

ACCELERATORS FOR THE ADVANCED EXOTIC BEAM FACILITY IN THE U.S.*

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Abstract

The Office of Science of the Department of Energy is currently considering options for an advanced radioactive beam facility in the U.S which is a reduced scale version of the Rare Isotope Accelerator (RIA) project [1,2]. This facility will have unique capabilities compared with others both existing and planned elsewhere. As envisioned at ANL, the facility, called the Advanced Exotic Beam Laboratory (AEBL), would consist of a heavy-ion driver linac, a post-accelerator and experimental areas. Secondary beams of rare isotopes will be available as high quality reaccelerated or stopped beams from a gas catcher and high power ISOL targets, as well as, high energy beams following in-flight fragmentation or fission of heavy ions. The proposed design of the AEBL driver linac is a cw, fully superconducting, 833 MV linac capable of accelerating uranium ions up to 200 MeV/u and protons to 580 MeV with 400 kW beam power. An extensive research and development effort has resolved many technical issues related to the construction of the driver linac and other systems required for AEBL. This paper presents the status of planning, some options for such a facility, as well as, progress in related R&D.

INTRODUCTION

The proposed facility [3] is based on a 200 MeV/u heavy-ion driver linac with a beam power at 400 kW. A simplified schematic layout of AEBL on the Argonne site is shown in Fig. 1. It consists of a driver linac, high-power production target areas, a post-accelerator based on the existing ATLAS accelerator and experimental areas. The primary features are:

- The driver linac comprises 207 SC cavities and uses the array of RIA-developed SRF cavities.
- The post-accelerator is based on the existing ATLAS facility and includes a new low charge-to-mass ratio ($q/m=1/66$) injector to boost ion energies to 1 MeV/u for stripping with a carbon foil.
- For most isotopes, the reaccelerated beam intensities are comparable to RIA, and in the worst cases intensities are 10-20% of RIA.
- One fragment separator optimized for the gas-cell catcher and also suitable for in-flight experiments.
- An ISOL target production area.
- Two new experimental areas for 1) stopped-beams and low-energy reaccelerated beams for astrophysics and 2) in-flight experiments.

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HEAVY-ION DRIVER ACCELERATOR

The driver linac [4] provides the primary, high-power, stable-ion beams required to produce the radioisotopes. To be able to fully exploit the various production mechanisms, it is imperative that the driver linac be capable of accelerating essentially all stable nuclei to sufficiently high energies 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 phased cavities enable efficient acceleration over a wide velocity profile. Our design analysis suggests that a linac optimized for 200 MeV/u uranium beams should have only one stripper. Although the one-stripper option increases the required number of SC cavities, the complex second stripper station and post-stripper magnet elements are eliminated in this way. A list of beam energies and intensities for selected ions from the driver is given in Table 1. The linac has been optimized for the simultaneous acceleration of U^{33+} and U^{34+} in the front- end and the first section of the linac up to the stripper and the acceleration of 5 charge states of uranium ions after the liquid lithium stripper. The baseline AEBL driver linac design comprises: (1) an advanced ECR ion source [5], (2) a 2-charge-state low-energy beam transport system and pre-buncher, (3) a low-frequency CW RFQ, (4) seven types of SC resonators covering a velocity range from 0.025c and higher as shown in Fig. 2, (5) a high-intensity liquid lithium stripper at 17 MeV/u for the uranium beam and associated multiple-charge-state beam transport sections.

Table 1: Beam list for selected ions from the driver linac. The ECR currents correspond to 400 kW beam power for all beams (W_{ST} is the stripping energy).

Z/A	I_{ECR} , μA	Q_{inj}	W_{ST} MeV/A	Q_{strip}	Energy MeV/u
1	865	1	95.2	-	578
2/3	390	2	70.7	-	427
1/2	728	1	57.1	-	344
8/18	101	6	41.8	8	305
18/40	47	8	27.6	18	297
36/86	26	14	23.0	35-36	266
54/136	18	18	18.9	50-52	237
92/238	6+6	33+34	16.5	77-81	201

An upgrade that provides extended multi-user capabilities with simultaneous light- and heavy-ion driver beams can be achieved by (1) adding a light-ion injector for ions with $q/m=1/3$ in the front of the high energy

