Heavy-Ion Physics

Basic Facilities U400 & U400M and theirs Development

04-0-0002-2000/2006

Priority of the project:	1
Status:	In-progress

Dubna Radioactive Ion Beam Accelerator Complex "DRIBS"

Leader from JINR: Yu. Oganessian

Participating countries and international organizations: Bulgaria, Czech Republic, France, JINR, Romania, Russia, Slovak Republic.

The Dubna radioactive ion beam accelerator complex (DRIBs) bases on two cyclotrons U400, U400M and MT-25 microtron. U400M and MT-25 are used for the production of radioactive nuclides, and the U400 cyclotron will accelerate them up to ≈20 MeV/nucleon.

Phase I: production and acceleration of light radioactive nuclei: $^{6,8}He$, ^{11}Be.

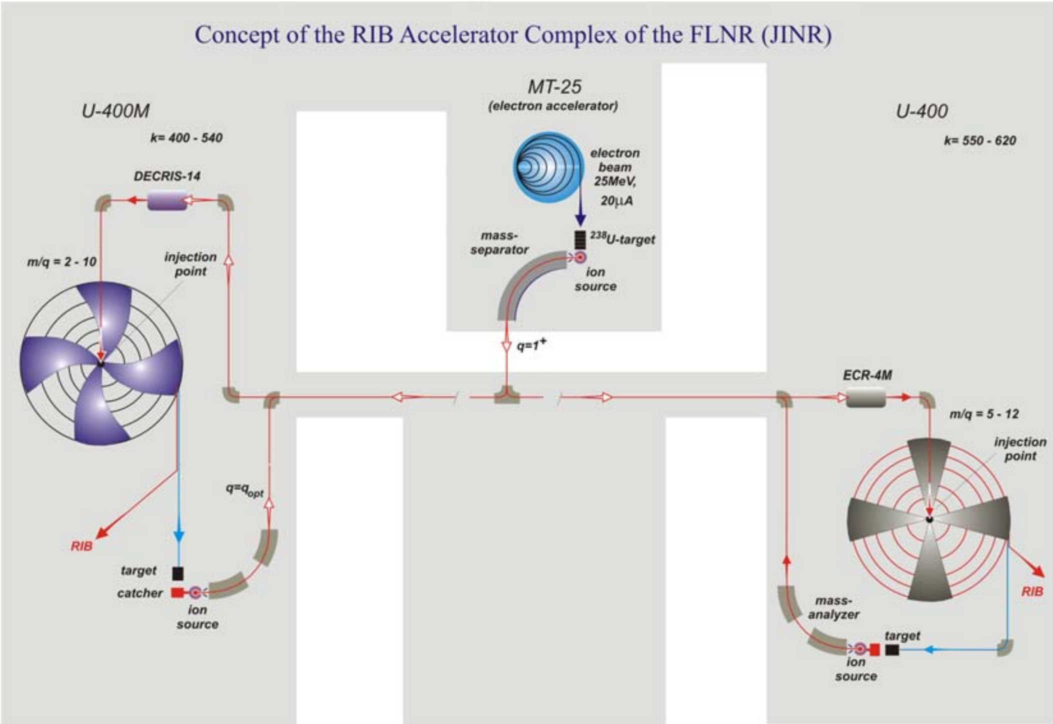
RIB	^{6}He	^{8}He	^{11}Be
Intensity	$9\cdot10^{9}$ pps	$3\cdot10^{7}$ pps	$2\cdot10^{8}$ pps
Energy	8÷13 MeV/n	6÷8 MeV/n	4÷16 MeV/n
Primary beam	^{7}Li	^{11}B	^{13}C
Intensity	10 pμA	10 pμA	10 pμA
Energy	32 MeV/n	34 MeV/n	42 MeV/n

Phase II: production and acceleration of ^{238}U photofission fragments (e.g. ^{90}Kr, ^{140}Xe.)

RIB	^{90}Kr	^{140}Xe
Intensity*	$5\cdot10^{6}$ pps	$5\cdot10^{6}$ pps
Energy	3.5÷16 MeV/n	5÷18 MeV/n

*For the electron beam energy 25 MeV and intensity 20 μA

Phase IIA: low energy RIB laboratory for nuclear, laser and mass spectroscopy of fission fragments.



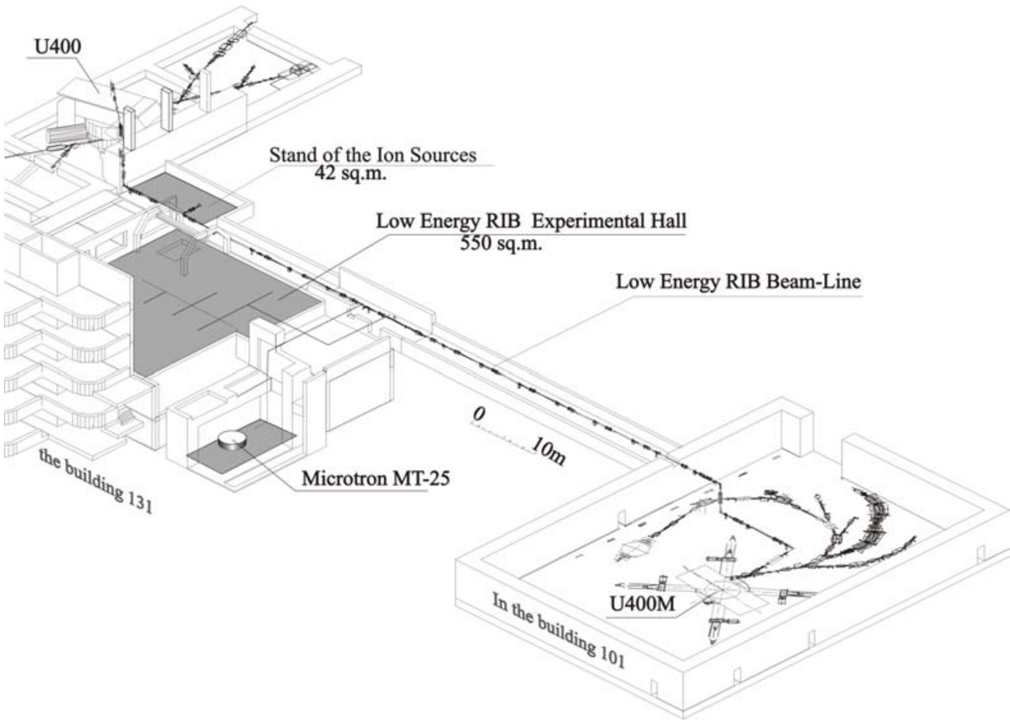


Fig. Schematic view of low energy beam transport channels of the DRIBs complex.

