THE LATEST FROM THE NEW HOLIFIELD RADIOACTIVE ION BEAM FACILITY AT OAK RIDGE NATIONAL LABORATORY

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The status of the new Holifield Radioactive Ion Beam Facility at Oak Ridge National Laboratory (ORNL), which is slated to start its scientific program late in 1996 is discussed, as is the new experimental equipment which is being constructed at this facility. Information on the early scientific program is also given.

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1. Background

The on-line isotope separator technology developed¹ at CERN and at other facilities has progressed to the extent that it is feasible to produce and accelerate beams of isotopes not occurring in terrestrial matter with sufficient intensity to address a myriad of nuclear structure, nuclear astrophysics, and material science problems²⁻⁴. First-generation isotope separator on line (ISOL) radioactive ion beam (RIB) facilities are being constructed in North America, Europe, and Japan based on this technology and existing accelerators and reactors. The Holifield Radioactive Ion Beam Facility⁵ (HRIBF) at ORNL will be the first such ISOL RIB facility operational which is capable of addressing both nuclear structure and astrophysics topics⁶. The present paper describes the status of this facility, which will become operational later this year. The plans for the early scientific program and future upgrades at the HRIBF also will be discussed.

2. Present Status of the Facility

The HRIBF is based on a reconfiguration of the accelerators and experimental facilities available since the early 1980s at the Holifield Heavy Ion Research Facility (HHIRF). A High Voltage RIB Injector, as shown in Figure 1, has been constructed where intense beams of light ions from the Oak Ridge Isochronous Cyclotron (ORIC) will be utilized to produce radioactive atoms. After defusion from the target, ionization, and mass and isobaric separation, these radioactive ions will be accelerated in the 25-MV Tandem Accelerator (the world's largest electrostatic accelerator).

The construction of the HRIBF and the associated radiation handling system, also shown in Figure 1, is complete. ORIC has provided beams to the target on the RIB Injection Platform, and stable beams of several elements, produced at the target position of the target-ion source on the injection platform, have been ionized, mass analyzed, charge

* This paper is a group report made on behalf of more than 50 scientists, engineers, technicians, and craft personnel who over the past 5 years have participated in planning, engineering, constructing, and commissioning the HRIBF and its associated experimental equipment.

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HOLIFIELD RADIOACTIVE ION BEAM FACILITY

Figure 1 Layout of the HRIBF showing ORIC, the RIB Injector Platform, the magnetic analysis system for the selection of the RIB of interest, the 25-MV Tandem Accelerator, and the radiation handling system.

exchanged, accelerated from the injection platform, isobaric analyzed, accelerated through the tandem accelerator, and identified after mass analysis.

Likewise at a separate location (the UNISOR mass identifier) a liquid germanium target has been developed and tested with beams from the Tandem Accelerator in a target ion source assembly identical to that which will be used on the RIB Injection Platform. For example, both radioactive ^{69}As and ^{70}As have been produced in the $^{70}\text{Ge}(p,xn)$ reactions with 40 MeV protons, ionized, extracted, mass analyzed, and identified. The measured intensities when scaled to the 20 mA proton beam of ORIC, isotopically pure ^{70}Ge targets, and realistic charge exchange fractions and transmission should provide beams of radioactive ^{69}As and ^{70}As with intensities of greater than 3×10^7 and 10^8 particles per second, respectively. In mid-August the liquid germanium target will be moved to the RIB Injection Platform and a demonstration radioactive arsenic beam will be produced on the platform and accelerated through the Tandem. Beams of heavier radioactive arsenic ions produced by (p,xn) reactions on heavier germanium isotopes and gallium ions produced in the $\text{Ge}(p,\alpha xn)$ reactions also have been identified in these target tests and could be provided as future RIBs. Similarly radioactive isotopes of selenium could be produced with $(^3\text{He},xn)$ and (α,xn) reactions and a slightly-modified liquid germanium target. However, such selenium beams have not been demonstrated. Due to the thinner effective target, associated with the larger energy loss of helium atoms than for protons, the selenium RIBs are expected to be somewhat less intense than the arsenic RIBs.

