Report on FY2004 RIA R&D Gas Catcher Development Activities

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The gas catcher system [1,2] is a key component of the RIA facility, providing access to low-energy beams of short-lived isotopes not amenable to the standard ISOL technique. We have developed a prototype RIA gas catcher system which has been characterized online at the ATLAS accelerator at Argonne. The device has been successfully operated in both on-line and off-line tests at low energy and was moved to the FRS facility at GSI at the end of FY2003 for operation at the full RIA energy.

The results obtained in low energy tests of the first gas catcher prototype at Argonne in FY2003 were reported last year and some aspects have been published [3,4]. These tests proved that the large gas catcher prototype can extract efficiently, as ions of the right mass, ions injected at any position within the full volume of the gas catcher. In these tests, ions were injected at a rate of up to 5 X 10^5 per second into a gas catcher with a stopping volume suitable for operation at the GSI FRS fragment separator. Two main topics of investigation remain on the gas catcher; 1) the demonstration of gas catcher operation on-line at RIA-like energies at GSI and 2) the demonstration and investigation of operation at high ionization densities (ultimately the effect that sets the limits of the gas catcher approach).

A total of $680k was requested for these efforts in FY2004. They were funded at a reduced level of $540k with these funds becoming available only half way through the fiscal year. Significant progress was achieved on both topics independently of these limitations but the funding amount and profile, together with the difficult financial situation of the physics division at Argonne, meant that essentially no M&S funds were available to this project for the first half of FY2004. Under these conditions emphasis was put on development of the space-charge dominated gas catcher simulations and design modifications required to improve properties of the gas catcher critical to high intensity operation and to install the high intensity test system.

High-energy gas catcher test

The first prototype gas catcher system was shipped to GSI at the end of FY2003 and in the beginning of FY2004 the device was unpacked, inspected and installed in its test stand location at GSI. A new large area all-metal 20 cm wide entrance window, large enough to accept the momentum compressed beams from the FRS, was installed. The gas catcher was then connected to the pumping system that was developed for it by our GSI collaborators and the gas delivery and purification system put together by our collaborators from Leuven (members of the S258 collaboration led by Argonne). The purification system is similar to that used at Argonne while the pumping system has 3-4 times the pumping speed of the one used at Argonne. It is a roots pump based system with a cold trap above the pumps to minimize contamination when no gas is flowing. The gas catcher and pumping system are on two independent platforms connected by a 25 cm diameter pumping line and both platforms will be moved from the test stand to the FRS focal plane for on-line runs. The whole assembly just fits around the gamma-ray detector array RISING in the open configuration at the FRS. A thorough leak testing of the closed gas catcher vaccum system revealed leaks along two of the large insulator rings that probably developed during the shipping. These sections are initially assembled in a heated environment at Argonne and after some effort these conditions could be reproduced at GSI and the joints were remade and the leaks fixed. The gas catcher was heated under vacuum to outgas contamination that could have accumulated in the shipping until a residual gas analyzer found the remaining outgassing to be acceptable. The circuits providing the DC gradient and RF fields on the gas catcher were rewired (some of them had to be removed to fix the leaks), tested, and the electronics providing power to these circuits was converted to 220 volts and installed. Power-to-field curves that matched those measured at Argonne were obtained. Diagnostics for radioactive ions were installed behind the extraction RFQ and tested with GSI electronics. The detection system proved very sensitive to the RF noise generated by the gas catcher extraction cone and the detector support was modified to better isolate it from the system. A ~5 μCi ^{252}Cf fission source was installed in the gas catcher and used to test the whole system. Yield measurements were performed under various RF, DC and pressure conditions that agreed with the results obtained with a fission source in more detailed tests at Argonne before shipping.

The gas catcher system has survived the move to GSI and now operates off-line with performances similar to those obtained at Argonne. The device has undergone some minor improvements related to automation of the vacuum system and improvements in the detection system since this initial flurry of activity but has essentially been waiting for scheduling of beamtime at the FRS. The backlog at the SIS accelerator at GSI is about 2 years so this can be a long process and we were not able to get on the schedule in 2004 but we have finally a scheduled run of 10 days starting February 9 2005. Final preparation for the test will require an increased presence at GSI this fall.

