RIA GAS CELL DEVELOPMENT

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Abstract

The gas catcher system 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 and is now being moved to the FRS facility at GSI for operation at the full RIA energy. The major uncertainty that will be left concerning the gas catcher system after these tests will be the operational limits of the device at high intensity. Studies to optimize operation in such conditions will proceed at Argonne with a second prototype.

Gas catcher development background and direction

The gas catcher system 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. The gas catcher concept for RIA is a new approach to the extraction of radioactive ions that was proposed in 1998 based on developments at lower energy at the CPT spectrometer at Argonne. The gas catcher stops fast recoils in high purity helium and uses a combination of DC and RF electric fields together with gas flow to obtain high efficiency and short delay times in the extraction of the radioactive ions. Since then significant R&D efforts have been invested at Argonne to yield a design scalable to the 0.5 atmosphere-meter stopping power of helium required for RIA. The RIA gas cell R&D efforts performed at Argonne in FY2000-FY2001 resulted in the demonstration of a ¼ scale prototype gas cell geometry capable of operating with 45% efficiency, more than double that originally specified for RIA. Possible limitations of the technology we have developed were investigated and the solution selected for RIA and resulting predicted yield seem robust. In the latter part of FY2001 and in FY2002 we designed and completed the construction of a full-scale RIA gas cell prototype, fulfilling a DOE/NP performance milestone for FY2002. The prototype is a scaled up version of the previous prototype, built with particular emphasis on maintaining gas purity which has been found to be an important contributor to our previous prototype's success this far and which becomes a much more difficult task as the surface area inside the device becomes larger and larger. We have achieved our purity goals with UHV techniques applied to the construction and assembly of over 4000 of the 7400 components of the gas catcher system. The prototype has been tested successfully and characterized with low energy radioactive beams at Argonne during most of FY2003. We are satisfied with the results obtained at low energy and are now preparing to move the device to GSI where it will be installed behind the FRS fragment separator for on-line tests at the full RIA energy. This will fulfill a DOE/NP performance target for FY2003. The operational experience gained with the gas catcher tests at GSI will be used to determine how the design can be further optimized. A second version of the large gas catcher prototype will remain in operation at Argonne for further testing (in addition to the continuous on-line operation of the CPT gas catcher) and optimization of operation at very high intensity. These further developments will be important for operation at RIA and are most easily performed at Argonne.

The following will describe the tests performed at Argonne this year and the upcoming high-energy and high-intensity tests at GSI and Argonne respectively.

RIA prototype gas catcher tests at low-energy

The gas catcher concept developed at Argonne uses a combination of DC and RF fields superposed on top of gas flow to extract effectively and quickly short-lived isotopes stopped in the high-purity helium gas. The combination of the three forces provides fast transport through the main part of the device (DC field), focusing towards the extraction nozzle (RF field) and rapid extraction through the nozzle (gas flow). It allows one to use much larger stopping gas volume than gas flow alone and to handle much higher intensity than DC field based system (the first such DC system was developed by us in 1998 and obtained about 20% efficiency at low intensity but saturated at very low ionization level, a problem inherent to all DC only designs proposed so far).

Figure 1. View of the extraction region of the RIA gas cell prototype. This section consists of 279 plates operating with RF voltage applied between the odd and even plates to focus the ions to the extraction aperture.

The mechanical construction and assembly of the full-scale RIA gas catcher prototype, with its more than 7400 components, was completed in August 2002. Figure 1 the completed extraction section of the RF cone, the most complex section of the device. The assembled full system was vacuum tested and baked and found to have an outgassing rate sufficiently low to maintain the ppb level purity of the helium gas under normal operatring conditions (a non-trivial task for a system that large with essentially no pumping speed in normal operation). The next step was construction and installation of tuned circuits to provide the required RF and DC voltages. Figure 2 presents the fully assembled gas catcher system with tuned circuits providing the DC and RF fields installed. The capacitance of the cone (278 plates separated by 0.015") is 97 nF which required significant RF power to generate the design RF amplitude but the task was completed successfully with an air-core inductance to tune the RF tank circuit and tolerate the stored RF power. The system was tested to full RF power and DC voltage specifications. The gas catcher system was installed in a high-voltage cage on a very rigid movable platform that hosts it throughout its displacements.

