

# THE U.S. RARE ISOTOPE ACCELERATOR PROJECT

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## Abstract

The Rare Isotope Accelerator (RIA) is the highest priority of the nuclear physics community in the United States for a major new facility. RIA is a next generation facility for basic research with radioactive beams that utilizes both standard Isotope-separator On-line (ISOL) and in-flight fragmentation methods with novel approaches to handle high primary-beam power and remove existing limitations in the extraction of short-lived isotopes. A versatile primary accelerator, a 1.4-GV, CW superconducting linac designed to simultaneously accelerate several heavy-ion charge states, will provide beams from protons at 900 MeV to uranium at 400 MeV/u at power levels of 400 kW. The wide variety of primary beams allows various production and extraction schemes to be used to optimize production of specific isotopes. These isotopes, at unprecedented intensities, are available for research at a broad range of energies. They can be delivered at ion source energy for stopped-beam studies, reaccelerated by a second superconducting linac, or directly separated in-flight for use at energies up to 500 MeV/u. The post accelerator uses a unique injection scheme, based on CW low-frequency RFQs, for efficient acceleration of singly charged heavy ions with masses up to 240 amu from ion source energy.

## 1 INTRODUCTION

The study of the properties and reactions of short-lived isotopes is a key to our understanding of fundamental questions in nuclear physics, nuclear astrophysics and the study of fundamental interactions at low-energy. This has long been recognized by the international nuclear physics community and is reflected by the investments in that field that have been or are being made in North America, Europe, and Asia. The US nuclear physics community addressed the importance of such studies in its 2002 Long Range Plan [1] where RIA is identified as its highest priority for new construction.

The RIA facility is a powerful combination of new technologies that will enable great advancements in this science. Some of the factors contributing to the enhanced capabilities are:

- Use of a variety of production techniques for short-lived isotopes including new approaches that remove the main previous limitations of standard ISOL techniques.
- A powerful superconducting driver linac capable of accelerating any stable ion from protons to uranium and designed to allow simultaneous acceleration of multiple charge states of a given ion to attain unprecedented power for the heaviest ions.

- A very efficient post-acceleration scheme based on a superconducting linac injected by low frequency RFQs capable of accelerating singly charged radioactive ions of mass up to 240 amu from ion source energy.
- First rate experimental equipment and multiple user capability to maximize use of the facility.

This paper is an update of other recent reports on the RIA project and the on-going national R&D program [2,3,4,5].

## 2 FACILITY DESCRIPTION

A simplified schematic layout of the RIA facility is shown in Fig. 1. The main functional components are described in the following.

### 2.1 Driver Accelerator

The driver linac produces the primary high-power stable ion beam required to produce the radioisotopes. The RIA facility will use a number of production mechanisms spanning the range from spallation on thick targets which requires high energy light ion beams (e.g. p, d,  $^3\text{He}$ ), fragmentation which requires heavy-ion beams at high-intensity and energies in the 100-1000 MeV/u range for mid-mass nuclei, to in-flight fission which requires high intensity uranium beams at energies up to about 400 MeV/u. To be able to fully exploit the various production mechanisms available at RIA it is, therefore, imperative that the driver linac be capable of accelerating essentially all stable nuclei to energies above 400 MeV/u with high efficiency. The broad mass-to-charge ratio of the species to be accelerated together with the higher energy for lighter ions and high current requirements dictate the use of a superconducting linac whose short independently

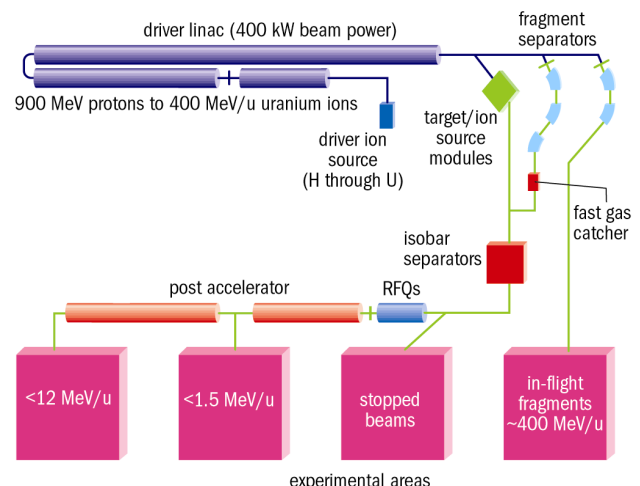


Figure 1. Simplified schematic layout of the Rare Isotope Accelerator (RIA) facility.

