RIA FRAGMENT SEPARATOR STUDIES

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Abstract

Important production mechanisms at RIA will involve fragmentation (or in-flight fission) of fast beams followed by selection in fragment separators leading the beams either to a gas catcher system to form high-quality low-energy radioactive beams or directly to experiments at high-energy. Both fragment separators that will be used at RIA to collect and separate the reaction products will have higher acceptance than device built before, they will also have to handle the high-power primary beam and dispose of unwanted contaminant radioactive ions. These problems will be much more serious at RIA than in any previous facility and a workable solution is required for the proper operation of these devices and the containment of high-level of radioactivity to areas of the facility with proper nuclear classification.

Work performed in FY2003

In the past year we have been developing optical layouts for the fragment separators that would meet the requirements for momentum and angular acceptance. We have developed software to investigate the production of contaminating reaction products in the wedge used in standard fragment separator design to obtain isotopic selectivity and have characterized this contamination (which will dominate the background for the weak reaction channels that will become available at RIA) for various designs. In addition, the location and power densities that will have to be handled where the primary beam will dump in the separator and where intense secondary beams will be collected have been characterized for a base design and approaches to deal with this power deposition and contain the radioactive contamination are being developed. Implications of failure of different components are also being looked at. We will continue this work and in particular optimize the monochromatization of the secondary products for stopping in the gas catcher and the transport of the resulting enormous emittance beam to the gas catcher.

The work performed this year can been separated along 3 lines of development that will lead us to a proper technical solution: 1) the locations where different reaction products can be produced must first be identified and the extend of the contamination characterized, 2) these reaction products and the primary beam must then be transported and the locations where they will deposit energy identified and the power deposition density estimated, and finally 3) the technology required to meet the requirements obtained from 1) and 2) must be developed. Progress on all 3 fronts is described below.

The first task is the identification of the isotopes produced in the fragment separator. This task is further complicated by the fact that the fragment separators will use various primary beams and reactions to produce different reaction products and that each case will vary from the others. The approach selected in this case is to develop the basic tools required to simulate the production and to run a number of representative cases that will outline the problem.

A new computer code was developed to perform these calculations. The present version of the code performs the following tasks:

- calculates production of radioactive ions in the primary target using the latest EPAX parametrization
- determines the momentum range over which these isotopes will exit this target
- finds optimum settings for the momentum selection slits in the initial section of the fragment separator
- removes the radioactive contaminants that will not meet this selection
- calculates the production of secondary recoils in the wedge by the initial reaction products
- determines the momentum to position along the wedge correlation for these fragments, including effects of non-uniformity in the wedge
- transport all of these fragments to the end of this section of the fragment separator
- provides a distribution of these fragments along the focal plane and the transmission for a given slit size

To our knowledge, no code before had allowed the effect of secondary reactions in the fragment separator wedge to be studied in any details and the results reveal important effects that will have to be considered with beam powers of the magnitude of those available at RIA. The code has now been run for two representative cases, one using fragmentation and one using in-flight fission, to produce the isotopes of interest. We can see below in figures 1, 2 and 3 the distribution of activities traveling along the fragment separator.

In figure 1, we observe the distribution of radioactive isotopes, with Bρ similar to the isotope of interest, produced in the primary 3 g/cm^2 flowing liquid lithium target by a 100 kW beam of ^{86}Kr at 400 MeV/u. The experiment is aimed at producing isotopes of ^{78}Ni which are highlighted by the blue circle. The intensity and the wealth of other isotopes also produced in this reaction are also shown, color coded according to intensity. Such a high rate of activity is intolerable for most experiment and the role of the fragment separator is to clean up this picture.