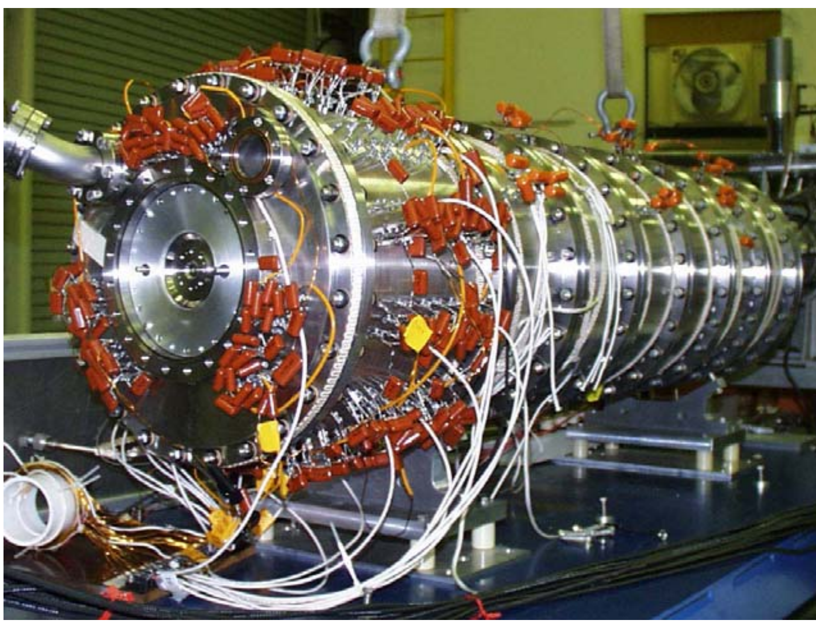

Figure 2. Assembled RIA gas catcher prototype with tuned circuit to provide RF and DC potentials to the body and cone electrodes. The extraction nozzle and chamber hosting the extraction cone can be seen on the left side of the picture.

The completed gas catcher prototype was moved to the general purpose experimental area at the ATLAS superconducting linac accelerator at Argonne for testing. A diagnostic station composed of two sections of RFQ quadrupole separated by differential pumping apertures and followed by a time-of-flight drift section terminated by movable MCP and Si detectors was built and connected to the extraction nozzle of the gas catcher. This allowed counting of the extracted radioactivity with the Si detector to yield absolute total efficiency, identification of the extracted ions by time-of-flight technique with the MCP detector, and mass-gated counting of the activity by opening a transmission gate in the time-of-flight system to let only ions in a specific mass range go through and then detect the mass selected activity with the Si detector. The initial section of RFQ was pumped by a clean booster pump backed by a large rotary pump, the second RFQ section and drift section were pumped by turbo pumps. Pressure in the gas catcher system was measured by an all-metal capacitance manometer and an all-metal valve was used as a bypass between the gas catcher and the first RFQ section for pumping down the device when not in operation or during bakeout. Heating tapes on the gas catcher vacuum system allowed the device to be baked regularly to about 80 C (to stay well below the 125 C melting point of the Indium seals). A problem with breaking of large insulating Alumina rings in the gas catcher when heated was eliminated by a redesign of the rings to minimize concentration of expansion stress and assembly of the device under elevated temperature to preload the rings. The gas catcher was connected to the ATLAS beam line via a ceramic insulating section and the vacuum isolated by a 3.1 mg/cm^2 HAVAR window supported by a 90% transmission stainless steel grid. A bypass pumping valve was incorporated between the ATLAS beamline and the first section of RFQ (which can be bypassed to the gas catcher) to minimize differential pressure across the gas catcher window during pumping down of the system.

Two techniques were used to inject radioactive ions in the gas catcher. First, a 5 μCi ^{252}Cf source was installed on the entrance window of the gas catcher system. This source provides a constant known source of short-lived isotopes of various chemical species between mass 95 and 150 and recoil energies between 90 and 140 MeV. This source has been used extensively to determine initial operating parameters for the device and perform systematic studies on stopping in the gas, charge state distribution and total and partial yield dependency on operating parameters. A second approach involved the production of short-lived isotopes by reaction of a high-intensity heavy-ion beam from the ATLAS accelerator with a cryogenic gas target, focusing of the reaction products with a superconducting solenoid, energy focusing with a superconducting resonator followed by a rough selection in a bending magnet. This technique was used to inject isotopes of ^{37}K ($t_{1/2}$ = 1.2 s) and ^{25}Al ($t_{1/2}$ = 7 s) in the gas catcher. The total ion flux reaching the gas catcher was measured with a movable Si detector and attenuators. The fairly good properties of the secondary beam allowed the position where the ions stopped in the gas catcher to be changed with variable thickness degraders installed on a target ladder located in front of the gas catcher entrance window.

