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# HIGH-RESOLUTION MAGNETIC ANALYZER **MAVR**

Воскобойник Е. И. и др. E13-2013-1
Магнитный анализатор высокого разрешения МАВР

Предлагается описание новой установки — магнитного анализатора высокого разрешения (МАВР), в которую входят ионно-оптическая и детекторная системы для сепарации и идентификации продуктов реакций в широком диапазоне масс $(5-150)$ и зарядов $(1-60)$.

С этой целью для магнитного анализатора МАВР создается детекторная система МУЛЬТИ, которая позволит детектировать и идентифицировать продукты ядерных реакций по заряду $Q$, атомному номеру $Z$ и массе $A$ с высокой абсолютной точностью. Идентификация по $A$, $Z$ и $Q$ будет осуществляться посредством измерения потерь энергии $(\Delta E)$, времени пролета (TOF) и полной энергии частиц (TKE). Также будет определяться траектория движения частиц в анализаторе, для чего используется дрейфовая позиционно-чувствительная камера, созданная совместно с GANIL (Франция).

Анализатор МАВР будет работать как на первичных пучках тяжелых ионов, так и на пучках радиоактивных ядер ускорительного комплекса циклотронов У400 и У400М. Он также будет использован непосредственно в качестве анализатора для измерения энергетических спектров продуктов ядерных реакций и в качестве монохроматора энергии.

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High-Resolution Magnetic Analyzer MAVR

A project of the high-resolution magnetic analyzer MAVR is proposed. The analyzer will comprise new ion-optical and detecting systems for separation and identification of reaction products in a wide range of masses (5–150) and charges (1–60).

The MULTI detecting system is being developed for the MAVR magnetic analyzer to allow detection of nuclear reaction products and their identification by charge $Q$, atomic number $Z$, and mass $A$ with a high absolute accuracy. The identification will be performed by measuring the energy loss $(\Delta E)$, time of flight (TOF), and total kinetic energy (TKE) of reaction products. The particle trajectories in the analyzer will also be determined using the drift chamber developed jointly with GANIL (France).

The MAVR analyzer will operate in both primary beams of heavy ions and beams of radioactive nuclei produced by the U400–U400M acceleration complex. It will be also used for measuring energy spectra of nuclear reaction products and as an energy monochromator.

The investigation has been performed at the Flerov Laboratory of Nuclear Reactions, JINR.

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## INTRODUCTION

One of the scientific research fields at the Flerov Laboratory of Nuclear Reactions (JINR) is studying the mechanism of nuclear reactions in beams of accelerated stable and radioactive nuclei. Another research direction is the study of properties of nuclei near the nucleon drip line. Experiments are carried out at the U400 and U400M cyclotrons of FLNR and in cooperation with the research centers GANIL (France), RIKEN (Japan), and Cyclotron Laboratory (Jyväskylä, Finland). The experimental procedure involves magnetic spectrometers and separators that provide high purity separation of reaction products from the primary beam and high resolution in momentum and accordingly in energy and mass.

