

Progress on the light ion guide

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The Light Ion Guide project [1,2] continued to advance, one of the main priorities being the increase of the efficiency of the entire system and installing new detection systems for radioactive ion-beam tuning.

Four new detection systems are installed (Fig. 1), all four similar in the design: a thin aluminum foil placed in front of a 300 μm thick silicon detector, coupled to a simple counting and acquisition system – HV detector power supply, preamplifier, amplifier and a multichannel analyzer. The first collection/detection system is mounted on a pneumatic linear actuator, after the extraction tube of the Light Ion Guide. The second collection/detection system consists of a fixed position detector, placed off beam axis, after the Charge Breeding – ECR (CB-ECR) and a collection plate mounted on a pneumatic linear actuator. This system operated as follows: the collection plate is placed in beam for approximately 2 half-lives of the radioactive ion produced, then retracted in front of the detector to measure the decay (positron, beta or alpha particles) of the radioactive product. The third and fourth detection systems are similar, with both the collection thin aluminum foil and the detector in a fixed position on the beam axis: one system is positioned at the first analyzing magnet and the other at the second analyzing magnet.

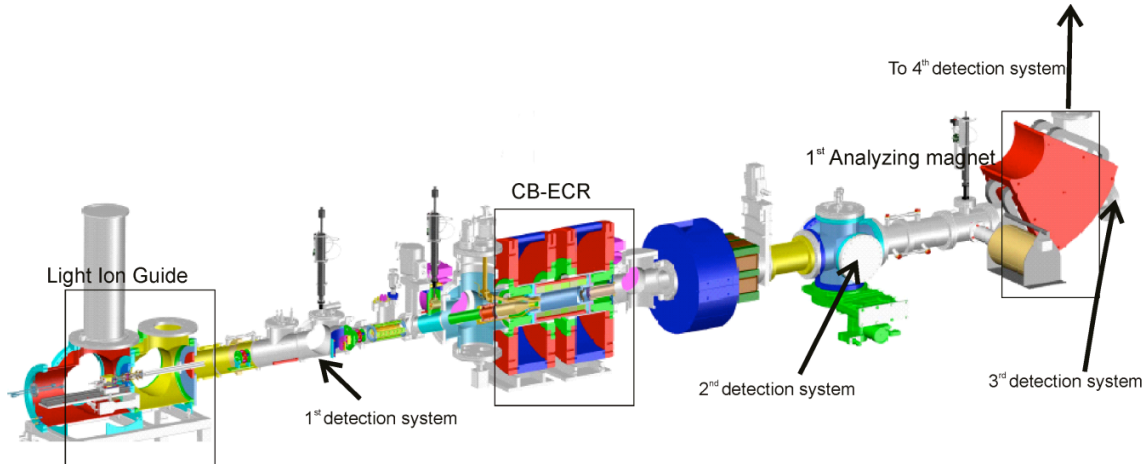


FIG. 1. Schematic of the Light Ion Guide coupled with the CB-ECR. The positions of the detection systems are shown.

Improvements in the pumping speed were made by replacing one 1000 l/s turbo molecular pump with a 2000 l/s water cooled turbo molecular pump at the second chamber of the Light Ion Guide. The replacement helped the extraction and transport of the radioactive ions produced, as well as a more consistent functioning of the entire system. Another improvement made was the purification of the helium gas buffer: a purifier from SAES Pure Gas, model MicroTorr was placed in-line, close to the entrance in the gas cell. The purifier, theoretically, provides impurity removal at part-per-billion levels, the targeted impurities being mainly water, oxygen, hydrocarbons and organic compounds. The tests done with and without the purifier showed a slightly better output of the gas cell in the radioactive products, when the purifier line was not by-passed.

