# Research at the cold neutron-beam facilities of the Institute of Isotopes

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# Content



- Motivations
- Experimental facility
- PGAA
- Research fields
- Highlight
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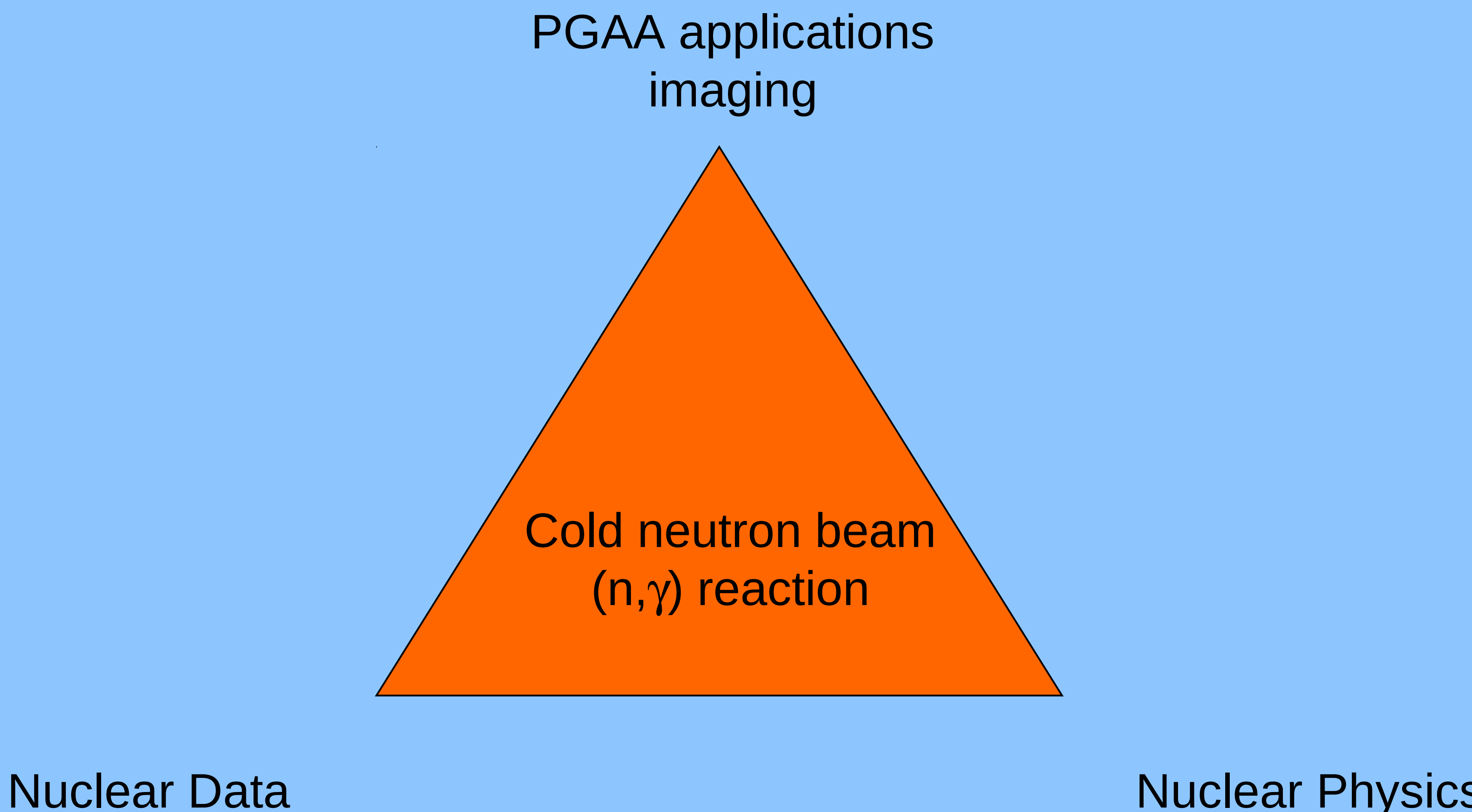
# Institute of Isotopes HAS



- Number of employee: 90
- Number of scientists: 40
- Annual budget: 2.3 MEUR
- Number of refereed journals/year: 70
- Number of citations/year: 1200
- DNR number of scientists: 8 scientists
- DRS (Dept. of Radiation Safety): 15 scientists
  - Safeguard, dosimetry, illicit trafficking, nuclear inventory

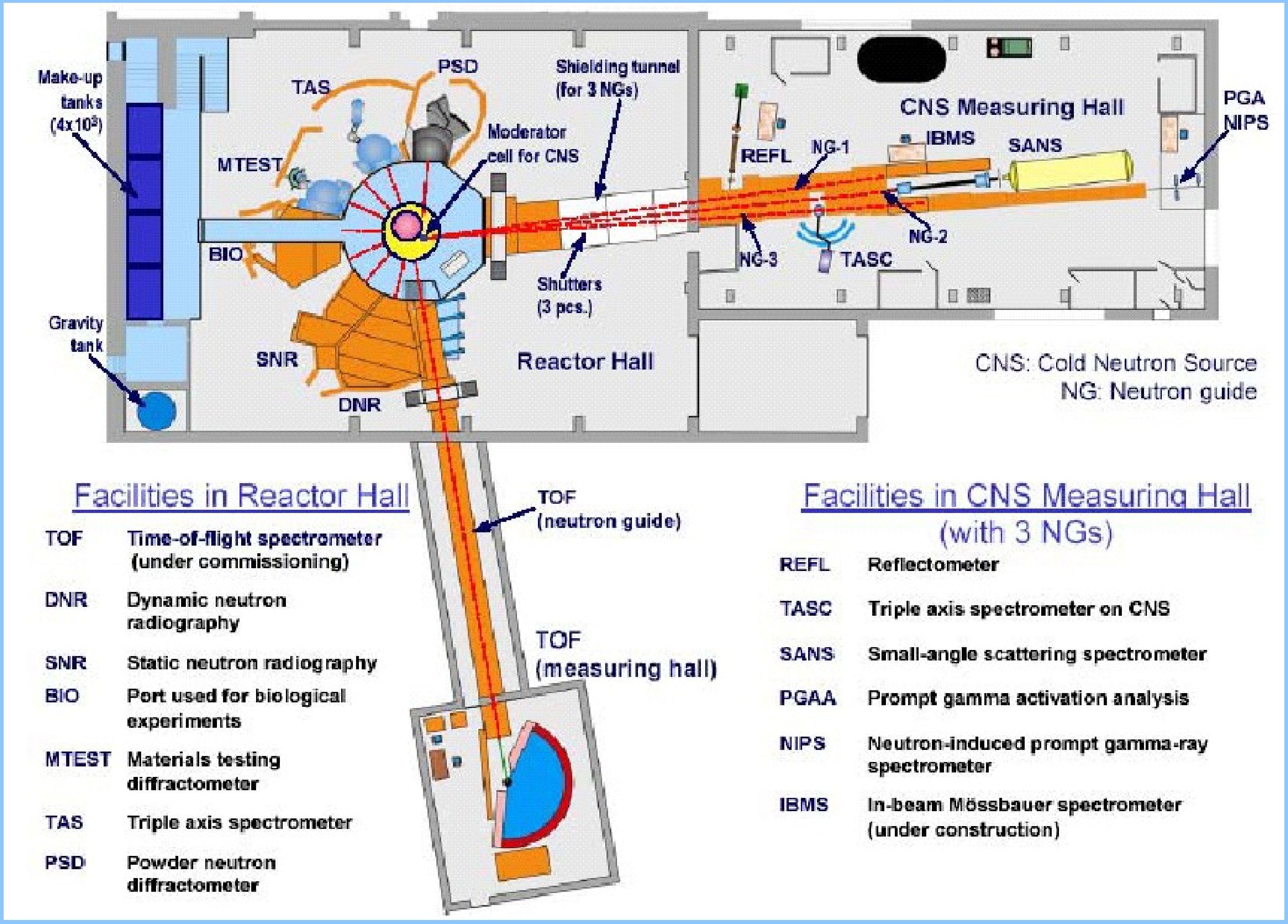
# Motivations





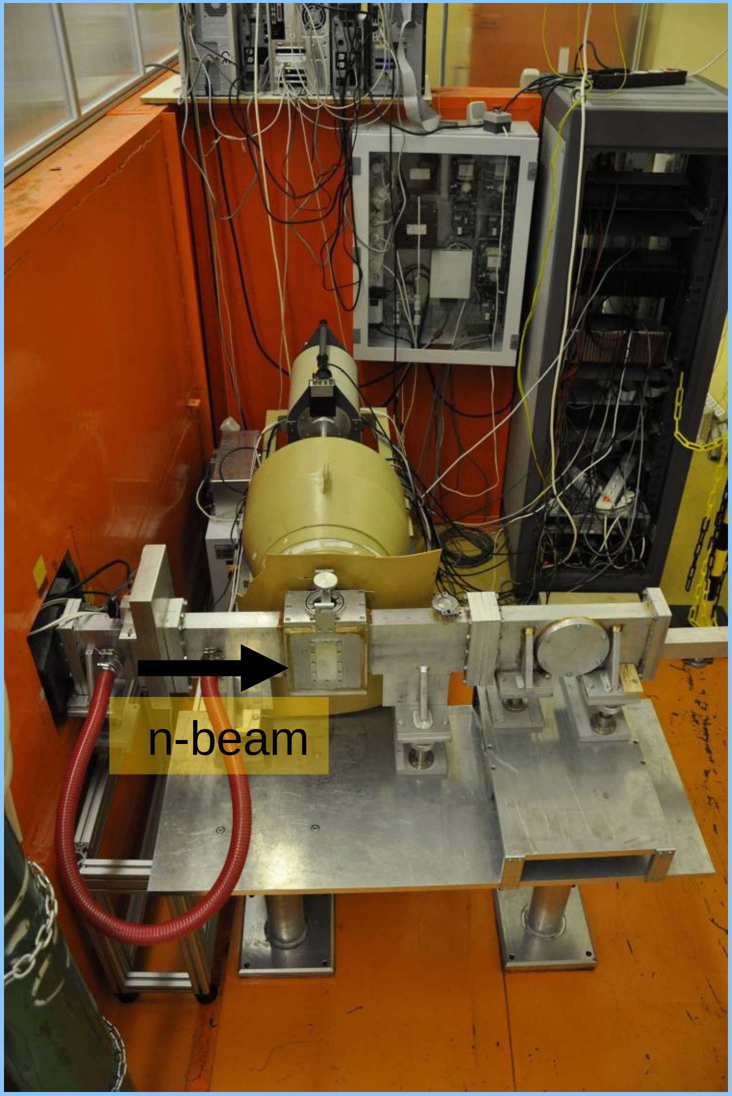
# The PGAA-NIPS facilities at Budapest RR