At FLNR, the stability and structure of very neutron-rich nuclei of the lightest elements ($^{7-10}$He, $^{9-11}$Li, $^{12-14}$Be) were investigated using the MSP-144 magnetic analyzer; the structure of heavy isotopes of these nuclei was investigated using the missing mass method, and their binding energy and stability were determined. The data on the energy levels in the nuclei $^{7,8,9}$He, $^{10,11}$Li, and $^{13}$Be were obtained for the first time. The experiments were simultaneously conducted in Dubna and Berlin using intense beams of $^{11}$B, $^{13}$C, and $^{14}$C heavy ions and the MSP-144 and Q3D precision magnetic spectrometers [1, 2]. In one of the U400 channels a beam energy monochromatization system was installed. In combination with the MSP-144 magnetic analyzer it allowed producing beams with a high-energy resolution (no worse than 250 keV). When it became possible to obtain relatively intense beams of radioactive nuclei at the U400M cyclotron, a system was developed for separating nuclear reaction products resulting from fragmentation of the 50 MeV/nucleon primary beam on the production target (QD spectrometer). This magnetic system allowed secondary beams of $^{6}$He and $^{9}$Li nuclei with an intensity of $10^4$ s$^{-1}$ to be produced and then used them in the first experiments for measuring angular distributions of the $^{6}$He and $^{9}$Li ions elastically scattered from various target nuclei. Data on interaction radii of these nuclei were obtained for the first time [3, 4]. Later experiments on measurement of excitation functions for complete fusion reactions with subsequent evaporation of neutrons and fission in a wide energy range (10–70 MeV) were carried out with $^{6}$He beams of the DRIBs acceleration complex using the MSP-144 spectrometer. These experiments were the first to yield results indicating to a possibility of deep sub-barrier fusion of $^{6}$He (neutron halo nucleus) with other heavy nuclei [5, 6]. These results stimulated further experimental and theoretical investigations of sub-barrier reactions with loosely bound nuclei in many research centers and are still a topic for discussion at practically all international conferences on physics of exotic nuclei. A series of experiments was carried out at the QD spectrometer to study energy dependences of total reaction cross sections for interaction of $^{4}$He, $^{6}$He, $^{6,7}$Li, and $^{9}$Li nuclei with Si nuclei [7]. A unique procedure based on the use of an active Si target, which is a multilayer semiconductor telescope of thin Si detectors, allowed one-by-one detection and identification of nuclear reaction products and determination of their total interaction cross section as a function of energy. It was an important step toward understanding the mechanism for interaction of loosely bound nuclei in a wide energy range.

Startup of the new DRIBs complex for acceleration of radioactive beams opened up new possibilities for those investigations [8]. Reactions with $^{6}$H nuclei near the Coulomb barrier energy were further investigated at a new experimental level (relatively high intensity of radioactive beams, good momentum resolution of the MSP-144. The intensity of the $^{6}$He beam on the physical target was $3-5 \cdot 10^{7}$ s$^{-1}$, which allowed the previous experimental sensitivity to be improved by several orders of magnitude. In addition, monochromatization of the secondary beam energy by the magnetic spectrometer made it possible to measure excitation functions for fusion and neutron transfer reactions with $^{6}$He nuclei with an accuracy no worse than 300 keV. The supporting evidence was obtained for the earlier observed enhancement of the cross section for complete fusion of $^{6}$He nuclei in the sub-barrier energy region [9]. Measurements of the cross section for fusion with $^{4}$He nuclei with the formation of the same compound nucleus as in the case of fusion with the $^{6}$He nucleus revealed a great difference between the interaction mechanisms of these two neighboring nuclei. Interesting results were obtained for transfer reactions involving loosely bound nuclei (single- and two-neutron transfers from the $^{6}$He nucleus [10] and deuteron transfer from the $^{6}$Li nucleus [11]). In both cases the maxima of the transfer reaction cross sections corresponded to the energy equal to the Coulomb interaction barrier and were as high as one barn. These results are of great interest to nuclear physics and astrophysics. It is worth mentioning that all those experiments were conducted in close collaboration with physicists from the JINR Member States: NPI ASCR (Rez, Czech Republic), IFIN–HH (Bucharest, Romania), NINP PAS (Cracow, Poland), and others.

The results of the investigations since 2007 have been published as scientific and methodological papers (more than 70) in refereed Russian and foreign scientific journals and reported practically at all large international conferences on investigation of exotic nuclei and nuclear reactions in stable and radioactive beams. They were most actively discussed at the Symposia on Exotic Nuclei EXON 2009 in Sochi and EXON 2012 in Vladivostok.

In 2013–2017, it is planned to continue investigations of mechanisms for nuclear reactions due to beams of rare stable nuclei, such as $^{36}$S, $^{48}$Ca, $^{58}$Fe, and $^{64}$Ni, and with beams of radioactive nuclei in a wide energy range from sub-barrier energies to several tens of MeV/nucleon. When started up, the upgraded U400R cyclotron and the DRIBs III acceleration complex for beams of radioactive nuclei will extend the experimental possibilities. Characteristics of nuclear reactions will be measured using the magnetic analyzer MAVR with a high-energy resolution. Investigations with the magnetic analyzer at a new experimental level include the following:

1. A possibility of detecting and identifying reaction products in the nuclear mass region $A = 40{-}100$.

2. An order-of-magnitude increase in the solid angle of the magnetic analyzer.

3. Higher degree of separation of reaction products from the high-intensity primary beam.

4. A possibility of performing correlation measurements at forward angles with a primary beam of relatively high intensity.

