THE SUGGESTED NEW FRAGMENT SEPARATOR ACCULINNA-2*

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We present new project of fragment separator ACCULINNA-2 that is being planned to be constructed in Flerov Laboratory of Nuclear Reaction, JINR. The ACCULINNA-2 facility is not intended to compete with the new large in-flight RIB facilities. It should complement the existing/constructed facilities in certain fields. Namely, ACCULINNA-2 should provide high intensity RIBs in the lowest energy range attainable for in-flight separators.

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1. Motivation for the ACCULINNA-2

At present, one of the principal fields of research at Flerov Laboratory of Nuclear Reactions (FLNR, Joint Institute for Nuclear Research, Dubna, Russia) is the Radioactive Ion Beam (RIB) research. This is conducted in the framework of the DRIBs initiative [1]. The construction of the in-flight fragment separator ACCULINNA-2 as the third generation of the DRIBs

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facilities should be in parallel with continuous operation of ACCULINNA fragment separator [2] and should gradually replace the latter after commissioning.

Evidently the next generation facility should enhance the advantageous features of the existing facility and eliminate/diminish the disadvantages as much as possible. The next generation fragment separator is expected to be a more universal and powerful instrument. The beam intensity should be increased, the beam quality improved, and the range of the accessible secondary radioactive beams broaden. Broadening of research program carried out at this facility should be foreseen. The proposed development of the ACCULINNA-2 fragment separator suggests a more universal scientific instrument giving a variety of clean and well-prepared secondary beams limited only by choice of the primary beams provided by the U-400M cyclotron. An important task of the ACCULINNA-2 project is the realization of the beam usage concept at FLNR complying with the modern trends inherent to large RIB facilities. The fragment separator, together with the beam diagnostics system, should become a standard instrumentation for the laboratory. The idea is that the exotic beam is delivered for the users into the low-background experimental area with full particle-by-particle identification and (energy/trajectory) diagnostics. This facilitates the RIB use by different groups running various experiments.

2. Anticipated scientific agenda

Research with radioactive beams is one of the most important modern trends in nuclear physics. The investigation of nuclei far from β-stability valley and even beyond the nuclear stability lines is important for understanding the properties of nuclear matter at the extreme conditions. It is also necessary for the further development of nuclear theory and indispensable for nuclear astrophysics. The new dripline nuclear physics intertwines the nuclear structure and reaction mechanisms more than ever before. The proposed ACCULINNA-2 project is focused on the study of nuclear properties far from the stability valley. Here, the lowest nucleon and cluster thresholds become close to the ground state (evidently, beyond the drip-lines these thresholds are below the ground state). Close to the thresholds clusterization phenomenon becomes increasingly important: some states possess expressed cluster structures and new forms of nuclear dynamics arise. Among these the following should be mentioned: nucleon haloes (neutron skins, Efimov states, *etc.*), soft excitation modes (*e.g.*, the soft mode of the giant dipole resonance), new magic numbers and intruder states, two-proton radioactivity (few-body decays in more general terms). The research focused on nuclear astrophysics and the novel forms of nuclear dynamics presumes dedicated scientific program, high intensity beams, and specialized instrumentation suitable for precision measurements. The main broad physical topics are: nuclear reactions, nuclear structure and astrophysical applications. Each major research direction has a preferable set of methods by which its problems could be best handled. Therefore, a way to look at the scientific agenda of the ACCULINNA-2 separator is to consider physical methods to study the properties of the nuclear systems which should be accessible with this instrument. ACCULINNA-2 is proposed to become a versatile instrument with broad range of accessible methods: elastic and inelastic scattering, resonant elastic scattering, transfer reactions, Coulomb dissociation, breakup reactions in general and the spectroscopy of a continuum, knockout reactions and the quasi-free scattering, radioactive decays, fusion-evaporation and incomplete fusion reactions. A thorough motivation of research program for this project is formulated in a Letter of Intent [3].

3. Proposed ACCULINNA-2 technical characteristics

The ACCULINNA-2 facility should provide high intensity RIBs in the lowest energy range attainable for the in-flight separators. We emphasize scientific importance of this specific field of research and consequently we choose a cost-effective technical solution for this project.

The prime objectives of ACCULINNA-2 are to provide a good energy resolution for the beams of radioactive nuclei and high efficiency for correlation measurements. The later, combined, for example, with the selection of certain reaction mechanisms and the choice of specific kinematical conditions, could provide the spin-parity identification. Relatively low-energy secondary beams in that case will provide for ACCULINNA-2 a unique position among the other fragment separators. A comparison of the proposed ACCULINNA-2 separator with the other fragment separators, existing or being projected world-wide, is made in Table I.

ACCULINNA-2 will have acceptance allowing one to capture and transmit to the physics target primary beam fragmentation products emitted from the production target within a solid angle of 5.8 msr and having 6% energy spread. This will result in RIB intensities increased by a factor of 10–15 as compared to the intensities achieved at the existing ACCULINNA [2].

The key condition of the ACCULINNA-2 design is its efficiency for high-precision studies of RIB reactions complemented with complete correlation measurements of emitted reaction products.

Also, the unique possibility to work with a cryogenic tritium target (otherwise available only at Sarov and Livermore) should be a distinctive feature of this facility giving unique possibilities for the reaction and nuclear structure studies carried out in vicinity and beyond the neutron drip-line.

