THE RARE-ISOTOPE ACCELERATOR (RIA) FACILITY PROJECT*

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Abstract

The envisioned Rare-Isotope Accelerator (RIA) facility would add substantially to research opportunities for nuclear physics and astrophysics by combining increased intensities with a greatly expanded variety of high-quality rare-isotope beams. A flexible superconducting driver linac would provide 100 kW, 400 MeV/nucleon beams of any stable isotope from hydrogen to uranium onto production targets. Combinations of projectile fragmentation, target fragmentation, fission, and spallation would produce the needed broad assortment of short-lived secondary beams. This paper describes the project's background, purpose, and status, the envisioned facility, and the key subsystem, the driver linac.

1 INTRODUCTION

During fall 2000, the U.S. Nuclear Science Advisory Committee (NSAC) of the U.S. Department of Energy and the National Science Foundation (NSF) will consider a proposal for a new research tool for nuclear physics and nuclear astrophysics: the Rare-Isotope Accelerator (RIA) facility. NSAC's 1996 Long Range Plan [1] provided the impetus for the formation of the ISOL Task Force (isotope separation on-line), whose 1999 report [2] endorsed RIA. Task force members were J. Beene, ORNL; D. Boyd, Ohio State; R. Casten, Yale; K. Gelbke, MSU and NSAC; H. Grunder, Jefferson Lab, Chair; S. Kowalski, MIT; C. Lyneis, LBNL; J. Marx, LBNL; J. Nolen, ANL; H. Ravn, CERN; P. Schmor, TRIUMF; and B. Sherrill, MSU.

The envisioned facility would multiply experimental opportunities for nuclear physics and astrophysics based on radioactive ion beams. RIA would combine increased intensities with a greatly expanded variety of high-quality rare-isotope beams. Its flexible superconducting driver linac would provide 100 kW, 400 MeV/nucleon beams of any stable isotope from hydrogen to uranium onto production targets. To maximize yields for some spallation processes, operation in the 200–400 MeV/nucleon range is also planned. Combinations of projectile fragmentation, target fragmentation, fission, and spallation would produce the needed broad assortment of short-lived secondary beams. After separation, the selected rare isotopes could be accelerated and directed to fixed-target experiments. Other experiments would use stopped and trapped isotopes. Prospective additional capabilities are the use of projectile fragment beams directly while in flight and an upgrade to 400 kW to increase experiment multiplicity and yields of rare species.

RIA's scientific purposes are to advance current theoretical models, reveal new manifestations of nuclear behavior, and probe the limits of nuclear existence [3]. Figures 1 and 2 show, respectively, examples of RIA research opportunities and the yields projected for pursuing them. Figure 3 outlines a conceptual approach for delivering the needed beams.

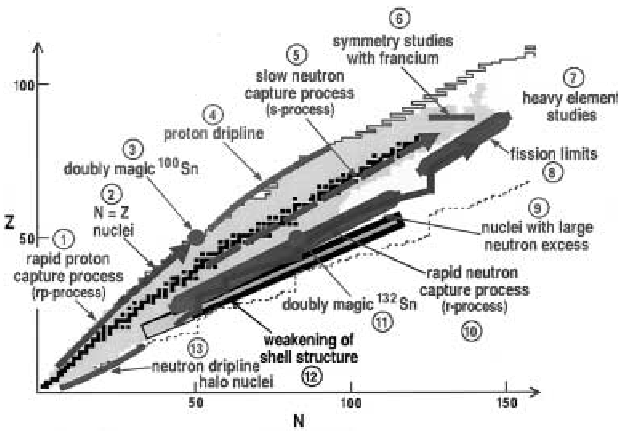

Figure 1: RIA research opportunities. (Courtesy ANL)

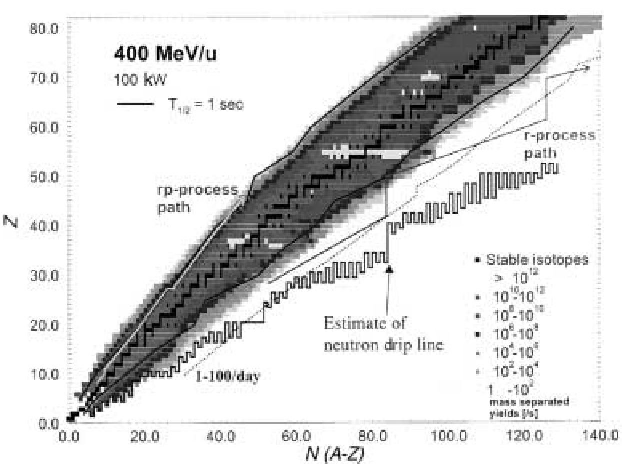

Figure 2: RIA yields from a multibeam driver; mass-separated intensities. (Courtesy ANL)

* Paper written under U.S. DOE contract DE-AC05-84ER40150.