These goals are supposed to be achieved by creating and using a high-resolution magnetic analyzer MAVR based on the magnet of the MSP-144 spectrometer. The analyzer will be characterized by a large solid angle (30 msr), high momentum resolution ($10^{-4}$), and high dispersion along the focal plane (1.9 m). It will allow nuclear reaction recoils at beam energies up to 30 MeV/nucleon to be detected with a high charge resolution, which is particularly important for separation of heavy nuclear reaction products.

It is also planned to use the MAVR analyzer at the DRIBs III acceleration complex with its beams of radioactive nuclei. In this case, MAVR can be used as a spectrometer for measuring energy spectra of reaction products and as monochromator of these products (the energy resolution will depend on the position of the product in the focal plane and its spatial extension).

One of the physical problems that can be solved with the setup is synthesis of isotopes of light and medium nuclei near the neutron or proton drip line and investigation of their properties and their formation mechanism in various reactions.

An important objective is also investigation of sub-barrier processes in fusion and transfer reactions with the participation of loosely bound halo-like nuclei $^{6}$He, $^{8}$He, $^{9}$Li, $^{11}$Li, and $^{8}$B produced as secondary beams. This experimental investigation is of great interest for solving fundamental problems of nucleosynthesis in astrophysics.

The program of investigations in this field can include the following:

- Determination of nucleon stability/instability of exotic nuclei.
- Measurement of their mass using the missing mass method.
- Investigation of excited states and resonances in exotic nuclei.
- Search for cluster states in light nuclei.

Thus, we can formulate two main goals of the project.

1. Measurement of mass, charge, and energy distributions of $A = 40{-}100$ products from nuclear reactions with heavy ions at energies $10 \leqslant E \leqslant 30$ MeV/nucleon with a high momentum resolution ($10^{-4}$ or better) at forward angles.

2. High-energy-resolution investigation of nuclear reactions induced by beams of light exotic nuclei from the DRIBs III complex at near-barrier energies.

Exotic nuclei are synthesized in various reactions, such as nuclear fragmentation, transfer reactions, reactions with emission of light charged particles, etc.

## 1. MULTINUCLEON TRANSFER REACTIONS

Until now few-nucleon transfer reactions have been systematically studied only at incident heavy ions energies of up to 10 MeV/$A$. It was shown that those were quasi-elastic reactions that proceeded with a considerable kinetic energy loss [12]. With the isotopic distributions of transfer reactions being of statistical character and on the assumption that the interaction in question is a binary process, the isotope production cross sections can be described using the so-called $Q_{\rm gg}$ systematics that defines dependence of the isotope production cross sections on the difference between the masses of the initial and final products $[Q_{\rm gg} = (M_1 + M_2) - (M_3 + M_4)]$ [12].

Joint Dubna–GANIL experiments with $^{112}$Sn and $^{48}$Ca beams on synthesis of nuclei near the nucleon drip line ($^{100}$Sn and $^{28}$O) at an energy of 50 MeV/nucleon [13] showed that a number of very neutron-rich nuclei are produced in multinucleon exchange reactions, or transfer reactions, even at higher energies (60–100 MeV/nucleon). Thus, there is still no unambiguous answer to the question of how the contributions of different interaction channels (nuclear fragmentation and nucleon transfer) vary with increasing energy of bombarding particles. This answer can be obtained by measuring cross sections for reactions of neutron or proton pickup/stripping by/from an incident ion or of nucleon exchange between the ion and the target.

One of the goals of the project is investigation of cross sections for production of neutron-rich isotopes at the neutron drip line in order to find optimum conditions (type and energy of accelerated beam particles, target nuclei, angular distribution of reaction products) for their synthesis in various reactions. These investigations yield important information for producing beams of exotic nuclei by both the ISOL method and the fragment separator method.

In addition, multinucleon transfer reactions with neutron-rich nuclei ($^{36}$S, $^{48}$Ca, $^{58}$Fe, $^{64}$Ni, etc.) can be the only effective method for synthesis of new nuclei in the region of the assumed shells $N = 32, 34$ ($^{45}$Al, $^{46}$Si, $^{50}$S, $^{52}$Cl). Production cross sections for Ca isotopes calculated by the LISE code (for fragmentation [15] as a function of $Q_{\rm gg}$-value) are compared in Fig. 1, which evidently reveals a considerable advantage of transfer reactions for production of neutron-rich Ca isotopes.