04-5-1014-96/2006

Priority of the project:

Status: Data taking

Isocronous Cyclotron U-400

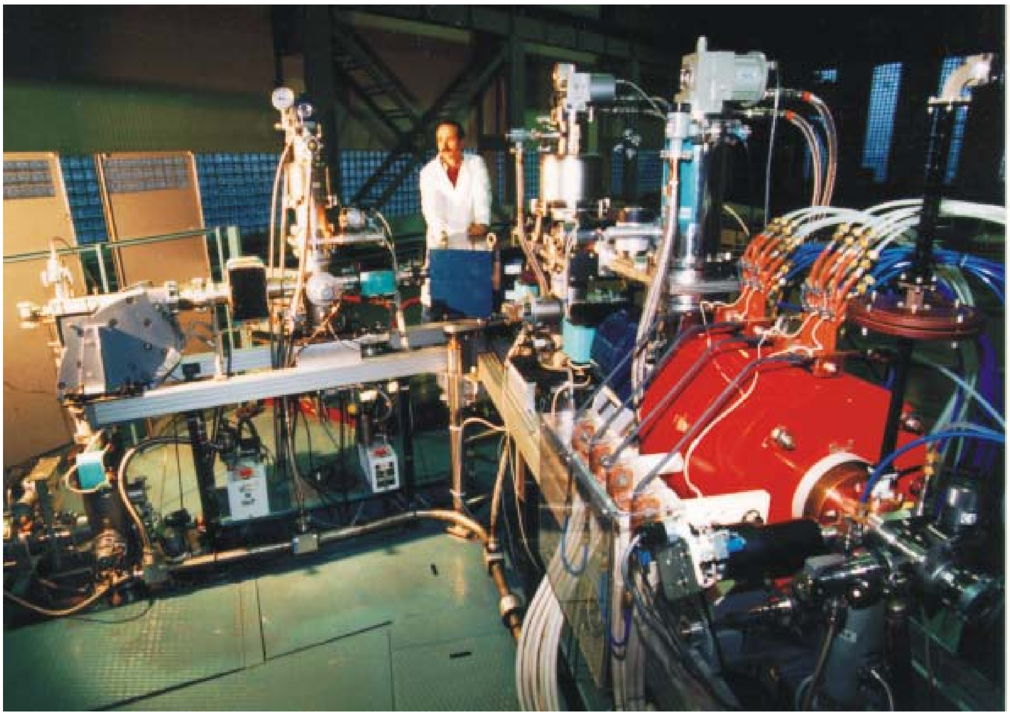
Leader from JINR: G. Gulbekyan

Participating countries and international organizations: Czech Republic, France, Germany, JINR, Poland, Romania, Russia, Slovak Republic.

The isochronous U-400 cyclotron produces ion beams of atomic masses from 4 to 100 and maximum energy up to 25 MeV/nucleon. The accelerator has been equipped with the ECR ion source at 14 GHz–ECR4M and axial injection beam line. Monochromatic ion beams with energies of 25 MeV/nucleon at $\Delta E/E=10^{-3}$ are obtained in the spectroscopic mode for ions lighter than Ar. The experimental devices are placed at 12 beam extracted channels.

Table. Beams of the U-400 cyclotron.

Ion	Energy, MeV/n	ECR beam current	Extracted beam intensity
$^{7}Li^{1+}$	16.6	100μA	$6*10^{13}$ pps
$^{6}Li^{1+}$	12.6	100μA	$6*10^{13}$ pps
$^{11}B^{2+}$	17.8	90μA	$4*10^{13}$ pps
$^{12}C^{2+}$	16.6	100μA	$4*10^{13}$ pps
$^{13}C^{2+}$	14.4	100μA	$3*10^{13}$ pps
$^{14}N^{2+}$	9.4	100μA	$3*10^{13}$ pps
$^{14}N^{3+}$	20.3	100μA	$3*10^{13}$ pps
$^{18}O^{3+}$	19.3	100μA	$2*10^{13}$ pps
$^{20}Ne^{4+}$	20.9	100μA	$2*10^{13}$ pps
$^{22}Ne^{4+}$	17.8	100μA	$2*10^{13}$ pps
$^{36}S^{6+}$	15	60μA	$9*10^{12}$ pps
$^{40}Ar^{8+}$	19.9	100μA	$1*10^{13}$ pps
$^{48}Ca^{5+}$	5.3	60μA	$7*10^{12}$ pps
$^{48}Ca^{9+}$	19	30μA	$3*10^{12}$ pps
$^{86}Kr^{9+}$	5.1	60μA	$2*10^{12}$ pps
$^{136}Xe^{14+}$	4.4	5μA	$3*10^{10}$ pps



Ion source ECR4M and injection beam line of U400

General view of the isochronous cyclotron U-400

04-5-1014-96/2006

Priority of the project:

