ISAC: RADIOACTIVE ION BEAMS FACILITY AT TRIUMF

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Abstract

A radioactive ion beam (RIB) facility is being built at TRIUMF. A novel design for the target/ion source station will allow us to bombard a thick target with TRIUMF's 100 µA, 500 MeV proton beam, producing a variety of very intense beams of nuclei far from stability. After mass separation the beams can be sent to two different experimental areas. One uses the 60 keV energy beam and the second one will use the 0.15 to 1.50 MeV/u post-accelerated beam. Singly charged ion beams, with A ² 30 delivered from the on line mass separator, with an energy of 2 keV/u, will be accelerated in a two stage linac consisting of an RFQ and a post-stripper drift-tube linac up to 1.5 MeV/u. CW operation mode is required to preserve beam intensity. As a consequence of the low q/A ions a low operating frequency for the RFQ is required to achieve adequate transverse focusing. The main features of this accelerator are: 35 MHz RFQ, stripping at 150 keV/u, beam energy continuously variable from 0.15 to 1.50 MeV/u and CW operation.

Introduction

A radioactive ion beam facility with a post-accelerator was first proposed at TRIUMF in 1984[1]. Although the full project was not funded at that time, an on-line target/ion source and mass separator test facility was installed on one of TRIUMF's proton beam lines, and has been used since 1987 to provide low energy radioactive beams and to develop the target-ion source system. The primary motivation at the time was to determine reaction rates involving short-lived nuclei in various nucleosynthesis processes. Furthermore, the possibility of producing intense radioactive nuclear beams with N/Z ratios largely different from those of natural isotopes opens a new area of research.

The high energy (500 MeV) and high intensity (>100 µA) of the H^- cyclotron beam make TRIUMF a cost effective choice for a RIB facility in North America. A new beam line will transport TRIUMF's proton beam from the cyclotron vault to two target stations in a new building of approximately 5000 m^2. This is divided into two parts, namely the heavily shielded and sealed target hall, and the post-accelerator/experimental hall, shown in Fig. 1.

Target/Ion Source System

The target stations are to be housed in the new heavily shielded target hall. All highly activated and potentially contaminated components such as production targets, beam dump, ion sources and initial focusing devices will be located at the target station within the target hall along with the primary radiation shield and services required to operate the target station components. Hot cell, assembly area and a decontamination and storage facility will be included. The target is located in a canyon surrounded by the required steel and concrete shielding, and consists of a large vacuum tank with 5 separate modules, entrance, target, beam dump and RIB optic components. The target module is made up of a 2 m long shielding plug on the bottom of which is mounted the target, ion source and the extraction system. The steel plug will be at ground potential and the target/ion-source assembly will be biased to give extraction voltages in the range 12 kV to 60 kV in order to match the 2 keV/nucleon required for injection into the RFQ. The target station modules are all designed to be handled remotely.

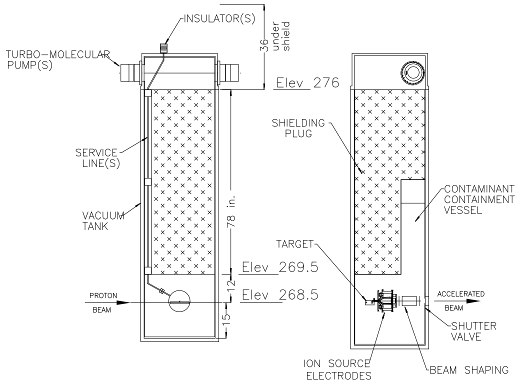

Fig. 1 Views of the target/ion source module showing the shielding plug and the services.

Mass Separator

There is no universal ion source for the production of all the elements required for the physics program. Beam properties will depend on the type of ion source used. The extraction system will be optimized for each individual ion source to give the highest brightness.

In our present design, the mass separator consists of a two stage system each with a total bend angle of 135°. It will have a source-defining entrance aperture. Aberrations will be corrected by surface coils in each dipole. This separator will have a dispersion at the focal plane of 6 cm/% in $\Delta M/M$ and a mass resolving power of 10,000 for a beam emittance of 5 ¹ mm mrad. A movable slit system will be placed on the focal plane to select the mass to be transmitted.

Accelerator

General Description

Most of the astrophysics and applied program can be performed within an energy range between 0.2 and 1.5 MeV/nucleon. Higher energies (≤ 10 MeV/u) would be desirable for nuclear structure studies, fusion reactions, etc. This could be viewed as a possible upgrade in the future. At present, for the ISAC accelerator, we limit ourselves to the specifications list in Table 1.

The layout in Fig. 2 illustrates the two-stage linac that would satisfy the ISAC specifications.

