluge@ikp.uni-koeln.de*

Introduction

Thanks to the increase of more diverse and research dedicated neutron sources as well as advancements in digital recording techniques, the range of available spectroscopy and imaging methods utilizing neutrons has significantly expanded in recent years. Especially the relatively new *Prompt Gamma Neutron Activation Analysis Imaging and Neutron Tomography* (PGAI-NT), a method to obtain and effectively visualize ever-higher resolving position-sensitive spectroscopy data sets, shows promising results for material research and archeometry.

The PGAI-NT method

PGAI-NT is the combination of a position-sensitive three-dimensional extension of the *Prompt Gamma Neutron Activation Analysis* (PGNAA) of a sample and the sample's *Neutron Tomography* (NT) for the purpose of an easy assignment and clear representation of spectroscopy data [1-2]. The via position-sensitive PGNAA obtained distribution of the various elements within a sample is visualized by differently colored voxels, hence the term PGA-Imaging. The relative abundance of a specific element itself is visualized by different intensities of the color assigned. The resulting voxel-matrix is finally embedded into the tomography-volume of the bulk sample (Figure. 1).

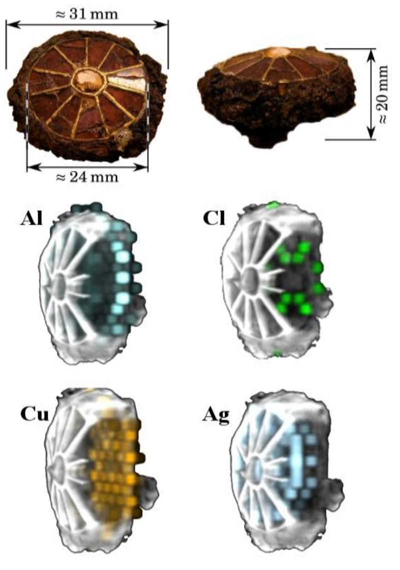

Figure 1: PGAI-NT recoding of a fibula from the 6. century showing the distribution and relative abundances of aluminum, chlorine, copper and silver via differently colored voxels embedded into the neutron tomography [2].

A PGAI sub-volume of a sample is established by the intersection of the collimated neutron beam and the collimated field of view (FOV) of one or more gamma detectors positioned in 90 degrees to the beam.

The Current Instrument

Because PGAI-NT is a method-combination with a strived application area, it should be as user friendly and cost effective as possible. For this reasons we opted for an all-in-one instrument approach by conducting the NT recoding at the same instrument site. To quicker parallelize the elliptically tapered beam of the facility for PGAI, a boron-lead collimator with a 2x2 cm^2 profile is used [3]. The pinhole-aperture used in combination with said collimator is a 3 mm thick boron-carbide (B_4C) plate with a 2 mm diameter. The resulting beam profile at sample position has a flux of 1.34×10^9 $/cm^2s$ and a PGAI-resolution determining diameter of 3.2 mm. The previously used gamma collimator was replaced by two 50 mm longer heavy-lead collimators with a conical 2x8 mm^2 profile. In this way, the γ-energy dependent resolution in beam direction was improved by an average of 42%. The measuring time can be reduced significantly by using two collimated detectors simultaneously. The parallel-beam tomography flight-tube system was replaced by a cone-beam setup, realized by introducing a pinhole-aperture into the focal point of the even further elliptically tapered beam [4]. The boron-carbide pinhole-aperture for this usage is of 3 mm diameter and thickness, resulting in a 47% greater L/D ratio of 247(2). The current 5.5 megapixel camera in combination with a 100 µm ^{6}LiFZnS(Ag)P scintillator achieves a 130% improved object resolution of 175(4) µm. The reconstruction under cone-beam algorithms resolves now 140 µm details for negative and 40 µm details for positive contrast differences (ideal).

[1] T. Belgya, Z. Kis, L. Szentmiklosi, Z. Kasztovszky, P. Kudejová, R. Schulze, T. Materna, G. Festa, P.A. Caroppi, and the ANCIENT CHARM collaboration, First elemental imaging experiments on a combined PGAI and NT setup at the Budapest Research Reactor, *J. Radioanal. Nucl. Chem.* **2008**, 278(3), p. 751 ff.

[2] R. Schulze, L. Szentmiklósi, P. Kudejová, L. Canella, Z. Kis, T. Belgya, J. Jolie, M. Ebert, T. Materna , K. T. Biró , Z. Hajnal, The ANCIENT CHARM project at FRM II: three-dimensional elemental mapping by Prompt Gamma Activation Imaging and Neutron Tomography, *J. of Ana. Atom. Spec.* **2013**, Vol. 28(9), p. 1508 ff.

[3] Z. Révay, P. Kudejová, K. Kleszcz, S. Söllradl, Christoph Genreith, *Nuclear Instruments and Methods in Physics Research A.* **2015**, Vol. 799, p. 114 ff.

[4] E. Kluge, Neutron Beam Simulations and the Optimization of the PGAA Instrument at MLZ for Neutron Imaging Applications, Dipl. Thesis, *University of Cologne*, **2015**, p. 91 ff.