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HOLIFIELD RADIOACTIVE ION BEAM FACILITY DEVELOPMENT AND STATUS*

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Abstract

The Holifield Radioactive Ion Beam Facility (HRIBF) is a national user facility dedicated to nuclear structure, reactions, and nuclear astrophysics research with radioactive ion beams (RIBs) using the isotope separator on-line (ISOL) technique. An integrated strategic plan for physics, experimental systems, and RIB production facilities has been developed and implementation of the plan is under way. Research objectives are defined for advancing our understanding of the nature of nucleonic matter, the origin of elements, solar physics, and synthesis of heavy elements. Experimental systems upgrade plans include new detector arrays and beam lines, and expansion and upgrade of existing devices. A multifaceted facility expansion plan includes a $4.75M High Power Target Laboratory (HPTL), presently under construction, to provide a facility for testing new target materials, target geometries, ion sources, and beam preparation techniques. Additional planned upgrades include a second RIB production system (IRIS2), an external axial injection system for the present driver cyclotron, ORIC, and an additional driver accelerator for producing high-intensity neutron-rich beams.

INTRODUCTION

The Holifield Radioactive Ion Beam Facility (HRIBF) is a national user facility funded by the DOE Office of Nuclear Physics to conduct research with radioactive ion beams (RIBs) produced using the isotope separator on-line (ISOL) technique, and to advance the technologies associated with RIB production and science. In production mode, light-ion beams from the Oak Ridge Isochronous Cyclotron (ORIC) produce radioactive atoms in thick targets. The atoms diffuse and effuse from the production target into an ion source closely coupled to the target, where they are ionized and accelerated at up to 60 keV. This integrated system is referred to as a target/ion source (TIS). The resulting RIB is mass analyzed and post-accelerated by the 25MV tandem electrostatic accelerator prior to delivery to one of several end stations where experiments take place.

An integrated, strategic plan for physics, experimental systems, and RIB production facilities has been developed to ensure that HRIBF will maintain a productive role in RIB science, while preparation for the Rare Isotope Accelerator (RIA), the next-generation RIB facility, proceeds.

SCIENCE PROGRAM

The unique suite of RIBs available at HRIBF are used to probe the nature of nucleonic matter and the effects of neutron/proton excess on nuclear properties, to study nuclear reactions relevant to nucleosynthesis in stellar explosions, and to explore physical processes occurring in our sun. The richness and diversity of the experimental program is illustrated by the following examples.

The nuclear astrophysics program has carried out a series of high-impact studies of various ^{17,18}F+p reactions [1-5] utilizing the silicon detector array (SIDAR) and gas ionization chambers. As new beams become available and RIB intensities increase, these measurements will be extended with radioactive ion beams such as ^{17}F, ^{18}F, ^{33}Cl, ^{34}Cl, ^{25}Al, ^{26}Al, and others to understand nuclear burning in nova explosions and x-ray bursts. Direct measurements of the (p,γ) reactions on these systems will be carried out using the Daresbury Recoil Separator to identify the capture reaction products and will require implementation of high-density gas target systems, as well as significant beam development. These same tools will be employed to study the ^{7}Be(p,p) and ^{7}Be(p,γ) reactions, using a ^{7}Be radioactive beam, to improve our understanding of neutrino generation and nuclear burning in our sun.

Transfer reactions are a key element of research of both the astrophysics and nuclear structure programs [5,6]. The study of (d,p) reactions in inverse kinematics on neutron-rich beams near the N=50 and N=82 closed shells can provide data to be used in an effort to better understand the astrophysical r-process. These challenging experiments will require major advances in both beam intensities and detector systems. The study of transfer reactions on neutron-rich nuclei near closed shells is also a priority of the nuclear structure program. The reactions (^{13}C,^{12}Cγ) and (^{9}Be,^{8}Beγ) have been employed in pioneering studies, and used successfully to locate unknown single-particle states [7]. Future experiments will employ (d,pγ) reactions as well as two-nucleon transfer studies with RIBs to probe nucleon-nucleon correlations in systems far from stability.

Early nuclear structure studies at the HRIBF focused on the measurement by Coulomb excitation of transition matrix elements to the first excited 2^+ states in even-even nuclei near the ^{132}Sn double closed shell and the N=50 shell in the vicinity of ^{82}Ge [8,9,10]. This work has produced interesting and unexpected results. Most of these experiments depend critically on the CLARION array of 11 clover Ge detectors, and HyBall, a high-efficiency, 95-element CsI charged particle array. There

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is a very large scope for extension of this RIB program. We plan higher-order Coulomb excitation measurements, and the study of odd-mass nuclei. We will also make systematic measurements of static M1 and E2 moments of excited states. Proof-of-principle experiments have already been done, but improvements in both detector systems and beams will be required.

