Discovery of new superheavy elements Z=114-118 at the Dubna Gas-Filled Recoil Separator: Sum of the Technologies

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FLNR, JINR +

@Collaboration Dubna-Livermore-Oak Ridge-Lanzhou (since 2016)
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1. **Introduction:** DGFRS, detection system, real-time algorithm to search for ER-α sequences, SHE

2. **Examples of application:** Og, Z=118, Ts, Z=117, 240,239Pu + 48Ca-*Fl (in brief)

3. (nearest future~2019) **Ultra high beam intensities. SHE Factory of FLNR.** (DC-280 project). ~5-10 μA 48Ca, 50Ti..! New separator design, new detection system

4. **Summary**

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- Discovery of nuclear fission
- Nuclear explosions
- Nuclear reactors with neutrons
- Chemistry of actinides
- Discovery of SF-isomers
- SHE may exist
- SF-modes
- Cold fusion reactions
- Recoil separators
- SCIENCE and TECHNOLOGIES

Watch movie: http://www.youtube.com/watch?v=oRkc521no94
sum of technologies...

- Cyclotron $\sim 1$ pmcA ($^{48}$Ca beam)
- Actinide target (rotating) to apply high intensity for a long time
- Rotating entrance window (to separate high cyclotron vacuum and 1 Torr H$_2$ separator working media)
- Gas–Filled Separator (to suppress primary beam and other backgrounds)
- Detection system (to extract ultra rare decays of SHN)
Lay-out of the DGFRS spectrometry complex for experiments with $^{48}$Ca projectiles

..subsystems

**Blue** – monitoring & protection

**Green** – detection

**Magenta** – “active” correlations search for ER-alpha

**Red** – aerosol control (rad. safety staff, **autonomous**)

PC with CAMAC controller

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Detection System

DSSSD

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Remote control room

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Aerosol Test

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Beam chopper
## The DGFRS Focal Plane Detectors since ~1990

<table>
<thead>
<tr>
<th>Type</th>
<th>Size</th>
<th>~year</th>
<th>manufacturer</th>
<th>Additional info</th>
</tr>
</thead>
<tbody>
<tr>
<td>n-Si(Au)</td>
<td>55 mm diam</td>
<td>1988-1989</td>
<td>FLNR, JINR</td>
<td>Adjustment of the DGFRS</td>
</tr>
<tr>
<td>P-Si(Al)</td>
<td>48 mm</td>
<td>1989-1992</td>
<td>FLNR, JINR</td>
<td>To measure Efficiency (separate chamber) Ruggeri zed surface- a little washing with acetone was possible</td>
</tr>
<tr>
<td>n-Si(Au)</td>
<td>18 mm x 6 det array</td>
<td>1990</td>
<td>FLNR, JINR</td>
<td>40Ar+207Pb→244Fm + 3n experiment (neg res)</td>
</tr>
<tr>
<td>n-Si (Au)</td>
<td>2x2.5 cm x 6 det</td>
<td>1991-1993</td>
<td>FLNR, JINR</td>
<td>Ch. St. systematic, Some HI exp-s e.g. U+Ne, O. 207Pb+40Ar→244Fm + 3n</td>
</tr>
<tr>
<td>PIPS pos. sens.</td>
<td>1x4 x 12 strip</td>
<td>1994-2008</td>
<td>CANBERRA NV, Belgium</td>
<td>48Ca beam+AcTag</td>
</tr>
<tr>
<td>PIPS pos. sens.</td>
<td>0.37 x 6 x 32 strip</td>
<td>2009 – 2013</td>
<td>CANBERRA NV, Belgium</td>
<td>48Ca+249Bk→117</td>
</tr>
<tr>
<td>DSSSD</td>
<td>6x12 cm² 48x128 strips (~330 µm depth)</td>
<td>2013 November, Micron Semiconductor, UK</td>
<td>48Ca +240Pu</td>
<td></td>
</tr>
<tr>
<td>Solid state (plastic)</td>
<td>14x6 cm²</td>
<td>1989</td>
<td>JINR</td>
<td>207Pb+40Ar→244Fm + 3n</td>
</tr>
</tbody>
</table>

**PIPS Canberra NV 32 strips**

\[ ^{40}\text{Ar}+^{207}\text{Pb} \rightarrow ^{244}\text{Fm} + 3n \]
It provides:

- Parameter monitoring, visualization associated with: cyclotron beam, detection system, separator by itself;

- Protection against any abnormal situations (very actual when one use high activity Actinide targets e.g.)
What is the experimentalist see (control & monitoring system)


#1 beam on Chopper off

#2 beam off Chopper ON!
Target for synthesis of the heaviest isotopes of element 118 in the $^{249-251}\text{Cf} + \text{^{48}Ca}$ reaction