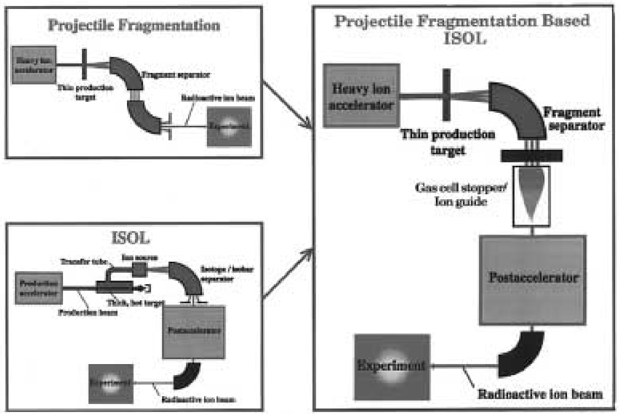

Figure 3: Concept for projectile-fragmentation-based ISOL with a multiple-beam heavy-ion driver, including millisecond extraction times, chemical independence, and isobar separation. (Courtesy ANL)

2 THE ENVISIONED FACILITY

NSAC chartered the ISOL Task Force in 1998 to assess available options, identify preferred technologies, prioritize R&D needs, and consider how to leverage existing U.S. accelerator and detector facilities and expertise. Besides the focused RIA Driver Working Group identified below, consultants aided the task force. These included J. Ätstö, U. Jyväskylä; J. Bennett, Rutherford Appleton; A. Chargin, LLNL; M. Dombsky, TRIUMF; C. Landram, LLNL; I-Y Lee, LBNL; F. Marti, MSU; P. Ostroumov, ANL; G. Pile, ANL, APS; C. Rode, Jefferson Lab; G. Savard, ANL; W. Schneider, Jefferson Lab; W. Talbert, Amparo; J. Vincent, MSU; A. Villari, GANIL; M. Wada, RIKEN; H. Wollnik, U. Giessen.

The task force found and recommended that RIA could and should be built based on modest extrapolations of existing technology; that no showstoppers exist, though modest R&D is needed in a few areas; that significant contributions are needed from several national laboratories; and that the key subsystem is a driver linac that should be based on superconducting rf (SRF) technology.

The determination of SRF as the optimum driver approach came from the focused RIA Driver Working Group commissioned by the task force and chaired by the author. Other members were G. Alton, ORNL; J. Bisognano, DOE and Jefferson Lab; J. Delayen, Jefferson Lab; S. Kowalski, MIT; Y. Y. Lee, BNL; C. Lyneis, LBNL; J. Nolen, ANL; C. Reece, Jefferson Lab; K. Shepard, ANL; B. Sherrill, MSU; J. Staples, LBNL; R. York, MSU; and W. Weng, BNL. Consultants Chargin, Pile, Rode, Schneider, and Vincent served as members of the driver costing team.

Requirements called for the driver to deliver a minimum of 400 MeV/nucleon for all ions up to uranium (with two nonmandatory desiderata in addition: that 200–400 MeV/nucleon be accessible, and that more than 400 MeV/nucleon be available for lighter ions). The driver must also provide current sufficient for 100 kW for all ions (about 1 pμA for uranium), cw operation, and normalized emittance less than 10 μm. It must face no intrinsic obstacles to reaching 400 kW beam power with source development, and it must cost less than $300M.

The working group considered four possible approaches for meeting these requirements. After due consideration, two approaches were discarded: the room-temperature linac and the rapid-cycling synchrotron with stretcher ring. The two remaining approaches were chosen for further study as “finalists”: the isochronous cyclotron and the cw SRF full-energy linac. The working group found no schedule difference between these two, but did find a slight cost advantage for the cyclotron. However, the cyclotron would require an order-of-magnitude improvement in injector current—and the SRF linac could automatically incorporate any improvement to the cyclotron front end. The SRF approach was recommended. So was an early start on R&D for the cavity, the cryostat, and rf control and on advancing the conceptual design to a point that would allow for a timely start of civil construction.

