MEASUREMENT OF NEUTRON CAPTURE CROSS SECTIONS OF $^{139}$La, $^{152}$Sm and $^{191, 193}$Ir ON FILTERED NEUTRON BEAMS OF 54 keV and 148.3 keV

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Outline

- General information
- Neutron filter technique
- Experiments
- Results
- References
General information

Precise measurement of radiactive neutron capture cross sections in the keV energy region are important need for:

- Researches on fundamental nuclear physics
- Calculation and/or simulation of neutron transport
- Design of reactors
- Safety analysis
- Study on nuclear astrophysics
- Application of nuclear techniques
Neutron filters technique

Basic principles (proposed by O.D. Simpson*, L.G. Miller):
The phenomenon of neutron filtration is conditioned by existence in the total neutron cross sections for some atomic nuclei of deep interference minimums which are the result of interference between the coherent waves of resonance and potential neutron scattering in these nuclei.

1. Transmission:
   \[ T(E) = \exp\left\{ -\sum n_i \cdot \sigma_i(E) \right\} \]

2. Relative intensity:
   \[ I(E) = \frac{\int e^{-\sum n_i \sigma_i(E)} \Phi(E) dE}{\int \Phi(E) dE} \]

MT-1 : (n,total) Cross section for SiNat from ENDFB 6.8 from Local

54 keV 148.3 keV
Materials for Neutron Filters

- **Natural elements:** Si, Al, V, Sc, S, Mn, Fe, B, Ti, Mg, Co, Ce, Rh, Cd, LiF.

- **Enriched isotopes:** $^{52}\text{Cr}$ (99.3), $^{54}\text{Fe}$ (99.92), $^{56}\text{Fe}$ (99.5), $^{57}\text{Fe}$ (99.1), $^{58}\text{Ni}$ (99.3), $^{60}\text{Ni}$ (92.8 – 99.8), $^{62}\text{Ni}$ (98.04), $^{80}\text{Se}$ (99.2), $^{10}\text{B}$ (85), $^{7}\text{Li}$ (90).
Basic demands to neutron filters

- The purity of the main energy line in neutron spectrum has to be as much close to 100 % as possible.
- Neutron intensity is to be the most possible, sufficient to obtain the necessary accuracy in experiment.
- Construction and composition have to provide the minimal possible gamma-background.
- In necessary case construction and composition have to allow to increase or to reduce the width of base line without essential worsening of filter quality.
- The amount of enriched isotopes in filter components has to be minimum necessary.
- Filter components have to provide the energy range of filtered neutrons up to 1 MeV and more.
Main tasks for scientific research

- High precision measurements (0.1 – 0.01 %) of total and partial cross sections for fundamental neutron-nuclear investigations.
- Measurements of neutron capture gamma-spectra.
- Measurements of activation cross sections.
- Isomeric ratio investigations.
- Investigations of Doppler-effect.
- Research of radiation damage energy dependence in materials.
- Neutron radiography and tomography.
- Boron-Neutron Capture Therapy (BNCT).
- Prompt Gamma-ray Activation Analysis (PGAA).
- Development of standard fluxes for neutron-dosimetry purposes.
- Energy calibration of proton recoil counters.
Filtered Neutron spectra calculations

- Unfolding neutron spectra of 54 keV and 148.3 keV filtered neutron beams at Dalat Research Reactor
Neutron spectrum measurement

Recoil proton spectrum due to 54 keV neutron

Recoil proton spectrum due to 148.3 keV neutron

764 keV from He-3 \((n, p)\) H-3

Recoil proton counter SNM-38

\((90 \% \ H_2 + 9.56 \% \ CH_4 + 0.44 \% \ ^3He, 3 \ atm)\)
## Properties of the filtered neutron beams