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Half-life (years)</th>
<th>Mass (mg)</th>
<th>Abundance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{249}\text{Cf}$</td>
<td>351</td>
<td>5.61 mg</td>
<td>50.7%</td>
</tr>
<tr>
<td>$^{250}\text{Cf}$</td>
<td>13</td>
<td>1.43 mg</td>
<td>12.9%</td>
</tr>
<tr>
<td>$^{251}\text{Cf}$</td>
<td>898</td>
<td>4.03 mg</td>
<td>36.4%</td>
</tr>
<tr>
<td>$^{252}\text{Cf}$</td>
<td>2.65</td>
<td>0.002 mg</td>
<td>0.02%</td>
</tr>
</tbody>
</table>

12 target sectors are in Dubna, Average thickness 0.35 mg/cm²

work on mixed Cf at REDC
Results of the experiments in 2002, 2005 and 2012.

\[ \text{Cf}^{249} + \text{Ca}^{48} \]
Steps in target $^{249}$Bk production (ORNL+JINR)

Isotopes $^{249}$Bk and $^{249}$Cf were produced in ORNL (USA)
By 250 days irradiation of targets Cm and Am
With thermal neutrons flow $2.5 \times 10^{15} \text{n/cm}^2\cdot\text{c}$ of HFIR reactor

22 mg pure Bk
..a few words about information technologies: Method of “active correlations”

// in use (different versions) ~ since 2000

**Time-energy-position correlation** ER-alpha detected in a real-time mode

Provides beam stop for a short time. In the case of detecting next alpha decay signal in the same position “beam-off” interval is prolonged for a few times. Beam interrupting is performed at the position of injection line (~ 18 kV)

1) Algorithm itself (ER-α)
2) Detection system
3) \[ E_{\text{ER}}(\text{registered}) = f(E_{\text{incoming}}) \]


Yu.S.Tsyganov & A.N.Polyakov

PC simulation ER spectra

Systematic with heavy nuclei measurements
...for **Dynamic** Background Suppression.

- **Active correlations method**
- *It means that:*

  - To search for in a real-time mode pointer to a potential ER(implanted)-alpha correlation;
  
  - To create short break points in target irradiation; (def)short = \( \sum_{i=1}^{N} \Delta t_i << T_{\text{experiment}} \)

  - To detect forthcoming alpha decays (or even SF decay) in a background free mode, that is, when suppression factor in the value of probability to be a random decreases by several orders of magnitudes (6-9, usually, depending on number of chains).

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**Data flow**

```
START EXPERIMENT
```

```
t1  t2  ...  ti  N
```

```
End Experiment
```

Short break points (pauses) in the target irradiation process 1,2...i..N

- **EVR**

- **beam On**

- **Time**

- **beam OFF**

- **N(N-1)/2 graph edges**

  If **N- number of nodes**

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METHOD OF “ACTIVE CORRELATIONS”

Detection System
~40 mcS

Separator

Actinide Target

Cyclotron
~60 mcS

Orbit life-time
~10 mcS

0/500 V

Beam Chopper

ON/OFF

Data Store

Synology DS1511+

Injection line

ECR ion source

243Am+48Ca → 288Mc+3n

E_{lab} = 248 MeV

beam-off

beam-on (1/10)

211Po

214Po

212Po

(α+e⁻)

213Po

(α+e⁻)

276Mt, 280Rg

276Bh

284

counts / 20 keV

α-particle energy (MeV)
ER registered energy

(due to large PHD, nuclei scattering in Si mostly, not recombination: \( PHD = \Delta_{\text{WIN}} + \Delta_{\text{ST}} + \Delta_{\text{R}} \))

Arrows - six events from two

\( ^{240}\text{Pu} + ^{48}\text{Ca} \rightarrow {}^{*}\text{Fl} \) experiments

Masses, z’s ~ from Th to No.. Stars \( \rightarrow \) from GSI, Riken (single events..from Dr.’s S.Hofmann, Morita Kosuke)...

PC simulation of ER (registered energy):
Yu.Tsyganov & A.Polyakov
Synthesis of neutron-deficient isotopes

$^{240}$Pu + $^{48}$Ca reaction

- **Target**: 0.49 mg/cm$^2$
- **Energy of $^{48}$Ca**: 245 MeV
- **Excitation energy**: 36.5 – 41.1 MeV
- **Beam dose**: $4.0 \times 10^{18}$

Diagram showing the synthesis of isotopes: $^{240}$Pu + $^{48}$Ca leading to various isotopes with their respective energy levels and lifetimes.
2\textsuperscript{nd} experiment (2016-2017)
E (lab) = 250 MeV Dose~$1.4\times10^{19}$

PC simulation of ER (registered energy):
Yu. Tsyganov & A. Polyakov

A588 (2006) 329-332

FLNR-ORNL-LLNL-IMP collaboration.
Measured cross section is lower by factor of 20 than theoretical predictions and by factor of 50 than values measured in the reaction with $^{244}$Pu. Decrease of stability (fission barriers) of neutron-deficient Fl isotopes.
Decrease of SF half-lives of even-even isotopes of Cn and Fl with receding magic number $N=184$

