STATUS AND PLANS FOR THE FACILITY FOR RARE ISOTOPE BEAMS AT MICHIGAN STATE UNIVERSITY*

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Abstract

The primary purpose of the Facility for Rare Isotope Beams (FRIB) is to produce and to perform fundamental research with rare isotopes. The rare isotope production will be accomplished using a heavy ion cw linac to provide a stable isotope beam (protons through uranium) at high power (up to 400 kW) and high energy (>200 MeV/u) on a particle fragmentation production target. The rare isotopes will be produced in quantities sufficient to support world-leading research by using particle fragmentation of stable beams. This will include research pertaining to the properties of nuclei (nuclear structure), the nuclear processes in the universe and tests of fundamental symmetries. Societal applications and benefits may include bio-medicine, energy, material sciences and national security. The overall facility status and plans will be discussed with a focus on the accelerator system.

SCIENCE

FRIB will greatly expand the variety and intensity of rare isotopes available to the scientific research community, and will enable the nuclear science research community to make major advances in our understanding of nature by accessing key rare isotopes that previously only existed in the most violent conditions in the universe. It will allow studies of individual, key nuclei, or nuclear reactions. It will also make available a broad range of isotopes for research in nuclear medicine, environmental science, nanoscience, and homeland security. This opportunity will lead to breakthroughs in understanding the nature of nuclear matter, the chemical evolution of the cosmos, and the fundamental symmetry laws of nature, as well as the production of a variety of rare isotopes for applied research in other fields. The new data will allow scientists to move beyond the greatly restricted perspective of nuclei near the stable isotopes found in nature, from which the existing patchwork of models have emerged, to develop a new, comprehensive theory of nuclei and their interactions.

FRIB FACILITY

Introduction

The FRIB facility will be located on the campus of Michigan State University (MSU). The Facility layout is given in Fig. 1. The technical design and construction specifications were driven by the scientific goals discussed above. Details of the FRIB design can also be found in references [1-10].

A schematic diagram of the FRIB facility is given in Fig. 2. A heavy-ion linac will provide beams of stable isotopes with a minimum energy of 200 MeV/u (higher energies for lighter ions) at a beam power of 400 kW using a high-performance ECR ion source and multiple charge-state beam acceleration. The facility will have a fragment production area followed by a fragment separator. The rare isotope beams can be used at velocity (fast beams), can be delivered to one of two gas stopping stations, or can be delivered to a solid catcher of complementary design, after which the ions can be extracted and reaccelerated [10]. Experimental equipment for a full program of fast, stopped, and reaccelerated beam research will be provided, as will the necessary infrastructure to accommodate the anticipated user demand.

Driver Linac

The driver linac is designed to reliably provide intense stable beams that will be used to produce rare isotope beams for world-class experiments. The FRIB linac accelerating systems are housed in a subterranean structure while the supporting equipment is housed in a surface structure. The linac is folded such that three linac segments and concomitant bending segments can be housed in a compact footprint (see Fig. 1-A). This arrangement provides a reduced cost for the conventional construction while meeting baseline performance as well as retaining future upgrade paths to higher energy (up to 400 MeV/u for uranium and higher for lighter ions). An upgrade path for Isotope Separation On Line (ISOL) rare isotope production with the implementation of an additional target area and light-ion linac is also provided.

Front End The driver linac (see Fig. 1 in relation to the FRIB facility and schematically in Fig. 2) will meet intensity requirements by the acceleration of multiple charge states from an Electron Cyclotron Resonance (ECR) ion source. The ions will be transported in a Low Energy Beam Transport system (LEBT) to a Radio Frequency Quadrupole (RFQ) accelerator operating at a frequency of 80.5 MHz. The Medium Energy Beam Transport system (MEBT) will deliver the beam from the RFQ to Linac Segment 1 of the driver linac at an energy of 0.3 MeV/u. Excepting the ECRs and MEBT, the Front End will rely on room temperature-based technology.

