SHELS - Separator for Heavy Element Spectroscopy

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for
GABRIELA-collaboration
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Electrostatic separator VASSILISSA

E/q < 2 MV
The joint JINR – IN2P3 (France) project entitled “Study of nuclear structure and nuclear reaction mechanism of heavy and superheavy elements: Gamma and electron spectroscopy of very heavy nuclei with $Z \approx 104$” started in year 2004.

The scientific aims of the collaboration were approved by the Scientific Council of IN2P3 in December 2003 and by the Scientific Council of JINR in January 2004.

The collaboration, which includes groups from CSNSM Orsay and IPHC Strasbourg for IN2P3 and for JINR, a group from the FLNR Laboratory, has led 5 experimental campaigns since 2004.

http://flerovlab.jinr.ru/flnr/vassilissa.html
http://www.csnsm.in2p3.fr/-GABRIELA-?lang=en
GABRIELA@VASSILISSA
Spectroscopy of transfermium elements:

- Alpha spectroscopy - $Q_\alpha$ values and partial half lives, identification of new nuclides using $\alpha-\alpha$ correlation method

- Spontaneous fission – TKE, prompt neutron multiplicity, partial half lives

- Beta and gamma spectroscopy – $E_\gamma$, $E_\beta$ (conversion electrons), isomeric states at mother and daughter nuclei

- Correlation analysis – prompt and delayed $\alpha$, $\beta$, $\gamma$ correlations, assignment of isomeric states.
The goals of modernisation:

- Study of heavy neutron rich isotopes, which can be produced in asymmetric combinations
- Study of isotopes, which can be produced in symmetric combinations
- Problem I: low transmission for asymmetric combinations
- Problem II: insufficient electric rigidity
Analyzed reactions

Reaction asymmetry $A_p/A_c$

Mass of the compound nucleus $A_c$
Magnetic rigidities of compound nuclei (T×m)
Electric rigidities of compound nuclei (MV)
Velocity filter SHELS 
(Separator for Heavy ELement Spectroscopy)

- Target Wheel
- Quadrupole Lens I
- Quadrupole Lens II
- Electric Deflector I
- Electric Deflector II
- Magnetic Deflector I
- Magnetic Deflector II
- Magnetic Deflector III
- Distance in Meters
- Beam Stop
- Position-sensitive detector array
- Time of Flight detector
- Velocity filter SHELS (Separator for Heavy ELement Spectroscopy)
- E/q < 10 MV
Movable plates of electrostatic deflectors
Determination of the transmission efficiency

May - July 2013

$^{22}\text{Ne} + ^{198}\text{Pt} \rightarrow ^{220}\text{Ra}^*$
Determination of the transmission efficiency

November 2013

$^{50}\text{Ti} + ^{164}\text{Dy} \rightarrow ^{214}\text{Ra}^*$

$E_{1/2} = 215 \text{ MeV}$

FWHM = 20 keV

$E_{1/2} = 225 \text{ MeV}$

FWHM = 30 keV
# Test experiments year 2013

<table>
<thead>
<tr>
<th>Reaction</th>
<th>$E_{\text{beam1/2}}$ MeV</th>
<th>Target thickness mg/cm$^2$</th>
<th>Old</th>
<th>New</th>
<th>Calc.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>May - July 2013</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{22}\text{Ne}(^{197}\text{Au,5n})^{214}\text{Ac}$</td>
<td>120</td>
<td>Met – 0.35</td>
<td>0.03</td>
<td>0.035 - 0.05</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>Bigger detector size</strong></td>
</tr>
<tr>
<td>$^{22}\text{Ne}(^{198}\text{Pt,6n})^{214}\text{Ra}$</td>
<td>115 -125</td>
<td>Met – 0.3</td>
<td>0.03</td>
<td>0.035 - 0.05</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>Bigger detector size</strong></td>
</tr>
<tr>
<td>$^{22}\text{Ne}(^{238}\text{U,5n})^{255}\text{No}$</td>
<td>115</td>
<td>$\text{U}_3\text{O}_8$ – 0.35</td>
<td>0.01</td>
<td>0.02</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td><em>for metallic U</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>November 2013</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{50}\text{Ti}(^{154}\text{Sm,6n})^{198}\text{Po}$</td>
<td>240</td>
<td>$\text{Sm}_2\text{O}_3$ – 0.3</td>
<td>0.3</td>
<td>0.4</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><em>(for $^{48}\text{Ca}^{176}\text{Yb}$)</em></td>
</tr>
<tr>
<td>$^{50}\text{Ti}(^{164}\text{Dy,5n})^{209}\text{Ra}$</td>
<td>240</td>
<td>$\text{Dy}_2\text{O}_3$ – 0.3</td>
<td></td>
<td>0.4</td>
<td>0.45</td>
</tr>
<tr>
<td>$^{50}\text{Ti}(^{208}\text{Pb,2n})^{256}\text{Rf}$</td>
<td>237</td>
<td>$\text{PbS}$ – 0.36</td>
<td>0.25</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><em>(for $^{48}\text{Ca}^{208}\text{Pb}$)</em></td>
</tr>
</tbody>
</table>
First research experiment with accelerated $^{50}$Ti beam at FLNR U400 cyclotron

April 2014

$^{50}$Ti beam intensity – $3 \times 10^{12}$ pps.

