TASCA 07

6th Workshop on
Recoil Separator for Superheavy Element Chemistry
September 28, 2007, Davos, Switzerland

ABSTRACTS

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Focal Plane Detector – Status and Test Results

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During the TASCA commissioning phase in 2006 and 2007 a position sensitive16 strip PIPS detector ("SHIP like") has been set up and used in various test runs. The read-out electronics is a copy of the one used at SHIP and has been composed mainly from modules of a similar set-up at the gas-filled separator RITU of the University of Jyväskylä. The results of the test runs checking the detector/read-out electronics performance itself as well as TASCA parameters like pressure dependence and ionoptical settings will be summarized. The detector was also used to adjust the spatial distribution of reaction products for their further use in the recoil transfer chambers mounted in the focal plane of TASCA for chemical investigations. A project for a new and dedicated data acquisition electronics has been defined and presented at various occasions for possible funding without much success. As an intermediate solution a reduced version is being prepared by the group from the University of Munich which will be reported on by A. Yakushev.

TASCA 07
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Recoil Separator for Superheavy Element Chemistry
September 28, 2007, Davos, Switzerland

Investigation of group 8 metallocenes @ TASCA

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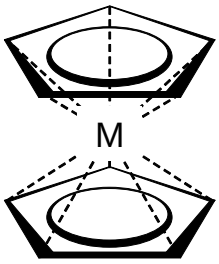
The technique of preseparation is expected to give access to compound classes of the transactinides that could not be investigated in conventional setups (such as a gas-jet fed through a recoil chamber attached directly to a target). One of the main advantages of preseparation is thought to come from the absence of the intense heavy-ion beam in the Recoil Transfer Chamber (RTC), allowing the direct introduction of relatively complex molecules such as organic ones into the RTC. Initial studies focused on β-diketonate complexes of group 4 elements. More specifically, hexafluoroacetylacetone (hfa) was fed into a RTC attached to the Berkeley Gas-filled Separator (BGS) in which relatively short-lived preseparated isotopes of the lighter homologs of Rf, i.e., Zr and Hf, were thermalized. Indeed, in these experiments, Zr and Hf were shown to form volatile molecules once the carrier gas (He) was enriched in hfa. Even though the "final" experiment with Rf is not yet performed, it is reasonable to start with initial studies on another chemical system.
All the lighter homologs of the group 8 transactinide hassium, i.e., Fe, Ru, and Os, are well known to form relatively stable metallocenes with the following general structure:



The central metal atom in its 2+ state is bonding to two cyclopentadienyl (Cp) ligands via η^5 bonds. The question arises if Hs forms compounds of a similar structure. According to the 18-electron rule, and in agreement with experimental observation, the group 8 metallocenes are fairly stable with ruthenocene the most stable of all known metallocenes. They are also fairly volatile, which gives rise to the hope that hassium would also form a relatively stable and volatile metallocene. Fully relativistic density functional calculations are planned to be carried out in our group to arrive at a detailed understanding of the stability and molecular structure of all four group 8 metallocenes including $Hs(Cp)_2$.
A proposal requesting beamtime for preparatory studies with the lighter homologs of Hs will be submitted to the G-PAC for the first meeting in 2008 (presumably in April 2008).

TASCA 07
6th Workshop on
Recoil Separator for Superheavy Element Chemistry
September 28, 2007, Davos, Switzerland

Recoil Transfer Chamber commissioning at TASCA

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In the framework of the Recoil Transfer Chamber (RTC) working group, two RTCs for TASCA - one for each ion-optical mode - have been built.

I will first describe the design of the most important components: the flanges accommodating the RTC windows (built at TU Munich), the High Transmission Mode RTC (built at U Mainz), and the Small Image Mode RTC (built at U Oslo).

Both RTCs were used in three test runs with a ^{40}Ar beam. The following isotopes were produced, preseparated, and transferred to counting setups with the RTCs:

1) α-particle emitting Hg isotopes produced with ^{144}Sm targets.
2) α-particle and γ-ray emitting Pb isotopes produced with ^{152}Gd and ^{nat}Gd targets.
3) γ-ray emitting Os isotopes produced with ^{nat}Ce targets.
4) ^{245}Fm produced with ^{208}Pb targets.