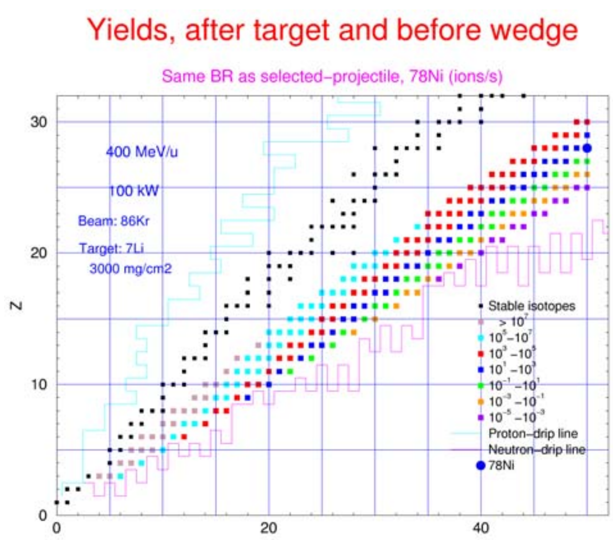
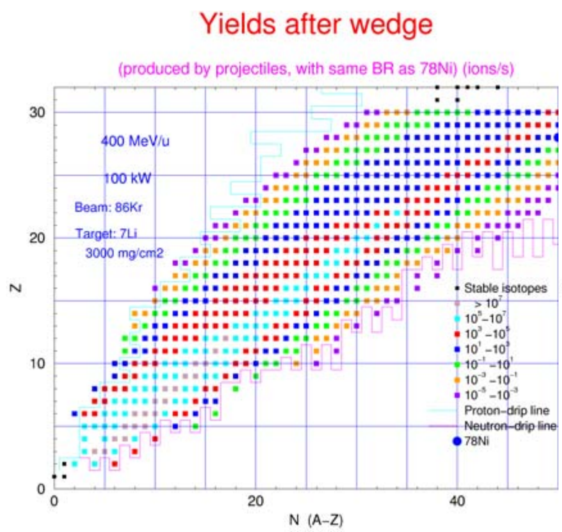


Figure 1. Isotope distribution produced by 100kW of ^{86}Kr beam in the primary liquid lithium target

Figure 2 shows the yield of the various isotopes after the wedge in the fragment separator. These isotopes are either isotopes produced in the primary target that have survived the momentum cut and the wedge degrader, or isotopes produced in the wedge degrader by those primary isotopes.



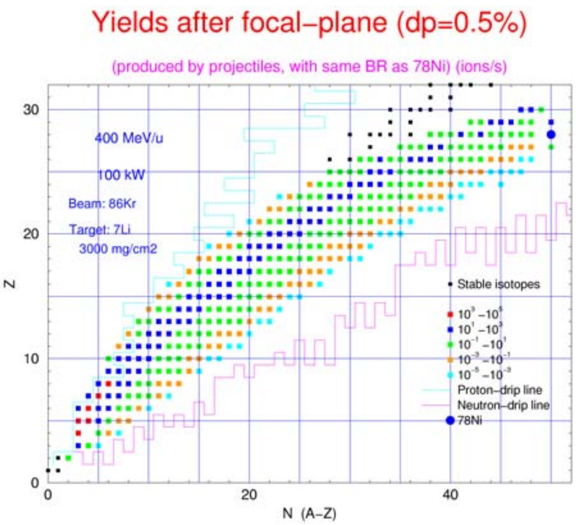


Figure 2. Isotope distribution present after the wedge and coming either from primary production of secondary production in the wedge

Figure 3. Final isotope distribution after all selections for an isotope separator tuned to extract ^{78}Ni isotopes (blue circle).

It is clear that the fragmentation of the radioactive beams in the wedge generates numerous other species in quantities similar to the original production. This is due to the fact that at these energies, the wedge is thick enough to yield a high nuclear reaction probability. This isotope distribution is then transported and selected by slits at the achromatic focal point at the end of this section. The isotope distribution making it past this selection is shown in figure 3.

Figure 3 is a realistic look at what will come together with the selected isotope (^{78}Ni in this case) with powerful beams like RIA can deliver and that is a very sobering picture. The primary beam intensity hitting the target corresponds to 1.8 X 10^{13} ^{86}Kr ions per second. The reaction products that reach the wedge degrader, that is to say that they have similar magnetic rigidity as the isotopes of interest and cannot be removed without also removing isotopes of interest, total 2.9 X10^{9}/s. A similar number is observed after the wedge but over a much broader range of species due to fragmentation reaction in the wedge. After the final slits we still observe about 1.6 X 10^{5} radioactive ions per second, among those 10 ions per second of ^{78}Ni, the isotope of interest. We however observe that the vast majority of the contaminants that are left are radioactive ions generated by reactions in the wedge that were not present in figure 1. This dramatic effect is the dominant source of background and was not present in previous calculations where reactions in the wedge were not included. The code also indicates the size of the final slit required to not loose too large a fraction of the isotopes of interest and the Bρ of the other isotopes created in the initial target. This is particularly important since the total power in these secondary isotopes can be 10s of kW, much more than the primary beam in existing facilities, and must be handled properly.

