

ADIGE: THE RADIOACTIVE ION BEAM INJECTOR OF THE SPES PROJECT

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Abstract

The Selective Production of Exotic Species (SPES) project is presently under development at INFN-LNL: aim of this project is the production, ionization and post-acceleration of radioactive ions to perform forefront research in nuclear physics. An ECR-based charge breeder (SPES-CB) will allow post-acceleration of radioactive ions: in particular, the SPES-CB has been designed and developed by LPSC of Grenoble, based on the Phoenix booster. It will be equipped with a complete test bench totally integrated with the SPES beam line: this part of the post-accelerator, together with the newly designed RFQ, composes the so-called ADIGE injector (Acceleratore Di Ioni a Grande carica Esotici) for the superconducting linac ALPI. The injector will employ a unique Medium Resolution Mass Spectrometer (MRMS, resolving power 1/1000), mounted downstream the SPES-CB, in order to avoid the typical drawback of the ECR-based charge breeding technique, that is the beam contamination. This contribution describes the ADIGE injector, with particular attention to the analysis of possible contaminations and the performances expected for the MRMS, showing the beam dynamics calculations for a reference radioactive beam.

THE ADIGE INJECTOR

SPES [1] is an INFN project with the aim at developing an ISOL Radioactive Ion Beam (RIB) facility as an intermediate step toward EURISOL. SPES is under realization at INFN-LNL: its main goal is the production and post-acceleration of exotic beams to perform forefront research in nuclear physics, by studying nuclei far from stability. To boost the charge state of the radioactive beam produced, and allow post-acceleration by a newly designed RFQ [2] coupled to the ALPI [3] superconducting linac (up to 10 MeV/amu for $A=130$), an ECR-based charge breeding technique (ECR-CB) will be employed: in particular, it will be an updated version of the Phoenix booster developed by Laboratoire de Physique Subatomique & Cosmologie (LPSC) [4]; the SPES-CB was successfully tested at LPSC in April 2015 and then delivered to LNL [5]. Its beam line was designed not only as a part of the final layout of the SPES project, but also as a test bench to characterize accurately this new device before operating it with radioactive ions: this part of the post-accelerator, together with the new RFQ, composes the so-called ADIGE injector, whose layout is shown in Fig. 1. The injector will include all the necessary elements to characterize properly the SPES-CB and allow an optimum transport of the RIB towards the RFQ. To verify

and optimize the breeding efficiency, singly charged stable beams will be produced by copies of the sources coupled to the UC_x target of SPES ($S1+$ in Fig. 1; in particular, surface ionization sources for the elements of I and II group, plasma ion sources for the others), and injected into the SPES-CB for its characterization. The $1+$ beams will be magnetically selected by a 90° bending dipole (BD in Fig. 1; $r=750$ mm, $\Delta M/M \sim 1/150$), analyzed in terms of intensity and emittance through beam instrumentation boxes (BI in Fig. 1), and transported through an electrostatic beam line towards the SPES-CB (ET in Fig. 1), where they will be focused and injected by means of an especially designed double Einzel lens incorporating electrostatic steeres (2EL in Fig. 1). The charge bred multiply charged RIB will be then extracted and transported in a fully magnetic beam line (SO and MT in Fig. 1): the desired charge state will be selected by the MRMS and finally delivered to the RFQ for post-acceleration.

One of the main concerns of an ISOL facility is the beam purity: the following sections will show an analysis of the possible contaminants induced by the breeding stage, and describe the strategies adopted to ensure pure post-accelerated radioactive beams for the future users of the facility.

