In-flight separator design, Range compression studies and Optimization of a high pressure gas stopping cell for the Rare Isotope Accelerator

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The supported research consists of two tasks: (1) the development and detailed modeling of the in-flight fragment separators for RIA and (2) studies of the range-compression technique for high-energy projectile fragments with the optimization of ion collection from a high-pressure gas stopping cell.

FRAGEMENT SEPARATOR COMPLETED WORK: The main goal to develop a baseline design for the two RIA separators that could be used to define magnet parameters and serve as a benchmark for comparison to future improvements has been completed. In order to meet this goal it was necessary to upgrade the main simulation code used worldwide to calculate fragment yields, LISE++. The improvements are outlined below, but a major accomplishment was to include rare isotope production from fission.

Based on the results of the simulations the specifications of the current baseline design were revised slightly from the Harrison Committee Report. These changes are expected to be cost neutral. RIA will have two high-energy fragment separators, the proposed changes for both separators are: (1) Maximum rigidity of 10 Tm rather than 8 Tm. This results in a nearly factor of 2 gain in the yield of some of the key very neutron-rich nuclei. (2) Reduction in the baseline momentum acceptance to 12% from 18%. This reduction results in only a loss of 20 to 30% in fragment yield, but significantly reduces the constraints on magnet apertures and higher order optical corrections. (3) Division of both separators into a pre-separator/separator concept in which the primary beam and most unwanted fragments are removed in the pre-separator. Such division also helps to limit the extent of the high radiation environment and helps to significantly increase rare isotope purity.

The high radiation, production and beam dump areas are a key issue in the baseline design and are the focus of another grant but about one-half of that effort relies on the fragment separator work, particularly ion-optical constraints and inclusion of adequate space for a primary beam dump. Often the desired fragments are close to the primary beam in rigidity and hence the dump must be located where there is significant separation between the beam and the fragments. A new concept was introduced to have a momentum focus directly after the first dipole and locate the dump at that focus. The new vertical pre-separator layout, shown in figure 1, helps to reduce cost since the pre-separator is also used to move the secondary beam from the level of the primary LINAC to the ground-level experimental areas.

Simulation of various options for the separators required substantial improvements to the well-established code LISE++. The code was upgraded to include models for Coulomb Fission and Abrasion-Ablation Fission. The charge-state and energy loss calculations in

LISE++ were upgraded to use the most tested and up to date codes for charge state distributions (GLOBAL) and for energy loss and straggling (ATIMA). A number of utilities were added to the program. These improvements have been documented in four recent publications [1-4].

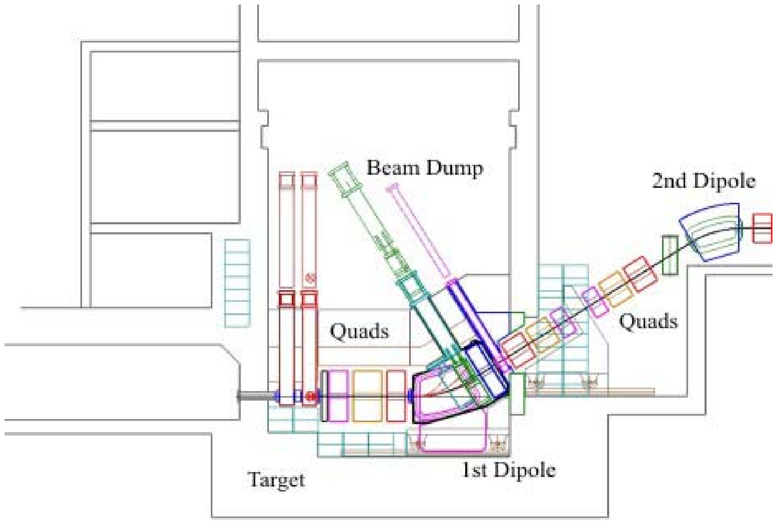

Figure 1. Vertical section through the baseline layout for the preseparator. The secondary beam follows the dark line, also shown are possible remote handling plugs for changing of the target and beam dump.

The improved LISE++ code was used to make a number of studies of the requirements for various components. Analysis of target thickness showed that non-uniformities of the lithium target as high as 10% could be tolerated. A detailed study of the fragmentation and fission yield as a function of separator acceptance was carried out. It was found that angular acceptance of ±50mr and a momentum acceptance of at least 10% are required. A higher momentum acceptance would yield fractionally higher gains in secondary beam yields, with an up to 50% gain in going to 18% momentum acceptance.