When the liquid germanium target is moved to the RIB Injector Platform, a Al_2O_3 target for the development of radioactive ^{17}F and ^{18}F will be installed at the UNISOR separator. Previous tests have demonstrated that essentially all of the radioisotopes of fluorine produced from proton bombardments can be released from a 3 micron Al_2O_3 gauze fiber target.

3. Experimental Apparatus

There is a tradition for nuclear structure studies with accelerated beams of heavy ions at ORNL, dating from the 1950s. Therefore, an assortment of experimental apparatus for such studies exists. Examples include an array of 20 Compton-suppressed germanium detectors, a 4π array of 72-NaI detectors, an array of 96 BaF_2 detectors for detecting high energy gamma rays, an Enge split pole magnetic spectrograph, the UNISOR on-line isotope separator featuring a helium dilution refrigerator, and a variety of scattering chambers. In addition new experimental stations especially suited for nuclear structure studies with RIBs and for the new ORNL nuclear astrophysics program have been constructed and are described in the ensuing paragraphs.

3.1 The Recoil Mass Spectrometer (RMS)

The focal point of the nuclear structure experimental station is a newly-designed recoil mass spectrometer⁷ (RMS) located in Robinson Hall, a recent addition to the Holifield Facility. A layout of this instrument, designed to select rare reaction products from the beam and other reaction channels at the level of one part in about 10^{13} , is shown in Figure 2. Besides the usual crossed electric and magnetic fields (labeled E1 and E2 and D3 respectively in Figure 1) for such mass separators, the "front end" of the RMS is designed so that the beam is stopped at a momentum focal plane in Q3. A position sensitive avalanche counter (PSAC) for establishing the horizontal and vertical positions of the recoiling reaction products is located at the RMS focal plane, and an ionization chamber is located "downstream" of the PSAC. The ionization chamber is used to establish the Z of the reaction products by an energy loss measurement. This Z "measurement" is effective for $A < 100$.

The construction of the RMS and its basic complement of focal plane detectors is complete. It is presently being commissioned. Preliminary measurements⁸ for the products of the reaction of 220 MeV ^{58}Ni and ^{60}Ni yielded a mass resolution of $M/\Delta M \approx 450$ for $A = 86$ with essentially no background at the focal plane.

Ancillary instrumentation provides information on both the prompt and delayed decay properties of the reaction products and their daughters. The transit time of a typical reaction product for the nearly 25 meter flight path from the target to the RMS focal plane, 10 to 100 ms, divides the experimental possibilities for this instrument into two types: "prompt" events in which the radiation is detected near the target and "delayed" events in which the radiation is detected at the focal plane.

Detectors being installed at the RMS focal plane include double-sided silicon-strip detectors for proton and α -particle decay studies as well as a moving tape collector with

Figure 2 Schematic layout of the HRIBF RMS^{7,8}.

germanium detectors and a pair spectrometer to study the gamma decay of the reaction products.

3.2 Gamma-ray and Particle Arrays for Nuclear Structure

Arrays of gamma-ray, light-charged-particle, and neutron detectors⁹, optimized for the study of weakly populated nuclei lying far from the valley of stability, are being constructed at the target position of the nuclear structure experimental station. A schematic diagram of this array is shown in Figure 3. Also shown in this figure is the "fantail" scattering chamber, designed to shield the germanium detectors from the buildup of scattered radioactive particles from the beam thereby minimizing the background gamma-ray activity.

The heart of this array is eleven "clover" detectors. Each detector consists of four individual germanium crystals, sharing a common cryostat. The four crystals may be operated either as four independent detectors, or as one large detector by summing their signals. In 10 of the 11 planned detectors each germanium crystal is electronically subdivided ("segmented") into halves, providing a lateral spatial resolution of less than 2 cm. In addition to providing excellent efficiency for detecting high-energy gamma rays (150% relative to a 3" x 3" NaI crystal), these detectors maintain a superior energy resolution even for gamma rays emitted from fast-moving recoiling nuclei by minimizing the effects of Doppler broadening. Such an arrangement also provides a means for measuring the linear polarization of the detected gamma rays.