<table>
<thead>
<tr>
<th>Neutron energy</th>
<th>Filter combination</th>
<th>Flux density ( (n \cdot cm^{-2} \cdot s^{-1}) )</th>
<th>FWHM (keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>148.3 keV</td>
<td>98 cm Si + 1.0 cm Ti + 0.2 g/cm² B-10</td>
<td>( 2.14 \times 10^6 )</td>
<td>22</td>
</tr>
<tr>
<td>54 keV</td>
<td>98 cm Si + 35 g/cm² S + 0.2 g/cm² B-10</td>
<td>( 5.61 \times 10^5 )</td>
<td>8</td>
</tr>
</tbody>
</table>
Experiments

- **Experimental arrangement**
  - Samples: La$_2$O$_3$, Sm$_2$O$_3$ and IrO$_2$, 99.99%
  - Standard: gold foils 0.01mm in thickness
  - Cd covers with 0.5mm in thickness
  - A fast-digital gamma-ray spectroscopy in compacted with a 58% efficient HPGe detector

- **The neutron capture cross sections for the reactions of:**
  - $^{139}$La(n,$\gamma$)$^{140}$La,
  - $^{152}$Sm(n,$\gamma$)$^{153}$Sm,
  - $^{191}$Ir(n,$\gamma$)$^{192}$Ir,
  - $^{193}$Ir(n,$\gamma$)$^{194}$Ir,
  - $^{197}$Au(n,$\gamma$)$^{198}$Au
## Decay properties of the product nuclei

<table>
<thead>
<tr>
<th>Product nucleus</th>
<th>Half-life</th>
<th>$\gamma$-ray energy (keV)</th>
<th>Intensity per decay (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{198}$Au</td>
<td>2.6952±0.0002 (d)</td>
<td>411.8</td>
<td>95.6±0.1</td>
</tr>
<tr>
<td>$^{140}$La</td>
<td>1.6781±0.0003 (d)</td>
<td>487.02</td>
<td>45.5±0.6</td>
</tr>
<tr>
<td>$^{153}$Sm</td>
<td>46.50±0.21 (h)</td>
<td>103.2</td>
<td>29.3±0.1</td>
</tr>
<tr>
<td>$^{192}$Ir</td>
<td>73.827±0.013 (d)</td>
<td>316.5</td>
<td>82.7±0.2</td>
</tr>
<tr>
<td>$^{194}$Ir</td>
<td>19.28±0.13 (h)</td>
<td>328.45</td>
<td>13.1±1.7</td>
</tr>
</tbody>
</table>
Data processing

- Reaction rate

\[ R = N \int \phi(E) \sigma_a(E) dE \]

- The average neutron capture cross section and neutron flux

\[ < \sigma_a > = \frac{\int \sigma_a(E) \phi(E) dE}{\int \phi(E) dE} \]

\[ < \phi > = \int \phi(E) dE \]

\[ R = N < \sigma_a > < \phi > \]
The radioactivity of sample at the end of irradiation

\[ A = R(1 - \exp(-\lambda t_1)) \]

\[ A = \frac{Cf_c \lambda}{\epsilon \gamma I \gamma \exp(-\lambda t_2)(1 - \exp(-\lambda t_3))} \]

- The average capture cross sections of the irradiated samples can be obtained

\[ < \sigma_a >^x = \frac{C^x f(\lambda, t)^x f_c^x I^x_{\gamma} \epsilon^x_{\gamma} N^{Au}^{Au}}{C^{Au} f(\lambda, t)^{Au} f_c^{Au} I^x_{\gamma} \epsilon^x_{\gamma} N^{x}} \]

\[ f(\lambda, t) = \frac{1 - \exp(-\lambda t_1))\exp(-\lambda t_2)(1 - \exp(-\lambda t_3))}{(1 - \exp(-\lambda t_1))\exp(-\lambda t_2)(1 - \exp(-\lambda t_3))} \]
Correction factors calculation

- Multi-scattering of neutron in sample
- Self-shielding effect
- Resonance capture with neutrons in low energy background region