GAS-CELL COMPLETED WORK: The goal of this work was to stop very energetic exotic projectile fragments in high-pressure helium and extract them from the gas with static electric fields. The entire system has been constructed and secondary fragments have been extracted and thus, this goal has also been attained. A number of radioactive ions were produced at the NSCL and their range profiles in helium were measured and compared to detailed predictions. Examples of range distributions were published this year [5,6] and were in agreement with the predictions of LISE++. The radioactive ions were then drifted in an electric field to a supersonic nozzle in tens of milliseconds, extracted, rapidly passed through an ion-guide, and detected through their radioactive decay. A report of the initial extraction studies performed with a secondary beam of ^{38}Ca ions has been submitted for publication [7].

The overall results are that on the order of one-third to one-half of ions at 100 MeV/A can be stopped in 0.5 m of helium at 1 bar and that approximately 10% of these stopped fragments can be extracted and observed through their radioactive decay. The range distribution and the total extraction efficiency are shown in figure 2. However, the results show a dramatic drop in efficiency as the implantation rate increases. Investigations show that the drop in efficiency is due to the effects of the space charge from positive ions in the drift volume and also near the nozzle. Subsequent studies were performed with ^{80}As and are continuing with neutron deficient Bromine isotopes. We have designed and constructed a second generation gas cell that incorporates a high-pressure rf-focusing field just before the nozzle and we are beginning detailed simulations of the ion-drift including space charge in a self-consistent framework.

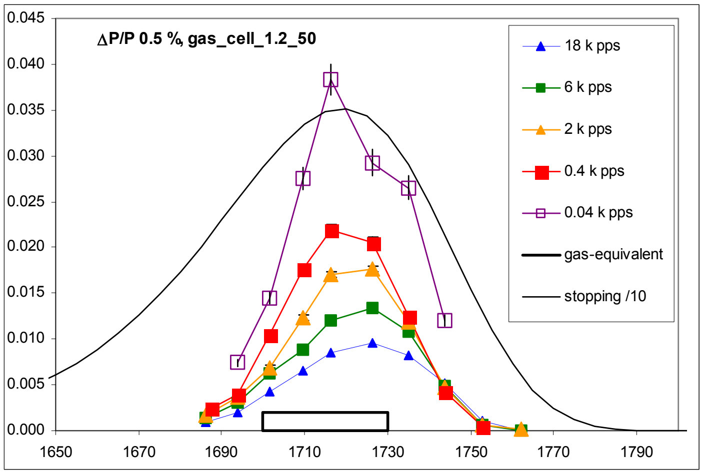

Figure 2. The measured total efficiency for stopping and extracting $^{38}Ca/^{37}K$ ions at 2.688 Tm (Δp/p=0.5%) from the NSCL gas cell as a function of total degrader thickness (microns of glass) and implantation rate. The thin solid curve represents the distribution of stopped ions, scaled down by a factor of 10.

Summary of Expenditures FY04:

Only $80k was provided for this work during FY04 and the funds were used to support two graduate students working on the simulation (~$60k). The balance of the FY04 funds was used to purchase supplies such as high purity helium for operation of the gas cell.

Future Needs and other Issues:

The next major goal for the fragment separator work is to complete higher order ion-optical designs for both fragment separators and search for ways to increase the separator acceptance. We plan to improve the model for fission production, implement secondary reactions in the wedge, and develop a Monte Carlo version of LISE++. The next goal for the gas cell is to measure and then model the effects of space charge on the ion-extraction efficiency.

Publications resulting from this work:

[1] O.B.Tarasov, Proc. Intl. Sym. on Exotic Nuclei, Peterhof, July 5-12, 2004, in press.

[2] O.Tarasov, Nucl.Phys. **A734** (2004) 536.

[3] O.B.Tarasov and D.Bazin Phys.Atomic Nuclei **66** (2003) 1578, and NIM **B204** (2003) 174.

[4] O.B.Tarasov and D.Bazin Preprint MSUCL-1248, Nucl. Phys. **A** in press.

[5] L. Weissman et al., Nucl. Instrum. Meth. **A522** (2004) 212.

[6] L. Weissman et al., Preprint MSUCL-1284, Nucl. Instrum. Meth. **A** (2004) in press.

[7] L. Weissman et al., Nucl. Instrum. Meth. **A** (2004) submitted for publication.