High-intensity gas catcher test

With the gas catcher test at RIA energy now well on its way, the main remaining uncertainty attached to the gas catcher system is the maximum radioactive ion intensity that the device can tolerate. We have been actively setting up for a realistic high intensity test of the gas catcher. The preparation has involved three main tasks: development of realistic simulations of space-charge build up in the gas catcher, completion of the second gas catcher prototype that will be used for these tests, and development of a suitable source of ionization and diagnostics.

Task 1: Over the years we have developed simulations of the gas catcher incorporating gas flow, static and RF fields and a realistic modeling of the ion/gas atom collisions. These state-of-the-art calculations reproduce the main features observed so far in the low-energy tests of the gas catcher at low intensity. They however do not take into account the interaction between ions in the gas. This task is actually enormously complicated since each ion stopping in the gas creates 10^5 to 10^6 helium ion-electron pairs which also interact with the stopped incoming ions and with each other and must all be transported by the program in a fashion similar to the initial ions. Treating this problem exactly is actually computationally intractable since dealing with even a single incoming ion, which would generate close to a million helium ions, would require accounting for close to 10^{12} pairwise interactions at each of the typically 10^7 steps of the Runge-Kutta program. It is however possible to obtain a realistic representation of the effect using the fact that the ion density is high enough that a bulk representation of the field distribution generated by this ion cloud would be sufficient. We therefore developed a Monte-Carlo program to create the initial ion stopping distribution and generate a representative helium ion cloud along each initial ion path to simulate the ionization created by the stopping. These ions are then transported by our standard gas catcher simulation program. By keeping track of the ions along their paths we can construct a time-averaged ion distribution inside the gas catcher. This ion distribution is then inserted into the proper boundary conditions and the Poisson equation solved to obtain the electrostatic field distortion created by the ion distribution. This field distortion is then added to the DC and RF fields of the non-perturbed simulations and the initial ion clouds transported under these new conditions. Repeating the procedure a number of times leads to a self-consistent solution that properly accounts for the field distortion created by the ion stopping distribution. The validity of this approach was tested in simplified cases that can be treated exactly and with simulations of the ¼ scale RIA gas catcher prototype (see figure 1). These calculations agree with the exact solutions in the simplified cases and yield general agreement with our experience with the ¼ scale prototype.

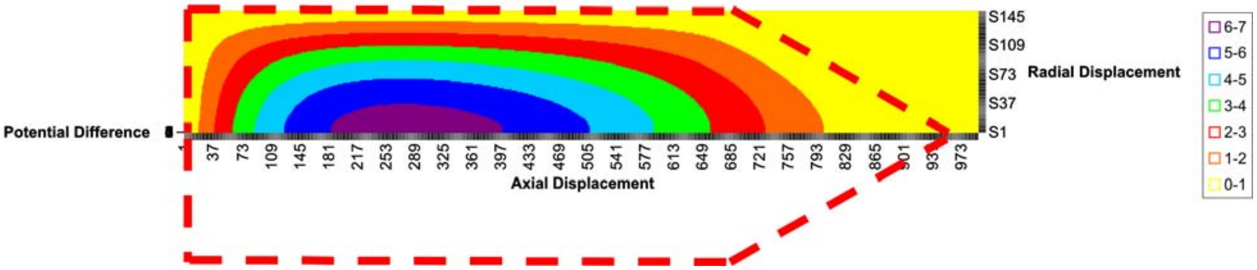

Figure 1. Potential perturbation created by 2.5 X 10^5 Cs ions stopping homogeneously in the ¼ scale RIA catcher prototype. The resulting ion density creates a potential distortion of almost 7 volts close to the center of the gas catcher. This distortion slows down the extraction of ions stopped closed to the window and exerts a diverging radial force that must be compensated to ensure that ions created off axis get to the RF cone and the extraction nozzle.