THE BEAM PURITY ISSUE

A well known drawback of an ECR-CB is the contamination induced by the breeding stage. Impurities are usually present in the gas fed into the plasma chamber (normally oxygen), or derive from the outgassing of the surfaces exposed to vacuum: we call this source gaseous contaminants. Another source consists in the materials of the surfaces exposed to vacuum, released due to their interaction with the plasma: we call them solid contaminants. To limit the first contribution, the SPES-CB will have almost all metal sealings, except for the vacuum window (O-ring on the wave guide) and the interface between the extraction iron plug and the plasma electrode. Additionally, special attention was paid to the surface treatments, in particular of the stainless steel plasma chamber and the iron plug at extraction (ARMCO) [5]. For the former, a sequence of two thermal treatments was applied: the first are performed on each part comprising the plasma chamber, machined with some mm of stock material so as to correct possible deformations; the second one after welding the parts together but before final machining, that was executed with isopropyl alcohol only. For what concerns the extraction plug made of ARMCO, "Normalising" and "Final Annealing" cycles were adopted, both in a vacuum atmosphere with a pressure below 10^{-5} mbar.

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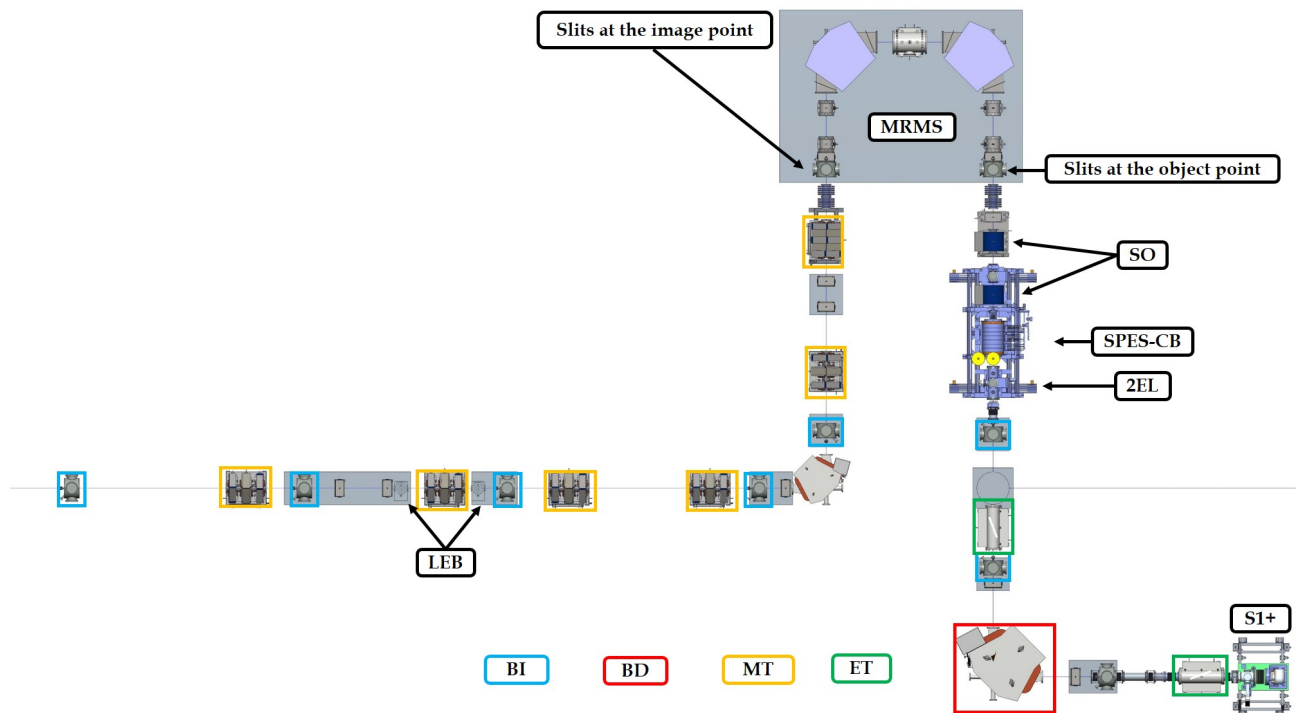


Figure 1: Layout of the ADIGE injector. S1+=1+ ion source; 2EL=double Einzel lens; SO=solenoids; LEB=low energy buncher; BD=bending dipole; BI=beam instrumentation boxes; MT=magnetic triplets; ET=electrostatic triplets.