Initial acceleration of the singly charged ion beam delivered by the mass separator is accomplished in a RFQ. To accommodate the fixed ion velocity requirement at the RFQ input it is necessary to adjust the extraction voltage of the ion source so that the ion input energy will be 2 keV/nucleon in all cases. After acceleration to 150 keV/nucleon in the RFQ, the beam passes through the matching and stripper section where its charge to mass ratio is increased to ³ 1/6. After the stripping and charge state selection the beam is injected into a drift-tube linac operating at 105 MHz, which is divided into several accelerating structures in order to provide continuous energy variation from 0.15 to 1.5 MeV/nucleon.

Table 1 - Basic specifications for ISAC-1.

Input beam	
Energy	2 keV/nucleon
Ion mass	A ² 30
Ion charge	1
Beam current	< 1 µA DC
Beam emittance (100%)	² 50 π mm mrad
Accelerated beam	
Output energy range	0.15 ² E ² 1.5 MeV/u
Resolution ΔE/E	² 0.1 %
Duty factor	100 %

LEBT

The ion beam from the mass separator is to be switchable between the Low Energy (LE) experimental area and the accelerator. At the same time, it is desirable to have an off-line source which is switchable between the same two areas, although its primary purpose is for commissioning the accelerators. A switch-yard has been designed which meets all these goals. At the heart is a cross-over switch which allows the off-line source to supply beam to either the RFQ or the LE, while simultaneously, the mass separator can supply beam to the LE or the RFQ, respectively. All the optics in the LEBT is electrostatic: quadrupoles are typically 50 mm long by 25 mm bore radius, bends are each 45°, with spherical electrodes, 250 mm in radius.

The RFQ, having no bunching section, accepts bunches ± 30° in length. A buncher located 5 m upstream of the RFQ, operates at 11.67 MHz, the third sub-harmonic of the RFQ frequency. This is to meet the requirement of bunch separation in the range of 100 ns. In order to place at least 80% of the beam within the RFQ longitudinal acceptance, the buncher waveform will be pseudo-sawtooth, with 4 harmonics.

RFQ

A radio-frequency quadrupole provides the initial acceleration of the ion beam delivered by the ISOL. Taking singly charged mass 30 as the reference particle and an operating frequency of 35MHz, to give a reasonable structure size, we are led to an inter electrode voltage of 73 kV, a characteristic radius to pole tip $r_0=0.74$ cm, focusing strength B=3.5 and r.f. defocusing $\Delta=0.0408$. The total length of the vanes is 7.60 m.

Given that the radioactive ion beam intensity will be small, space-charge can be neglected and a truncated Yamada-style recipe used for the vane profiles. The vane modulation index ramps quickly from 1.12 to 2.5, while the bore shrinks from 0.70 to 0.38 cm. Due to a requirement from the experimenters for 86 ns time structure, beam bunching is achieved in an external, quasi-sawtooth prebuncher; and so the shaper and gentle buncher portions of the RFQ are omitted, leading to substantial shortening. The prebuncher is located in the LEBT section.

From a structural point of view, the low frequency of the RFQ dictates that a semi-lumped resonant structure be used to generate the required RF voltage between the electrodes. The structure proposed for the ISAC accelerator is a variant of the 4-rod structure developed at the University of Frankfurt[3]. A 4-rod split-ring RFQ structure has been chosen because of its relatively high specific shunt impedance, its mechanical stability, and the absence of voltage asymmetries in the end regions [4].

To confirm the manufacturability of the design and to verify the mechanical stability a prototype section consisting of three 40 cm long modules is being built. One module has been tested at full CW power (85 kV inter-electrode voltage). The thermal and dynamic stability has been measured and they are well within tolerances[5].

Stripper and matching section

After the stripper, we must accomplish two different functions, i) selection of the charge state; ii) matching of the transverse and longitudinal phase space into the next linac acceptance.

To minimize multiple scattering by the foil, and thus limit transverse emittance growth, we need a strongly converging beam in both the xz and the yz planes. Four quadrupole magnets will transform the RFQ output beam to the required small double waist at the stripper. After the stripper we need a charge state selector in order to 1) facilitate the tuning and 2) minimize the contamination by radioactive elements which otherwise would be implanted in the DTL. Furthermore, this charge-state-selector should be achromatic. This is done using a symmetric QQDQQDQQ section. A pair of slits located in the mid-plane of the charge-state-selector (after the third quadrupole) allows a unique charge state selection. A four quadrupole system and a 23 MHz $\lambda/4$ rebuncher provide the transverse and longitudinal match into the DTL. Provision is also made for installation of a rebuncher between the RFQ and the stripping foil to produce an upright ellipse for the longitudinal emittance at the stripping foil.

Drift-Tube Linac

Several accelerating structures were investigated. The first proposed structure was based on the RILAC accelerator[6]. The major problem was the power requirement of 1 MW for only 1 MeV/nucleon. A second study was devoted to investigate the suitability of superconducting accelerating structures[7]. Finally we decided on a room temperature structure to avoid the high cost of cryogenic equipment and the relatively long period to acquire this technology.

