RADIOACTIVE BEAMS FROM ^{252}CF FISSION USING A GAS CATCHER AND AN ECR CHARGE BREEDER AT ATLAS*

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Abstract

An upgrade to the radioactive beam capability of the ATLAS facility has been proposed using ^{252}Cf fission fragments thermalized and collected into a low-energy particle beam using a helium gas catcher. In order to reaccelerate these beams an existing ATLAS ECR ion source will be reconfigured as a charge breeder source. A 1 Ci ^{252}Cf source is expected to provide sufficient yield to deliver beams of up to ~10^6 far from stability ions per second on target. A facility description and the expected performance will be presented in this paper.

INTRODUCTION

After over a century of research in nuclear physics, the information needed to address many of the current outstanding questions of the field is obtained with greater and greater difficulty by the experiments that can be carried out with stable beams. Often these questions cannot be addressed at all with these beams. Experiments with stable beams naturally tend to explore the proton-rich side of the valley of stability and the nearby neutron-rich region of the isotope landscape.

Most existing RIB facilities can probe the proton-rich side in-depth but only access the periphery of the much larger neutron-rich region. Facilities that will reach further into this region and provide interesting beams into the far neutron-rich region, such as the Rare Isotope Accelerator (RIA) [1], are still years away.

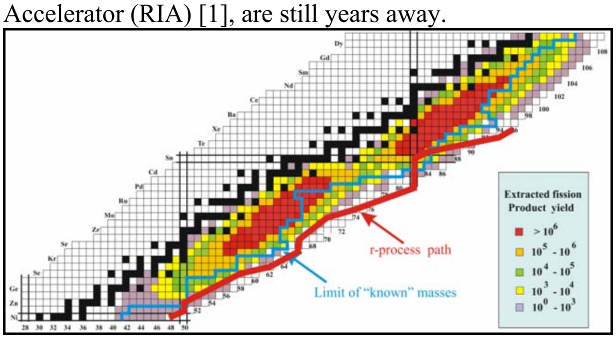

Figure 1: Distribution of fission products from the spontaneous fission of ^{252}Cf. The color code gives the extracted low-energy ion beam intensity (s^{-1}) for a 1 Curie source.

In the interim, an interesting, transitional facility, based on fission fragments of ^{252}Cf can allow a large class of important measurements. Figure 1 shows the distribution of fission fragments from ^{252}Cf [2]. The distribution covers a wide region of the neutron-rich side populating some of the most important nuclei, such as ^{132}Sn and $^{100-106}$Zr, for nuclear physics studies. In addition the mass distribution of ^{252}Cf is quite complimentary to that of proton or neutron-induced fission of ^{235}U [2].

At Argonne National Laboratory we propose to make use of this unique fragment distribution to provide nuclei which will then be thermalized in a helium gas-catcher system scaled from a prototype design being developed for the RIA facility. The remainder of this paper gives an overview of the proposed facility, describes its main features, discusses the challenges in implementing such a facility, and describes the expected performance.

TECHNICAL PLAN

The proposed facility consists of six major components:

a. A one Curie ^{252}Cf fission source mounted on a strong backing but open in the forward direction except for a thin gold layer.
b. A Havar-windowed helium gas catcher and RFQ system to thermalized the fission products and collect them into a singly- or doubly-charged ion beam with very low emittance and energy spread.
c. A sophisticated mass analysis system tailored to this excellent quality beam with a mass resolution of 1:20,000.
d. An ECR charge-breeder ion source for stripping the 1+ ions to a charge state suitable for further acceleration.
e. The ATLAS superconducting linac for acceleration to the necessary beam energy.
f. Additional diagnostics systems in ATLAS to provide the necessary information for beam tuning and delivery.

A schematic overview of the planned facility and its relationship to the existing ATLAS linac is shown in figure 2. The entire assembly of fission source, gas catcher and ECR ion source will be mounted on high-voltage platforms in order to provide the ions with the necessary velocity(0.086c) for injection into the linac.

The ^{252}Cf source will be deposited on a tantalum backing to provide sufficient mechanical strength. A thin gold foil will provide isolation from the rest of the vacuum system and will also serve as an energy degrader to match the fission fragment range in the helium gas to the available volume. The source will be installed in a vacuum assembly which will mate to the gas catcher system by remote control. The assembly will be enclosed in a neutron and gamma shield consisting of 0.75 m polyethylene and heavy metal.

The use of helium gas catchers to slow down and thermalize ions produced in nuclear reactions as well as fission fragments has been demonstrated over the past few years and is in routine use at ATLAS [3]. In addition this

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technology is key to the RIA project and a prototype gas catcher system suitable for RIA has been developed [4]. The ion distribution stopped in such a gas catcher for ^{143}Ba is shown in figure 3 as calculated with SRIM[5].

