SPIRAL1 CHARGE BREEDER: PERFORMANCES AND STATUS

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Abstract

In the framework of the SPIRAL1 upgrade under progress at the GANIL lab, the charge breeder based on a LPSC Phoenix ECRIS, first tested at ISOLDE [1] has been modified as to benefit of the last enhancements of this device from the 1+ / n+ community [2].

Prior to its installation in the middle of the low energy beam line of the SPIRAL1 facility, it has been tested at the 1+/n+ LPSC test bench to validate its operation performances. Charge breeding efficiencies as well as charge breeding times have been measured for noble gases and alkali elements. The experimental results demonstrated that the modifications done were on the right track leading the SPIRAL1 charge breeder to the top worldwide in terms of performances. The experimental outcomes have shown a strong interrelationship between the charge breeding efficiency and the charge breeding times which is still under active discussion.

This paper will summarize the experimental results obtained and will discuss the specific phenomenons observed but still not fully explained as the charge breeding time evolution, the depletion of highly charged ions in the buffer gas etc.

INTRODUCTION

The SPIRAL 1 facility is under operation since 2001 and almost 35 Radioactive Ion Beams (RIBs) have been delivered to the Physicist. The first Target Ion Source System (TISS) developed at GANIL [3] was very chemically selective: only gaseous elements as noble gases, N, O and F could be ionized. These RIBs allowed numerous results in Nuclear Physics [4] but physicists need an enlarged palette to study the nuclear properties and to test the nuclear models including isotopes of condensable elements. The 1+/n+ [5] technique has been chosen as many different TISS providing 1+ beams can be developed for specific chemical family elements with high efficiency. The charge breeder is requested to boost the charge state from 1+ to n+ prior to the post-accelerator: the cyclotron CIME [6] is delivering a RIB with energy in the range 2 – 20 MeV/u suitable for the nuclear physicists. The charge breeder is based on one developed at LPSC and modifications have been already described in other papers [7, 8]. In the following, the experimental results of the charge breeder operation on the LPSC test bench will be presented as well as its status at the SPIRAL1 facility.

EXPERIMENTAL RESULTS

The installation of the SPIRAL1 charge breeder in the middle of the 1+/n+ test bench at LPSC needed a modification thereof. The Figure 1 is the layout of the experiment at LPSC. The Reference 8 describes the experimental conditions.

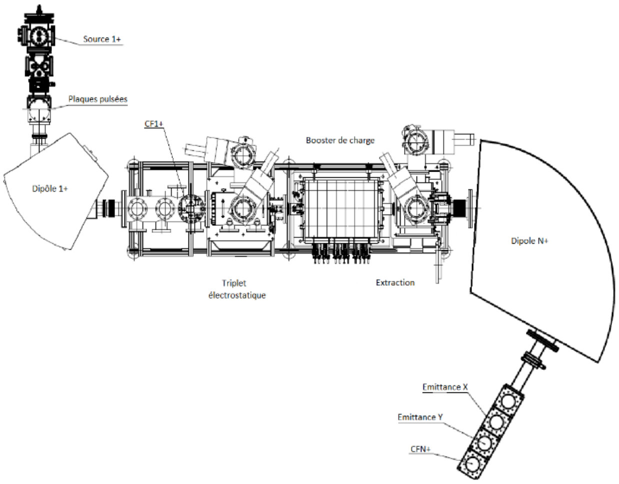

Figure 1: Layout of the Spiral1 charge breeder at LPSC laboratory.

Effect of the Residual Gas Pressure

The residual gas pressure value plays a major role on the charge breeding efficiencies as demonstrated at the CARIBU facility: charge breeding efficiencies get their higher values as soon as the pressure drops down to the level of few 10^{-8} mbar. The Figure 2 reports the evolution of the charge breeding efficiency of the Rb^{19+} versus the product of the pressure at injection times the pressure at extraction. The charge breeding efficiency drops continuously with the increase of the residual gas pressure. The CB has been modified such the conductances to the plasma chamber are optimized.

Effect of the 1+ Injected Current

The question is the following: is the charge breeding efficiency measured with a stable beam in the nA range still valid with RIBs in the pA even less range?