A He/KCl gas-jet was used to transport i) the reaction products of 2) and 3) to a glass fiber filter in the chemistry lab through a ~10-m long polyethylene (PE) capillary ($\varnothing_i$=2 mm), ii) the reaction products of 2) to a glass fiber filter inside the irradiation cave just before the entrance to ROMA through a 5.5-m long PE capillary ($\varnothing_i$=1.5 mm), and iii) the reaction products of 2) and 4) to the Rotating wheel Multidetector Apparatus (ROMA), a detection system suitable for registering α-particles and fission fragments again located in the irradiation cave (through the same 5.5-m long PE capillary). The dependence of the gas-jet yield on a number of parameters such as RTC depth and configuration, recoil velocity or gas flow rate was measured to gain a systematic understanding of the setups. The obtained values were normalized to the 100% value obtained in experiments with a catcher foil positioned directly behind the RTC window. Preliminary analysis of the most recent results indicates that transport yields of the order of ~70 % were achieved with both RTCs. In another experiment, short-lived Hg isotopes 1) were transported with pure He carrier gas to a gold-covered detector array suitable for detecting α-decaying Hg isotopes with high efficiency.

I will present the current status and give an overview of the results of the commissioning experiments.

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TASCA 07
6th Workshop on
Recoil Separator for Superheavy Element Chemistry
September 28, 2007, Davos, Switzerland

Coupling of isothermal vacuum chromatography (IVAC) to TASCA

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Recently first chemical studies with transactinide elements 112 and 114 revealed them unambiguously as elements with enhanced volatility compared to their lighter homologues. Surprisingly, element 112 exhibits a higher adsorption interaction with gold compared to element 114. These experiments prove that the investigation of adsorption properties of transactinide s- and p- elements (groups 12-20 in the periodic table) on metal surfaces holds promising possibilities regarding the assessment of relativistic effects in their electron structure. For these investigations the cleanness of the chromatographic surfaces and the reproducibility of experimental conditions is a basic requirement. Therefore, we propose to use the method of isothermal vacuum chromatography (IVAC) for further studies. Working at vacuum conditions allows for avoiding of unwanted surface contaminations, which were observed using carrier gases. Hence, other stationary chromatographic surface materials, e.g. Ni, W, Ta, Pd or Pt can be used. However, it is crucial to develop a coupling scheme for IVAC to a physical separator. First experiments at the BGS at LBNL Berkeley revealed several difficulties of a the Catcher and Release Apparatus for Transactinide Elements (CRATE), where the products are implanted at the focal plane position and then released at temperatures up to 1500°C into IVAC. We consider using a metal aerosol gas-jet to transport the elements into CRATE. There, in a quasi continuous sample-release mode the aerosol particles are first impacted at a sampling position held at vacuum conditions onto a tantalum foil. Subsequently, this foil is moved into a release position held at high temperatures and connected to the IVAC. For the design and modeling phase of this demanding experimental scheme we suggest using neutron deficient Hg and Pb isotopes preseparated at TASCA. First experiments performed at the PSI Phillips cyclotron without preseparation revealed promisingly stable transport results for Hg and Pb using metal aerosol gas-jets (particles of Ni, Pd, Pt, and Rh suspended in He and Ar).

TASCA 07
6th Workshop on
Recoil Separator for Superheavy Element Chemistry
September 28, 2007, Davos, Switzerland

Perspectives of the superheavy element chemistry at RIKEN GARIS

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Perspectives and future plans of the SHE chemistry at RIKEN are reviewed. A gas-jet transport system for the SHE chemistry was coupled to the gas-filled recoil ion separator GARIS at the RIKEN Linear Accelerator. Using the GARIS/gas-jet system, productions of SHE nuclides for chemical experiments such as ^{261}Rf, ^{262}Db, ^{265}Sg, ^{269}Hs, and ^{283}112 will be studied based on ^{238}U and ^{248}Cm targets. Chemistry experiments using new chemistry devices such as a gas-chromatograph column directly coupled to GARIS and a micro-chemical chip for solvent extraction are proposed.

