Prompt Gamma Activation Imaging:

a new technique for determination of spatial element distribution

Ancient Charm Collaboration

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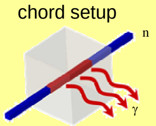
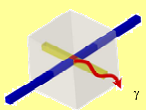
INTRODUCTION AND OBJECTIVES Prompt Gamma Activation Analysis (PGAA) is a neutron-based tool for non-destructive bulk elemental analysis, where the measured concentrations represent the average composition of the irradiated volume, in most cases of few cm^3. To obtain the spatial distribution of the elements one possibility is to scan the sample with a highly collimated neutron beam and γ-detector: this method is called Prompt Gamma Activation Imaging (PGAI). To avoid the complete scanning of the object, PGAI is combined with Neutron Radiography (NR) or Neutron Tomography (NT). NR/NT produces high-resolution 2D/3D images that characterize the geometrical structure and neutron attenuation features of the object. Then the elemental composition needs to be measured only at selected spots. This makes the technique, called radiography/tomography-driven PGAI much less time consuming. By overlaying the PGAI and NT data one obtains a complete data set of morphological properties and elemental distribution of the sample. We have constructed a PGAI-NR/NT setup at the Budapest Research Reactor and also at the Forschungsneutronenquelle Heinz Maier-Leibnitz (FRM II) research reactor, Garching, in the framework of the European ANCIENT CHARM collaboration. Both setups consisted of a high-resolution neutron tomograph, a germanium gamma-spectrometer and a xyzω-moving table for the positioning of the samples. A spatial resolution better than 3 mm has already been achieved. Element maps for complex test samples and replicas of genuine museum objects were obtained by scans driven by tomography or radiography.

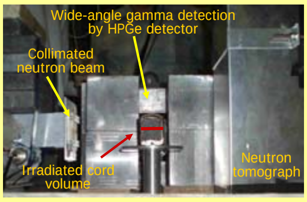
PGAA / PGAI at the BNC - Hungary

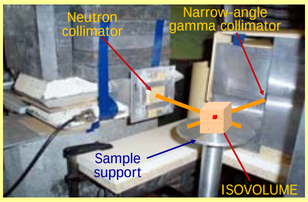
chord setup



isovolume setup



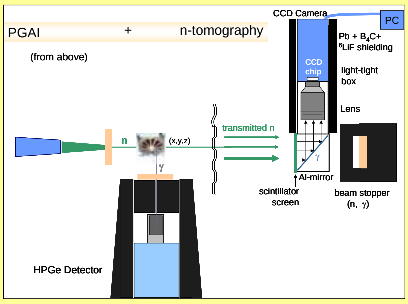


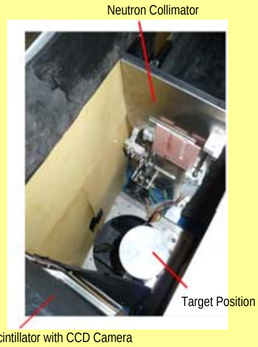


Main features:

- 7×10^7 cm^{-2}s^{-1} cold neutron beam shaped by a neutron collimator (2 × 10 mm^2 or 2 × 2 mm^2)
- Hundreds of gamma spectra depending on spatial resolution; 200 – 3600 sec per spectrum
- Accurate positioning of interesting parts of the boxes based on neutron radiography images
- Neutron penetration depth: in the order of centimetres
- Self-absorption correction is in progress ➔ qualitative elemental composition only

PGAA / PGAI at the FRM2 - Germany





Main features:

- Standard PGAA with homogeneous neutron beam up to 20×20 mm^2; 6×10^9 cm^{-2}s^{-1} with a mean λ of 6.7 Å
- Prompt gamma activation imaging (PGAI) with achievable n-intensity of 2×10^{10} cm^{-2}s^{-1} collimated to 1 mm^2
- Cold neutron tomography with either cone or parallel neutron beam of about 40×50 mm^2
- Nuclear structure experiments with an array of four germanium detectors involving highest possible neutron intensity on a small area (few mm^2)

Common to BNC and FRM2

Chord features:

- Higher count rates
- Best applicable to elongated parts of objects
- Lower spatial resolution

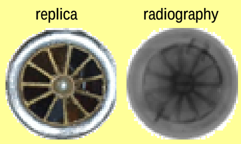
Isovolume features:

- Low count rates
- Applicable to point-like parts of the object
- Smallest isovolume used: ~20-30 mm^3

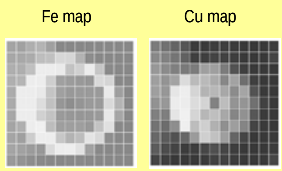
RESULTS

Measurements of replica at BNC – Hungary (radiography-driven PGAI)

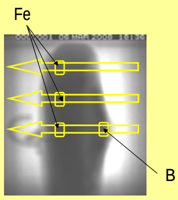
disk fibula



chord setup

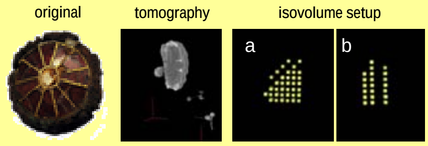


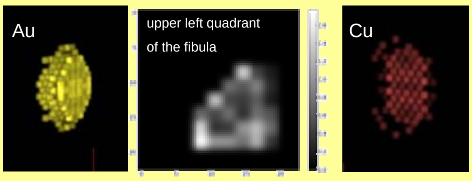
isovolume setup



Measurements of originals at FRM2 – Germany (radiography and tomography-driven PGAI)

1. disc fibula





- based on tomography:
  - grid covering one quadrant of the fibula (a)
  - in three layers (b)
- Elements found: Au, S, Al, Cu, Fe, Ag
- Mapped, symmetry assumed:
  - Au : front, ring in middle layer, back
  - Cu : back and ring in middle layer
- 2D picture of Au:
  - using interpolation algorithms
  - fibula recognizable

2. iron belt

- 8 positions (marked in the attached picture) in isovolume setup
- No 3D visualization for this very flat object
- Elements found:

#1: Fe, Cu, Ag	#5: Fe, Cu, Cl
#2: Fe, Cu, Cl	#6: Fe, Cu, Cl
#3: Fe, Ag, Cl	#7: Fe, Ag
#4: Fe, Ag	#8: Fe, Ag

CONCLUSION

PGAA is a standard non-destructive method for elemental analysis. It provides information averaged over the irradiated volume. Narrowing the neutron beam to a few millimetres makes possible the determination of element distributions in 3D.

According to our experiments on the objects, NR/NT produces high-resolution 2D/3D images that are required to survey the object for its geometrical structure and attenuation features. The contrast in the NR/NT images provides chemical and structural interpretation only if information from PGAI is added. PGAI can 'see' the elements in the chord and/or isovolume, which is an important analysis requirement in archaeological sciences.

In some cases, complementary information from other methods is neccessary because none of them being sufficient alone for characterising a material. Among them Time-of-flight Neutron Diffraction is phase sensitive and can identify structures and phases; Neutron Resonance Capture Imaging and Neutron Resonance Transmission could be sensitive to other elements than PGAI.

Furthermore, for a quantitative PGAI analysis, neutron self-shielding and gamma self-absorption corrections should be introduced, using Monte Carlo calculations.

ACKNOWLEDGMENTS

- Financial support by the European Community "New and Emerging Science and Technology" Contract No 15311 is gratefully acknowledged.
- We acknowledge the contributions by neutron tomography group of ANTARES, FRM-II Garching, Germany, and the X-ray tomography group of Ghent University, Belgium.

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