SYNTHESIS OF THE HEAVIEST NUCLEI AT FLNR: MAIN RESULTS AND PROSPECTS

Yu. OGANESSIAN

Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research
141980 Dubna, Moscow region, Russia

The observation of atomic numbers Z that are 40% larger than that of Bi, the heaviest stable element, is an impressive extension of nuclear survival. Although the super heavy nuclei (SHN) are at the limits of Coulomb stability, shell stabilization lowers the ground-state energy, creates a fission barrier, and thereby enables the SHE to exist. The fundamentals of the modern theory concerning the mass limits of nuclear matter have been experimentally verified. We are going to upgrade an active cyclotron U-400 for the purpose of creation a SHE-factory for the further synthesis of superheavy nuclei and investigating of their properties.

1. Introduction

A fundamental outcome of modern nuclear microscopic theory is the prediction of the “islands of stability” in the region of hypothetical superheavy elements. One important consequence of these calculations [1-8] was the disclosure of a significant gap in the spectrum of low lying levels in the region of the deformed nuclei around N = 162, Z=108 (deformed shells) and of the hypothetical superheavy nuclei, viz. of a new (following N = 126) closed spherical neutron shell N = 184 and proton shell Z=114 in macro-microscopic (MMM)-model and Z=120, 122, 126 in purely microscopic models, such as the Hartree-Fock-Bogoliubov (HFB)-model and the Relativistic-Mean-Field (RMF) [9-12]. The general conclusion of theory that in the large interval of masses from 250-320 an “*islands of stability*” may arise as shown on Fig.1

The remarkable success in the past few years achieved in the synthesis of heavy nuclei in cold fusion reactions are related basically to isotopes in the vicinity of the N = 162 shell, mainly at N < 162. The decay properties (α-decay energies and half lives, as well as spontaneous fission half-lives) of practically all synthesized nuclei up to the heaviest one (^{277}112) are well explained by model calculations reflecting the effect of the deformed shells Z = 108 and N = 162.

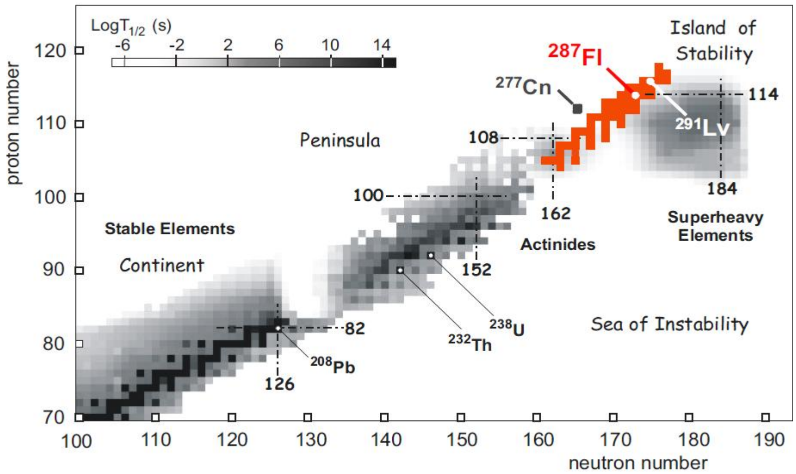

Figure 1. Half-lives (upper scale) for various proton and neutron number of the heaviest nuclei according to the prediction of the micro-macroscopic theory. The appearance of an Island of Stability in the region of the hypothetical very heavy (superheavy) elements caused by the effect of the new spherical shells Z=114 and N=184. Red squares – nuclei synthesized in ^{48}Ca-induced reactions. Symbols correspond to the names given to elements 112, 114 and 116.

But in order to probe the effect of the next, spherical shells, which influence a much wider charge and mass region of heavier nuclei, it is necessary to synthesize nuclei with $Z \geq 112$ and $N \geq 172$. This is hard to achieve in cold fusion reactions. A number of superheavy nuclides with significant neutron excess has been synthesized in the fusion reactions with ^{48}Ca and heavy isotopes of the actinide elements (see below).