These first results with the new code are most interesting in that they yield the required Bρ distribution of the power that must be absorbed. They also yield the activity distribution that must be contained. Refinement to this code are still needed and more cases must be run but clearly this is a great progress and much insight in the separator design has already been gained by this effort in particular with respect to the use of a pre-separator that will remove most ions that might otherwise reach the final wedge degrader.

A more general picture of the source of contamination can be obtained by varying parameters such as the wedged degrader thickness for example as is shown in figure 4. We see a clear increase in the background for thicker degraders related to production in the wedge. Similar graphs have been obtained for in-flight fission.

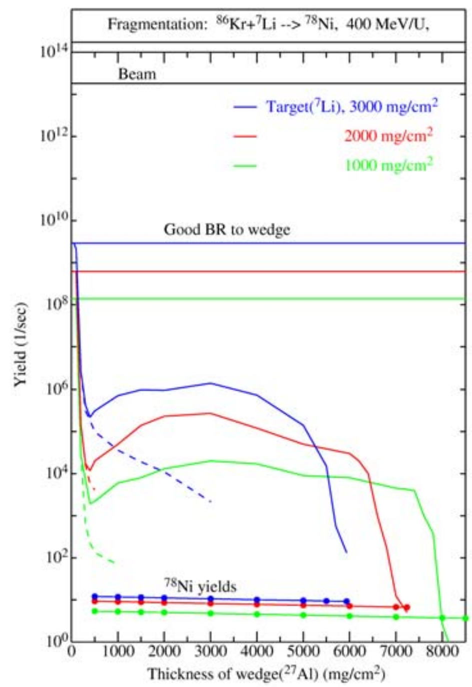


Figure 4. Variation of the yield of ^{78}Ni and of the total contamination after the final slits as a function of the wedged degrader thickness. The top line is the beam intensity, the horizontal blue, red and green lines are the amount of contamination reaching the wedge for various target thicknesses, the curved lines are the contamination yield after the final slits and the bottom lines are the yield of ^{78}Ni after the final slits.

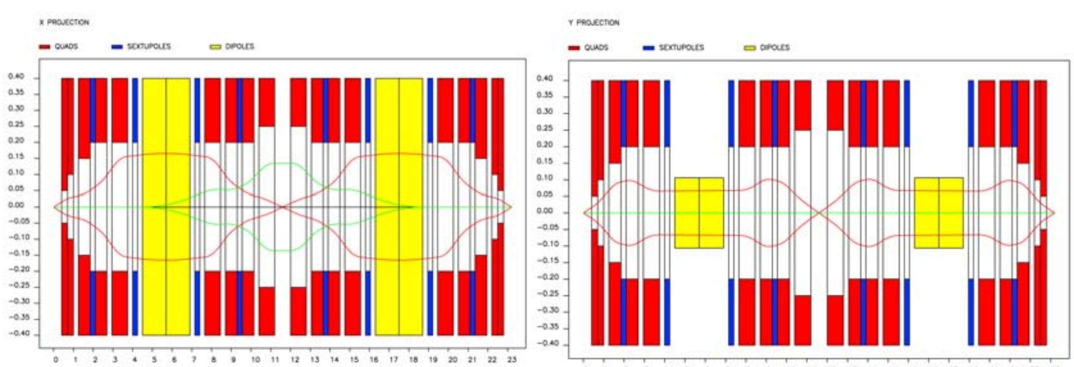


Figure 5. Layout of one of the initially proposed high-acceptance fragment separator for RIA. The dipoles are in yellow, the quads in red and the hexapoles in blue. The left side of the figure shows the X envelope of a typical reaction product beam and the right side the Y envelope.