With the new detection systems in place, our ^{228}Th open source has been used in order to check the Light Ion Guide setup, coupled together with the CB-ECR. First the Light Ion Guide was tuned to get maximum output of ^{220}Rn ($T_{1/2} = 55.6$ s) and ^{216}Po ($T_{1/2} = 0.15$ s) products, the daughters from ^{228}Th decay chain. The CB-ECR was also retuned for charge breeding, based on previous experimental data and tests. For the first time, the charge breeding of ^{220}Rn and ^{216}Po was observed on the detection system situated after the CB-ECR. The charge state distribution of the ^{220}Rn and ^{216}Po was determined using the last detection system placed at the second analyzing magnet. The maximum of the charge state distribution was found at 21+ (Fig.2). Different charge states of ^{220}Rn and ^{216}Po are mixed and superimposed due to the limited resolution of the analysis system (Fig.3). The extra voltage applied to the Light Ion Guide system in order to overcome the plasma potential and achieve the charge breeding, was in a wide range, varying between 30 V to 80 V.

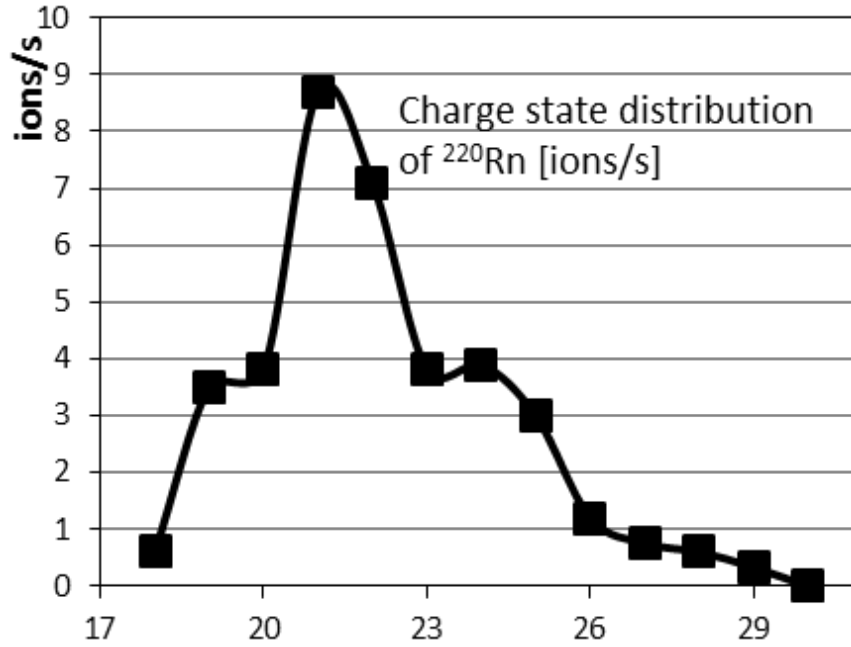


FIG. 2. Charge state distribution for the ^{220}Rn . The distribution is peaked at the charge state 21+.

We continued to use the $^{64}\text{Zn}(p,n)^{64}\text{Ga}$ ($T_{1/2} = 2.6$ min) reaction as a test and tuning reaction for the Light Ion Guide. The energy of the proton beam from the cyclotron was 15.7 MeV (15.0 MeV on target). The pressure of the helium in the gas cell, for maximum ^{64}Ga output was 180 mbar. The exit aperture diameter used for the gas cell was 1.5 mm. Other exit apertures were used: 1.2 mm, as well as 2.0 mm, but the 1.5 mm exit aperture proved to be the most efficient. Using the new installed detection systems, the device was carefully tuned: first, find the maximum outputs of ^{64}Ga from the gas cell and the Light Ion Guide extraction system; second, optimize the transport of $^{64}\text{Ga}^{1+}$ radioactive ions through the CB-ECR with the microwave transmitter turned off. Following $^{64}\text{Ga}^{1+}$ transport optimization, the CB-ECR microwave transmitter was turned on, and charge breeding of ^{64}Ga was detected on the second and

third detection system. The analyzing magnet was changed for O^{3+} transport, which corresponds to $^{64}\text{Ga}^{12+}$ transport and the b^+ decay of ^{64}Ga was detected on the fourth detection system.

