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THE PROPOSED TRIUMF ACCELERATOR MASS SPECTROMETER

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Summary

We describe an Accelerator Mass Spectrometer to be operated by TRIUMF Applied Programs for a consortium of earth scientists. The equipment will provide routine determinations of ^{14}C, ^{10}Be and ^{26}Al in mg-sized samples derived from natural materials. The measurement system is designed around a used, but suitably upgraded, EN Tandem Van de Graaff accelerator. The design is an improved version of our first-generation AMS system which we currently operate at McMaster University.

Introduction

The use of Tandem Van de Graaff accelerators for Accelerator Mass Spectrometry (AMS) is now well established [1]. The technique is commonly applied to the measurement of the very low natural concentrations of long-lived cosmogenic isotopes in natural materials, either for dating or for tracer studies. In general, all AMS systems function by ionizing a suitably prepared sample, selecting the ions of interest with an 'injector', and then accelerating them. The ions emerging from the accelerator are magnetically analyzed, and the stable isotope beams are measured with Faraday cups. The radioisotope ions undergo further magnetic and electrostatic filtering and are counted with a ΔE-E detector telescope which distinguishes them from any remaining contaminants. The concentration of radioisotope is determined from the measured isotope ratio and the known amount of stable isotope in the sample.

Since 1977 we have developed and tested an AMS system as part-time users of the McMaster University FN Tandem accelerator. Our method differs in detail from all others, in that the rare and the stable isotopes are accelerated and detected simultaneously, instead of sequentially. This equipment [2] now allows us to measure ^{14}C to 1% accuracy, with a background sensitivity for the ratio $^{14}C/^{12}C$ of 2×10^{-15} (50,000 radiocarbon years). $^{10}Be/^{9}Be$ ratios can be measured to 3%, with a sensitivity of 2×10^{-14}. The system has also been used to detect ^{26}Al, but no serious measurements have been undertaken.

In this paper we describe a proposed second-generation AMS system designed specifically for routine measurents of ^{14}C, ^{10}Be and ^{26}Al, with the possibility of including other isotopes as they become of interest. The system will be operated by the Applied Programs Division of TRIUMF for a consortium of earth scientists from Western Canada and the U.S.A.. The lessons of our McMaster experience and some of the actual equipment from this system are incorporated in the new design, as shown in Fig. 1. In the remainder of the text, we first identify aspects of tandem system design which are critical for AMS, and then show how our design satisfies these requirements.

AMS System Requirements

The major requirements for a dedicated AMS facility are good detection sensivity, high measurement accuracy and high sample throughput.

High sensitivity requires good vacuum in the accelerator tubes and in the beam filter elements to minimize interferences arising from interactions of the particle beam with residual gases. As well, the accelerator voltage range must be sufficient to allow each isotope of interest to be measured at an energy where contaminants are least troublesome.

The prime requirement for high accuracy is that the system remain stable, so that unknown samples may be accurately compared to standard samples. Fluctuations must not cause beam losses which are isotope dependent and which thus affect the measured isotope ratios. The accelerator terminal and the power supplies for all beam steering and focussing elements voltage must then be highly stabilized. It is important that the transmission of particle beams through the entire beam transport system is as close to 100% as is possible, so the optical elements must be designed to transmit the beam without losses, and the system must be adequately provided with beam diagnostic devices. Electrostatic focussing and steering elements should be used where possible for mass-independent beam handling.

If these criteria of stability and beam transmission cannot be satisfied, precision measurements are simply impossible. Therefore, the