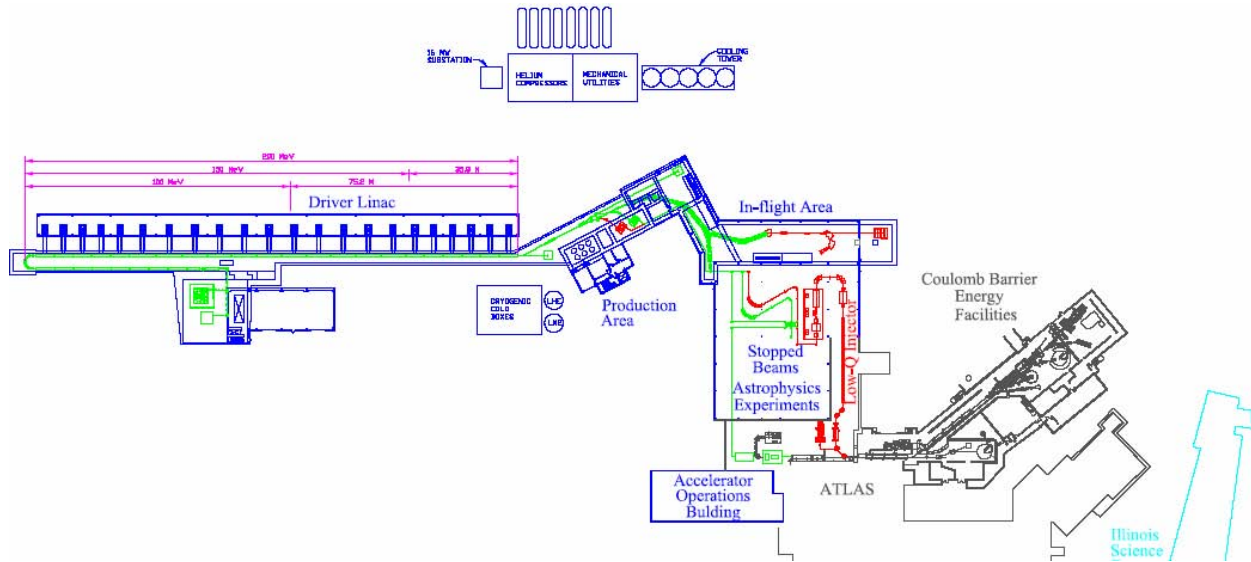


Figure 1: A simplified schematic layout of AEBL at Argonne. The color code: the black is the existing facility, the green and blue are AEBL.

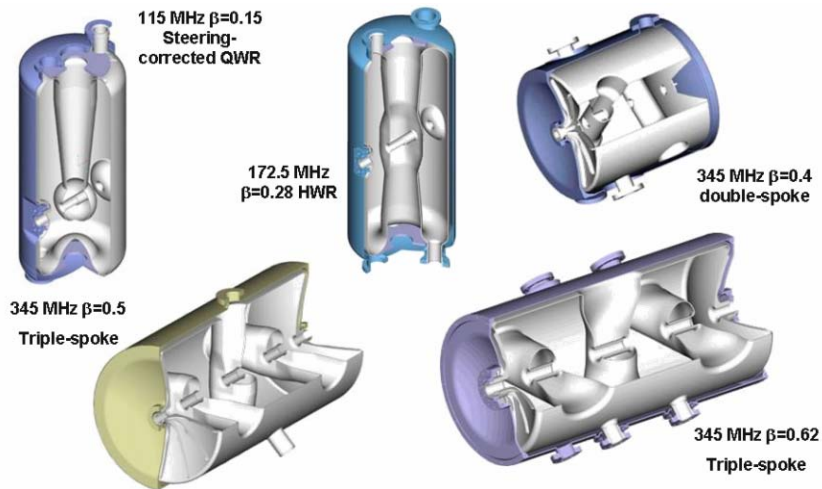


Figure 2: Five types of SC cavities developed for the AEBL driver linac.

section, (2) an appropriate RF deflector to funnel two ion beams into different accelerating buckets of the high-energy section of the driver linac, and (3) an RF switcher to provide beams simultaneously both to ISOL and fragmentation targets.