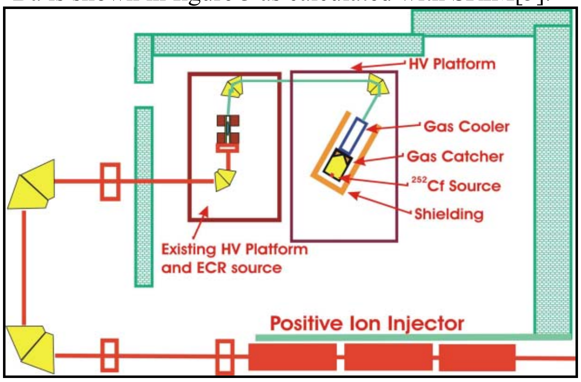

Figure 2: Schematic overview of the proposed ^{252}Cf fission fragment beam facility. An existing ECR ion source will be modified for charge breeding and then inject these beams into the ATLAS linac.

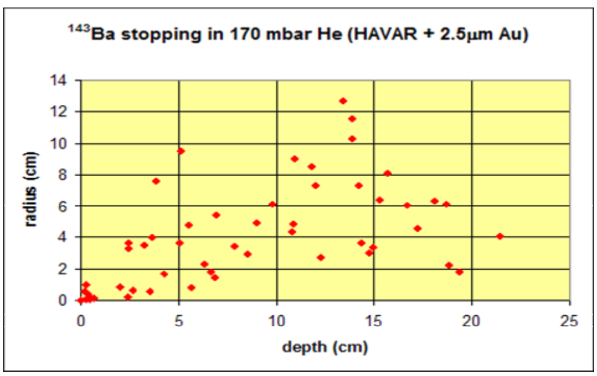

Figure 3: Distribution of stopping positions for ^{143}Ba fission fragments in 170 mbar He.

A shortened version of the RIA gas catcher system will be used for this project. The gas catcher volume has a radius of 13 cm and length of ~0.5 m. Once thermalized the ions remain charged in the gas and are pushed toward the extraction end by DC fields, focused toward the nozzle and kept away from the electrodes by an RF cone and finally extracted by gas flow into a radio frequency quadrupole (RFQ) focusing channel collecting ions extracted from the nozzle of the gas catcher. The RFQ guides and cools the ions while the helium extracted with the ions is pumped away. This results in extracted ion beams with excellent energy spread and transverse emittance - $\delta E \sim 1$ eV and $\varepsilon \sim 3\pi$mm mrad at 50 keV [6]. The assembled RIA prototype gas catcher is shown in figure 4.

Good beam purity is desirable is all cases, but is very difficult to achieve due to the extremely small mass differences for differing isobars. This is most serious near the valley of stability where good separation requires a mass resolution of 1:50,000. As one moves further away from the stable region the mass differences increase and, for most cases, a mass resolution of 1:20,000 is adequate or at least provides significant discrimination from the unwanted isotopes. With the expected beam quality, it is possible to achieve a mass resolution of 1:20,000 using a scaled-down version of a mass spectrometer designed for RIA [7] without energy correction. The geometry of such a layout is indicated in figures 2 and 6 with a total bend of 120 degrees. The mass analysis must be performed at a beam energy approximately 50 kV higher than provided by the ECR source/fission fragment bias and will be accomplished by floating the spectrometer at this voltage relative to the platform.

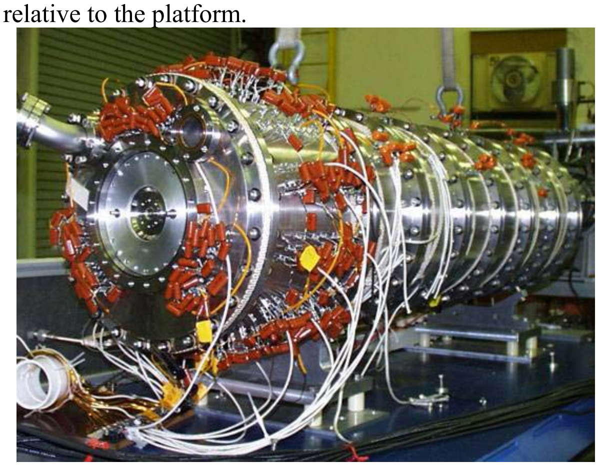

Figure 4: The assembled RIA prototype gas catcher as seen from the nozzle/RF cone end. A shorter version of this device will be used for this project.

To reach Coulomb barrier energies (E/A ≥ 5 MeV/u), the ATLAS linac must be provided with ions whose charge-to-mass ratio (q/M) is at least 0.15. Thus the 1+ ions provided by the gas catcher system must be stripped to higher charge states. This task will be accomplished by transporting the ions to an ECR ion source operating as a charge breeder [8], stopping the ions in the ECR source and stripping the ions, as in normal ECR ion source operation. An existing ATLAS ECR ion source, known as ECR-I, will be modified into a charge breeder for this purpose. This source operates in a two-frequency mode using 10 and 14 GHz RF frequencies. Our experience shows that two-frequency mode provides a significant increase in source performance; especially with regard to total efficiency. Work by Sortais and others [9] has shown charge breeding efficiencies of around 5% for solid materials and as high as 12% for some gases. A view of ECR-I modified as a charge breeder is shown in Figure 5.