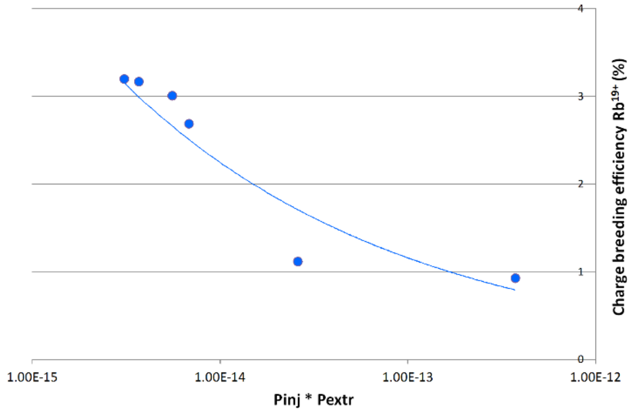

Figure 2: Influence of the residual gas pressure onto the charge breeding efficiency for the case Rb^{19+}.

Figure 3 shows the evolution of the Rb^{17+} current versus the Rb^{1+} injected. There is a plateau followed by a fall-off around 1500 nA. It means that as long as the RIB 1^+ intensity is small enough compared to 1 μA, the charge breeding efficiency is constant and can be used to determine the yields of RIBs. That conclusion is corroborated by a 1+/n+ carbon measurement [9] done with the CB of the LPSC lab.

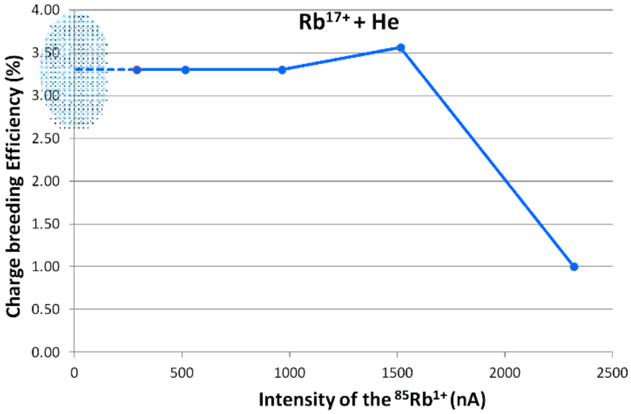

Figure 3: Evolution of the RB17+ charge breeding efficiency with the injected 1+ current (the light blue zone corresponds to the RIB work area).

Effect of the Deceleration Tube Position

The deceleration tube at the injection side is mobile. In the case of $^{39}K^{9+}$, it has been moved over a 50 mm range. For a wide domain of 30 mm, the charge breeding variation is tiny and a regular decline occurs afterwards. The best position of the exit of the deceleration tube is a little ahead from the entrance of the CB iron plug as it is displayed on the Figure 4. This parameter has not a dramatic effect on the charge breeding efficiency.

Effect of the Buffer Gas

The Figure 5 exhibits the charge state distributions of the ^{39}K with three different buffer gases O_2, He and H_2. Lighter is the buffer gas used narrower is the charge state distribution and higher is the charge breeding efficiency for the potassium case. That result opens up a new way to tune the booster depending on the final energy of the requested post-accelerated RIB. As the final energy is function of the Q/M ratio, higher is the charge state higher will also be the final energy. Thus, for a low energy RIB using the 8+ charge state, He should be chosen. In contrast for a higher energy RIB requiring the 9+ charge state H_2 is more suitable. Consequently, the buffer gas type is a new parameter to tune in order to deliver the RIB with the highest yields at the right energy.

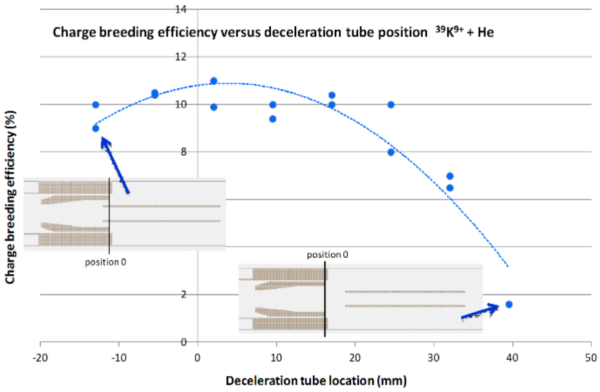

Figure 4: Evolution of the $^{39}K^{9+}$ charge breeding efficiency with the position of the deceleration tube.