The design of the driver accelerator uses a number of bold steps to enhance the scientific capabilities of the AEBL facility. A vigorous R&D program led to the development of the multiple-charge-state acceleration concept, its experimental demonstration at the ATLAS facility at ANL, the development of the spoke-cavity superconducting structures to fill the gap in the velocity regime between the low- β ATLAS-type cavities and the CEBAF-type velocity-of-light structures [6]. Successes with the R&D program for the baseline RIA driver linac support the technological approach for the AEBL driver at one-half the beam energy and twice the beam current. For example, the high currents of uranium achieved recently

with the LBNL VENUS ECR ion source [5] operating at 28 GHz combined with the detailed studies of the multiple-charge-state operation of the driver with very low beam losses supports the goal of achieving 400-kW uranium beams at 200 MeV per nucleon with 8 particle microamperes of beam on target. The excellent beam dynamics associated with the very large longitudinal acceptances of the 345 MHz triple-spoke resonators and the successful operation of the prototypes of these resonators support a robust and cost-effective design of the high power driver. The high power uranium beams require stripping at an energy of 17 MeV/u and a beam intensity of 10 particle microamperes. The development of high-velocity, windowless, thin-film, liquid-lithium stripper foils is an ongoing project at Argonne. Operation of a 15 μm -thick liquid lithium film has been recently demonstrated [3].

Detailed physics design of the driver linac with associated end-to-end beam dynamics simulations is reported elsewhere [7].

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. 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 production area will house standard ISOL, two-step fission (actinide) targets, high power fragmentation targets such as liquid lithium, a large acceptance fragment separator and its associated high power beam dumps, and the gas catcher. The issues to be faced in the design of this area will be very similar to those that were required for the full RIA complex. The targets for in-flight fragmentation and fission of intense very heavy beams up to uranium present a major challenge. For the very high power densities produced by the intense uranium beams with small beam spot diameters, a windowless liquid lithium target concept has been developed and demonstrated in a prototype with a high power electron beam that simulates the power density encountered at AEBL [8].

One of the features that makes AEBL globally competitive is its unique combination of high power uranium and other very heavy ion beams, large acceptance fragment separator, gas catcher technology, and a flexible and efficient post accelerator. Radioactive isotopes are produced by fragmentation (or in-flight fission) of fast heavy-ion beams on thick low-Z targets. A large acceptance fragment separator is configured to collect, separate, and compensate for the fragment energy spread so that the rare isotopes are slowed down and stopped in a gas catcher system. Here they are thermalized, but remain singly or doubly charged and can be extracted by a combination of gas flow, DC, and RF fields to be delivered to the stopped beam area or to the post accelerator. This results in beams of a quality as good or better than those obtained by ISOL techniques, without the chemical limitations associated with the ISOL technique in the diffusion and release out of thick, solid targets. The same separator can provide in-flight beams to an in-flight area as is shown in Fig. 1.

POST-ACCELERATOR

The most efficient production mechanisms for slow radioactive ions yield these ions in the 1+ or 2+ charge states. The post-accelerator must, therefore, be able to accept such low charge-to-mass ratio ions from the ion source energy. One approach is to increase the charge state of the ions before acceleration via a charge booster stage, be it an ECR-type breeder or an EBIS-based system. In general, the breeders are more competitive with stripper methods for heavier isotopes. To ensure maximum efficiency in the post-acceleration process,

especially for light isotopes, AEBL can use a very efficient, low-charge-to-mass ratio injector based on a SC linac accelerator coupled to low frequency CW RFQs [9]. The singly-charged radioactive ions extracted from the ion source or gas catcher are first mass separated by a large acceptance, high-resolution ($m/\Delta m = 20,000$) isobar separator. The selected isotopes are then bunched by a pre-buncher and accelerated through a series of 3 low frequency RFQs followed by a low-beta SC linac section capable of accelerating ions from 75 keV/u with $q/m=1/66$ [9]. Final acceleration takes place in ATLAS after which the radioactive ions are available at all energies up to 12 MeV/u for up to $A \sim 150$ ions (10 MeV/u for U). Currently ATLAS is being upgraded with a RIA-type cryostat which comprises 8 new SC resonators.

The acceptance of all parts of the linac being very large when compared to typical emittances from ISOL sources and gas catchers, the transmission is also very high, limited by the bunching efficiency (about 92%) and the stripping efficiencies for the heavier beams. Multiple-charge-state acceleration can be used following the second stripper to further increase the efficiency for experiments that are not sensitive to the resultant emittance growth.

The layout shown in Fig. 1 can also accommodate a charge breeder branch. The final configuration will depend on the cost constraints and relative priorities that are set for various facility capabilities. The ultimate combination is to use both types of injectors so that it is possible to deliver the most intense beams to the astrophysics area and, simultaneously, beams to the Coulomb barrier instruments.

CONCLUSION

The proposed AEBL facility will provide world-class capabilities critical for scientific research with rare isotopes. By focusing on the unique reaccelerated beams made possible by a superconducting heavy-ion driver, AEBL will complement the science programs at the major international rare isotope facilities under construction.

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