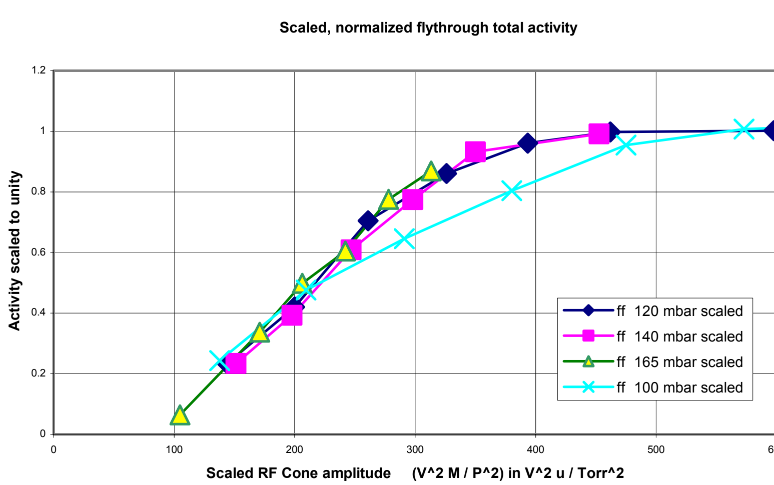

Figure 3. Normalized mass-gated activity extracted from the gas catcher system as a function of the effective RF focusing force exerted by the RF cone. The RF force calculated scaling yields essentially a universal curve in agreement with our simulations.

Various tests were performed on the gas catcher system with these two sources of radioactive ions. The main goals were to determine the efficiency of the device and demonstrate that the device behaved as calculated under various operating conditions. The effectiveness of the RF focusing and its scaling was demonstrated by studying the fraction of extracted activity versus RF focusing amplitude for various pressure and isotope mass regimes. A typical plot for fission fragments extracted under various pressure conditions in the gas catcher is shown in figure 3. An essentially universal curve is obtained which agrees with our simulations. Data from other radioactive species obtained both on-line and off-line confirms the agreement. The behavior of the extraction efficiency versus stopping position inside the gas catcher is best determined with the on-line produced radioactive isotopes which can be stopped in well defined location along the length of the gas catcher. The result of such a study is shown in figure 4 for radioactive ions of ^{37}K. The efficiency along the gas catcher system is essentially constant over a wide range of operating parameters.

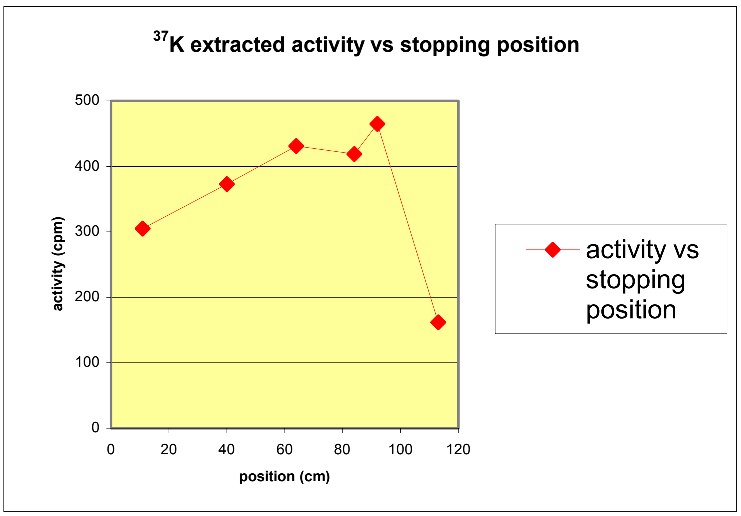

Figure 4. ^{37}K activity extracted from the gas catcher system as a function of the position along the gas catcher where the activity was stopped. The stopping position was varied by changing the thickness of a degrader in the ATLAS beamline.

The exact form in which the activity is extracted is obviously also of interest. We used the time-of-flight identification of the activity to verify that the radioactive ions were extracted as ions and not as molecular ions or adducts. In our on-line experiments with ^{37}K we determined that within experimental uncertainty all activity was extracted at a mass to charge ratio below 40. From this we can conclude that at least 95% of the activity is extracted as singly charged ions for these light ions produced on-line. In our fission fragment studies, we also determined that essentially all activity is extracted as ions but we found a mixture of singly-charged and doubly-charged ions for most of the heavy fragments (similar behavior has been observed in our CPT gas catcher system and use to an advantage there in measurements on heavy fission fragments). The fraction of doubly-charged ions depends on the operating conditions and this behavior is still being investigated.