Modernized VASSILISSA separator and neutron detector at the focal plane.

$^{50}$Ti + $^{208}$Pb = 2n + $^{256}$Rf

more than 1500 events detected.

Detector system at the focal plane of separator

TKE spectra for $^{256}$Rf isotope

Neutron multiplicity measured for spontaneous fission of $^{256}$Rf isotope.
Tests of $\gamma$ detection at the target position

- Beam intensity about 20 pnA
- Counting rate without target 2 kHz
- Counting rate with $^{208}$Pb target (C backing foil) 3 kHz
- Counting rate with $^{164}$Dy target (Ti backing foil) 3.5 kHz

• Total counting rate at the focal plane at beam intensity 0.6 pμA – 700 Hz.
Double sided strip detectors

48x48 strips
size 60 x 60 mm$^2$

128x128 strips
size 100 x 100 mm$^2$

Factor of 2 in detection efficiency
Present status: Tests of new 128x128 strip DSSD

Left panel – double sided strip detector 128x128 strips, 100x100 mm$^2$ size.

Right panel – $^{242}$Pu alpha spectrum. Energy resolution obtained is about 15 keV.
### Calculated transmission efficiency of SHELS

<table>
<thead>
<tr>
<th>Reaction</th>
<th>$E_{p1/2}$ MeV</th>
<th>Target thickness mg/cm²</th>
<th>Transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{22}\text{Ne}(^{238}\text{U,5n})^{255}\text{No}$</td>
<td>115</td>
<td>$\text{U}_3\text{O}_8 - 0.2$</td>
<td>0.06 (now –0.02)</td>
</tr>
<tr>
<td>$^{22}\text{Ne}(^{238}\text{U,5n})^{255}\text{No}$</td>
<td>115</td>
<td>Met – 0.2</td>
<td>0.09</td>
</tr>
<tr>
<td>$^{22}\text{Ne}(^{197}\text{Au,5n})^{214}\text{Ac}$</td>
<td>110</td>
<td>Met – 0.2</td>
<td>0.14</td>
</tr>
<tr>
<td>$^{40}\text{Ar}(^{181}\text{Ta,4n})^{217}\text{Pa}$</td>
<td>182</td>
<td>Met – 0.3</td>
<td>0.28</td>
</tr>
<tr>
<td>$^{40}\text{Ar}(^{162}\text{Dy,7n})^{195}\text{Po}$</td>
<td>198</td>
<td>DyO$_2$ – 0.3</td>
<td>0.28</td>
</tr>
<tr>
<td>$^{242}\text{Pu}(^{22}\text{Ne,5n})^{259}\text{Rf}$</td>
<td>120</td>
<td>PuO$_2$ – 0.2</td>
<td>0.07</td>
</tr>
<tr>
<td>$^{48}\text{Ca}(^{208}\text{Pb,2n})^{254}\text{No}$</td>
<td>216</td>
<td>Met – 0.4</td>
<td>0.42</td>
</tr>
</tbody>
</table>

### Estimated counting rates

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Cross section</th>
<th>Transmission %</th>
<th>ERs counting rate per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{242}\text{Pu}(^{22}\text{Ne,5n})^{259}\text{Rf}$</td>
<td>3.0 nb</td>
<td>7</td>
<td>115</td>
</tr>
<tr>
<td>$^{244}\text{Pu}(^{22}\text{Ne,5n})^{261}\text{Rf}$</td>
<td>5.0 nb</td>
<td>7</td>
<td>190</td>
</tr>
<tr>
<td>$^{248}\text{Cm}(^{18}\text{O,5n})^{261}\text{Rf}$</td>
<td>13 nb</td>
<td>4</td>
<td>270</td>
</tr>
<tr>
<td>$^{243}\text{Am}(^{22}\text{Ne,5n})^{260}\text{Db}$</td>
<td>2.0 nb</td>
<td>7</td>
<td>70</td>
</tr>
<tr>
<td>$^{243}\text{Am}(^{22}\text{Ne,4n})^{261}\text{Db}$</td>
<td>1.5 nb</td>
<td>7</td>
<td>55</td>
</tr>
<tr>
<td>$^{248}\text{Cm}(^{22}\text{Ne,5n})^{265}\text{Sg}$</td>
<td>0.3 nb</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>$^{208}\text{Pb}(^{54}\text{Cr,1n})^{261}\text{Sg}$</td>
<td>0.5 nb</td>
<td>50</td>
<td>90</td>
</tr>
</tbody>
</table>
GABRIELA 2015: Gamma detection efficiency estimations for new detector set up

Clover detector

Preliminary GEANT4 detector arrangement including a Clover and 4 EUROGAM phase-I. These surround the 10x10 cm$^2$ implantation detector (in blue) and its PCB (green).

Right: A first estimate of the achievable singles efficiency as a function of photon energy for a distributed source.
New insights into the $^{243}$Am+$^{48}$Ca reaction

Cross section $\sim 8$ pb
Target thickness $\sim 10^{18}$ at/cm$^2$
Beam intensity $\sim 5 \times 10^{12}$ pps
If $\varepsilon \sim 40\%$
1 event per day.
Conclusion:
The separator SHELS is prepared for experiments!