Neutron Activation Analysis for life sciences

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The sector of neutron activation analysis and applied research

International students practice in JINR (Dubna,08.09.2018)
Neutron Activation analysis

NAA
Introduction

Stop, stare and listen!

Innovation

Idea

Crushing boundaries

Jumping out of the box
Neutron Activation Analysis in a nutshell

**History:**
- Discovery of Neutrons - James Chadwick
- Discovery of NAA - George Charles de Hevesy and Hilde Levi

**Definition:**
The conversion of the stable nuclei to a radioactive one and the release of a measured gamma rays.
Nuclear Interactions

Neutron Capture by a target nucleus followed by emission of gamma rays

Prompt Gamma Ray

Beta Particle

Radioactive Nucleus

Product Nucleus

Delayed Gamma Ray

Compound Nucleus
Neutron Activation Analysis Flow Chart

- Sample Collection
- Sample Preparation
- Irradiation
- Radioactivity Measurements
- Gamma Spectra Processing
- Calculation of Concentration
Sample Collection

Samples Types

- Environmental samples (vegetation)
- Liquids (wine)
- Geological samples (Soil, rocks, ores)
- Biological samples (blood, liver, hair)
- Foodstuffs
- Filters
A) Moss Sample Collection

- There are two moss species are collected for metal analysis:

1. Big Red Stem Moss (*Pleurozium schreberi*)

2. Stair-steps Moss (*Hylocomium splendens*)
B) Soil Sample Collection

- The longitude and latitude of the sample location should be recorded
- Samples need to be Separated from other impurities
- Packed in zip-bags and the numbers need to be written on the bag.
- The sample after collection are sent to the lab
Soil Sample Collection Strategies

a) Random Sampling

b) Stratified Random Sampling

c) Search Sampling
Sample Preparation

A) Devices and equipment:

- AA spectrometer (iCE™ 3000 Series)
- Microwave digestion system
- Ball mill homogenizer
- Hydraulic compressor
- Freeze dryer
- Electrical oven (30-300)°C
- Balance
Sample Preparation

B) Materials:

- Sealing machine
- Poly ethylene plastic bags
- Aluminum covers
- Pelletizer
Sample Preparation

C) Preparation steps for NAA: “For Moss and Soil Samples”

I. • Drying

II. • Pelletizing

III. • Weighing & Recording

IV. • Packing
Sample Preparation

D) Preparation steps for AAS: “For Moss and Soil Samples”

- Drying
  - Air-dried then in the oven
- Homogenization
  - (soil, lichens)
- Weighing and Recording
  - Using the lab program
- Sample digestion
  - Using microwave system
- Sample dilution
  - To specified volume
Sample Preparation

E) Handling precautions During preparation of the sample:

- To **remove impurities** from the sample
- To be sure that the **samples well dried**
- To **write down the numbers** on the bags clearly
- To use the **plastic zip-bags for the short live** radiation and **the aluminum one for long live radiation**
- To use **the metallic tweezers in packing the samples** and **the plastic one for weighting**
**IBR-2M Pulsed Fast Reactor**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average power (MW)</td>
<td>2</td>
</tr>
<tr>
<td>Fuel</td>
<td>PuO$_2$</td>
</tr>
<tr>
<td>Number of fuel assemblies</td>
<td>69</td>
</tr>
<tr>
<td>Maximum burnup(%)</td>
<td>9</td>
</tr>
<tr>
<td>Pulse Repetition rate (Hz)</td>
<td>5.10</td>
</tr>
<tr>
<td>Pulse Half width, µs:</td>
<td></td>
</tr>
<tr>
<td>• Fast neutron</td>
<td>245</td>
</tr>
<tr>
<td>• Thermal neutron</td>
<td>340</td>
</tr>
<tr>
<td>Rotation rate (rev/min):</td>
<td></td>
</tr>
<tr>
<td>• Main reflector</td>
<td>600</td>
</tr>
<tr>
<td>• Auxiliary reflector</td>
<td>300</td>
</tr>
<tr>
<td>Coolant</td>
<td>Sodium</td>
</tr>
<tr>
<td>Thermal neutron flux density from moderator surface (n.cm$^{-1}$.s):</td>
<td></td>
</tr>
<tr>
<td>• Time average</td>
<td>$\sim10^{13}$</td>
</tr>
<tr>
<td>• Burst maximum</td>
<td>$\sim10^{16}$</td>
</tr>
</tbody>
</table>
Experimental facility REGATA at IBR-2 reactor
Transport capsules for irradiation

<table>
<thead>
<tr>
<th>Container material</th>
<th>Irradiation time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyethylene</td>
<td>Up to 30 minutes</td>
</tr>
<tr>
<td>Aluminum</td>
<td>Longer time irradiation</td>
</tr>
</tbody>
</table>
Irradiation Channels