Figure 4 sketches the conceptual layout of the envisioned facility.

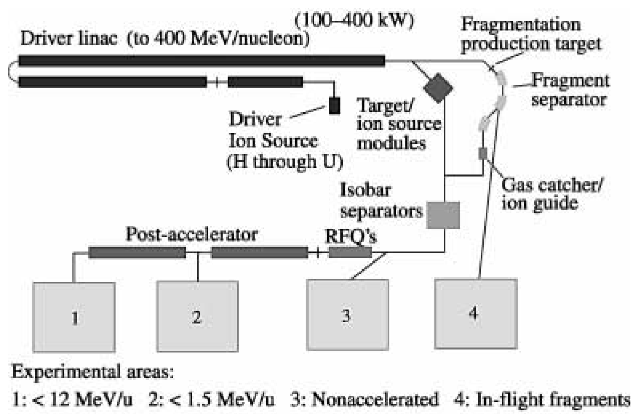

Figure 4: Simplified RIA facility schematic.

3 DRIVER ACCELERATOR

Figure 5 sketches the 805 MHz SRF driver accelerator for RIA. References 4 through 8, by authors at Argonne National Laboratory and several other institutions, provide substantial information either directly about the driver or closely relevant concerning it.

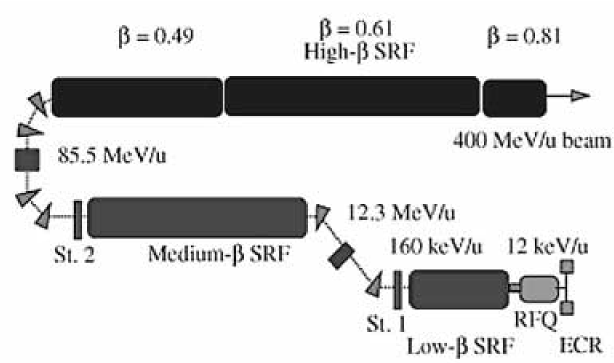

Figure 5: RIA driver layout.

3.1 Multiple-Charge-State Beams

More than one charge state can be accelerated simultaneously through most of the driver linac, since SRF technology offers large transverse and longitudinal acceptance, and since the heaviest ions' high charge states involve small fractional differences (for example, 75+ and 76+ for uranium). Multiple-charge-state operation provides advantages in that it allows:

- Circumventing ion-source limitations on beam powers for heavier ions.
- Enhancing charge-stripping efficiency by making virtually all of the stripped beam usable, thus enabling use of multiple strippers and reducing linac size.
- Reducing beam dumped at stripping points, thus reducing shielding requirements.

3.2 ECR Ion Source and Low-Energy Beam Transport

The linac uses one of a pair of ECR (electron cyclotron resonance) sources for cw, high-charge-state ionization from hydrogen through uranium. The ECR/LEBT (low-energy beam transport) performance required for uranium, the heaviest beam, is as follows:

- Driver requirement: 100 kW at 400 MeV/nucleon, or 1.05 pμA.
- Driver efficiency, including two stages of stripping: 66%.
- The consequently needed ECR/LEBT output: 1.6 pμA of U^{30+}. This will represent a factor of 2 improvement over AECR-U (Figure 6) at Lawrence Berkeley National Laboratory (LBNL). To reach 400 kW would require a factor of 8 improvement.

Needed to be developed is a high-magnetic field, high-frequency ECR coupled to an LEBT that can handle the high-intensity beams and match the acceptance of the RFQ. The VENUS ECR (Figure 7) at LBNL could serve as a prototype for the needed RIA ECR.

