HOLIFIELD RADIOACTIVE ION BEAM FACILITY STATUS*

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Abstract

The Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory (ORNL) produces high-quality beams of short-lived radioactive isotopes for nuclear science research, and is currently unique worldwide in the ability to provide neutron-rich fission fragment beams post-accelerated to energies above the Coulomb barrier. HRIBF is undergoing a multi-phase upgrade. Phase I (completed 2005) was construction of the High Power Target Laboratory to provide the on-going Isotope Separator On-Line (ISOL) development program with a venue for testing new targets, ion sources, and radioactive ion beam (RIB) production techniques with high-power beams. Phase II, which is on schedule for completion in September 2009, is the Injector for Radioactive Ion Species 2 (IRIS2), a second RIB production station that will improve facility reliability and accommodate new ion sources, new RIB production targets, and some innovative RIB purification techniques, including laser applications. The Phase III goal is to substantially improve facility performance by replacing or supplementing the Oak Ridge Isochronous Cyclotron (ORIC) production accelerator with either a high-power 25-50 MeV electron accelerator or a high-current multi-beam commercial cyclotron. Either upgrade is applicable to R&D on isotope production for medical or other applications.

DESCRIPTION OF HRIBF

The Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory is a national user facility funded by the Nuclear Physics program in the DOE Office of Science and has a mandate to operate a dedicated user program in nuclear physics using exotic beams. Primary research programs include nuclear astrophysics, studies of nuclear structure far from stability, and investigations of nuclear reaction mechanisms of exotic nuclei. In general, this is accomplished using the Isotope-Separation-On-Line (ISOL) technique where radioactive nuclei are produced in a thick target, transported to an ion source, ionized, and extracted to form a radioactive ion beam (RIB). Radioactive species are produced by intense light-ion beams from the Oak Ridge Isochronous Cyclotron (ORIC) [1] and post-accelerated by the 25 MV Tandem [2], the world's highest voltage electrostatic accelerator. ORIC is currently capable of delivering proton beams at energies up to 50 MeV and intensities up to ~20 μA, deuteron beams up to 50 MeV and ~10 μA, and 100 MeV alpha-particle beams up to 10 μA. The tandem can accelerate an extremely wide variety of species ranging from protons to uranium. Two radioactive beam production stations (Injectors for Radioactive Ion Species), referred to as IRIS1 [3] and IRIS2, link production and post-acceleration. A floor plan of the facility is shown in Figure 1. More than 175 isotopes can be accelerated and approximately 30 additional species are available as low-energy beams (from 40 keV up to 250 keV) [4]. More than 60 post-accelerated beams, including ^{132}Sn, have intensities of at least 10^6 particles per second. The first radioactive ion beam (RIB) experiments at the HRIBF were completed in 1998 [5] and the facility has since delivered an average of more than 1000 hours of radioactive beams on target each year with a high of 1952 RIB hours in FY07. The ability of HRIBF to deliver reaccelerated beams of neutron-rich fission fragments at energies above the Coulomb barrier is unique worldwide.

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RIB EXPERIMENTS

An important part of any RIB facility is the experimental equipment. RIB experiments can be quite challenging due to low beam intensities and high β-particle and γ-ray background from the decay of the beam and its daughter nuclei. The HRIBF has a number of versatile and powerful detector systems that have been optimized for use with low-intensity beams. There are two major experimental end stations using post-accelerated beams at the HRIBF; the Recoil Mass Spectrometer (RMS) [6] used mainly in nuclear structure experiments, and the Daresbury Recoil Separator (DRS) [7] used in support of the astrophysics research program. In addition, an Enge Spectrograph [8] and two general purpose beamlines are available for experiments with radioactive beams accelerated in the tandem. A recently-commissioned detector array, the Low-energy Radioactive Ion Beam Spectroscopy Station (LeRIBSS) [9], is available to study the decays of exotic nuclei utilizing beams at low energy directly from either of the RIB production platforms. Both positive-ion and negative-ion radioactive beams can be delivered to the LeRIBSS setup, which consists of a fast-moving tape collector and detectors for γ-rays, β-particles and neutrons.

Early RIB experiments at the HRIBF (see Ref. [10] and references therein) consisted of several high-impact studies of capture cross-sections important to the astrophysics program, measurements of B(E2) values for the first excited 2^+ states of even-even nuclei near ^{132}Sn, and fusion studies with neutron-rich beams in this region.

