

Accelerated Radioactive Beams at TRIUMF

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Abstract

An isotope separator (TISOL) has been installed at TRIUMF to study the generation of radioactive beams for use in an accelerated radioactive beams facility (ISAC). As part of this program a single staged ECR ion source has been designed and connected to the isotope separator. This source is now operational and delivering radioactive ions extracted from the production target. Accelerator studies have shown that a superconducting interdigital structure is an attractive alternative to the room temperature DTL of the original ISAC proposal. The recently demonstrated high gradients in a RFQ test structure hold promise for the development of a RFQ suitable for the initial stage of ISAC.

I. INTRODUCTION

In recent years many proposals for building an accelerated radioactive beams facility based on an isotope separator have evolved. One of these proposals has been the ISAC facility [1-3] at TRIUMF where a test facility for the front end of a radioactive beams facility has been built (TISOL). At the same time studies have continued to optimize the postaccelerator design.

The isotope separator is in its second year of operation. A major beam line extension is now in progress which will allow experiments at TISOL to begin this summer.

II. THE ISOTOPE SEPARATOR TISOL

A. TISOL Layout

TISOL is a thick target (several g/cm^2) isotope separator [4,5] located at a 500 MeV proton beam line of the TRIUMF cyclotron.

Figure 1 displays an overview of the expanded TISOL facility, to be assembled by May 1991, however, the data reported here were taken at another (lower) collection point.

The TISOL facility consists of the following components: A thick target in an oven, heatable up to 2000°C , a transfer line, an ion source (shown here is the ECR configuration), the extraction electrode system, including an einzel lens, two magnetic quadrupoles, a magnetic steerer doublet, a mass analysing magnet, resolution defining slits and an electrostatic beam transport system. The extraction voltage of the system is typically 18 kV. The mass resolution ($M/\Delta M$) of the analysing magnet has been determined to be 1000 - 3000 depending on the slit setting. The electrostatic quadrupole system consists of a number

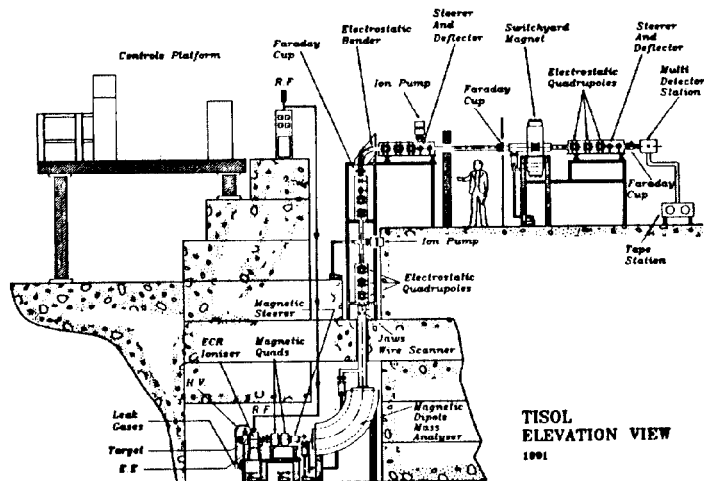


Figure 1. Overview of the TISOL facility as planned for May 1991. NB that the actual position of the beam lines is somewhat different from this schematic layout. A description of the facility is given in the text.

of electrostatic quadrupole triplets/doublets and steerers. The beam can be directed into one of three beam lines via a switching magnet. Several Faraday cups and wire scanners serve for beam diagnosis.

Targets of Ta, Hf, Ti, Nb, Zr, SiC, ScC, ZrC, UO/C, MgO, CaO, LaC₂, AlN, NaAlSiO₄ have been explored under varying conditions. For the surface ionization source radioactive species of Li, Na, Al, K, Rb, Sr, Ga, In, Cs, Yb, Fr have been observed by their characteristic $\beta\gamma$ -decays. A new design of a surface ionization source is in development.

At present proton beam currents are limited to $0.5\ \mu\text{A}$ because of target activation and handling considerations. To increase the current a better target handling system is under construction.

B. The ECR Ion Source

An overview of the ECR source including the target system is given in Fig. 2.

The ion source consists of two quartz tube liners, with the inner one being the plasma chamber with the rf coupled in radially. An iron yoke is used in the generation of the magnetic field, with the ECR mirror condition being axially produced by an iron ring in the middle of the source. Radial electron confinement is provided by a SmCo hexapole (surface field 0.52 T). The source is presently operated at 6 GHz, but can be used up to a maximum frequency of 10 GHz.

