Instrumental Neutron Activation Analysis

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SUPERVISOR

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Neutron activation analysis is an isotope specific analytical technique for the qualitative and quantitative determination of elemental content [1].

The method is based upon the conversion of stable atomic nuclei into radioactive nuclei by irradiation with neutrons and the subsequent detection of the gamma radiation emitted during the decay of these radioactive nuclei. Activation by neutrons may result in radionuclides from all elements (that have radioactive daughter products) present in the sample, with sometimes strongly different production rates.

“A primary method of measurement is a method having the highest metrological properties, whose operation can be completely described and understood, for which a complete uncertainty statement can be written down in terms of SI units”.

More specifically, a primary method was defined as “a primary method of measurement that measures the value of an unknown without reference to a standard of the same quantity”; and a primary ratio method as “a primary method of measurement that measures the value of a ratio of an unknown to a standard of the same quantity; its operation must be completely described by a measurement equation.”[4]
the method is fully physically and chemically understood; that a measurement equation can be written down in which the values of all parameters have dimensions in SI units and thus having the potential for metrological traceability to these units; that all contributions to uncertainty of measurement can be quantitatively evaluated, underpinning the metrological traceability;

**NAA is a primary technique**
Principles of NAA?

1. Neutron capture: Neutron entering the target nucleus.
3. Prompt gamma radiation: Prompt gamma radiation emitted from the compound nucleus.
5. Decay gamma radiation: Gamma radiation emitted during decay.

The diagram illustrates the process of neutron activation analysis (NAA), showing the steps from neutron capture to decay gamma radiation.
TYPES OF NAA

- **INSTRUMENTAL** NAA
  - The application of purely instrumental procedures is commonly called (INAA). INAA is one of NAA's most important over other analytical techniques.

  *(Non destructive)*

- **RADIOCHEMICAL** NAA
  - Is done to samples after irradiation to remove interferences or to concentrate the radioisotope of remove interest. The resulting radioactive sample is chemically decomposed, and the elements are chemically separated [2].

  *(destructive)*
Moreover

We can divide types of NAA according to some other criteria such as:

**According to the time at which we do the measurements:**
- Prompt gamma ray NAA (PGNAA). during irradiation.
- Delayed gamma ray NAA (DNAA). enough time after irradiation.

**According to type of neutrons used:**
- Thermal neutron activation analysis.
- Epithermal Neutron Activation Analysis.
- Fast neutron activation analysis.
Neutron Sources

1. Isotope neutron sources
   - \(^{252}\text{Cf},\ 242\text{Am}\)

2. Neutron generators
   - IREN at JINR

3. Nuclear reactors
   - Research reactor
   - IBR-2
   - Used
Neutron flux spectrum

Scheme of the nuclear-reactor neutron spectrum [3]
Technique procedure

1. Sample identification (Data of sample and client) “chemical laboratory”
2. Preparation at the “chemical laboratory”
3. Irradiation at the reactor “IBR-2”
4. Measurement “REGATA”
5. Analysis results.
   • Interpretation.
The chemical laboratory
Crushing, Blinding & Milling
General view of IBR-2
Ch1-Ch4 – irradiation channels, S- intermediate storage, DCV- directional control valves, L- loading unit, RCB- radiochemical glove-cell, U- unloading unit, SU- separate unit, SM- storage magazine, R- repacking unit, D- detector, CB- control board, R1-R3- the rooms where the system is located.
IRRADIATION AT THE IBR-2 REACTOR.
The practical stages of Irradiation in REGATA

Control board

“Hot” cell
Neutron energy spectra and irradiation channels

### Neutron flux density (n/cm² s) $10^{12}$

<table>
<thead>
<tr>
<th>Irradiation site</th>
<th>Neutron flux density</th>
<th>T°C</th>
<th>Channel diam., mm</th>
<th>Channel length, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thermal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ch1</td>
<td>Cd-coated</td>
<td>3.31</td>
<td>70</td>
<td>28</td>
</tr>
<tr>
<td>Ch2</td>
<td>1.23</td>
<td>2.96</td>
<td>60</td>
<td>28</td>
</tr>
<tr>
<td>Ch3</td>
<td>Gd-coated</td>
<td>7.5</td>
<td>30-40</td>
<td>30</td>
</tr>
<tr>
<td>Ch4</td>
<td>4.2</td>
<td>7.6</td>
<td>30-40</td>
<td>30</td>
</tr>
</tbody>
</table>

