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Large projects at the accelerator mass spectrometry facility at the China Institute of Atomic Energy during the last 12 years

Jiang Shan [a,*], He Ming [a], Dong Kejun [a], Ouyang Yinggen [a], Hu Yueming [a], You Qubo [a], Bao Yiwen [a], Yuan Jian [a], Wang Wei [a,b], Li Chaoli [a], Wu Shaoyong [a]

[a] China Institute of Atomic Energy, P.O. Box 275-80, Beijing 102413, China
[b] China National Nuclear Corporation, Beijing 100822, China

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ABSTRACT

Progress made by the Accelerator Mass Spectrometry (AMS) facility at the China Institute of Atomic Energy (CIAE) since 1999 is reported in terms of system upgrades, exploration with other long-lived isotopes, advancements in methodology, and new applications.

1. Introduction

Twenty-two years have past since the Accelerator Mass Spectrometry (AMS) became operational at the China Institute of Atomic Energy (CIAE) in 1989. As described in the last report [1], the HI-13 tandem accelerator at the CIAE is a multi-user facility: for many years only a small part of beam time was allocated to AMS. Also, the AMS research was mainly focused on capability development and applications with the nuclides of ^{10}Be, ^{36}Cl, ^{26}Al, and ^{41}Ca. The AMS portion of beam time has increased in recent years, allowing us to initiate projects to upgrade the facility and to enhance existing methods for the classic range of nuclides and develop new methods for lesser-explored ones. More recently, we have begun measurements of fission products such as ^{79}Se, ^{93}Zr, ^{99}Tc, ^{107}Pd, ^{121m}Sn, ^{126}Sn, and heavy nuclides such as ^{182}Hf, ^{210}Po, and ^{236}U. The latter group is of great interest in the fields of geoscience, environmental science, astrophysics, and nuclear environment engineering. Here, we discuss some key upgrades of the AMS system at CIAE and demonstrate how they have impacted on performance.

2. Improvement of AMS system

A schematic diagram of the CIAE-AMS system is shown in Fig. 1. Negative ion beam is produced in a Multi-Cathode Source of Negative Ions by a Cesium Sputtering (MC-SNICS) and pre-accelerated to energies of 100–120 keV. The negative ion beam is then analyzed by a 90° spherical electrostatic analyzer followed by a 112° double-focusing magnet analyzer before being injected into the accelerator. The mass resolution of the injection magnet depends on beam optics and the width of the defining slits. The tandem accelerator is a High Voltage Engineering Corporation (HVEC) product with four acceleration tubes on each side of the terminal. A high terminal voltage, up to 14 MV, is supplied in the middle of the acceleration tube (normally, the typical terminal voltages of 7.5–12 MV are used for AMS. Carbon foil (3 μg/cm^2) is presently used to break-up the molecular ions and strip some electrons off the ions of interest. After acceleration, the ion beam is analyzed by a 90° double-focusing analyzing magnet and then transported to one of the AMS beam lines by a switching magnet.

There are now two beam lines devoted to AMS. The original line, beam line 1, is on the L20 port of the switching magnet, and the second line has been established on the R20 port. The beam line 1 is dedicated to AMS experiment [1]. Between the switching magnet and the detection system there exist ion-optical elements, and a 16° electrostatic analyzer. This beam line is equipped with a variety of versatile home-built detection facilities including a time-of-flight (TOF) system, a multi-anode gas ionization chamber and a Si surface-barrier particle detector (SBD). The TOF system consists of a micro-channel plate (MCP) start detector and a SBD stop detector, separated by a flight path of 1.8 m. The energies of the ions are measured by the ionization chamber filled with isobutane and/or the SBD. Four independent energy loss signals are available from the

* Corresponding author. Tel.: +86 10 6935 8335; fax: +86 10 6935 7787.
E-mail address: jiangs@ciae.ac.cn (J. Shan).

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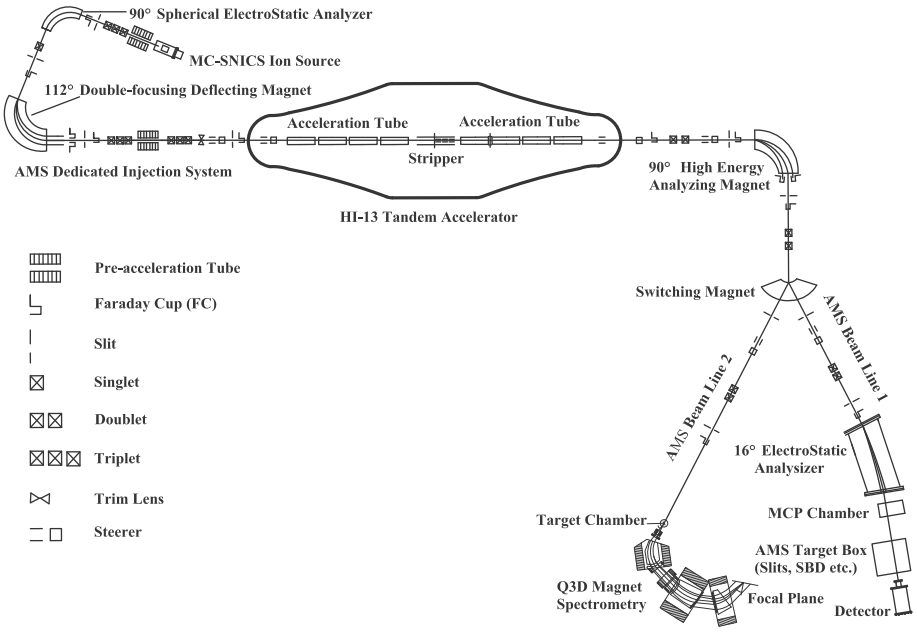

