LONG RANGE PLAN PROPOSAL FOR AN EXTENSION TO ISAC

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Abstract

A radioactive ion beam facility, ISAC, is presently under construction at TRIUMF. The post-accelerator comprises a 35 MHz RFQ to accelerate ions of $A/q \leq 30$ from 2 keV/u to 150 keV/u and a post-stripper room temperature 105 MHz DTL to accelerate ions of $3 \leq A/q \leq 6$ to a final energy fully variable up to 1.5 MeV/u. Both linacs are required to operate in cw mode. For the next five year plan, it is intended to increase the final energy above the Coulomb barrier (roughly 6.5 MeV/u) and broaden the mass range up to roughly $A = 150$. The ISAC-2 proposal will utilize the existing RFQ. Masses higher than 30 will require ECR ion sources and/or charge boosters. The optimum design consists of an IH linac to reach a 400 keV/u stripping energy, and superconducting modules to reach the final energy. The superconducting option is preferred because the short modules allow significantly higher energy – up to 13 MeV/u – for light ions. In this paper we compare the various ISAC2 options and present first order linac designs and staging scenarios.

1 INTRODUCTION

The ISAC facility currently under construction at TRIUMF[1] (ISAC1) will have the capability of accelerating singly-charged radioactive ion masses up to 30 atomic mass units ($A = 30$) to an energy of 1.5 MeV per amu (MeV/u). As a next step, experimenters would like to go to the Coulomb barrier (roughly 6.5 MeV/u) with masses up to roughly 150.

One option considered[2] was to take the singly-charged ions up to 12 keV/u with a low frequency RFQ (11.67 MHz), use a gas stripper to reach $A/q = 60$, then with a combination of RFQ and IH linac accelerate to 0.55 MeV/u, strip to $A/q = 6$ and finally accelerate to 6.5 MeV/u using more IH linacs. Although this is an intensity-efficient option, it is expensive, requiring 60 m of linac.

Ions of mass A can be accelerated in ISAC1 if their charge is greater than $A/30$. The first step in an upgrade is therefore to upgrade to a higher charge state. ECR ion sources can easily reach the required $A/q = 30$. Such sources which can withstand the radiation fields due to the 500 MeV, 10-100 μA primary beam are already under development at TRIUMF. Another possibility is a device which boosts the charge state of the 60 keV beam from the ion source. Such charge state boosters are under intensive development at GANIL/Grenoble[3]. For example, from singly-charged initial ions they have achieved Kr^{9+} with an efficiency of 9% and Zn^{7+} with an efficiency of 2%.

An attractive option is to develop a charge state booster which would give $A/q \leq 6$. This would obviate the need for any stripping and the ISAC1 stripper could be discarded. Subsequent linacs could then be optimally short and inexpensive. However, there is no guarantee that such high charge states ($q = +25$ for $A = 150$) can be obtained. Moreover, experiments indicate that the higher the charge state, the longer the 'cooking' time needed in the charge booster: up to 100 ms for very high charge states. This obviously would make it difficult to use isotopes far from stability in ISAC2.

Although ISAC1 would allow acceleration of all masses to 1.5 MeV/u, intensities for masses beyond ∼70 would be too low to be useful. The reason is that the stripper in ISAC1 is at an energy of 0.15 MeV/u and $A/q \leq 6$ required for the Drift Tube Linac (DTL) cannot be achieved for masses beyond about 70. This rules out a simple extension to the ISAC1 DTL to take the ions from 1.5 to 6.5 MeV/u, unless the ISAC1 MEBT and DTL are upgraded to higher A/q. The drawback of this approach is that approximately an order of magnitude in intensity would be lost because a second stripper would be needed after ISAC1 to lower the A/q else the 1.5 MeV/u to 6.5 MeV/u linac would be too expensive.

A better approach would be to optimize the total design to use only one stripper to reach 6.5 MeV/u while keeping the total linac length to a minimum. In that case, the optimum stripping energy is 0.4 MeV/u with a maximum $A/q = 7$ for $A = 150$. A higher stripping energy makes the pre-stripper linac (where A/q is 30) too long. A lower stripper energy does not strip to a high enough charge state, making the post-stripper linac too long.

2 ISAC2 DESIGN

2.1 Acceleration from 0.15 MeV/u to 0.4 MeV/u

A cost effective configuration to reach 400 keV/u is to continue the acceleration straight north of the RFQ MEBT1 line (Fig. 1). This would require an addition to the present building to widen it northward. The energy gain of 0.25 MeV/u requires a total rf voltage of $(0.25 \times 30 =)$ 7.5 MV. A DTL very similar to the ISAC1 DTL IH linac[4] would be about 5 m long assuming an average gradient of 1.5 MV/m and could be placed downstream of the first MEBT bender after a short matching section.

After the new DTL, the beam would go through a beam transport system (MEBT2) consisting of a short matching section, stripping foil, a 90° bend for charge selection and a matching section to the post-stripper linac.

