# Study of the transfer and fragmentation reactions near Fermi energy. Production of exotic nuclei beams

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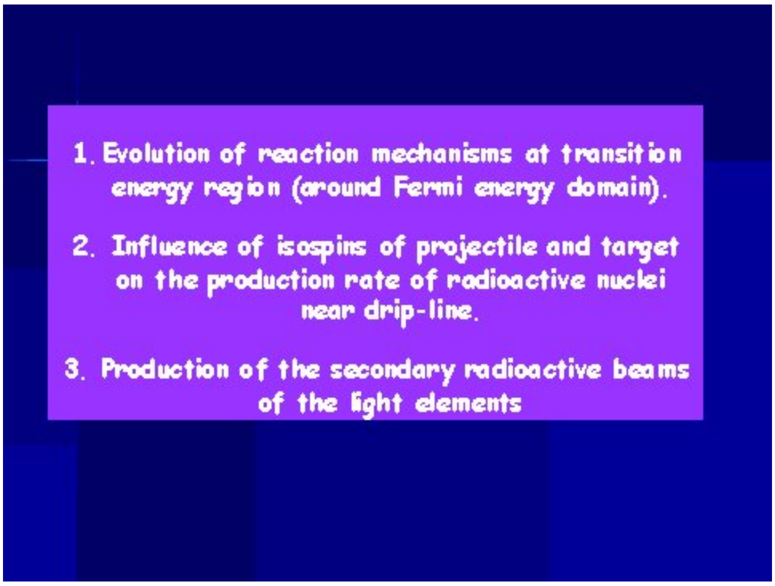
The project is based on the Topical Plan for JINR Research and International Cooperation, 2007 – 2009:

"Nuclei close to the drip lines. Fragment-separator COMBAS"

FLNR JINR, theme 03-5-1004-94/2009 №6

**Aims**




**1. Motivation**

**Heavy ion reactions around Fermi energy**

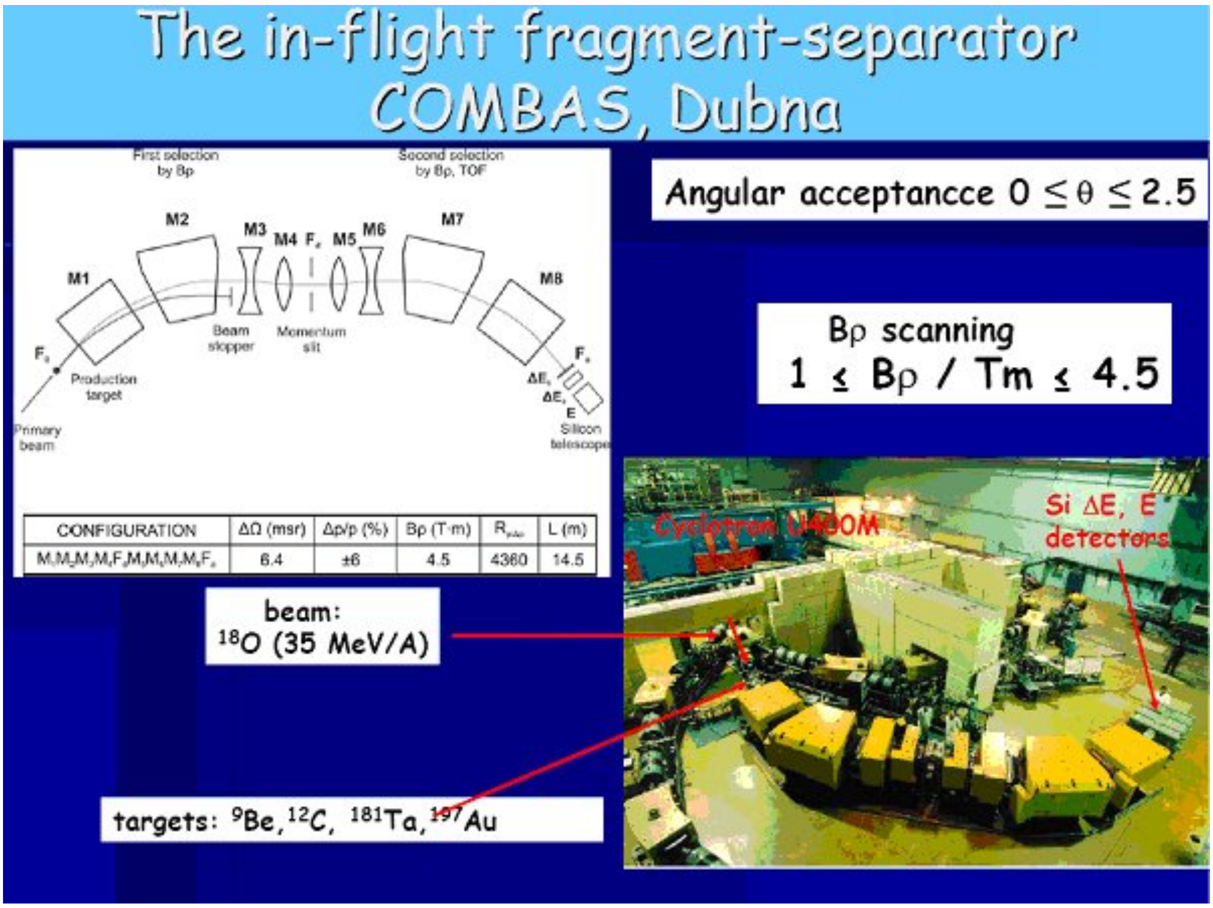
The energy of the projectile in heavy ion reactions studied in the past two decades subtends a wide range from a few MeV per nucleon up to energies exceeding 1 AGeV. In the low energy domain the relative velocities of colliding nuclei are small with respect to the internal Fermi motion of nucleons constituting heavy ions. This in turn causes that individual nucleon-nucleon interactions are hindered by the Pauli principle, so the nuclear interaction at these energies is mostly understood in terms of the mean held approach. The peripheral and semiperipheral collisions lead to quasielastic and deep in-elastic processes characterized by two massive, more or less excited fragments in the reaction exit channel, while the central and semicentral collisions lead to a fusion. The low energy reaction scenarios which clearly distinguish binary processes and the complete fusion become invalid at higher energies. At projectile velocity approaching the velocity of sound in nuclear matter (corresponding to energy around 14 AMeV) new processes do appear. These are noneqiulibrium emission of nucleons and clusters, projectile break-up and multifragmentation of the entire system, considered as a sort of liquid to gas phase transition of highly excited nuclear matter. At energies exceeding the Fermi limit *(E* > 30.4MeV) the mean field role is significantly reduced and two-body interactions begin to take over. At energies above ~ l00 AMeV the strength of the mean field becomes negligible in comparison to the single nucleon kinetic energy. In consequence the Pauli principle loses its blocking power, the mean free path for nucleon-nucleon collisions decreases and the intra nuclear cascade of collisions can develop. The variety of phenomena observed in heavy ion reactions depends not only on the energy but also on the impact parameter and mass available in processes.

