ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPAF041

RESIDUAL GAS IONS CHARACTERIZATION FROM THE REXEBIS

N. Bidault*, M. Lozano, J. A. Rodriguez, CERN, CH-1211 Geneva, Switzerland

Abstract

The Isotope mass Separator On-Line DEvice (ISOLDE) is a user facility located at CERN where Radioactive Ion Beams (RIBs) are produced from proton collisions onto a target, mass separated and transported to user experimental stations either directly at low energy or after being post-accelerated, notably for nuclear physics studies. Prior to acceleration through the REX/HIE-ISOLDE linear accelerator, the ion beam is accumulated, bunched and cooled in a Penning trap (REXTRAP) and afterwards charge-bred in an Electron Beam Ion Source (REXEBIS). Multi-charged radioactive species of interest are then selected by a mass-to-charge (A/q) ratio separator dipole in the Low Energy Beam Transfer Line (LEBT). A method is presented to characterize the Residual Gas Ion (RGI) background contamination for different operational conditions of the REXEBIS. More particularly, a discussion is held about the influence of the confinement time inside the charge-breeder on the residual gas spectrum. Finally, a method to identify sub-pico-Ampere contaminants is demonstrated.

INTRODUCTION

The beam purity at a designated A/q is an essential figure of merit for a RIB facility and its users, it will define in particular the feasibility for the detection of specific nuclear physics events. The REXEBIS charge breeder allows the ion beam of interest to reach a mass-to-charge ratio within the acceptance of the REX/HIE-ISOLDE LINAC, which ranges from $A/q = 2.5$ to $A/q = 4.4$ [1]. The selection of the charge state of an isotope to study is a compromise between meeting the LINAC specifications, minimizing the trapping time while preserving a sufficient charge breeding efficiency and providing the purest beam after A/q separation through a bending magnet. Beam contamination comes from various origins (gas desorption, sputtering, discharges, etc.) and is, in a non-negligible range of A/q, barely detectable from a Faraday cup. Additionally, the REXTRAP is operated with neon as a buffer gas to thermalize the accumulating ions and its presence is inevitable before the A/q-separator. A first iteration presents the characterization of absolute quantities of abundant RGI species for different trapping times inside the REXEBIS. Furthermore, an experimental method for the identification of very low intensity contaminants is exhibited.

EXPERIMENTAL SETUP

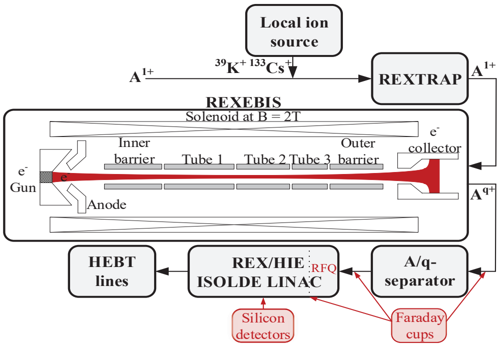

Figure 1: Schematic of the experimental setup.

The low energy part of REX/HIE-ISOLDE consists in the REXTRAP and the REXEBIS (both reside on high tension platforms) and the bending magnet A/q-separator, part of the LEBT lines. The linear accelerator is divided into two parts: a normal-conducting section and super-conducting section. Finally, the ions of interest are transported to an experimental station through one out of three High Energy Beam Transfer (HEBT) lines (Fig. 1).

The ionization processes inside the REXEBIS notably depend on the parameters of operation of the charge breeder, the residual gas partial pressures and the electron beam performance. A LaB_6 cathode (from which RGI traces are found) is operated in the emission limited regime. To extend the cathode lifetime, the electron beam produced does not exceed 250 mA during experimental runs. Auxiliary from ISOLDE ion beams, a local ion source can be used to externally produce and inject $^{39}K^{+}$ and $^{133}Cs^{+}$ beams into the REXTRAP. The Table 1 summarizes the main REXEBIS parameters used during all RGIs characterization measurements illustrated hereafter. With the experimental setup 1 (from Table 1), the high tension platform of the REXEBIS is at a fixed voltage and only the A/q-separator magnetic field is modulated to observe the contaminant spectrum on a Faraday cup prior to acceleration. The experimental setup 2 refers to mass scans measured at a beam energy of 0.3 MeV/u after the Radio-Frequency-Quadrupole (RFQ): the first accelerating structure. Consequently, the potential of the REXEBIS platform during extraction is scaled with respect to the A/q, for an injection into the RFQ at a constant energy of 5 keV/u. A scaling is simultaneously applied to the RFQ electric gradient and to all the beam optics elements.