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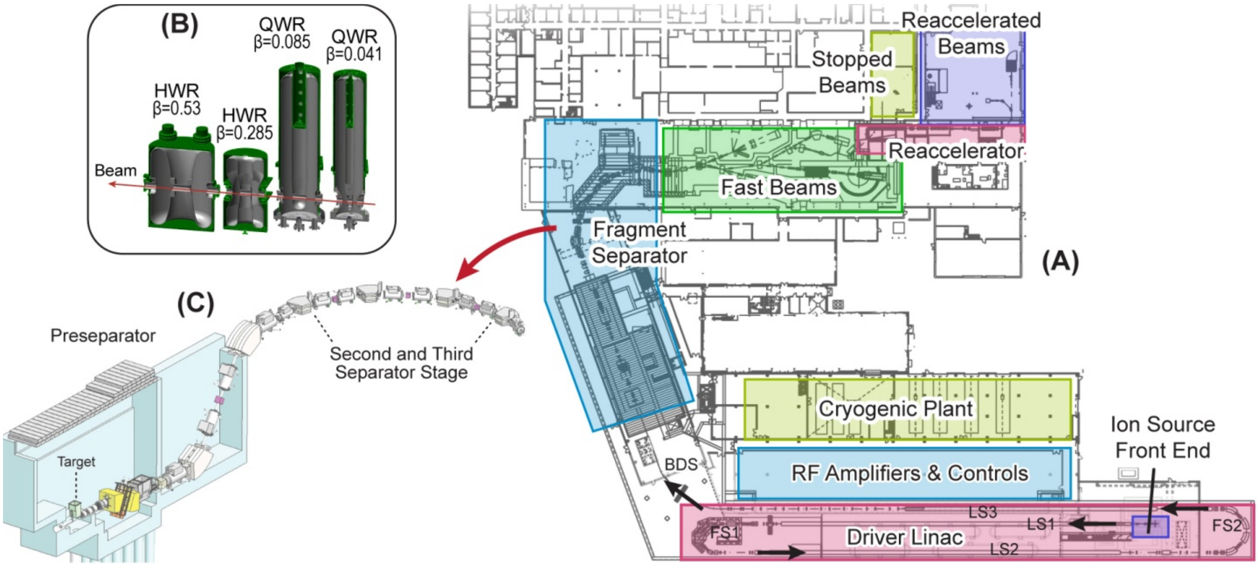

Figure 1: (A) The proposed FRIB facility at MSU showing the driver linac extending from the Front End building through Linac Segments (LS1,2,3), connected by Folding segments (FS1,2). The beam delivery system (BDS) will transport the linac beam to the Target where the rare isotope beams will be produced and filtered by the Fragment Separator system (C) after which they will be delivered to the experimental area. The four superconducting accelerating structures of the baseline design are shown in (B).

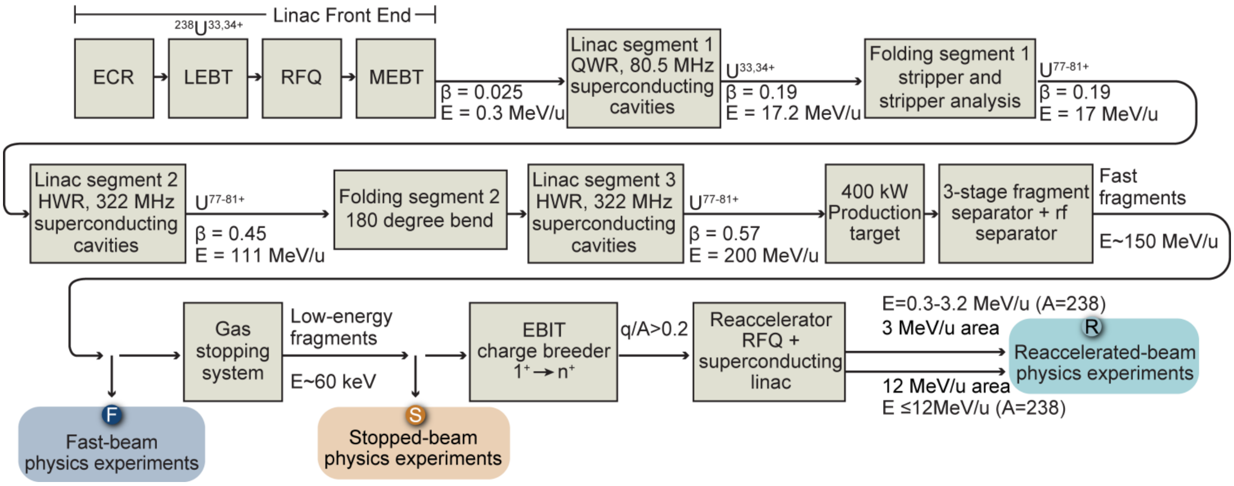

Figure 2: Conceptual schematic of FRIB. The block diagram represents the items within the FRIB technical scope. Sample beam parameters are given.

Superconducting technology will be used for downstream elements of the driver linac since it most efficiently achieves the 100% duty factor operation needed to reach the required beam power.

Superconducting Cavities To minimize R&D and technical risk, the driver linac has a minimum number of cavity types and uses passive control of microphonics via a mechanical damper in the center conductor of the QWRs. In addition, the effects of microphonics will be mitigated through the use of rf drive with Piezo electric and stepper motor driven tuners.