# PGAA-NIPS facilities







L. Szentmiklósi, T. Belgya, Zs. Révay, Z. Kis, J. Radioanal. Nucl. Chem. 286:501-505 (2010)

# PGAA-NIPS facilities



- A member of the Budapest Neutron Centre (BNC)

BNC Budapest Neutron Centre
Budapest XII, Konkoly Thege út 29-33, KFKI H-1525 Budapest, Pf. 49. Hungary

- Operated as a user facility
  - NMI3 - Integrated Infrastructure Initiative for Neutron Scattering and Muon Spectroscopy


CHARISMA Cultural Heritage Advanced Research Infrastructures Synergy for a Multidisciplinary Approach to Conservation/Restoration

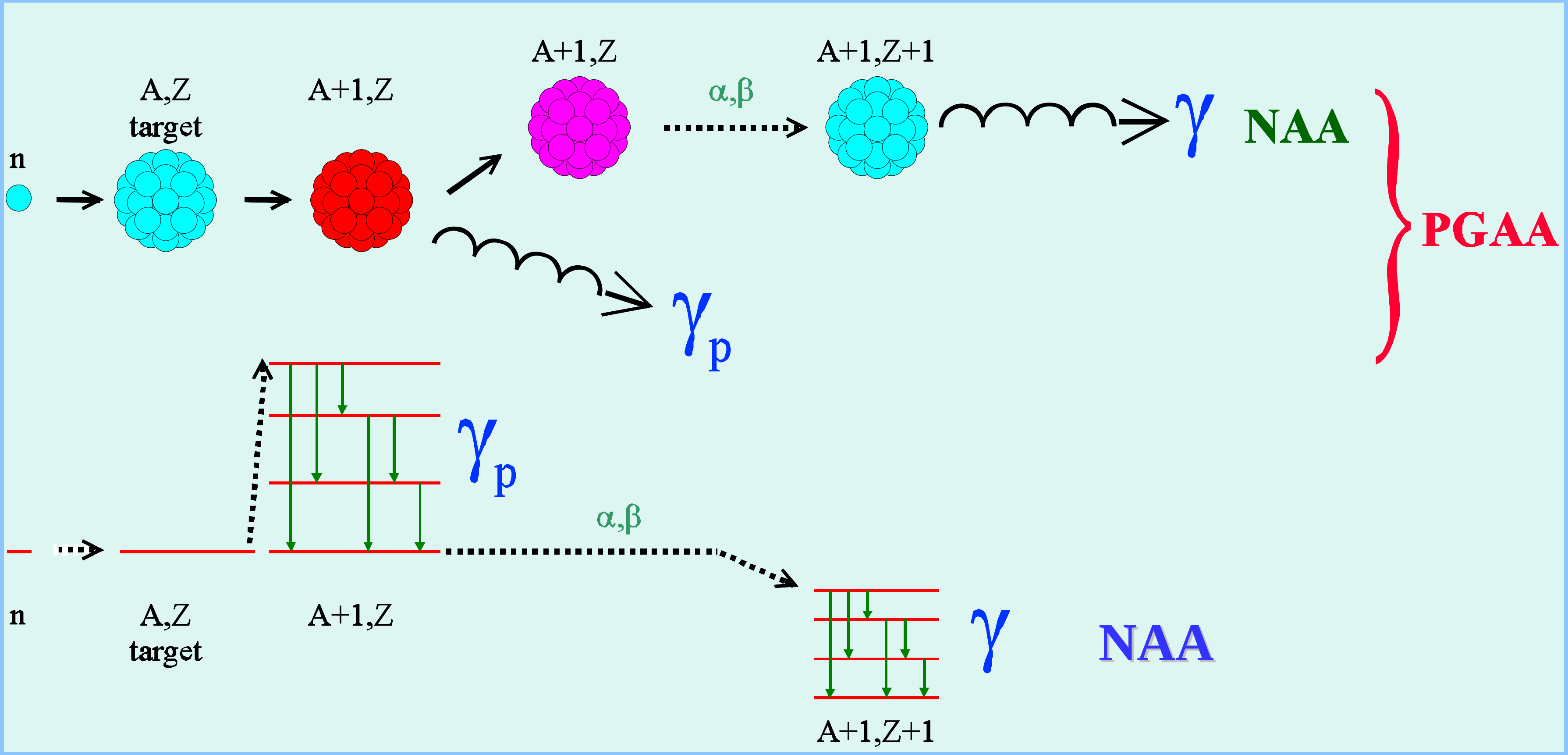
  - ERINDA EURATOM FP7

ERINDA
European Research Infrastructures for Nuclear Data Applications

# The Prompt Gamma Neutron Activation Analysis

(principles of PGNAA)

PGAA is a radiative neutron-capture based analytical technique




- The gamma energy is characteristic for the element or isotope
- The gamma-ray intensity is characteristic for the quantity of the element or isotope

# Main features of Prompt Gamma Neutron Activation Analysis



- Nuclear analytical method
  - Sample irradiated with neutrons
    - Energy → element
    - Intensity → quantity
  - Nondestructive ☺
  - Multi-elemental, multi-isotopic ☺
  - Minimal sample preparation ☺
  - Average composition of the irradiated volume 😐
  - Exact for homogeneous samples ☹
  - Negligible residual activity ☺
  - Fast, instant result ☺
  - No external standard is necessary (Library needed) ☺
  - Good for major, minor components and some traces, unique for H, B ☺
  - Great variety in elemental sensitivities, detection limits 😐
  - No chemical composition ☹

Molnár, G. L., Ed. (2004). Handbook of Prompt Gamma Activation Analysis with Neutron Beams. Budapest, Kluwer Academic Publisher Dordrecht, Boston, London

# Determination of chemical composition



$$A_\gamma = m \cdot S \cdot t; \quad S = \frac{N_A}{M} \cdot \theta \cdot \underbrace{\sigma_0 \cdot P_\gamma}_{\sigma_\gamma} \cdot \phi \cdot \varepsilon(E_\gamma) \cdot f(E_\gamma)$$

From our measured PGAA library

Fit from γ-spectrum

$$m = \frac{A_\gamma}{S \cdot t}$$

$m$ : Mass of the element

$S$ : Sensitivity

$A_\gamma$ : Peak area

$N_A$ : Avogadro-number

$M$ : Molar weight

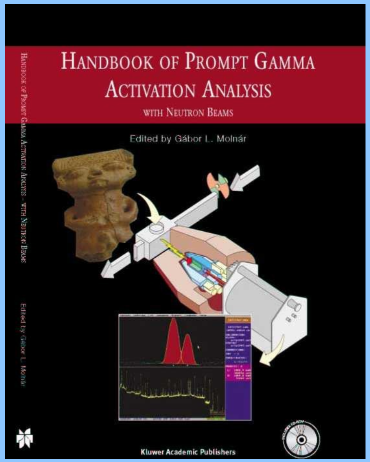
$\theta$ : Isotopic abundance

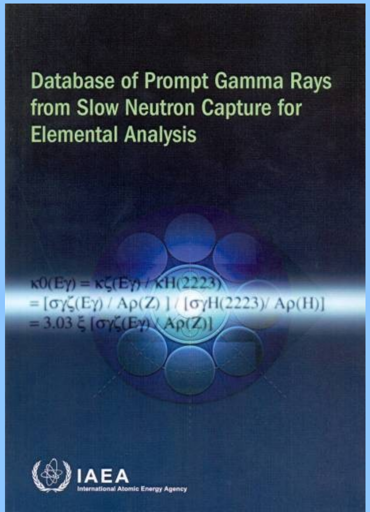
$\sigma_0$ : Neutron capture cross-section

$P_\gamma$ : Gamma-yield

$\phi_0$ : Neutron flux

$\varepsilon(E_\gamma)$ : Detector efficiency



# Summary of Activities



## (n,γ) reactions

### PGAA

**Research**

- Archaeology (IAEA, CHARISMA)
- Geology (ELTE)
- Catalyst (FH inst.)
- Material sciences (KFKI)
- Safeguard (OAH)
- N. Waste (FZ Jülich)
- PGAI/NT (NMI3 JRA, IAEA)

**Methodology**

- PGAA library (IAEA, LBL)
- Chopped beam PGAA
- Standards (IAEA)

### Cross sections

**Research**

- Xsections for ADS & GEN-IV
- LLFF
  - $^{99}$Tc, $^{129}$I (FZJ, IRMM)
- Fuel
  - $^{238,235}$U,$^{232}$Th (IAEA, IRMM)
- Structural mat.
  - $^{209}$Bi, $^{204,206,207}$Pb (IRMM)
- **Nuclear Astrophysics**
  - $^{22}$Ne, Fe, Ni (FZK, CERN)

**Methodology**

- Internal comparator
- Chopped beam

### Nuclear Physics

**Research**

- Decay schemes
  - $^{204,206,207}$Pb (IRMM)
  - $^{99}$Tc, $^{101}$Ru (ILL)
  - Fe, K, Pd (LBNL)
- Strength functions
  - $^{57}$Fe (Oslo, Frank L.)
  - $^{78}$Se, $^{196}$Pt, $^{114}$Cd (FZD, EFNUDAT)