TASCA 07
6th Workshop on
Recoil Separator for Superheavy Element Chemistry
September 28, 2007, Davos, Switzerland

Structure of Very Heavy Nuclei – First Possible Experiments at TASCA

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The gas-filled separator TASCA offers as a complementary device to the velocity filter SHIP the unique opportunity to study the structure of actinide and trans-actinide nuclei by the means of decay spectroscopy. Its high transmission as compared to SHIP for evaporation residues produced in asymmetric reactions will allow for an extension of the successfully ongoing investigation program at SHIP into the region of more neutron rich nuclei. With the highly intense beams provided by the UNILAC linear accelerator of GSI and a combination of particle and photon detectors mounted in the TASCA focal plane position similar to the set-up at SHIP or to GREAT at the gas-filled separator RITU at the cyclotron laboratory of the University of Jyväskylä, this configuration will be unique in terms of efficiency for that type of investigations. Ideas for first experiments will be presented.

TASCA 07
6th Workshop on
Recoil Separator for Superheavy Element Chemistry
September 28, 2007, Davos, Switzerland

Synthesis and Separation of Fm and No isotopes using TASCA

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The TransActinide Separator and Chemistry Apparatus (TASCA) detector and data acquisition system is designed similar to the SHIP (Separator for Heavy Ion Products) data acquisition system. Commissioning experiments at TASCA using ^{22}Ne, ^{40}Ar and ^{48}Ca beams were performed with "SHIP like" electronics. The trans-uranium elements Fm and No were produced using the TASCA separator. The transmission of TASCA was determined for the separation of Fm and No isotopes in the reactions ^{22}Ne+^{238}U and ^{40}Ar+^{208}Pb. Further, the transmission of TASCA for the evaporation residues of ^{245}Fm was measured as a function of the helium gas pressure in the separator.

TASCA 07
6th Workshop on
Recoil Separator for Superheavy Element Chemistry
September 28, 2007, Davos, Switzerland

Electrodeposition Experiments planned @ TASCA

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The electrodeposition (underpotential deposition)of carrier-free metal ions on electrode materials such as Pd was demonstrated to be able to deposit and detect, e.g. , short-lived α-emitting Pb isotopes if the electrode material is supplied as a tape that is stepped in front of successive PIN-diode detectors [1]. This method was shown to be applicable for Os, Hg, Tl, Pb, Bi, and Po and is expected to be suited for the electrodeposition of superheavy elements up to Z=116. As Po is commonly producing undesired background in the α-particle spectra, its separation in the new gas-filled separator TASCA will be of prime importance.

It is planned to run a first experiment with 22-s ^{270}Hs [2] which will be transported from the Recoil Transfer Chamber (RTC) of TASCA with a He/KCl gas-jet to the collection device ALOHA where the deposited aerosol will be dissolved by an aqueous electrolyte supplied by a syringe. The electrolyte is directly transferred into the heated electrolytic cell and the electrodeposition occurs on two metallic tapes within 10 seconds at 90 °C. The tapes are stepped every 10 seconds in front of two arrays of successive PIN diodes for α-particle spectroscopy. The He/KCl transport of the homolog Os in the absence of oxygen has been demonstrated to occur at a yield of 75%. Details of the apparatus are being presented.

[1] H. Hummrich et al., Radiochim. Acta, submitted
[2] J. Dvorak et al., Phys. Rev. Lett. 97, 242501 (2006)

TASCA 07
6th Workshop on
Recoil Separator for Superheavy Element Chemistry
September 28, 2007, Davos, Switzerland

Future Plan of the Experimental Program on Synthesizing the Heaviest Elements at RIKEN

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A recoil separator for the study of the heaviest elements is under designing at the RIKEN Nishina Center. The separator will be constructed and installed at the end of fiscal year 2008. A main subject of the new recoil separator is to study chemical properties of the heaviest elements as well as to search for new nuclide of the heaviest elements.

