RADIOACTIVE ION BEAM FACILITY DEVELOPMENT AT VECC KOLKATA

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Abstract

An ISOL type Radioactive Ion Beam (RIB) facility is being built at Variable Energy Cyclotron Centre (VECC), Kolkata. The design of the facility and present status of development is presented in this report.

INTRODUCTION

A project to develop an ISOL type Radioactive Ion Beam (RIB) facility has been undertaken at the Variable Energy Cyclotron Centre, Kolkata [1]. The first phase of the project is planned so that the basic design of all the critical components, accelerators and subsystems is completed during this phase. Initially, RI beams will be accelerated up to about 400 keV/u.

RIB FACILITY DESCRIPTION

A schematic layout of the facility outlining the plan up to the year 2007 is shown in figure 1. Radioactive nuclei will be produced inside thick targets using proton and α-particle beams from the K=130 cyclotron at VECC. Multiply charged radioactive ions with $q>1^+$ will be produced in a charge breeder consisting of a surface ion-source coupled to a 6.4 GHz on-line ECRIS. The desired RI Beam with an energy of 1 keV/u and q/A=1/16 will be separated in the low energy beam transport line after the ECRIS and accelerated to about 86 keV/u in a heavy-ion Radio Frequency Quadrupole (RFQ) linac. Subsequently the RI Beams will be accelerated to the desired final energy using heavy-ion IH Linac. A brief description of the various systems is given below.

Thick target R&D

In order to achieve fast and efficient release of activity from the target the trick is to maximize the surface to volume ratio so that diffusion is enhanced. Low-density target materials like grains, fibres, etc. are chosen in which the diffusion time is mainly governed by the grain size and the temperature. Target materials can be deposited on Graphite matrices (RVCF fibres) that can withstand high temperature and have sufficient porosity to allow radioactive atoms to diffuse out.

As a first R&D , we have deposited pure ‘Al’ (17.4 mg) on Carbon fibres (RVCF) to test the release of isotopes from the composite target experimentally. In order to see the effect of increase of surface area we compared the activity from the “thick target” with that from a 25 μm “thin” Al foil. The targets were irradiated by 140 MeV ^{16}O beam and the activity was transported to a low background counting station using a He-jet recoil transport system. The 2169 keV gamma from ^{38}K was used for comparison of relative yields (figure 2).

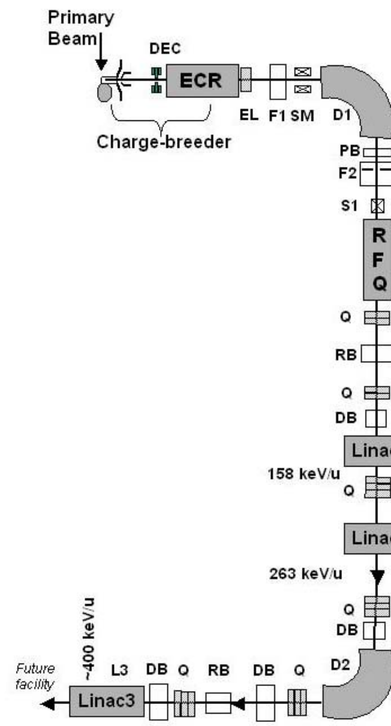

Figure 1: Layout of VEC RIB facility.

We observed enhancement of yield by about one order of magnitude for the ‘equivalent’ target thickness. The thick target was not heated in the experiment. Thus the enhancement in yield can be clearly attributed to the increase in the surface to volume ratio.

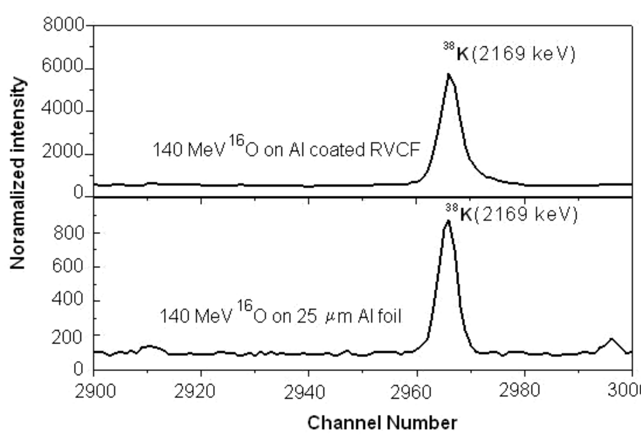

Figure 2: The normalized intensity of 2169 keV gamma ray from the decay of ^{38}K produced from “thick” and “thin” aluminum targets.

Since our RIB facility is being built around the cyclotron delivering low energy light ions, the development of a large number of thick targets will be of key importance. The targets should be able to sustain beam irradiation for at least a week, allow good release efficiency uniformly over the entire beam run and with the minimum possible release time. Thus an extensive R&D programme for the development of thick targets will continue at VECC.