Table 1: REXEBIS Specifications for the Two Types of A/q-Spectrum Measurements

REXEBIS	**Setup 1**	**Setup 2**
Magnetic field	2 T	2 T
Electron beam current	130 mA	130 mA
Electron cathode potential	–3.8 kV	–3.8 kV
Trapping region potential	0.7 kV	0.7 kV
Outer barrier potential	1.2 kV	1.2 kV
Inner barrier potential	1.3 kV	1.3 kV
High tension platform	19.8 kV	**9.9 –24.8 kV**
Breeding time	**5 –195 ms**	95 ms

---

* niels.killian.noal.bidault@cern.ch

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPAF041

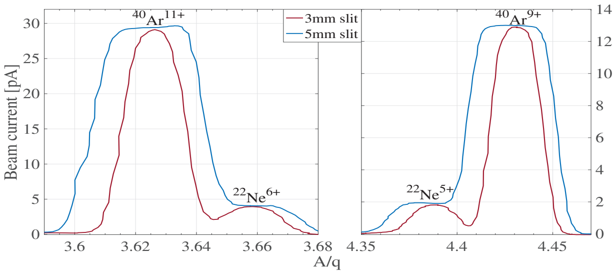

Figure 2: Measurements of four A/q peaks with a 3 mm slit or a 5 mm slit at the focal point of the A/q-separator.

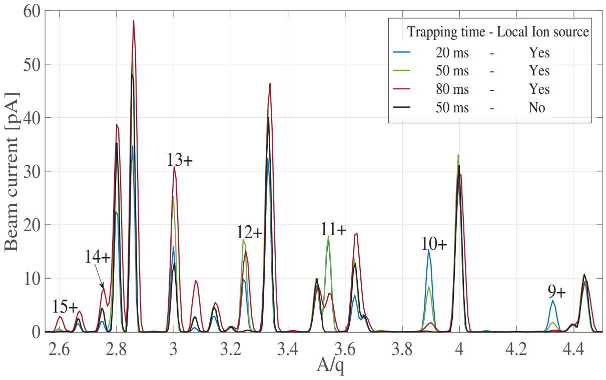

Figure 3: A/q-spectra with and without local ion source injection, ^{39}K charge states are displayed.

Downstream the REXEBIS, the A/q-separator is of a Nier-type spectrometer and describes a vertical "S"-shape beam line towards the RFQ. The main components are an electrostatic 90° cylinder deflector of 0.6-m radius and a 90° magnetic bender of 0.5-m radius. Beam optics simulations estimate the total (100 %) transverse emittance acceptance of the A/q-separator to be 200 mm-mrad and a factor ten lower in the dispersive plane when a 5-mm slit is introduced at the focal point [2]. Mass spectra around four different A/q-peaks were measured using a 3-mm slit or a 5-mm slit (Fig. 2). The beam optics and ion source emittance were not specifically optimized in the purpose of increasing the A/q-separation but were sufficient to reach $\Delta(A/q)/(A/q) = 1/300$, with the 3-mm slit typically preferred. Such a resolving power does not allow isobaric separation: an increase by two orders of magnitude would be necessary.

REXEBIS TRAPPING TIME INFLUENCE

The first presented mass-spectrum measurement technique makes use of the A/q-separator as a mass spectrometer, by sweeping the magnetic field intensity and measuring the out-going beam current in a Faraday cup. During this type of mass-scan performed with the experimental setup 1 (from Table 1), the REXEBIS platform and the separator beam optics are at a fixed reference potential.

The mass spectra measured during the re-commissioning of REX/HIE-ISOLDE in March 2018 (Fig. 3), with and without ^{39}K^{+} and ^{133}Cs^{+} beams produced from the local ion source, illustrate two points. First, it appears clearly that one would not encourage the study of ^{39}K at the charge state of 13+, as the A/q-peak cannot be separated from an intense RGI background. Secondly, the trapping time is a key operational parameter for efficient charge breeding to a given charge state. In order to fully characterize the RGI continuum from the low energy part of REX/HIE-ISOLDE, one needs to measure its variations in the range of trapping times that will be used during the experimental runs.

