Synthesis of Superheavy Nuclei

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Introduction

We use the term SuperHeavy Elements (SHE) to refer to the elements in the transactinide region, which can exist only due to the stabilizing effects of closed nuclear shells. Predictions of properties of SHE are model dependent [1]. Following the well-known proton and neutron shells with Z=82 and N=126 (^{208}Pb), the next shell closure according to the predictions, based on macro-microscopic models is expected at Z=114 and N=184. After calculations, performed using the Hartree–Fock–Bogoliubov (HFB)-model or self-consistent relativistic mean-field models, the closed spherical proton shells are predicted at Z=120 or 126. Over the past decades, numerous transuranium isotopes have been synthesized.

The first transfermium elements - Md – Sg have been produced in the so called "hot" fusion reactions of U, Pu with ions from B to Ne and later heavier targets and projectiles. The elements - Bh – Nh (Z=107 – 113), were synthesized using ^{40}Ar – ^{70}Zn as projectiles and double magic nuclei ^{208}Pb and ^{209}Bi as targets ("cold" fusion reactions).

The progress in development of accelerator technic, especially that, of ion sources, new data on reaction mechanisms and properties of transactinide nuclei allowed one to return by the end of 90-th to the use of double magic nucleus ^{48}Ca for the synthesis of superheavy elements.

In this report, the results of experiments on the synthesis of superheavy nuclei in ^{48}Ca-induced complete fusion reactions, carried out at the Flerov Laboratory of Nuclear Reactions in the framework of a large international collaboration are presented.

Experimental approach

The targets consisted of enriched isotopes of ^{233,238}U, ^{237}Np, ^{239,240,242,244}Pu, ^{243}Am, ^{245,248}Cm, ^{249}Bk ^{249}Cf and a mixture of $^{249-251}$Cf isotopes. The long-term average intensity of ^{48}Ca ions achieved at the FLNR cyclotron U400 was of about 0.6 pμA and the calcium consumption less then 1 mg/hour.

The evaporation residues (ER) were separated in-flight from beam particles and other reaction products by the Dubna Gas-filled Recoil Separator (DGFRS) [2]. It was shown that of about 35% of EVRs, produced with the ^{48}Ca projectiles could reach the focal plane detector. The background from a primary beam was eliminated by a factor of $> 10^{17}$ and target-like products of incomplete fusion reactions were suppressed by a factor of $> 10^5$.

The data on energy, deposited in the focal plane detectors, time and position of appearing signals and auxiliary data were stored in a reference list mode. The analysis of events has been performed to find generic decay links of the implants.

Experimental results

In reactions of ^{48}Ca projectiles and actinide targets studied in 2000 – 2017, decays of the heaviest isotopes of Rf – Cn (Z=104 – 112) and more than 20 isotopes of the new elements Nh – Og (Z=113 – 118) were observed. Figure 1 shows the transactinide isotopes at the "north-east" corner of the chart of the nuclides. The data for the figure were taken from [3–6].

After the Dubna data were reproduced independently, the International Union of Pure and Applied Chemistry (IUPAC) recognized the discovery and approved the names of SHE with Z=113–118. The new elements were

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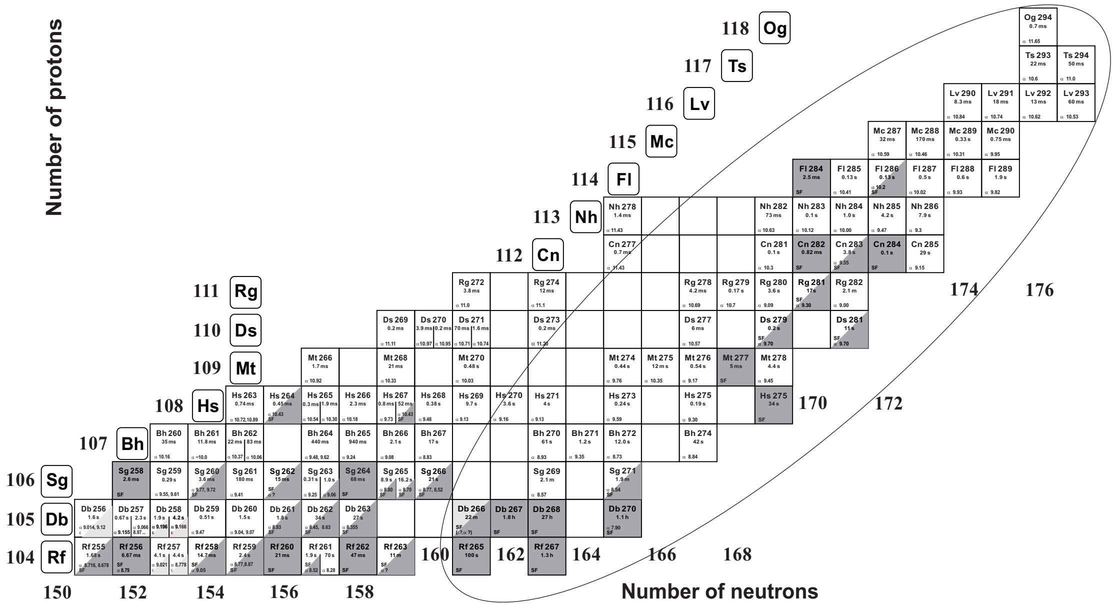

FIG. 1: Transactinide isotopes at the "north-east" corner of the chart of the nuclides. Nuclide produced in ^{48}Ca+Act reactions are shown inside the ellipse.

named: nihonium (Z=113, Nh), flerovium (Z=114, Fl), moscovium (Z=115, Mc), livermorium (Z=116, Lv), tennessine (Z=117, Ts) and oganesson (Z=118, Og) [7, 8].

Outlook

The investigation of chemical properties of the latest discovered elements is of separate interest. Some of them have half-lives ranging from several seconds to $\approx$ 1 d, times - reachable by radiochemical methods [9].

The heaviest isotope from which a target for SHE synthesis can be manufactured is ^{251}Cf, thus, to get access to elements with higher Z, one needs to use beams of ^{50}Ti, ^{54}Cr, ^{58}Fe, etc. Symmetric fusion reactions, like ^{136}Xe +^{138}Ba, and ^{150}Nd +^{150}Nd, and transfer reactions, like ^{136}Xe +^{208}Pb and U+U, are of interest but have been insufficiently explored.

The new experimental FLNR complex will be based on a high-current DC-280 cyclotron capable of producing beams of accelerated ions with A$\leq$238, E$\leq$10 MeV/A, and with the intensity I$\leq$10 pμA of ions with A$\leq$100 [10].

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