**Methodology**

- (n,γ), (n,γγ), (γ,γ')
- Monte Carlo

# PGAI/NT

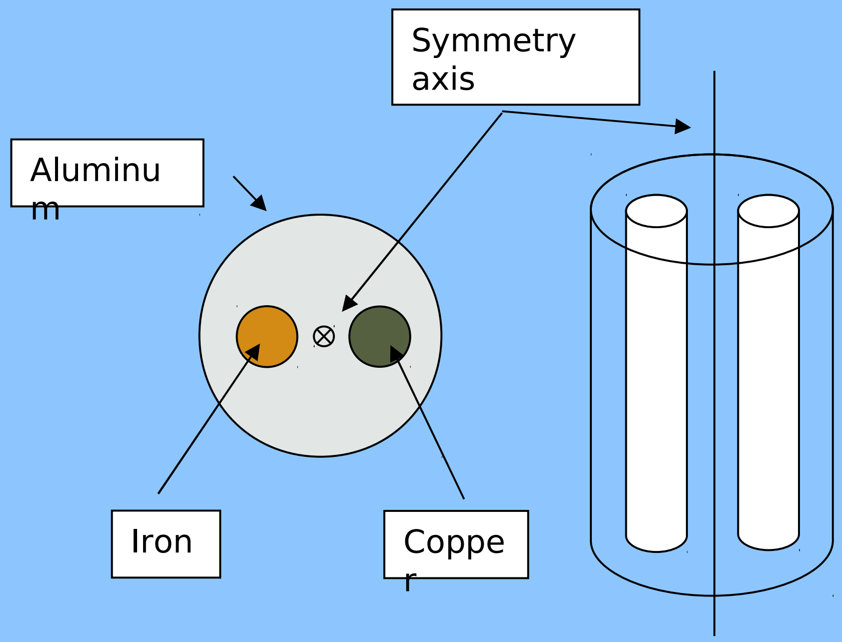
Neutron tomography driven Prompt Gamma Activation Imaging

Nondistructive measurement of elemental distribution in samples

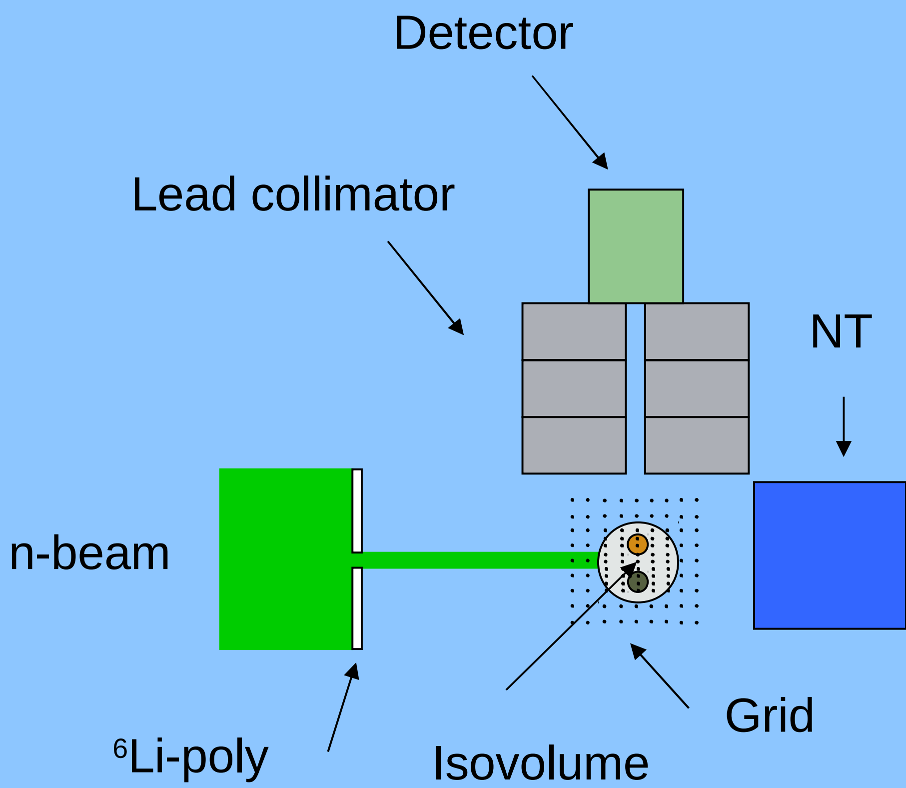
ANCIENT CHARM EU FP6 NEST project (2005-2009)

- PGAI/NT sample and grid scanning
- Choice: a simple known object in order to understand the main features of the experiments

**The sample**




**Grid scanning**

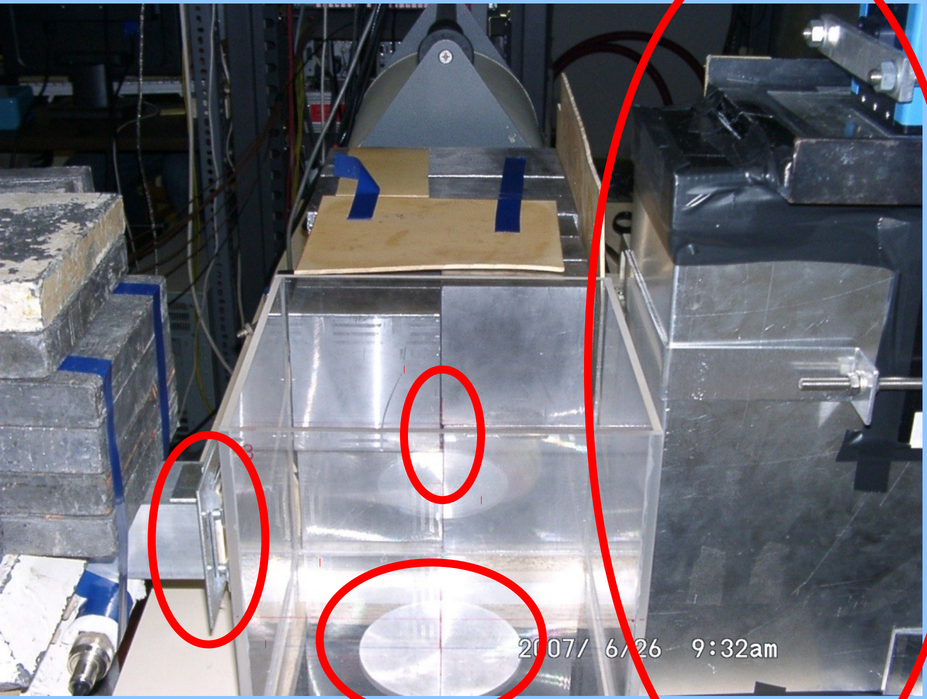


# PGAI/NT setup of DNR



PGAI-NT setup and calibration object

Simple benchmark sample and shielding





Al cylinder Ø 12 mm
Fe rod Ø 1.9 mm
Cu rod Ø 1.6 mm

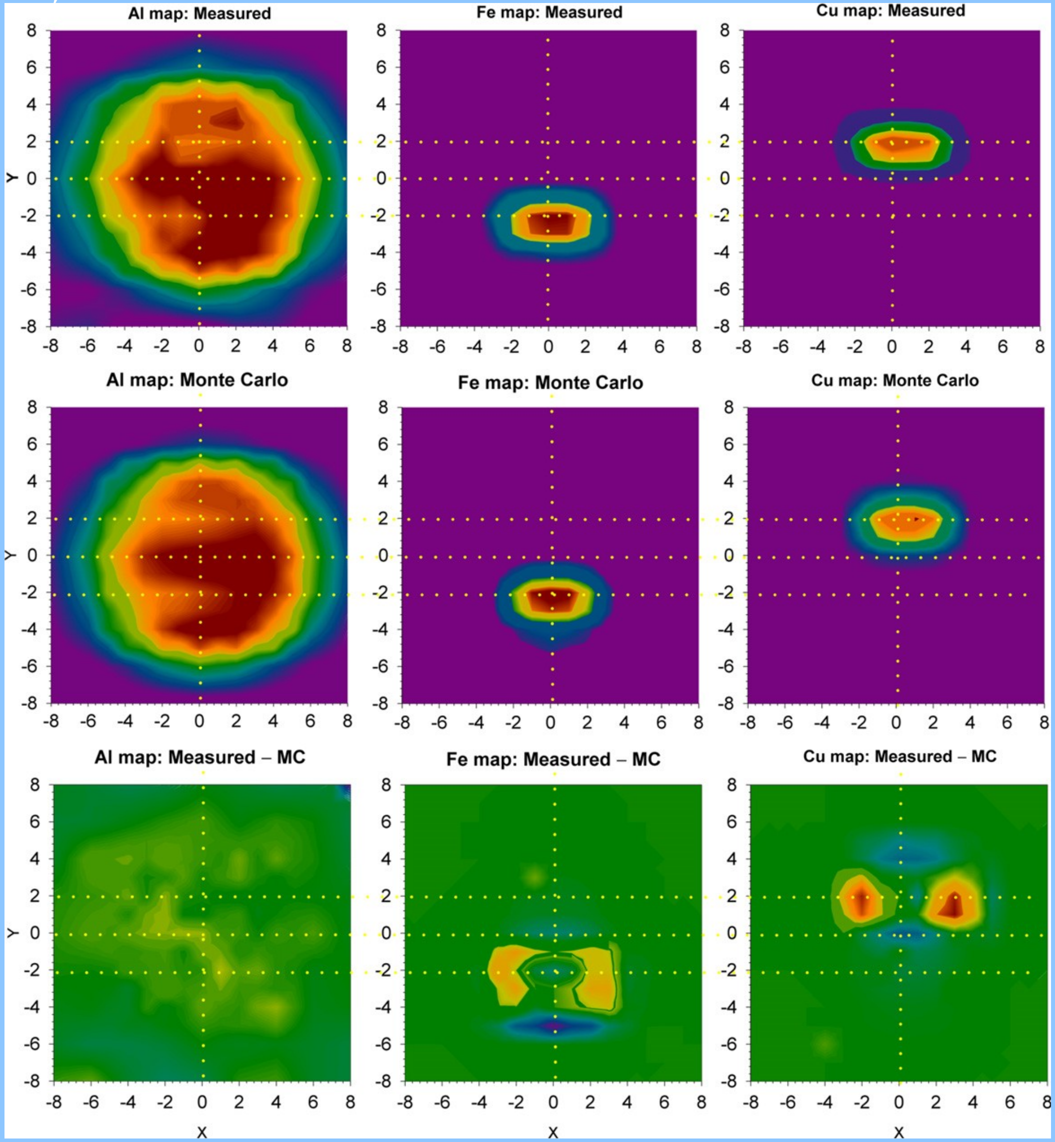
Belgya, T., Z. Kis, et al. (2008). "A new PGAI-NT setup at the NIPS facility of the Budapest Research Reactor." J. Nucl. Radioanal. Chem. **278**(3): 713-718

