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Performance report for the low energy compact radiocarbon accelerator mass spectrometer at Uppsala University

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ABSTRACT

A range of ion beam analysis activities are ongoing at Uppsala University, including Accelerator Mass Spectrometry (AMS). Various isotopes are used for AMS but the isotope with the widest variety of applications is radiocarbon. Up until recently, only the 5 MV Pelletron tandem accelerator had been used at our site for radiocarbon AMS, ordinarily using 12 MeV $^{14,13,12}C^{3+}$ ions. Recently a new radiocarbon AMS system, the Green-MICADAS, developed at the ion physics group at ETH Zurich, was installed. The system has a number of outstanding features which will be described. The system operates at a terminal voltage of 175 kV and uses helium stripper gas, extracting singly charged carbon ions. The low- and high energy mass spectrometers in the system are stigmatic dipole permanent magnets (0.42 and 0.97 T) requiring no electrical power nor cooling water. The system measures both the $^{14}C/^{12}C$ and the $^{13}C/^{12}C$ ratios on-line. Performance of the system is presented for both standard mg samples as well as μg-sized samples.

1. Introduction

A variety of research activities within ion beam interaction with materials is ongoing at Uppsala University with Accelerator Mass Spectrometry (AMS) being a major one. The Uppsala 5 MV Pelletron tandem accelerator and the corresponding AMS system have been in use since 2001 and are utilized for a variety of rare-isotopes including ^{129}I, ^{36}Cl, ^{10}Be and ^{14}C. Even after three decades of AMS-based applications, we have seen no decline in the interest from the various communities. On the contrary, the number of applications is increasing, specifically for radiocarbon in general and for the biomedical niche in particular, some of which requiring specific AMS technical performance. Consequently, we have noted the need for a state-of-the-art AMS system for a few years, addressing the following improvements: (1) dedicated radiocarbon system, requiring minimal handling of the system, (2) higher accuracy as a result of higher stability and reproducibility of the system, (3) on-line $\delta^{13}C$ measurement, and (4) environmentally friendly system addressing the considerable water flow as well as the total power consumed by conventional AMS systems. A new compact AMS system, manufactured at ETH, Zurich, Switzerland was installed at Uppsala in December 2014; the Green-MICADAS (mini carbon dating system) addressing the issues above. Here, we report on our experience during the first 4 months of operation.

2. Methods

2.1. Sample preparation

We use two separate sample preparation methods in connection with the Green MICADAS system. The first is the in-house Uppsala Ultra Small Sample (UUSS) preparation method addressing standard sized samples as well as small samples down to a few μg C [1–3]. The other is the AGE automated graphitization system, developed at ETH, Zurich [4], currently marketed and manufactured by IonPlus AG (Zurich, Switzerland). We have acquired two separate systems, one including the automated carbonate handling system (CHS). Results presented here for mg samples are from samples prepared using the AGE system, whereas all small μg samples have been prepared using the UUSS-method.

2.2. The Green-MICADAS system

The Green-MICADAS measures 3.2 m × 2.6 m and is placed in a standard laboratory room at our institution. The system is similar to the original MICADAS system described earlier [5,6] with a number of improvements. Two major distinctions are noteworthy:

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(1) As the system is dedicated for radiocarbon, both the low energy- and the high energy magnets are manufactured from high grade NdFeB with the possibility of fine tuning with electrical coils (Danfysik A/S, Taastrup, Denmark). The temperature stability hitherto a technical concern has been improved to below 20 ppm/°C, more than adequately stable for AMS applications. The complete Green-MICADAS system consumes less than 8 kW (including 9 turbo-pumps and various power supplies) during normal operation.
(2) The terminal voltage is nominally 175 kV and the stripper gas is helium, facilitating low straggling, high stripping yield and consequently high ion transmission at the high voltage terminal.

The operating conditions of the system are briefly outlined below:

The sputter ion source uses a spherical ionizer with extraction energy of up to 40 keV. The sample loading system is a load lock for rapid exchange of magazines with 40 positions. The low-energy fast beam-switching magnetic spectrometer has a deflection angle of 90° and a bending radius of 25 cm, using a stigmatic dipole permanent magnet centered at 0.426 T with field variability of 2%. A focal-plane offset ^{12}C Faraday cup is placed between the low energy analyzer and the high voltage terminal. The latter is achieved using a 220 kV solid state power supply in combination with a vacuum insulated high voltage terminal nominally operating at 175 kV. Helium gas is used as stripper gas delivered using capillary tubes and differentially pumped using three turbo pumps. The high energy analyzer is a 90° stigmatic dipole permanent magnet with a bending radius of 35 cm and 1% field variability, centered at 0.97 T. Faraday Cups are placed after the high energy analyzer for $^{12}C^+$, $^{13}C^+$ and $^{13}C(H)^+$ detection, the latter being a proxy for measuring the molecular break-up efficiency and subsequently the ambiguous background radiocarbon counts [5,6]. A spherical electrostatic analyzer with a deflection angle of 90° and bending radius of 35 cm with maximum field strength of 2700 kV/m is used to steer the ^{14}C ions into a gas ionization Bragg detector through a 30 nm silicon nitride entrance window. A number of software packages are used for various functions such as BATS for data reduction of the acquired data [7]. The ^{12}C ion transmission of the system is typically in the range of 46–48%.

