A PROPOSED SUPERCONDUCTING BOOSTER LINAC FOR THE HRIBF

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Abstract

A 42 MV Superconducting (SC) Booster Linac is proposed for the Holifield Radioactive Ion Beam Facility (HRIBF). The linac, consisting of 56 superconducting, quarter wave, 120 MHz, independently phased, 2 gap resonators, will be used to boost Radioactive Ion Beams (RIBs) accelerated by the 25 MV NEC tandem, to Coulomb barrier energies for use in nuclear physics research near the proton and neutron drip lines. The design potential of 42 MV is sufficient to boost the beams of mass 180 above the Coulomb barrier using the most probable charge state, 15+, from single foil stripping in the tandem terminal. Linac parameters and layout are presented with accompanying beam dynamic calculations. In addition, an upgrade of the existing pre- tandem beam bunching system is proposed to further preserve the RIB intensity through better longitudinal phase space matching into the linac.

1 INTRODUCTION

HRIBF is providing RIB's for nuclear physics and astrophysics experiments using the ISOL technique. Radioactive atoms are created from nuclear reactions with light-ion beams from ORIC, a compact flexible K100 cyclotron. After diffusing from the target and desorbing from surfaces, these radioactive atoms are ionized, magnetically separated, charge exchanged, and then transported through a second high-resolution separator into the 25 MV tandem, where they are accelerated to energies of interest for nuclear and astrophysics. The tandem is capable of accelerating mass 80 above the Coulomb barrier with single foil stripping in the terminal, and mass 130 above the Coulomb barrier with a second foil stripping 1/3 of the way down the high energy acceleration tube. RIB's are very difficult to produce and have very low intensity, so maximizing the total transmission from the RIB source target to the experimental target is essential.

The Nuclear Science Advisory Committee has identified the National Isotope Separator On Line (ISOL) RIB Facility as the next major construction by the DOE Nuclear Physics program[1]. A possible very cost effective reconfiguration of the existing HRIBF into the National ISOL Facility would be to: (1) use as much of the existing building-6000 heavily shielded area and experimental apparatus as possible, (2) replace ORIC with an approxinmately 200 MeV proton linac or cyclotron, (3) extend the existing RIB injector with a new platform for the production of intense neutron-rich fission fragment RIBs produced by proton bombardment of a high-temperature thick actinide target, and (4) construction of a SC linac booster for the tandem to allow acceleration of fission fragment RIBs above the coulomb barrier with single foil stripping in the tandem[2]. These changes, shown in Fig. 1, will allow physicists to explore nuclei far from stability, learning more about solar processes, and the neutron and proton drip lines.

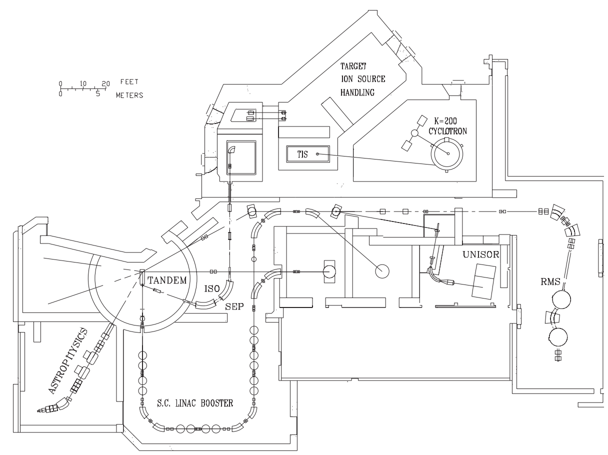

Figure 1 Floor plan depicting the conversion of the HRIBF into the National ISOL Facility. The main changes are a new driver accelerator, a modified target ion source platform, and the addition of a superconducting linac to boost the tandem beam.

These changes can be constructed together or in a phased approach. This paper describes a SC linac for this approach. As a booster, this linac could be used to accelerate fission fragment RIBS produced using ORIC with the existing RIB injector, or from a 200 MeV proton accelerator with a new high-power RIB injector. It can also be built without shutting down the present facility, with only minimal interruptions to the schedule.

2 LINAC LAYOUT

The most important requirement for the booster is to accelerate fission fragments above the Coulomb barrier with single stripping which corresponds to the accelera-

* Research sponsored by the Oak Ridge National Laboratory, managed by Lockheed Martin Energy Research Corporation for the U.S. DOE under contract number DE-AC05-96OR22464.
† The Joint Institute for Heavy Ion Research is the University of Tennessee, Vanderbilt University, and the ORNL; it is supported by the members and by the U.S. DOE under contract number DE-FG05-87ER40361 with the University of Tennessee.

tion of 15+ A=180 to 5.5 MeV/A. This maximum mass is 180 for two reasons: (1) the maximum fission fragment mass is ~180, and (2) the elements with A>180 tend to be refractory and will not readily release from targets. To provide RIBs of A<180 using the most probable charge state with single stripping with the tandem operating at 22 MV terminal, requires the addition of an effective 42 MV booster linac.