Status: Data taking

Isocronous Cyclotron U400M

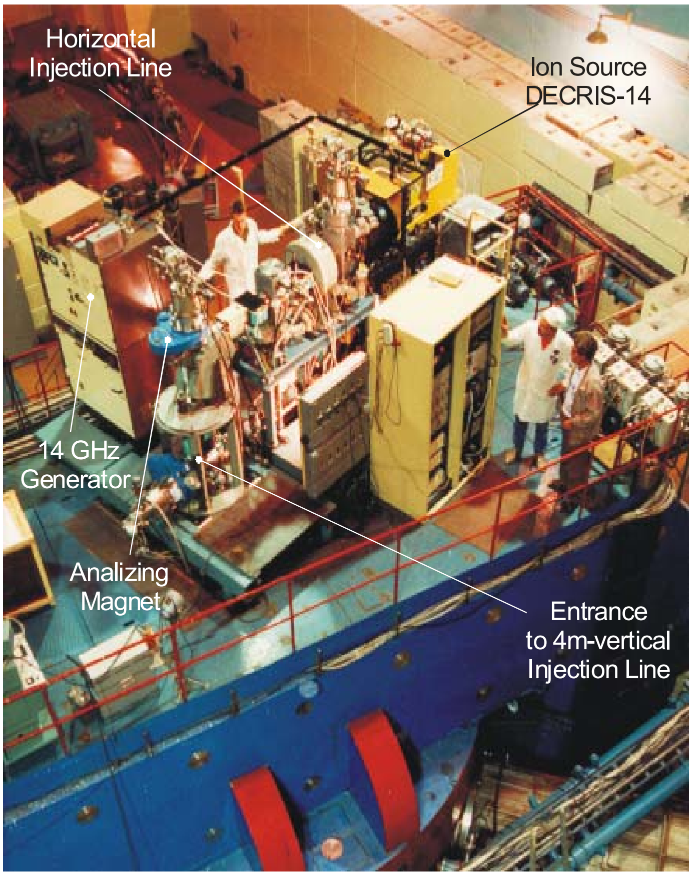
Leader from JINR: G. Gulbekyan

Participating countries and international organizations: Czech Republic, France, Germany, JINR, Poland, Romania, Russia, Slovak Republic.

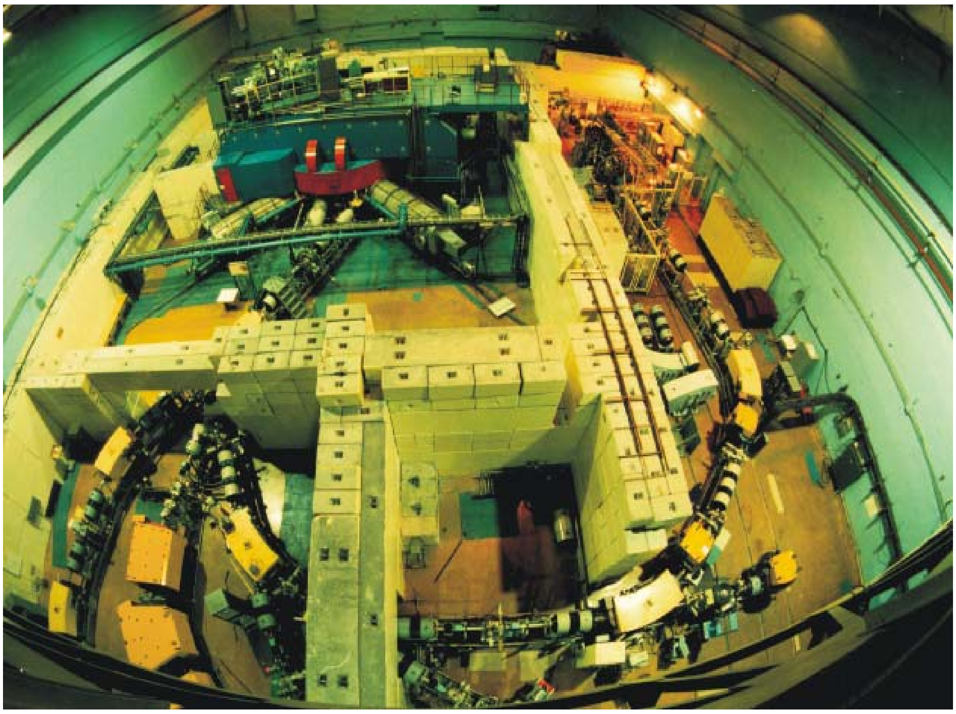
At the U-400M cyclotron extracted ion beams of light elements from D to Ar with energies up to 50 MeV/nucleon (maximum energy is 100 MeV/nucleon) can be produced. The accelerator has been equipped with the ECR ion source at 14 GHz — DECRIS-14 and axial injection beam line. U-400M is used both for delivering ion beams to experimental setups and for producing light radioactive nuclei in the tandem operation mode together with U-400 (DRIBs).

Table. Beams of the U-400M cyclotron.

Ion	Energy, MeV/n	ECR beam current	Extracted beam intensity
$^{7}Li^{2+}$	35	100μA	$6*10^{13}$ pps
$^{11}B^{3+}$	32	90μA	$4*10^{13}$ pps
$^{12}C^{4+}$	47	100μA	$4*10^{13}$ pps
$^{14}N^{4+}$	35	100μA	$3*10^{13}$ pps
$^{14}N^{5+}$	54	50μA	$1.5*10^{13}$ pps
$^{18}O^{5+}$	33	100μA	$2.5*10^{13}$ pps
$^{22}Ne^{6+}$	32	50μA	$1*10^{13}$ pps
$^{22}Ne^{7+}$	43	50μA	$1*10^{13}$ pps
$^{36}S^{10+}$	33	10μA	$6*10^{11}$ pps
$^{40}Ar^{12+}$	40	12μA	$7*10^{11}$ pps
$^{48}Ca^{10+}$	20	10μA	$5*10^{11}$ pps