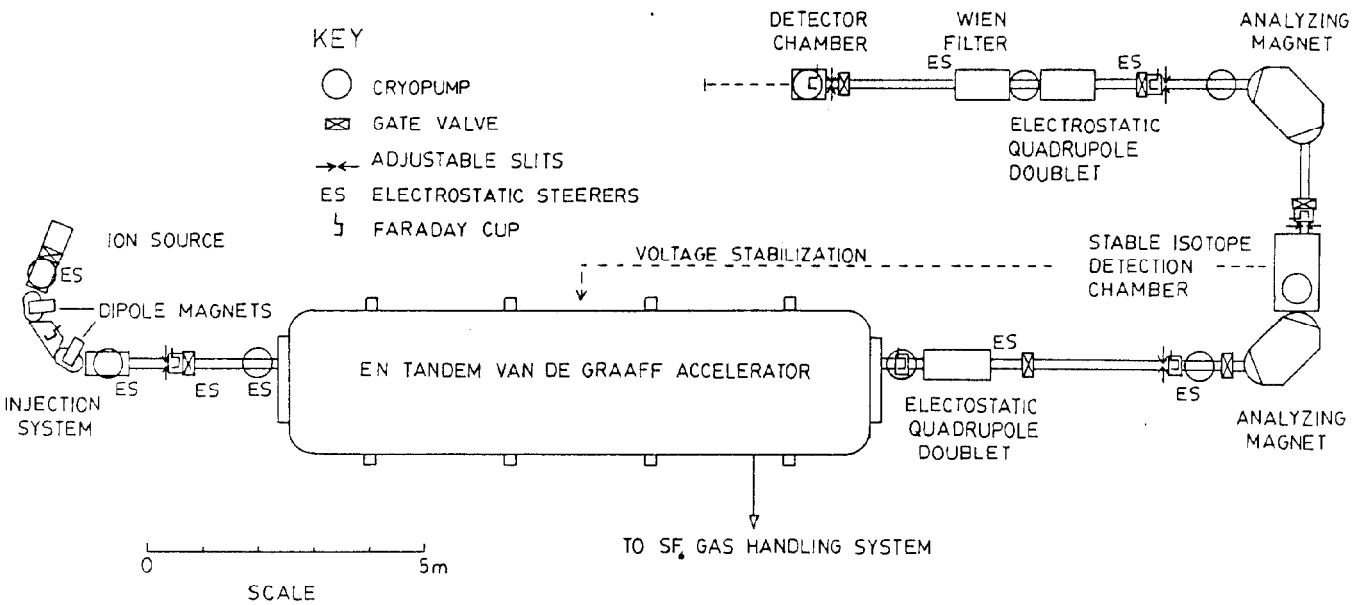

Figure 1. Layout of the proposed AMS system.

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system cannot be allowed to 'limp along' : it must be both reliable and easily repairable.

The demand for high throughput of samples requires that the ion source produce high beam intensities and be constructed for fast sample changing. The particle beams must be transmitted efficiently, and the accelerator must operate at voltages which maximise the production of positive ion charge states of interest. An automatic means of setting up the beam transport system should be provided to shorten the often laborious process of tuning up. Furthermore, if the facility is to be used efficiently and the high cost of a large staff avoided, it must be operated routinely by researchers who are not accelerator experts. Minimal operator intervention should be required during normal operation, but the researchers should be warned if faults develop. A computer-based control system which first sets up and then monitors the system parameters is clearly required.

The Proposed Design

Ion Source and Injector

A 30 keV reflected-beam Cs sputter source will generate negative ions for the spectrometer. Our present source operates with suitably-sized samples of graphite, BeO or Al_2O_3. These are mixed with Ag powder for good thermal conductivity, and produce outputs of up to 50 μA of C^-, 1.5 μA of BeO^-, and 200 nA of Al^-. An easily changed 20 sample carousel gives short sample turnaround times. So far, we have seen no evidence for cross-contamination between samples. This present source will be installed on the new system, but we expect that other ion sources will be developed later to provide higher currents, new beams of interest, etc.

The injection system which we will use splits the ion source output into beams of different masses, filters out unwanted ions, and recombines all beams of interest for simultaneous input into the accelerator. This is done by two 55° dipole magnets and two electrostatic quadrupoles which separate and recombine the beams, with apertures at the midpoint of the system to select the beams of interest. A detailed description of the concept has appeared elsewhere [3]. This simultaneous method has several advantages over the alternative technique of cycling the isotopes through the accelerator one by one. Instabilities in the system tend to affect all isotopes equally and hence leave isotope ratios unchanged. A stable isotope beam is always present, so that the standard accelerator voltage stabilization system (which works by sensing a beam position) can be used. The beam current loading on the accelerator remains constant, and so stable operation is easier to attain.

Our operating experience with this device at McMaster has shown that it transmits the particle beams with ≈100% efficiency, providing ^{14}C measurements to better than 1% precision. We have also shown that, contrary to earlier fears, there are no significant background problems due to ions scattered from the stable beams reaching the detectors. The apparent ^{14}C background from this effect is equivalent to a radiocarbon age of at least 65,000 years.

Accelerator

The proposed measurement system will be based on a modified EN Tandem accelerator, operating at 6-7 MV. This model is no longer manufactured, but used machines are becoming available. Smaller accelerators of 2-2.5 MV are widely used for ^{14}C dating [1], but there are several arguments that higher beam energies lead to increased versatility. Beam scattering and straggling in the accelerator stripper are less important at higher energies, so the design of a selective yet efficient beam transport and filtering system is made easier. The increased voltage offers a wider choice of positive charge states. Hence, more strategies for avoiding troublesome contaminants exist, and the chances of operating the system at peak efficiency and sensitivity are increased. Finally, particle identification techniques typically work better at higher energies, particularly for heavier ions. The EN can comfortably exceed the voltage of about 6 MV required for measurements using $^{14}C^{4+}$, $^{10}Be^{3+}$ and $^{26}Al^{7+}$ ions. The system should therefore be very reliable at 6 MV, and the extra voltage capability provides some latitude for developing measurement techniques for other isotopes.