A gas-filled recoil separator, GARIS, has been intensively used for these years for the study of the heaviest elements produced by reactions with ^{208}Pb and ^{209}Bi targets and ^{64}Ni and ^{70}Zn beams. While the existing GARIS has a large transmission (～ 80 %) for the products of these reactions, which are rather symmetric combinations of the targets and beams, it has smaller transmission (～6 %) for the products of the reaction with more asymmetric reaction e.g. ^{22}Ne + ^{238}U → ^{255}No + 5n. The decrease of the transmission of the gas-filled type recoil separator is mainly caused by the multiple scattering of the products and gas atoms filled in the separator. The effect of the multiple scattering is more serious for product of a small momentum, produced by asymmetric reaction than that of a large momentum, produced by a rather symmetric reaction. A simulation shows that a gas-filled recoil separator with half length of the existing GARIS gains 6 times of the transmission to the existing one. We are going to make a gas-filled recoil separator shorter than the existing one for the study of the nuclide produced by the ^{238}U and ^{248}Cm based reactions.

TASCA 07
6th Workshop on
Recoil Separator for Superheavy Element Chemistry
September 28, 2007, Davos, Switzerland

Developments for SISAK experiments @ TASCA

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The successful SISAK experiments [1-4] with the short-lived Rf isotope ^{257}Rf at LBNL depended on using the Berkeley Gas-filled Separator (BGS) as a preseparator in front of the chemistry apparatus. Based upon the experience gained from these experiments, the SISAK group has been heavily involved in the development of Recoil Transfer Chambers (RTC) for TASCA. The RTC couples the separator to a gas-jet transport system and is mandatory for enabling chemistry experiments to be performed after preseparation.

So far only lead-targets were used in SISAK BGS experiments, this limits the available elements which can be studied to Rf and Db. This will change as transuranium targets for use with TASCA (and the BGS) becomes available - on-going development work on such targets opens up new possibilities for SISAK liquid-liquid extraction experiments.

This presentation will give a brief summary of plans for SISAK TASCA experiments in the upcoming years, based upon what is currently possible and what will be possible once new targets become available (e.g. ^{244}Pu targets).

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[1] J. P. Omtvedt, et al., in *The Eighth Actinide Conference (Actinides 2005)*, edited by I. May, R. Alvares and N. Bryan (The Royal Society of Chemistry, University of Manchester, UK, 2006).
[2] J. P. Omtvedt, et al., Eur Phys J D **10.1140/epjd/e2007-00214-6** (2007).
[3] J. P. Omtvedt, et al., JNRS **3**, 121 (2002).
[4] L. Stavsetra, et al., NIM A **543**, 509 (2005).

TASCA 07
6th Workshop on
Recoil Separator for Superheavy Element Chemistry
September 28, 2007, Davos, Switzerland

Status of TASCA – an overview

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The **T**rans**A**ctinide **S**eparator and **C**hemical **A**pparatus (**TASCA**) project [1,2] to built a gas-filled recoil separator for the separation and investigation of neutron-rich transactinide nuclides produced in hot-fusion reactions with actinide targets has completed the installation of all major components. A large number of commissioning experiments has been performed in a wide range of nuclear reactions making use of ^{22}Ne, ^{30}Si, ^{40}Ar, ^{48}Ca and ^{54}Cr beams from the UNILAC and targets of ^{144}Sm, ^{152,nat}Gd, ^{181}Ta, ^{197}Au, ^{206,208}Pb, and ^{238}U. The heaviest nuclides studies in the course of these commissioning experiments were ^{245}Fm produced in the ^{40}Ar on ^{208}Pb reaction and ^{252}No and ^{254}No synthesized in reactions of ^{48}Ca beam with ^{206}Pb and ^{208}Pb targets.