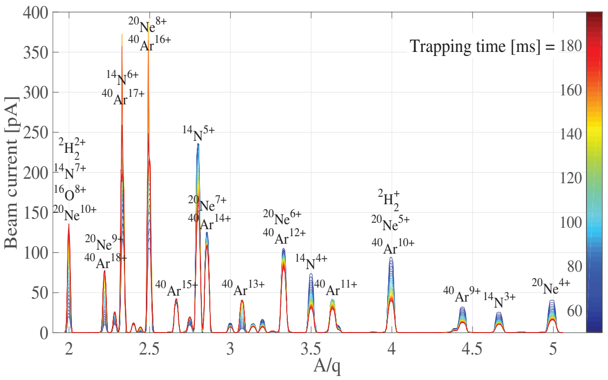

Figure 4: A/q-spectra for different trapping times.

The knowledge of RGI spectra on a wide range of trapping times allows to better anticipate on the attainable beam purity of a similarly wide variety of isotope masses of interest. In August 2017, several RGI spectra were measured for A/q-ratios in the range of 2 to 5 and trapping times between 45 ms and 195 ms (Fig. 4). For those measurements, the repetition period of REX/HIE-ISOLDE, defining the trapping and extraction cycles was fixed at 200 ms. For consistency with operational conditions, the beam intensity per spectrum was normalized by its respective trapping time.

Spectra at the same trapping times in Figs. 3 and 4 show differences that suggest the need to characterize the RGI background spectra periodically and especially after any venting of a sector. The partial pressures of contaminants may vary during long-term operation depending on progressive baking out effects. The trend of the total beam intensity extracted from the REXEBIS for long trapping time will also depend on the electron beam performance and its charge compensation factor. For this purpose and rather than proceeding to series of mass-scans, it is more evocative to measure the total current intensities extracted from the REXEBIS without injected beam, at different trapping times (Fig. 5). The total charge capacity of the REXEBIS electron beam is by two orders of magnitude greater than the total contaminant charge, according to the formula [3]: $C_{\text{ions}}[\text{C}] = 1.69 \cdot 10^{-6}\, I_e[\text{A}]\, L[\text{m}]\, E_e[\text{eV}]^{-1/2}$, which represents 7 nA for $I_e = 130$ mA, over 400 ms.

VERY LOW INTENSITY RGI SPECTRUM

The absence of visible RGI peaks measured with a Faraday cup, on several areas of A/q's, provides a first hint at a reasonable beam purity but does not necessarily guarantee a pure injected beam. An identification technique is

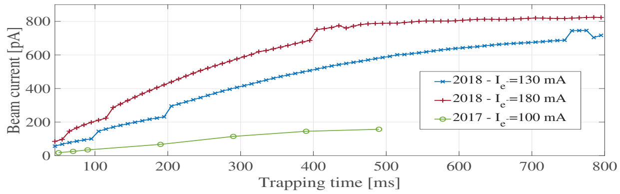

Figure 5: Total beam current measured before the A/q-separator, in August 2017 and March 2018.

detailed in this section which benefits from the particle detection efficiency of one of the silicon detectors located at the beginning of the superconducting LINAC [4]. In the perspective of measuring a RGI spectrum with a silicon detector, the beam of contaminants is accelerated at RFQ energy (0.3 MeV/u) and as previously mentioned in the experimental setup section, the setup 2 (from Table 1) was used. Moreover, one has to prove that in the whole range of A/q's there is a conservation of the transmission factor from the exit of the REXEBIS to the silicon detector. For the proof of concept of this technique, mass-scans were first measured with Faraday cups directly after the RFQ and at the position of the silicon detector.