### Gamma-Spectrometers

<table>
<thead>
<tr>
<th>No</th>
<th>Type of detector</th>
<th>Model</th>
<th>Manufacturer</th>
<th>Efficiency, resolution</th>
<th>Start-up date</th>
<th>High voltage Power Supply</th>
<th>Amplifier</th>
<th>ADC</th>
<th>Program</th>
<th>Used size range</th>
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</thead>
<tbody>
<tr>
<td>2</td>
<td>HPGe</td>
<td>GC4019-7500SL</td>
<td>Canberra</td>
<td>41.8%, 1.74 keV</td>
<td>2007</td>
<td>3106D Canberra</td>
<td>2026</td>
<td>Multiport II</td>
<td>Genie-2000</td>
<td>8k</td>
</tr>
<tr>
<td>3</td>
<td>HPGe</td>
<td>GX4020-CRIO-JT</td>
<td>Canberra</td>
<td>42.6%, 1.81 keV</td>
<td>2009</td>
<td>Incorporated</td>
<td></td>
<td>DSA-1000</td>
<td>Genie-2000</td>
<td>8k</td>
</tr>
<tr>
<td>4</td>
<td>HPGe</td>
<td>GC3018-7500SL</td>
<td>Canberra</td>
<td>30.3%, 1.74 keV</td>
<td>2011</td>
<td>3106D Canberra</td>
<td>2026</td>
<td>Multiport II</td>
<td>Genie-2000</td>
<td>8k</td>
</tr>
</tbody>
</table>
Applications of INAA at IBR-2

Life Sciences

- Biomonitoring of atmospheric deposition of heavy metals and other elements (Project REGATA)
- Control of quality and safety of foodstuffs, grown in industrially contaminated areas of RF and South Africa (grant of SA)
- Assessment of different ecosystems and their impact on human health

Material Sciences

- Biotechnologies: development of new pharmaceuticals, cleaning the environment from toxic elements (biosorption) and synthesis of nanoparticles
- NAA for the technological process of synthesis of diamonds and NB (boron nitride)
- Analysis of archaeological and museum objects from Russian and other countries
- NAA for decommissioning of Nuclear Power Plants and utilization of industrial wastes
Assessment of the environmental situation in the River Nile basin using nuclear and related analytical techniques (2011-2015)
• River-Nile samples
Vegetation Samples from industrial and Residential Areas Sadat city

Industrial Areas

Residential Areas

Wind direction
Performing Energy calibration
Performing an efficiency calibration (standard sources)
Performing background spectrum and save it
Using Gamma-ray Counts to Calculate Element Concentration

1. Irradiation & accumulation of the sample and reference (etalons).
2. Analyze the sample by genie2k and determine elements.
3. Concentration is calculated using a special software developed by the section of Neutron activation.
4. Conversion from activity to concentration.

\[ N_{\text{sample}} = \frac{N_{\text{std}} \times A_{\text{sample}}}{A_{\text{std}}} \]
• Analysis and results.
<table>
<thead>
<tr>
<th>sample</th>
<th>Na Mg/kg</th>
<th>Na %</th>
<th>MDC Mg/kg</th>
<th>Mg Mg/kg</th>
<th>Mg %</th>
<th>MDC Mg/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>W-02</td>
<td>4150</td>
<td>3.93</td>
<td>80.7</td>
<td>5920</td>
<td>3.4</td>
<td>402</td>
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<tr>
<td>W-03</td>
<td>11400</td>
<td>3.15</td>
<td>103</td>
<td>12700</td>
<td>6.47</td>
<td>580</td>
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<tr>
<td>W-04</td>
<td>9970</td>
<td>4.45</td>
<td>238</td>
<td>9290</td>
<td>9.62</td>
<td>879</td>
</tr>
<tr>
<td>W-05</td>
<td>7900</td>
<td>3.75</td>
<td>118</td>
<td>11500</td>
<td>3.23</td>
<td>616</td>
</tr>
<tr>
<td>W-06</td>
<td>6360</td>
<td>3.96</td>
<td>126</td>
<td>7180</td>
<td>3.45</td>
<td>512</td>
</tr>
</tbody>
</table>


[4] Neutron activation analysis: A primary method of measurement
Robert R. Greenberg a, b, Peter Bode b, Elisabete A. De Nadai Fernandes c
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Thanks...for your interest!