TABLE I

Characteristics of in-flight RIB separators. Presented in table are: (1) $\Delta\Omega$ — the solid angle defined by the angular range of RIB nuclei, coming from the production target, which are delivered to the final focal plane of the separator; (2) $\delta_p = \Delta P/P$ — the momentum spread of the RIB accepted by the ion-optical system of the separator; (3) $(B\,\rho)_{\max}$ — the maximum attainable magnetic rigidity; (4) L — the length of the device; (5) $E_{\min}$ and $E_{\max}$ are the minimum and maximum attainable RIB energies.

	ACC/ ACC-2	LISE	A1900	RIPS/ BigRIPS	FRS/ SuperFRS
$\Delta\Omega$, msr	0.9/5.8	1.0	8.0	5.0/8.0	0.32/5.0
δ_p%	2.5/6.0	5.0	5.5	6.0/6.0	2.0/5.0
$(\mathrm{B}\cdot\rho)_{\max}$, Tm	3.2/3.9	4.3	6.0	5.76/9.0	18/18
L, m	21/38	42	35	21/77	74/140
$E_{\min}$, AMeV	10/5	40	110	50/—	220/—
$E_{\max}$, AMeV	40/50	80	160	90/350	1000/1500

TABLE II

Estimated energies and intensities of some primary beams and RIBs attainable from the upgraded U-400M cyclotron and ACCULINNA-2, respectively.

Beam	E AMeV	I pμA	RIB	E AMeV	I pps	Purity (%)
^{7}Li	34	5	^{6}He	22	4.1×10^{7}	>99
^{7}Li	34	5	^{6}He	13	1.1×10^{7}	>99
^{11}B	33	5	^{8}He	22	8.6×10^{4}	> 99
^{11}B	33	5	^{8}B	16	2.2×10^{6}	28
^{18}O	48	3	^{15}B	32	4.3×10^{5}	97
^{20}Ne	54	5	^{13}O	24	1.5×10^{6}	10
^{20}Ne	54	5	^{17}Ne	29	5.4×10^{6}	69
^{36}S	49	3	^{24}O	23	2.5×10^{3}	62
^{36}S	49	3	^{11}Li	30	1.3×10^{4}	80
^{32}S	52	3	^{24}Si	11	7.2×10^{3}	31
^{48}Ca	42	1	^{36}Mg	28	1.2×10^{2}	2
^{48}Ca	42	1	^{27}F	23	4.4×10^{2}	1

A two-stage separation ion-optical system is projected for ACCULINNA-2, see Fig.1.

The first stage, which is an energy loss achromat, a 15-meter straight beam line is suggested to be installed in the new separator. Besides the usual function to host the beam diagnostics detector array this part of the separator involves a (RF) kicker allowing to considerably improve the RIB purity. The energies and intensities estimated for some ACCULINNA-2 RIBs are given in Table II. The planned construction time for the main part of the facility makes 5 years.

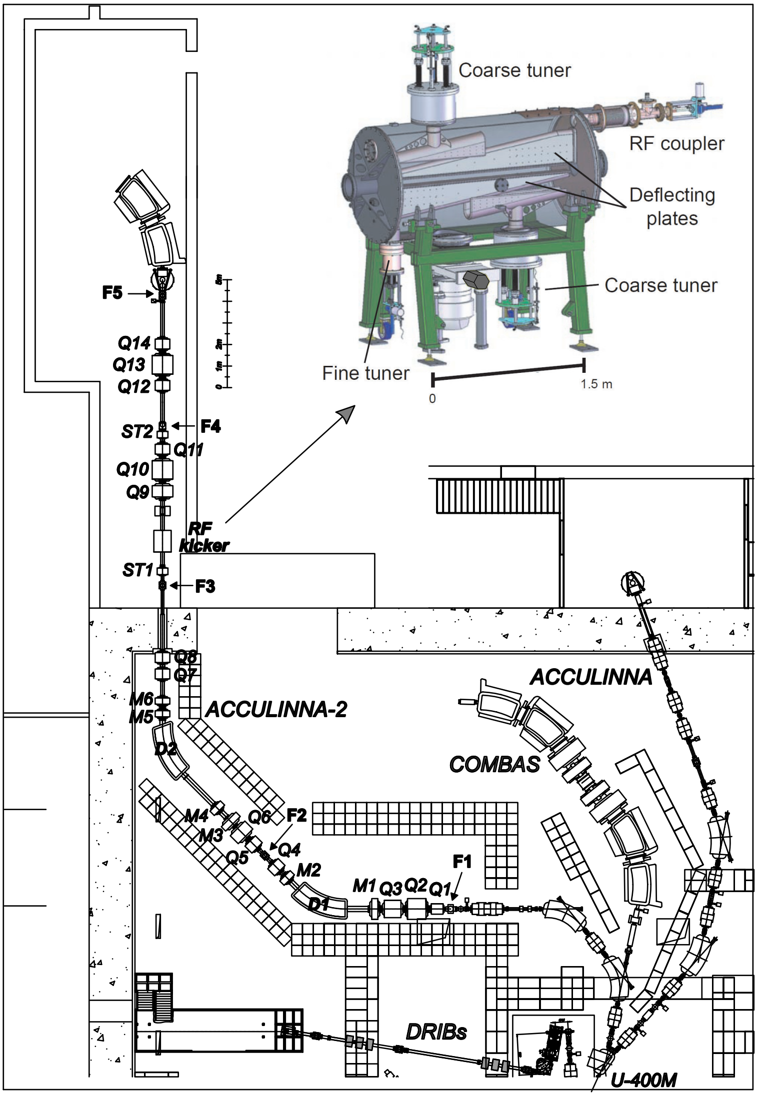

Fig. 1. Schematic layout of the existing ACCULINNA and projected ACCULINNA-2 fragment separators in the U-400M hall. The inset shows the view of the MSU RF-kicker [4].

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