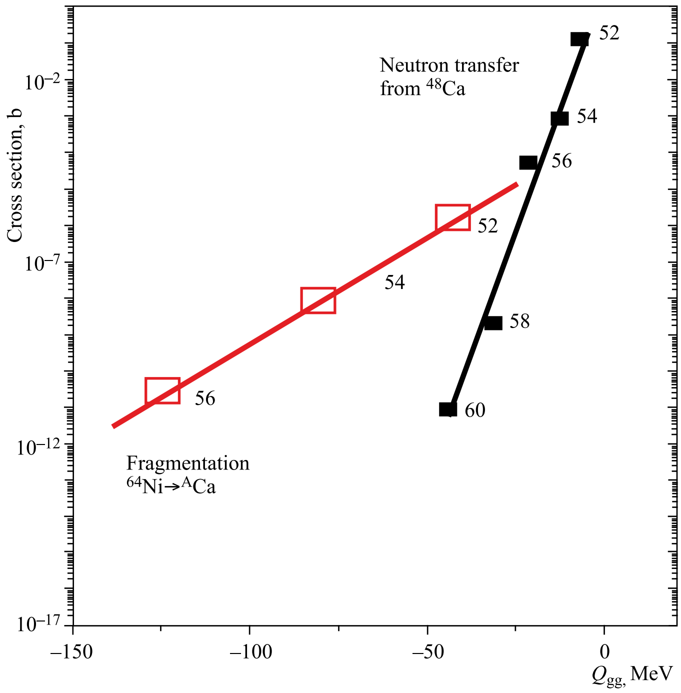


Fig. 1. Total cross sections for production of Ca isotopes in the fragmentation reaction using the $^{64}$Ni beam (left line) and in the nucleon transfer reaction using the $^{48}$Ca beam (right line) as a function of $Q_{gg}$-value

Definite data on the production cross sections, yields, and production mechanisms (fragmentation or multinucleon transfer) of the isotopes can only be gained from the experiment with the MAVR magnetic analyzer that allows nuclear reaction products in this region of nuclei ($A = 30-100$) to be identified with a high $Z$ and $A$ resolution.

It is equally important to investigate deep inelastic transfer reactions in the beam of ions with a mass $A > 100$ and ultimately the $\mathrm{U}+\mathrm{U}$ reaction.

As was shown in [16], those reactions could result, with a relatively high probability, in production of neutron-rich nuclei near the neutron drip line. It is not improbable that these reactions can be effective for synthesis of superheavy elements. In [17], where mass distributions of $\mathrm{U}+\mathrm{U}$-reaction products were studied, manifestations of shell effects were convincingly revealed in the yield of heavy products from that reaction. This confirms the possibility of synthesizing magic nuclei in reactions like that and conservation of stabilizing shell effects. Characteristics of similar reactions with heavy nuclei (mass and charge distributions) are also planned to be investigated using the MAVR analyzer.

## 2. COMPLETE AND INCOMPLETE FUSION REACTIONS IN BEAMS OF LOOSELY BOUND RADIOACTIVE NUCLEI

An important objective of heavy-ion nuclear physics is investigation of the mechanism for deep sub-barrier reactions with loosely bound and halo nuclei $^6$He, $^8$He, $^9$Li, $^{11}$Li, etc.

Reactions with loosely bound nuclei have a few specific features. One of them is an increase in the interaction cross sections in the sub-barrier energy region. This effect is especially strong for neutron-halo nuclei ($^{6,8}$He, $^{9,11}$ Li) [11, 18]. The main interaction channels for these nuclei are transfer reactions, breakup reactions, and complete fusion reactions. According to the classical concepts, interacting nuclei undergo fusion after overcoming the barrier defined by the long-range Coulomb forces and the component of the short-range nuclear potential. However, fusion in the interaction of loosely bound nuclei is a more complicated process because of a great probability for the breakup of these nuclei followed by the capture of the residual nucleus (incomplete fusion). This makes interaction of such systems appreciably difficult to describe and leads to new unexpected effects at energies near the Coulomb barrier: deep sub-barrier fusion and reactions of neutron, or rather cluster transfer from loosely bound nuclei, which usually have a cluster structure. Cross sections for these reactions can be about a barn at an energy near the Coulomb barrier (Fig. 2), which confirms the existence of an unusual mechanism for fusion and nucleon transfer in the interaction of halo and loosely bound cluster nuclei with target nuclei. The breakup process followed by the residual nucleus fusion is also a subject of numerous theoretical and experimental investigations.