It is expected that in the new regions, due to the considerable increase of nuclear stability relative to spontaneous fission the nuclei will undergo α-decay. The consecutive α-decays will follow until the shell effect weakens and spontaneous fission becomes the main decay mode. In the region of $N < 162$ this is observed for even-even isotopes. In the case of odd nuclei, due to the large hindrances to spontaneous fission α-decay may occur down to long-living nuclei without competition from spontaneous fission. In fact, this is observed also in the experiments [13]. For the heavier neutron-rich nuclei, the decay sequences of both even and odd isotopes will end by spontaneous fission. The total decay time will be then determined to a great extent by the neutron number of the parent nucleus. When approaching the N = 184 shell, we may expect a strong increase in the decay time

2. Reactions of synthesis of superheavy nuclei

Since 1974 the cold fusion reactions ^{208}Pb, ^{209}Bi + massive projectile ($A_P \geq$ 50) have been used in the synthesis of the heaviest elements with Z = 107-113. In reactions of this type, with practically the same target mass (^{208}Pb or ^{209}Bi), the increase of the atomic and mass numbers of the evaporation products are entirely connected with the increase of the mass (charge) of the projectile. When the projectile becomes more and more heavy, the excitation energy of the compound nuclei decreases down to $E_x \approx$ 15-10 MeV (cold fusion).

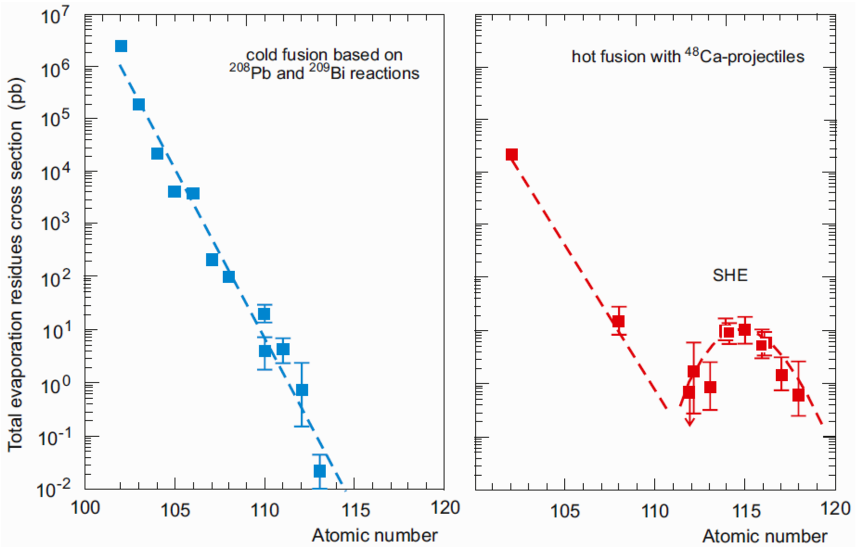

Figure 2. Nuclear reactions used for the synthesis of the heaviest nuclei.

a) Maximum cross sections of the 1*n*-evaporation channel in the cold fusion reactions of ^{208}Pb and ^{209}Bi target nuclei with different projectiles as a function of the compound nucleus atomic number.

b) Same at the maximum of the sum 3n+4*n*-evaporation channels in hot fusion reactions induced by ^{48}Ca projectiles leading to the formation of isotopes of elements 102, 108 and 112-118 as a function of the compound nucleus atomic number. The dashed line is drawn to guide the eye.

The transition to the ground state takes place by the emission of only one neutron and γ-rays [14]. As a result, the survivability of the compound nucleus significantly increases, this being the main advantage of the cold fusion reactions. However, as can be seen from Fig.2a, the production cross section of the evaporation products strongly decreases with the growth of Z_{CN}. If Z_{CN} changes from 102 to 113 the cross section decreases almost by a factor of 10^7 [15]. The further advance into the region of Z > 113 seems to be problematic. Another peculiarity of this type of reactions is that fusion of the stable nuclei ^{208}Pb or ^{209}Bi with stable isotopes from ^{54}Cr to ^{70}Zn as projectiles lead to the production of evaporation residues with 10-15 mass units shifted from the β-stability line. This, in turn, leads to a considerable decrease in their half-lives. To decrease the factors hindering fusion, it is desirable to make use of more asymmetric reactions, and to obtain an increase in the neutron number of the evaporation residues by using both target and projectile nuclei with maximum neutron excess. As target material, it is reasonable to use neutron-rich isotopes of the actinides (Act.), such as ^{244}Pu, ^{248}Cm and ^{249}Cf, produced in high-flux reactors and thus having largest neutron excess. Among the projectiles, the doubly magic nucleus ^{48}Ca has the undoubted advantage. The compound nucleus ^{292}114, produced, for example, in the fusion of ^{244}Pu and ^{48}Ca, acquires 8 additional neutrons compared to the mentioned case of the ^{208}Pb + ^{76}Ge reaction. These 8 neutrons, as will be shown below, play a key role in the production and study of the decay properties of superheavy nuclei.