# Neutron collimator and the simple benchmark sample



# Monte Carlo simulation of the experimental results

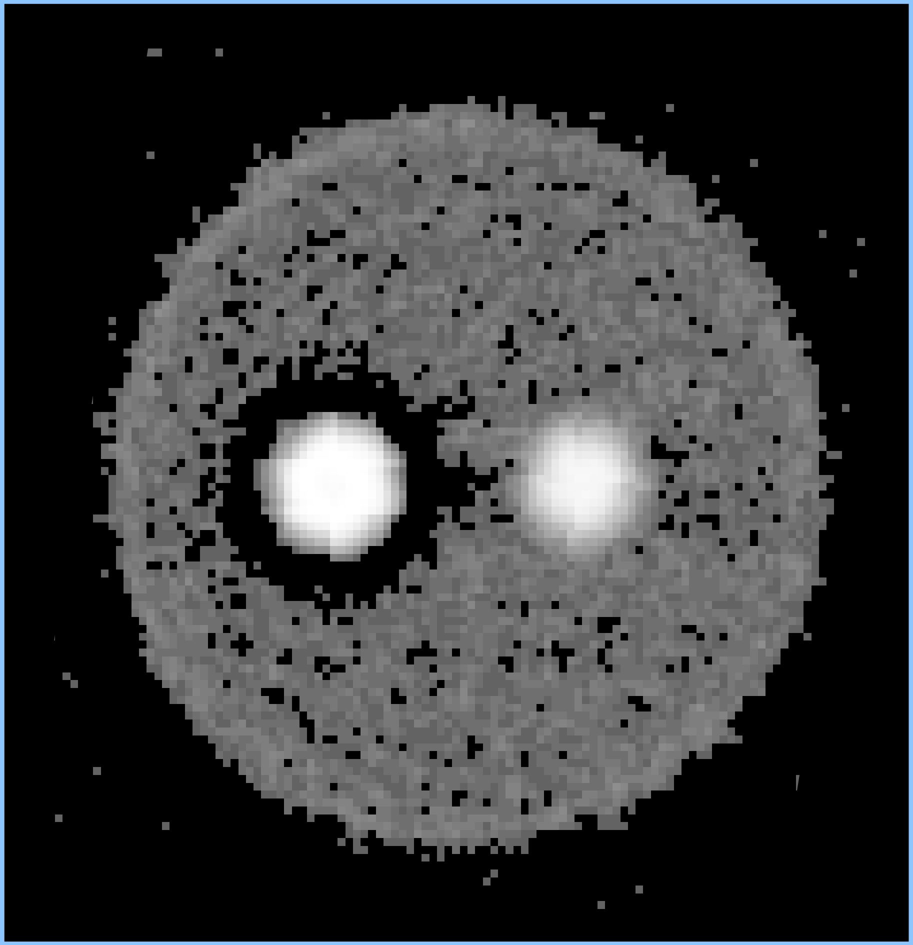


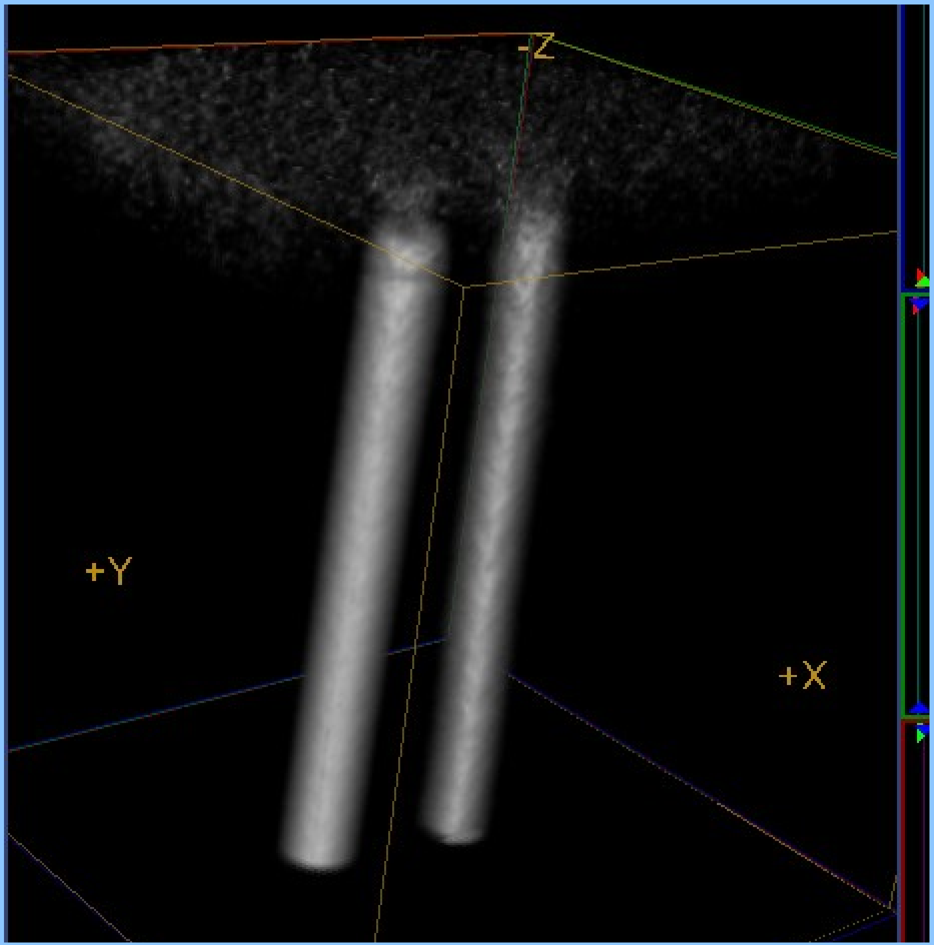



Kis, Z., T. Belgya, et al. "Monte Carlo simulations towards semi-quantitative prompt gamma activation imaging" Nucl. Instr. And Methods A 638(1): 143-146.

# Neutron tomograph slice and 3D view of the sample







# The selected object for 3D imaging studies and the replica




•Disc fibula with almadine inlays imported in to the territory of the Avar Empire from the Frankish settlement area. The main iron structure with silver or guilded silver is very rare. Origin: Köled 2nd half of 6th c. AD, grave A 279;76.1.45

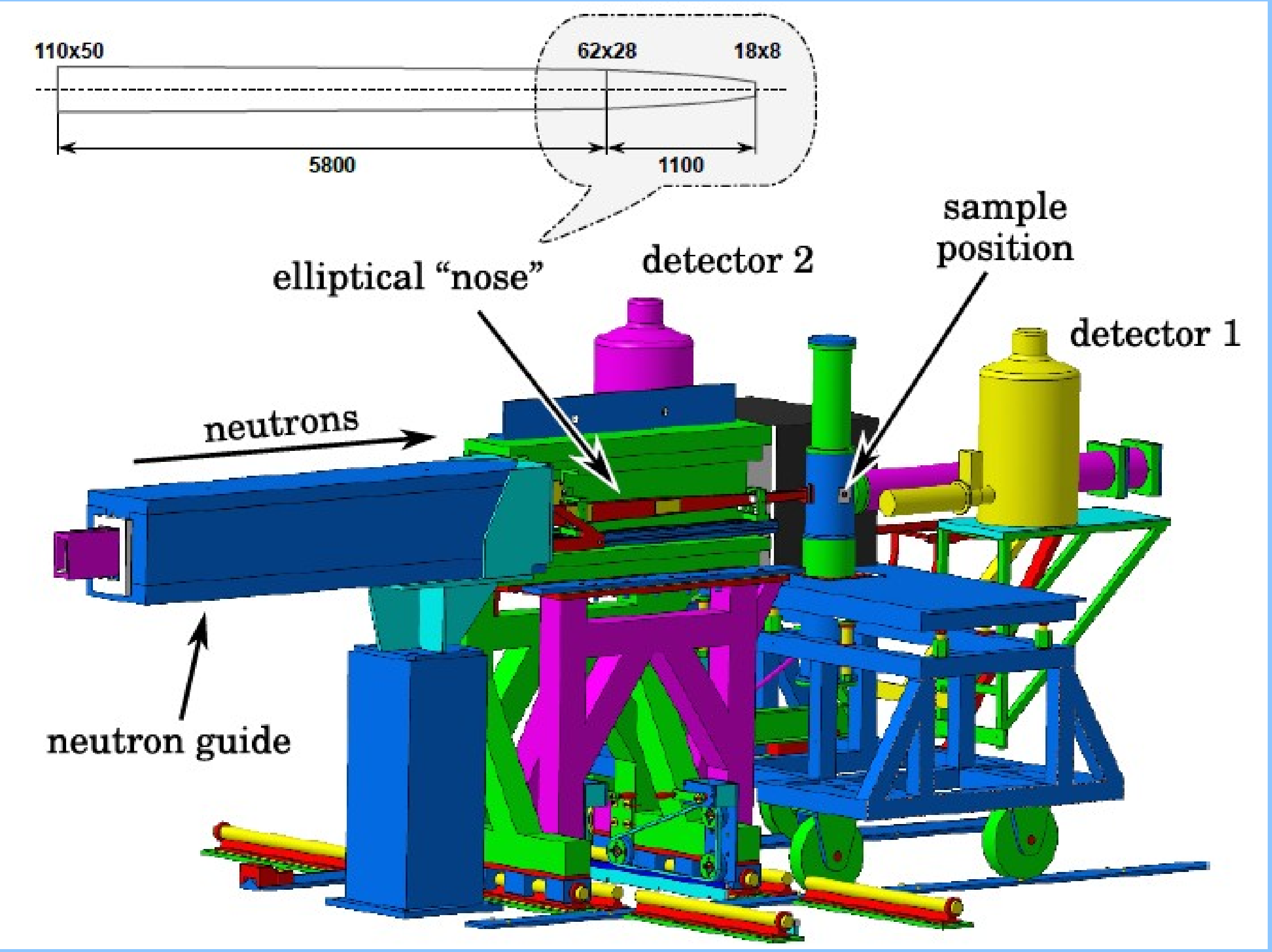
•This object is the logo of ANCIENT CHARM project