The next step, task 2 in our approach, consists of devising an actual ion package with proper output to visualize the trajectories followed by the primary beam and radioactive fragment beams whose Bρ distribution is determined in step 1. This is done within the framework of GIOS that we are modifying to improve its outputs and add the optical elements required in a fragment separator. A result of these improvements is shown in figure 5 which shows the x and y envelopes of secondary beams obtained with a simulation of the layout initially proposed in the Grunder committee report for one of the fragment separators at RIA. The study above however confirms the finding of groups at GSI and RIKEN that such a separator cannot perform the task of cleaning up the reaction products at RIA. The next step is therefore to develop layouts more suitable to this task including a pre-separator section that will remove most of the activity before it reaches the final wedge. Such layouts have been generated for both the high-energy separator and the separator leading to the gas catcher system. We have now started feeding the information obtained in step 1 and determine typical energy deposition distribution in this separator. Results obtained with this large acceptance separator (± 9% momentum acceptance, ± 50 mrad angular acceptance in both x and y directions) are yielding interesting information with respect to the beam dump location. Because of the large momentum acceptance, it is found that the primary beam (shown as circles of different colors depending on the energy separation from the reaction products in figure 6) is not separated from the reaction products in the first dipole magnet (left of figure 6) but can be separated in the following quads (right of figure 6).

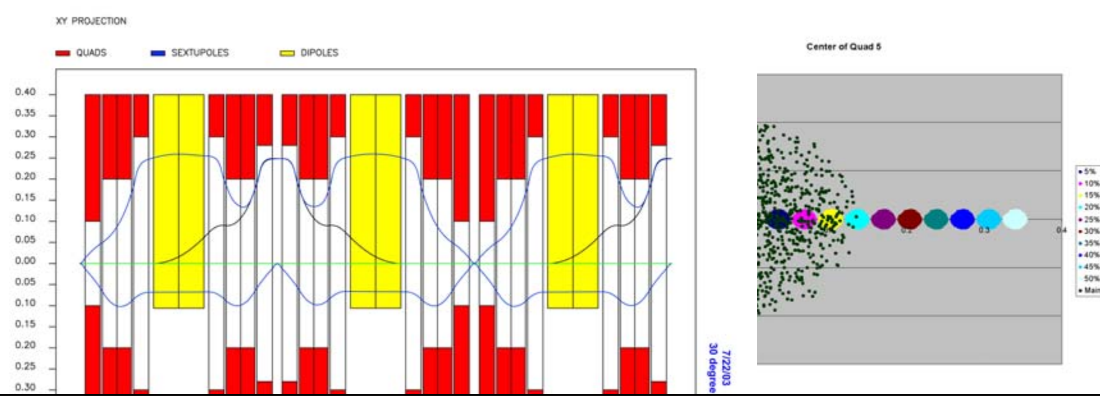


Figure 6. X and Y distribution of reaction product acceptance in green, size and position of primary beam for different energy difference varying from 0% to 50%. The left panel represents the distribution inside the first dipole, the right panel is in the following quadrupoles.

A beam stop could be located around the quadrupole location. The primary beam still carries typically about half of the initial beam power. The beam properties of the primary beam are still good after going through the primary target and the beam size at the dump is calculated to be typically about 3 centimeters diameter. This corresponds to an energy deposition of about 5 kW/cm^2 when this beam hits a surface with normal incidence. This power deposition is above what essentially all solid materials can tolerate. Since this power density can occur essentially at all locations on both sides of the reaction products (depending on the relative Bρ of the reaction products and beam), an approach compatible with a movable beam dump is required. The basic design envisioned involves maximizing the surface area over which the beam impinges by tilting the beam dump in one or both planes. This reduces the power density but the total power is still high and must still be removed. Essentially 50 kW of cooling power must be available on each side of the magnet, most probably from cooling water, and high heat transfer must be achieved between the shield and the water. A final consideration must be to minimize secondary reactions and the generation of neutrons and that implies that the stopping must be done in high-Z material. A refractory high-Z material joined to a copper backing for high thermal conductivity might be able to handle such power load. Techniques to improve the heat transfer between the metal backing and the cooling water are being investigated as this appears to be the limiting factor in such an approach.

Auxiliary beam dumps for the high power contaminants closer to the reaction products of interest must still be considered. More calculations will be required to define the requirements here but the power deposition here, although still high, will be closer to those that have been dealt with in the past.

Plan for FY2004

For FY2004, we plan to continue the calculations started and obtain complete layouts and higher order optical designs for both separators, update our software to handle secondary production and separation in both separator and pre-separator, run different representative cases through them to obtain purity and fragment and beam distributions, use them to obtain complete requirements for the beam dump power and location variability required, and attain a workable design for the beam dump system and distribution of contamination. The proposed work is mostly simulation work with some engineering efforts on the beam dump aspects. It is critical that the fragment separator layout be completed as early as possible in that it essentially determines the whole site layout since it couples the driver linac to the rest of the facility.