Compared to the cold fusion ^{208}Pb + ^{76}Ge ($Z_P \cdot Z_T = 2624$), the Coulomb repulsion in the reaction ^{244}Pu + ^{48}Ca ($Z_P \cdot Z_T = 1880$) decreases by almost 40%, which, in turn should lead to the decrease of the factors hindering the formation of the compound nucleus. However compound nucleus formed in asymmetric reactions Act. + ^{48}Ca even at the Coulomb barrier will have an excitation energy 30-35 MeV. High value of excitation energy significantly decreased a survival probability for compound nuclei which have been produced in the reaction with Act.-target. The experimental cross sections of nuclei with $Z = 102$-110, produced in the 4n-evaporation channel of the fusion reactions Act. + ^{22}Ne, ^{26}Mg and ^{36}S (5n), [16-22] are indeed shown very low value of the survival probability for the evaporation reaction products due to compound nuclei deexcitation.

However, if the predictions of the theoretical models (see above) about the existence of the next closed shell $N = 184$ is justified, the fission barrier height will again increase when advancing to the region where $N_{CN} \geq 174$ and $Z_{CN} \geq 112$. In turn, the nuclear survivability will increase too and as a result, one can expect even a rise in the cross section σ_{EVR} for heavy nuclei with large neutron excess (Fig.2b). Moreover such a correlation between the calculated $B_f(Z,N)$ values and the experimental cross sections $\sigma_{xn}(Z,N)$ gives direct evidence of the existence and the strong effect of a neutron shell located at $N \geq 180$. In fact, this is observed also in the experiments [23].

3. Setting the Experiments

The Gas-Filled Recoil Separator (DGFRS) used in the experiments with ^{48}Ca-projectiles is schematically presented in Fig.3. The typical beam intensity of ^{48}Ca ions at the target was 1.0-1.2 pμA. In the experiments, targets of actinide oxides of the highly enriched neutron-rich isotopes of U-Cf were used. [24-32].

The calculated transmission efficiency of the separator for Z = 112-118 nuclei is about 35-40% [29], whereas full-energy ^{48}Ca projectiles, projectile-like ions, and target-like nuclei are suppressed by factors ~10^{17}, $6\cdot10^{14}$, and 10^4-10^6, respectively.

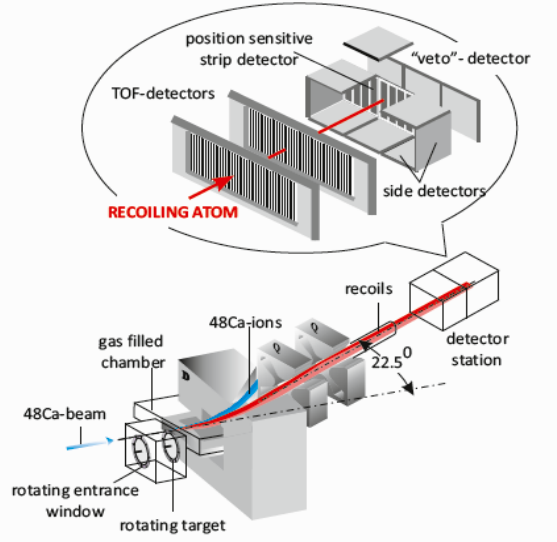

Figure 3. Layout of the Dubna Gas-filled Recoil Separator (DGFRS)

EVRs passing through the separator were implanted in a 4x12-cm^2 semiconductor detector with 12 vertical position-sensitive strips. To detect escaping α's, the front detector was surrounded by eight 4x4-cm^2 side detectors, forming a box open to the front (beam) side (see Fig. 3). In this geometry, the position-averaged detection efficiency for full energy α-particles of implanted nuclei increases to 87% of 4π.

An additional details of the focal detector array description, etc. can be found in [33 and in Ref.].

From model calculations and the available experimental data, one can estimate the expected α-particle energies of the evaporation products and their descendant nuclei that could be produced in a specific reaction of synthesis. For α-particles, emitted by the parent or daughter nuclei, it is possible to choose wide enough energy and time gates and employ a special low-background detection scheme [34-36]. During the irradiation of the target, the beam was switched off after a recoil signal was detected with parameters of implantation energy and *TOF* expected for evaporation residues, followed by an α-like signal with an energy in the interval $\delta E_{\alpha 1}$ in the same strip within a 1.4-1.9-mm wide position window and a time interval $\delta t_{\alpha 1}$. If the first α-particle was not detected (the probability being about 13%), then the switching off the beam was done when a second α-particle in the corresponding $\delta E_{\alpha 2}$ and $\delta t_{\alpha 2}$ intervals was detected.

