Status of the Holifield Radioactive Ion Beam Facility

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Abstract. The Holifield Radioactive Ion Beam Facility received authorization in December 1996 to commence routine operation as a National User Facility. Significant progress has been made toward the goal of providing high-quality radioactive ion beams. The task of producing radioactive ion beams of sufficient intensity to do research has required extensive research and development on target materials and ion-source design. During 1997-1998, our radioactive beam research and development program concentrated on target/ion source systems for the production of $^{17,18}F$ and neutron-rich isotopes. Reliable and robust systems were successfully developed and, in 1999-2001, the facility provided over 3000 hours of radioactive ion beams for nuclear structure and astrophysics research. In this report, we discuss our operational experience and development activities since routine operation began.

INTRODUCTION

The Holifield Radioactive Ion Beam Facility (HRIBF) was formally dedicated as a National User Facility in December 1996 and has now been in routine operation for almost five years. Production of radioactive ions is done using the Isotope-Separator-On-Line (ISOL) technique with subsequent injection into a 25-MV tandem electrostatic accelerator where the ions are accelerated to energies of 0.1 – 10 MeV per nucleon for light nuclei and up to 5 MeV per nucleon for nuclei heavier than 100 amu. The ISOL technique for producing nuclei of interest requires bombarding a thick target with high-intensity beams of light ions. The radioactive ions diffuse out of the target, are transported to an ion source, ionized, extracted at 40 keV, and then mass separated. A diagram of the ISOL process as implemented at the HRIBF is shown in Figure 1. Brief descriptions of the accelerators and the injector will be given, but the main emphasis of this paper is the development and provision of high-quality radioactive ion beams.

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ACCELERATOR SYSTEMS

The production accelerator for HRIBF is the Oak Ridge Isochronous Cyclotron (ORIC), which is a variable-energy cyclotron (k=100) commissioned in the early 1960's. ORIC has come full circle from its beginnings as a light-ion accelerator, its change to a heavy-ion booster, and back to a light-ion accelerator. Besides the necessary changes to transform ORIC back to a light-ion accelerator, there have been numerous

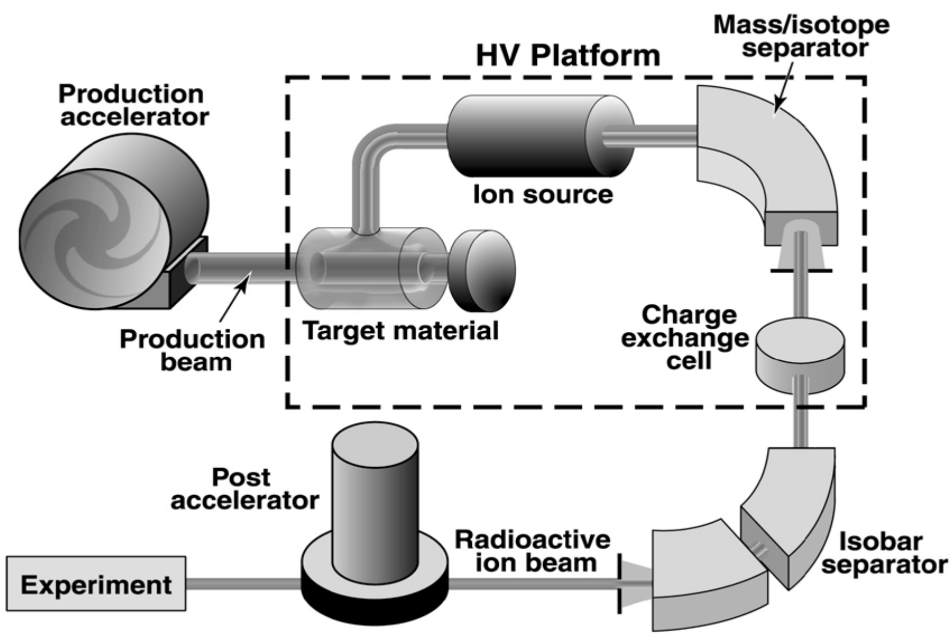

Figure 1. Shown are the various elements of the HRIBF for the production and acceleration of radioactive ion beams. (not to scale)

improvements and upgrades to improve reliability, increase energy and intensity, and decrease machine activation.[1] ORIC has delivered high-intensity beams of protons at 42 MeV, deuterons at 44 MeV, and ^{4}He at 85 MeV to the radioactive ion beam (RIB) production target. The maximum beam intensity has been limited at times by the ability of the target to dissipate the deposited power, but proton and deuteron beams with intensities of up to 12 μA have been delivered.