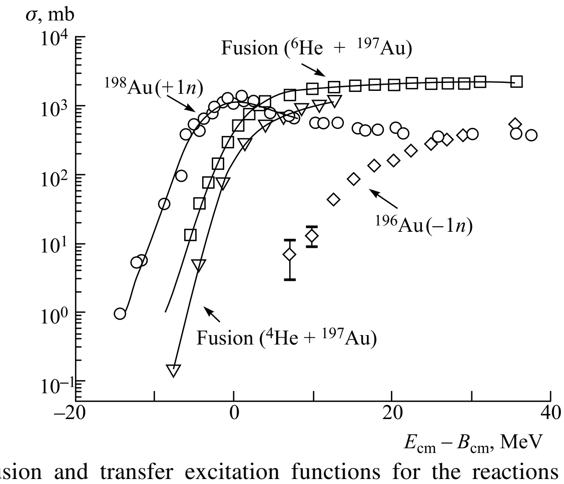


Fig. 2. The fusion and transfer excitation functions for the reactions $^{197}\mathrm{Au} + {}^6\mathrm{He}$ and $^{197}\mathrm{Au} + {}^4\mathrm{He}$ as a $E_{\mathrm{cm}} - B_{\mathrm{cm}}$

**Table 1**

| Reactions | | Compound nuclei | Reactions | | Compound nuclei | | Recoil nuclei |
|---|---|---|---|---|---|---|---|
| $^{14}\mathrm{N}+{}^{9}\mathrm{Be}$ | $\rightarrow$ | | $^{4,6,8}\mathrm{He}+{}^{44,42,40}\mathrm{Ca}$ | $\rightarrow$ | $^{48}\mathrm{Ti}$* | $\rightarrow$ | |
| $^{11}\mathrm{N}+{}^{9}\mathrm{Be}$ | $\rightarrow$ | | $^{4,6,8}\mathrm{He}+{}^{12}\mathrm{C}$ | $\rightarrow$ | $^{16,18,20}\mathrm{O}$* | $\rightarrow$ | $^{15,17,19}\mathrm{O}+n$ |
| $^{16}\mathrm{O}+{}^{7}\mathrm{Li}$ | $\rightarrow$ | $^{23}\mathrm{Na}$ | $^{4,6,8}\mathrm{He}+{}^{14}\mathrm{C}$ | $\rightarrow$ | $^{18,20,22}\mathrm{O}$* | $\rightarrow$ | $^{17,19,21}\mathrm{O}+n$ |
| $^{19}\mathrm{F}+{}^{4}\mathrm{He}$ | $\rightarrow$ | | $^{6}\mathrm{He}+{}^{13}\mathrm{C}$ | $\rightarrow$ | $^{19}\mathrm{O}$* | $\rightarrow$ | $^{18}\mathrm{O}+n$ |

Experiments with loosely bound cluster nuclei are planned to be conducted within the DRIBs III project, where the U400R cyclotron serves as a post-accelerator.

In this case, the MAVR magnetic analyzer can be used not only as a setup for identification and separation of nuclear reaction products but also as a monochromator, which allows reaction cross sections at near-Coulomb-barrier energies of the particle beam to be measured with a high-energy resolution.

Complete fusion reactions with light beam nuclei followed by neutron evaporation are also of interest. They are decisive reactions for the nucleosynthesis scenario in astrophysics [20]. Table 1 presents examples of these reactions. The problem of identifying residual nuclei from fusion reactions of light nuclei can also be effectively solved within the proposed project.

These investigations are carried out most effectively with the magnetic analyzer and monochromatic beams of loosely bound nuclei.

## 3. PROPOSED MAVR TECHNICAL CHARACTERISTICS

The investigations described above require high $Z$ and $A$ selectivity of reaction products, a large solid angle of reaction product detection, a high-energy resolution, and a high purification factor in separation from the primary beam. In addition, it is necessary to segregate events from the background, which is $10^{10}$ to $10^{12}$ times higher, with an energy resolution of up to $10^{-3}$, i.e., it is needed to combine the high-energy resolution with a high degree of purification from the primary beam.