In recent years a number of models has been developed to explain the mechanism of heavy ion reactions. These models may be divided into two basic categories. The first class of models is based on the assumption that the reaction mechanism is governed by mean field effects. The individual nucleon-nucleon interactions are suppressed by the Pauli principle and the process is described by the one-body formalism. The second category of models assumes that heavy ion collisions proceed vastly by two-body interaction. In between these extremes there are models linking the mean field and nucleon-nucleon dynamics.

Heavy ion reactions at intermediate energies, especially in the transitional Fermi energy domain, are of considerable interest both for studying of nuclear dynamics, such as compression and expansion modes, and for producing of secondary radioactive beams. The aim of these works is to answer the questions: *(i)* how rapidly does reaction mechanism evolve from low to high energy regime, *(ii)* does the neutron excess of the projectile and target influence the production of exotic nuclei. *(iii)* what a new phenomena can be met. In order to test our understanding of the heavy ion reaction mechanism in the Fermi energy domain, where the transition effects are expected to occur, the experimental data obtained for the $^{18}$O (35 AMeV)+$^{9}$Be($^{181}$Ta) reactions have been compared with model results employing the Quantum Molecular Dynamics transport code.

## 2. Fragment-separator COMBAS

The COMBAS (Fig. 1) large solid angle and high momentum acceptance and high-resolving in-flight separator has been created at the Flerov Laboratory of Nuclear Reactions, JINR. to efficiently collect extremely short-lived nuclei near the zero angle which are produced in intermediate energy heavy ions reactions with wide momentum and wide angular distributions. For the first time the $M_1M_2M_3M_4F_dM_sM_($,$M_7M_8F_a$ magneto-optical configuration of the COMBAS separator has been realized on the strong focussing principle. The separation and trajectory analysis of particles by the separator are carried out by three parameters: the magnetic rigidity (B· ρ), the energy loss difference in the degrader (ΔE/ΔX)and the time-of-flight (ΔT) of the analyzed particles. The COMBAS separator can be used efficiently both in the mode of a high- resolving spectrometer to study reaction mechanisms and in the mode of an in-flight separator in experiments on the synthesis and study of properties of short-lived exotic nuclei near the drip-lines.