These calculations are used to guide our setting up of the high-intensity test and will be crucial in our analysis of the results. Simulations of the large gas catcher system indicate that the initial distribution of ionization can strongly influence the transmission at a given ion implantation rate. That might make the gas catcher system much more difficult to tune in cases of high intensity operation. At low intensity, we essentially have one common mode of operation for all radioactive ions implanted above mass 60 or so. For lighter species the RF focusing force decreases slowly and operating parameters are readjusted accordingly. For high intensity operation, the early results of our simulations indicate a much more complex interplay between the different forces present. They also indicate that an additional complication sets in since depending on the purity of the gas, part of the ionized helium will transfer charge to impurities in the gas and that these impurities have different transport properties in the gas catcher and will change the averaged charge distribution and hence the distortion of the field by the space charge. The simulations are extremely time consuming, one iteration of one configuration takes over a day for a representative sample of ionization, convergence on one configuration at one ionization rate takes over a week, and any change means restarting anew. We are running the code extensively to define boundary conditions that must be obeyed and get an estimate of how much more sensitive to contamination the device will be in high intensity mode. These results have consequences that are being implemented in the two following tasks.

Task 2: We have been assembling the second gas catcher prototype with the spare components remaining after the first prototype left for GSI. New electronic circuits feeding the DC and RF voltages have been put together and connected to the system. We also worked on improving the RF distribution on the system which was not ideal in the initial gas catcher. A new balanced circuit reduces RF noise from the cone region. Also, detailed amplitude matching of the 278 electrodes on the cone was difficult since standard measurement devices were affected by RF pickup and amplitudes measured depended at the 20% level or so on the inductance created by the path of the probe wires. We developed a new probe that takes its ground essentially at the measurement point and rectifies the RF signal at that point so that a DC signal proportional to the RF amplitude (but insensitive to RF pickup) is measured. With this we were able to achieve a more homogeneous RF amplitude distribution (variations below 10%) on the new cone and we plan to retune the cone at GSI using a similar technique later this year. A new movable platform and high voltage cage were constructed and the new catcher was installed in area II. A new bent RFQ was designed so that the system can be connected to the CPT diagnostics system which will allow much better identification of the extracted activities than was possible in the earlier tests of the large gas catcher. Machining of the components of this transfer line is completed and assembly and testing will proceed shortly. With the emphasis on contamination that the simulations indicate at higher intensity we feel that not only diagnostics needed to be improved but also active steps needed to be taken to reach optimum conditions. The pumping system was improved with the addition of a dry screw-type backing pump that replaces a large roots blower that failed during the year. The pumping speed is not affected and the system will be much cleaner. Further cleanliness improvements are being investigated in particular with the possible use of a different approach to seal the large insulating rings in the gas catcher using techniques developed for the AGS at BNL. This modification could be retrofitted to the system and would remove the present 80 C limitation on heating temperature and make the system more sturdy overall. The existing gas purification system available in area II will feed gas to this gas catcher. The required modifications to this system are in the design stage. Overall the installation and commissioning of this second large gas catcher has progressed very satisfactorily once funds became available in March 2004 and we expect it will become operational by the end of 2004.

Task 3: The creation of the ionization density in the gas catcher and of specific activities to diagnose transport efficiency and delay time is the final task in preparation for the high intensity tests. The simulations indicate that an ionization pattern similar to that expected at RIA is required and that delay time measurements provide important diagnostics at the onset of saturation. Creating the ionization required in a roughly uniform manner over a 20 cm diameter spot and a meter or so length cannot be easily accomplished with existing beam transport systems at ATLAS. A solution requiring a large solenoid was however identified. Such a solenoid was being surplussed at University of Manitoba and was given to us free of charge. Optical calculations were performed to find conditions under which the required quasi-homogeneous illumination of the gas catcher from secondary products at the required intensity levels can be obtained. The scheme requires a total distance of 4 to 5 meters between the target and gas catcher and a beam stop after the target to remove the concentrated primary beam below 3 degrees scattering angle. This can be accommodated in area II. The large momentum acceptance of this transport system yields a range profile similar to that of the monochromatized fragmentation products but with an aerial distribution, mass distribution and overall intensity that no fragmentation facility can provide at present. The transport system will provide the required ionization density and yield overall efficiency versus ionization information for various mass ranges. Extraction delay times will be obtained by sources mounted behind rotating shutters that will provide pulses of radioactive ions against which extraction time and position dependent efficiency can be measured. Status of this third task is that the solenoid and related equipment are now at Argonne, the ion optics calculations are completed and the support structure for the beamline is being designed.

References

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