The momentum resolving power $\Delta p/p \sim 10^{-4}$ obtained by magnetic analysis allows one to have the energy resolution of about 100 to 200 keV for the bombarding particles like $^{12}$C, $^{16}$O, $^{20}$Ne at energies up to 30 MeV/$A$. In view of this, the experimental setup should meet the following requirements:

1. The solid angle of the setup should be no smaller than 30 msr to allow carrying out highly efficient correlation experiments.

2. It should be possible to detect nuclear reaction products, including neutrons, in a wide range of angles, among them the angle $\Theta_{\mathrm{lab}} = 0°$.

3. It should be possible to compensate for the kinematical spread of nuclear reaction products at a large solid angle.

Various detector techniques in combination with a high-resolution magnetic analyzer MAVR are supposed to be used for ensuring better efficiency of heavy ion beams and beams of radioactive nuclei from the DRIBs acceleration complex. The proposed magnetic analyzer will have a large solid angle for detection of reaction products (up to 30 msr), a high momentum resolution ($10^{-4}$), and a high dispersion in the focal plane (1.9 m). This analyzer will allow products of nuclear reactions at energies up to 30 MeV/nucleon to be detected with a high charge resolution ($\sim 1/60$), which is especially important for separation of heavy nuclear reaction products. It is planned to construct the analyzer in two stages.

At the first stage, the analyzer will be equipped with a special beam collimation system, instrument transducers for precision measurement of the magnetic field (NMR teslameter), profilometers based on multiwire proportional chambers, and a time-of-flight measurement system. A new detector module based on drift chambers and VME electronics will be made and tested.

At the second stage, the MAVR analyzer will be mounted in the new U400R hall. The layout of the spectrometer in the U400R experimental hall, now under construction, is shown in Fig. 3. The MAVR construction is supposed to involve the following activities.

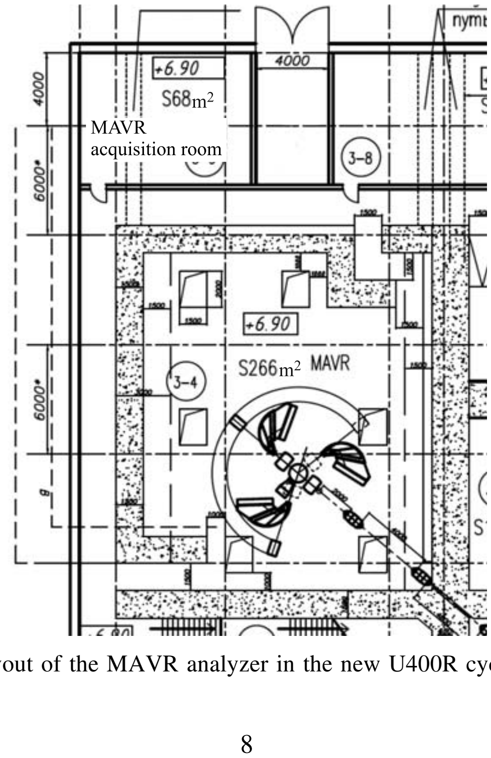


Fig. 3. Layout of the MAVR analyzer in the new U400R cyclotron hall

**3.1. Development of the Magnetic Optical System for the MAVR Analyzer.** The MSP-144 magnetic spectrometer is intended for analyzing and detecting products of nuclear reactions in beams of accelerated ions with the maximum magnetic rigidity up to 1.45 Tm. This broad-range stepped-poles magnetic spectrometer was developed for analysis of light products of nuclear reactions with protons. High ion-optical parameters of the spectrometer allow its electromagnet to be used for analyzing heavy nuclear reaction's products with masses $A = 40 - 100$. The magnet consists of two regions. The magnetic field in the first region is 1.46 to 1.5 times lower than in the second region. This magnet is characterized by a wide energy range of detected reaction products ($E_{\min}/E_{\max} = 5.2$), high dispersion-to-enlargement ratio $D_\triangle/M_x \approx 6.3$ m, and relatively large solid angle $\Omega$ up to 5 msr. It has a high resolving power $R_\triangle = 2000$ and a high dispersion $D_\triangle = 1.9$ m. This spectrometer is second to those currently available in other research centers only in the solid angle.

