**13-1. Neutron detector NeuRad**

**V. Chudoba** on behalf of EXPERT working group

The experiment EXPERT (EXotic Particle Emission and Radioactivity by Tracking) arisen in a broad international cooperation is part of the scientific program to be performed within [SuperFRS@FAIR](mailto:SuperFRS@FAIR) collaboration [1,2]. It is aimed at studies of the up to now unknown exotic nuclear systems in vicinity and beyond the drip-lines. Among the main objectives of the EXPERT project belongs investigation of novel types of radioactivity (4p, 2n, 4n) and studies of p, 2p, 4p, n, 2n, 4n resonance decays.

The EXPERT experiments will use the first half of the SuperFRS as a radioactive beam separator and its second half as a high-resolution spectrometer. The exotic nuclei of interest are expected to decay in flight, and outgoing fragments (i.e., precursor-like decay products) will be tracked and then identified by the spectrometer part. For this purpose, the EXPERT working group will equip the SuperFRS focal planes with dedicated particle (charged particles and neutrons) and gamma-ray detectors. Complementarily, 2p-radioactivity will be studied by means of the Optical Time-Projection Chamber placed at the final focus of the SuperFRS. Essential feature of the EXPERT is that the listed individual detectors will provide correlated information on decay products, which promises a significant synergy effect in analysis of the obtained data. The NeuRad (Neutron Radioactivity) neutron detector is aimed at providing precise information on angular correlations of nuclear-decay neutrons with a charged decay product, which is used for measuring the decay energy of the neutron precursor and deriving the corresponding life time. High angular resolution in detection of such correlations is essential for experiments planned at SuperFRS. Details of the intended realization of the NeuRad detector for the EXPERT project and current state of the prototype tests will be reported.

**13-2. Study of beta-delayed charged particle emission from 27S and 26P**

**A.A. Bezbakh** for the OTPC collaboration

Flerov Laboratory of Nuclear Reactions, JINR, Dubna

The principle of operation of a novel class of charged particle radiation imaging detector: Optical Time projection Chamber (OTPC) [1,2] will be presented. The main application of the OTPC is investigation of exotic decay modes of the nuclei at the borders of the stability line, especially proton-drip line [2]. The spectrometer represents a TPC coupled with a CCD and a PMT as an optical readout. The novel idea of recording of optical signals from a TPC-type detector is unique worldwide.

The results of the experimental study of β-delayed particle emission from 27S and 26P performed at the ACCULINNA separator, FLNR are presented. The goal of this work was the search of new, so-far unobserved decay channels of the proton drip-line nucleus 27S. β-delayed proton and two-proton emission from 27S already was observed in [3], but the measurement technique used in [3] was not ideally suited for detection of rare processes and did not allow to measure easily the number of emitted particles in the decay. In our approach the Optical Time Projection Chamber has been used, which is ideal instrumentation for this type of studies [2].

The secondary beam has been produced in fragmentation of 32S (51.3 MeV/n) on 9Be target at the ACCULINNA separator. The method is effectively applied for the beam when a contamination of27S and 26P isotopes was <1%. The time-of-flight (TOF) and energy-loss measurement has been applied for identification of 27S ions. At the focal plane of ACCULINNA the OTPC has been used to detect charged particles emitted from the 27S ions. The results obtained for the decay of 26P were found to be consistent with the previous study [4]. In contrary, in case of 27S, we got a new results for low energy protons. We have reconstructed the spectrum of β-delayed protons, starting from Ep> 0.15 MeV. In this region the strongest emission at 320 keV and 710 keV has been found, and the new branching ratio for βp and β2p channels were determined.

References:

[1] Ćwiok M, et al., IEEE Trans. Nucl. Sci. 2005; 52: 1895.

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**13-3. Monitoring, detection and control systems for ACCULINNA-2 fragment separator**

1. **V. Gorshkov**

Fragment separator ACCULINNA-2 was newly built in FLNR JINR [http://aculina.jinr.ru/acc-2.php]. The capacity of this set-up to grant the projected high transmission and purification level of radioactive ion beams (RIBs) will be tested in 2017. This report shows a status of the project and provides an overview of the developing monitoring, detection and control systems necessary for many precision experiments with RIBs [1]. The distributed data acquisition system, constructed in the VME standard and significantly upgraded than the previous one [2] is foreseen. This fast operating system allows to readout data from the monitoring and detection systems, which can be located at a distance of 100 meters from each other and carried out in the VME, and in any other popular standards. The modern beam monitoring detectors based on multiwires proportional chambers, position-sensitive silicon and thin scintillators are reported too.

1. L.V. Grigorenko et al., *“Studies of light exotic nuclei in the vicinity of neutron and proton drip lines at FLNR JINR”*, Physics-Uspekhi, **59** (2016) 321.