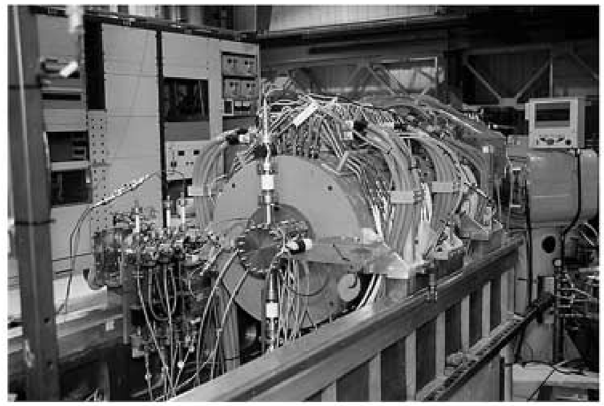

Figure 6: AECR-U at Berkeley's 88-Inch Cyclotron. (Courtesy LBNL)

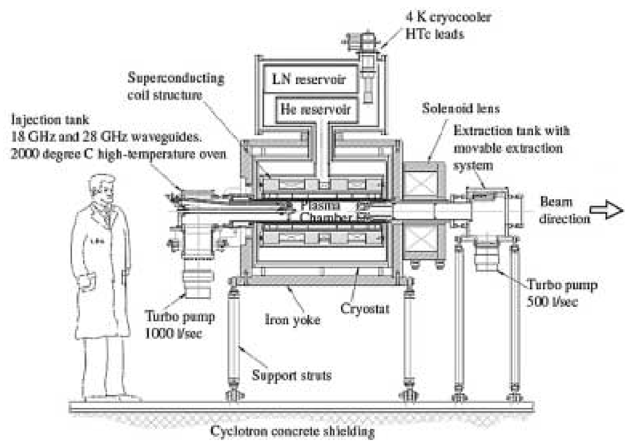

Figure 7: Concept for Berkeley's VENUS ECR. (Courtesy LBNL)

3.3 Performance and Beam Parameters

Figures 8 through 11 reflect key aspects of projected RIA driver performance. Tables 1 and 2 give details of the cavity array and beam energy through the driver, with stripping energy and charge states detailed. Table 1 reports the low-, medium-, and high-beta superconducting resonator configuration (configured for uranium 28-29+ input at β = 0.01749, with stripping at frequency transitions). Table 2 details the beam parameters. Table 2 assumes 80% bunching efficiency, 6% energy loss in the second stripper, and 1998 ECR performance extrapolated to the lower charge states.

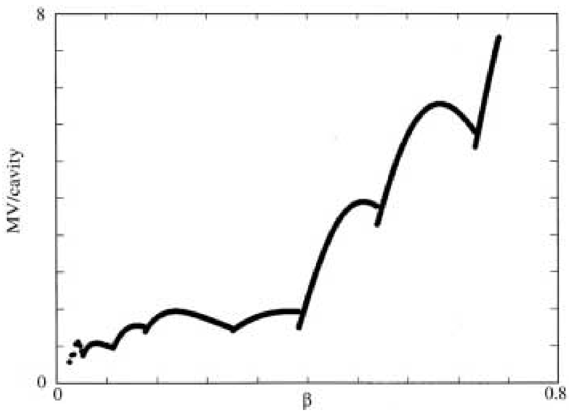

Figure 8: Effective voltage per cavity for a RIA driver uranium beam, illustrating the velocity acceptance of each type of structure. β = *v/c*. (Courtesy ANL)

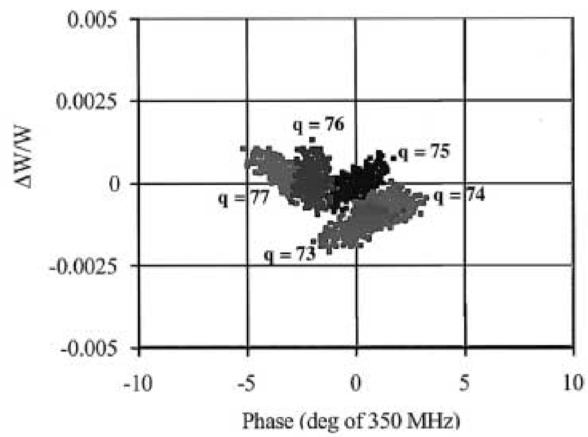

Figure 9: Phase-space plots, five-charge-state U beam at the second stripper (85.5 MeV/u) [9].

