PRODUCTION OF ^{7}Be RADIOACTIVE BEAMS AT IAE CYCLOTRON

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Abstract: At the I.V.Kurchatov IAE cyclotron the conditions are provided for obtaining a beam of ^{7}Be nuclei, which may turn out to be fit for performing scientific (e.g. to study reactions occurring in the interior of stars), as well as applied (with the use of deep implantation of these nuclei) investigations:

1) The external currents of ^{7}Li ions of a few μA are obtained in the energy range of 28 - 82 MeV.

2) The MASE device was developed, ensuring the ^{7}Be ion beam separation with a good degree of purification of other nuclei, the primary beam nuclei included.

3) A gas hydrogen target has been developed, which endures, at the first stage, the ^{7}Li currents up to 1 μA at the energy of 30 MeV with the controllable hydrogen pressure up to $3\cdot10^5$ Pa. The target is being constructionally modified and optimized in order to obtain the ^{7}Be beam intensity up to $10^7\ s^{-1}$.

In the experiments perfomed the maximum ^{7}Be beam intensities reached $\sim 5\cdot10^6\ s^{-1}$ at the energy of $\sim$20 MeV, and $\sim 2\cdot10^5\ s^{-1}$ at 75 MeV.

The localization of radioactivity from deeply implanted ^{7}Be nuclei is shown.

1. Introduction

Recently, the production and use of beams of radioactive nuclei [1] have attracted much interest. Special attention is paid to the production of a beam of ^{7}Be nuclei [2] used for studying nuclear reactions proceeding in stars.

The ^{7}Be beam with a sufficiently small energy spread (E $\sim$ 1 - 2 MeV), the energy of a few tens of MeV and intensity of $10^6 - 10^7\ s^{-1}$ can additionally have a number of interesting applications, since the thickness of implanted ^{7}Be nucleus layer in materials at the depth of a few tens or even hundreds of μm amounts to a few per cent of the implantation depth, and this thin layer is a source of monochromatic gamma-radiation (E_γ = 478 keV) during a long period of time (since the half-life of ^{7}Be is $T_{1/2} \sim 53$ days). The gamma-radiation measurement of ^{7}Be nuclei implanted into the thin layer can be used, e.g., for studying wear or corrosion of important parts in engineering industry, as well as in investigating the diffusion of nuclei in matter.

The ^{7}Be beam with the above parameters without significant impurities of other nuclei (otherwise, the results of experiments with the ^{7}Be nuclei would be of low quality) can be produced on a small-sized (D = 15 mm) target by means of a cyclotron, provided the following conditions are satisfied.

1) The cyclotron should produce external ^{7}Li ion beams with their adjustable energy in the range of 20 - 80 MeV with the currents of several μA. The accelerated ^{7}Li ions are necessary for employing the H(^{7}Li, ^{7}Be)n reaction for the production of the ^{7}Be nuclei. This reaction has a very high ($\sim$ 300 mb) cross section [3] in the energy range from 15 to 40 MeV, which, thereupon, decreases monotonically with energy. The ion energy adjustment is required for changing the energy of ^{7}Be nuclei in performing experiments in order, e.g., to implant these nuclei at some preselected depth in a rather wide possible interval (for aluminium down to 0.3 mm at the ^{7}Be energy of about 70 MeV). In this reaction in the ^{7}Li energy range of 20 - 80 MeV the ^{7}Be nuclei are produced in the ground ($\sim$85%) and excited states and their kinetic energy at 0° with the primary beam direction differs less than by 1 MeV, so that the ^{7}Be energy spectrum is sufficiently narrow and will be determined, mainly, by the ^{7}Li beam energy spread and the hydrogenous target thickness. In this reaction the ^{7}Be nuclei are emitted, for the most part, at small angles with the primary beam (for the ^{7}Li energy of 30 MeV the maximum angle of emission for the ^{7}Be nuclei amounts to $\sim \pm 6^\circ$, and for the 80-MeV energy, to $\sim \pm 7.5^\circ$).

