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

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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

PGAA applications
imaging

Cold neutron beam
\((n,\gamma)\) reaction

Nuclear Data

Nuclear Physics
The PGAA-NIPS facilities at Budapest

Facilities in Reactor Hall
- TOF: Time-of-flight spectrometer (under commissioning)
- DNR: Dynamic neutron radiography
- SNR: Static neutron radiography
- BIO: Port used for biological experiments
- MTEST: Materials testing diffractometer
- TAS: Triple axis spectrometer
- PSD: Powder neutron diffractometer

Facilities in CNS Measuring Hall (with 3 NGs)
- REFL: Reflectometer
- TASC: Triple axis spectrometer on CNS
- SANS: Small-angle scattering spectrometer
- PGAA: Prompt gamma activation analysis
- NIPS: Neutron-induced prompt gamma-ray spectrometer
- IBMS: In-beam Mössbauer spectrometer (under construction)
PGAA-NIPS facilities

PGAA-NIPS facilities

• A member of the Budapest Neutron Centre (BNC)

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

• ERINDA EURATOM FP7
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 😊

Determination of chemical composition

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

From our measured PGAA library

Fit from \(\gamma\)-spectrum

- \(m\) : 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
- \(\phi\) : Neutron flux
- \(\varepsilon(E_\gamma)\) : Detector efficiency
Summary of Activities

Institute of Isotopes HAS, Dept. of Nuclear Research
NuPECC meeting, KFKI
RMKI, 07 October 2011

(n,γ) reactions

PGAA

Cross sections

Nuclear Physics

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)

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

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
Nondistruuctive measurement of elemental distribution in samples
ANCIENT CHARM EU FP6 NEST project (2005-2009)
FIRST ELEMENTAL IMAGING EXPERIMENTS ON A COMBINED PGAI AND NT SETUP OF DNR AT THE BUDAPEST RESEARCH REACTOR

- 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**

- Detector
- Lead collimator
- Grid
- n-beam
- $^6$Li-poly
- Isovolume

Sample:
- Aluminum
- Iron
- Copper

Symmetry axis
PGAI/NT setup of DNR

PGAI-NT setup and calibration object  Simple benchmark sample and shielding

Neutron collimator and the simple benchmark sample
Monte Carlo simulation of the experimental results

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 into 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)

Institute of Isotopes HAS, Dept. of Nuclear Research

NuPECC meeting, KFKI 07 October 2011

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:
    - $2.42 \times 10^{10} \text{ n/cm}^2/\text{s}$ (no nose)
    - $5.5 \times 10^{10} \text{ n/cm}^2/\text{s}$ (with nose)
  - Usable beam size:
    - (14x38) mm (no nose)
    - (4x10) mm (with nose)
PGAA setup at FRM-II
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

Natural Uranium oxide ($U_2O_3$)

Aluminum cylinder

Fe screw

Pb container

Click on this

n-beam direction

Corrections by Monte Carlo calculations for quantitative analysis

Geometry or voxel model

Neutron source overlaid on the geometry

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,\gamma) reaction rates

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

Overlay of calculated n-beam absorption in the objects

z: Beam direction
Future: a new setup for PGAI-NR at Budapest: NORMA

Projects start in 2012
1. NMI3 JRA imaging
2. IAEA CRP imaging

Design is ready, expected to be completed in Q4 2011
(depending 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!