Zs. Kasztovszky and T. Belgya, Archeometriai Műhely 2006/1, 12-17

# Our 3D PGAI experiments at FRM-II
(high flux)



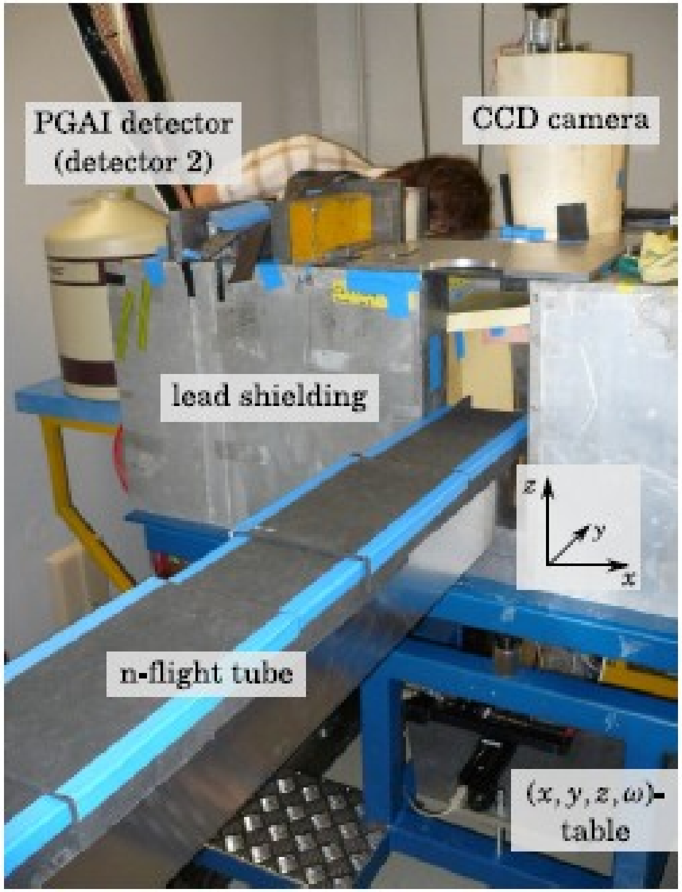
## PGAA setup at FRM-II, Garching, Germany



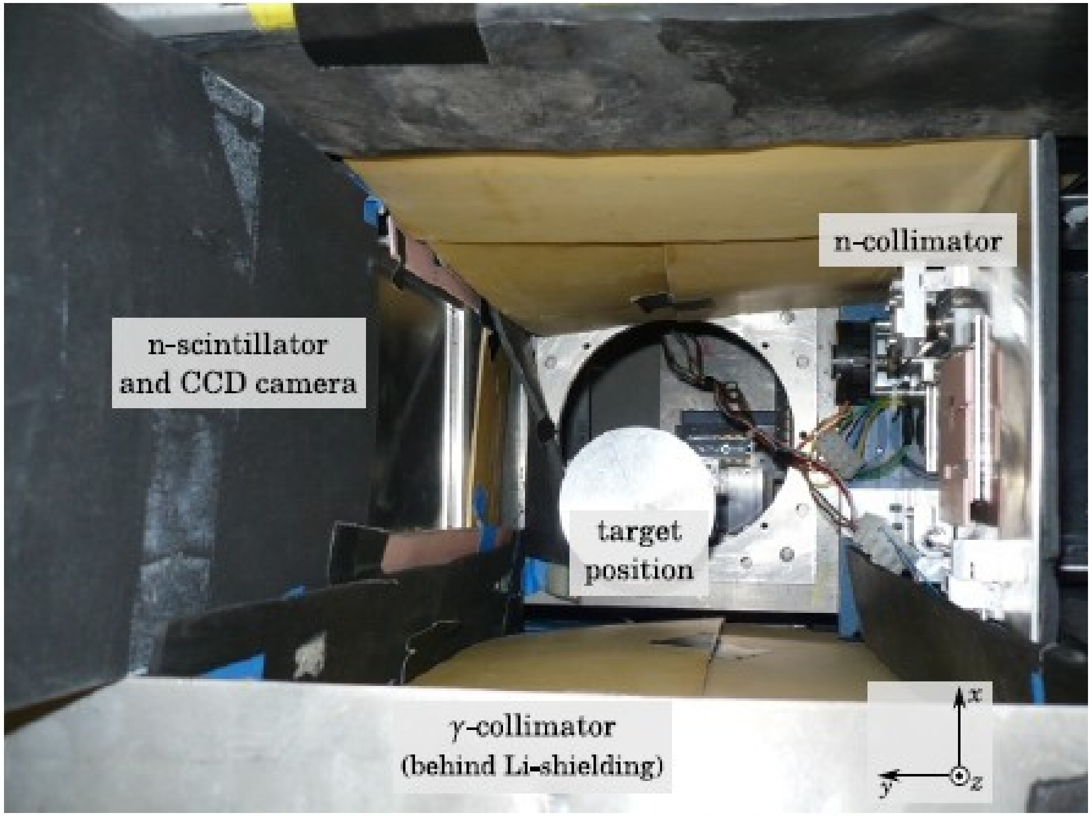

- Beam parameters:
- mean neutron spectrum energy 1.83 meV
- mean neutron wavelength 6.7 Å
- thermal equivalent neutron flux
- $2.42 \cdot 10^{10}$ n/cm$^2$/s (no nose)
- $5.5 \cdot 10^{10}$ n/cm$^2$/s¤ (with nose)
- usable beam size: (14x38) mm (no nose)
- (4x10) mm (with nose)

# PGAA setup at FRM-II





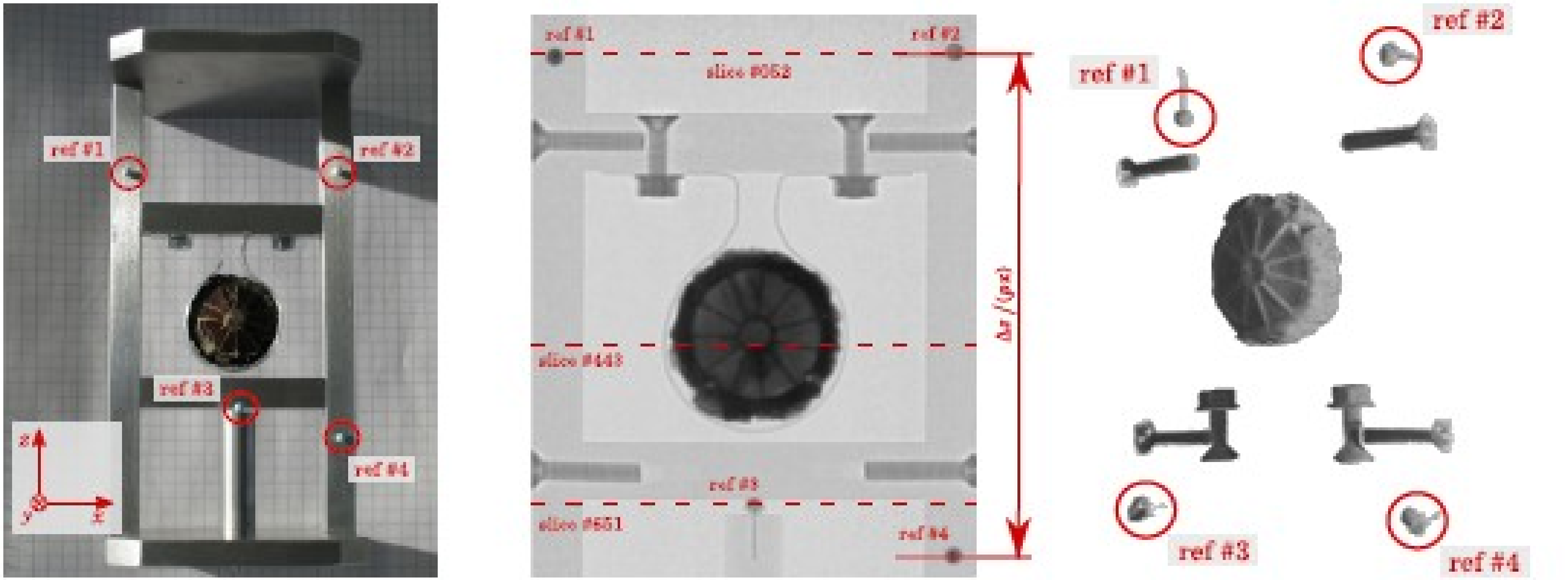

(a) Setup in NT configuration




(b) PGAI/NT measurement chamber

# NT of fibula at FRM-II in collaboration





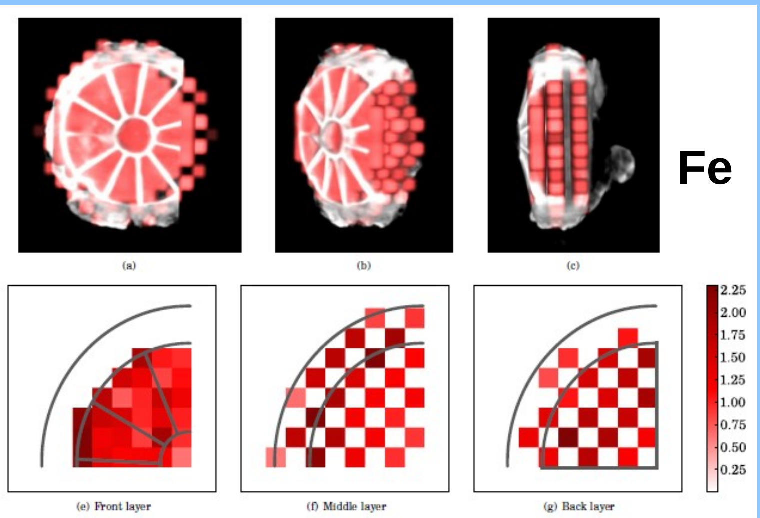

(a) Reference markers at four distinct positions on the sample holder for a fibula object (see. chapter 4.7)

