RECENT MODERNIZATION OF IAE CYCLOTRON IN MOSCOW

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Summary. A review of a number of recent works on modernization of the IAE 150-cm isochronous cyclotron used to carry out scientific and applied researches is presented.

The accelerator was reconstructed so as to work with a kW external beam of protons. A regular production of radioisotopes was arranged with its help.

The ion-optic beam transport system was reconstructed to extend the cyclotron possibilities for performing physical experiments. A system of low-background collimation of the beams was created.

Experimental comparison of various types of sources of multicharge lithium ions and with various types of working matter has been made on the cyclotron.

A magnetic achromatic selector of ion energies intended to study nuclear reactions at small angles, 0° included, has been developed.

Text

A 150-cm isochronous cyclotron[1] based on the old one operating at the Kurchatov Institute of Atomic Energy (IAE) was put into operation in 1977. The new cyclotron provides scientific and applied researches with external beams having the following parameters.

Ions	Energy, MeV	Intensity, μA	Restrictions
p	10 - 35	30	deflector
d	5 - 31	30	same
^{3}He	18 - 70	25	same
^{4}He	10 - 62	30	same
^{6}Li	15 - 93	15($^6Li^{2+}$) 2.5($^6Li^{3+}$)	source of ions same
^{7}Li	12 - 82	12(2^+) 2(3^+)	same same
^{9}Be	$\leqslant 55$	7(2^+) 2(3^+)	same same
$^{12}C^{4+}$	$\leqslant 72$	30	same
$^{14}N^{5+}$	$\leqslant 110$	13	same
$^{16}O^{6+}$	$\leqslant 136$	1	same
heavy ions	$\leqslant 62z^2/A$	f (z)	

In 1981 a new beam transport system was developed and put into operation, which permitted experiments to be carried out in five rooms (Fig. 1) designed for eight targets

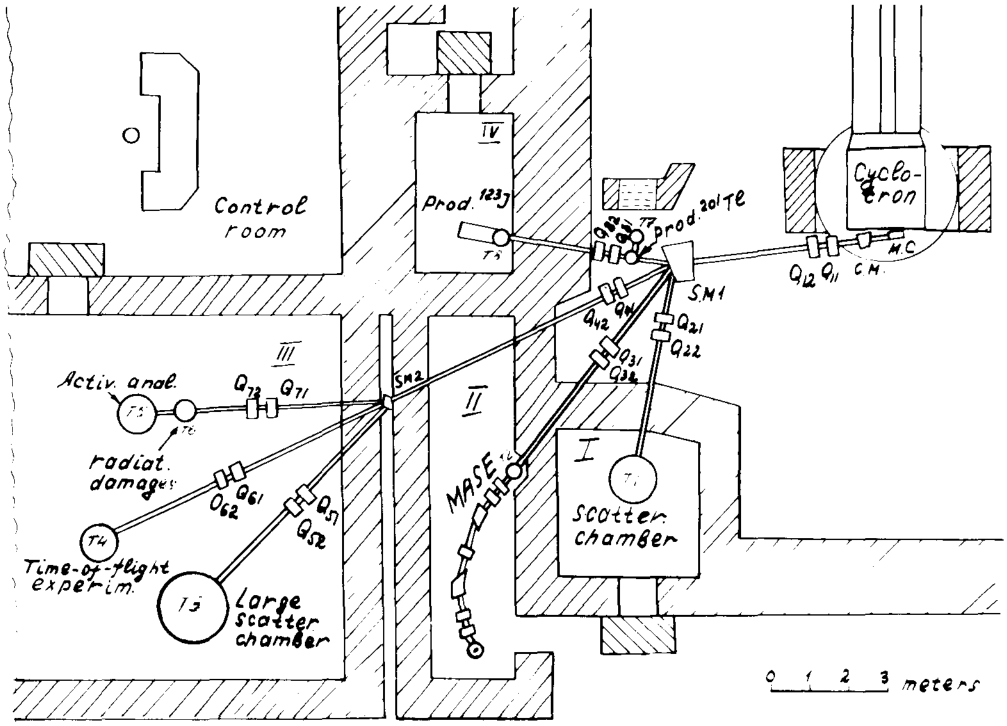

Fig. 1. Scheme of ion transport system: Q- quadrupole magnet; m.c.- magnetic channel; c.m.- correcting magnet; SM1 and SM2- switching magnets.

with the following specialization: T1, T2, T3 for correlation experiments, multipole resonance investigations and search for neutron-rich nuclei; T4 for time-of-flight neutron experiments (measurement of neutron constants, study of preequilibrium states); T5 for activation analysis; T6 for radiation damage studies; T7, T8 for radioisotope production for medical purposes, mainly.

Special attention was paid to production of lithium ions since these ions were used by most groups of physicists in their experimental investigations, and earlier we had developed intensive sources of multicharged lithium ions[2].

To perform nuclear-physical experiments which require detection of particles emerging from the target at small angles (including the 0° angles) relative to the primary beam, the MASE device was developed[3] and installed in room II (Fig. 1). Need for the development of such a device arose from investigations of giant multipole resonances where already in decreasing the detection angle to 10° the background of elastically scattered primary particles overloads the detecting equipment so that it makes it practically impossible to use conventional methods of measurement. And at the 0° angle being of greatest interest the number of elastically scattered particles may exceed the measured effect by more than 10 orders of magnitude. The magneto-optical system of this device is a symmetric achromat (Fig. 2) where two pairs of quadrupole magnet doublets are used for spatial focusing; the pulse beam analysis is performed by a dipole uniform-field magnet with a 54° bevelled outlet edge; dispersion trajectories are symmetrized by a quadrupole singlet and collected by a focusing magnet bilaterally symmetric to the analyzing magnet and by a quadrupole doublet.

