THE PRODUCTION AND TRANSPORT OF RADIOACTIVE ^{17}F AT ATLAS FOR RESEARCH

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Abstract

A secondary beam of radioactive ^{17}F was produced at the ATLAS accelerator and delivered to an experimental target station with an intensity of as much as $5 \cdot 10^5$ ions/s for use in the research program. Beams of ^{17}F were produced via the p(^{17}O,^{17}F)n or d(^{16}O,^{17}F)n reactions by bombarding a gas-filled cell with up to 300 pnA beams of ^{17}O or ^{16}O from the ATLAS superconducting linac. The gas target, with HAVAR windows, was maintained at pressures as high as 500 Torr. The beam quality was dominated by small-angle scattering in the gas cell windows, by the reaction kinematics and beamline acceptance. Detailed beam parameters are presented. Plans for relocation of the target to allow improved capture efficiency and acceleration or de-acceleration of the secondary beam will also be discussed.

1 INTRODUCTION

Interest in the use of radioactive beams for research in nuclear physics and astrophysics has become intense in recent years and several accelerator laboratories around the world have begun to develop techniques to produce radioactive beams with useful intensities and controllable beam properties. At ATLAS[1] techniques have been developed to produce a beam of ^{17}F($T_{½}$ = 65s) in-flight using inverse reactions, i.e. bombarding light targets with heavier projectiles. The goal of the effort is to produce a beam of ^{17}F in sufficient quantity, purity and quality to allow the determination of cross-sections relevant to astrophysical environments as well as for the investigation of other nuclear reactions.

2 EXPERIMENTAL CONFIGURATION

For our first measurement with an ^{17}F beam, the inverse reaction p(^{17}F,^{14}O)α was chosen for study. To study this reaction at the E_{cm} = 3.43 MeV, resonance an energy for ^{17}F of 62 MeV is required.

A gas target cell of hydrogen or deuterium was bombarded with a primary ^{17}O or ^{16}O beam and partially transformed into a ^{17}F beam. A bending magnet following the production target filters out most of the ^{17}O isobar nuclei. Finally the ^{17}F beam was delivered over a distance of 12 m to a secondary CH_2 target. Since p(^{17}F,^{14}O)α is forward peaked in the laboratory system, a coincidence requirement between ^{14}O particles detected in the ATLAS spectrograph and α-particles measured with a silicon detector was used to separate the particles of interest from the background reactions.

The physical layout showing the relationship of the ^{17}F production target, the connecting beamline to the secondary target and the ATLAS spectrograph is shown in Fig. 1.

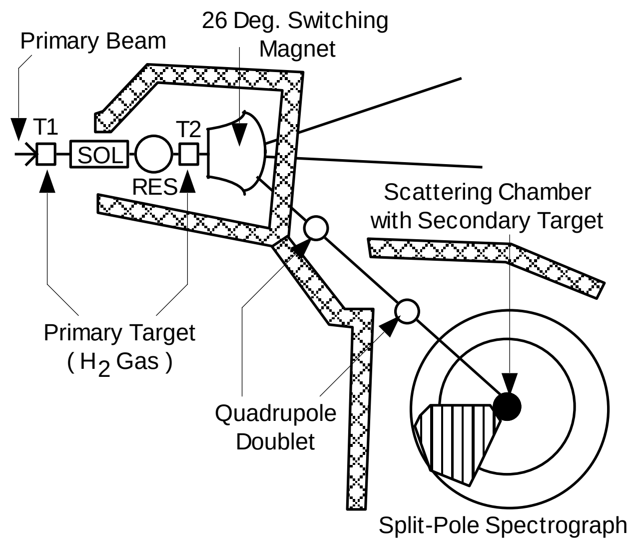

Fig. 1. Floor plan of the ATLAS radioactive beam region. The future (T1) and present (T2) positions of the primary gas target are shown as are the beam transport elements to the secondary target at the spectrograph. The relative positions of the super-conducting solenoid (SOL) and resonator (RES) which will be installed are also indicated.

2.1 Design of the ^{17}F Production Target

Our goal was to deliver at least 10^5 ^{17}F ions per second onto the secondary reaction target. For a ^{17}F production cross-section [4] as low as 10 mb and a 1% transport efficiency, the production target must be capable of sustaining an ^{17}O beam current of one pμA and have an effective thickness of 250 μg/cm^2.

Experience indicates that foil (CH_2) targets, even in rapid rotation, cannot take the high beam current necessary. Therefore, a gas target with an effective length of 7.5cm and thin HAVAR [5,6] windows was chosen (see Fig. 2). To keep the temperature of both the windows and the hydrogen gas low, the chamber has double walls to accommodate a constantly flowing cooling liquid in the outer cylinder. Four support pipes supply cooling fluid and H_2 gas.