My contribution will very briefly summarize the status of the separator installation. An overview of the performed commissioning experiments will be given together with some examples of preliminary results. We made use of the high transmission mode (HTM) and the small image-size mode (SIM) when operating TASCA in a DQ_hQ_v and DQ_vQ_h mode, respectively. Many tests concentrated on finding the best settings for the dipole and the quadrupole magnets and aimed at obtaining the He pressure and target thickness dependence of the TASCA efficiency and separation quality. Catcher foil techniques together with off-line nuclear spectroscopy measurements were used to directly measure the TASCA efficiency and to compare these results with Monte Carlo simulations. One of the most recent highlights was a direct comparison of the TASCA performance when separating ^{254}No with helium and with hydrogen as a separator gas.

To summarize, TASCA as a highly efficient separator is about ready to make the transition form the commissioning phase into a scientific program in the region of transactinide elements.

[#] For the TASCA collaboration.

[1] M. Schädel, D. Ackermann, A. Semchenkov, A. Türler, *The TASCA Project*, GSI Report 2006-1, GSI Scientific Report 2005, p. 260.
[2] http://www.gsi.de/tasca and contributions to http://www.gsi.de/tasca06

TASCA 07
6th Workshop on
Recoil Separator for Superheavy Element Chemistry
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TASCA Control System

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As complex technical system TASCA separator need modern and useful control system, which will consists of two levels.

TASCA control system will be based on the two Compact Field Point (cFP) microcontrollers as low level control units and several PCs at the high level control part. The cFP microcontrollers at the low level of the system for the safety reasons will be used. All most important fast signals and time critical signals will be controlled by the NIM electronic modules and cFPs. A main fetcher to use the cFP is a possibility to use LabView system [1] for programming. The PCs will be used as slow control elements for low speed processes, such as start and stop pumping regimes, magnet control, beam current reading and others. High level programming will be performed under LabVIEW [1] too.

All parts of the system will be connected by an Internet (TCP/IP) and MIL-bus or serial interfaces. We have possibility to access to the accelerator NODAL control system using TCP/IP. Most safety and time critical computers and microprocessors of the system are placed in the internal accelerator network. All other computers (by TCP/IP protocol) will have possibility to connect to the data in these main computers for visualization of current status of the system using special TASCA network.

References

[1] http://www.ni.com/labview

The gas-filled recoil separator RITU at JYFL

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The JYFL gas-filled recoil separator RITU is a versatile device. Originally this apparatus was planned for studies of heaviest elements produced in fusion evaporation reactions using light-A beams on heavy-A targets. A very successful nuclear structure program has been performed in the 254No region using 48Ca beams. In addition to this RITU has been proven to be able to separate the fusion products from beam when using symmetric reactions even below the mass 80 region. And for example in the neutron deficient lead region RITU has been successfully used in plunger life-time measurements where symmetric reactions are needed and then thick degrader foils are used to slow down the recoils to see the shifts in gamma-rays. An overview of the versatility of the RITU separator will be given.

TASCA 07
6th Workshop on
Recoil Separator for Superheavy Element Chemistry
September 28, 2007, Davos, Switzerland

The TASCA FPD + DAQ – new developments

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In the first year of the commissioning phase of TASCA the Focal Plane Detector (FPD) at TASCA has been successfully tested. At the moment a SHIP like detector is installed – 16-strip position sensitive detector with dimensions 80x35 mm^2. According the TRANSPORT und Monte Carlo calculations, the image size of separated in TASCA products in the focal plane is 140x40 mm^2 for High Transmission Mode (HTM) or 30x40 mm^2 for Small Image Mode (SIM), respectively. A new detector setup, consisting of larger FPD, side detector box and veto detector is required, especially for physical experiments. The FPD working group turned to a new concept of FPD detector: a Double Sided Silicon Detector (DSSD). The main advantage of DSSD is good and stable position resolution without any position calibrations. However, a large number of spectrometric channels are necessary for DSSD with large area. In the talk different detector setups will be discussed and compared.
The first successful test of DSSD detector (60x60 mm^2) made in Zelenograd, Russia was already performed. The new TASCA detector is designed in the framework of the collaboration between TU Munich and ITE Warsaw and its production is started. A new analog electronics for Data Acquisition system similar to COMPACT electronics will be built for the intermediate stage. For the future, an integrated electronics for pulse shape analysis is under development at GSI Darmstadt.