The "two-ion-source" charge breeder

In order to produce high charge states of RI ions with good enough efficiency the vacuum inside the on-line ECR ion-source needs to be kept ~ 10^{-7} torr. This cannot be achieved if the ECRIS is kept in close vicinity of the thick target due to the residual gas pressure. Moreover, the permanent magnets of the ECRIS may undergo radiation damage in the hostile environment close to target. The possible solution is what is called a "two-ion-source" charge breeder consisting of two ion-sources in tandem, a 1^+ thick-target integrated ion-source coupled to an n^+ ECRIS. This concept has been successfully tested at Grenoble [2] for n^+ production of *Ar, Rb, Zn, Pb* and some other elements.

The *charge breeder* for the VEC RIB facility consists of a surface ionization source coupled to a 6.4 GHz on-line ECRIS. The 1^+ ions from the first ion-source are decelerated to about 20-50 eV and focused into the ECRIS plasma so that they can be efficiently trapped and further ionized to charge state $q>1^+$. A scheme for stepwise and gradual deceleration consisting of a multi-electrode decelerator and a tuning electrode placed outside the ECRIS plasma chamber ensures soft landing of the 1^+ beam [3].

The installation of the ECRIS has been just completed. In the first beam test, about 20 μA, O^{4+} beam was measured at the focal plane F2 for an RF power of 10 Watts. Presently efforts are on to improve the vacuum inside the ECRIS, which is ~ few times 10^{-6} mbar. The ECRIS is operated in the "High B mode" having a peak solenoidal field of 1.0 Tesla at the injection end and 0.7 Tesla at the extraction end. The radial field at the surface of the plasma chamber is 0.7 Tesla. The first ion-source is being fabricated.

The heavy-ion RFQ post-accelerator

The Radio Frequency Quadrupole (RFQ) linac is the most suitable linear accelerator for bunching, acceleration and focusing of low-β heavy-ion beams with low *q/A*. We have chosen a four- rod type structure for the RFQ, similar to the one developed by Fujisawa [4]. For the VECC-RIB project a RFQ linac has been designed for an input beam energy of 1.0 keV/u and $q/A \geq 1/16$. The output energy will be ≈ 86 keV/u for a 3.2 m long, 35 MHz structure. The calculated Q value and shunt impedance are 9830 and 87 kΩ at a resonance frequency of 35.18 MHz. The estimated total power loss is 14.3 kW for a vane voltage of 49.5 kV.

A bunched beam will be injected into the RFQ. For this purpose an external, sinusoidal, single gap pre-buncher operated at 35 MHz is placed so that the longitudinal focus for the pre-buncher is the entry of the RFQ. At the RFQ input the phase width is ± 42 degree. In the RFQ, a very short bunching section is retained. The energy width (FWHM) and the transmission efficiency for a pre-buncher voltage of 40 V are ± 0.28% and 74% respectively. For a pre-buncher voltage of 78 V, the corresponding numbers are a ± 0.59% and 83% respectively. The phase widths in the two cases are ± 10 and ± 15 degree respectively. The beam dynamics has been calculated using PARMTEQ.

A half-scale cold model with un-modulated vanes has been fabricated to carry out RF structure studies and the tests confirm the design (table 1). The *Q* value is measured to be about 3500. The shunt impedance R_p was measured by the capacitance variation method. The R_p/Q value comes out to be about 10.1Ω (figure.3) which gives the R_p value of about 35 kΩ. The measured *Q* and R_p values are both slightly more than 50% of the values calculated by MAFIA. The measured resonance frequency is about 4% higher.

Table 1: Results of RFQ Cold model tests

Quantity	**MAFIA (full scale)**	**Expected (theoretically) ½ scale**	**Measured**
f (MHz)	35	70.00	73.00
Q	9830	6951	3500
R_p (kΩ)	87	61.52	35

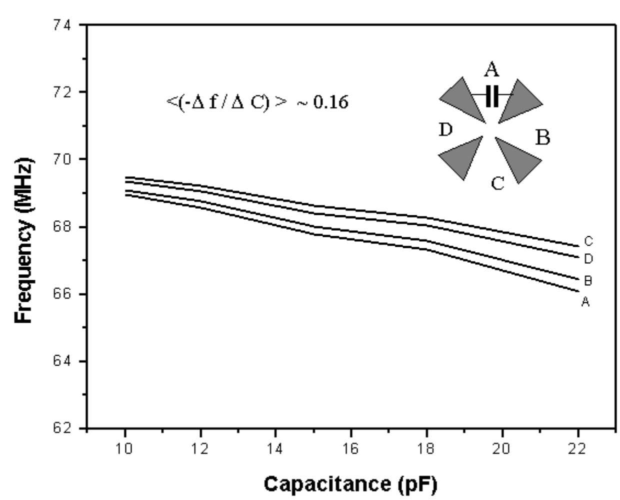

Figure 3: The variation of resonance frequency as a function of capacitance in the four quadrants of the RFQ ½ scale model. The value of R_p/Q is determined from *Δf/ΔC*.