The total efficiency of the system has been obtained under various conditions. An efficiency of about 40% has been obtained for fission fragments stopped in the gas catcher. That is consistent with results obtained at our smaller scale CPT gas catcher. That efficiency can be maintained up to the maximum pressure the pumping system in the test stand at Argonne can tolerate which is just above 200 mbar (level of funding received in FY2003 did not allow us to upgrade that pumping system). For the lighter species produced in our on-line tests we obtained efficiencies between 10% and 35% depending on operating parameters. In particular, the RF amplitude required on the RF cone to obtain the highest efficiencies for light ions exceeds our RF capabilities at this point. For example, we have obtained 35% efficiency for ^{37}K at 120 mbar but that number drops to about 20% at 160 mbar. That behavior is in agreement with our modeling of the RF focusing force and the situation can be improved with a technique we are developing to apply higher RF amplitude to the cone structure.

We have also investigated the effect of space charge on the efficiency and do not see any effect within the range of ionization density that has been studied. These measurements have been performed on-line and have been extended to close to 10^6 particles per second entering the gas catcher. These investigations must be continued at higher intensities and that work will be continued at Argonne with a second prototype gas catcher.

RIA gas catcher development in FY2004

We are satisfied with the results obtained at low-energy with the gas catcher prototype and the device is being moved to GSI for operation behind the FRS fragment separator there. A more powerful pumping system has been commissioned there that will allow operation at higher pressure than what could be done at Argonne. The large roots blower system was tested and an analysis of the residual gas above the roots blower has been satisfactorily completed. All electronics of the gas cell was purchased to be easily convertible from the local 120V 60 Hz power to the 220V 50 Hz European standard and we expect little difficulty in reproducing the operation of the device after the move.

The site preparation at GSI has involved the installation of a test stand for off-line preparation of the device and design of a stand to install the gas catcher behind the FRS in a space compatible with the RISING project which has a germanium detector array installed at the focal plane of the FRS. The solution selected is depicted in figure 5. The preparation of the FRS for operation as an energy buncher for the reaction residues has been tested already in previous years and the mode of operation selected for the gas catcher will use the target to S3 part of the separator has a separator while the S3 to S4 section will be used as a range buncher. The newly developed glass degrader with optical quality tilted surfaces that provide the required degrader homogeneity will be used. Beam time is approved at GSI for the gas catcher tests.

These tests will demonstrate operation at the RIA energy and allow us to identify possible improvements to our approach. The main remaining uncertainty attached to the gas catcher system after these tests will be the maximum intensity that the device can tolerate. Testing the high-intensity limits of the device and determining how to best push them further will be a time consuming task that is best done at the ATLAS facility. We have already built from spares the main components of a second gas catcher prototype that will remain at Argonne. We plan to investigate over the coming years the intensity limits of the device: determine the actual present limits (instead of extrapolating from lower intensity which is all we have been able to do this far) and find the best approaches to raise these limits to higher levels. It can be shown that the approach used here for the gas catcher can handle much higher intensity than a DC only approach. It can just as easily be shown that RIA can in certain circumstances produce more activity than even our approach can handle. These high intensity studies should therefore be a very high priority item in the RIA R&D list.

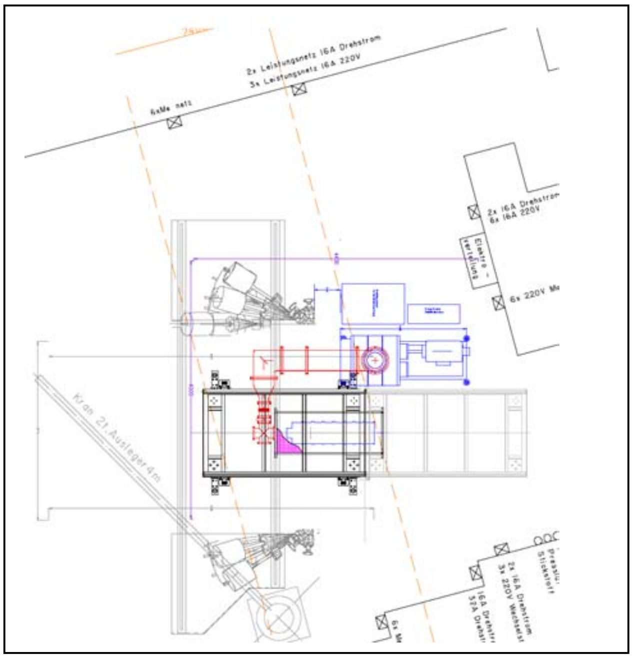

Figure 5.Layout of the gas catcher system at the focal plane of the FRS. The gas catcher is resting on a movable frame which fits between both halves of the RISING detector array. The large roots blower pump is located besides the support frame and the large pumping line is shown in red in the drawing.

This year's R&D is part of a multiyear effort that first demonstrated the feasibility of the concept, built, tested and characterized prototypes and now will operate the prototypes under battle condition at high energy and high intensity. The gas catcher still being a key component of the RIA design and it being still in its infancy, it is clear that this should be a very high priority item.