The linac will be similar to the linac at ALPI[3], which provides accelerating fields of 5 MV/m, and is one of the latest in a long line of improvements on heavy ion superconducting booster linacs. Simple niobium quarter-wave resonators with 18 cm inside diameters will be cooled, by pot boiling of liquid He, in sets of four, inside ~1.1 m diameter cylindrical stainless steel cryostats. Quarter-wave resonators were chosen because of their wide use, mechanical stability, simple construction, and high accelerating fields.

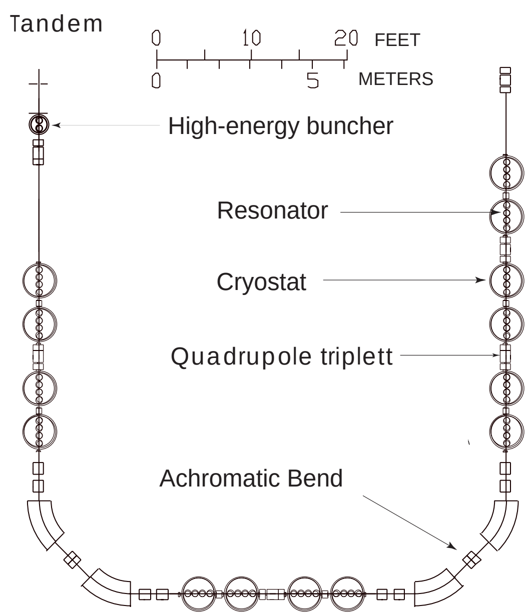

Figure 2 The linac has 14 cryostats, each cooling 4 niobium superconducting 1/4λ resonators. The configuration depicted uses quadrupole triplets for transverse focusing. Achromatic bends are used to wrap the linac back upon itself**.**

About 56 resonators operating at 5 MV/m are needed for an average transit time factor of 95%, using a synchronous phase of 20 degrees, and allowing for a downtime fraction of 5%. Various velocity and frequency configurations of these resonators were investigated in detail to obtain the highest possible energies for A=6-180 with single stripping and A=40-238 with a second stripping at the linac entrance. Many configurations are more than adequate; however, the simple and flexible configuration of 56 β=0.086 120 MHz resonators seems about optimum. Longitudinal phase space matching between the Tandem and the linac, will be achieved with the addition of a high energy buncher before the linac, and a possible modification of the tandem low energy buncher. A high energy chopper may also be added in the tandem exit line. A two frequency linac design was discarded because of a loss of longitudinal phase space.

A possible layout for the booster is shown in Fig. 2. As shown, the linac consists of three sections separated by 90 degree achromatic bends. Quadrupoles, in FODO cells and in doublets and triplets, each separated by one or two cryostats, were investigated to confine the beam radially. Figure 2 shows a round-beam triplet configuration. Other configurations are also acceptable. RIBs could be accelerated by the tandem and transported to the nuclear physics areas with or without the booster. A new ~5000 sq. ft building will be needed to house the booster.

3 OPTICS

The tandem beam has a 1 π mm mrad transverse emmittance, with a waist at the exit slits of the tandem[4]. Small energy variations in the tandem translate through the mass and energy analyzing magnets into a small walk in the beam centroid. In high intensity operation, the vertical part of this walk is used to control the tandem potential, and beam energy to 10^{-5}[5]. For low intensity, the energy can be regulated to 10^{-4} using terminal potential stabilizers. Figure 3 shows a typical energy spread produced by stripping in the tandem terminal calculated with TRIM92[6]. This energy spread is lower than the tandem energy regulation of 35 keV, but, because of the long drift path in the tandem terminal, it can dominate the time spreading of the beam. The RIB source energy spread is dominated by the charge exchange canal, measured at 50 eV for an As beam.