The main characteristics of the irradiation channels at 1.5 MW

<table>
<thead>
<tr>
<th>Irradiation site</th>
<th>Neutron flux density (n/cm² s) $10^{12}$</th>
<th>$T^0C$</th>
<th>Channel diam., mm</th>
<th>Channel length, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thermal</td>
<td>Resonance</td>
<td>Fast</td>
<td></td>
</tr>
<tr>
<td>Ch1</td>
<td>Cd-coated</td>
<td>3.31</td>
<td>4.32</td>
<td>70</td>
</tr>
<tr>
<td>Ch2</td>
<td>1.23</td>
<td>2.96</td>
<td>4.1</td>
<td>60</td>
</tr>
<tr>
<td>Ch3</td>
<td>Gd-coated</td>
<td>7.5</td>
<td>7.7</td>
<td>30-40</td>
</tr>
<tr>
<td>Ch4</td>
<td>4.2</td>
<td>7.6</td>
<td>7.7</td>
<td>30-40</td>
</tr>
</tbody>
</table>

Neutron energy spectra in irradiation channels CH1 and CH2 (curve)
closer look on REGATA
Radioactivity measurement of the irradiated samples

1. Interaction of Gamma with matter:

There are three modes of interaction (depending on photon energy)

A- Photoelectric effect
B- Compton Effect
C- Pair production
A) Photoelectric effect:

- Most important interaction of low-energy photons with matter

- Cross-sections for photoelectric effect increase strongly, especially for high-Z media

- Photoelectric effect totally predominates over the Compton Effect at low photon energies
Con’t

B) Compton scattering:

- Only part of the incident energy is absorbed to eject an electron (Compton electron)

- During interaction:
  The photon disappears, a secondary photon is created with reduced energy – propagating in a changed direction.
C) Pair production:

- For photoelectric and Compton effects the interaction of photon is with electrons of atom

- Pair production involves interaction of photons with the nucleus of the atom

- The photon disappears and a positron and an electron appear
Con’t

2. Gamma spectrometer

A gamma-ray spectrometer (GRS) is an instrument for measuring the distribution of the intensity of gamma radiation versus the energy of each photon.

Gamma-ray spectroscopy is laboratory equipment for determination of γ-radiation spectrum with a scintillation counter.
3. Measurements

- Long lived isotopes are measured twice after 3-4 days and 20-22 days of decay. Measurement time is 30 mins. And 90 mins. respectively.

- Short lived isotopes are measured 15 mins. Of decay
Processing of gamma spectra using G2X

- Software systems (Genie 2000™):
  - Provides full energy calibration, peak width and detector efficiency
  - Allows you to search the spectrum, search for statistically significant peaks, assign them nuclides and calculate the activity of the sample.
**Database**

**Con’t**
Calculation of Concentration

“Main window of the conc. program”
Con’t

Functional scheme of the Concentration program
## Advantages and limitations of NAA

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-element analysis</td>
<td>Need for nuclear reactor</td>
</tr>
<tr>
<td>Simultaneously detect all elements in the sample</td>
<td>Work with radioactive materials</td>
</tr>
<tr>
<td>Customizable analysis</td>
<td>Time of analysis</td>
</tr>
<tr>
<td>Wide possibilities of applications</td>
<td>Sample preference</td>
</tr>
<tr>
<td>Non destructive analysis</td>
<td>Not all elements are detectable</td>
</tr>
<tr>
<td>Time-efficient for analyzing many samples</td>
<td></td>
</tr>
</tbody>
</table>

The main applications of NAA

- Geology
- Semiconductor industry
- Environment
- Archeology
- Biomonitoring
- Bio-nanotechnology
- Forensics
- Toxicology
- Nutritiology
- Cosmos
- Geology
- Semiconductor industry
Joint projects (Belarus - Egypt)

A) Belarus:

1. Neutron activation analysis and electron microscopy in investigation of processes of crystallization and characteristics of diamonds in the systems C-Mn-Ni-Fe (Yulia Aleksiayenak, S.V. Leonchik, O.V. Ignatenko, V.A. Komar, A.V. Konovalova, M.V. Frontasyeva);

2. 137 Cs in moss samples from Belarus collected 2006-2007 (Yu. Aleksiayenak)
Con’t

B) Egypt:

- **1st Phase:**
  - Assessment of the environmental situation in the basin of the River Nile using nuclear and related analytical techniques (2011-2014)

- **2nd Phase:**
  - Environmental studies in Egypt using neutron activation analysis and other analytical techniques (2015-2018)

- **3rd Phase:**
  - Environmental Assessment of the marine environment in Egypt (Mediterranean sea and Red sea)
Our Journey was EXTRAORDINARY!
Our Journey was **INSIGHTFUL!**
This is our three-week story!
Thank you.