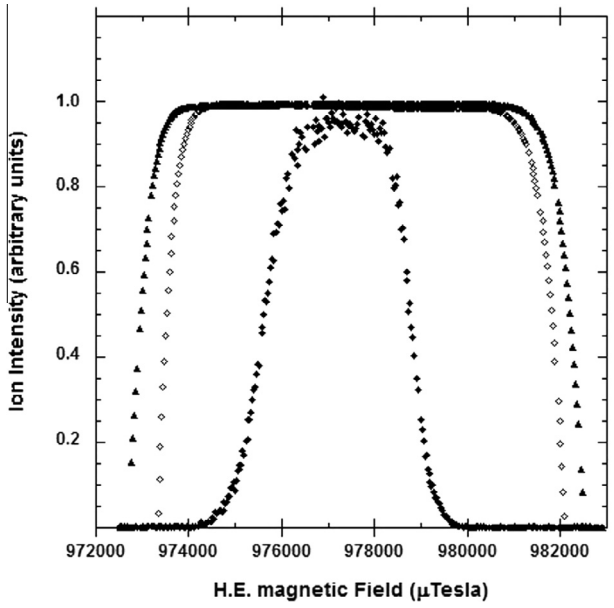

Fig. 1a. The normalized measured intensity of ^{12}C (closed triangles), ^{13}C (open rhombi) and ^{14}C (closed rhombi) during a scan of the high energy magnet.

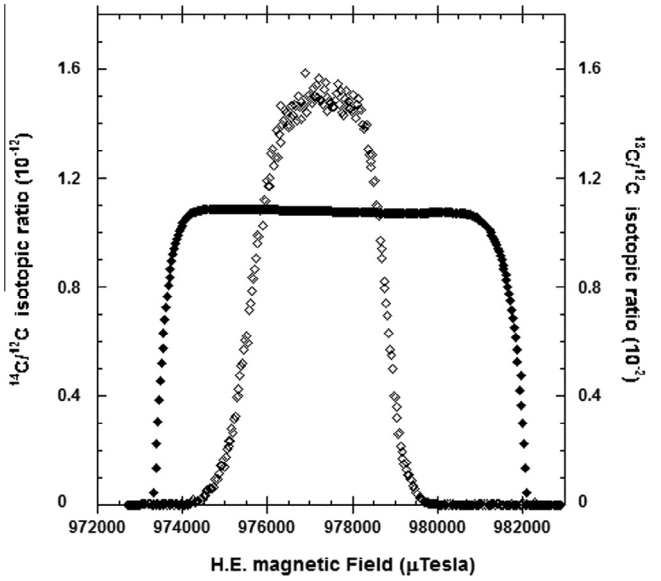

Fig. 1b. The absolute isotopic ratios for $^{13}C/^{12}C$ (closed rhombi) and $^{14}C/^{12}C$ (open rhombi), measured during a scan of the high energy magnet. The ion intensities and isotopic ratios have been normalized to the low energy ^{12}C current to compensate for drifts during the scan time of 65 min.

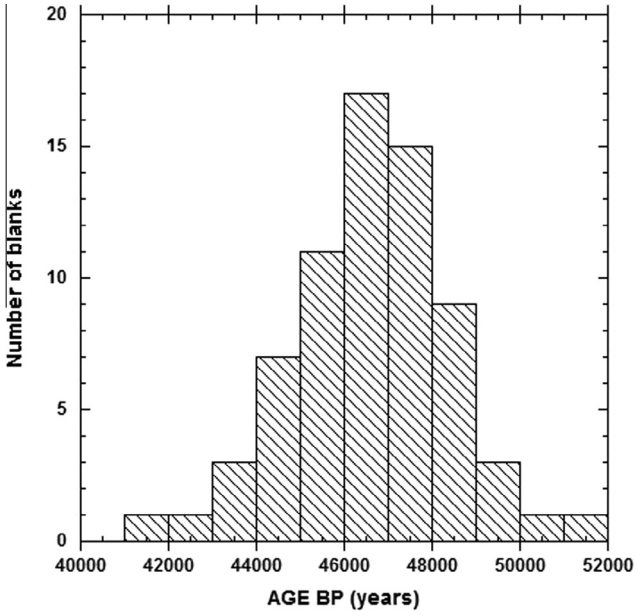

Fig. 2. The distribution of the measured age of the graphite blanks.

3. Results and discussion

The system has been operating in a stable manner since installation with some minor setbacks requiring the exchange of two high voltage power supplies. However, as a whole the system operation has been smooth and stable. Of particular concern was the stability of the high energy magnet which affects the performance of the whole AMS system. The temperature stability was measured to be <20 μT/°C, sufficiently stable for our purpose. To further characterize the system, the beam-profiles have been measured during