TASCA 07
6th Workshop on
Recoil Separator for Superheavy Element Chemistry
September 28, 2007, Davos, Switzerland

New chemical compounds of seaborgium in the gas phase

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Since major separator parameters, like magnet field settings, optimum gas pressure, target thickness, RTC yield etc., have been tested and optimized during the commissioning stage, TASCA enters into a new phase where it will be used in experiments dedicated to study the physics and chemistry of SHE. Two special futures of TASCA as a pre-separator distinguish chemical experiments with TASCA from experiments where the beam passes through a recoil chamber: (i) no contact between carrier or/and reactive gas and beam, and (ii) lighter elements with similar volatility are separated in TASCA. Chemistry experiments at TASCA in the near future have to meet following requirements: (i) nuclear reaction and SHE nuclei are known, (ii) production cross section should be relatively high, (iii) produced SHE nuclei could be measured efficiently after chemical separation. The main advantage is that new chemical systems including organometallic ones can be investigated. We aim at developing a new chemical separation approach for the group 6 elements including element 106, seaborgium, based on the synthesis and separation of volatile hexacarbonyls $M^{VI}(CO)_6$. The hexacarbonyls of molybdenum and tungsten are well known to be volatile even at ambient temperature. Therefore, a very efficient detection technique such as COMPACT can be applied after chemical separation. A fundamental study of the formation process of group 6 element carbonyl complexes in the Recoil Transfer Chamber (RTC) with “hot” molybdenum and tungsten atoms as lighter homologs of Sg is the goal of preparatory experiments in the first stage.

TASCA 07
6th Workshop on
Recoil Separator for Superheavy Element Chemistry
September 28, 2007, Davos, Switzerland

Evolution of the new experimental set ups for studies of transfermium elements in the reactions with heavy ions at FLNR JINR.

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Today's nuclear physics is oriented to pushing the limits of our knowledge to the extremes of nuclear existence. The synthesis and study of new elements (with very large numbers of protons Z) is one of the most challenging prospects in nuclear structure research. However, searching for the limits of the Table of Mendeleyev and probing the extension of the nuclear chart is not only a scientific challenge, it is also an experimental one. Indeed, the last discovered elements (Z = 111, 112, 113, 114, 115, 116 and 118) have production cross-sections which are extremely small and the identification of a handful of events requires long irradiation times (many months).

In the synthesis of transfermium nuclei using the heavy ion fusion reactions two parameters play the limiting role: decay properties of nuclei to be investigated and their formation cross sections. Modern experimental set ups, the so--called recoil separators, could be used for the synthesis of heavy nuclei having half lives of more than 1 μsec and less than tens of minutes. The limit of the formation cross section which could be reached in experiments lasting 3 – 4 months is about 0.2 - 0.5 pb. In the course of planning the new experiments one should have a possibility to predict decay properties (decay mode and half life) as well as formation cross section of heavy nuclei with a maximal accuracy.

In the past, various types of reactions and identification techniques were applied in the investigation of formation cross sections and decay properties of transuranium elements. The fusion - evaporation reactions with heavy targets, recoil - separation techniques and identification of nuclei by the parent -- daughter generic coincidences with the known daughter-nuclei after implantation into position - sensitive detectors were the most successful tools for production and identification of the heaviest elements known presently. This technique may be further improved and presently it may be very promising for the identification of new elements, search for new isotopes and measurement of new decay data for the known nuclei.

At the Flerov Laboratory of Nuclear Reactions (JINR, Dubna), investigations of the complete fusion reactions leading to the synthesis of heavy and superheavy nuclei with the use of heavy ion beams from a powerful U400 cyclotron have been an important part of the experimental program. It is planned in Dubna to upgrade second cyclotron of the FLNR, U400M, to deliver beams at energies close to the Coulomb barrier.

Many possibilities for the investigations of the transfermium elements could be fulfilled taking in mind new possibilities for the beams from U400 and U400M projects and development of the high resolution, large acceptance experimental set - ups.