Table I. Beam list for selected ions from the RIA Driver Linac. The output currents indicated correspond to 400-kW beam power.

A	$q_{\text{source}}$	$I_{\text{source}}$	$q_{\text{out}}$	$I_{\text{out}}$	Energy
		$\mu\text{A}$		$\mu\text{A}$	MeV/u
1	1	556	1	445	899
3	2	232	2	186	717
2	1	416	1	333	600
18	6	54	8	40	551
40	8	29	18	18	554
86	14	17	36	9	515
136	18	12	53-54	6	476
238	28-29	8	87-90	4	403

phased cavities enable efficient acceleration over a wide velocity profile. Beam power up to 400 kW is specified for the driver linac to enable high intensity secondary beams while simultaneously irradiating more than one production target. A list of beam energies and intensities for selected ions from the driver is given in Table I.

The present status of the RIA Driver Linac design and component prototyping is given in another paper at this conference [6]. The current baseline design comprises: (1) an advanced ECR ion source [7] and high intensity beam analysis system [8], (2) a 2-charge-state LEBT and pre-buncher [9], (3) a low-frequency CW RFQ [10], (4) six classes of low to medium velocity superconducting resonators [6,11], (5) three classes of high-velocity compressed elliptical resonators [12,13], (6) two high-intensity charge-state strippers and associated multiple-charge-state beam transport sections [14, 15, 16, 17], and a (7) multiple-charge-state RF switcher and beam transport system for beam sharing [16, 18].

Design studies are also in progress for an alternative driver front-end starting at 80 MHz rather than 57.5 MHz [19, 20, 21]. Some aspects of this alternative design, as well as, another alternative that would incorporate triple-spoke resonators in place of the compressed ellipticals are presented in [6].

The design of the driver accelerator took a number of bold steps to meet the requirements of the RIA facility. A vigorous R&D program led to the development of the multiple charge state acceleration concept [22], its experimental demonstration at the ATLAS facility at ANL [23], the development of the spoke-cavity superconducting structures [24,25] to fill the gap in the velocity regime between the low- $\beta$  ATLAS-type cavities and the CEBAF-type velocity-of-light structures, and development of the SNS-type high- $\beta$  cavities [12,13] that will be used for the higher energy section of the linac. The development of windowless thin film liquid lithium stripper foils [16] indicated schematically in Fig. 2 is ongoing at ANL.

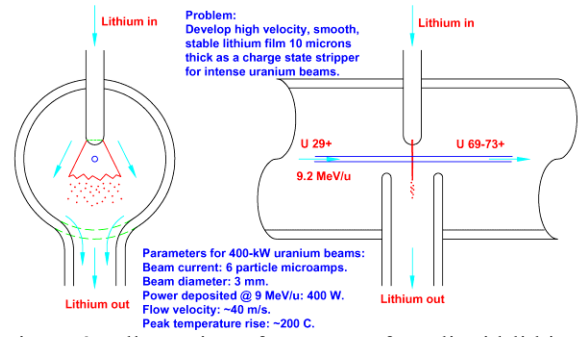


Figure 2. Illustration of a concept for a liquid-lithium stripper film with parameters necessary for the first stripper required for a 400-kW uranium beam.

## 2.2 Isotope Production complex

The production of the radioisotopes will occur by interaction of the high-power primary beams on targets located in an enclosed production building. Remote handling capabilities and the required radiation control mechanisms will be present in this building. The radioactive isotope inventory that will be present in this building require it to be a category 3 non-reactor nuclear facility and all required conditions for operation of such a facility will be met. The production of radioactive isotopes in this complex can occur through 4 main mechanisms, all of which are enabled by the versatile driver described above.