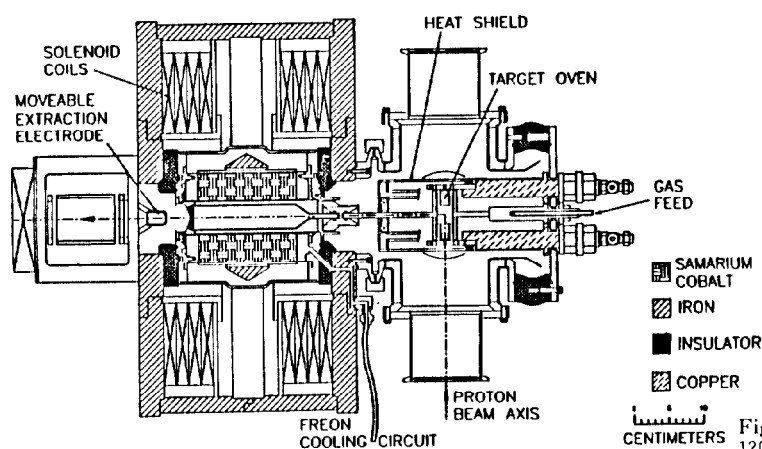


Figure 2. Top view of the TISOL ECR system as described in the text.

The inner quartz tube can be removed together with the coupling piece to the target assembly. Due to heat problems and resulting sparking the plastic insulation at the coupling end is cooled by a closed freon circuit. The target unit can be easily pulled away from the coupling.

The target unit is mounted on a flange consisting of the heatable oven and the watercooled transfer line as well as several service connections. A 7.5 cm long graphite cylinder resistively heated serves as the oven with the target of choice being contained in a 5.5 cm long graphite crucible. Radioisotopes released by the target matrix diffuse through the transfer line into the ECR plasma chamber. Watercooling of the transfer line provides partial chemical selection. It is possible to add several gases to this chamber with the gas being fed through the target unit. Quite extensive watercooling is necessary for all parts of the target chamber which are not deliberately heated.

The source has been tested with several gases. Ionization efficiencies of up to 30% for stable neon have been observed. Radioactive isotopes of He, C, N, O, Ne, Cl, Ar, Kr, and Xe have been detected, partially as molecular, partially also as multiply charged species. Figure 3 shows yields of radioactive noble gases, multiply charged. These yields make it a viable option to consider the acceleration of heavy masses using multiply charged ions to start with. Many of the yields obtained exceed those reached at the separator ISOLDE at CERN [6].

III. ACCELERATOR STUDIES

A room temperature linac was originally proposed for ISAC [2,7,8]. It consists of an RFQ to capture, bunch and preaccelerate the very low energy, singly charged ions from the isotope separator to 60 keV/u, followed by a stripper to increase the ion charge to mass ratio to at least $q/A=1/20$, before further acceleration in a Wideröe type drift-tube linac (DTL) to a final energy of 1 MeV/u. This conventional room temperature structure would have required more than 1 MW of cw rf power.

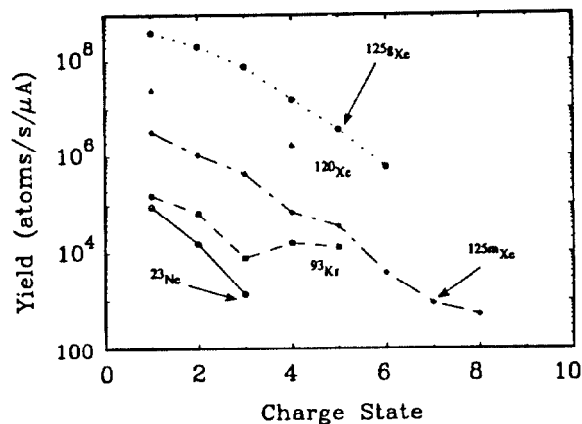


Figure 3. Yields for the radioactive isotopes of ^{125g}Xe , ^{125m}Xe , ^{120}Xe , ^{93}Kr , and ^{23}Ne up to a charge state of 8^+ extracted from either a LaC_2 or a UO_2 target.

A. A Superconducting Interdigital Accelerator Structure

In recent years significant progress has been made in the development of superconducting accelerator structures, in particular at the Argonne National Laboratory (ANL). By using an interdigital structure similar to that of the ANL ATLAS linac, it has been found possible to develop a conceptual design of a superconducting linac to replace the DTL of the original ISAC proposal [9,10].