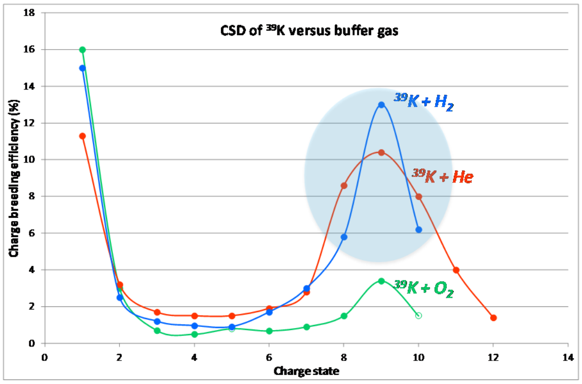

Figure 5: Charge state distributions of the 39K versus the buffer gas.

Charge Breeding Efficiencies

The Figure 6 is a summary of the charge breeding efficiencies measured depending on the ratio of A/Q. The yellow points, corresponding to the measurements of the CARIBU facility, are almost always on the top but mostly the SPIRAL1 CB results are on second position (red points) excepted for the case of $^{40}Ar^{8+}$ with 18.9% of charge breeding efficiency. Within the domain of the light element (Na, K zone), there is still a margin of a factor 2 to gain if one compares to the CARIBU facility. As SPIRAL1 targets this area, a deeper comparison of both machine conditions should be undertaken as to find out the relevant parameters which limit the charge breeding efficiency in our case. Among the possible parameters, the double frequency heating, which has not yet been tested with the SPIRAL 1 charge breeder, could possibly help in increasing the capture efficiency.

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CHARGE BREEDING TIME

The physicists are interested by exotic nuclei far away from the stability valley, with ratios of protons over neutrons depending on the case as large or as small as possible, meaning often isotopes with short half life (<100ms). The production of an accelerated RIB using such isotopes requiring a charge breeder implies a real care on the charge breeding time. We are taking the following examples: for the first experiments, the ^{30}Na ($T_{1/2}$=48 ms) and ^{35}K ($T_{1/2}$=190 ms) are expected to be requested. Using the charge states 7+ and 9+, their charge breeding times are expected to be 52 ms and 117 ms respectively, as observed with the corresponding stable isotopes and H_2 as support gas, inducing yield losses by radioactive decay.

But depending on the tuning of the charge breeder, the charge breeding time can vary over a wide range. For the $^{39}K^{9+}$, two charge breeding times have been measured: 35 ms and 117 ms, the major difference between both measurements being the use of two types of buffer gas: He and H_2 respectively while the other parameters (coil current, drain current, injected current etc.) were quite similar with a global charge breeding efficiency of ~50%. At the same time the charge breeding efficiency decreases from 13% down to 11.7% with a smaller ratio: 0.9 (charge breeding efficiency) compared with 3.3 (charge breeding times). Similar dramatic changes in the charge breeding time were also observed at at the CARIBU facility for the Xe-132 case [10], originating this time from a small change of the RF frequency.

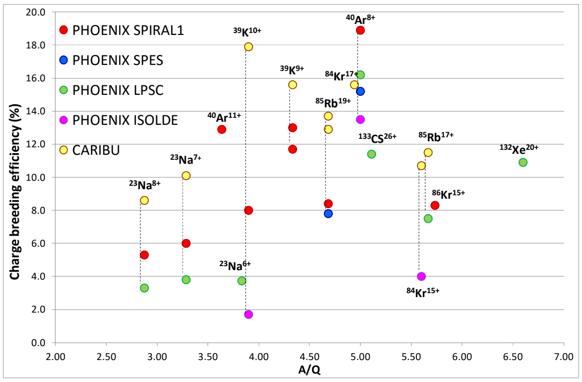

Figure 6: Recapitulation of the charge breeding efficiencies obtained with the SPIRAL1 charge breeder and compared with the results obtained with similar Charge breeders.