2) An appropriate facility is required for shaping the ^{7}Be beam on a secondary target with a sufficiently small dimensions and for its purification of other nuclei emitted from the primary target (including those from the primary beam). For example, at the Lawrence Livermore National Laboratory (LLNL) the quadrupole sextuplet system [2] with an electrostatic deflector downstream from the first half of the device is employed for this purpose, which allows the ^{7}Be beam purification of the primary scattered ^{7}Li beam. The disadvantage of such a system is the necessity to mount a primary beam stopper downstream from the target, which excludes the region of angles in the vicinity of 0° and creates a high background of primary nuclei.

3) It is necessary to develop thermally stable targets with a high hydrogen content. For example, at the LLNL [2] a polypropylene film 1 mg/cm^2 ($\sim 10^{20}$ atoms of hydrogen per cm^2) thick, covered with a 1000-Å thickness copper layer and continuously crossing the beam in irradiation, is used a target. However, the life time of such a target in irradiation by three-charge lithium ions with the energy of 28 MeV and current of 0.5 μA ($\sim 10^{12}\ s^{-1}$) amounts merely to about an hour.

2. Experimental Technique

The I.V.Kurchatov IAE cyclotron undergoes modernization so as to ensure that all the three conditions for producing the intensive ^{7}Be beam be fulfilled.

1) The external beams of $^7Li^{2+}$ ions with the variable energy up to 30 MeV and current of 12 μA ($3.6\cdot10^{13}\ s^{-1}$), and of $^7Li^{3+}$ ions with the energy from 30 to 82 MeV and current of 2 μA ($4\cdot10^{12}\ s^{-1}$) were obtained [3]. Such lithium ion beams are provided for by the earlier developed [4] and recently updated ion source employing a powerful arc discharge through metallic lithium vapour.

2) To separate the ^{7}Be beam and to purify it of other nuclei, use is made of the MASE device developed in 1982 [5], which is shown schematically in Fig. 1. The magneto-

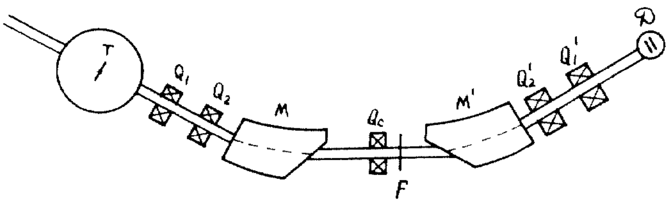

Fig. 1. Scheme of MASE device: T- target; Q_1 - Q_2, Q_2' - Q_1'- quadrupole magnet pairs; Q_c- symmetrizing lens; M- analyzing magnet; M'- collecting magnet; F- foil-degrader for beam purification; D- secondary target (or detector).

optical system of this device is symmetric achromat where two pairs of quadrupole magnets are used for spatial focusing. A momentum analysis is performed by a dipole magnet with a uniform magnetic field and one edge bevelled by an angle of 54° to strengthen the vertical focusing. The particle trajectories with different momenta are symmetrized by a quadrupole singlet and collected on the target by a collecting dipole magnet being reflection symmetrical to the analyzing one. The beam envelopes in both the planes and the trajectory dispersion are shown in Fig. 2.

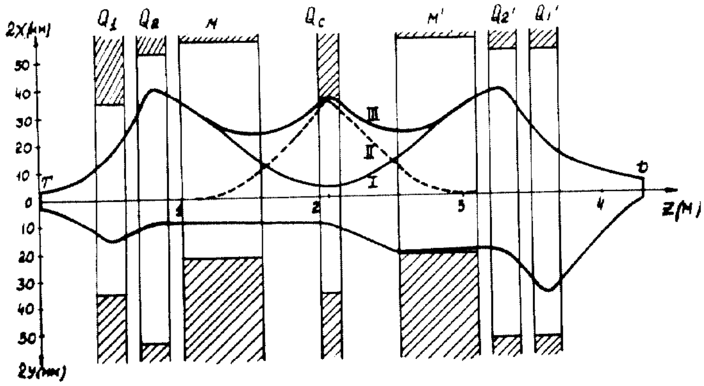

Fig. 2. MASE beam envelopes in horizontal (x) and vertical (y) planes: I- for monoenergetic beam; II- dispersion trajectory (E = ±7.5% of E_o); III- summary one.