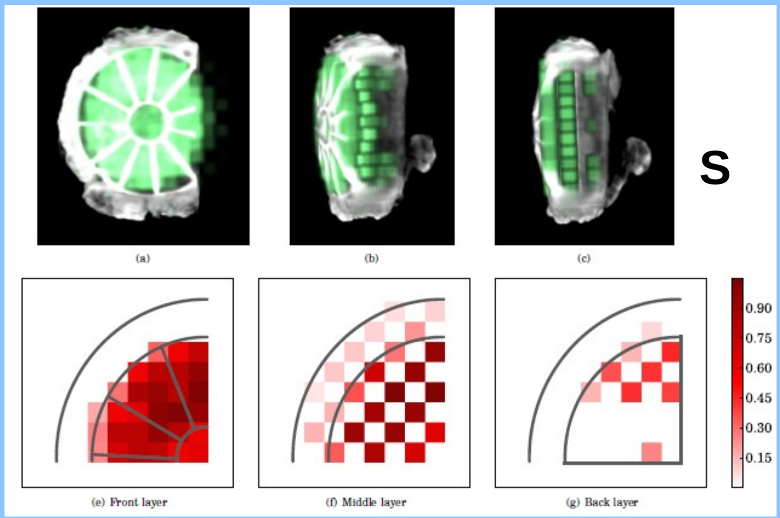
(b) Normalized radiography of the fibula. The reference markers are clearly visible and can be used for (pixel ↔ mm)-conversion

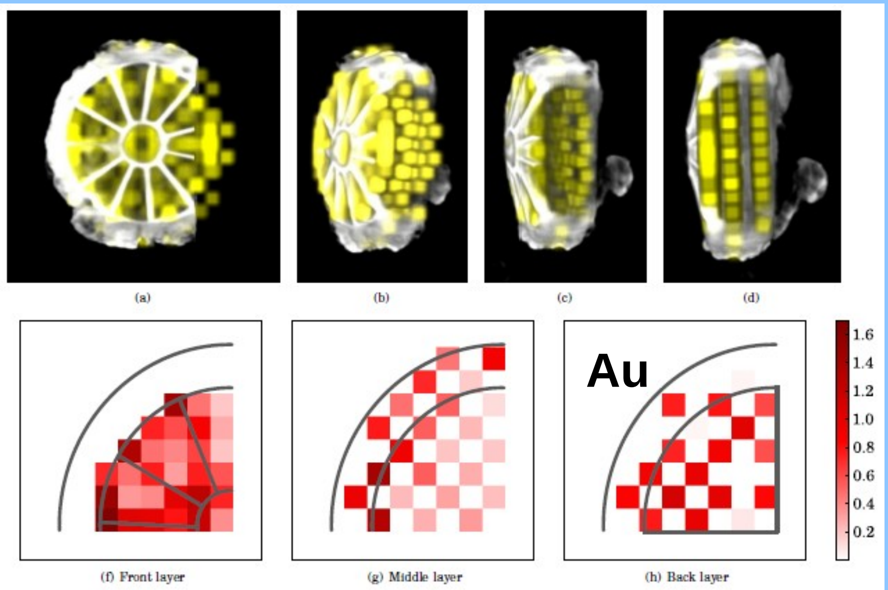
(c) Reference marker positions in the final NT reconstruction

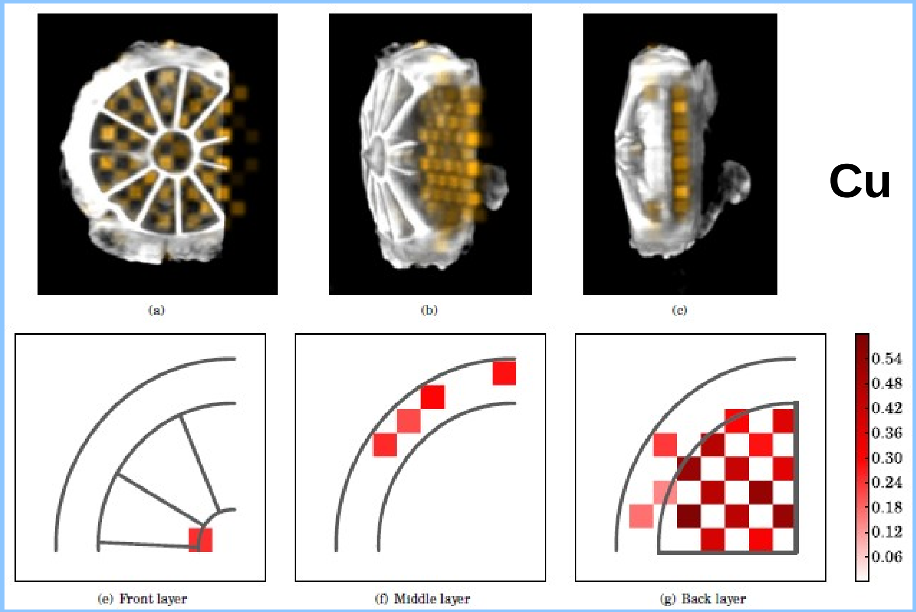
# PGAI measurements on the fibula in collaboration
## (grid scanning)