Ion source ECR4M and injection beam line of U400



General view of the U-400M experimental hall

Experiments and Facilities at U400 & U400M

04-5-1004-94/2003		Priority of the project: 1
		Status: Data taking

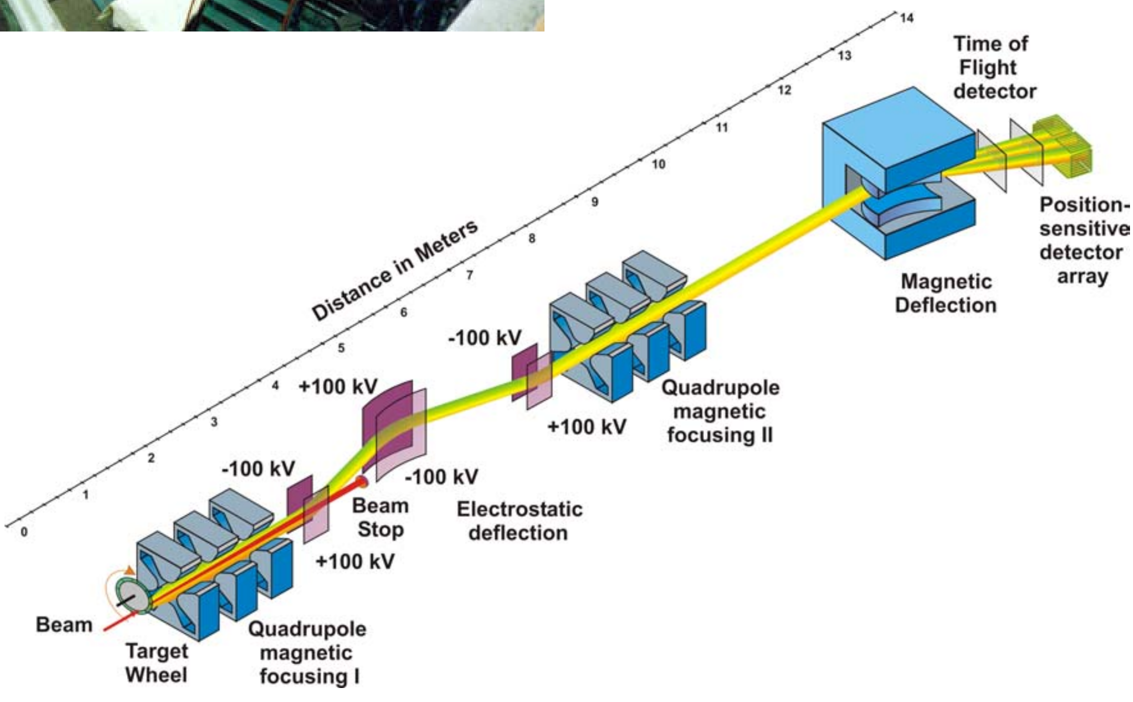
Electrostatic Separator “VASSILISSA II”

Leader from JINR: A. Yeremin

Participating countries and international organizations: France, Germany, Italy, Japan, JINR, Poland, Russia, Slovak Republic, Switzerland, the USA.

The electrostatic separator VASSILISSA is used for the exploring of fusion reactions. In the course of modernization, the magnetic 37^o-dipole was installed downstream the second quadrupole triplet of the separator for the mass identification of evaporation residues. Mass determination is an additional method for the identification of new isotopes when traditional methods are insufficient. In experiments with “VASSILISSA II”, the mass resolution $\Delta m/m$ in test reactions of better than 1% was achieved, for single events the mass resolution is better than 2%.

Electrostatic separator VASSILISSA



Ion-optical elements of the VASSILISSA II

04-5-1004-94/2003

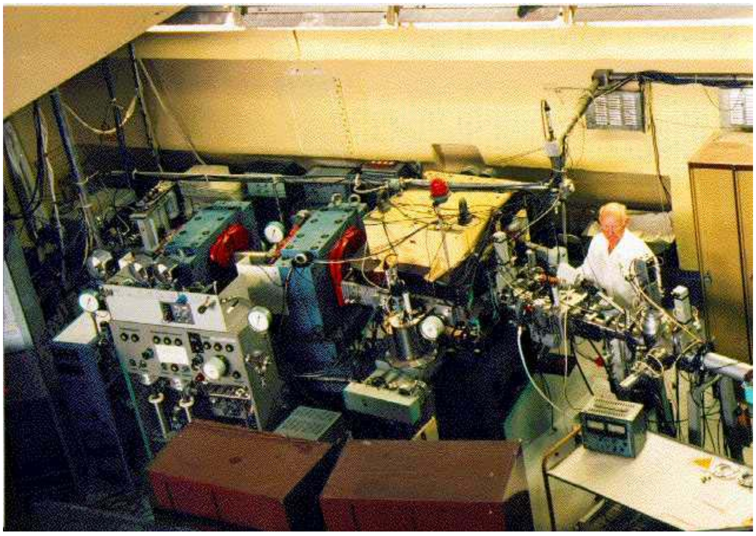
Priority of the project:	1
Status:	Data taking

Dubna Gas-Filled Recoil Separator "DGFRS"

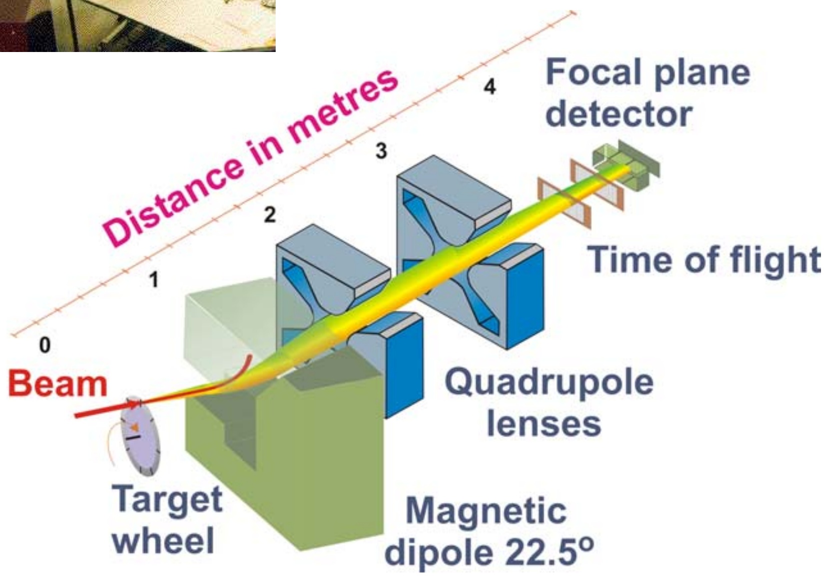
Leader from JINR: V. Utyonkov

Participating countries and international organizations: Bulgaria, JINR, Russia, the USA, Yugoslavia.