**3. Research program for the nearest years**

For several years ahead, the Program includes –

1. Study of the mechanisms of reactions involving heavy ions (S, Ar, Ca, Ni) at intermediate energies (30–50 MeV/A) and light (Be, C) and heavy (Ta, Au) element targets.
2. Production of beams of radioactive nuclei from C to Ar.
3. Modeling and interpretation of the obtained data array within known theoretical approaches, including the most realistic modern method of Anti-Symmetrized Molecular Dynamics (AMD). Using the AMD method, it is possible to describe equally well both shell-like and cluster structure of light nuclei without any model assumptions. The AMD method has been successfully applied to recent experimental data on nuclear reactions and cluster structures of the $^{6-11}$Li and $^{8-12}$ Be isotope series.

**References**

**A. The COMBAS fragment separator:**

1. A. G. Artukh, Yu. L. Obukhov, V. A. Stchepunov, M. G. Nagayenko, Yu. P. Severgin, V. A. Titov, V. S. Belavenko and I. N. Vishnevski, **"The magnetic channel designed for separating beams of radioactive nuclei COMBAS"**, Nucl. Instr.& Meth. A306(1991)123-127

2.A.G. Artukh, G.F. Gridnev, M. Gruszecki, F. Koscielniak, A.G. Semchenkov, O.V. Semchenkova, Yu.M. Sereda, V.A. Shchepunov, J. Szmider, Yu.G. Teterev, P. G. Bondarenko, L. A. Rubinskaya, Yu.P. Severgin, Yu.A. Myasnikov, B.V. Rozhdestvenski, A. Yu. Konstantinov, V. V. Koreniuk, I. Sandrev, S. Genchev and I.N. Vishnevsky ,"**Wide aperture kinematic separator COMBAS realized on the strong focusing principle",** Nucl.Instr.& Meth. A426(1999)605

3.A.G. Artukh, A.G. Semchenkov, G.F. Gridnev, M. Gruszecki, F. Koscielniak, O.V. Semchenkova, Yu.M. Sereda, V.A. Shchepunov, J. Szmider, Yu.G. Teterev, Yu.P. Severgin, B.V. Rozhdestvensky, Yu.A. Myasnikov, N.F. Shilkin, E.A. Lamzin, M.G. Nagaenko, S.E. Sytchevsky and I.N. Vishnevsky, **"3D magnetic measurements of the combined function magnets in separator COMBAS"**, Nucl.Instr. & Meth. A479 ( 2002) 467-486

4.A.G. Artukh, A. Budzanowski, F. Koscielniak, E. Kozik, V. P. Kukhtin, E. V. Lamzin, A. G. Semchenkov, O. V. Semchenkova, Yu. M. Sereda, V. A. Shchepunov, S. E. Sytchevsky, J. Szmider and Yu G. Teterev, **"Reconstruction of 3-dimensional magnetic fields of the strong focusing separator COMBAS", Nukleonika 2003;** 48 (Supplement 2) : S49-S53

5.A.V.Belov, T. F. Belyakova, O. G. Filatov, V. P. Kukhtin, E. A. Lamzin, N. A. Shatil, S. E. Sytchevsky, K. A. Gridnev, A. G. Semchenkov, O. V. Semchenkova, A.G.Artukh, Yu.M. Sereda, Yu. G. Teterev, A. Budzanowski, F. Koscielniak and J. Szmider, "**Program packade for the accurate three dimentional (3D) reconstruction of magnetic fields from the boundary measurements",**Nucl.Instr. & Meth., A 513 (2003) 448-464

6. A.G. Artukh, A. G. Semchenkov, V. A. Shchepunov, G. F. Gridnev, O. V. Semchenkova, Yu. M. Sereda, Yu G. Teterev, A. Budzanowski, F. Koscielniak, J. Szmider, V. P. Kukhtin, E. V. Lamzin, Yu. P. Severgin and S. E. Sytchevsky, **"The FLNR JINR wide aperture separator COMBAS",** Nucl.Instr. & Meth., B 204 (2003) 159-165

