RIB FACILITY AT VECC KOLKATA : A STATUS REPORT

Alok Chakrabarti† and R.K.Bhandari,
VECC, 1/AF Bidhannagar, Kolkata-700 064, India

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.

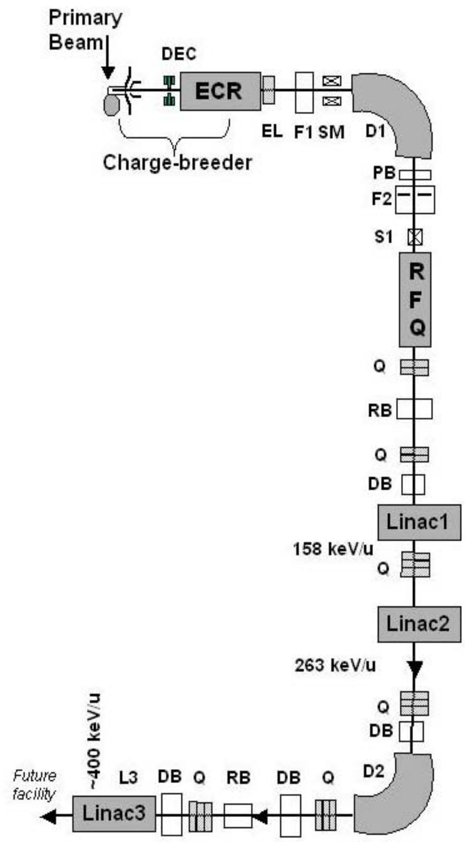

Figure 1: Layout of VEC-RIB Facility.

Thick Target R&D

The production of radioactive ions depends primarily on the thickness of the target, that is, on the number of target atoms per unit area of the target apart from primary beam intensity & nuclear reaction cross-section. Proton induced reactions are often used for production of radioactive atoms. In order to achieve fast and efficient release of activity from the target, the trick is to maximize surface area so that diffusion is enhanced. We have worked out in detail the prospect of using fibrous and composite targets like carbon fiber (RVCF) as backing matrix for deposition of several selected target compounds. Optimum target length for specific choices of RI beam with maximum allowable beam current are calculated for a number of targets [2]. The development of each target is very complicated keeping in mind the stringent requirements, as already discussed.

As a first initiative in this direction, we have deposited pure 'Al' (17.6 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). We observed enhancement of yield by 7.1 times for the 'equivalent' target thickness. The thick target was not heated in the experiment. Thus the enhancement in yield is clearly attributed to increase in surface to volume ratio.

† alok@veccal.ernet.in

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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,1^+ thick-target integrated ion-source coupled to an n^+ ECRIS. This concept has been successfully tested at Grenoble 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.

ECR-RFQ Beam-Line

The ECR-RFQ beam line is designed to transport the 1keV/u beam extracted from ECR to match with the acceptance of RFQ. The basic design consists of a separation stage followed by a matching section. The separation stage uses a 90^O dipole and the matching section uses a solenoid magnet. The 2.8 m long separation stage is designed for dispersion of 1.94 cm/% and the magnification in the dispersive plane is –0.88. The mass separated beam must be matched to the acceptance at the entry of RFQ. RFQ demands converging beam in both the planes. A reasonable match could be obtained using a solenoid of magnetic length 0.3 m and maximum field of 0.65 T.

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*. For the VECC-RIB project a four-rod type RFQ [4] 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.

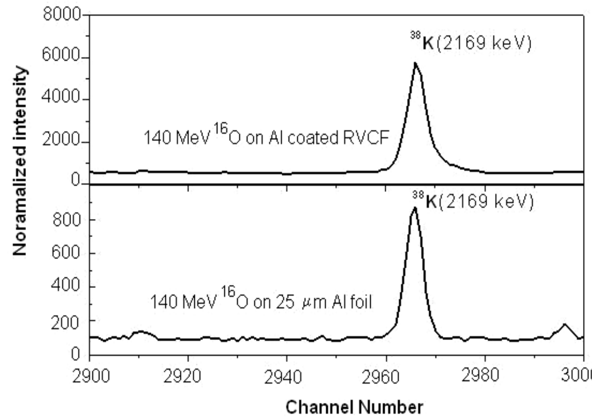

Figure 2: The normalized intensity of 2169 keV gamma ray from the decay of ^{38}K produced from "thick" and "thin" aluminum targets.