The Dubna gas-filled recoil separator was put into operation in 1989. Since then many improvements have been accomplished. Special emphasis was laid on the possibility of applying very intense heavy-ion beams delivered by the JINR U400 cyclotron to radioactive and exotic target species like $^{242,244}Pu$, ^{243}Am, ^{248}Cm, ^{249}Cf. The separator has DQQ design and is filled with the dilute hydrogen. The separated evaporation residues pass through a time-of-flight measurement system and are implanted in a position-sensitive detector (PSD) array. A remarkable long-term stability of the separator operation was achieved in numerous experiments.



The Dubna Gas-Filled Recoil Separator



Ion-optical elements of DGFRS

04-5-1004-94/2003

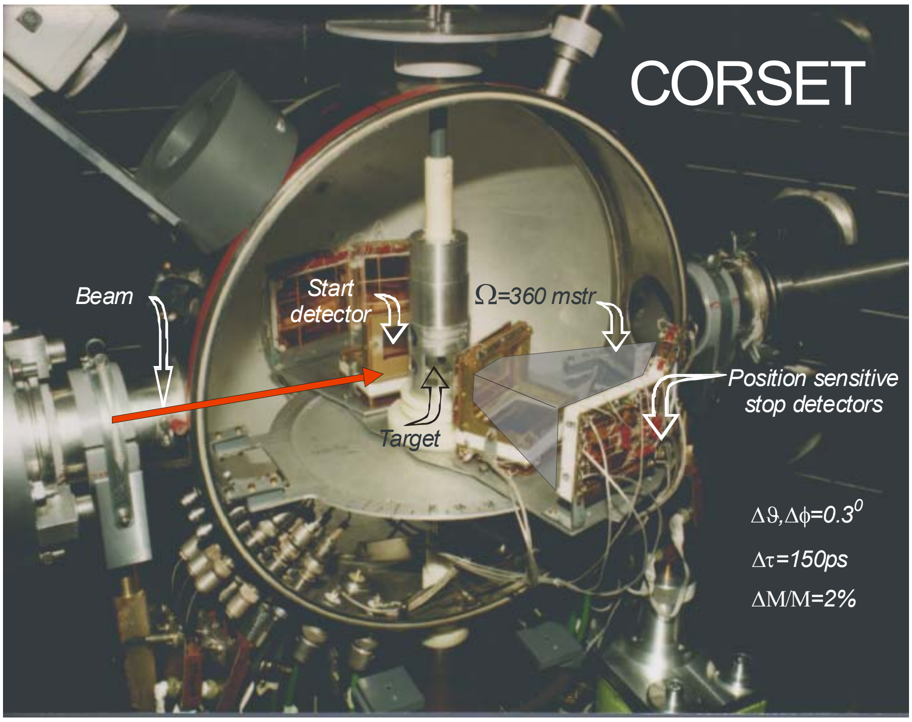
Priority of the project:	1
Status:	Data taking

Spectrometer of Fission Fragments "CORSET"

Leader from JINR: M. Itkis, J. Kliman

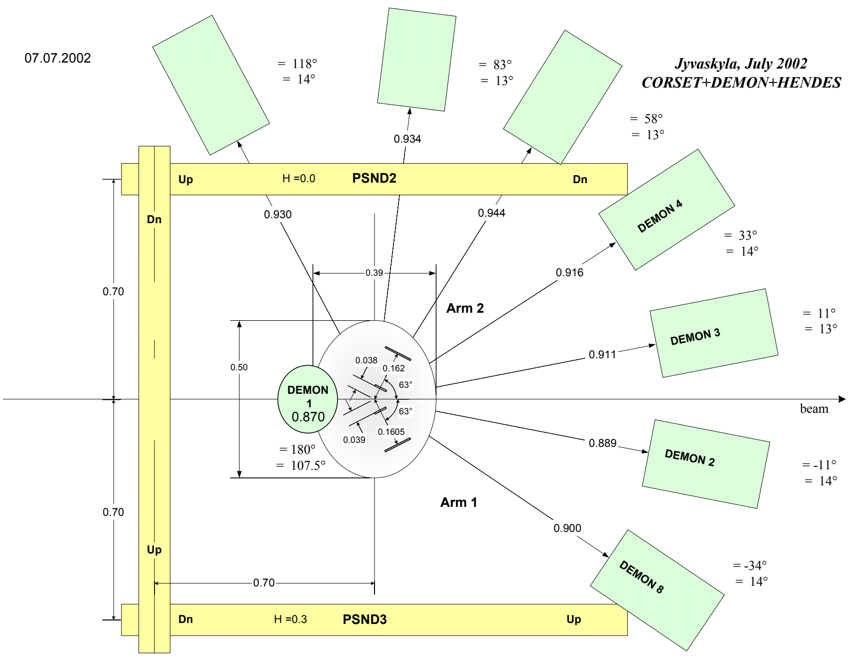
Participating countries and international organizations: Belgium, Finland, France, Italy, JINR, Kazakhstan, Russia, Slovak Republic, the USA.

The time-of-flight spectrometer CORSET is designed for the registration of fission fragments in correlation with emission of pre- and post-scission neutrons and γ-quanta. The modernization was performed in view of using the CORSET set-up in tandem with the multidetector neutron spectrometer DEMON. An important peculiarity of the work was the use of the "neutron clock" method for the study of time characteristics of the process of formation and decay of superheavy nuclei formed in reactions with heavy ions. CORSET provides high time (~150 ps→ΔA\A~1.5% for charged reaction products) and position resolution. The geometry efficiency of the setup is ~3–5%.



