RIA R&D Status Report (DE-FG02-03ER41242)

Solutions for Beam Stripping at RIA
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1. Introduction

a) R&D Topic

The current concept for the RIA accelerator complex foresees four beam-stripping positions. Two of these will be in the driver accelerator and two in the post-acceleration of radioactive ion beams. The RIA Driver Linac design is optimized for accelerating high power uranium beams starting from an ECR ion source at charge state 29. To keep the total accelerating voltage relatively low two stripping stages are assumed, the first at ~10.5 MeV/u and the second at ~85 MeV/u for uranium ions. For the final design goal of 400 kW of uranium beam at 400 MeV/u, the uranium beam current at the first stripper location will be ~ 5 particle μA. In the post-acceleration scheme a 1^+ radioactive ion beam exits a conventional ion source or a gas catcher/ ion guide system. Predicted maximum currents are normally limited by space charge effects in the gas catcher to 10^9 ions/s, but in those cases where traditional ISOL sources can be used ion currents up to 10^{12} pps are predicted. The current proposal accelerates the beam to a first stripping stage at 5-30 keV/u using RFQ's. Further acceleration with a linac leads to a second stripping at about 600 keV/u, before further linacs accelerate to the energies requested by the users. In all stripping stages, the use of solid (there is no conclusive data for liquid) materials is preferred compared to gaseous materials, as a multitude of measurements show that solid strippers achieve the higher average charge state distribution, which leads to more cost effective acceleration schemes. In order to keep energy and angle straggling low, low Z materials, just thick enough to achieve charge state equilibrium, are preferred. They are also thought to lead in most energy regimes to higher average equilibrium charge states. In those cases where high beam currents or low beam energies make solid stripper solutions impossible, extended gas or gas jet targets can be and are used, but will lead to lower charge states and require more expensive acceleration schemes. Argonne National Laboratory is trying to develop as an alternative a liquid Lithium stripper. Its efficiency is unknown but believed to be similar to solid strippers.

b) The RIA R&D group at the Colorado School of Mines (CSM)

The RIA R&D group at CSM is part of the Nuclear Group (2 faculty, 9 graduate students, 9 undergraduate students), that is predominantly working in the field of nuclear astrophysics with active collaborations at the Holifield Radioactive Ion Beam Facility (HRIBF) at ORNL, the ISAC Radioactive Ion Beam Facility at TRIUMF and the LANSCE Facility of LANL. The Colorado School of Mines (CSM) is a public research university devoted to engineering and applied science. The Physics Department currently consists of 14 full time faculty and offers the ABET-accredited B.S. degree in Engineering Physics with an enrollment of currently 234 majors. The graduate program in applied physics (M.S. and Ph.D.) currently has a total of 42 students enrolled doing research in our three areas of specialization (applied nuclear, applied optics, condensed matter). Participating in the research described in this proposal were the P.I. Uwe Greife and a new faculty member Fred Sarazin, two graduate students (Jake Livesay, Ellen Simmons) and several undergraduate students. Our efforts are funded by this program at the level of $45k/year since now 1.25 years. The funding is used for a graduate student position, some travel and consumables. It is mostly encumbered and will be expended by the end of our current funding period (May 2005).

2. 10.5 MeV/u stripper position in the RIA driver

Requirements/Benchmark: Has to take a beam of app. 5 pμA of ^{238}U at 10.5 MeV/u, strip to charge states around 70, 5 charge states are to be transported further.
Experiments for charge state and straggling information: For parameters like equilibrium charge states, equilibrium thickness and straggling very little or no information exists at the beam energies relevant for the RIA acceleration scheme. Even at other energies, data are too spotty to be readily extrapolated. Initial experiments were performed at the Texas A&M cyclotron facility with 10.5 MeV/u ^{238}U beam before we joined into this project, but data were turned over to us for analysis.
Analysis and comparison to empirical descriptions: Analyzed data from the Texas A&M measurement exist now on charge state distributions and energy straggling and were provided to the ANL beam

development group. The stripping foils were either Carbon, Beryllium evaporated on Carbon or a thick Beryllium foil. The analysis shows that (as expected) the lighter element produces the equilibrium charge state distribution with the larger centroid. The widths of the distributions are comparable for all stripping foils leaving the advantage for the lighter element also for the anticipated simultaneous transport of 5 charge states after this stripper position. If 5 charge states (70-74) can be transported, about 75% of the incident beam can be further accelerated, leaving this stripper position incurring a 25% loss in beam intensity.
As straggling seemed to be dominated in all foils by thickness variations (10-20%), numbers on real straggling are difficult to extract. We are though comparing two codes (SRIM2003 and GEANT4) with the data to find ways to provide descriptions that can be used more universally. It should be noted that straggling in GEANT4 is about a factor 2 stronger than in SRIM.
Evaluation of different stripper possibilities (open questions): Charge state distribution centroid and width favor the use of light stripper materials. Argonne's liquid Lithium stripper, if it can be made to work, seems to be the preferred stripper solution at this station. A backup solution would be the use of a rotating Carbon wheel stripper, as the Beryllium melting point is definitely too low. However, our design studies and temperature estimates show that it will be very difficult to construct, operate and maintain a system like this at these energies due to the small thickness of the foils (~500 $\mu g/cm^2$). Thus, we think it is time to think about the use of gas stripping at this position, design a possible system and evaluate the impact such a solution would have on the driver acceleration scheme.
Design/construction work: See below the description of the Carbon wheel test setup.
Work to be finished in the remaining 8 months of this funding period to achieve initial timeline: More exact calculations of temperature distributions in a Carbon wheel stripper using the Mathematica package. Comparison of extracted charge state distributions to semi-empirical descriptions.
Work to be done in future funding periods: Design of a gas stripping system including pumping schemes. Further evaluation of GEANT4 and SRIM codes and comparison to literature data to determine the usefulness of these codes in a universal description of the beam parameters after the stripping process.