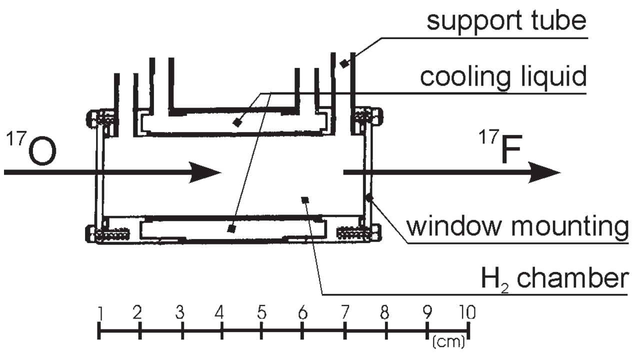

Fig. 2. A simplified cross-section of the cylindrical gas target used. The diameter of the windows is 1.27cm

The selection of window material and thickness was made as a compromise between the maximum sustainable gas pressure and the deleterious effect of thick windows on angular and energy straggling. The effect on the energy spread is negligible, since usually the reaction kinematics dominates this even near the reaction threshold. On the other hand, the contribution of the small-angle scattering to the beam divergence can dominate the transverse beam emittance. The required energy on the secondary target led to reaction energies between 73 to 77 MeV (threshold at 63.8 MeV) resulting in an maximum divergence of ±1.5° from kinematics (average of about ±1°). This relatively small cone is due to the negative Q-value of p(^{17}O, ^{17}F)n. A reaction with a positive Q-value would result in a much larger angular spread.

For two 1.9 mg/cm^2 HAVAR windows, the small angle scattering is also of the order of ±1°, which made this type of window a good choice. Glued in a mounting ring with an inner diameter of 1.27 cm, they withstood a 250 pnA beam of 83 MeV ^{17}O at H_2 pressures up to of 500 Torr. A higher pressure was not tested.

The divergence and energy width of the ^{17}F is estimated to be ±1.6° and ±4 MeV from the combined contribution of all effects. Calculations of the beam optics and examination of the windows after the run suggest a beam spot radius of 2 mm on the entrance windows. This makes a spot with a 3 mm radius on the exit windows. From this, we estimate the un-normalized emittance of the secondary ^{17}F to be 84 π·mm·mrad.

2.2 Transport of the ^{17}F beam to the secondary target

The program TRANSPORT [7] was used to calculate the beam optics for ^{17}F and predict the transport efficiency. For such a large emittance beam, a transmission of 3.5% is predicted, assuming a uniform density profile. It is also estimated that 50% [8] of the ^{17}F beam is in the 9^+ charge state, resulting in another attenuation factor of 2. The calculated beam envelope is shown in Fig. 3 and compared to the limiting mechanical aperture in the system.

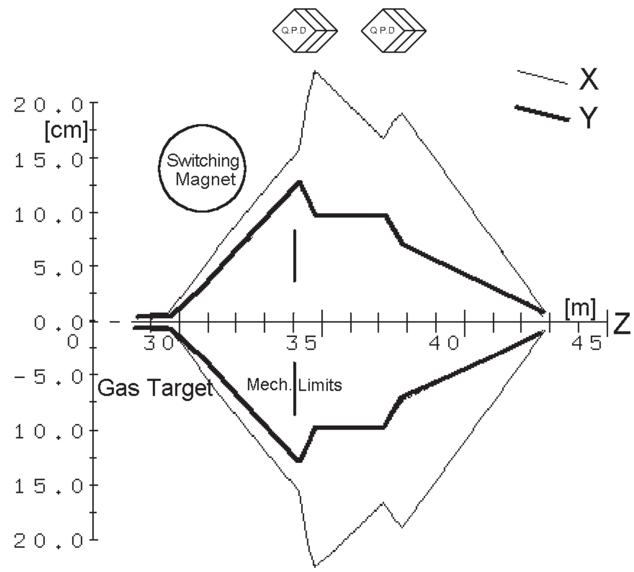

Fig. 3. The calculated envelope of the produced ^{17}F beam from the production target, located at 30m, to the reaction target, located at 43m. The quadrupole doublets are in a YX-YX-configuration.

Both energy and angular distributions of the ^{17}F beam are strongly affected by the reaction kinematics. Therefore, a correlation between energy and angle of a particle is to be expected. These correlations are not included in the TRANSPORT studies and place some uncertainty on the predicted transmission. However, this simple model leads to an expected overall efficiency of 1 to 2%.

3 PARAMETERS AND RESULTS

With a primary beam of 250 pnA ^{17}O, a cross section of 50 mb, and a gas pressure of 500 Torr, one expects a ^{17}F production rate of ~$2\cdot10^7$ per second. At the spectrograph, a ^{17}F current of $1\cdot10^5$ per second was observed. The upper limit of the vertical spot size on the secondary target is calculated to be 1cm. The y-magnification of the spectrograph is three, and so the detector [9] in the spectrograph focal plane is unable to intercept all beam particles. We estimate a detection efficiency of only 50% due to this effect, resulting in a transport efficiency of 1%, in reasonable agreement with the estimate in the previous section.