2.2 Acceleration from 0.4 Mev/u to 6.5 MeV/u

To reach 6.5 MeV/u from 0.4 MeV/u with $A/q = 7$ requires a total voltage gain of 42.7 MV. A room temperature linac should be composed of long, many-gap modules (like the ISAC1 IH DTL), else the rf power supply and running costs become prohibitively large. Such a structure running cw would have a gradient of 2.2 MV/m and including the required focusing quadrupoles between tanks would therefore be at least 28 m in length. Higher electrical gradients are possible in principle, but in cw operation rf power dissipation in the drift tubes becomes a limiting factor. These problems disappear if we instead use superconducting cavities. In that case, an accelerating gradient of 3 MV/m is conservative (5 MV/m has been achieved).

Superconducting technology is technically more difficult than the room temperature IH structure but would offer a shorter more flexible accelerating structure. Typically superconducting booster linacs are composed of two- to four-gap cavities. Two gaps give a larger velocity acceptance at the expense of a reduced voltage gain per cavity when compared to three- and four-gap cavities. Two-gap cavities have been made in both a spiral and QWR (quarter wave resonator) configuration. Three-gap cavities have been made in a split-ring structure. The four-gap cavities are constructed in a QWR geometry. The QWR shape has been found to be inherently more stable than the ring structures[5]. Acceleration efficiencies ($=$ energy gain$/(q \times$ peak voltage$)$) are more than 80% for the velocity range $0.81 \leq \beta/\beta_0 \leq 1.60$ for two-gap cavities and $0.85 \leq \beta/\beta_0 \leq 1.34$ for three-gap cavities.

2.3 Cavity Dimensions

A zeroth order linac concept is presented here as an example. Obviously a full optimization considering cavity type, stability, cost, etc, is required to achieve a first order design. This example consists of three different cavity geometries. The three models have design velocities of 3.5%, 7% and 11% respectively with the lowest velocity cavity being a two-gap resonator and the other two models being three-gap resonators. The two-gap cavity is chosen in the low velocity section because of its broader velocity acceptance but also because the device is inherently more phase stable and the longitudinal emittance in this region is relatively large. Cavity details are presented in Table 1, Table 2 and Table 3. In Table 1 ($A/q = 7$) and Table 2 ($A/q = 3$) the efficiency of acceleration can be determined from the ratio of the velocity to the cavity design velocity. The regions have been chosen to yield at least ∼80% acceleration efficiency for acceleration of the higher masses ($A/q = 7$). In Table 2 the particle velocity is estimated for the case where $A/q = 3$ assuming a flat velocity acceptance for the cavities. This shows that energies of 15 MeV/u can still be accelerated with reasonable efficiency.

Table 1: Energy range, velocity range and maximum voltage gain required for the three cavity types for $A/q = 7$.

Cavity	Cells	E (MeV/u)	β (%)	ΔV (MV)
1	2	0.4 – 1.5	2.9 – 5.6	7.7
2	3	1.5 – 3.5	5.6 – 8.6	14
3	3	3.5 – 6.5	8.6 – 11.7	21

Table 2: Energy range, velocity range and voltage gain for $A/q = 3$ assuming a flat effective energy gain for the three cavity types.

Cavity	Cells	E (MeV/u)	β (%)	ΔV (MV)
1	2	0.4 – 3.0	2.9 – 8.0	7.7
2	3	3.0 – 7.7	8.0 – 12.8	14
3	3	7.7 – 14.7	12.8 – 17.6	21

In Table 3 the cell structure for each cavity type is given assuming rf frequencies of 105, 140 and 175 MHz (resp. 3, 4 and 5 times the RFQ frequency). The rf frequency can be increased down the line as the relative longitudinal emittance is reduced. (The frequencies are conservative compared to the room temperature equivalent due to the higher Q and possible resultant reduction in longitudinal acceptance.) The length of the two-gap cavity is $L_2 = \beta\lambda$ and of the three-gap cavity is $L_3 = 3\beta\lambda/2$. A conservative gradient of 3 MV/m is assumed to calculate the effective voltage gain per cavity.

Table 3: Specifications for the three cavity types. The effective voltage assumes an accelerating gradient of 3 MV/m.

Cavity	Cells	β_0 (%)	f (MHz)	L (cm)	V_{eff} (MV)
1	2	3.5	105	10	0.3
2	3	7.0	140	22.5	0.68
3	3	11.	175	28.2	0.85

The proposed structure was used to estimate expected final energies. Assuming a conservative gradient of 3 MV/m, ISAC2 could reach 13 MeV/u for the lightest ions decreasing monotonically to 10 MeV/u at $A \sim 60$ and to 6.5 MeV/u at $A = 150$.