The setup allows investigation of nuclei in a range of half-lives from 10^{-5} s to more than 10^{5} s.

From the characteristics of the DGFRS, which are given above, it follows that with a ^{48}Ca-beam intensity of 1.2 pμA, 0.35 mg/cm^2 target thickness and a beam dose $5\cdot10^{18}$ (realized for 200 hours of operation) the observation of one decay event corresponds to the production cross section of about 0.7 pb.

4. Experimental Results

For synthesis of superheavy nuclei at DGFRS, the fusion reactions of ^{48}Ca with target nuclei, the isotopes of Ra, U, Np, Pu, Am, Cm, Bk and Cf (11 isotopes of 8 elements), were used. All 95 decay chains of the nuclei with atomic number 112-118 synthesized in these experiments represents individual peculiarities of the decay modes of the superheavy nuclei (Fig.4).

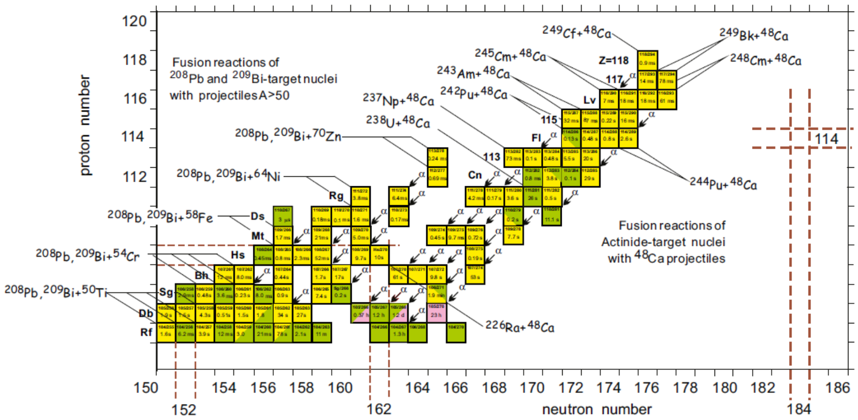

Figure 4. Chart of the heaviest nuclei with $Z \geq 104$ and $N \geq 151$ produced in cold fusion and ^{48}Ca induced reactions. The decay modes of the nuclei shown by different colors: yellow – alpha decay, green – spontaneous fission, rosy – electron capture. Reactions of the synthesis are shown also.

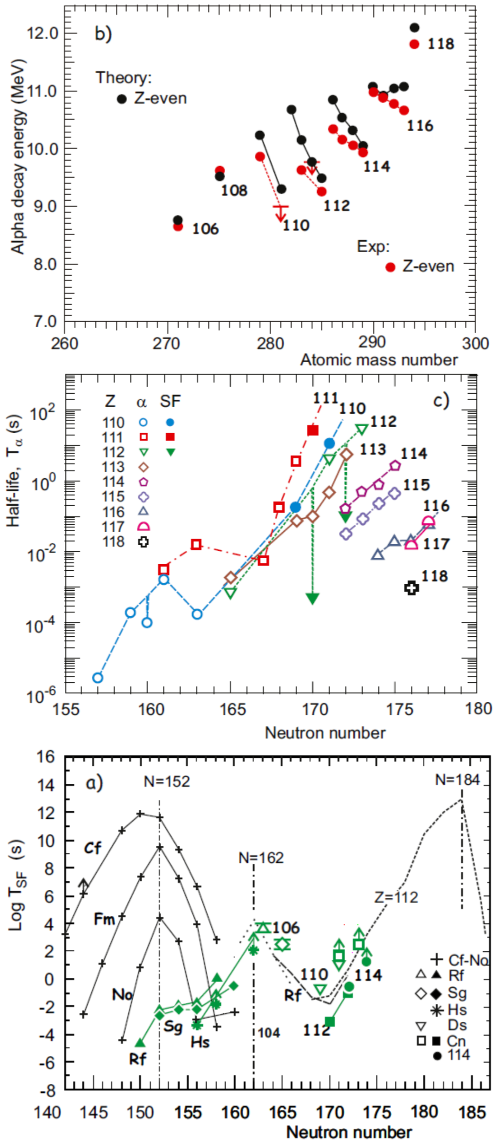

Figure 5. Decay properties of the heaviest nuclei:

a) Partial half-lives of spontaneous fission of even-Z nuclei. Black crosses connected with solid lines mark the known domain of actinides. Experimental values for the nuclei with Z=104-108 and N≤162 were obtained in the reactions of cold fusion and hot fusion with light projectiles (A_i≤26). All the data for the nuclei with Z≥108 and N≥162 originate from the reactions Act.+^{48}Ca. a) Alpha-decay energies (theory and experiment). c) Half-lives of the heaviest nuclei.