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 40V are ±0.28% and 74% respectively. For a pre-buncher voltage of 78 V, the corresponding numbers are a ±0.56% and 83% respectively. The phase widths in the two cases are ± 10^o and ± 15^o respectively. The beam dynamics has been calculated using PARMTEQ.

The 3d-co-ordinates of the vanes have been calculated using the program CUT3d. The process of surfacing, modeling as well as ball cutter profile and tool path generation for the vanes is done using CATIA. In order to optimize and critically examine the complications in the vane and vane joints, a number of sample vanes with three-dimension modulated profile have been fabricated. The vane joints have been tested inside vacuum with water flow. The resonant structure is shown in Fig 3.

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 2).

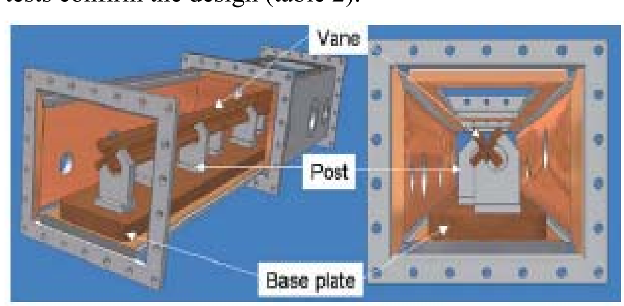

Figure 3: The lateral and cross-sectional view of RFQ.

Table 2: Results of RFQ Cold Model tests

Quantity	MAFIA (Full Scale)	Expected (1/2scale) (theoretically)	Measured
F (Mhz)	35	70.00	73.00
Q	9830	6951	3500
R_P(kΩ)	87	61.52	35

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 design of the transverse optics is done by using two sets of quadrupole doublets. The longitudinal focusing is achieved with the help of a 4-gap re-buncher operating at 35 MHz. The re-buncher and the transverse optics are 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 2.2 m and 1.5 m respectively.

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 TE mode.

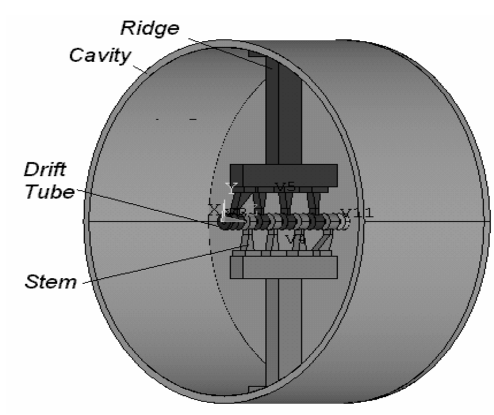

Figure 4: Schematic diagram of IH-Linac Tank.

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 cavity and the end covers were made out of aluminum. The inner components i.e. the drift tubes and the ridges were given the initial shape by sand casting of aluminum followed by machining. The measured and calculated frequencies and Q-values of first three excitation modes are shown in Table 3.

As can be seen that the measured and calculated frequency values match reasonably well whereas the measured Q-values are in the range of 35-45% of the calculated values. Two main causes of lower Q-values in our case compared to generally what is achieved are surface imperfections of the inner components (drift tubes and ridges) due to the use of casting technique and imperfect joints as no RF contacts were used in our cold model. We expect to improve upon this situation in the actual cavity.

The axial component of the RF electric field was measured using bead perturbation technique using an insulating teflon spherical ball. The arrangement allowed us to measure frequency deviation at a step of 5 mm. Results of this measurement shows reasonably uniform field strength pattern in all the gaps.

Table 3: Calculated & measured values of frequency and Q-value for the first three excitation modes of the cold model cavity

Mode	Frequency (MHz)		Q-Value	
	Meas.	**Calc.**	**Meas.**	**Calc.**
1	36.87	37.49	3258	9088
2	59.39	60.21	3835	11582
3	94.79	96.18	11210	25637

Table 4: Parameters of first 3 Linac Tanks

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

REFERENCES

[1] The Radioactive Ion Beam facility at VECC Calcutta-a status report, Alok Chakrabarti ,Journ. Phys. G : Nucl. Part. Phys., **24** (1998) 1361

[2] Preparation and optimization of targets for the production of radioactive ions at VECC, D. Bhowmick et.al, Nucl. Instrum. Method **A 539**(2005) 54

[3] Design of two ion source (2-IS) beam transport line for the production of multi-charged radioactive ion beams, V. Banerjee et. al., Nucl. Instrum. Method **A447** (2000) 345.

[4] The design of four rod RFQ linac for the VEC-RIB facility, A. Chakrabarti et. al., Nucl. Instrum. Method **A535** (2004) 599.

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