Radioactive molecule production by ion-gas reaction chemistry in RFQ's

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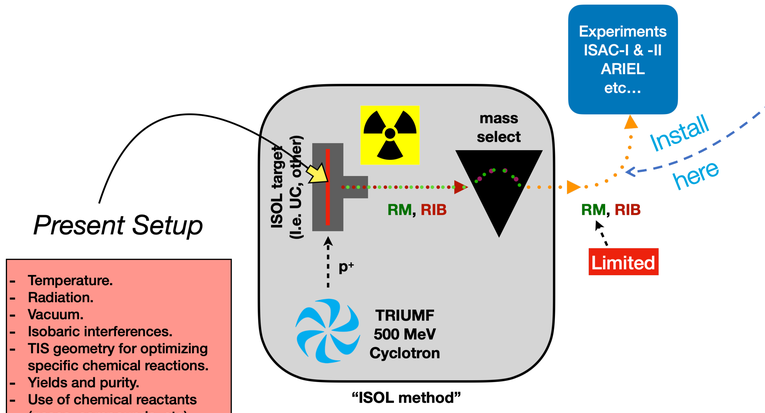
Introduction

Radioactive molecules (RM) are any unstable molecular species containing rare radioisotopes that spontaneously dissipates energy by emission of radiation as alpha, beta or gamma particles.

New precision BSM physics (i.e. C-P-T symmetry violations, etc) require efficient, pure production of RM ions for next-generation experiments. However, Isotope Separation On-Line (ISOL) methods are known to limit RM diversities, purities and yields due to unfavorable conditions (**Figure 1**).



- Temperature.
- Radiation.
- Vacuum.
- Isobaric interferences.
- TIS geometry for optimizing specific chemical reactions.
- Yields and purity.
- Use of chemical reactants (gases, compounds, etc).
- Effects on target degradation.
- etc …

formidable / unsolved challenges to RM production

FIGURE 1 – Isotope Separation On-Line (ISOL) method used at TRIUMF for radioactive ion beam (RIB) production. Key unsolved problems limiting RM yields, purities and diversities are shown.

Here we propose **two** novel "on-line" radiofrequency quadrupole (RFQ) approaches for RM production by using: (1) a dedicated RFQ chemical gas-reaction cell, and (2) the recently commissioned RFQ cooler-buncher at CANREB-ARIEL.

Approach #1
Dedicated RFQ chemical gas-reaction cell

Ion Reaction Cell (IRC)

The IRC is a commercial RFQ gas-reaction system for molecule production (or destruction) in-line with accelerator systems (**Figure 2**).

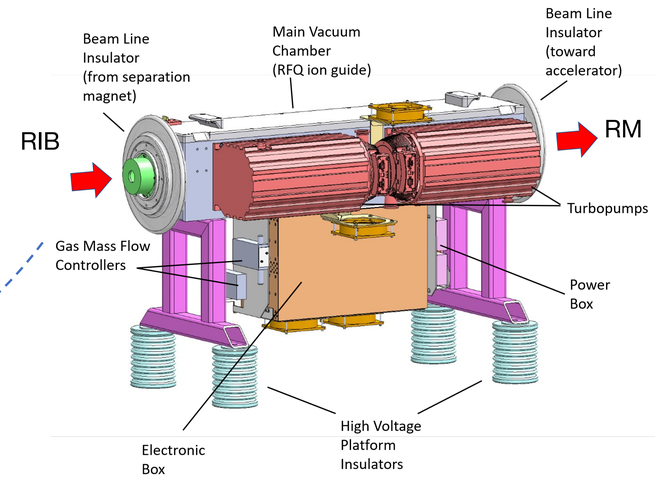
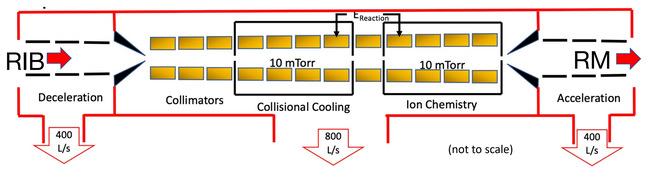


FIGURE 2 – Ion Reaction Cell (IRC) showing major external (top) and internal (below) features. The IRC is set in-line with TRIUMF beamlines, away and downstream from the ISOL target to directly produce RM from mass-selected RIB. Gas-ion interactions occur in the RFQ column shown (below).