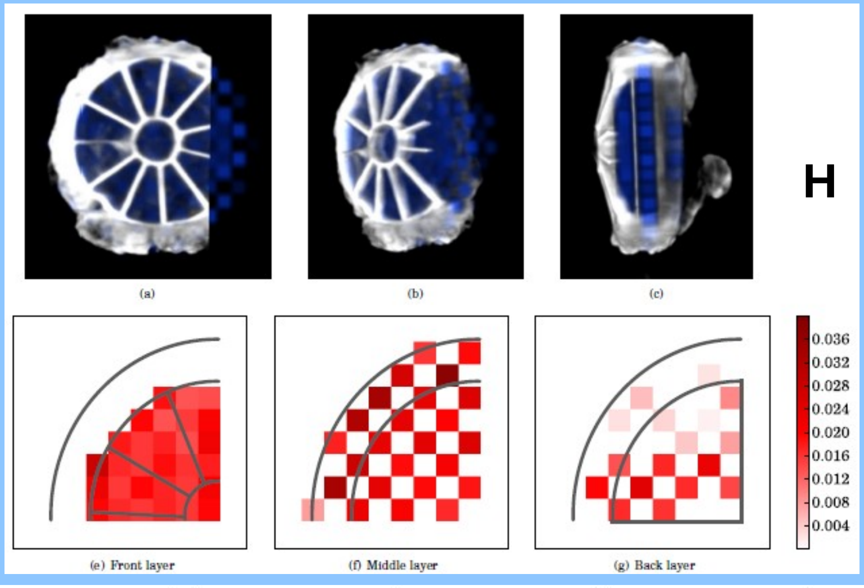



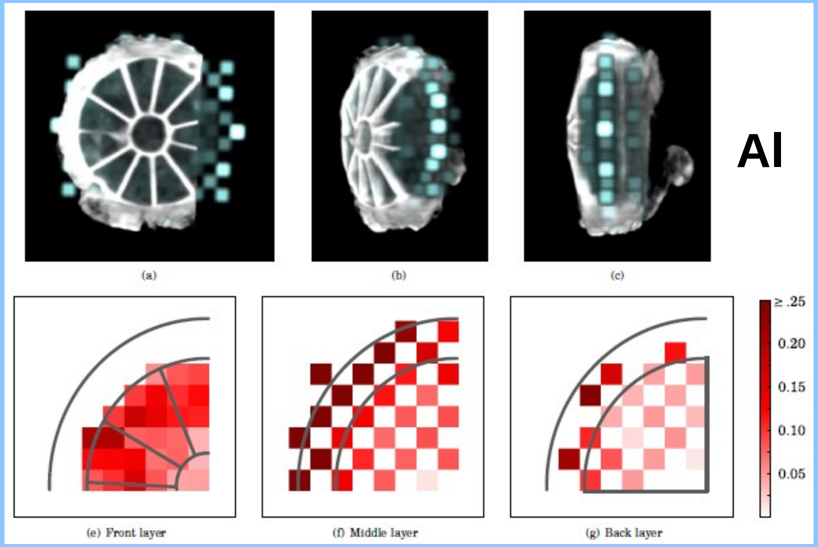



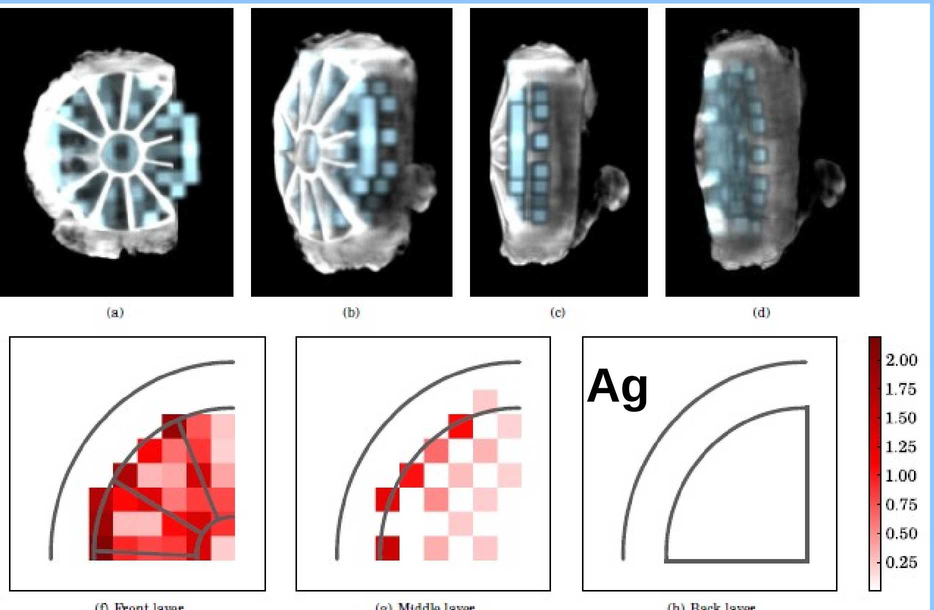



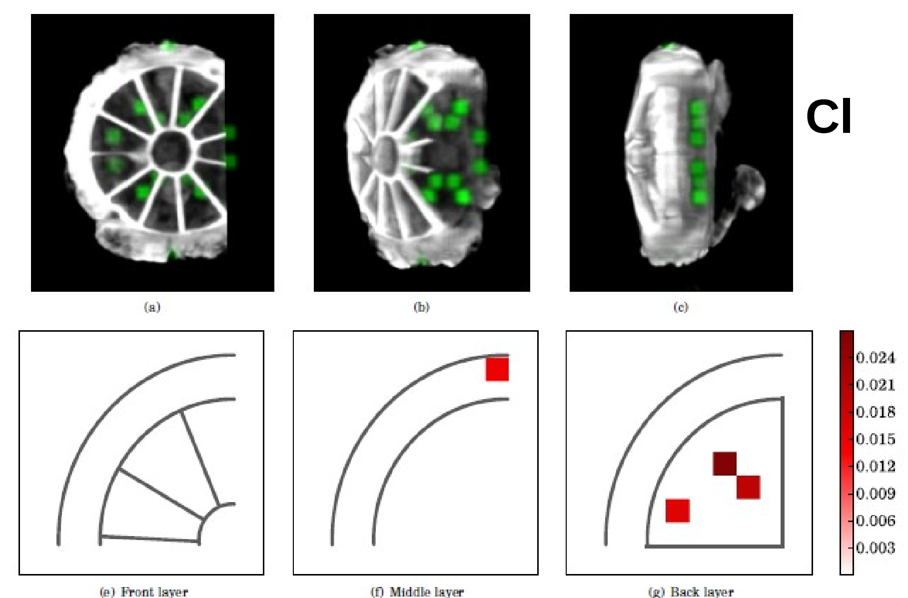
# PGAI measurements on the fibula in collaboration continued





# Safeguard development at DNR



**Rotated samples in lead container with tomograph and PGAI-NT at the cold beam of BRR**

**Copper balls**

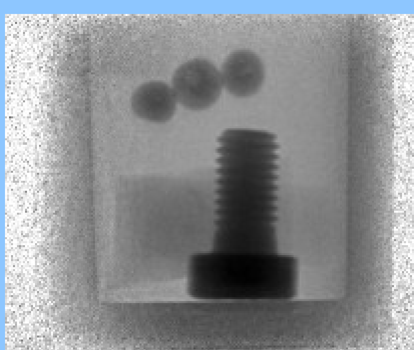
**Aluminum cylinder**

**Natural Uranium oxide** ($U_2O_3$)

**Fe screw**

**Pb container**

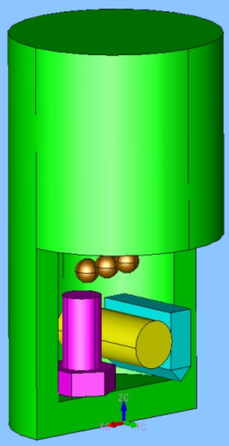
Click on this



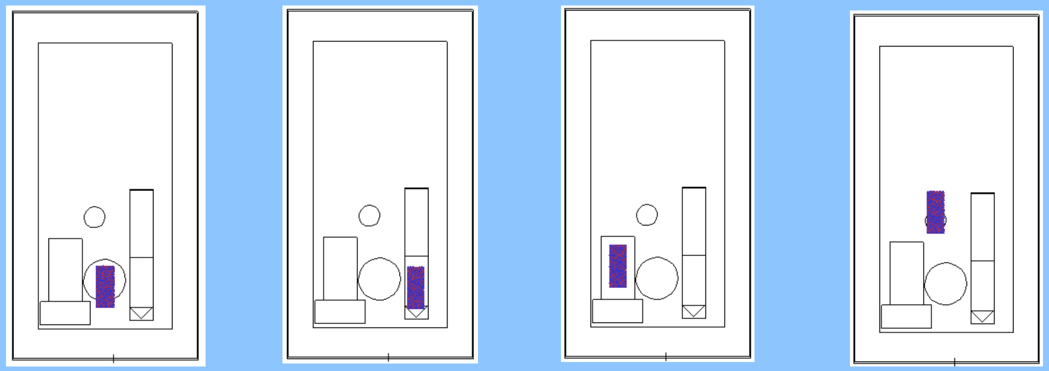
n-beam direction

Szentmiklósi, Z. Kis, T. Belgya, Z. Kasztovszky, P. Kudejova, T. Materna, R. Schulze, A new PGAI-NT setup and elemental imaging experiments at the Budapest Research Reactor, NRC7 - SEVENTH INTERNATIONAL CONFERENCE ON NUCLEAR AND RADIOCHEMISTRY, Budapest, Hungary 24-29 August 2008, (2008) pp. 1-4.

## Neutron source overlaid on the geometry



Geometry or voxel model



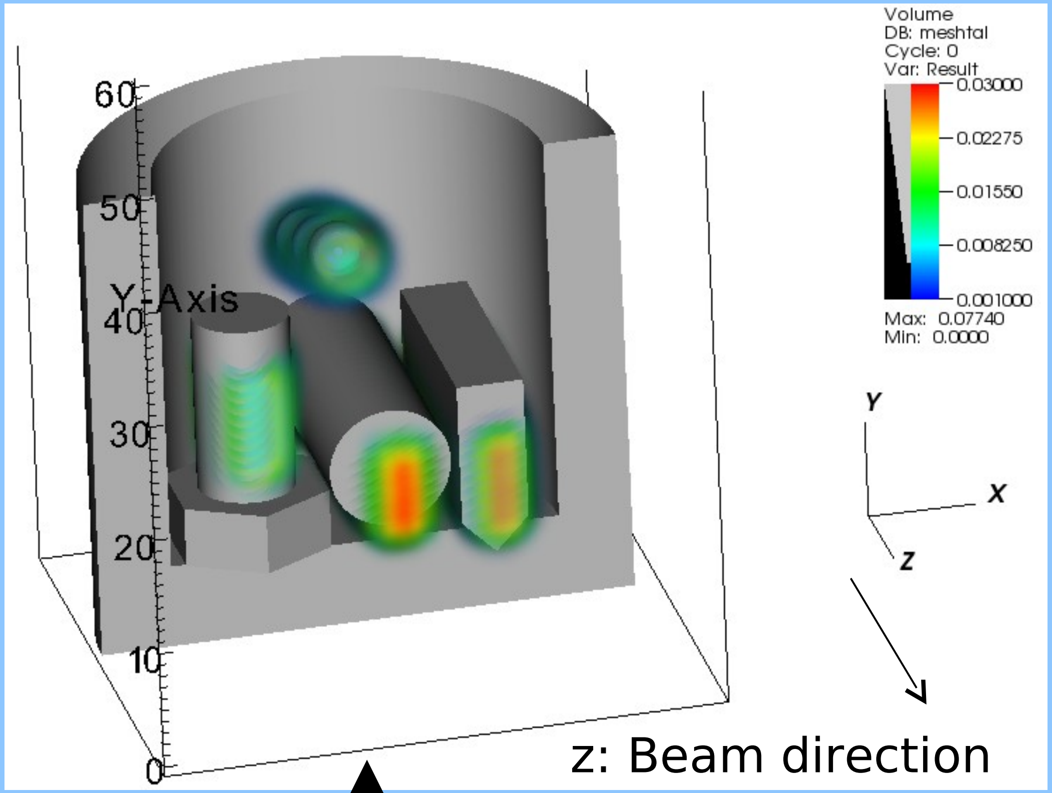
MCNP5 mesh tally simulations for neutron and gamma transport

1. Local neutron flux
2. Neutron transmission: radiography
3. (n,$\gamma$) reaction rates
4. Detection efficiency of emitted gammas

- Dimensions and positions from the radiographies,
- Materials from the gamma spectra
- Properties of the setup and the beam must be known