2. R.S. Slepnev et al., “VME-based data acquisition system for multiparameter measurements”, Instruments and Exp. Techniques, **55** (2012) 645.

**13-4. SHELS (Separator for Heavy ELement Spectroscopy)**

**Alena Kuznetsova, Alexander Yeremin, Oleg Malyshev**

*Flerov Laboratory of Nuclear Reactions, JINR, Dubna, Russia*

**Karl Haushild, Araceli Lopez-Martens,**

*Centre de Sciences Nucleaireset de Sciences de la Matiere, IN2P3-CNRS, Orsay, France*

**Olivier Dorvaux**

*Institut Pluridisciplinaire Hubert Curien, CNRS, Strasbourg, France*

Over the past 15 years, the electrostatic recoil separator VASSILISSA has been used for investigations of evaporation residues (ERs) produced in heavy-ion fusion reactions. In the course of the experimental work, a bulk of data on ERs formation cross sections was collected. In 2004-2010, the isotopes of Fm, Md, No, and Lr were studied using the GABRIELA (Gamma Alpha Beta Recoil Investigations with the ELectromagnetic Analyzer) detector system. These experiments showed that the efficiency of the existing set-up was not sufficient.

The goals of the modernization of the VASSILISSA electrostatic separator were to increase the transmission of asymmetric reactions, like 22Ne + 238U or 16O + 244Pu products, by the factor of 2–3 and to extend the region of reactions to be investigated up to symmetric combinations like 136Xe + 136Xe. For this purpose, 3 electrostatic deflectors in the central part of the separator were replaced by a combination of two electrostatic and two magnetic deflectors. This modernization converted the energy selector VASSILISSA into the velocity filter SHELS. The new separator will be used together with the detector GABRIELA to carry out spectroscopic studies of heavy and superheavy isotopes. First tests of the set-up were performed with the beams of accelerated 22Ne, 40Ar, 48Ca, and 50Ti ions.

**13-5.** **Chemical investigation of the superheavy elements copernicium and flerovium: kinetic studies on the mercury – selenium interaction using inverse thermochromatography**

***A. Madumarov1****, N. M. Chiera2,3, N. Aksenov1, R. Eichler2,3, D. Piguet2, A. Türler2,3, A. Vögele2*

*1Flerov Laboratory of Nuclear Reactions, JINR, Dubna, Russian Federation; 2Paul Scherrer Institute, Villigen, Switzerland; 3University of Bern, Bern, Switzerland.*

In preparation of chemical experiments with copernicium (Z = 112) and flerovium (Z = 114), produced in heavy ion induced nuclear fusion reactions, model experiments with mercury - copernicium’s lighter homologue - were conducted. For this purpose, trigonal (t-Se, crystalline) and red amorphous selenium (a-Se) have been used as stationary phase in gas chromatographic experiments, allowing for the determination of the adsorption enthalpy limits ΔHadst-Se(Hg) < 60 kJ/mol and -ΔHadsred-Se(Hg) > 85 kJ/mol, respectively [1]. Considering the thermodynamic stability of HgSe, a kinetic hindrance on the adsorption behavior of elemental mercury towards trigonal selenium is observed.

Unexpectedly, first on-line experiments with copernicium indicated that Cn reacted with trigonal Se with a lower kinetic formation hindrance compared to the interaction of Hg with t-Se [2].

In order to understand the kinetic process of the HgSe interaction towards both red amorphous and trigonal selenium allotropes, useful later on for the interpretation of the CnSe(s) formation, inverse thermochromatographic (IT) studies will be performed [3]. This approach for the determination of the reaction kinetics is based on a two-step interaction process: 1) a reversible adsorption interaction; eventually followed by 2) an activated complex formation and the final covalent bond formation. For this purpose, an inverse thermochromatographic (IT) setup was developed.

The aim of these IT experiments is to derive the lower temperature at which the HgSe(s) formation is promoted on both allotropic Se surfaces. This temperature will then be used for the estimation of kinetic parameters by means of a Monte Carlo simulation approach. First experimental results will be presented.

First on-line test experiments using the COLD detector array with Se covered detector surfaces were performed. For this purpose, a mixed 242Pu/natNd oxide target (1 mg/cm2242Pu, 50 mg/cm2 natNd) was prepared by molecular plating on a 2 μm Ti foil. A 48Ca18+ beam with a primary energy of 272 MeV was delivered from the U-400 cyclotron at FLNR (Dubna). After passing through a 4 μm Ti window, a 0.5 cm cooling gas slit, and the Ti backing foil, the beam entered the target with an energy of about 244 MeV, producing 185Hg and 287Fl in the nuclear fusion reactions 142Nd(48Ca,5n) and 242Pu(48Ca,5n), respectively [2].