<table>
<thead>
<tr>
<th>Nuclides</th>
<th>54keV region</th>
<th>148keV region</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Self-shielding</td>
<td>Multi-scattering</td>
</tr>
<tr>
<td>Au-197</td>
<td>0.9985</td>
<td>0.9901</td>
</tr>
<tr>
<td>La-139</td>
<td>0.9962</td>
<td>0.9785</td>
</tr>
<tr>
<td>Sm-152</td>
<td>0.9988</td>
<td>0.9856</td>
</tr>
<tr>
<td>Ir-191</td>
<td>0.9959</td>
<td>0.9782</td>
</tr>
<tr>
<td>Ir-193</td>
<td>0.9959</td>
<td>0.9774</td>
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</tbody>
</table>
## Experimental Results

<table>
<thead>
<tr>
<th>Neutron energy</th>
<th>$&lt;\sigma_a&gt;$La-139 (mb)</th>
<th>$&lt;\sigma_a&gt;$Sm-152 (mb)</th>
<th>$&lt;\sigma_a&gt;$Ir-191 (mb)</th>
<th>$&lt;\sigma_a&gt;$Ir-193 (mb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>54 keV</td>
<td>22.4 ± 0.55</td>
<td>345.5 ± 8.2</td>
<td>1016.5 ± 21.1</td>
<td>566.7 ± 14.9</td>
</tr>
<tr>
<td>148.3 keV</td>
<td>12.01 ± 0.2</td>
<td>258.7 ± 5.2</td>
<td>514 ± 11.7</td>
<td>404.5 ± 9.8</td>
</tr>
</tbody>
</table>
$^{139}\text{La}(n,\gamma)^{140}\text{La}$

- A.E. JOHNSRUD
- A.R. DEL MUSGROVE
- D.C. STUPEGIA
- A.R. DEL MUSGROVE
- J.H. GIBBONS
- G.G. ZAIKIN
- R.PANAND
- This work

Cross section (barn) vs. Neutron energy (eV)

- ENDF/B-6.8
- JENDL 3.3
$^{152}\text{Sm}(n,\gamma)^{153}\text{Sm}$

Cross section (barn) vs. Neutron energy (eV)

- K. WYGSHAK
- K. GUBER
- B. DJAMET
- LUC XIAO-BING
- This work
- ENDF/B-VII.1
- JENDL 3.3
Publication

CINDA Like Entry for Proceedings of 2006 Symposium on Nuclear Data

An index to the nuclear reaction data presented in SND2006 is given in this text. The format is that of the Computer Index to Nuclear Reaction Data (CINDA)\(^1\), which is available from nuclear data centers world-wide. The format is as follows:

<table>
<thead>
<tr>
<th>Element</th>
<th>Quantity</th>
<th>Type</th>
<th>Energy Min</th>
<th>Energy Max</th>
<th>Lab.</th>
<th>Type</th>
<th>Documentation</th>
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</thead>
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<tr>
<td>C</td>
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<td>1.40E+7</td>
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<td>La 139</td>
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<tr>
<td>Ir 191</td>
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<tr>
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<td>2.00E+7 2.00E+8</td>
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<td>U 235</td>
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<td>JPNJAE</td>
<td>Theo</td>
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</table>

Conclusions

- The neutron capture cross sections of $^{139}$La, $^{152}$Sm and $^{191,193}$Ir within the uncertainties of about 3-6% have been measured at energies of 54 keV and 148.3 keV by the activation foil method.

- The neutron filtered beams of 54 keV and 148.3 keV are available and useful for measurement of nuclear data at these energies.

- In the next term, we are planning to produce new filtered compositions of 24.3 keV, 58.8 keV and 133.3 keV in order to expand the potentiality of nuclear data measurement in other energy regions at Dalat Nuclear Research Institute.
References


[2] Stefano Marrone, Measurement of the $^{139}$La(n,$\gamma$) Cross Section at n_TOF, 12th Conference on Capture Gamma-Ray Spectroscopy and Related Topics, CGS12, 4-9 (2005).


THANK YOU