The standard ISOL technique where a high energy light ion beam impinges on a thick target producing short-lived isotopes via spallation or induced-fission reactions. The target is heated to release the activity quickly. The activity then diffuses to an ion source where it is ionized and extracted and made available for experiments at low energy or at higher energy after post acceleration. A second approach is that of production of radioactive species by fragmentation of a fast heavy ion beam on a thin target capable of handling the high beam power. The reaction products are pushed forward by the kinematics and can be separated from the beam in a fragment separator. These beams are then available for experiments at high-energy but with limited beam quality.

These two conventional approaches are implemented with unprecedented power at RIA where new technology based on flowing liquid lithium targets [26,27] will allow the full driver beam power to be used effectively. These two approaches are supplemented by two new complimentary approaches that remove the main limitations of the standard approaches. The first new approach is the two-step neutron generator technique [26] where the high-energy light ion beam is converted to fast neutrons in a cooled converter which is surrounded by a production target where fissions induced by the fast neutrons produce the radioactive species which are then extracted in a fashion similar to that used in the standard ISOL technique. This yields significant gains since the power deposited by the light ion beam (mostly via

electromagnetic interactions) is in a volume which can be cooled efficiently, while only the neutron and the fission power is deposited in the releasing target where power removal is much more difficult to perform without affecting the other functions of the device.

A second new approach brings together the advantages of the in-flight fragmentation approach with that of the ISOL techniques. Radioactive isotopes are produced by fragmentation (or in-flight fission) of fast heavy-ion beams on a “thick” thin target, the reaction products are again pushed forward by the kinematics and after selection by a large acceptance fragment separator are slowed down and stopped in a gas catcher system [28] where they are thermalized but remain singly charged and can be extracted by a combination of gas flow, DC, and RF fields to be further reaccelerated. This results in beams of quality similar to those obtained by ISOL techniques, without the chemical limitations encountered by the ISOL technique in the diffusion and release out of thick targets.

Again, a vigorous R&D program is ongoing on these different topics. A prototype windowless liquid lithium target shown schematically in Fig. 3 is currently being evaluated at Argonne [27]. Also, the full-scale prototype gas cell shown in Fig. 4 is currently being assembled [28] for testing at GSI during 2003 with heavy ion fragments at 400 MeV/u.

### 2.3 Post-Accelerator

The most efficient production mechanisms for slow radioactive ions yield these ions in the  $1+$  charge state. The post-accelerator must therefore be able to accept such low charge-to-mass ratio ions from ion source energy. One approach to this problem is to increase the charge state of the ions before acceleration via a charge booster stage, be it an ECR-type device or an EBIS-based system. While both of these approaches have shown significant progress over the last decade, for a versatile system they present too low an efficiency at this point. To ensure maximum efficiency in the post-acceleration process, RIA

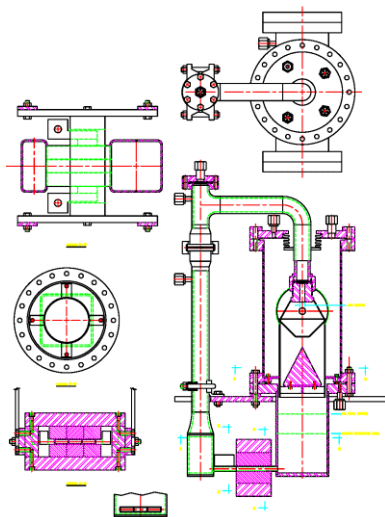


Figure 3. Drawing of the prototype windowless liquid lithium test loop that is currently being tested at Argonne.

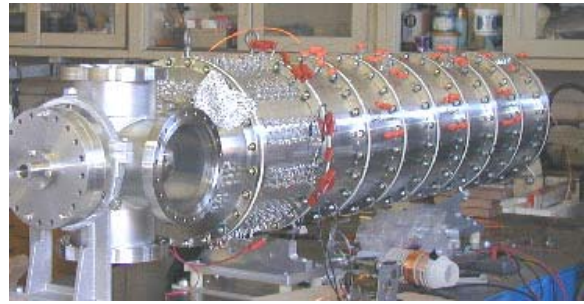


Figure 4. Photograph of the full-scale prototype fast gas catcher currently being assembled at Argonne. The cell is 25-cm inside diameter and 1.2-m long. The helium gas thickness will be 0.5 atmosphere-meters.

proposes a different approach [29] based on a superconducting linac accelerator injected by low frequency RFQs.