Time-of-flight spectrometer CORSET

Multidetector neutron spectrometer DEMON



Scheme of the CORSET+DEMON+HENDES setup

04-5-1004-94/2003

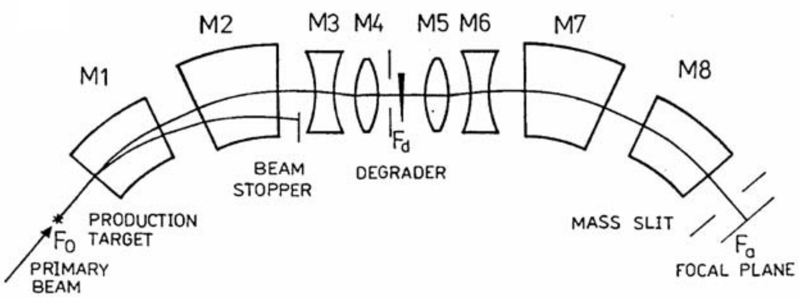
Priority of the project:	1
Status:	Data taking

Wide Aperture Fragment Separator "COMBAS"

Leader from JINR: A. Artyukh

Participating countries and international organizations: Germany, JINR, Poland, Russia, Slovak Republic, Ukraine.

The kinematic separator COMBAS with large solid angle and high momentum acceptance was specially designed to collect efficiently short-lived nuclei close to zero angle which are produced in intermediate energy massive transfer reactions. It 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 the properties of nuclei near the drip-lines.



Ion-optical elements of COMBAS

Fragment separator COMBAS

04-5-1004-94/2003

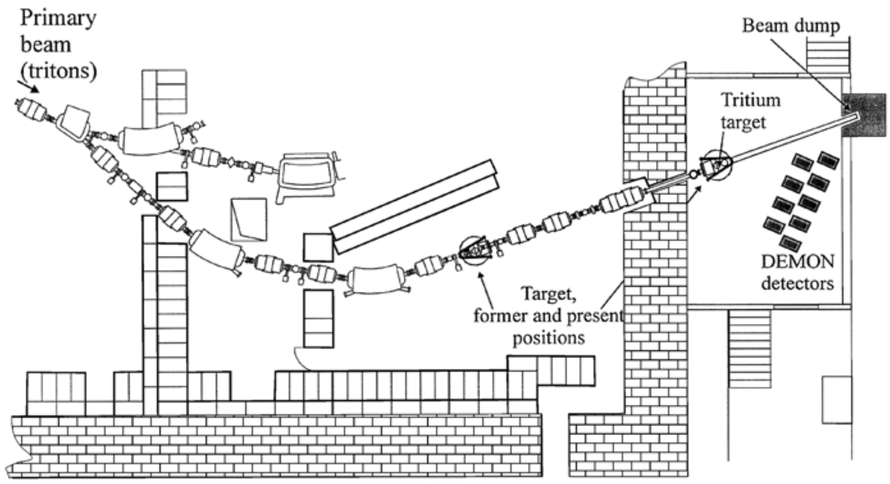
Priority of the project:	1
Status:	Data taking

High Resolution Beam Line "ACCULINNA"

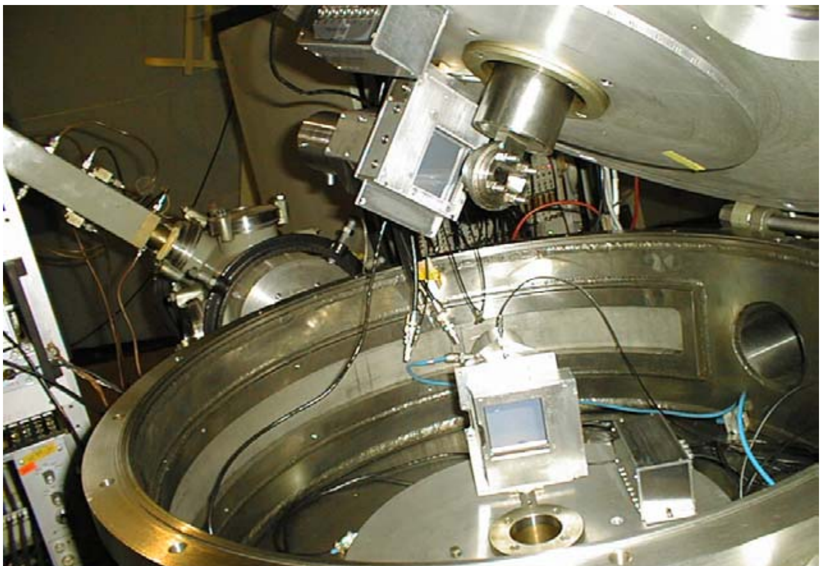
Leader from JINR: G. Ter-Akopian

Participating countries and international organizations: Belgium, France, Germany, Italy, Japan, JINR, Poland, Russia, the USA.

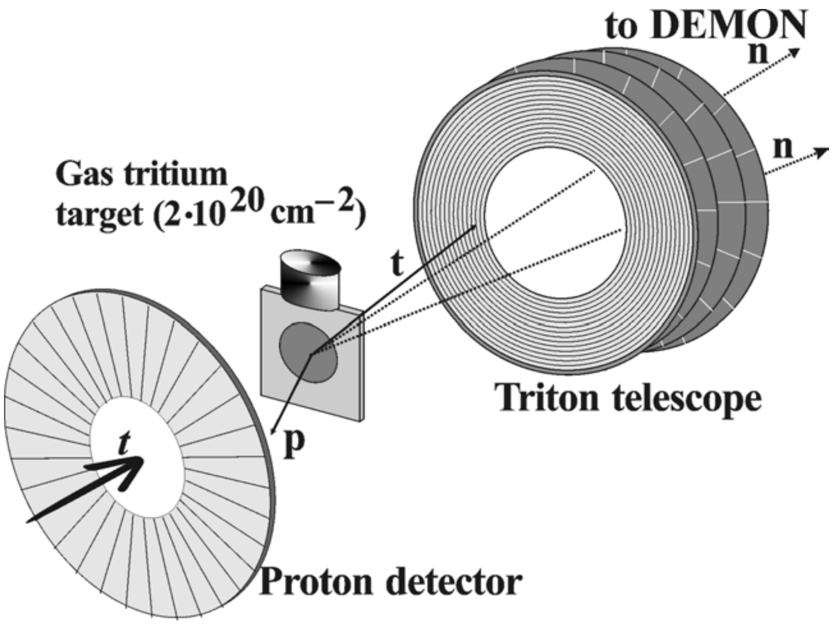
The set-up ACCULINNA involves an achromatic ion-optical system (two 35 degree dipole magnets, eight quadrupole and two sextupole magnetic lenses intended for separation of secondary exotic beams of the magnetic rigidity of up to 3.8 T·m emerging from the production target close to the zero angle in respect to the primary cyclotron beam direction.