Recent experiment highlights include the first-ever direct measurement of the $^{17}F(p,\gamma)^{18}Ne$ cross-section [11], β-decay and neutron emission rates for very neutron-rich isotopes of copper and gallium to study the evolution of shell structure around ^{78}Ni [12], and a number of experiments with long-lived isotopes, ^{26g}Al, ^{10}Be, and ^{7}Be, including measurements of transfer reaction cross-sections and molecular states in light nuclei. As beam intensity and purity improve, nuclear structure studies will move to the proton-rich nuclei, employing fusion-like reactions to study N~Z systems.

RIB PRODUCTION AT IRIS2

One of the more critical vulnerabilities at the HRIBF has been a lack of redundancy in the RIB production system. A large percentage of facility down-time has been associated with failures in components associated with the IRIS1 production systems. The production target and ion source exist in a harsh thermal environment that is compounded by the high radiation levels present during operation. The high level of residual radiological activity makes maintenance more time-consuming, resulting in decreased operational efficiency. This particular vulnerability has been addressed during Phase II of the current HRBIF upgrade plan with the construction (begun in FY06) of a second Injector for Radioactive Ion Species (IRIS2). This new production facility was built at a cost of $4.7M and is nearing completion. Commissioning with stable beams is scheduled to begin in May 2009. This additional capability will result in an increase of about 50% in HRIBF operational hours, improve overall reliability, decrease transition times between RIB experimental campaigns, and allow new ion sources and beam purification techniques to be used to improve the radioactive beam quality.

At both of the production facilities, IRIS1 and IRIS2, light-ion beams from the cyclotron irradiate a RIB production target that is close-coupled to an ion source on a +/- 60 kV platform. The target is typically operated at temperatures in excess of 2300 K, which helps radioactive nuclei to more quickly diffuse out of the target and to be transported through a hot tantalum tube to an ion source. The standard HRIBF target and ion source enclosure can accommodate a variety of target materials and geometries [13] and several different ion sources producing both positive and negative ion beams.

A magnetic mass analysis system with a resolving power of 1000 selects the mass of interest from the total beam extracted from the ion source. The tandem accelerator requires negative-ion injection, so if a positive-ion source is used, the beam passes through a