The accelerator will be extensively upgraded for AMS work. The accelerator tubes will be rebuilt to the Dowlish spiral inclined field design, using Al electrodes. A gridded lens at the entrance to the #1 tube will be used to focus the beam into the stripper canal. It has been shown at McMaster and elsewhere [4] that this configuration gives exceptional beam transmission and voltage holding capability, and requires very little voltage conditioning. The tubes will be pumped from both ends of the accelerator by cryopumps, and by a small Ti sublimation pump in the high voltage terminal. The Dowlish tubes are not a 'hard vacuum' design, but our experience shows that tube vacuums adequate to provide good detection sensitivity are readily achievable.

The standard belt charging system will be replaced by two Pelletron chains, which offer improved voltage stability and resistance to spark damage. Unlike belts, chains do not absorb moisture when exposed to the atmosphere. The pumpdown and voltage conditioning times following tank openings for maintenance are therefore reduced. Furthermore, the chains are located on the outside of the accelerator column and hence are readily accessible.

Other improvements will include the provision of high impedance grading resistors for the accelerator column to reduce the current drain on the terminal, and the installation of terminal steerers and a multi-position stripper foil holder. The voltage stabilizer electronics will also be upgraded: a fast control loop driving a light link to the terminal will modulate a control voltage on the accelerator stripper, supplementing the standard corona circuit.

The terminal will be insulated using SF_6 gas rather than with a N_2/CO_2 mixture. The superior insulating qualities of SF_6 extend the operating voltage of the EN and provide a greater safety margin for normal operation. Higher charging currents can be maintained, and the accelerator is less vulnerable to spark damage. The SF_6 will be stored as a gas and transferred using standard refrigeration compressors, following methods developed by Brassard [5]. This technique requires a large storage volume, but the system is relatively inexpensive, and the short transfer time of about 1 hour reduces the difficulty of carrying out repairs inside the tank.

Beam Analysis and Particle Detection

The beam characteristics in the high energy beam transport system are primarily determined by scattering in the accelerator stripper, and hence depend strongly on the ion species, the beam energy, and the stripper thickness. Our approach was to calculate the worst case beam which could emerge from an EN equipped with the Dowlish accelerator tubes, and to design a beam transport system which could handle this beam without loss. Faraday cups and adjustable 4-jaw slits will be provided at all beam waists, and fixed 4-jaw slits will be placed upstream of all beamline constrictions, to assist with beam tuning. All slits will be equipped with beam current readout, and several beam scanners will also be used for beam diagnostics. Corrective steerers will be placed as shown in Fig. 1, and all steerers and quadrupoles will be electrostatic to ensure that all isotopes are treated alike.

A large (r = 80 cm) 90° double focussing magnet with momentum resolution $p/\Delta p \approx 800$ will form the first stage of the isotope filtering system. The magnet poles and the vacuum box will be wide enough to transmit beams of several isotopes (e.g., ^{12}C, ^{13}C and ^{14}C, or ^{26}Al and ^{27}Al) simultaneously. Stable isotope beams will be detected with Faraday cups after this analysis. Beam position sensing slits will be provided inside each cup for connection to the stabilization system to regulate the terminal voltage. The slit and Faraday cup currents will be added together electronically to give accurate current readings.

Ions of the wrong magnetic rigidity which fortuitously scatter around the first magnet will be removed by a second magnet. A Wien filter required to suppress other sources of background would remove most of these ions anyway, but a second magnet is a more selective filter. Our own experience and that of other groups [6] has shown that the extra element provides a great increase in detection sensitivity. A second 90° bend was adopted because of the compact layout which results, and because the two identical magnets form a first-order achromat and so produce a small final beam spot.

An additional filtering stage is necessary to remove contaminants which happen to have the correct magnetic rigidity. An electrostatic analyzer or a Wien velocity filter can be used. We chose the latter for the versatility afforded by its variable sensitivity and for the ease of alignment which results from its straight line beam path. A suitable instrument is now operating on our system at McMaster. When set up in the new system and tuned for 30 MeV $^{14}C^{4+}$, it will have a velocity resolution of 2%.

The ions of interest will be identified and counted using the gas ionization and solid state particle detectors already in use. Space will be left at the end of the beam line to permit time-of-flight particle identification to be developed if required, The proposed data collection system consists of NIM and CAMAC electronics and a small VAX computer. This is a smaller version of the data acquisition system we currently use, so the powerful data acquisition and analysis software we have already developed can be transferred easily to the new system.

Conclusion

We have discussed the requirements for a dedicated AMS system to measure ^{14}C, ^{10}Be and ^{26}Al and have shown how they can be met by a design based on a modified EN tandem. Since the critical design elements have already been successfully tested, we are confident that the proposed design will work as planned and will provide a first-class instrument for the application of this new analytical technique.

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