The decay properties of the 48 new nuclides, produced in experiments with ^{48}Ca projectiles, all of them being evaporation products and their daughter nuclei in the region of Z = 104÷118 and A = 266÷294 [23, 34, 37-39] are given in Fig5.

The atomic numbers for the odd nuclides (taking into account their long lifetimes) and for all nuclei in the decay chain can be, in principle, determined by means of the chemical isolation of the most long-lived nuclide. Such an experiment was performed including the identification of the odd-odd SF-nuclide ^{268}Db ($T_{1/2} \approx$ 30h), which terminated the 5-step chain of sequential decay of the mother nucleus ^{288}115, synthesized in the ^{243}Am + ^{48}Ca reaction and ^{283}Cn ($T_{1/2} \approx$ 3.6s) produced in the ^{238}U and ^{242}Pu + ^{48}Ca reaction [40].

A/Z	Setup	Laboratory	Publications
^{283}112	SHIP	GSI Darmstadt	Eur. Phys. J. A32, 251 (2007)
^{283}112	COLD	PSI-FLNR (JINR)	NATURE 447, 72 (2007)
$^{286, 287}$114	BGS	LNRL (Berkeley)	PRL 103, 132502 (2009)
$^{288, 289}$114	TASKA	GSI - Mainz	PRL 104, 252701 (2010)
$^{292, 293}$116	SHIP	GSI Darmstadt	Eur. Phys. J. A48, 62 (2012)

Independently, the charge and mass of the nuclides were determined by cross bombardment and by the measurement of excitation functions of the evaporation reaction channels. With this purpose, for all the studied reactions, the production cross sections of a given evaporation product were measured as a function of the energy of the bombarding ion (the excitation energies of the compound nucleus), varying the target isotope (or the mass of the compound nucleus).

Further verification of the identification of the mass number of the isotopes follows from the decay properties. Because of the high suppression of spontaneous fission of nuclei with odd neutron numbers, their decay chains are longer and the total decay time is noticeably higher than in the neighboring even-N isotopes. This tendency is well seen for all known isotopes with $Z \leq$ 112, it takes place also for the synthesized new nuclides with Z = 112-116 (Fig5).

All the above-mentioned data give a consistent picture of the charges and masses of the nuclei, obtained in the experiments of ^{48}Ca-induced reactions. The production cross section, the identification, as well as the decay properties of the Z = 112, 114 and 116 were recently confirmed in several independent experiments [Table I].

5. Decay Properties of Superheavy Nuclei

5.1. *Alpha – decay*

The odd isotopes of element 112 and all isotopes (even and odd) with $Z \geq 113$ predominantly undergo α-decay. The spectra of the α-particles Z-even and particularly even-even nuclei are characterized by well defined decay energy. The data for all isotopes with even proton numbers from Z = 106 to 118, produced in ^{48}Ca-induced reactions, are presented in Fig.5a. It can be seen that for all even-Z nuclei with Z = 106-118 and A = 271-294, and for nuclei with even as well as with odd number of neutrons, the quantity $\Delta Q_\alpha = Q_\alpha(exp) - Q_\alpha(th)$ does not exceed 0.5 MeV. In the decays of odd-Z nuclei the energy spectra of α-transitions much larger than energy resolution of the detector. For odd-Z nuclei: $\Delta Q_\alpha \leq 1.0$ MeV. The values ΔQ_α are given for the calculation performed in the macro-microscopic model of ref. [41,42]. In both cases, we can assume that there is quite good agreement of theory with experiment, moreover if we keep in mind that the calculation has been performed before obtaining the experimental data.

The comparison of $Q_\alpha(exp)$ with the values $Q_\alpha(th)$, calculated within the Skyrme-Hartree-Fock-Bogoliubov (HFB) and the Relativistic Mean Field models (RMF), was carried out, too (see [38]). In the HFB model a better agreement is obtained with masses from [43] calculated with 18 parameters. Finally, in the RMF model the agreement between theory and experiment is the least satisfactory. But it cannot be excluded that a better agreement can be achieved in this model also, if a different set of parameters is used. As a whole, the measured values of $Q_\alpha(exp)$ are in agreement with theory within 0.6 MeV.