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. Work in this area is already under way using the techniques of decay spectroscopy to probe the structure of nuclei at and beyond the proton drip line.

Fusion studies using very neutron-rich beams have produced some of the most interesting and surprising results yet found at HRIBF [11]. Extension of these studies with improved beams and detectors could provide new insights into production of superheavy elements.

EXPERIMENTAL SYSTEMS

The primary research endstations at HRIBF are the Recoil Mass Spectrometer (RMS), used primarily for nuclear structure and decay spectroscopy studies, and the Daresbury Recoil Separator (DRS), which is optimized for reactions relevant to nuclear astrophysics. Two general-purpose beam lines, an Enge spectrograph, and an isotope separator used as an On-Line Test Facility (OLTF) for ISOL beam development, are also available.

The RMS is equipped with a powerful set of detectors including the CLARION and HyBall arrays, plus a highly segmented Si forward wall, a liquid scintillator array for neutron detection, and ion-chambers for beam assay. In addition to these target-position detectors, the RMS is instrumented with a variety of focal-plane detector systems employing advanced digital readout and processing systems. The DRS beam line is also well instrumented with the SIDAR and ion chamber systems.

The experimental program outlined here will require enhancement of these systems. The most critical needs are a substantial enhancement of the CLARION array which will improve its $\gamma\gamma$ efficiency by a factor of four, the development of a high-density hydrogen and helium gas-jet target for astrophysics experiments, and the development and implementation of a new, large solid-angle, highly-segmented Si detector system known as the Oak Ridge Rutgers University Barrel Array (ORRUBA). ORRUBA is optimized for (d,p) and (d,pγ) studies in inverse kinematics, and will require the development of a new endstation to be shared with a resurrected Spin Spectrometer [12], a 72-element 4π NaI array. A beam line for decay spectroscopy with unaccelerated beams is also being developed.

RIB PRODUCTION FACILITIES

A multifaceted production facility upgrade is also under way [13]. The first phase, presently being constructed, is the High Power Target Laboratory (HPTL), a $4.75M addition that will provide a dedicated venue for testing new target materials, target geometries, ion sources, and beam preparation techniques using high-power beams from ORIC [14]. Present test facilities include two off-line development test stands, and one on-line low-power test stand that utilizes low-intensity stable ion beams from the tandem accelerator. The only available location for high-power on-line testing is HRIBF's single RIB production platform. Such testing entails significant risk and requires interruption of the RIB experimental program and is limited due to physical constraints imposed by the room size and platform configuration.

Components of the HPTL are new heavily shielded space for target bombardment, lightly shielded space for instrumentation, and equipment for target and beam development. The heavily shielded Target Room has been constructed within the existing facility, replacing stacked concrete caves with a poured concrete shield structure made of standard density concrete, with seven-foot-thick walls and a five-foot-thick ceiling. A companion Instrumentation Room has been constructed with two-foot thick poured walls.

Primary technical equipment components are a new target station and RIB analysis system located on a high-voltage platform, and a new light-ion beam transport system from ORIC to the target station. The ORIC beam line is elevated above existing beam lines and handling equipment for activated TIS enclosures, and will provide beams incident on the target at an 8-degree downward angle to facilitate development of thin and liquid targets. Project completion is scheduled for September 30, 2005.

Phase two of the upgrade plan addresses the most vulnerable component in an ISOL facility, the production system. HRIBF presently employs a single production station known as the Injector for Radioactive Ion Species #1 (IRIS1). IRIS1 consists of a TIS, beam optics components, RIB diagnostics, and a first-stage mass analysis system, with resolving power of one part per thousand, located on a -300kV injector platform. The platform voltage imparts energy to the RIB for injection into the tandem accelerator. A 1 part in 20,000 isobar separator is also part of the transport system from the platform to the tandem. Because of the extremely harsh high radiation, high voltages, and high temperature environment, component failure rates can be high and maintenance difficult. Thus a second RIB production station, known as IRIS2 (Fig. 1), has been proposed to provide critical redundancy for the heart of the facility. IRIS2 would be co-located with the HPTL, providing an alternate production station when target and ion source testing is not taking place. IRIS2 would consist of an expanded platform structure, first-stage mass separator, and a beam transport system to deliver beam to the existing isobar separator and tandem. The project is proposed for FY2006-FY2008 at a cost of ~$4.6M.