Optimization of beam-optics design for ECR to RFQ beam line

After ionization inside the ECRIS, the reaction product of interest will be separated from the rest in an isotope separator and will be injected in the RFQ for subsequent acceleration. The design of the low energy beam transport line between the ECRIS and RFQ is done to achieve the matching of RFQ acceptance with the ECR emittance. In this design, we have tried to minimize the number of elements and also to keep the required length a minimum. The separation stage uses a 90° dipole and the matching section uses a solenoid magnet apart from a pair of steering magnets. The entire design has been optimized using TRANSPORT.

It has been assumed that the beam from the ECRIS can be matched to lie within an ellipse of size ±1.2 cm and divergence ±10 mrad at a distance of 0.8 m from the plasma electrode by adjusting the position of the extraction electrode and voltages of a pair of Einzel lenses placed just after the extractor electrode. The 2.8 m long separation stage is designed for a dispersion of 1.94 m for 100% change in momentum and the magnification in the dispersive plane is -0.88. With the beam size stated earlier, the expected mass resolving power of the system will be 90 for 100% transmission of the extracted beam, which is a very important consideration for the RIB acceleration.

The RFQ to Linac beam-line

An output beam of about 85.5 keV/u from the RFQ would be injected into the 35 MHz IH-Linac for acceleration to about 158 keV/u in the first tank. The RFQ to Linac beam-line is designed to match the emittance of the beam at the exit of RFQ with the acceptance of the Linac. The present design ensures transverse focusing by using a set of four magnetic quadrupoles and longitudinal focusing with the help of a 4-gap re-buncher operating at 35 MHz. The re-buncher and the transverse optics is designed to ensure a beam of correct energy width, phase width and radial dimension at the entry of the Linac tank.

The RFQ to re-buncher and re-buncher to Linac distances have been taken to be 1.8 m and 2 m respectively. The maximum beam size inside the re-buncher, as obtained from TRANSPORT simulation is ± 6.1 mm. At the entry of Linac tank-1 the beam size ± 6.2 mm both in X and Y - direction, which is much smaller than the inner diameter of the drift tubes (25 mm). The phase width and energy width at the entry of Linac tank-1 are about ± 11^{O} and ± 1 % respectively, which are well within the acceptance limit of the Linac.

Heavy-ion LINAC post accelerator

After the initial stage of acceleration in the RFQ linac the subsequent acceleration of RI beams will be done in LINAC tanks. For these low-β and low *q/A* RI beams the IH- LINAC structure is the preferred choice. In this type of structure, the LINAC cavities are excited in the TE mode. The IH structure offers quite high shunt impedance at lower frequencies. The transverse focusing will be taken care by placing quadrupole triplets in between the tanks.

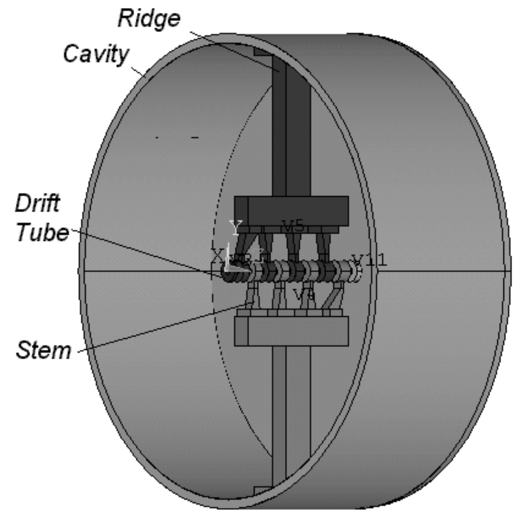

Figure 4: A schematic of IH-Linac tank.

The design of the first three LINAC tanks has been frozen and the fabrication of cold model for the Linac first tank has been completed. The RF power tests on this cold model will be conducted shortly. The first indigenously built 40 kW, 35 MHz transmitter for the Linac tank -1 has been installed. The RI beam energy would be about 158 keV/u after the first tank and about 400 keV/u after the third tank of the Linac.

Table 2: Parameters of the first 3 tanks of the Linac.

Quantity	**Tank1**	**Tank2**	**Tank3**
f (MHz)	35	35	35
E_{out} (keV/u)	158.2	263.0	397.5
Q value (cal.)	15878	21571	26284
R_p (MΩ/m) (cal.)	369	487	474
Drift tube pot. (kV)	171.8	202.0	217.6
Power (kW)	10.5	10.2	11.5
No. of Cells	9	11	13
Cavity length (m)	0.618	0.996	1.476
Cavity diameter (m)	1.72	1.72	1.72

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