The drift tube linac is required to accelerate, in CW mode, ions with a charge to mass ratio ^{3} 1/6 from 0.15 MeV/nucleon to a final energy variable from 0.15 to 1.5 MeV/nucleon. An IH structure[8] is chosen for the drift-tube linear accelerator because of its very high shunt impedance.

A *separated function* DTL concept has been adopted[9]. Five independently phased IH tanks operating at $\phi_S = 0°$ provide the main acceleration. Longitudinal focusing is provided by independently phased double gap spiral resonator structures positioned before the second, third and fourth IH tanks. A schematic drawing of the DTL is shown in Fig. 2. When operating at full voltage the beam dynamics resembles that of a so called ‘Combined 0° Synchronous Particle Structure’[8]. To achieve a reduced final energy the IH tanks may be turned off while the voltage and phase of the last powered tank is varied. The spiral resonators are all designed for $\beta = 0.023$ and are effective over the whole DTL velocity range. They also permit the beam to be kept well bunched over the entire energy range. The total effective gradient is 1.5 MeV/m with an estimated power consumption of 91 kW.

HEBT

The HEBT provides three dimensional beam transport using 10 m long periodic sections comprised of 2 quad doublets and a rebuncher. A first triplet matches the beam while the periodic sections and achromatic bend deliver the beam to the high energy experimental stations. Simulations show that the longitudinal beam emittance ^{2} 50 ^{1} keV ns will be available for the full energy range.

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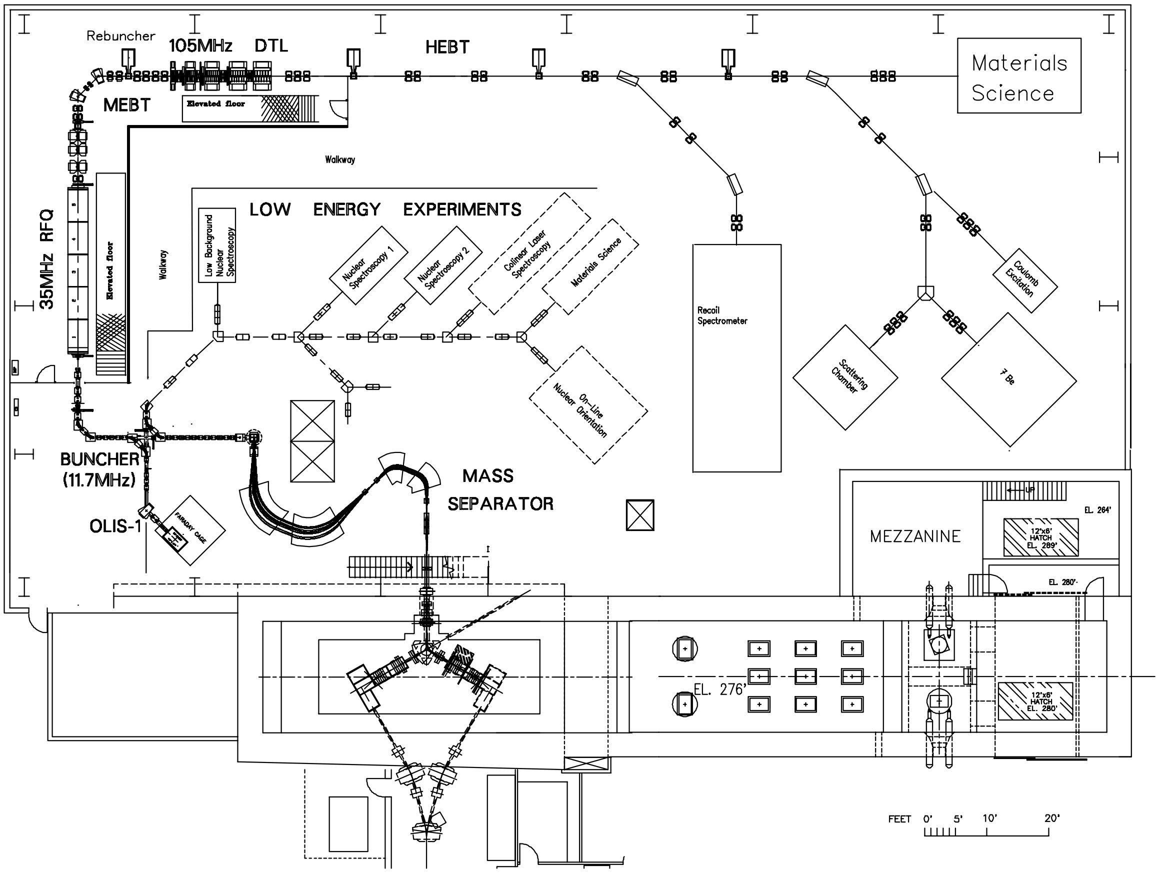

Fig. 2 Schematic drawing of the new target/experimental hall. The mass separator target and the new beam line are at 264’ elevation. At the final focal point of the mass separator the beam is bent up 90° and sent to the RFQ or to the Low Energy experiment stations.