Figure 3 Schematic layout of the detector arrays being constructed at the target position of the RMS.

The twelve high-purity 25% germanium detectors with their associated bismuth germinate anti Compton shields and one clover detector are presently available from the existing ORNL germanium array. By the beginning of 1997 the target chamber, new detector support system and six shielded clover detectors should be available; however, only five clover detectors will be operational with existing electronics prior to May 1997 when the new electronics becomes available. The completion of this array is slated for late in 1997 if sufficient capital funds become available in fiscal year 1997.

The construction⁹ of a microball for detecting light charged particles is scheduled for completion in mid-1997. This instrument, similar in design¹⁰ to the microball currently in use with the GAMMASPHERE, also is shown in Figure 3 together with an array of neutron detectors.

3.3 The Astrophysics Experimental Station

The foci of the astrophysics experimental station and indeed the newly established nuclear astrophysics program¹¹ at the HRIBF is the Daresbury Recoil Separator (DRS). This instrument was given to ORNL by the British Natural Science and Engineering Council, when the Nuclear Structure Facility at Daresbury Laboratory was closed. It was moved to the HRIBF late in 1994, where it is currently being installed. Its design as a velocity filter makes it well-suited for studying inverse (p,γ) reactions which occur in stellar

explosions. This instrument and its associated detectors should be ready for commissioning late in 1996.

4. Experimental Program

The scientific program of the HRIBF has been discussed previously (see *e.g.*, reference⁶). Thirty-four letters of intent were received in August 1995 from 99 scientists at 36 institutions. The scientific content of these letters of intent are characterized in Table 1, where the programs that can start with radioactive arsenic and fluorine beams also are indicated. In response to a call for proposals for research with beams of radioactive ⁶⁹As and ⁷⁰As, 960 hours of running were recently requested for nuclear structure studies. Two thousand eight hours of associated experiments with beams of stable ions were also requested. The HRIBF Program Advisory Committee (PAC) will meet August 6 to consider these proposals for the scientific program which will start late this year.

Table I Scientific Topics Represented in the Letters of Intent

Topic	Number of Letters
Astrophysics	
rp-process & CNO breakout*	5
Solar neutrinos	1
Nuclear Structure	
Light nuclei	2
Self-conjugate nuclei	7
¹⁰⁰ Sn region	2
A = 110 - 130 nuclei*	6
Heavy nuclei	1
Coulomb excitation*	1
Proton & α decay*	3
Giant dipole resonances	1
Ion traps	1
Reactions	
Transfer reactions*	3
Subbarrier fusion*	1

*Denotes topics which can be addressed with radioactive arsenic and fluorine beams.

The production and acceleration of neutron-rich RIBs also are feasible at HRIBF. Intense proton beams from ORIC can be used to produce neutron-rich fission fragments from a ^{238}U target. Preliminary projections indicate that up to about 10^7 particles per second of "doubly magic" $^{132}\text{Sn}_{82}$ could be accelerated above the Coulomb barrier with the addition of an actinide target to the present facility. Of course, the radiation handling system would have to be adequate to deal with the additional long-lived radioactivity of the fission fragments. Neutron-rich RIBs from such an actinide target are planned for 1998.

Note added in proof: August 30 the first ^{69}As and ^{70}As beams were produced on the RIB Injection Platform and accelerated through the 25-MV Tandem Accelerator. On August 6 the HRIBF Program Advisory Committee met and granted 800 hours of running time with radioactive ^{69}As and ^{70}As beams and 1000 hours of associated experiments with stable beam. A list of approved experiments can be accessed on the HRIBF web site (www.phy.ornl.gov). Recent measurements indicate that radioactive ^{17}F and ^{18}F can be produced and released from the Al_2O_3 gauze fiber target and can be ionized. When intense beams of radioactive ^{17}F and ^{18}F have been demonstrated, proposals for experiments utilizing these beams, which are ideal for a variety of nuclear astrophysics and nuclear reaction studies, will be called for.

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