As an example, Fig. 4 shows the result obtained with the MSP-144 to illustrate the possibility of achieving good separation of products that result from the reaction due to $^{32}$S beam [21]. The proposed MAVR analyzer is supposed to have a larger solid angle for more effective collection of nuclear reaction products. To this end, additional focusing elements will be installed behind the physical target in front of the entrance to the spectrometer, which will increase the solid angle $\Omega$ by a factor of 5 to 6.

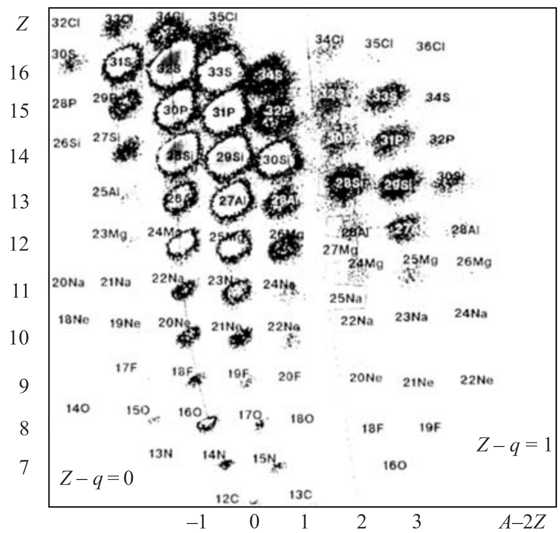


Fig. 4. Identification matrix for $^{32}$S(14.5 MeV/$A$) + C reaction products in the ($A - 2Z$, $Z$) form obtained at the MSP-144 magnetic spectrometer

**3.2. Increasing the Solid Angle of the Magnetic Analyzer.** The solid angle of the reaction product capture can be increased to 30 msr by installing two quadrupole lenses and moving the target from its current position as far as $S = 1.7$ m. For this purpose, it is necessary to manufacture two quadrupole lenses with magnetic field gradients $-1018$ Gs/cm and $+895$ Gs/cm.

A doublet of quadrupoles in front of the analyzer will decrease the distance $S$ between the entrance to the magnet and the new position of the target as compared with a single quadrupole [22], and increase the horizontal acceptance of the analyzer by a factor of 3. The vertical size for reaction product capture in front of the entrance to the analyzer will decrease to the size of its vertical aperture, and the vertical acceptance of the separator $y'_0$ will increase by a factor of 6. The dispersion in the focal plane of the analyzer will practically stay unchanged whereas the resolving power will decrease by about a factor of 3.

The calculations [22] show that the most effective way to increase the solid angle of the existing spectrometer is to use a doublet of quadrupoles. Given the calculated geometry of the quadrupoles and the field gradients $G_1 = -1018$ Gs/cm and $G_2 = +895$ Gs/cm, the product of the angular acceptances of the separator (solid angle) will be about 30 msr. This, in turn, will require manufacturing a new receiving chamber for the focal detector, in view of a change in the position of the focal plane.

Table 2 presents the expected characteristics of the MAVR analyzer in comparison with the spectrometers at other research centers.

**Table 2. Characteristics of magnetic analyzers**

| | $D$ (cm/%) | $\Delta p/p$ (%) | Br (Tm) | $d\Omega$ (msr) | Energy resolution, $dE/E$ | TOF resolution, $dT$ |
|---|---|---|---|---|---|---|
| MAVR | 1.9 | 10 | 1.5 | 30 | $5 \cdot 10^{-4}$ | |
| VAMOS | 2.5 | 10 | 2.3 | 80 | $5 \cdot 10^{-4}$ | |
| SPEG | 7 | 7 | 3.2 | 4.9 | $5 \cdot 10^{-4}$ | |
| PRISMA | 4.0 | 10 | $\sim 2.0$ | 80 | $1 \cdot 10^{-3}$ | |
| Q3D(HMI) | 9.5 | 10 | 1.7 | 10 | $2 \cdot 10^{-4}$ | $< 1$ ns |

**3.3. Detecting System.** The MAVR magnetic analyzer is supposed to accommodate a specially developed MULTI detecting system capable of detecting and identifying nuclear reaction products by charge $Q$, atomic number $Z$, and mass $A$ with a high absolute accuracy.