5.2. *Spontaneous Fission*

For 11 out of the 47 synthesized nuclei spontaneous fission is the predominant mode of decay. In two more nuclei, ^{271}Sg and ^{286}114, spontaneous fission competes with α-decay. For the remaining nuclides spontaneous fission was not observed. The partial *SF* half-lives of nuclei with $N \geq 163$, produced in fusion reactions with ^{48}Ca, together with the half-lives of *SF*-nuclides with $N \leq 160$, are shown in Fig.5b. Four isotopes of element 112 with N = 170-173 are located in a region, where a steep rise of $T_{SF}(N)$ is expected. Indeed, in the even-even isotopes ^{282}112 and ^{284}112 the difference of two neutrons increases the partial half-life T_{SF} by two orders of magnitude. The neighboring odd isotopes $^{283}112$ and $^{285}112$ undergo α-decay. For them, only lower limits of T_{SF} can be determined (shown in the figure). From the measured *SF*-half-lives for the even-even isotopes $^{282}112$ and $^{284}112$ it follows that the odd neutron in the $^{283}112$ nucleus imposes a hindrance to spontaneous fission of the order of $\geq 3{\cdot}10^3$. Such a picture is observed also for the even-even isotopes of element 114: the additional two neutrons in the nucleus $^{286}114$ ($T_{SF} \approx 0.13$ s) lead to significant increase of the stability of the nucleus $^{288}114$ relative to spontaneous fission. In fact, α-decay was registered in 17 out of 18 decay events of the nucleus $^{288}114$ ($T_\alpha \approx 0.8$ s), which was produced in the ^{244}Pu(^{48}Ca,4*n*) $^{288}114$ and ^{248}Cm(^{48}Ca,4*n*)$^{292}116$-α → $^{288}114$ reactions.

It is significant that the rise of stability relative to spontaneous fission is observed for the heavy nuclei with $Z \geq 110$ (Fig.5b) which are 10-12 neutrons further from the closed neutron shell $N = 184$. On moving to the nuclei with $Z < 110$ and $N < 170$ (in the experiments, spontaneous fission was observed for the 7 odd nuclides ^{279,281}Ds, ^{271}Sg, ^{267}Db, ^{266,268}Db [*SF/EC*] and ^{267}Rf), the probability for spontaneous fission decreases again when the closed deformed shell $N = 162$ is approached. The stabilizing effect of the $N = 162$ shell manifests itself in the properties of the even-even isotopes of Rf, Sg and Hs with $N \leq 160$, which, as seen from Fig.8, are also well described by the mentioned model calculations. The odd *SF*-isotopes with $Z = 104$-110, produced in the ^{48}Ca-induced reactions, are located in the transition region, where the larger the neutron number, the smaller the effect of the $N = 162$ shell. In this region, the $N = 184$ shell comes into effect. Such a behavior of T_{SF}(exp) as a function of *Z* and *N* correlates with the SHE fission barrier heights and has been predicted by all models, MM [41,44] , HFB [45] and RMF [46,47].

For the odd-Z nuclei produced in the reactions ^{237}Np+^{48}Ca and ^{243}Am+^{48}Ca a different decay pattern is observed. Because of the high hindrance of spontaneous fission for the nuclei with odd number of protons (and neutrons) and relatively low T_α the isotopes of elements 113 and 115 with N=169-173 undergo α decay. In the products of the sequential α decay of these nuclides the T_{SF} values increase upon approaching to the shell N=162. In the nuclei with $Z \geq 107$, $T_\alpha < T_{\mathrm{SF}}$; they are α emitters. Spontaneous fission is observed only in the isotopes of element 105 whose α-decay half-life reaches $T_\alpha \geq 10^5$ s for ^{268}Db.

In the reaction ^{249}Bk+^{48}Ca the daughter nuclei that originate from the evaporation residues $^{293}117$ and $^{294}117$ have one or two extra neutrons. Therefore, approaching to the shell N=184 should result in decrease in their decay energy Q_α and increase in T_α with respect to the neighboring lighter isotopes. This regularity is clearly observed experimentally for all the isotopes with $Z \geq 111$. In analogy with the neighboring even-*Z* isotopes all the nuclei in the decay chains of $^{293}117$ and $^{294}117$ with $Z > 111$ and $N \geq 172$ will undergo α decay. For these isotopes $T_\alpha < T_{SF}$. The nucleus ^{281}Rg (N=170) belonging to the "critical" region might avoid spontaneous fission due to the hindrance resulting from an odd proton. The hindrance of the spontaneous fission in ^{281}Rg with respect to its even-even neighbor ^{282}Cn is ~3×10^4. Despite this, the isotope ^{281}Rg undergoes spontaneous fission with a probability $b_{SF} \geq 83\%$. Accordingly, even the high hindrance governed by oddness does not "save" the odd nucleus from spontaneous fission which is caused by the weakening of the stabilizing effect of the neutron shells at N=162 and N=184.