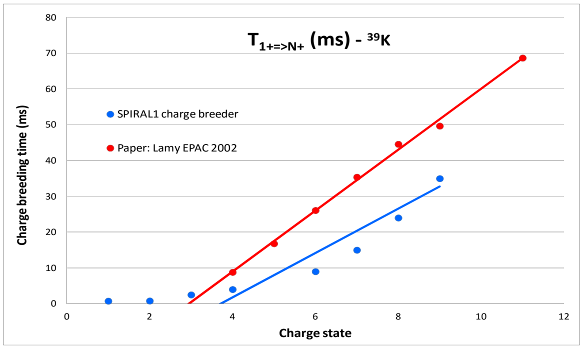

Figure 7: Charge breeding time (ms) of the $39K^{n+}$ charge states.

Figure 7 is another demonstration of the large variation of this parameter according to the experimental conditions. Figure 7 displays the evolution of the charge breeding time with the charge state in the case of the ^{39}K + He and for two Phoenix charge breeder types. As it is shown; the values vary up to a factor 2.

Figure 8: Top: low energy beam line before modifications Bottom: low energy beam line after inclusion of the Spiral1 charge breeder.

At GANIL, within the framework of a PhD work program, studies will be focusing on this specific, topic to gain control over the charge breeding time. A new simulation will be started involving recent results [11, 12] and based on realistic coulomb collisions modellisation. In parallel, an experimental work will be started either with stable or radioactive charge bred ions for collecting data on the dependence of the charge breeding time versus the various CB relevant parameters.

STATUS AND COMMISSIONNING

Currently, the Spiral1 CB came back to Caen to be assembled inside the Spiral1 facility. As it can been seen on the Figure 8 (bottom), the charge breeder as well as its injection and extraction boxes are in the middle of the low energy beam line. The comparison with the low energy beam line before the modification (Figure 8 top) shows clearly how the magnetic quadrupoles have been moved to insert the charge breeder leading to a new beam optic which must be tested during the commissioning.

The last optimizations done on the Spiral1 CB are

- ✓ firstly a fine pure Al (99.999%) layer (few µm) which was deposited on the plasma wall chamber,
- ✓ secondly a new plasma electrode using a grid to enhance the global conductance to the plasma chamber.

Those last adjustments have been done, on the one hand, as to go on decreasing as much as possible the residual gas pressure and, on the other hand, to improve the charge bred beam purity.

The commissioning program is defined and will last around four months. The final goal is to deliver a low energy RIB to the LIRAT facility [13] as well as a post-accelerated RIB to physicists at the end of the first semester of 2017. Several challenges should be overcome to reach the final goal:

- ✓ getting a residual gas pressure close to 1.10^{-8} mbar within the Spiral1 CB,
- ✓ validating all the beam optics downstream the Spiral1 CB: as a large modification has been done with insertion of new diagnostics, the tuning will be tricky to match the beam requirements before the injection into CIME, especially for keeping a high resolving power,
- ✓ validating the measurements done at the 1+/n+ LPSC test bench; an alkali ion source is under development for the 1+ injection into the Spiral1 CB,
- ✓ validating the operation of the previous TISS Nanogan by reaching a high transmission efficiency (>80%) through the Spiral1 CB.

CONCLUSION

Based on the results obtained, the SPIRAL1 CB matches the characteristic requested for the post-acceleration of the RIBs by the CIME cyclotron.

However, best efforts are to be made for increasing the charge breeding efficiency especially for the light elements as Na and even lighter as Li. To deliver RIB of very short half-life (< 100ms), charge breeding time must be fully controlled to minimize as much as possible losses by radioactive decay through the Spiral1 CB.

In order to keep on enlarging the RIB palette at GANIL as well as the RIB yields, two objectives shall be pursued: development of specific TISS [14] and development of new production targets using material other than carbon.

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