The RIB injector system consists of a 300-kV platform, an isobar separator, and associated beam lines. The high-voltage platform contains the production target, the ion source, the initial mass separator, and a Cs-vapor charge-exchange cell, as well as other optic components. Both positive and negative ion sources of different types have been used, with the choice of ion source made to maximize the particular RIB of interest. The negative ions are accelerated off the platform and transported to an $m/\Delta m=20{,}000$ second-stage mass separator to filter out isobars.

The post-accelerator at the HRIBF is a folded-geometry, 25-URC, tandem electrostatic accelerator manufactured by National Electrostatics Corporation. This accelerator has been in routine operation since 1982 and its operational characteristics have been previously reported.[2,3] Before becoming a RIB accelerator, the 25-URC had provided more than 70 different stable ion beams for research and had operated at terminal potentials up to 25.5 MV (highest in the world) with exceptional reliability. There have been three major changes to better accommodate acceleration of RIBs. The first was the change from corona-point voltage grading to a resistor voltage grading system.[4] Resistor-based voltage grading has resulted in more stable operation, as well as allowing operation at the very low terminal potentials which are required for some nuclear astrophysics experiments. The second change was to install low-intensity beam diagnostics.[5] Faraday cups and beam profile monitors that have been in use on the accelerator and associated beam lines have a lower limit of a few picoamperes, but many RIBs are much lower in intensity. A continuous dynode-electron multiplier is used to collect and amplify electrons or Rutherford backscattered ions from a target placed in the beam path, depending on the target's bias. These low-intensity diagnostics are, in general, not calibrated and are used for tuning purposes as an up/down indicator of beam. A more sophisticated diagnostic, which uses a microchannel plate detecting secondary electrons from a thin foil,[6] is used to measure intensity and position at most experimental end stations. The third change was a decision to convert all accelerator system controls to EPICS, which allows more flexibility to add controls for new and different devices. The tandem and its associated beam lines have presently been converted, with conversion of the RIB injector and the RIB transport line to the tandem under way. ORIC conversion will follow.

RADIOACTIVE ION BEAMS DELIVERED

Producing radioactive beams of sufficient intensity for performing meaningful research requires extensive research and development for each species. The HRIBF beam development philosophy has been physics driven and has tried to maximize contribution to the field in selected areas. Table 1 shows all the RIBs delivered to an experimental end station to date. Perhaps our most notable success has been in delivering $^{17,18}F$, which has been of great interest to the nuclear astrophysics community. The target/ion source system used to produce the fluorine beams consisted of a novel Kinetic Ejection Negative Ion Source[7] coupled to a target of hafnium oxide fibers.[8] The radioactive isotopes were produced in the oxide target via the $^{16}O(d,n)^{17}F$ and the $^{16}O(\alpha,pn)^{18}F$ reactions, using 44-MeV deuterons and 85-MeV α-particles. The target had a liner of alumina fiber since previous tests had shown that a small amount of Al_2O_3 enhanced the yield of $^{17}F^-$. The final target/ion source configuration was selected after testing many different varieties of metal-oxide targets and ion source parameters. Development of each beam typically begins at an ion source test stand where the candidate ion source and target are selected or developed and then characterized to maximize yield of the beam of interest. The target/ion source is then tested on line at the UNISOR Facility with bombardment by beams of low-intensity from the tandem accelerator. Finally, the target/ion source is mounted on the RIB injector platform where high-intensity testing and delivery of the beam to the tandem accelerator takes place.

A highlight at the HRIBF was the first acceleration of a neutron-rich RIB. For a time, we will be the only facility in the world capable of both producing neutron-rich RIBs and accelerating them to energies above the Coulomb barrier. Interest from the nuclear structure physics community led to testing of a uranium-carbide target at the UNISOR Facility[9] using low-intensity proton beams from the tandem, after which administrative approval was granted to use a fissionable target on the RIB injector. The target is a low-density, highly permeable, graphite matrix coated with a thin layer of uranium carbide[10] and the ion source used was an Electron-Beam-Plasma Ion Source (EBPIS)[11]. More than 5000 μA-hours were logged on the first target/ion source of this type and it performed above expectations with its enclosure enduring the thermally and radiologically harsh environment. A survey of positive ion yields from this target/ion source was made using a tape system and a γ-ray detector that were located just off the RIB injector platform. At least 130 isotopes of 20 different elements were observed between ^{78}Ga and ^{144}La. Not all elements in that range were observed since some would not be released from the target and not all those observed as positive ions can be made into negative ions to inject into the tandem. A table of the measured yields can be viewed on-line on the HRIBF Website.[12]