Along with this, an extra neutron and the double effect of oddness in the neighboring isotope ^{282}Rg favor the α decay of this nucleus. Now it is also clear that going further into the region with N<170, due to lowering of T_α with increase of neutron deficit and increase of T_{SF} upon approaching to the shell N=162, the lighter isotopes of element Rg will mainly undergo α decay.

6. Half-lives of the heaviest nuclei

In Fig.5c the half-lives of the isotopes of elements 110-118 are shown.

It can be seen that the stability of the heavy nuclides in the region $N \geq 165$ rises considerably with the increase of N; the increase of the neutron number in the isotopes of elements 110-113 by $\Delta N = 8$ leads to half-lives greater by about 4-5 orders of magnitude. The rise in nuclear stability is observed also for the nuclides with $Z = 114$ and 116, in an interval $\Delta N = 4$. In the macroscopic models, such as the classical liquid drop model (or its modifications), trans-actinide nuclei in the absence of a fission barrier will undergo fission within some 10^{-19} s. The experimental half-lives, as it follows from Fig. 6, are about 17-19 orders of magnitude longer than expected from this model. Apparently, such a sharp distinction offers evidence of the strong influence of the shell structure of superheavy nuclei on their decay properties. While the relatively high stability in the region of the neutron-deficient deformed nuclei Z = 110-112 and N = 160-165 can be explained as due to the N = 162 shell, the further rise in the region of $N \geq 165$ definitely comes from the effect of another shell, situated at $N > 177$. According to the predictions of all microscopic models, this spherical shell is at N = 184 and comes after the lead shell at N = 126. We should note the strong effect of the N = 184 shell; it manifests itself even in nuclei that are at a distance of 12-14 neutrons (see Fig. 6).

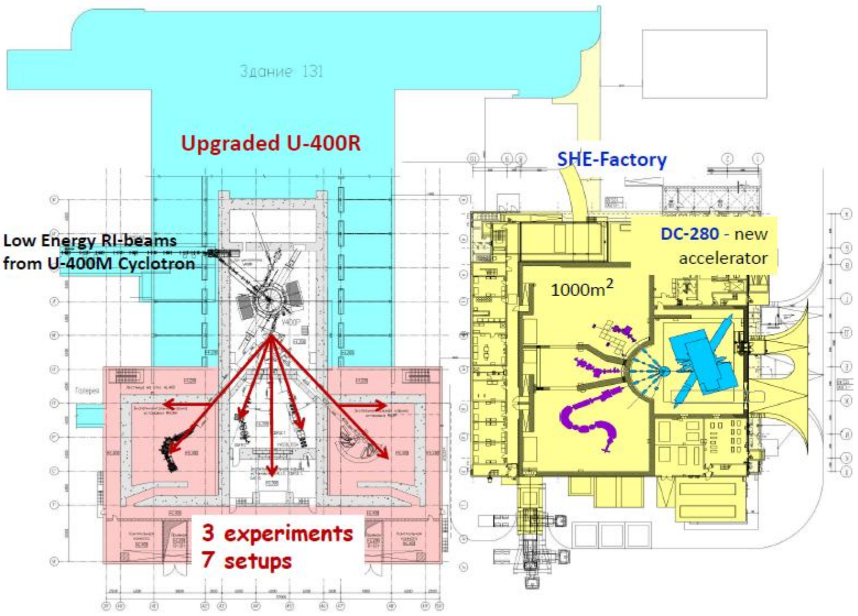

Figure 6. Left-side: the cyclotron U-400 building. This cyclotron will be modernized for the purpose of providing larger energy range (0.8÷25.0 AMeV), alignment, beam intensity, energy resolution. The experimental hall reconstruction area are marked by rose color. Right-side: it is a "SHE-Factory" building with a new cyclotron inside which will be created for production high intensity (up to Y~ 10-20 pμA) and low energy (up to I~ 10-20 pμA) heavy ion beam.