Shielding design and radiological monitoring and protection are important issues for this proposed facility. We expect to perform hands-on maintenance to most of the facility and to work near the source during beam development. The entire facility will be housed in a large high bay area that also contains the positive ion injector and support utilities and facilities. The initial mass separation takes place on the first high voltage platform so as to contain as much of the unwanted activity as possible to that platform. We have developed a shielding concept which will allow remote control during installation of the source as well as storage of the source during

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maintenance requiring access to the gas catcher interior or other portions of the nearby beam transport system.

Shielding from the fission-generated neutrons requires about 0.75 m of polyethylene as well as a few centimeters of lead shielding to attenuate the γ-ray flux. This level of shielding will reduce the on-contact radiation field to approximately 1 mrem/hr. To create 4π shielding, the associated beamline must also be heavily shielded. In addition to neutron shielding, significant quantities of decaying fission fragments will be accumulated on the gas catcher walls, magnet chamber and other beamline walls. Shielding of this radiation is simple during operation, but it does present a challenge for maintenance activities both from potential direct exposure and limiting any possibility for spreadable contamination. Temporary tent enclosures and the use of attachable glove boxes appear to be good solutions for this problem. The shielding concept is shown in Figure 6.

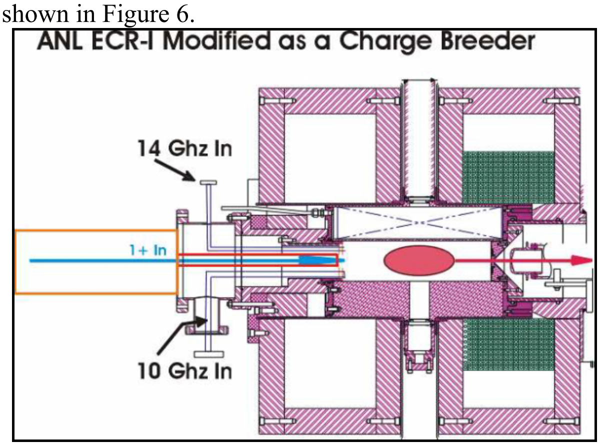

Figure 5: 10 & 14 GHz ECR-I ion source modified on the injection side for charge breeding operation.

FACILITY PERFORMANCE

The fission mass distribution from ^{252}Cf is shown in figure 1. The yields identified in that figure assume approximately 2% total system efficiency for delivery to an experiment target location. Some specific additional examples are listed in Table 1. The efficiencies assumed in this estimate include: a) 50% of fission fragments enter the gas catcher, b) 45% of fission fragments entering the gas catcher emerge as a beam of 1+ ions, c) 10% ECR breeding efficiency for gases and 5% for solids, d) 85% bunching efficiency and acceleration in linac, and e) 90% beam transport efficiency.

SUMMARY AND STATUS

A ^{252}Cf fission source delivers a new class of radioactive species that can provide tools to address important physics questions during the era leading up to RIA. Unique technologies and expertise available at ATLAS can provide the necessary capabilities in a timely manner and at low cost (approximately $3.5M). The proposed upgrade has great synergy to RIA on both the technical and physics fronts and will provide a very smooth transition toward RIA research. This upgrade will keep ATLAS and the US competitive in radioactive beam physics until RIA becomes available.

The proposal was submitted to DOE early in 2005 and is under review.

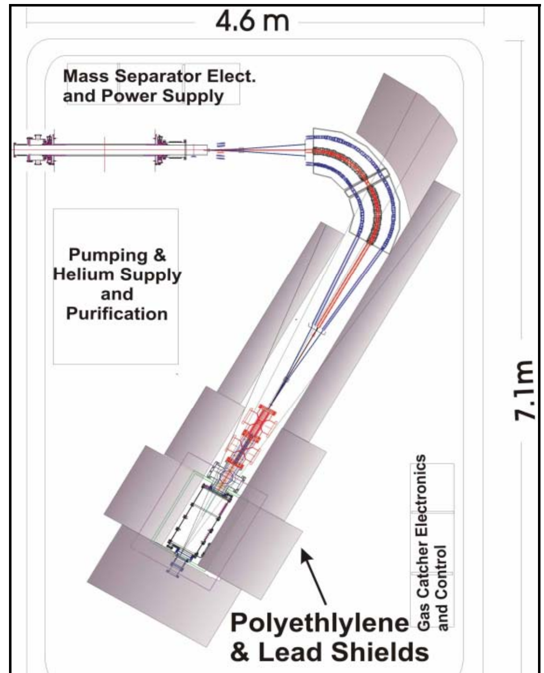

Figure 6: ^{252}Cf fission source and gas catcher beam transport shielding plans on the HV platform.

Table 1: Expected maximum accelerated beam intensities for a 1 Ci ^{252}Cf fission source using efficiencies in text.

Isotope	Half-life (s)	Yield (s^{-1})
^{143}Ba	14.3	4.3×10^5
^{145}Ba	4.0	2.0×10^5
^{130}Sn	222	3.6×10^4
^{132}Sn	40	1.4×10^4
^{110}Mo	2.8	2.3×10^3
^{111}Mo	0.5	1.2×10^2

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