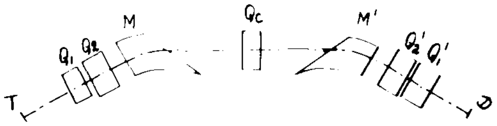

Fig. 2. Ion-optical system MASE: T- target; Q_1, Q_2 and Q_2', Q_1'- quadrupole magnet pairs; Q_c- symmetrizing quadrupole singlet; M- analyzing magnet; M'- collecting magnet; D- detector system.

The beam envelopes in both the planes and the dispersion trajectory are shown in Fig. 3. The main parameters of the device are as follows.

Rated magnetic rigidity	1.17 T·m
Length	~4.0 m
Dispersion in MASE centre	2.3 mm/1% E_0
MASE displacement angle range	-2° - +20°
Maximum selected angle	2°
Maximum range of selected energies	15% E_0
Total weight of magneto-optical system	650 kg

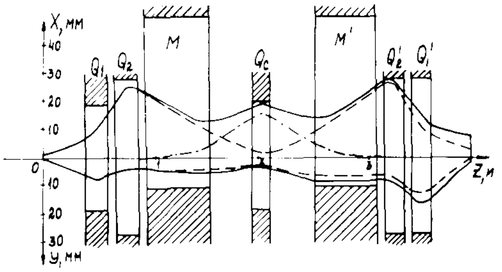

Fig. 3. MASE beam envelopes in horizontal (x) and vertical (y) planes: for energy range of ±7.5% E_0 (———); for monoenergetic beam (- - -); dispersion trajectory (-•-).

After its physical start-up the device is being prepared for the first nuclear physical experiment.

As has been mentioned above, the nuclear-physical experiments on the IAE cyclotron are performed predominantly using lithium ions. Though the IAE crucible-type source of lithium ions[2] provides us with highly intensive external lithium ion beams, lithium contamination of the acceleration chamber during the operation requires weakly cleanings which breaks the vacuum in the chamber and, thus, reduces the cyclotron operation efficiency. Therefore, other types of lithium ion sources were developed which were tested both at the test bed and at the cyclotron[4].

In the first type of the source investigated ion sputtering of the LiF crystal is used, similar to that used in Ref.[5], with lithium penetration into the accelerating chamber being essentially reduced as compared with that in the crucible-type source because the crystal sputtering is not a continuous process and occurs only when the RF voltage is applied to the dees. A conventional sputtering by discharge ions cannot be applied to the LiF crystal which is a dielectric with a quickly charged surface. For this reason the sputtering by xenon ions (on which the discharge is initiated) returning to the source in the nonpotential RF field of the dees at energies up to 100 keV and overcoming the electric field of the crystal charged surface is used. Such a source with the LiF monocrystal (the monocrystal is preferable because it has essentially higher mechanical strength and thermal conductivity than the polycrystalline LiF) has been tested at the cyclotron for the $^6Li^{2+}$ ions. The external beam current was 3 - 5 μA; that operation mode could not be kept as stable as that in the crucible-type source; adjustment of the source is complicated; dusting of the crystal working surface with the material of the cathode and anticathode was observed. Therefore, in spite of the reduced lithium contamination of the acceleration chamber, this source has been rejected as noncompetitive as far as the IAE cyclotron is concerned.

In the second type of the source investigated the intermetallic compound Li_3Bi was used as a working substance. This compound has the following advantages over LiF:

- electrical conductivity suffucient for the electric charge drain;
- a high melting temperature (1140°C);
- a high lithium content (75% by the number of atoms);
- a sufficiently high thermal conductivity;
- a reasonable corrosion resistance.

This source was tested at the cyclotron in the $^7Li^{2+}$ acceleration regime with xenon or argon as a ballast gas and the electric voltage up to 1.5 kV applied between Li_3Bi and the case. The tests have shown that the adjustment of this source is simpler than that of the LiF source; the lithium contamination is essentially lower than that in the crucible-type source but lithium ion currents provided are 3 - 4 times lower as compared with the latter. Therefore, the crucible-type source with metallic lithium has been used so far in the IAE cyclotron.

Since 1984 the IAE cyclotron has been used for radioisotope production as well.[6] For this purpose measures were taken to increase the external beam power up to 1 kW; on one hand, the efficiency of extraction of protons with the energy up to 30 MeV was increased up to 60% by means of an adjustable radial-phase collimator in the central region and, on the other hand, the thermal resistance of the extraction system was improved. Those improvements have not affected the high intensities of the main (lithium) regimes which, in contrast to the proton ones, require high magnetic field inductions. For irradiation of the targets and their discharge into the container a remote-controlled system with a great number of blockings intended to protect them from burning-out has been arranged. Twice a month targets of Thallium-203 are irradiated by the external beam of the cyclotron to produce Thallium-201 from the reaction: $^{203}Tl(p, 3n)^{201}Pb \rightarrow Tl^{201}$, which is used to diagnose heart diseases. About 3 - 4 curies of ^{201}Pb are produced in each exposure.

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