7. Conclusion

With Z >40% larger than that of Bi, the heaviest stable element, that is an impressive extension in nuclear survival. Although the SHN are at the limits of Coulomb stability, shell stabilization lowers: the ground-state energy, creates a fission barrier, and thereby enables the SHN to exist.

Decay properties of the nuclei obtained in Act. +^{48}Ca reactions show that the basic concept on the existence of closed shells in the region of the hypothetical very heavy (superheavy) elements and their decisive role in the stability of heaviest nuclei have conformed.

The fundamentals of the modern nuclear theory concerning the mass limits of nuclear matter have been experimentally verified.

8. Consequences and prospects

Relative to the 30-year old history of investigations on heavy nuclei in cold fusion reactions that have led to the discovery of 6 new elements, the results obtained in Act. + ^{48}Ca reactions are the next step in the synthesis and studies of the properties of new, heavier elements. The neutron-rich and rather long-lived nuclides, produced with cross sections of few picobarns in Act. + ^{48}Ca reactions, are unique objects whose nuclear structure, decay modes, spontaneous fission, atomic and chemical properties have to be studied.

All fields of investigations can advance, if a way to increase the production rate of nuclei is found. This task is connected with the improvement of the experimental techniques and the search for new possibilities to produce and study the sought-for nuclei. Having limited ourselves to these examples that are far from representing the interest to studying SHE in full, we have to note that unfortunately the object under study itself is produced in extremely tiny amounts. Attempts of going beyond the reactions Act.+^{48}Ca by using heavier projectiles like ^{50}Ti, ^{54}Cr, ^{58}Fe and ^{64}Ni gave no results so far. They indicate considerable drop of the production cross section of evaporation residues with Z=119 and 120. Advance to the shell N=184 (synthesizing of nuclei with N>177) is so far beyond accessibility because of low available intensity of beams of radioactive nuclei that have neutron excess above that of the stable ^{48}Ca (N/Z=1.4).

In our opinion, along with advance to nuclei with Z>118, it would be reasonable to study in detail the properties of the already synthesized nuclei that are known to be produced in the reactions Act.+^{48}Ca with cross sections of 1 to 10 pb. It is possible that the new more detailed data on the properties of these nuclei based on larger statistics could be not less informative than single events of decay of heavier unknown nuclides. However, both these areas of investigation require significantly higher sensibility of experiment.

We estimate that current progress in accelerator technology, more efficient accumulation of heavy actinide isotopes (Z=94-98) in high-flux nuclear reactors, their high enrichment in separators together with the new techniques of isolating and registering of rare decays of the heaviest nuclei could boost production rate of SHE by almost two orders of magnitude compared to the present-day experimental opportunities.

The increase of the production rate of super-heavy nuclei will allow for their spectroscopic studies. The results of these can be directly compared to the predictions of nuclear structure proposed by various theoretical models. As it seems to us, this is the closest perspective.

In more distant future, winder area of investigation of super-heavy elements most likely will be connected with:

- -Spectroscopy of super-heavy nuclei with high statistics,
- -Electronic structure of super-heavy atoms,
- -Chemical properties of new elements,
- -Spontaneous fission and fission modes in wide region of Z and N of super-heavy nuclei,
- -Theoretical studies of fundamental processes of the formation of atomic nuclei, their properties, and decay modes under conditions of strong Coulomb fields and high nuclear density, as well as many other areas, which may appear suddenly and cannot be predicted today,

We hope that these ideas will be implemented in the new facility that is under development in Flerov Laboratory of Nuclear Reactions (JINR) – the SHE-Factory (Fig.6) as a part of investigation program and wide international cooperation in this field of physics.

The experiments were carried out at the Flerov Laboratory of Nuclear Reactions (JINR, Dubna) in collaboration with the Lawrence Livermore National Laboratory (LLNL, Livermore), the Oak Ridge National Laboratory (ORNL, Oak-Ridge), the Cyclotron Institute of the Texas A&M University (CI, College Station), the Vanderbilt University (VU, Nashville) and the Research Institute of the Atomic Reactors (RIAR, Dimitrovgrad, Russia) ; the experiments on the chemical identification of the isotopes ^{268}Db and ^{283}112 – within the collaboration: Paul Scherrer Institute (PSI, Villigen) - Department for Chemistry and Biochemistry of the University of Bern – FLNR (Dubna) - LLNL (Livermore) - Institute of Electronic Technology (IET, Warsaw) with the participation of Dr. M. Hussonois from the Institute of Nuclear Physics (IPN, Orsay).

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