NEUTRON EMISSION FROM SPONTANEOUS FISSION OF HEAVY ELEMENTS AT THE FLNR

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The **transuranium elements** are the chemical elements with atomic numbers greater than 92 (the atomic number of uranium). All of these elements are unstable and decay radioactively into other elements.

In nuclear physics, the **island of stability** is a set of predicted, but as-yet undiscovered, heavier isotopes of transuranium elements which are theorized to be much more stable than some of those closer in atomic number to uranium.
II. Spontaneous fission

a) Definition

Spontaneous fission is a form of radioactive decay that is found in only a very heavy elements. Presently, the available experimental information on the spontaneous fission of transfermium elements mainly concerns partial half-lives.

b) Conditions

Bohr and Weeler estimated that the limit of stability of the nucleus was at value $Z^2/A = 47.8$. SF has been observed in $^{238}\text{U}$, $^{235}\text{U}$, $^{232}\text{Th}$, but the probability is low (all have mean lifes greater than $10^{16}\text{sec}$). SF with shorter mean life is now known to occur in many of the man-made transuranian elements, like $^{239}\text{Pu}$, $^{241}\text{Am}$.
II. Spontaneous fission

c) Neutron emission

The number of neutrons emitted during fission directly depends on the degree of excitation of fission fragments and thus aids the exploration of the nuclear properties. On the other hand, the mean number of neutrons per spontaneous fission is a unique characteristic of the nucleus.

d) Methods

- What does it mean to “detect” a neutron?
  → Need to use nuclear reactions to “convert” neutrons into charged particles.

- Then we can use one of the many types of charged particle detectors, but in our experiment we used neutron detectors with $^3$He filled counters placed in a moderator.
IV. Goals of our experiment

The main goal of our project is preparing the detection system for experiments aimed to investigation of neutron properties of spontaneous fissioning heavy nuclei. The preparing of detection system include:

- Calibrating of Si-detector with α sources.
- Testing and measuring the efficiency of neutron detector with known SF neutron source ($^{248}$Cm).
- Testing and tuning of electronic and data-collecting system.
Studies of the dependence of the number of neutrons on the nuclear mass can significantly facilitate the identification of super-heavy nuclei obtained both in off-line experiments (for long-lived isotopes) where chemically isolated samples are placed inside the detector, and in on-line heavy-ion beams experiments (for short-lived isotopes) using kinematic separators (VASSILISSA separator).
The focal plane semiconductor Si-detector system provides the possibility to measure the energy of both fission fragments from the spontaneous fission of the implanted evaporation residues(ER).
Si-detector calibration

### A. Top 2

<table>
<thead>
<tr>
<th>Source</th>
<th>Bi²¹²</th>
<th>Po²¹²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Channel</td>
<td>1181</td>
<td>1731</td>
</tr>
<tr>
<td>FWHM Channel</td>
<td>21</td>
<td>17</td>
</tr>
</tbody>
</table>

### A. Top 3

<table>
<thead>
<tr>
<th>Source</th>
<th>Bi²¹²</th>
<th>Po²¹²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Channel</td>
<td>1092.7</td>
<td>1602.6</td>
</tr>
<tr>
<td>FWHM Channel</td>
<td>18</td>
<td>16</td>
</tr>
</tbody>
</table>
This spectrum is given by Bi-212 and Po-212 coming from the decay chain of Thorium-232. We used these two isotopes for the calibration of the Si-detector.

Initial spectrum

Spectrum after calibration
c) Neutrons detector (He-3 counters)

The neutron detector consists of separate modules comprising a $^3$He filled proportional counter, a moderator, a high-voltage input and a preamplifier. Our detector uses 54 counters and the moderator is made of polyethylene.

Helium counters detect neutrons by using the thermal neutron-induced reaction: $^3$He + n → $^3$H + p + 780 keV, with a cross section of 5320 barns.

Characteristic curve of $^3$He proportional counter.
Spectra provided by our set-up

Typical double-humped spectrum of fission fragments.

Neutron spectrum from $^3$He counter

$\gamma$ rays under threshold
The multiplicity distribution of registered neutrons from the spontaneous fission of $^{248}\text{Cm}$

Only those neutrons that are registered in a time less than 128μs after the SF are taken into account.

To determine the detector efficiency, we use some known ratios between the numbers of emitted neutrons.

The efficiency of the neutron detector

<table>
<thead>
<tr>
<th>Number of neutrons</th>
<th>Ratio</th>
<th>Efficiency (%)</th>
<th>Average efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_1=126142$</td>
<td>$N_1/N_2=1.74$</td>
<td>35</td>
<td>38</td>
</tr>
<tr>
<td>$N_2=72626$</td>
<td>$N_1/N_3=5.61$</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>$N_3=22486$</td>
<td>$N_2/N_3=3.23$</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>$N_4=4150$</td>
<td>$N_3/N_4=5.42$</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>$N_5=450$</td>
<td>$N_2/N_4=17.5$</td>
<td>38</td>
<td></td>
</tr>
</tbody>
</table>
Neutron detection time

Using this distribution of neutron detection times, by exponential fitting we obtained that the average neutron detection time is equal to \((20,81 \pm 0,28) \mu s\) for the configuration used.
VI. Conclusions

✓ We calibrate the Si-detector with Bi-212 and Po-212.
  - 1 channel = 5.34 keV
  - resolution = 100 keV

✓ We have tested electronic and data-collecting system by acquiring some known spectra.

✓ We studied the neutron multiplicity in two ways (with a c++ program and using the CAMAC system).

✓ We calculated the efficiency of neutron detector and we obtained a value equal to 38%.

✓ We achieved the distribution of neutron detection times for which the neutron life-time is equal to (20.81±0.28) μs.
Thank you very much for your attention!

спасибо за внимание!