A projected third major enhancement to HRIBF addresses the intensity of ORIC light-ion beams and the durability of the ORIC ion source. ORIC operates with an internal Penning source that produces proton, deuteron, and alpha beams, and a three-part extraction system that deflects the accelerated beam from its orbit. Intensities of all beams are limited by the extraction efficiency (typically 45%-55%), and heavier beams are further limited by source emittance. Source cathode lifetimes are excellent for protons and deuterons, reaching up to 800 hours, but can be an order of magnitude smaller for heavier beams. It is proposed to replace the internal ion source with two external ion sources that can inject a wider array of species axially into ORIC by means of a spiral inflector [15]. Extraction of negative ions such as H^- and D^- beams could be accomplished with foils, yielding near 100% extraction efficiency and substantially higher beam intensity on target with minimal machine activation. Heavier beams could also be injected at higher efficiency and the source would not be subject to short-lived cathodes. Ion source maintenance would be greatly simplified by being removed from the high radiation environment. The availability of higher intensity light-ion beams as well as heavy ions should have a substantial impact on RIB intensity, particularly for proton-rich beams. The cost of the new external ion sources, axial-injection system, and improved extraction system is estimated to be substantially less than $1M.

Finally, it is desirable to add an additional driver accelerator to the HRIBF RIB production system, providing an alternative to the 45-year old ORIC. Our present preference is for a high-power (50-100kW), modest-energy (30-50 MeV) electron accelerator. Such a machine would have essentially no impact on our ability to produce proton-rich species, but could result in very large increases in the yield of neutron-rich species via electron-induced photo-fission in actinide targets. For example, intensities of Sn RIBs with masses A>132 could be increased by 2 to 3 orders of magnitude compared to current HRIBF capabilities. This upgrade would cost around $10M. A modest increase in the maximum energy of accelerated RIBs would also be desirable, but no final identification of a sufficiently cost-effective path has yet been made.

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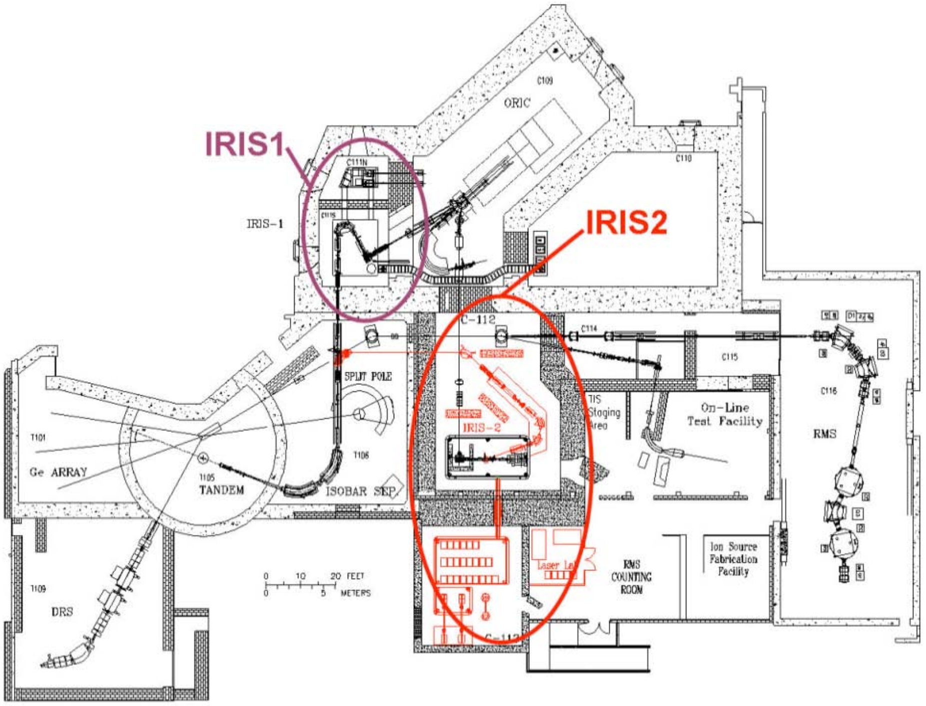

Figure 1: HRIBF Facility Layout with IRIS2

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