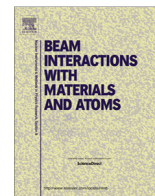




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journal homepage: www.elsevier.com/locate/nimbPreliminary AMS measurements of ^{10}Be at the CENTA facilityMiroslav Jeřkovský^a, Peter Steier^b, Alfred Priller^b, Robert Breier^a, Pavel P. Povinec^{a,*}, Robin Golser^b^a CENTA Laboratory, Faculty of Mathematics, Physics and Informatics, Comenius University, 84248 Bratislava, Slovakia^b VERA Laboratory, Faculty of Physics, University of Vienna, 1090 Vienna, Austria

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ABSTRACT

Very sensitive methods, presently mainly accelerator mass spectrometry (AMS) are necessary for analysis of cosmogenic ^{10}Be in the environment. AMS is mainly limited by the stable isobar ^{10}B , while the requirements for mass separation are the least stringent of all standard isotopes analyzed by AMS. We tested a possibility to measure ^{10}Be using a small switching magnet as an analyzer of accelerated ions, and an ionization chamber with a silicon nitride foil stack used as a passive absorber. A detection limit of 10^{-12} for the $^{10}\text{Be}/^9\text{Be}$ isotopic ratio was obtained using this technique, which was mainly determined by scattering of $^9\text{Be}^{+2}$ ions on residual gas inside the switching magnet.

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1. Introduction

^{10}Be is a cosmogenic radionuclide, which is one of the several radionuclides studied mostly by accelerator mass spectrometry (AMS). It is used for a wide range of applications from climate research [1,2], exposure studies in geology [3] to nuclear astrophysics [4]. Raisbeck et al. [5] developed the first method of the ^{10}Be analysis using a particle accelerator as a mass spectrometer. The background during the AMS measurement of ^{10}Be is mainly caused by the much more abundant stable isobar ^{10}B . The conventional magnetic/electric mass spectrometers of an AMS system cannot distinguish between ^{10}Be and ^{10}B , therefore additional separation is needed. Several methods were developed for the suppression of ^{10}B based on the different energy loss of B and Be in matter, because boron has a higher nuclear charge Z, which results in a higher energy loss.

Gas ionization chambers utilize this effect, and the gas filled volume with an entrance window can be used for energy loss measurements. Signals from segmented anodes with different energy deposition in the gas, can be used for separation of ^{10}B and ^{10}Be peaks in two-dimensional spectra.

Even after chemical separation, the count rate from ^{10}B is still far beyond the capabilities of the ionization chamber, and another suppression method is needed. A possible option is to use a degrader foil or gas volume inserted into the beam after the acceleration, and an electrostatic or magnetic analyzer, just in front of the

ionization chamber. If the energy of the ions is sufficient (the smallest energy is about 20 MeV), a thick foil can fully stop the ^{10}B ions. But this is not the case for small facilities, where for obtaining a higher energy, a higher charge state has to be chosen, with much lower stripping efficiency.

In general, two methods have widely been used by laboratories – absorption of ^{10}B in gas/foil in front of the detector [6–9], and using of a degrader foil followed by a magnetic separator [10,11] or a combination of both methods [12]. The method with degrader foil suffers by several disadvantages. By passing the beam through the degrader, the ions are stripped again and are spread to several charged states. Therefore another electrostatic/magnetic separator is needed, but only one charged state can be chosen. Also angular scattering by passing the foil limits the transmission of the ions and reproducibility of the measured $^{10}\text{Be}/^9\text{Be}$ ratios. The reproducibility of this method was estimated at around 3% at the VERA facility [13]. A background of the order of 10^{-16} can be achieved by this method in combination with an ionization chamber [14].