The charge breeding efficiency was extremely low, under 0.1%, and our efforts were focused to improve this efficiency. A series of factors have been determined to be crucial in the increasing of the

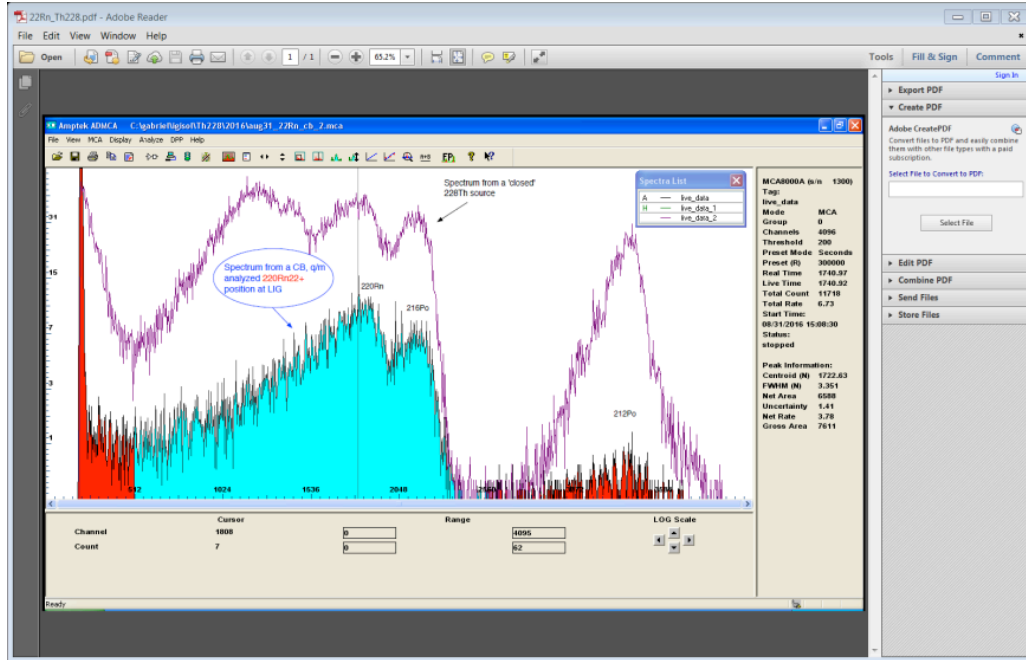


FIG. 3. Screenshot of the acquisition system of the 4th detection system, showing in blue the alpha particle peaks of $^{220}\text{Rn}^{22+}$ and ^{216}Po (daughter of ^{220}Rn and $^{216}\text{Po}^{21+}$). The purple line/empty area is the detector response from a regular ^{228}Th source in secular equilibrium.

efficiency of the charge breeding: injection of the $1+$ ions into the plasma chamber, backward extracted beam from CB-ECR hitting elements in the beam line, creating more electrons that disturb plasma and creating vacuum issues or discharge problems. Solving a few of these complications proved to be problematic and, in spite of our efforts, no major improvement in the charge breeding efficiency has been achieved. However we were able to improve the stability and reproducibility of the entire system, the Light Ion Guide coupled with the CB-ECR, reducing the time for tuning and optimization.

The conclusions after almost a year of working to achieve charge breeding of radioactive ions, are the following: reliable detection systems are needed and their importance for tuning, diagnostic and characterization of the device is being essential; the charge breeding efficiency is critical in obtaining good, reliable re-accelerated radioactive ion beams; any advances in the vacuum systems and helium gas-transfer will improve the stability, reproducibility and overall radioactive ion beam output of the Light Ion Guide and CB-ECR couple. In the near future, our efforts will be intensified towards increasing the charge breeding efficiency, considering major changes in the injection scheme of the $1+$ ions.

[1] H.L. Clark *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2014-2015), p. IV-15.

- [2] G. Tabacaru *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2013-2014), p. IV-9. http://cyclotron.tamu.edu/2014%20Progress%20Report/cyclotron_progress_2014.pdf