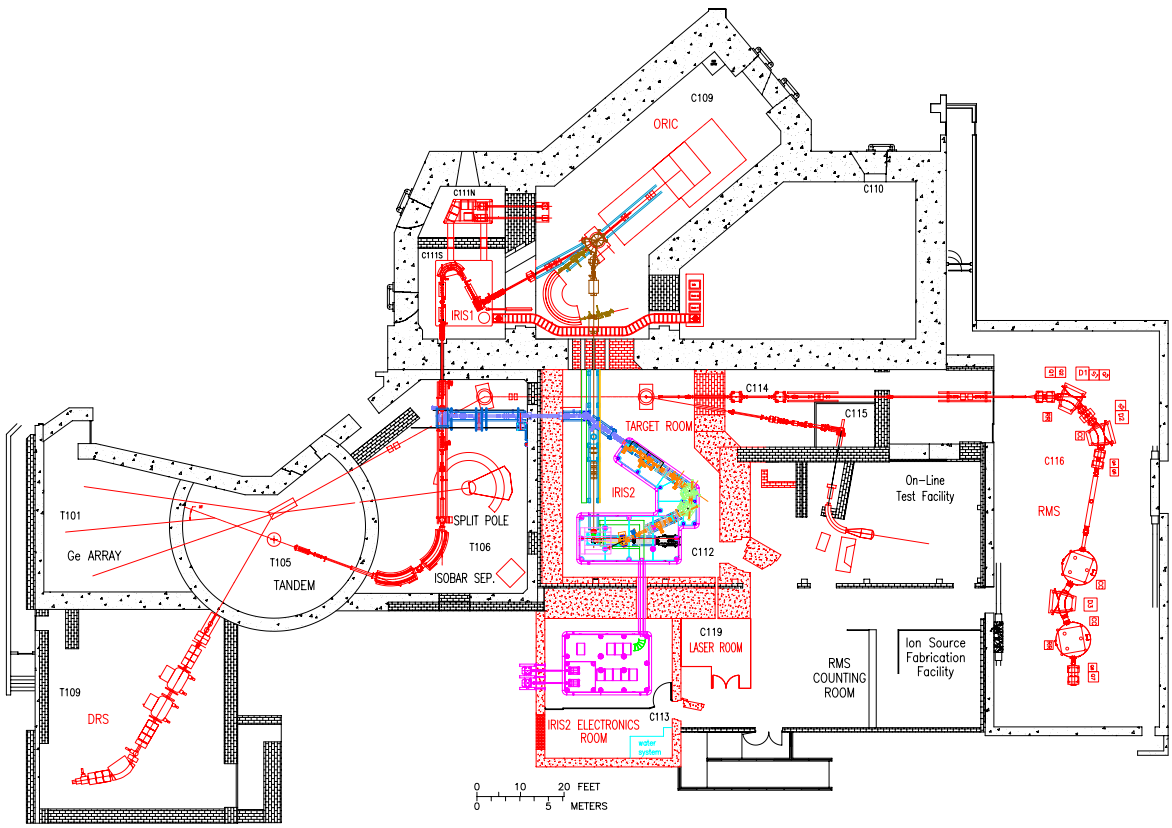

Figure 1: The current HRIBF floor plan showing the production accelerator (ORIC), the post-accelerator (Tandem), the two ISOL production platforms (IRIS1 and IRIS2), and the beam lines to the experiment endstations.

Cesium-vapor charge exchange cell [14] while still at energies less than 60 kV. In a 2-step process, electrons are transferred to the positive ions and a negative ion beam is formed. The efficiencies for this process are element specific and energy dependent, but they can range from as high as 40% down to values much less than 0.1%. The negative-ion beam is accelerated up to a typical energy of 200 keV for transport to the Tandem.

The HRIBF floor plan [Fig. 1] shows how the new IRIS2 production system is integrated into the facility and it emphasizes one major advantage of IRIS2 over IRIS1. The IRIS2 target and electronics rooms are about four times as large as the corresponding rooms for IRIS1. This will allow new beam purification techniques to be implemented that were space-limited at IRIS1. Included in this list is an ion source based on laser resonance ionization to provide pure beams of many different elements. At one of the off-line ion source development facilities [15] we have assembled and tested a laser system based on all solid-state lasers; a Nd:YAG pump laser and three tunable Ti:Sapphire lasers with frequency doubling, tripling, and quadrupling capabilities [16]. Also, the IRIS2 platform will have room for a unique beam purification technique based on the selective neutralization of contaminant ions in a negative-ion beam, which is accomplished by shining a laser beam onto an ion beam that has been cooled in a gas-filled RFQ [17].

IRIS2 is co-located with the High Power Target Laboratory (HPTL) [18], which was completed during Phase I of the HRIBF upgrade plan at a cost of $4.75M. The HPTL has been used for testing RIB production targets with high-intensity beams from the cyclotron and will continue to be utilized after the IRIS2 facility is complete. These capabilities are complementary to those at the On-Line Test Facility [19] where low power beams from the tandem are used to test RIB production targets and ion sources. The availability of two RIB production platforms will allow for more high-power target development time than was previously possible.

FACILITY UPGRADES

As the IRIS2 production platform comes on-line, it becomes important to proceed with Phase III of the HRIBF upgrade plan, which addresses the need for driver accelerator improvements that will lead to new production capabilities, improved operational efficiency, higher reliability, and lower operating cost. At this point, three options have been and continue to be carefully considered and evaluated. The least expensive option, which promises enhanced reliability but offers only small potential for any significant advancements in facility capabilities, is to devote resources to refurbish the present driver accelerator, ORIC. A more attractive option is to purchase a commercial cyclotron that can replace ORIC, providing all of the functionality of ORIC with reduced operating cost and increased reliability. This could be accomplished by purchasing a commercial cyclotron that has only recently become available. Capabilities of this cyclotron include multi-species acceleration at variable energies and dual port extraction. It can deliver 70 MeV proton beams with intensities up to 750 μA, which could be used to substantially increase the production rate of fission fragments, extend existing proton-rich capabilities, and allow for production of long-lived isotopes that may be used for medical applications [20]. The third, and most expensive option (due, in part, to a substantial level of civil construction), is to incorporate a relatively low-energy (25–50 MeV) electron accelerator with modest-power (50-200 kW) to produce neutron-rich radioactive beams via photofission in an actinide target [21]. This particular plan would greatly enhance the capabilities of the facility to deliver high quality beams of neutron-rich nuclei far from stability. As the facility continues to address vulnerabilities in a systematic fashion, HRIBF will stay in the forefront in research and development of post-accelerated radioactive beams and maintain its role as a leader in ISOL science and technology.

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