The ACCULINNA set-up upgraded for experiments with the cryogenic tritium target



The reaction chamber of ACCULINNA



Detector array and target

Cryogenic target array and neutron spectrometer DEMON

04-5-1004-94/2003

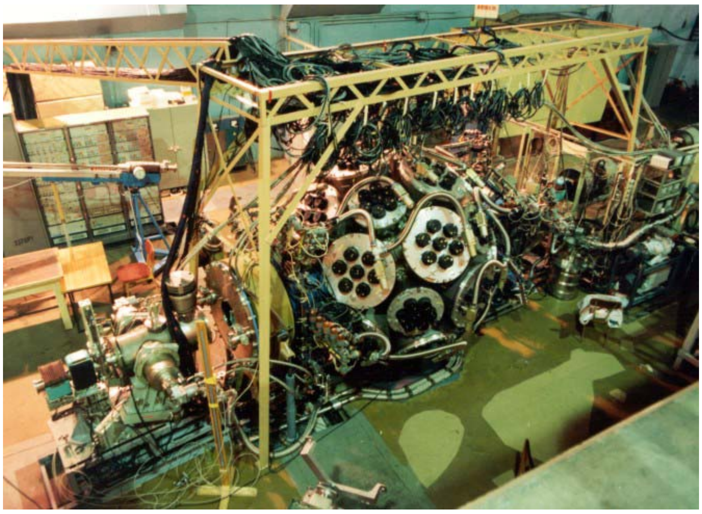
Priority of the project:	2
Status:	Data taking

4π Fragment Spectrometer “FOBOS”

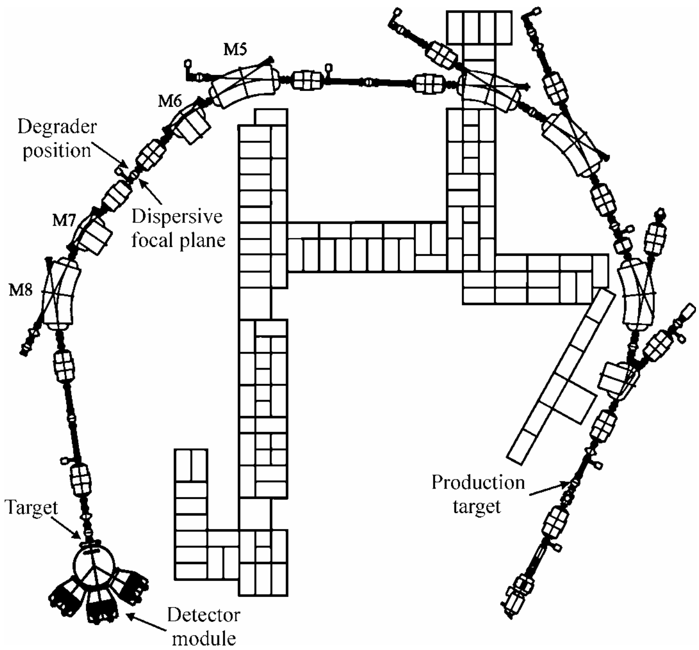
Leader from JINR: A. Matthis

Participating countries and international organizations: Armenia, Belgium, Bulgaria, Finland, France, Germany, Italy, Japan, JINR, Poland, Russia, the USA.

The 4π fragment spectrometer “FOBOS” is designed for studying reactions at incident energy of 10–100 A·MeV in direct kinematics, i.e. a light projectile impinges upon a heavy target nucleus. The measuring system of the FOBOS facility includes the time-of-flight channel, 16 gas filled measuring modules and 80 CsI (Tl) detectors which allowus to make a detailed analysis of energy and angular dependencies of the emission of fragments of intermediate mass of the decay of highly excited nuclei into three fragments. In combination with the Q4DQ-spectrometer it becomes possible to investigate secondary beam induced reactions.



Fragment spectrometer “FOBOS”