The reference points for the scaling of the low energy part of REX/HIE-ISOLDE and the RFQ are at $A/q = 4$ and $A/q = 2$. This implies that the REXEBIS high tension, the RFQ electric gradient and optics were optimized at those two A/q's to maximize the transport efficiency from the exit of the A/q-separator to the silicon detector position. Then, all the necessary scaling factors are interpolated from those two reference points. In particular, the scaling of the REXEBIS platform potential had to be adjusted to include the drift zone potential minus the electron beam space charge (assumed constant in the wholeA/q range). The transmission efficiency at $A/q = 4$ and $A/q = 2$ from the A/q-separator to the exit of the RFQ is 96 % and from the A/q-separator to the silicon detector position is 80 %. Consequently, one would expect the A/q-peak intensities on the RGI spectra after the RFQ to approach 96 % or 80 % of the A/q-peak intensities measured before the RFQ. The averages of the relative differences from those reference transmission points for all the most abundant A/q-peaks above 5 pA are satisfactory: 4.1 % right after the RFQ and 5.2 % at the silicon-detector position.

Once the RGI spectrum collected after acceleration and transport were deemed to be enough in accordance with the spectra obtained before the RFQ, a mass-scan over a range of A/q from 4.05 to 4.36 - indistinctly resolved by a Faraday cup - was acquired using a silicon detector (Fig. 6). The detection capability of the silicon detector and its preamplifier is 500 MeV/pulse. Therefore, the transport of the ions was deliberately reduced by inserting a 1 mm collimator hole and by turning off one quadrupole triplet before the silicon detector. As the size of the silicon detector used for this measurement was already twice smaller than the total beam size, we chose to focus on the feasibility of such very low intensity RGI characterization, at the prejudice of a spectra with representative peak intensities. Another attractive aspect of using a silicon detector is to record in the meantime the total energy of the incoming ions. This information allows to identify the RGI species and one is for instance able to notice the presence of Kr isotopes, that a Faraday cup measurement would not have revealed. Ions are progressively extracted from the REXEBIS over a 1-ms-long pulse to decrease the instantaneous rate and to avoid pile-up effects on the detector.

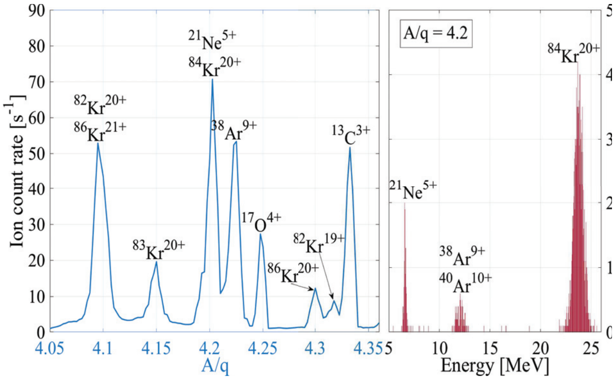

Figure 6: Mass-spectrum measurement with a silicon detector and total energy histogram specifically for $A/q = 4.2$.

CONCLUSION AND PERSPECTIVES

Two definite types of mass-scan measurements have been done. Spectra of abundant RGIs are presented and, as the REXEBIS trapping time is a major operational parameter, its effect on the total extracted background current is analyzed. Another intensity scale of the contamination background is then examined via mass-scans acquired with a silicon detector and demonstrates the identification of sub-femtoampere RGI species.

More detailed representations of the complete very low intensity RGIs mass-spectra distribution in the range $A/q = 2.5$ to 4.4 will be communicated soon. Future experimental prospects are to implement a large aperture silicon detector directly after the RFQ, with a preamplifier and digitizer resolution adapted to an energy of 0.3 MeV/u and eventually achieve an absolute representation of the very low intensity A/q-peaks.

REFERENCES

[1] Y. Kadi *et al.*, "Post-accelerated beams at ISOLDE", *J. Phys. G: Nucl. Part. Phys.*, Vol. 44, No. 4, 2017.

[2] M.A. Fraser *et al.*, "Beam dynamics simulations of the REX-ISOLDE A/q-separator", *CERN-ACC-NOTE-2017-0017*, HIE-ISOLDE-PROJECT-Note-0027, Oct. 2013.

[3] F. Wenander, "Charge breeding of radioactive ions with EBIS and EBIT", *J. Inst.*, Vol. 5, pp. 21-28, Oct. 2010.

[4] F. Zocca *et al.*, "Development of a silicon detector monitor for the HIE-ISOLDE superconducting upgrade of the REX-ISOLDE heavy-ion linac", *Nucl. Instr. Meth. Phys. Res. A*, Vol. 672, pp. 21-28, Apr. 2012.