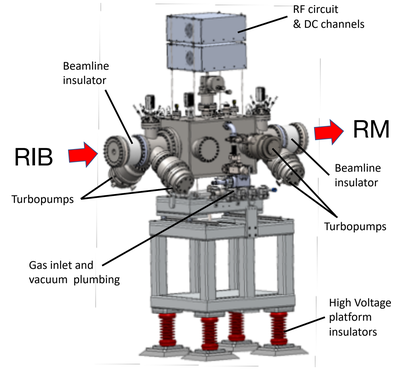
- Removable RFQ column (telescopic operation between entry/extraction lenses).
- Differential pumping, gas inlets, HV and PLC infrastructure already designed and integrated.
- Gas-cell segments reconfigurable.
- Positive / negative operation with 40 keV, 1 uA (max) RIB up to U.
- RF circuit tunable to 6 MHz.
- Individual DC channels.
- Robust ALTEM reaction cell for difficult-reactive gases or compounds.
- PLC fully EPICS integrable.
- Detailed beam dynamics simulations are now underway.
- Future technique developments are being explored (RM beam bunching and improved collisional cooling with cryogenic He gas).
- See: *Charles et al (2015) NIMB 361 (189-192)* for operation with negative ions.



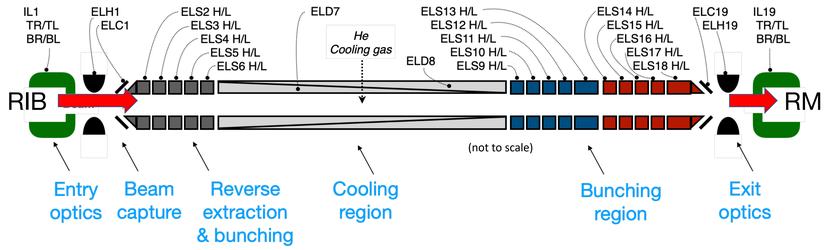
Approach #2
ARIEL cooler-buncher as a gas-reaction cell

ARIEL Radiofrequency Quadrupole cooler-Buncher (ARQB)

The ARQB (**Figure 3**) is the newest commissioned RFQ cooler-buncher for RIB preparation at the CANadian Rare isotope facility with Electron Beam ion source (CANREB). To fully exploit upcoming RIB capabilities of ARIEL, and by analogy to the IRC, the ARQB should be capable of RM beam production.



- 3 pressure (cooling) regions.
- 6 large turbos (2 x 800 L/s, 1 x 700 L/s, 1 x 500 L/s) for diff. pumping.
- Hyperbolic rods to approach ideal RFQ field.
- Positive ion operation with 60 keV, 1 nA (max) RIB up to U.
- RF 3 or 6 MHz up to 1.5 kV_{pp}.
- Production up to 10^7 ions/bunch for RIB bunched beams at 100 Hz repetition rate.
- Cryogenic cooling of He buffer gas and RFQ structure is possible, to further decrease emittance of ejected ion bunches.
- Requires substantial R&D to test feasibility of RM production and delivery from CANREB to ISAC.



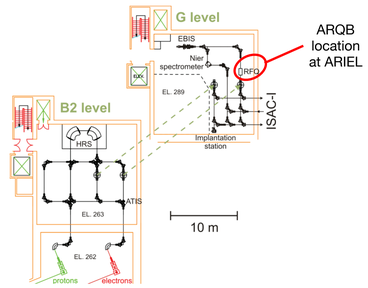


FIGURE 3 – ARQB showing external (top) and internal (centre) features. Location of the ARQB at the ARIEL facility is shown (bottom-left).

Discovery, accelerated