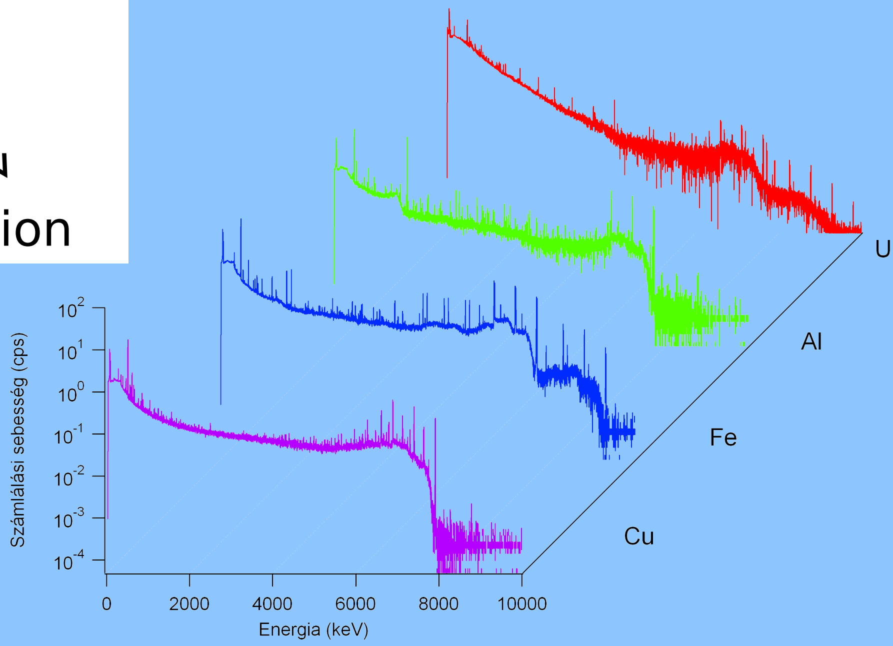
# (n,γ) reaction rates






Overlay of calculated n-beam absorption in the objects

Elemental spectra measured on the objects in the container by PGAI/NT experiments



# Future: a new setup for PGAI-NR at Budapest: NORMA

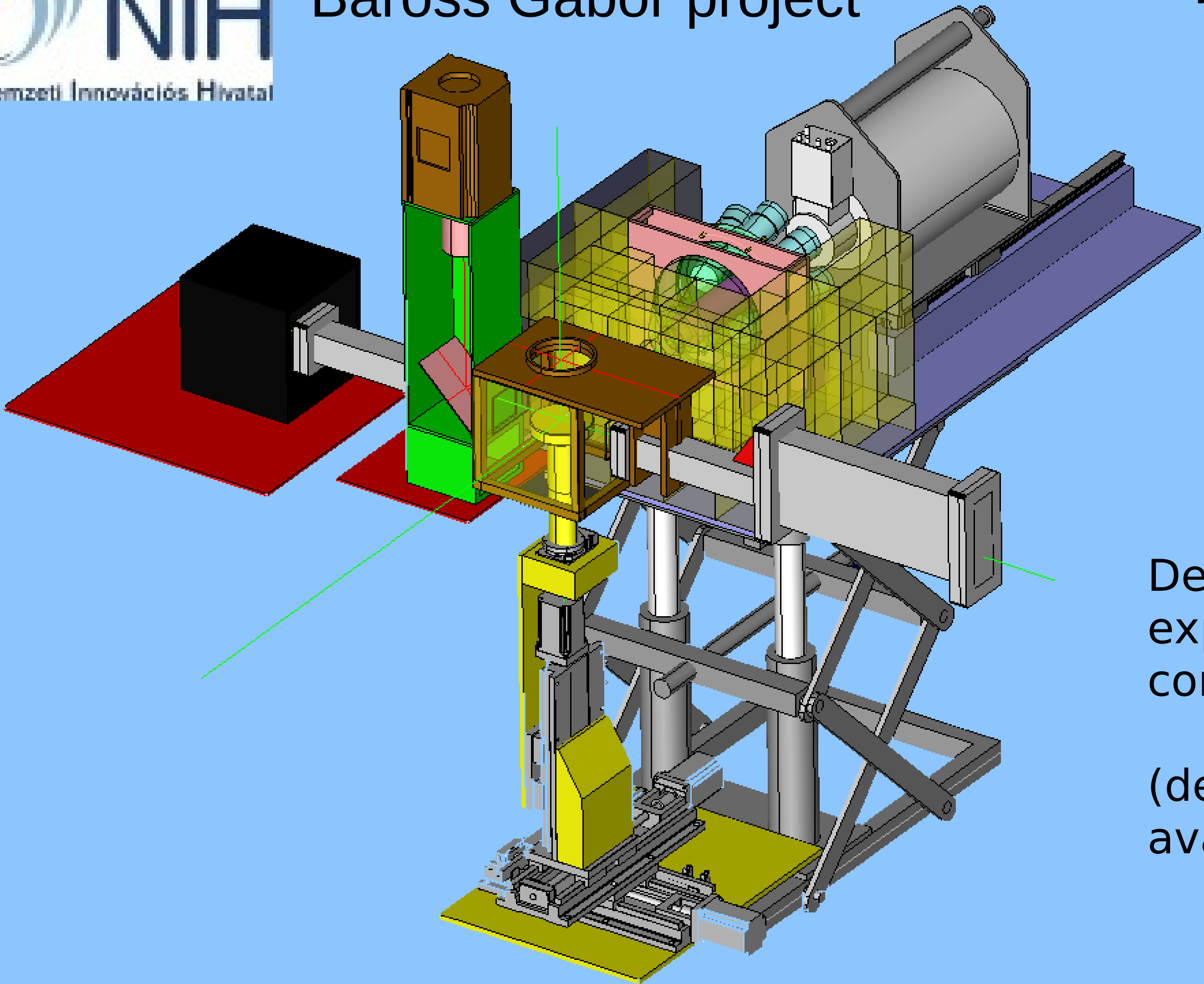


Nemzeti Innovációs Hivatal

Baross Gábor project

Projects start in 2012

1. NMI3 JRA imaging
2. IAEA CRP imaging



Design is ready, expected to be completed in Q4 2011

(depends on the availability of funding)

# Summary



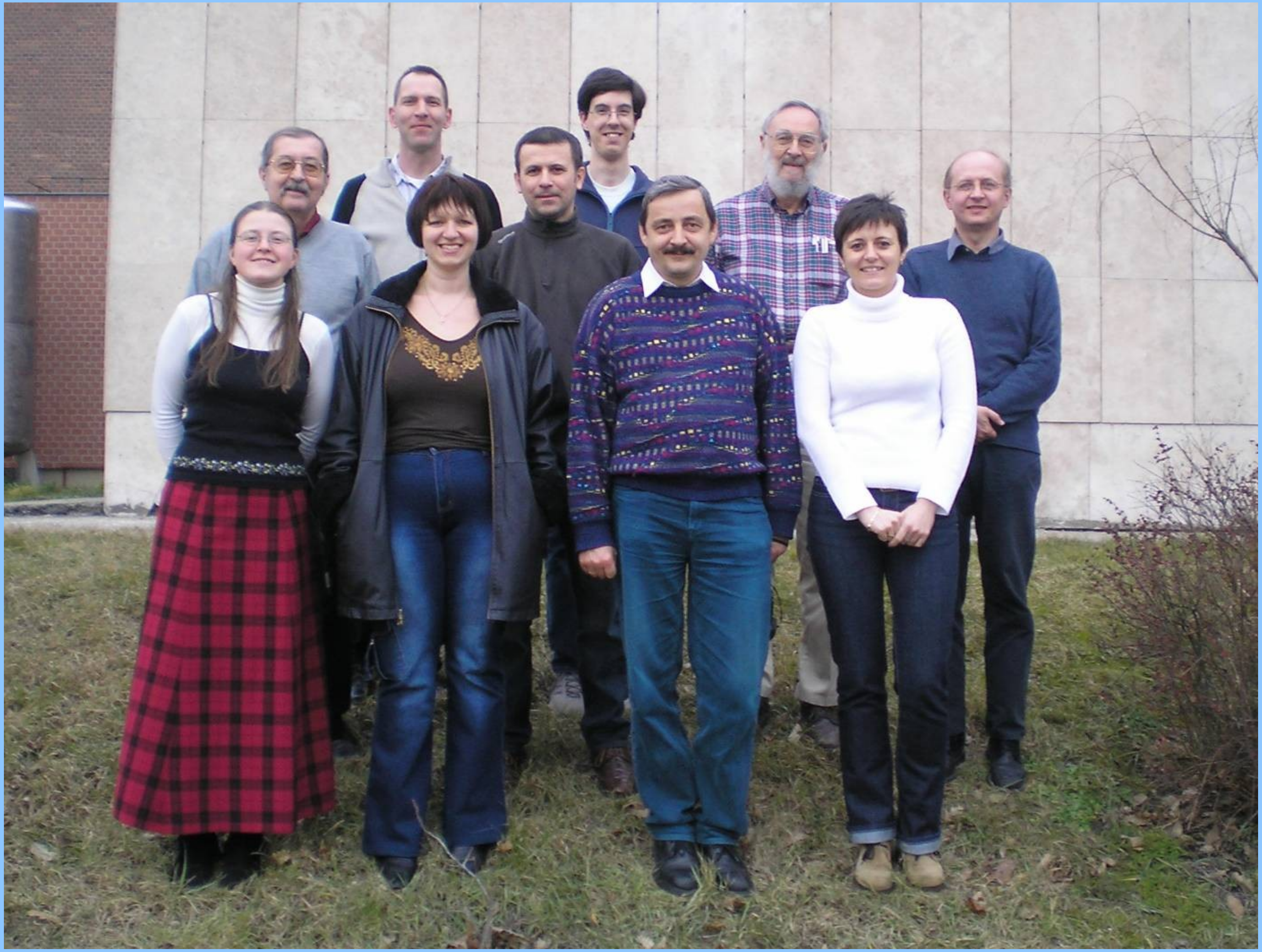
- The cold neutron beam PGAA-NIPS facilities successfully used in the field of
  - PGAA inter disciplinary research (archaeometry, geology, material sciences, safeguards …)
  - Determination of nuclear data
  - Nuclear structure

- The recently invented PGAI/NT technique is capable
  - To provide 3D imaging of elemental distributions of sample interior
  - The Neutron tomography  driven PGAI can be used to speed up the determination of elemental distributions of composite objects

# STAFF MEMBERS IN 2008



A. Simonits, Zs. Kasztovszky, Z. Kis, L. Szentmiklósi, J. Weil, Zs. Révay



V. Szilágyi, Z. Tóth, T. Belgya, K. Gméling


THANK YOU FOR YOUR ATTENTION!
Matyó