Approaching the border of region of SHN
ПЕРИОДИЧЕСКАЯ ТАБЛИЦА ЭЛЕМЕНТОВ
Д. И. МЕНДЕЛЕЕВА

Лантаноиды

Актиноиды

За последние 60 лет 10 новых элементов были открыты в ОИЯИ

Карта нуклидов

Остров стабильности — петля, в которой области с равной степенью стабильности (исключая нуклиды, временно нестабильные, и одноядерные женские магнитные волокна) расположены вдоль ограничивающих кары Мантина. Остров стабильности равен 116. С 1999 года ОИЯИ началась активная работа по поиску новых элементов.

Элемент 118 под номером 118 (Og) в 2017 году успешно создан в ОИЯИ. Элемент 118 является членом острова стабильности и получает название 'Og'.
## Confirmations (2007-2014)

<table>
<thead>
<tr>
<th>A/Z</th>
<th>Setup</th>
<th>Laboratory</th>
<th>Publications</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{283}_{112}$</td>
<td>COLD</td>
<td>PSI-FLNR (JINR)</td>
<td>NATURE 447, 72 (2007)</td>
</tr>
<tr>
<td>$^{286, 287}_{114}$</td>
<td>BGS</td>
<td>LRNL (Berkeley)</td>
<td>P.R. Lett. 103, 132502 (2009)</td>
</tr>
<tr>
<td>$^{287, 288}_{115}$</td>
<td>TASCA</td>
<td>GSI – Mainz</td>
<td>P.R. Lett. 111, 112502 (2013)</td>
</tr>
<tr>
<td>$^{294}_{117}$</td>
<td>TASCA</td>
<td>GSI-Mainz</td>
<td>P.R. Lett. 112, 172501 (2014)</td>
</tr>
</tbody>
</table>
Changing the projectile into $^{50}$Ti, $^{54}$Cr, $^{64}$Ni

$GSI, TASCA: ^{50}$Ti + $^{249}$Bk $\rightarrow$ 119 limit < 70 fb

V. Zagrebayev calc. $^{50}$Ti + $^{243}$Am $\rightarrow$ $^{293}$117

DC 280 high intensity HI cyclotron (FLNR, JINR)

SHE Factory of FLNR (JINR)

Status: May 25, 2018

Status: 10/05/2017

Status 11/09/2015

Status 11/09/2015
It will be very interesting and important similar calculation of Prof. Feng-Shou Zhang BNU Group!!!
SHE-Factory

U-400 Cyclotron

existing building 131

DGFRS

Low Energy RI-beams from U-400M Cyclotron

DC-280 - new accelerator

1000m²
Increase a beam dose

- It requires to increase:
  - Beam intensity
  - Beam time

<table>
<thead>
<tr>
<th>New accelerator</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHE-Factory</td>
</tr>
<tr>
<td>~ 7000 h/year</td>
</tr>
</tbody>
</table>

Production today: $4.5 \cdot 10^{19}$

With factory: $1.3 \cdot 10^{21}$

Factor: 30

A limit of the beam intensity is defined entirely by target resistance and available amount of target material.
Electricity power supply devices
room for new physical setups
Operating together with DC-280
On-line separators for the Dubna Superheavy Element Factory

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ABSTRACT

The main goal of creation of a Superheavy Element Factory at the Flerov Laboratory of Nuclear Reactions (FLNR) is to sufficiently improve the efficiency of studies on heavy and superheavy nuclei. The factory will be based on a high-current DC-280 cyclotron. The use of beams with the intensity up to $6 \times 10^{13} \text{s}^{-1}$ (10 pA) requires effective separators providing high suppression of unwanted reaction products. Following the analysis of the kinematic characteristics of several hundreds of reactions, a conclusion was drawn that it is necessary to construct three separators optimized for specific tasks: a universal gas-filled separator for synthesis and study of the properties of heavy isotopes, a velocity filter for spectroscopic investigations, and a pre-separator for further chemical separation and precise mass measurements.
More flexible design of active correlation method.
Idea: to use probabilities except for fixed time intervals.
Condition to stop irradiation: $P_{ij} < \varepsilon$
SUMMARY:

Yu.Tsyganov // IWND2018

1) After discovery Z=114-118 (Fl,Mc,Lv,Ts,Og) elements to go to Z=119,120 synthesis new DC-280 ultra intense cyclotron of FLNR will put into operation together with new gas filled recoil separator in the beginning of 2019.

2) Prototype of new GFS (DC-280 project) is designed and tested at U-400 main FLNR cyclotron $^{50}$Ti beam.

3) New version of active correlation method more flexible algorithm design is in progress now.
Thank you for your attention!