Another method is in placing a foil in front of the detector, so ^{10}B ions are stopped in the foil, while ^{10}Be with the same initial energy can pass into the detector. For the sufficient suppression of ^{10}B ions, the beam passing through the foil should have an initial energy of about 1 MeV/amu in order to reduce the angular straggling of the beam. Therefore higher charge states of ions have to be used. The type of the absorber is another important factor, usually a gas or a foil can be used. The gas is usually separated from the vacuum by a foil window and the absorption can be tuned by the gas pressure. For the foil absorber, the homogeneity is

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important, but also channeling of the crystal foils should be avoided. The hydrogen content in the foil should be as low as possible to avoid penetration of ^4He ions from the ^1H (^{10}B , ^4He) ^7Be reaction into the sensitive volume of the detector. A method using amorphous silicon nitride foil stack as absorber in front of the ionization chamber was recently developed at the VERA facility.

A new experimental facility CENTA (Centre for Nuclear and Accelerator Technologies) for the ion beam physics and accelerator mass spectrometry was built in 2013 at the Department of Nuclear Physics and Biophysics of the Faculty of Mathematics, Physics and Informatics of the Comenius University in Bratislava (more details about the facility can be found in [15]). Part of the scientific program includes the accelerator mass spectrometry. In this work we present results of ^{10}Be measurements in the CENTA facility using a switching magnet at 45° as an analyzing magnet, and SiN foil as absorber of ^{10}B ions.

2. Materials and methods

The MC-SNICS ion source produced by the National Electrostatic Corp. (USA) was used to produce negative BeO ions from blank samples [16] ($^{10}\text{Be}/^9\text{Be}$ ratio of 10^{-15}). The ^{10}Be standard (S555 standard developed by ETH lab.) with $^{10}\text{Be}/^9\text{Be}$ isotopic ratio of $(8.71 \pm 0.24) \times 10^{-11}$ was used during measurements [17]. After the ions were produced, they were accelerated by 60.5 kV potential, and electrostatically selected for the injection magnet. Masses of 25 ($^9\text{Be}^{16}\text{O}$) and of 26 ($^{10}\text{Be}^{16}\text{O}$) were separated by the injection magnet from the sputtered ions for ^9Be and ^{10}Be measurements, respectively. Separated ions were injected into the 9SDH-2 Pelletron accelerator operating at 3 MV terminal voltage. For molecule dissociation and charge exchange, the stripper canal with nitrogen gas was used. After the acceleration of ions, the 45° port of the switching magnet was used for $^9\text{Be}^{2+}$ and $^{10}\text{Be}^{2+}$ separation with energies of 7.14 MeV and 7.18 MeV, respectively. Since the CENTA AMS line is not yet equipped with an analyzing magnet with sufficient energy separation, the foil stack method was used for the background suppression of ^{10}B ions in the spectrum. As a degrader foil, a stack of 13 silicon nitride foils of 5×5 mm in size (in 10×10 mm frames), with an areal density of $2650 \mu\text{g}/\text{cm}^2$ (a total thickness of $8.56 \mu\text{m}$), was used. The foils were mounted in a tray, which can hold up to 15 foils with 1 mm spacing between their positions.

In the final stage, the ions were registered and identified by an ionization chamber with split anode, which allows for $\Delta E/E$ measurements. The ionization chamber of the ETH design [18], provided by the VERA laboratory was used in the experiment. The entrance window of the ionization chamber was also made of silicon nitride with thickness of 100 nm, at a distance of 3 mm from the last foil in the stack. For the operation of the ionization chamber, a continuous flow of isobutane gas was used. The pressure inside the chamber was regulated to about 18 mbar. While the ionization chamber was retracted from the beam, a Faraday cup with sensitivity up to 0.1 pA was used for measuring of the $^9\text{Be}^{2+}$ current (307 nA in final measurements). Just in front of the ionization chamber, a 3 mm retractable aperture was mounted for the beam tuning to the detector and the Faraday cup.