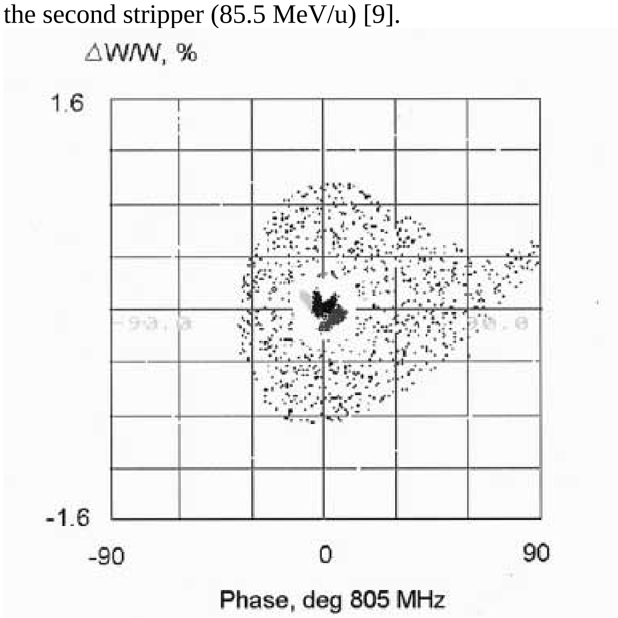

Figure 10: The five-charge-state-beam phase-space plots from Figure 11 are shown together with the longitudinal acceptance of the high-energy section of the driver linac [9].

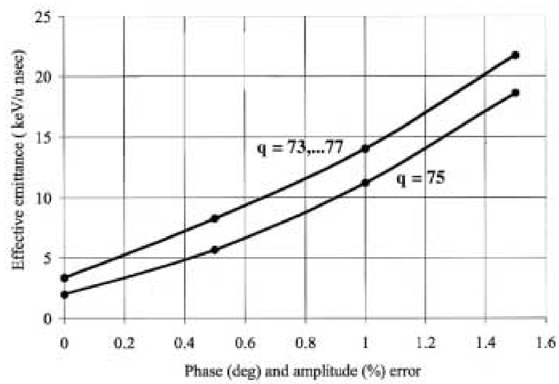

Figure 11: Longitudinal emittance in the medium-beta section as a function of rf phase error [9]. The figure demonstrates that multiple-charge-state acceleration is only moderately more sensitive to rf phase and amplitude errors.

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Table 1: Superconducting resonator configuration for 805 MHz RIA driver linac
(Courtesy ANL)

Beta	Type	Freq (MHz)	Length (cm)	Eacc (MV/m)	Voltage (MV)	Phase deg.	No. Cavities / Section Injector	Middle	Final
0.0	3 DT	57.5	18.0	4.0	0.6	-30	2.0		
0.0	3 DT	57.5	26.0	4.0	0.9	-30	5.0		
0.1	1 DT	57.5	20.0	5.0	0.9	-30	32.0		
0.1	2 DT	115.0	36.0	4.0	1.2	-30	40.0		
0.19	2 DT	172.5	36	5	1.5588	-30		72	
0.38	2 DT	345	36	5	1.5588	-30		96	
0	6 Cell	805	55	8	4	-25			76
1	6 Cell	805	68	10	6	-25			84
1	6 Cell	805	91	13	10	-25			28
Total Cavities =		435		Section Cavities		=	79.0	168	188
Total Voltage =		1421	(MV)	Section Voltage		=	77.6	261.878	1081

Table 2: Beam parameters for 805 MHz RIA driver linac
(Courtesy ANL)

A	-------ECR------- I source pmicroA		Qinj	First Stripper Qstrip	Frac	----Second Stripper---- Qfinal	Frac	I out pmicroA	---- U/A ---- Strip 1	---- Strip 2 ---- Before	After	OUT	Beam Power kW
1	447	*	1	-	-	-	-	445	-	-	-	898	400
3	188	*	2	-	-	-	-	186	-	-	-	716	400
2	338	*	1	-	-	-	-	334	-	-	-	599	400
18	54	*	6	8	0.95	-	-	40	22.0	-	-	551	400
40	29	*	8	18	0.80	-	-	18	15.1	-	-	554	400
86	15		14	33-34	0.73	36	1	9	12.7	105.7	99.4	515	388
136	12	*	18	46-48	0.75	53-54	1	6	10.4	93.6	88.0	478	400
238	3		28-29	69-73	0.76	87-89	1	2	9.3	80.3	75.5	405	173

* Limited by RF Power