3 STAGING

The flexibility of short superconducting modules has other advantages as well. Since they are short and have wide

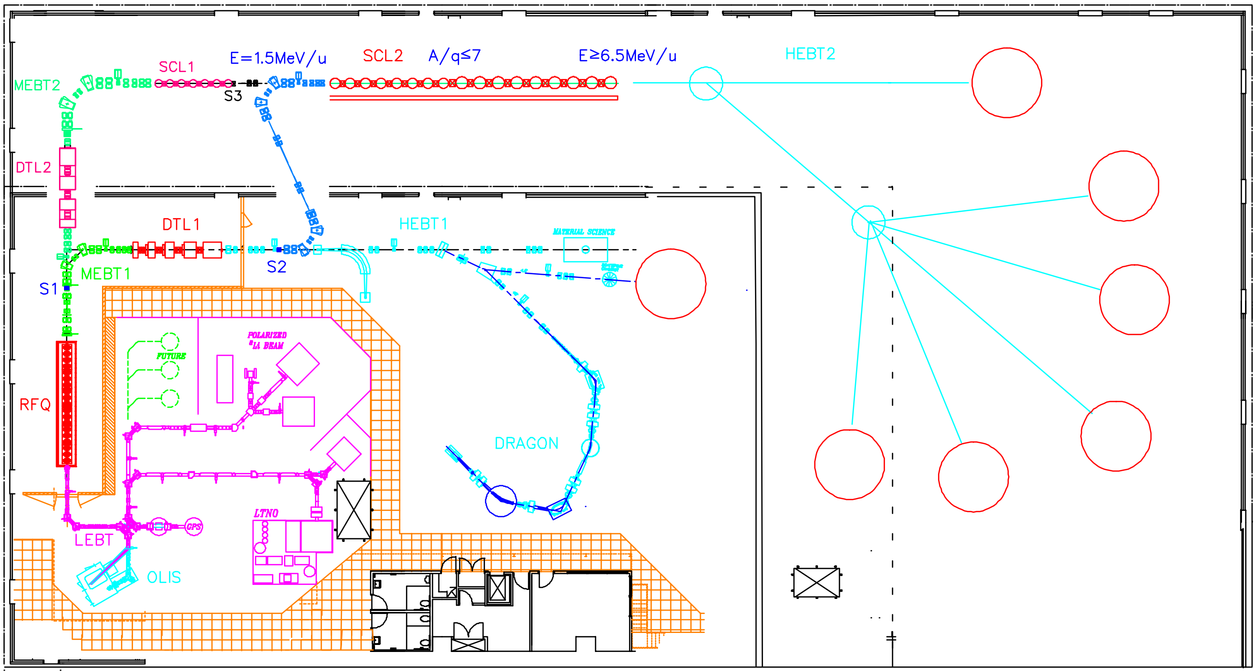

Figure 1: ISAC2 layout, including link from ISAC1, as would be needed for a 2-stripper stage

velocity acceptance, they can be built and tested even before the building addition for ISAC2 (see Fig. 1) is completed. Modules can be installed downstream of DTL1 as they become available and before the building needs to be expanded. At reduced, but usable intensity, masses up to 60 and energy up to 7 MeV/u could be available with an outlay of as little as 1/3 the cost of the complete ISAC2. This is stage 1 in Fig. 2.

Intensity for masses higher than 60 are low in stage 1 because the ISAC1 DTL requires $A/q \leq 6$ and the stripping energy is 0.15 MeV/u. However, by pushing the DTL voltage, raising the top fields of the MEBT dipoles and the DTL quads by a factor of 7/6, $A/q \leq 7$ becomes possible. This allows acceleration by ISAC1 up to mass 110 before intensity drops off. Accordingly, the ISAC1 design has been upgraded from $A/q = 6$ to 7. This is stage 2 in Fig. 2. In this stage, the building would have the expanded size shown in Fig. 1, the superconducting modules would be installed in their final location in preparation for ISAC2, and a transfer line would be used to bring the beam from DTL1 to SCL2.

Finally, DTL2 and MEBT2 would be installed to allow stripping at 400 keV/u to reach $A = 150$. This is stage 3 in Fig. 2.

4 REFERENCES

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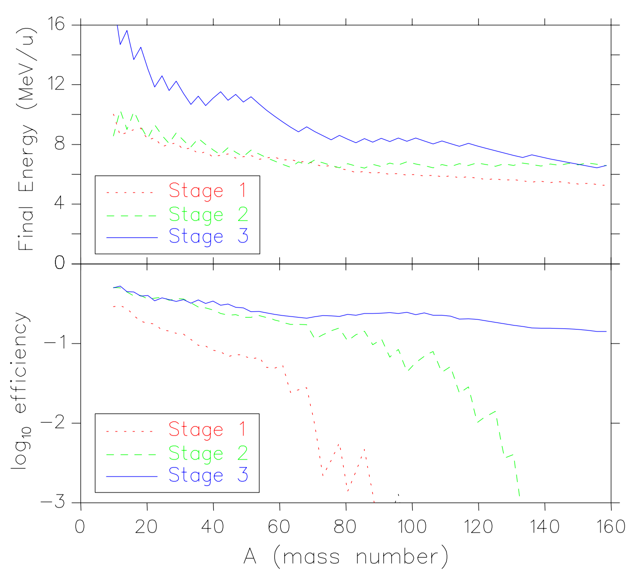

Figure 2: Relative intensities and energies for the 3 stages