TABLE 1. Radioactive Ion Beams Delivered to Experimental End Stations

RIB	Energy Range	Highest Intensity	ORIC Current	Purity
	(MeV)	(pps on target)	(μA on target)	(%)
^{17}F	10-170	1.0×10^{7}	3	100
^{18}F	10-25	3.0×10^{5}	1	10
^{67}Ga*	160	2.5×10^{5}	5	>90
^{69}As	160	2.0×10^{6}	5	~10
^{70}As*	140	2.0×10^{3}	0.01	$<10^{-6}$
^{78}Ge	175	1.5×10^{6}	7	38
^{80}Ge	179	1.8×10^{6}	7	10
^{117}Ag*	460	1.2×10^{6}	9	95
^{118}Ag	455	1.5×10^{6}	11	90
^{126}Sn	378	1.0×10^{7}	5	50
^{128}Sn	384	2.5×10^{6}	5	20
^{132}Te	350-396	5.0×10^{6}	5	87
^{134}Te	396-560	2.4×10^{6}	7	70
^{136}Te	396	5.0×10^{5}	7	50

*Used for commissioning

RADIOACTIVE ION BEAM DEVELOPMENT

Radioactive ion beam development at HRIBF is important for two reasons. Obviously, the facility must develop new beams with higher intensities for our user community, but the second part of our mission is to serve as a test bed for development of ISOL radioactive ion beam science and technology. Therefore, a great deal of effort is put toward this end with new beams and techniques in various stages of development at any time. The effort may be toward producing a new RIB, increasing the intensity of a RIB already produced, or increasing the purity of an existing RIB. One of the latest developments was the production of pure Sn beams. For example, mass 132 produced by proton bombardment of UC_2 and extracted from the EBPIS consists of 87% Te, 12% Sb, and 1% Sn and cannot be separated by the second-stage mass separator. If mass 164 is extracted, however, it is entirely SnS^+, which can then be converted to Sn^- in a Cs-vapor cell. Sulfur contamination in the uranium carbide target allowed the production of SnS originally, but it has been found that the addition of H_2S gas enhances that production.[13] Pure Sn beams will be available for the experimental program in early 2002.

Neutron-rich bromine isotopes have good positive-ion yields from the uranium-carbide source coupled to an EBPIS, but the charge-exchange efficiency is very low. To increase the yield of negative ions, a source is being developed to make negative ions directly using negative surface ionization from a LaB_6 surface. Bromine yields are pure and are 25 times greater than with the EBPIS followed by charge exchange. This source can also be used to produce pure iodine beams, which will be 10 times greater. Emittance of the beams from this source is smaller than for the EBPIS so transmission should improve also.

Rubidium and strontium also have high production rates in the uranium-carbide target, high release rates, and low charge-exchange efficiency. In this case, a positive-surface-ionization source using a hot tantalum or tungsten surface is being developed and tested for use with these electropositive elements. This type of source has been shown to have a very high efficiency (up to 90%) for the Group I elements and good efficiencies for many other elements.[14] This is a source with simple design and operation and should result in at least a factor of 10 increase over present Rb and Sr yields with higher beam purity.

Long-lived RIBs ($T_{1/2} \geq 2$ hr) may be produced by a batch-mode source such as one that has been tested extensively off line and has been tested on the RIB platform. This source[15] is a multi-sample, Cs-sputter-type source that produces negative ions directly. While the ORIC beam is bombarding one of the eight target positions, another target position, at ninety degrees from the bombardment position, is being sputtered to produce ions for extraction from the source. The frequency at which the targets are rotated depends on the half life of the isotope of interest. This source is still undergoing development and testing.

Other targets under development include SiC (powder and fibers) for ^{25}Al beams, CeS fibers for beams of ^{33,34}Cl, and a Pd target for proton-rich Ag beams. There is also development of a new technique to make uranium carbide targets so the uranium density and the matrix porosity can be varied. Since experiments with radioactive beams are almost invariably extremely challenging, there is also a large development effort on a world-class suite of experimental instruments optimized for RIB science.

SUMMARY

Since the facility dedication ceremony in December 1996, much progress has been made to fulfill our mission to provide accelerated radioactive ion beams and experimental facilities in support of the U.S. nuclear science research program and to serve as a test bed for development of ISOL radioactive ion beam technology. Highlights have included (1) the first RIB experiment in June 1997, (2) the first neutron-rich RIB in October 2000, (3) providing 10^7 ions/second of pure ^{17}F on target in August 2001, and (4) providing more than 3000 hours of RIBs on target between 1999 and 2001. Upgrades of the accelerators are continuing, as is development of new targets and ion sources. Since this will be the only ISOL-RIB facility in the U.S. until ~2010, plans are being made to upgrade the facility to provide more and better quality radioactive ion beams.

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