The singly charged radioactive ions extracted from the ion source are first mass separated by a large acceptance, high-resolution ( $\Delta m/m = 1/20000$ ) isobar separator [30]. The selected isotopes are then bunched by a multi-harmonic buncher and accelerated through a series of 3 low frequency RFQs, the first two located on an adjustable high-voltage platform. The first RFQ is a CW split-coax RFQ structure [31] recently developed at Argonne and capable of accelerating ions with mass-to-charge ratio as high as 240. The second and third RFQs use a novel hybrid structure [32] that mixes RFQ and IH type sections to obtain higher accelerating gradient with still enough focusing force. The following low-beta superconducting linac section can accept ions of  $\beta = 0.011$  with  $q/m \geq 1/66$  so that ions with mass larger than 66 must be stripped. This is done in helium gas to achieve a high efficiency with essentially no emittance growth [33].

The ions are then accelerated at that charge state by low-beta interdigital superconducting cavities up to an energy of at least 600 keV/u after which they are further stripped to  $q/m \geq 0.15$  for further acceleration in ATLAS type superconducting cavities. The beam is, therefore, available at all energies from ion source energy up to energies above 10 MeV/u for mid-mass ions. The acceptance of all parts of the linac being very large compared to typical emittance from ISOL sources, the transmission is also very high, limited by the bunching efficiency (about 85%) and the stripping for the heavier beams. Multiple-charge-state acceleration can be used following the second stripper to further increase efficiency for experiments that are not sensitive to the resultant emittance growth [34].

### 2.4 Experimental Areas

RIA will host four experimental areas for users, corresponding to different energy regimes for the radioactive ion beams. The ions produced by the three mechanisms leading to low energy radioactive ions will be available directly at ion source energy to a low energy experimental area for decay spectroscopy, ion trap work, laser spectroscopy or implantation at low energy. These



ions will also be available for re-acceleration to an astrophysics experimental area where beam with energies up to about 1.5 MeV/u will be available for reaction experiments at the regime relevant to quiescent and explosive astrophysical processes. They will also be available at Coulomb barrier energy in a nuclear structure experimental area where beams with energy up to about 12 MeV/u will be available.

In addition, radioactive beams produced by fragmentation and separation at high energy will be available directly for experiment at energies of about 400 MeV/u. This area will concentrate on short-lived isotopes with very low yield using the fact that the ability at high energy to use thicker targets enhances the sensitivity for certain types of experiments.

### 3 EXPECTED PERFORMANCE

The proposed RIA facility will provide yields of short-lived isotopes far in excess of those available at existing facilities. This is due to the high primary beam power intensity, the flexibility in the primary beam selection which allows the best production mechanism to be used, the new target technologies that allow the normal limitations of ISOL type systems to be overcome, and finally the use of the most efficient post-acceleration scheme proposed to date. Yields have been calculated for the different reaction mechanisms and are available on the web [35].

### 4 COST AND SCHEDULE

A site independent costing of the facility was undertaken jointly by ANL and NSCL and reviewed by an NSAC subcommittee in January, 2001. It was found that the cost of the facility, including the required experimental equipment, a fragmentation facility and a 35% contingency, was \$644M in fixed FY01 dollars. Adding the cost of the R&D, the CDR and environmental studies, and finally the pre-operation, yields a total project cost of \$834M. The facility has an estimated operating cost of about \$75M per year.

The timescale for construction is set by final approval of the facility, site selection, CDR and environmental studies. If funding of preliminary engineering design is received in FY2004 RIA could become operational in about FY2010. A national program for RIA R&D with current participation from ANL, JLAB, LANL, LBNL, LLNL, NSCL, ORNL, and Texas A&M is developing prototypes and testing concepts for critical components.

### 5 ACKNOWLEDGEMENTS

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