Figure 5 shows a model of the MAVR magnetic analyzer with a new reaction chamber and a doublet of lenses. The MAVR can rotate through an angle up to 112° relative to the beam axis.

Nuclear reaction products will be identified by $A$, $Z$, and $Q$ through measurement of the energy loss ($\Delta E$), time of flight ($T$), and total energy ($E$) of

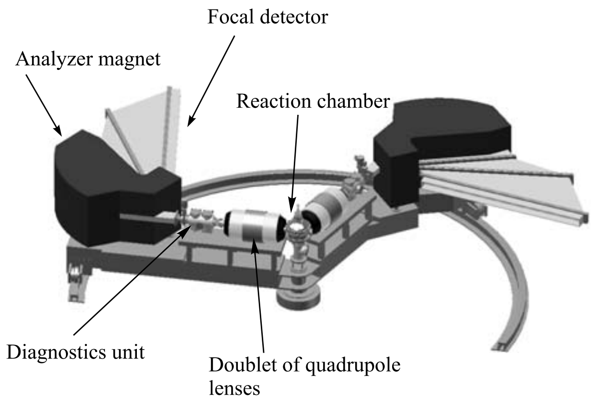

Fig. 5. General view of the MAVR high-resolution magnetic analyzer

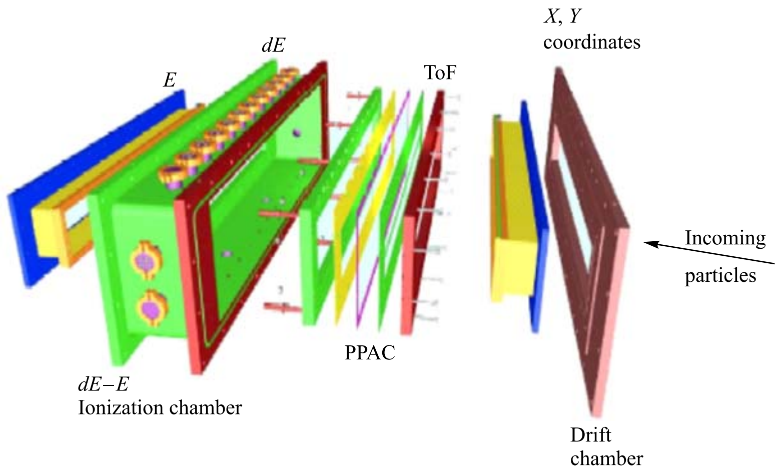

Fig. 6. Schematic view of the detecting system

particles, i.e., the dependences $\Delta E{-}E$ and $\Delta E{-}T$ (or $E{-}T$), which requires reproduction of the particle motion trajectory in the analyzer. This will be done using the drift chamber developed together with the VAMOS group (GANIL).

The drift chamber to be used for measuring the particle energy loss ($\Delta E$) and total energy ($E$) is schematically shown in Fig. 6. The time of flight will be measured using the parallel-plate-avalanche detector (PPAC).

Correlated reaction products arriving at the focal detector can be detected by position-sensitive semiconductor telescopes and also by a multiwire proportional chamber [23]. Since the range of problems to be solved by the proposed setup is rather wide, the focal detector will be made as a set of individual compatible modules.

## 4. EXPECTED PERIOD OF CONSTRUCTION AND ESTIMATED COST OF WORK

It is planned to construct the MAVR setup in 4 years. Preparatory work and manufacture of individual units will be carried out independently of the construction of the extension to the U400R accelerator hall.

The estimated cost of the work to design and manufacture MAVR setup units and to mount and test the MAVR setup is about $750,000.

**Collaborating organizations.** INRNE, BRV, BAS (Sofia, Bulgaria); NPI, AS, CR (Rez, Czech Republic); INP, PAS (Cracow, Poland); GANIL (Caen, France), IPN (Orsay, France); NRC Kurchatov Institute (Moscow, Russia); AANL (Yerevan Phys. Inst., Yerevan, Armenia); JYFL (Cyclotron Laboratory, University of Jyväskylä, Finland); IP VAST (Institute of Physics, Vietnam Academy of Science and Technology, Hanoi, Vietnam).

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