3. Results and discussion

For the beam tuning, the $^9\text{Be}^{16}\text{O}^-$ molecules were injected to the accelerator with typical current of about $1 \mu\text{A}$. By using the nitrogen gas, 30% of the Be ions were stripped to the 2+ charge state in the terminal of the accelerator. After the tuning of the beam to the detector, $^{10}\text{Be}^{16}\text{O}^-$ ions were injected into the accelerator and several peaks were registered in the ionization chamber

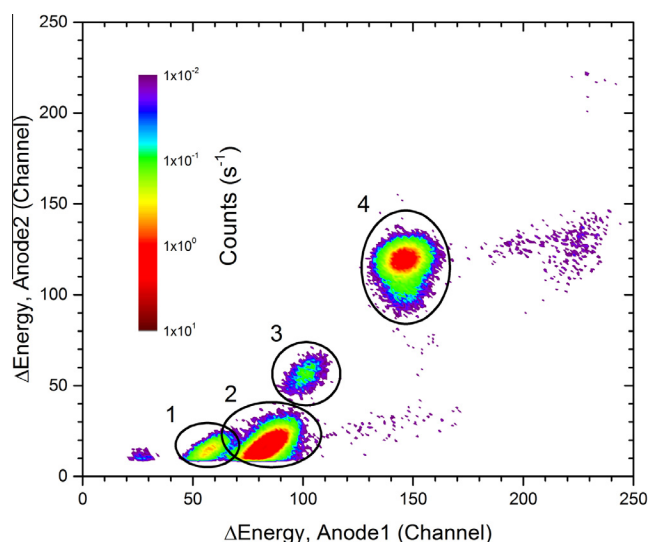


Fig. 1. Several peaks were measured after the tuning of the ion beam. The peaks 1 and 2 are related to the products of the broken $^9\text{Be}^1\text{H}^{2+}$ molecules entering the detector. The peaks 3 and 4 are the result of ^9Be , ^{10}Be and ^{16}O energy deposition in the ionization chamber.

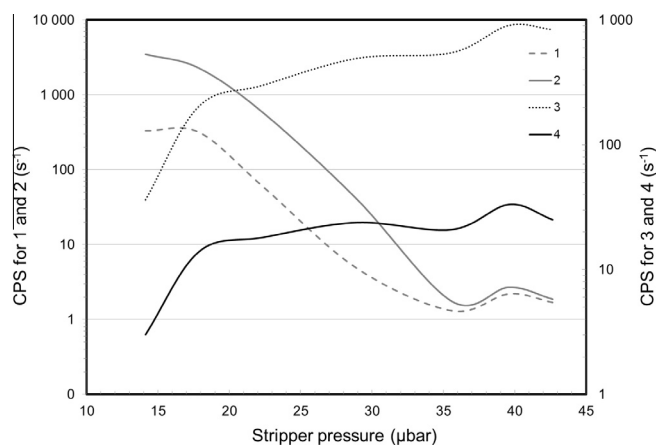


Fig. 2. Count rate dependency on the stripper pressure for several peaks shown in Fig. 1.

(Fig. 1). By increasing the stripper gas pressure, different behavior of the most intense peaks was observed, depending on the pressure of the stripper gas. The counting rates under the peaks correlated with the stripper pressure, suggesting the same properties of the ions or molecules.

The first group, counts in the peaks 1 and 2, is related to the products of the broken $^9\text{Be}^1\text{H}^{2+}$ molecules entering the detector. These molecules originate from $^9\text{Be}^{16}\text{O}^1\text{H}^-$ (injected into the accelerator together with $^{10}\text{Be}^{16}\text{O}^-$), which then break up into ^9BeH and ^{16}O in the terminal stripper. As we can see from Fig. 2, the probability of disintegration of molecules increased with increasing of the stripper gas pressure, and therefore much less molecules entered the detector. When the $^9\text{Be}^1\text{H}^{2+}$ molecule hits the first foil, it brakes and the total energy is distributed between the two fragments, therefore three different peaks can be registered in the spectrum. The total initial energy of the molecule is divided into 0.71 MeV for the ^1H and 6.39 MeV (peak 1 in Fig. 1) for the ^9Be , which can enter the detector separately or simultaneously (summed signals generate peak 2 in Fig. 2).

The behavior of the second group, peaks 3 and 4, is different, and the count rate is increasing with the stripper pressure to some

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