Table 1: Main Radioactive Species Produced at SPES

Species	Mass [amu]	Species	Mass [amu]
Al	24-26	Cu	69-74
Ni	78	Kr	88-90
Rb	86-94	Sr	94-100
Sn	123,125-132	Xe	135,137,138
Cs	131,132,134-141	Ba	141-143

Table 2: Possible Contaminants Induced by the SPES-CB

Species	Mass [amu]	Species	Mass [amu]	Species	Mass [amu]
C	12-13	N	14-15	O	16-18
Mg	24-26	Al	27	Si	28-30
P	31	S	32-34,36	Ar	36,40
Cr	50,52-54	Fe	54,56-58	Mn	55
Ni	58,60-62,64	Co	59	Cu	63,65
Zn	64,66-68,70	Mo	92,94-98,100		

The contribution from solid contaminants is more problematic, mostly because consisting in heavy elements ($A > 40$) that once ionized produce a dense spectrum of several peaks: the materials to be considered are stainless steel (AISI 316 L) for the plasma chamber and aluminum (AU4G) for the extraction electrode. As a first step, we analysed the possible superpositions between the expected peaks of the radioactive ions produced at SPES and the contaminants (see Tables 1 and 2), including the gaseous ones for the sake of completeness, and considering a charge-to-mass ratio (M/q) between 4 and 7. The analysis revealed that a resolving power $R = \Delta(M/q)/(M/q) = 1/1000$ for the MRMS is a good compromise between complexity of the design on one hand, and the possibility to find a clean radioactive peak in the range of M/q of interest for most of the elements shown in Table 1 on the other hand. At the same time, the analysis produced the following information:

- To have clean $^{24-26}\text{Al}$ peaks, stainless steel and aluminum should be avoided, and the use of other materials must be explored.
- The isotope ^{70}Cu would show clean peaks if aluminum were not used.
- The isotope ^{78}Ni would show clean peaks if Kr were absent.
- The isotopes $^{86,93}\text{Rb}$ would show clean peaks if, respectively, Kr were absent and stainless steel (Mo presence) were not used.
- The isotopes $^{94-98,100}\text{Sr}$ would show clean peaks if stainless steel (Mo presence) were not used.

From the results shown above it comes out that, besides the well known positive effect on the performances of an ECR source in general, presently the "cleanest" material among the ones commonly used for the plasma chamber is aluminum (except for radioactive Al and ^{70}Cu), and this will

be in fact one of the first upgrades which will be carried out in the next future on the SPES-CB.

CLEANING EFFECT OF THE MRMS

A description of the MRMS is reported in [4]. An analysis of the possible superpositions has been done considering the fact that contaminants have usually a much higher intensity, up μA in some cases, than the radioactive ones, that barely reach the nA level and only in few cases. The initial hypothesis considers two beams separated of 1/1000 in mass, with one of the two (the stable one) two orders of magnitude larger compared to the second (the radioactive or nominal one, in the present case $^{132}\text{Sn}^{19+}$), both with $M/q \sim 7$. For both beams it has been assumed a rms normalized emittance of $0.1 \pi \cdot \text{mm} \cdot \text{mrad}$ (much higher compared to what has been measured during the SPES-CB acceptance tests, see [5]), and a Gaussian spatial profile up to 6σ . In the analysis, the beam is transported from the slit at the object point to the slit at the image point, both mounted on the HV platform housing the MRMS (see [4]), and the separation is carried out for a total beam energy 3.04 MeV ($40 \text{ kV} \cdot q$ due to the charge breeder extraction plus $120 \text{ kV} \cdot q$ due to the HV platform; $q=19+$), thus limiting the effect of the energy spread induced by the SPES-CB ($\sim 10\text{-}15 \text{ eV}$) by reducing the value of $\Delta E/E = 2\Delta p/p$. We proceed in two ways: on one hand, by doing multiparticles simulations of beam transport through the MRMS with the TraceWin code; on the other hand, by using an analytic calculation: this was done assuming two Gaussian beams with relative areas proportional to the beam intensity, and then calculating the overlap between the two. Both results showed a good agreement. Figure 2 reports the simulation results after the image slits with an aperture of $\pm 6 \text{ mm}$: the nominal beam is preserved at the 98%, while the contaminant is reduced at 0.08% the intensity of the former. This result confirm that, with this slits aperture, it is possible to separate the nominal beam from a contaminant two order of magnitude higher in intensity than the radioactive beam. To check the effects of a reduction of the split aperture, we