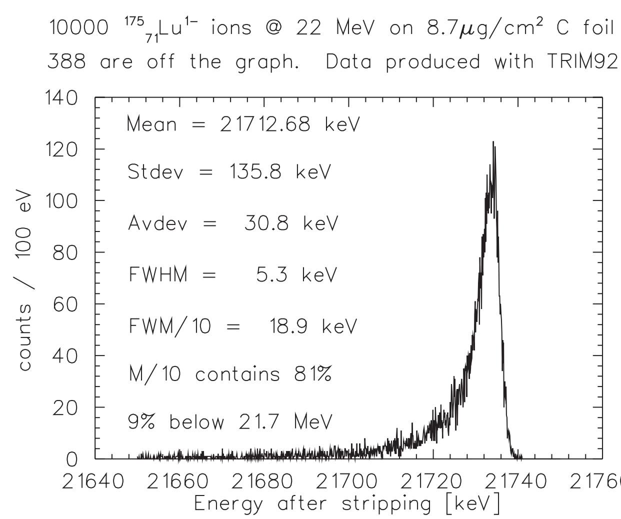

Figure 3 Beam energy spread from stripping ^{175}Lu to 15+ in an equilibrium thickness ^{12}C foil, in the tandem terminal. This translates into time spreading, and is a major component of the time spreading in the tandem beam ~1 ns.

The low energy buncher will be operated at 10 MHz. The present double drift buncher routinely bunches 50% of the beam into 6° RF, or 1.7 ns. A replacement 4f buncher based on that of Lynch[7], will bunch 66% into 4° RF, or 1.3 ns. A small debunching will occur due to path length differences and beam energy spread and variations. This debunching is ≅1 ns. The beam pulse width seen by the high energy buncher will then be ~2 ns.

The high energy buncher, operating at the linac frequency with a 1f and a 2f SC resonator, sees a pulse ~90° RF wide with an energy spread of 40 keV. As a buncher, it can add about ±1.3 qMeV to the beam energy spread. Table 1 shows the longitudinal acceptance of the SC linac when operated at a synchronous phase of 15°, for a range of heavy ions, and their most probable charge state after stripping in the tandem terminal operating at 22 MV. The longitudinal acceptance is at maximum energy spread, and does not correspond to maximum phase spread. The corresponding distances to bunch a 2 ns bunch are also given. An 8 m drift will be sufficient to longitudinally match the bunched tandem beam to the SC linac acceptance. Figure 2 shows a 5 m drift length. The extra 3 m of drift will require moving a cooling tower, and a 14 in. water pipe.

Table 1 SC Linac longitudinal acceptance at maximum energy spread, and drift length necessary to bunch a 2ns wide bunch, for various beams exiting a 22 MV tandem using the most probable charge state.

A	6	40	80	100	120	140	175	238
Q_{mp}	3	11	13	14	15	15	15	16/43
ΔE MeV	3.8	6.6	5.4	5.2	5.8	4	4.2	10
Δφ deg	17	15	13	9	9	8	5	9
L_{bun} m	5.0	5.7	6.2	6.4	5.8	7.8	6.6	2.6

The 90° achromatic bends present a rather long drift space for the beam to unbunch. This causes a reduction in phase space acceptance, but as shown above, the beam can still be bunched into the reduced phase space, and transmitted through the tandem. If the decision is made to extend the new building addition, it would be advantageous to accelerate only on the first and third legs, using a rebuncher in the middle of the second leg to improve the linac transmission and optics.

The transverse optics are designed by subdividing the linac into cells consisting of two cryostats separated a quadrupole triplet. Each cell is designed with a 90° phase advance. The achromats are designed with point to point focusing.

Figure 4 shows the results of a survey of linac performance over the range of useable fission fragments. Useable is defined as a combination of long half lives, and intense productions[8]. The SC linac will provide Coulomb barrier energies over the entire range.

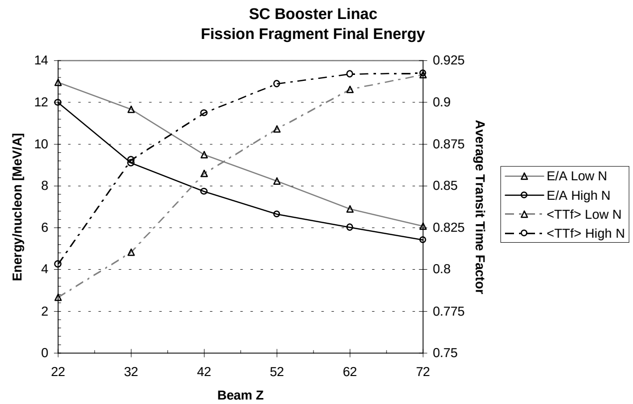

Figure 4 Final beam energy of useable fission fragments as a function of Z. Results for both the high and low mass useable fission fragments are shown. Also shown are the corresponding average transit time factors. Optimized for high masses, the SC linac is still efficient over the fission fragment mass range.

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