The ratio of ^{17}F particles to other nuclei detected in the focal plane of the spectrograph in the experiment was better than 10:1, in a measurement taken at 0° and therefore with a much weaker primary ^{17}O beam of only 175ppA on the gas target (See Fig. 4). The contaminating ^{17}O peaks are due to the energy-distribution tail of particles scattered into the bending magnet's momentum acceptance.

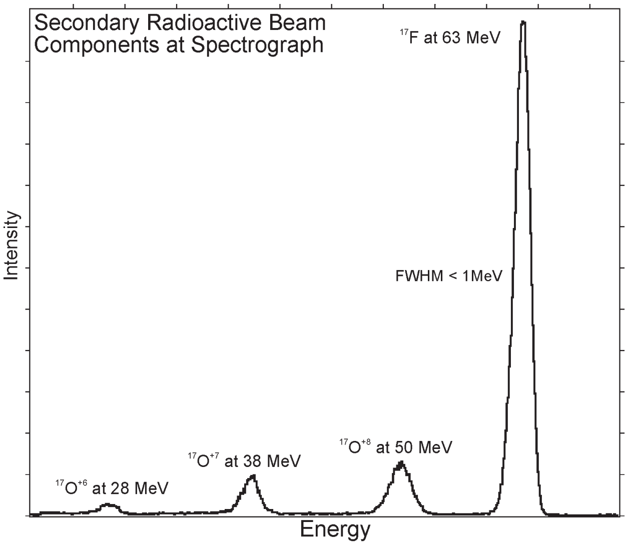

Fig. 4. The energy spectrum of the secondary beam in the ATLAS spectrograph at 0°.

The goal of the experiment was to detect ^{14}O nuclei from $^{17}F(p,\alpha)^{14}O$ in inverse kinematics. To provide discrimination between ^{14}O nuclei and background, the α particle was detected in coincidence in a silicon detector. While the spectrograph covered the angular range of 2° to 8° on the right side of the beam, the alpha detector measured α-particles on the left side between 6° and 20°. In the coincidence spectrum, the ^{14}O particles are the most prominent group (see Fig. 5). The ^{17}F and ^{17}O particles scattered in the spectrograph are in random coincidence with uncorrelated particles in the silicon detector.

By slightly changing the field of the 26° switching magnet, a certain energy control of the secondary beam was available without retuning the accelerator. Due to the large energy spread in the ^{17}F particles, the current of the secondary beam did not change more than 50% when swept over a 2 MeV energy region. In an independent test run, the production of ^{17}F was measured over an energy range from 85 to 112 MeV. The yield of ^{17}F changed less than 10% over this range.

4 IMPROVEMENTS IN PROGRESS

The production technique used in these experiments suffers from the large transverse emittance produced by angular straggling and the reaction kinematics as well as the large energy spread created from the reaction. These effects and the acceptance of our beamline limits the transport efficiency to target to approximately 1%.

The transport efficiency can be increased significantly by a modification of the beam optical elements in the vicinity of the primary gas target to significantly improve the transverse capture efficiency and reduce the energy spread of the secondary beam. We have begun a modification of our production region which moves the primary production target to a new location indicated in figure 1. A superconducting solenoid will follow the production target in close proximity (about 50 cm) to capture more of the rapidly diverging beam. The beam divergence will be reduced and the maximum secondary beam size limited to a radius of less than 2 cm.

The solenoid is then followed by a superconducting resonator, approximately 1.5 meters from the target. The resonator provides approximately 1 MV of accelerating potential and will be used in a 'debunching' mode which will decrease the energy spread of the secondary beam from ~±4 MeV to ~±0.75 MeV. Energy variability of about ±4 MeV will also be possible using the resonator.

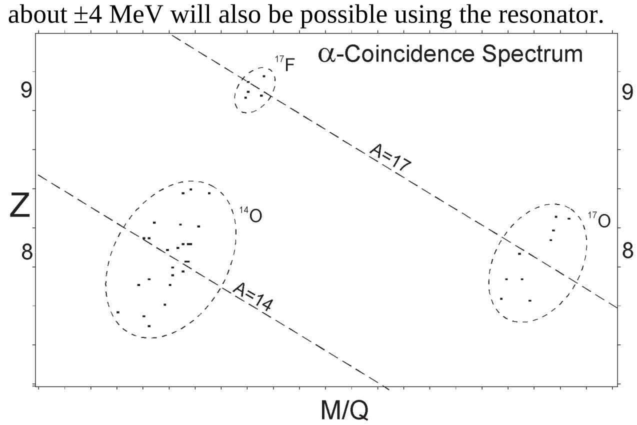

Fig. 5. The spectrum of nuclei in the spectrograph in co-incidence with α-particles in the silicon detector. The values of Z and M/Q have been linearized.

With these changes we expect the transport efficiency to increase by approximately a factor of 10. Therefore beam intensities greater than 10^6 ion/s should be available by October, 1997.

5 ACKNOWLEDGMENTS

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