3. 85 MeV/u stripper position in the RIA driver

Requirements/Benchmark: Has to take a beam of app. 5 pμA of ^{238}U at 85 MeV/u, strip to charge states around 90, 4 charge states are to be transported further.
Experiments for charge state and straggling information: In December 2003 an experiment was performed at GSI with our participation to determine parameters similar to the Texas A&M experiment at 85 MeV/u Uranium beam energy. A 73^+ Uranium beam was selected with the first half of the FRS separator and guided onto a selection of Carbon and Beryllium foils. The second half of the FRS dispersed the different charge states onto the focal plane where they were detected by a multi wire chamber.
Analysis and comparison to empirical descriptions: As a first result directly from the raw data, the Carbon foils from some inexpensive suppliers had to be eliminated as possible candidates for use at RIA due to significant density and thickness variations. One foil type produced by Panasonic seems to be a viable solution and was further investigated in the analysis below.
Our first analysis of the charge state distributions (with Gaussian fits to the charge states) concentrated on the analysis of the Beryllium foils as we expected to achieve higher charge state distributions with the lighter elements. Adding up 4 charge states, as it is planned to further accelerate 4 charge states after this stripper position, to our surprise the Carbon foil produces the more advantageous charge state distribution as a sum of four higher charge states (87-90) (compared to 86-89 in the Beryllium case) can be used in achieving larger than 80% probability. This can lead to significant savings in the LINAC construction. Further analysis of the exact charge state distribution of the Carbon run showed a sharp drop-off in charge state probability above charge state 90 (Helium-like Uranium) giving a sum of 4 charge state fractions (87-90) of above 90%.
Evaluation of different stripper possibilities (open questions): It seems that at this stripper position at RIA the use of Carbon should be more advantageous then Beryllium and probably also liquid Lithium, leading to a preferred use (if possible) of a gas cooled Carbon foil wheel. Thermal estimates show the feasibility but calculations need to be repeated more rigorously. The open question is certainly if the heat load can be dissipated and if the foils survive the power density deposited in them. As a backup solution possible scenarios for liquid or gaseous stripping need to be investigated.

Design/construction work: In this reporting period (1.25 years) we have made a simple (and inexpensive) design of a stripper wheel test setup with Helium gas cooling and have started building the equipment. Currently the chamber, stand, flanges, some vacuum pumps and motor have been built or acquired and we are in the process of putting the setup together.
Work to be finished in the remaining 8 months of this funding period to achieve initial timeline: Our current funding does not allow us to go beyond mechanical construction and tests in this funding period. However, we will prepare everything so that the cooling and temperature measurement can be added fast when the funds become available. More exact calculations of temperature distributions in a Carbon wheel stripper based on the Mathematica package will be done. We will continue to fully evaluate the data from this run at GSI.
Work to be done in future funding periods: We will apply in the next round of RIA R&D solicitations for money to finish the construction and start with tests of our wheel setup with intense light ion beams at a suitable accelerator. We have identified the ORIC cyclotron at ORNL with its new high power target station as probably the best place in the US to perform these tests. The installation of the external ion source and the long anticipated repair of several trim coils will make this facility able to cover a large fraction of the beam power range that will be deposited in the strippers in both RIA driver positions. Further evaluation will be done of the GEANT4 and SRIM codes and comparison to literature data to determine the usefulness of these codes in a universal description of the beam parameters after the stripping process.

4. Few keV/u stripper position in the RIA postacceleration

Requirements/Benchmark: Narrow charge state probability distribution (40-50% in one charge state) for low energy (few keV/u heavy ions), able to withstand typically 10^{12} ions/s ^{208}Pb.
Experiments for charge state and straggling information: Viability of gas stripping had been shown several years ago by Decrock et al. at ANL.
Analysis and comparison to empirical descriptions: Not done yet.
Evaluation of different stripper possibilities (open questions): Gas stripping with windowless targets is the only option here. Open questions include the use of different gases like Hydrogen compared to Decrock et al. and if it is possible to describe beam parameters like straggling with available programs like SRIM or GEANT4.
Design/construction work: We have done a design study on a short Helium or Hydrogen gas stripper system to be used as a first stripper in the RIA post-acceleration. At this position in the RIA system the radioactive ions will be very slow and the beam size might require apertures in the gas stripper larger than 1 cm diameter. In close collaboration with the accelerator design at Argonne National Laboratory we have defined the specifications for the gas stripper and performed the necessary gas flow calculations.
Work to be finished in the remaining 8 months of this funding period to achieve initial timeline:
Comparison of straggling values from Decrock et al. to GEANT4 and SRIM2003.
Work to be done in future funding periods: In the next round of solicitation for RIA R&D we will apply for the funds to build the gas stripper and test it at a suitable accelerator. A good possibility here is the KN single ended machine at the Notre Dame accelerator laboratory. These tests will concentrate on energy and angle straggling as well as the determination of equilibrium thickness of the high Z beams in Helium and Hydrogen, where, for these slow velocities, very little data exists and current semi-empirical codes are unreliable. The results from these measurements will have to be fed back into beam transport calculations and eventually into RIA accelerator design.

5. General Comments

Beam Stripping in the RIA driver seems to us to be a critical component that can change the current concept of the acceleration schemes. The high power target station at ORIC (ORNL) seems to us the best place where during the next 2-3 years all components can be tested if the planned upgrades to the cyclotron are implemented.

Uwe Greife, Golden, 10/15/04