**B. Detectors and electronics:**

7. A.G. Artukh, G.F. Gridnev, A.N. Denikin, S.A. Klygin, V.Z. Maidikov, S.V. Perov, A.G. Semchenkov, O.V. Semchenkova, Yu.M. Sereda, Yu.G. Teterev, V.I. Zagrebaev , N. I. Zamiatin, A.N. Vorontsov, A. Budzanowski, F. Koscielniak, and I. Szmider **"Detecting system for correlation experiments in inverse kinematics"**, Proc. on International Symposium on Exotic Nuclei "EXON-2001", Baikal Lake, 24-28 July 2001, World Scientific Pages 682-689

8. L. A. Popeko, I. M. Kotina, G. A. Shishkina, L. A. Grigorieva, A. G. Artyukh, Yu. G. Teterev, Yu. M. Sereda, **"Thick Si(Li) coaxial detectors for registration of intermediate energy heavy ions"**, препринт ОИЯИ E7-2007-5, 2007 г., to be published in NIM.

9. A.G. Artukh, S.A. Klygin, Yu.M. Sereda, Yu.G. Teterev, A.N. Vorontsov, G. Kaminski, A. Budzanowski, J. Szmider, N.I. Zamiatin, D.A. Smolin, N.V. Gorbunov, A.A. Povtoreiko and P.G. Litovchenko, **"Multichannel electronic module for COMBAS separator",** Proc. of Int. Symposium on Exotic Nuclei " EXON-2004", 5-12 July 2004, World Scientific Pages 579-581

**C. Research**

10. A.G. Artukh, G.F. Gridnev, M. Gruszecki, F. Koscielniak, A.G. Semchenkov, O.V. Semchenkova, , Yu.M. Sereda, I. Szmider and Yu. G. Teterev, **"Forward-Angle Yields of 2£*Z*£11 Isotopes in the Reaction of $^{18}$O (35 *A* MeV) with Be"**, Ядерная Физика, т. 65(2002)419-425

11. A.G. Artukh, G.F. Gridnev, M. Gruszecki, F. Koscielniak, A.G. Semchenkov, O.V. Semchenkova, Yu.M. Sereda, I. Szmider and Yu. G. Teterev, **"Some regularities in the beam-direct production of isotopes with 2£*Z*£11 induced in reactions of $^{18}$O (35 *A* MeV) with Be and Ta"**, Nuclear Physics A701(2002)96c-99c

12. A.G. Artukh, G.F. Gridnev, S.A. Klygin, V.Z. Maidikov, S.V. Perov, A.G. Semchenkov, O.V. Semchenkova, Yu.M. Sereda, Yu.G. Teterev, I.N. Vishnevski, A.N. Vorontsov,A. Budzanowski, M. Gruszecki, F. Koscielniak and J. Szmider, **"Forward-angle yields of isotopes with $3 \le Z \le 10$ in the reaction of $^{22}$Ne (40A MeV) with $^{9}$Be"**, Proc. on International Symposium on Exotic Nuclei "EXON-2001", Baikal Lake, 24-28 July 2001, World Scientific Pages 269-276

13. A. G. Artukh, A. Budzanowski, G. Kaminski, W. Kantor, S. A. Klygin, E. Kozik, O. V. Semchenkova, Yu. M. Sereda, J. Szmider, Yu. G. Teterev and A. N. Vorontzov, **"QMD approach in description of the $^{18}$O + $^{9}$Be and $^{18}$O + $^{181}$ Ta reactions at $E_{proj}$ = 35 AMeV"**,

Acta Physica Polonica B vol. 37, No 6 , 2006 p. 1875-1892

14. V.P. Aleshin, A.G. Artukh, G. Kaminski, Yu.M. Sereda, **"On fragmentation mechanism of $^{18}$O on $^{181}$Ta and $^{9}$Be at 35MeV/U"**, talk on Int. Conference "*Current problems in nuclear physics and atomic energy" NPAE-Kyiv2006*, 29.05.2006-03.06.2006 Kiev, Ukraine, published in Ядерная Физика, НАН Украина.

15. A.G. Artiukh, A.S. Denikin. Yu.M. Sereda, G. Kaminski, G.A. Kononenko, S.A. Klygin, A.N. Vorontsov, B. Erdemchimeg, Yu.G. Teterev, Ye.A. Shevchik, **"Reconstruction of the Parameters of the Cluster Decay of Light Element Nuclei"** (JINR preprint P7-2007-8, 2007; published in the ПТЭ journal.

**4**. **No more than two Polish and South African students can participate in the Project.**

**5. The Project supervisor: Dr. Anatoly Artyukh, Senior Scientist (Sector 7, Experimental Department of Physics, Flerov Laboratory of Nuclear Reactions)**