The basic parameters of the MASE device are:

Magnetic rigidity	1.4 T·m
Length	4.0 m
Solid angle	1 msr ($Q_x = \pm 1^o$) ($Q_y = \pm 1^o$)
Dispersion in MASE centre	2.3 mm/1% E_o
MASE displacement angle range	-2^o - $+20^o$
Maximum range of selected energies	15% E_o

The device carries out the focusing of an achromatic ($\Delta E/E = 15\%$) beam into a spot with a diameter of ~15 mm. To purify the ^{7}Be beam both from the primary ^{7}Li and other secondary nuclei having the same magnetic rigidities, use is made of a degrader being an aluminium foil of a certain thickness positioned between the first and second halves of the MASE device. In passing this foil, the momenta of different nuclei change differently, due to their dE/dx difference, and there takes place their space separation on the secondary target (detector) of the MASE due to the collecting magnet dispersion. The measurement of energy spectra upon passing the MASE device, as well as the monitoring of the primary beam crossing the primary target are effected by telescopes of silicon ΔE-E detectors.

3) A gas target with variable thickness along the beam up to $3\cdot10^{20}$ hydrogen atoms per cm^2 (the target length is 2 cm, the hydrogen pressure in it is up to $3\cdot10^5$ Pa) has been worked out. To improve its thermal resistance, the target copper casing is cooled by running distilled water; a closed-circuit hydrogen circulation through the target volume is possible by using a compressor. The target inlet and outlet apertures, 9 mm in diameter, are foils made of the "Havar" alloy, 8 μm thick (~6 mg/cm^2), soldered onto the target casing.

To measure the depth distribution of implanted ^{7}Be nuclei, a set of thin (10 μ) aluminium foils located at the place of the secondary target installation in the MASE was irradiated by the beam of these nuclei with a subsequent radioactivity measurement of ^{7}Be nuclei ($E_\gamma = 478$ keV), implanted in each foil, by means of a gamma-spectrometer with a 120-cm^3 volume of the germanium detector.

3. Experimental Results

The maximum $^7Li^{2+}$ current with the 30-MeV energy, which the gaseous hydrogen target can withstand without hydrogen leakages at the pressure of $3\cdot10^5$ Pa, amounts so far to less than 1 μA, which ensures the maximum ^{7}Be beam on the MASE secondary target, $\sim 5\cdot10^6$ s^{-1}. Since the $^7Li^{2+}$ current on this target may be obtained higher by several fold, the target design undergoes modernization. As a result, we hope to produce ~ 10^7 nuclei of ^{7}Be per second (maybe, we shall have to optimize the hydrogen pressure in the target at that). At a higher ^{7}Li energy the target should bear a higher current due to the dE/dx decrease with increasing energy. However, no such tests have been performed.

The results of measuring radioactivity of implanted ^{7}Be nuclei in the 10-μm aluminium foils positioned downstream from the MASE (at two ^{7}Li beam energies of 30 and 82 MeV) are presented in Fig. 3, from which one can see that the radioactivity concentrates in the thin layer shifted inwards the matter with increasing energy of nuclei. This can be successfully used in different scientific and applied investigations.

References

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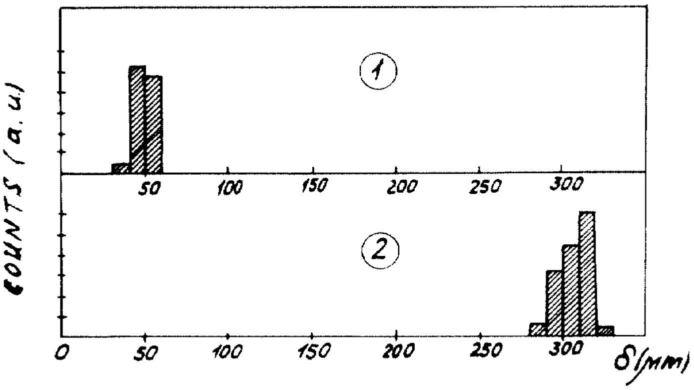

Fig. 3. Histograms of measured radioactivity of ^{7}Be nuclei implanted in aluminium foils placed in MASE second focal plane. The ^{7}Be beam is produced in the hydrogen target at the primary ^{7}Li beam energy of 30 MeV (1) and 82 MeV (2).

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