Beam dynamics calculations were performed with the code PARMION which is a modification of the PARMELA code. The code uses tabulated rf field values in the cells for integration of the particle equations of motion through the linac. It accepts particles of arbitrary charge to mass ratios. Four contiguous cells are treated as a tank in which the acceleration field is constant and the entrance phase of the reference particle can be specified at each cell.

The complete SC DTL consists of twelve 50 MHz tanks with six-intertank solenoids, contained in two cryostats each about two metres long, followed by 21 100 MHz tanks with seven solenoids in four two metre cryostats. The overall length of the DTL is 16.3 m with an output energy of 1.6 MeV/u for masses $A \leq 60$; the overall accelerating gradient is about 1.9 MV/m.

B. Development of Superconducting RFQ's

J. Delaven *et al.* [11,12] have recently reported achieving surface fields in excess of 100 MV/m in a superconducting niobium test structure designed to simulate a RFQ geometry. Such fields are about ten times larger than those considered in the earlier room temperature RFQ for ISAC and suggest interesting alternatives for the initial acceleration stage.

Not only do the higher fields make possible shorter RFQ's, but also because the focussing strength is proportional to $\lambda^2 V$, where λ is the rf wavelength and V the vane voltage, higher frequency operation is also possible.

Schempp *et al.* [13] have explored a number of RFQ design possibilities utilizing the higher gradients of the superconducting structures. They find for example a linac for radioactive ions proposed at ISOLDE/CERN would need

to be only 7 metres in length to accelerate singly charged ^{27}Al to 1 MeV/u, if one assumes maximum surface fields of 130 MV/m. For the ISAC accelerator we find that for a more conservative assumption of 50 MV/m a RFQ to accelerate singly charged ^{60}Ar to 60 keV/u could be operated at 50 MHz and would be only 2.25 metres long. For comparison, the room temperature RFQ studied earlier would have been 9 metres long and operated at 23 MHz. Table 1 lists some of the principal design parameters for the superconducting RFQ.

Table 1. Basic design parameters for a 50 MHz SC RFQ for ISAC.

Ion	$^{60}\text{Ar}^+$
Frequency	50 MHz
Input Energy	1 keV/u
Output Energy	60 keV/u
Vane Voltage	158 kV
Minimum Aperture Radius	0.3 cm
Number of Cells	196
Normalized Emittance	$0.5 \pi \text{ mm mrad}$
Capture Efficiency	93%

IV. CONCLUSION

With the variety of source and accelerator developments that have taken place over the last couple of years the ISAC proposal has come to age and needs updating. For example, the remote handling of an ECR source has to be taken into consideration.

However, most excitingly, the development of superconducting heavy ion accelerators has changed the possible layout of the postaccelerator. Its design is now far less fixed than it was five years ago, as SC RFQ's have to be fully explored both in computer simulations as well as with some initial devices.

In North America a collaboration called IsoSpin Laboratory (ISL) has been founded [14] with some 200 scientists signed up working actively on a proposal for a radioactive beams facility which goes beyond the scope of the original ISAC proposal. Specifically an energy of 10 MeV/u for the radioactive ions is asked for with the possibility of accelerating masses up to $A=240$, though not necessarily injecting

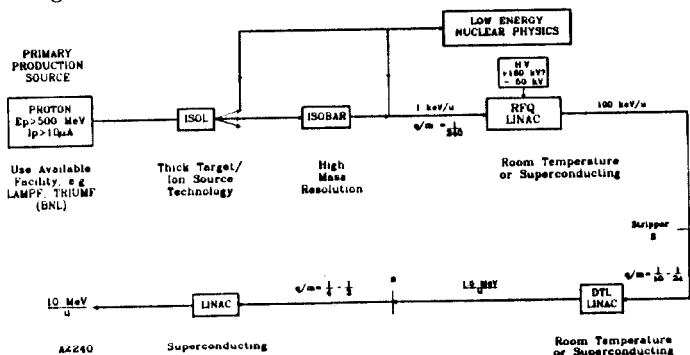


Figure 4. A benchmark facility for radioactive beams as proposed by the ISL initiative.

these high masses as singly charged ions. Figure 4 shows a benchmark facility being proposed as a North American radioactive beams factory. The development of SC RFQ's may tie such a facility smoothly into the present plans for ISAC.

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