Four cavity types can efficiently cover the necessary velocity range. Each cavity type (see fig 1-B) is a two-gap structure characterized in terms of its optimum β (β_{opt}). The number of cavities required is given in Table 1.

Table 1: Driver linac cavity, superconducting solenoid, and cryomodule count. Numbers in [] are for matching cryomodules, numbers not in [] are accelerating cryomodules

Type	λ/4	λ/4	λ/2	λ/2	
β_{opt}	0.041	0.085	0.29	0.53	**Total**
Cavities	16	96	78	144	
	[0]	[2]	[4]	[4]	344
Solenoids	16	36	13	8	
	[0]	[0]	[2]	[2]	87
Cryomodules	4	12	13	18	
	[0]	[1]	[2]	[2]	52

The rf drive will be supplied by solid state amplifiers that will be fabricated by combining smaller units each of approximately 1 kW capacity.

Linac Segment 1 Beam from the linac Front End will be injected into Linac Segment 1 of the superconducting heavy-ion linac (see Fig. 1 and Fig. 2). Linac Segment 1 will utilize two types of Quarter Wave Resonators (QWRs) operating at a frequency of 80.5 MHz with β_{opt}=0.041 and 0.085 to increase the uranium beam energy to about 17 MeV/u and higher for lighter ions. Both QWR types used in Segment 1 have been successfully prototyped. In addition, an MSU-funded reaccelerator [10] requiring these types of QWRs provides significant opportunities to substantiate FRIB design parameters and to test approaches to cavity acquisition.

Folding Segment 1 A stripping system [4,5] is located in Folding Segment 1 connecting Linac Segments 1 and 2 to increase the downstream acceleration efficiency by increasing the charge state of the beam. Local shielding and remote handling systems will be used in this area to accommodate controlled beam losses of about 20% of the beam power. Simulations indicate that uncontrolled losses will be orders of magnitude less. The remaining beam line elements will match the multi-charge state beams (e.g. five charge states for uranium) in a manner appropriate for acceleration in the Linac Segment 2.

Linac Segment 2 After stripping, Linac Segment 2 will accelerate up to five charge states to energies of at least 110 MeV/u. Linac Segment 2 will use two types (β_{opt} = 0.285 and 0.53) of Half Wave Resonators (HWRs) operating at a frequency of 322 MHz.

Folding Segment 2 This segment connects Linac Segments 2 and 3. The elements of this segment provide full 6-dimensional phase matching of the multiple charge states from Linac Segment 2 into Linac Segment 3.

Linac Segment 3 Linac Segment 3 will accelerate up to five charge states to energies of at least 200 MeV/u using β_{opt} = 0.53 Half Wave Resonators (HWRs).

Beam Delivery System This beam transport system from the end of the linac (see Fig. 1) to the production target is achromatic and can deliver up to five charge states of uranium within a beam-spot diameter of less than 1 mm as required to achieve the resolution necessary for the downstream fragment separator system.

Beam Dynamics The accelerator design will use four basic cryomodule configurations (one for each cavity type) and three additional smaller configurations providing longitudinal matching between Linac Segments 1 and 2 and Linac Segments 2 and 3. The transverse focusing will be provided by 9 T solenoids with additional coils to produce two steering dipoles for beam-centroid corrections.

End-to-end simulations of the linac design have been performed, including error studies [1]. To maintain hands-on machine maintenance, the specification for uncontrolled beam loss was set at less than 1 W/m.

Cryogenic Facilities The cryogenic plant will have a capacity of approximately 12 kW at 4.5K corresponding to a 50% overcapacity to ensure reliable operations. All cryogenic loads will operate at 4.5 K excepting the HWRs which will utilize 2 K with the temperature conversion occurring at the load.

Experimental Systems

The target facilities will contain a production target for fast-ion beams able to sustain high power densities to accommodate 400 kW operations and a 1 mm diameter beam spot size.

FRIB will employ a three-stage projectile fragment separator (see Fig. 1-C) to separate and contain the intense primary beam at a well-defined location, and will provide separated rare isotope beams with high purity.

A full complement of experimental systems will be situated downstream of the fragment separator for the science program with fast, stopped, and reaccelerated beams (see Fig. 1-A).

FRIB PROJECT

The FRIB project has finished National Environmental Policy Act evaluations and a Conceptual Design Report. The FRIB Project received Critical Decision 1 approval on September 1, 2010. Project completion is planned for 2020, the project intends to manage to an early completion in 2018 subject to availability of funds.

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