**References**

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copernicium - selenium bond formation observed”, *LCH Annual Report,* 2015

[3] N. M. Chiera et al., “Kinetic studies on the mercury – selenium interaction“, *LCH Annual Report,* 2015

**13-6. α-particle emission in the reaction 48Ca+Ta**

***K. Mendibaev****1****, B.M.Hue****2****, S.M. Lukyanov****1****,D.Aznabayev1 C.Borcea****3****,***

***V.A. Maslov****1****, Yu.E. Penionzhkevich****1;4****, F.Rotaru****3****, I. Sivacek****5****,***

***N.K. Skobelev****1****, Yu.G. Sobolev****1* ***and K. Kuterbekov****6*

1 Flerov Laboratory of Nuclear Reactions, Dubna, Russian Federation

2 Institute of Physics, Hanoi, Vietnam

3 National Inst. for Physics and Nuclear Engineering, IFIN-HH, Bucharest Magurele,

4 National Research Nuclear University \MEPhI", Moscow, Russian Federation

5 Nuclear Physics Institute, Rez, Czech Republic

6 Eurasian Gumilev University, Astana, Kazakhstan

E-mail: [lukyan@jinr.ru](mailto:lukyan@jinr.ru), [kayrat1988@bk.ru](mailto:kayrat1988@bk.ru)

**Abstract.** Inclusive energy spectra have been measured for light charged particles emitted in the bombardment of Ta target by 48Ca ions at 261 MeV and 471 MeV. The reaction products were analyzed and detected by means of a ΔE-E telescope placed in the focal plane of a magnetic spectrometer located at forward angles with respect to the beam direction. In all the reactions studied light charged particles with an energy close to the respective calculated kinematic limit for a two-body exit channel are produced with relatively great probability. The results obtained make it possible to draw some conclusions about the reaction mechanism involving the emission

of light charged particles.

**13-7. FUSION REACTIONS WITH LIGHT NEUTRON-REACH NUCLEI: PATHWAY TO SYNTHESIZE OF NEW HEAVY NUCLEI**

**V.A. Rachkov**, A. V. Karpov

*Flerov Laboratory of Nuclear Reactions, JINR, 141980 Dubna, Russia,*

E-mail: rachkov@jinr.ru

During recent years, significant progress has been achieved in the experimental and theoretical investigations of the region of heavy and superheavy nuclei. Note that for elements with Z>100, only neutron-deficient isotopes (located to the left of the stability line) have been synthesized so far, while the unexplored area of heavy neutron-rich nuclides (located on the stability line and to the right of it) is extremely important for nuclear astrophysics investigations and, in particular, for the understanding of the r-process of astrophysical nucleogenesis (a sequence of neutron capture andβ-decay processes). Fusion reactions of stable nuclei do not allow one to explore this area. The developments of the modern powerful accelerators and creation of radioactive ion-beam facilities provide the possibility to receive the high intensity radioactive ion beams (RIB). It may help to synthesize new isotopes of heavy and superheavy elements up to Z = 108 [1].

In this work the formation of heavy and superheavy nuclei in the fusion of radioactive projectiles with actinide targets are discussed. The corresponding predictions of the fusion cross section for several combinations of colliding nuclei have been made with the use of Web knowledge base on low energy nuclear physics, NRV [2]. These results may be useful for planning and data analysis of the corresponding experiments.

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**13-8. Combined mass method for study of exotic nuclei**

P. **Sharov**

Precise measurement of the continuum energy spectra is often needed for nuclear structure studies. The problem of two-proton decay of 17Ne first excited state is a good example. First excited state of the 17Ne 3/2- is located only 344 keV above 2p-decay threshold and it 2p-decay partial width is greatly lesser then gamma-decay partial width. The existing experimental threshold for the 2p/γ ratio (0.77 %) [1] is a few order of magnitude greater than theoretical predictions for the value (2.5e-6) [2]. At the same time one should needs in high beam integral (to populate 2p-channel) and in high energy resolution (to suppress background from states above) to observe such rare decay branch. These requirements are usually contradict each other.

In the recent experiment at the ACCULINNA [3] fragment-separator (Flerov Lab. JINR) the two-proton decay of the low-lying states of 17Ne populated in the p(18Ne,d)17Ne transfer reaction was studied. An original method of the combined mass was used in the experiment. This method allows to get relatively good energy resolution (σ~130 keV) without serious restriction on luminosity. As result new 2p/γ ratio threshold for (3/2-) state equal to 0.03 % was achieved, that is more one order of magnitude lesser than existing value.

The proposed method is very perspective and could be applied for other exotic systems, for example population of 10Li in the reaction d(9Li,p)10Li. Full Monte-Carlo simulation of the experiment was done and it's also reported.

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**13-9.**