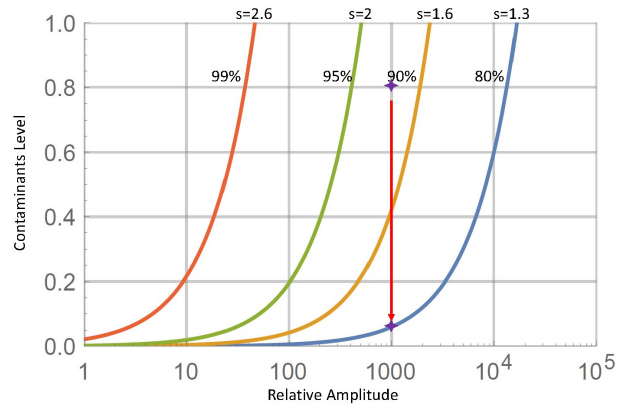


Figure 3: Level of contaminants: 1 means 100% fully contaminated beam, versus the contaminants relative amplitude, 10 means the contaminants have 10 times larger current with respect to the nominal beam. The percent figure is how much of the nominal beam survives after the slits. The "s" values indicated for each curve is the semiaperture of the slits.

considered two gaussian functions separated by the nominal dispersion of the line $D=8000$ that, considering a value of $\Delta p/p=1/2000$, gives a nominal separation $d=4$. Then, we calculated the superposition area at various contaminants amplitude assuming the effects of the separation due to the MRMS (the aforementioned d): results are shown in Fig.3 The graph shows the contamination for different slit aperture: the amount indicated on the top of the graph is the nominal beam quantity not cut by the slit. It can be seen that, by reducing the slit aperture at $\pm 1.3 \text{ mm}$, even contaminants with a relative intensity 10^3 times the nominal one can be reduced below 10%, preserving the 80% of the nominal beam. In conclusion, the results showed that it is possible to significantly limit beam contamination by reducing the slits aperture, even if the contaminants are orders of magnitude higher in intensity.

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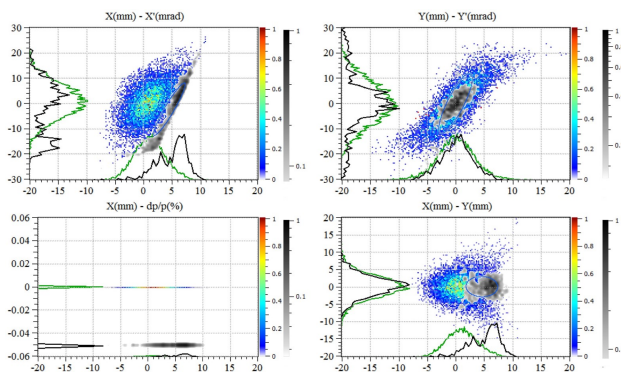


Figure 2: Output beams conditions at image slit: nominal beam colored, contaminant black; both separated of 1/1000 in mass: 98% of the peak consists in the nominal beam, 0.08% the contaminant.