Fig. 1. Schematic diagram of CIAE-AMS system.

ionization chamber. The beam line 2 is a multi-user beam tube, and some beam time can be used for AMS measurement of some medium mass nuclides after a series of improvements. This beam line mainly consists of ion-optical elements, a Q3D magnetic spectrometer, and associated detectors.

2.1. Reconstruction of an injection system dedicated for AMS

One of the prerequisites in AMS measurement of heavy nuclides is to have an injector with high mass resolution to separate the interferences from nuclides with neighboring masses. The original injector consists of a trim lens and a 90° double-focusing analyzing magnet (Fig. 1) with a mass resolution ($M/\Delta M$) of about 80. It can just bend singly charged ions with a maximal mass number of 240 and an energy of 40 keV, which is well below the requirement of AMS with nuclides beyond $A = 180$. Therefore, a dedicated AMS injection system with high mass resolution was reconstructed. The new dedicated AMS injection system merging with the original one at upstream position adopts achromatic technique. It is composed of a 90° spherical electrostatic analyzer (SESA), a 112° double-focusing analyzing magnet (DFMA) and some ion-optical elements, as shown in Fig. 1. The SESA has a curvature radius of 750 mm and a maximum electric field strength of 4 kV/cm. It provides both horizontal and vertical focusing. An electric quadrupole triplet and an electric quadrupole singlet were mounted at the entrance and the exit of the SESA beam line, respectively, for ion beam focusing. The DFMA has a bending radius of 800 mm and a maximum magnetic field of 1.3 T. Two removable offset Faraday Cups (FCs) were installed after the DFMA located at 26 cm upstream from the image slit (Slit 3) allowing of continuous real-time monitoring of the abundant reference isotope beam during the measurement of the nuclide of interest. The dedicated injection system is fully remote-controlled through an infrared and fiber optics link, operated either manually or controlled by computer. The hybrid system controlled by both infrared and fiber optics devices ensures safe and reliable operation. The beam line is routinely operated for the injection of negative ions.

The experiment showed that when the ESA slits (Slit 1) and MA object slits (Slit 2) are fully open, and the image point slits (Slit 3) of MA is ±1 mm, the mass resolution of the injector system is about 430. If the Slit 2 and Slit 3 were respectively set at ±2.5 and ±1 mm, the mass resolution can be increased to 630, which leads to a decrease of beam current only by 5%, compared with the beam current with all slits completely opened up [2]. Under both the above two sets of settings, the isotopic suppression factor of 10^4–10^8 could be obtained, that makes the energy resolution of the electrostatic deflector and the mass resolution of the analyzing magnet good enough to clearly distinguish ions containing neighboring isotopes for heavy mass nuclides measurement.

2.2. Modification of high-energy electrostatic analyzer

In AMS an analyzer is often required with sufficient resolution to remove interfering ions with different m/q from the ions of the interfering nuclides on the high-energy side of the accelerator system. As the ion mass increases, the relative mass difference between the nuclide of interest and its neighboring isotopes generally becomes smaller, so the analyzer must provide better mass resolution for heavy nuclides. Several elements with high resolution and transmission are usually required for obtaining better selectivity. A 90° double focusing High Energy Analyzing Magnet (HEAM) with a maximal mass energy product of 200 MeV amu and a high energy resolution electrostatic analyzer (ESA) with deflection angle of 16° were installed at a CIAE-AMS beam line 1 to reduce the isotopic backgrounds and other unwanted beams.

The ESA deflector manufactured by CIAE experiment factory has a curvature radius of 360 cm, and two parallel flat aluminum electrodes with a gap of 3 cm. The deflector has a maximal deflection voltage of 180 kV, and an electric field of 57.5 kV/cm. The ESA was originally mounted downwards, limited by the space available twenty-one years ago, and has not been in its optimal working condition of particle transmission for some time due to the misalignment of the beam line after years' operation, which made the beam adjustment difficult and the transmission efficiency lower than expected. Several years ago, there has been enough space on both sides of the beam line for the lateral deflection of ESA on the horizontal plane of the beam line system. So, the beam line was realigned, and the ESA was modified in order to improve the beam current quality, facilitate the particles transmission adjustment and increase the chromatic dispersion. As a result, the ESA