Q4DQ-spectrometer for secondary beam production

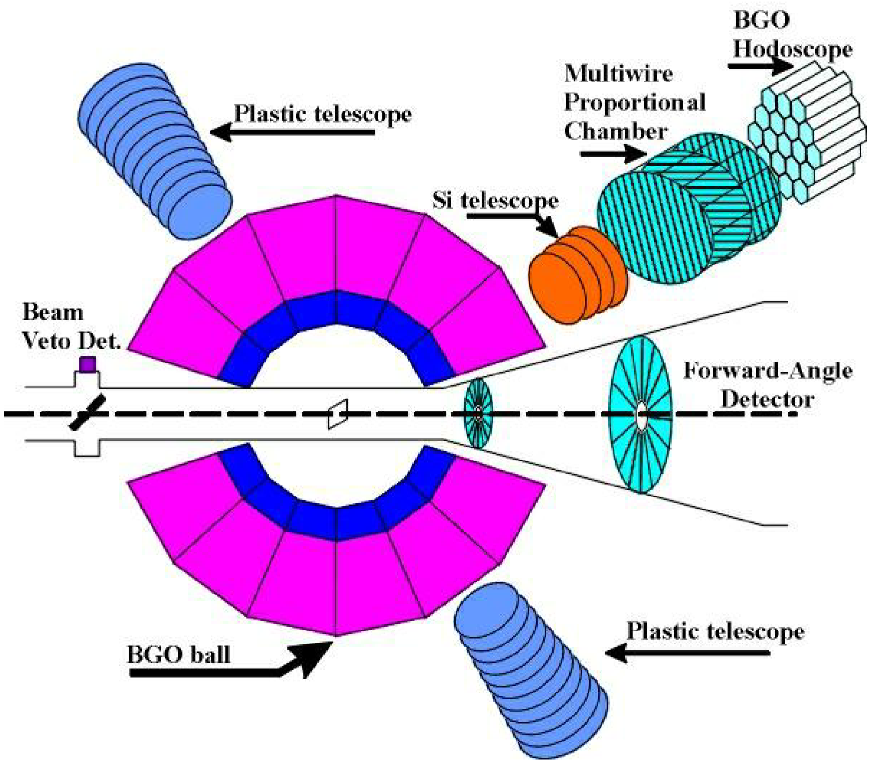
04-5-1004-94/2003	Priority of the project: 1
	Status: Data taking

Multidetector Setup “MULTI”

Leader from JINR: Yu. Penionzhkevich

Participating countries and international organizations: Armenia, Bulgaria, Czech Republic, Finland, France, Japan, JINR, Poland, Russia, Slovak Republic, the USA.

The setup “MULTI” has been constructed for the study of a very exited nuclear system produced by heavy ions at intermediate energies and for the investigation of exotic nuclei provided by secondary radioactive beams. The 30 module BGO-Ball constitutes the basic part of the MULTI setup. It ensures a geometrical efficiency for registration of γ-quanta and charged particles equal to $\varepsilon \approx 0.8*4\pi$. The forward angle spectrometer (a multi-layer semiconductor telescope Δ E,Δ E,E and 12–sector Δ E,E scintillator detectors) is used for detecting projectile-like fragments. The small-angle correlations of charged particles are measured with a multi-module plastic-BGO phoswich spectrometer, a very compact combination of scintillation detectors and a multiwire position-sensitive proportional chamber.



The detector array of the MULTI setup

04-5-1004-94/2003

Priority of the project: 1
Status: R&D

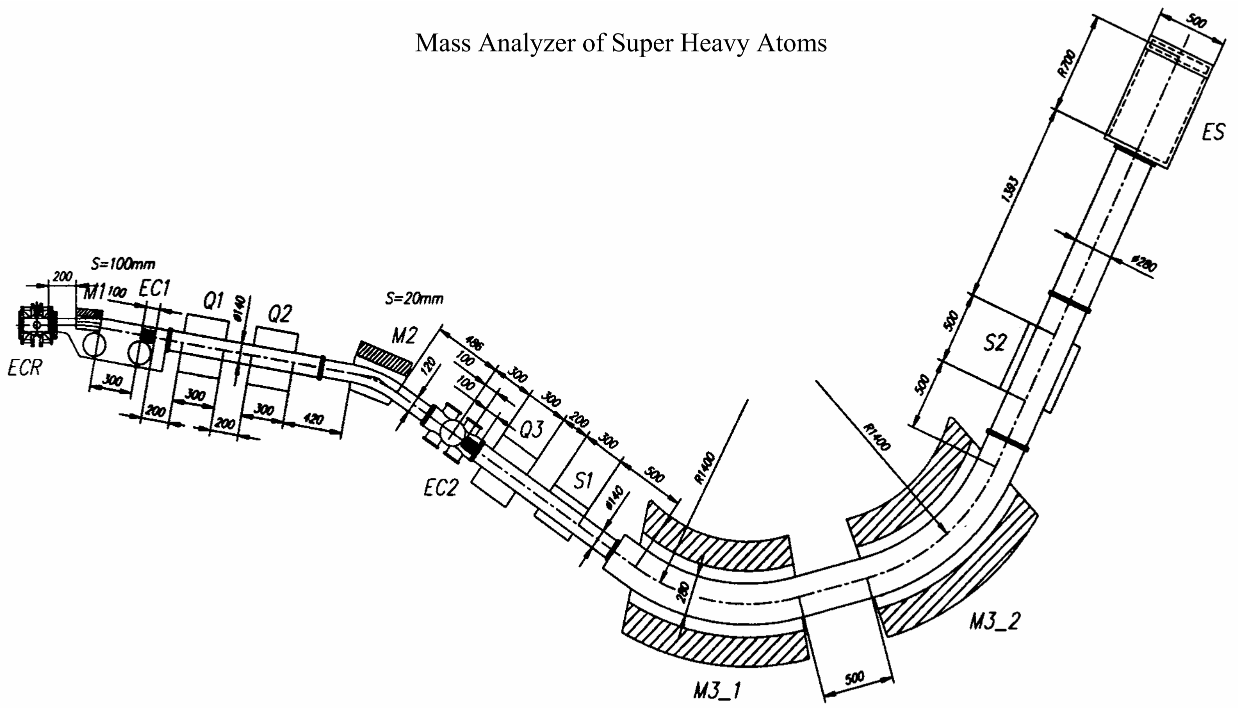
Mass Analyzer of Super Heavy Atoms "MASHA"

Leader from JINR: Yu. Oganessian

Participating countries and international organizations: Belgium, Germany, JINR, Poland, Russia.

A new separator and mass analyzer — MASHA (Mass Analyzer of Super Heavy Atoms) has been designed to separate and measure masses of nuclei and molecules with the resolution of 1000. The set up can work in the wide mass region from A~20 to A 500, its mass acceptance is as large as ±3% and it allows unambiguous mass identification of super heavy nuclei with a resolution better than 0.3 amu at the level of 300 amu.

Mass Analyzer of Super Heavy Atoms



Ion-optical elements of MASHA