2003-181-N0 -- ISOBARIC MASS SEPARATION AND THE BEAM PROPERTIES EXTRACTED FROM A RIA TYPE GAS CATCHER

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Purpose: The Rare Isotope Accelerator (RIA) is the highest priority for nuclear physics in the US and a major strategic initiative for Argonne. The main components of RIA are a high-power multi-beam superconducting heavy-ion accelerator, a production complex where isotopes are created via ISOL techniques, fragmentation techniques, or new approaches combining advantages of both techniques, and finally a high-efficiency post-accelerator based on the ATLAS-like linac. All 3 major components rely heavily on new technologies developed at Argonne. In particular, the novel approach of stopping fast reaction products in a large gas catcher to remove standard ISOL chemical limitations and allow beams of essentially all species to be available at low energy will be a key component of RIA. This universal technique has however limited selectivity so that additional measures are required behind this device to purify the extracted beam delivered to experiments. Various isobar separation schemes are possible but must be matched to the properties of the extracted beam to determine applicability and optimize efficiency.

Approach: The approach taken for this study involved the determination of the beam properties extracted from the existing gas catcher test devices (the CPT gas catcher and the full scale RIA gas catcher devices) under various conditions and the effectiveness of simple techniques to modify them; then to determine the requirements an isobar separator would need to meet in order to perform the purification task; and finally to determine the properties and scalability of a device using a novel concept for isobar separation based on a resonant cooling technique.

Technical Progress and Results: The properties of ions extracted from a gas catcher system were studied with the quarter-scale RIA gas catcher test device now in use at the CPT mass spectrometer at Argonne. Transmission through a well-characterized transport system was monitored under various conditions to determine transverse and longitudinal emittances. Typical transverse emittance values equivalent to 3π mm-mrad at 60 keV were observed under both continuous and pulsed extraction for low ion current. Transverse emittance increased with ion number in pulsed ejection mode but remained roughly constant in continuous mode within the current regime studied. Longitudinal energy spread below one eV was observed in continuous extraction and longitudinal phase-space below a few eV-µs for pulse extraction at low ion intensity,

increasing rapidly with ion number above 10^5-10^6 ions per pulse. Typical cooling time required to obtain cooled bunches was about 5-10 ms, limiting the repetition rate to about 100 Hz and yielding a maximum throughput of 10^7 to 10^8 ions per second in pulsed mode before extracted beam properties deteriorate. Continuous extraction can handle one or two orders of magnitude more ion throughput without emittance growth. In typical operation the pulsed extraction is not synchronized to the transverse focusing RF so that the observed emittance is averaged over all possible orientation of the transverse phase-space ellipse. It was attempted to lock the extraction to a well-defined RF phase and found that a reduction in the transverse emittance could only be observed if the ion pulse went through the stray field of the device over a small fraction of an RF cycle. While this can be done experimentally, it could only be achieved at the expense of a large energy spread introduce by the tight time focus required to meet the above condition. The transport system used after the ion catcher system could not properly handle this increased energy spread. It might be possible to correct for that effect and profit from the transverse emittance reduction with a debunching system after extraction but the small resulting gain does not warrant that additional complication.

The total extracted ion number was then connected to the number of radioactive ions stopped in the gas catcher using the full scale RIA gas catcher test device. This connection is rather non-trivial and system dependent. A radioactive ion stopping in the gas catcher will lose typically 100 MeV of energy and create in the high-purity helium gas roughly 1 ion-electron pair per 30 eV of energy loss. The RF focusing in the gas catcher is designed to focus the heavier radioactive ions but not the helium ions. For a perfect system with no impurities present, only the radioactive ions would be focused on the extraction nozzle and extracted. In practice, impurities present at the ppb level in the helium will be ionized by charge-exchange reactions with the helium ions and a small fraction of the charge initially created by the ion stopping will be transferred to impurities that will be extracted. Keeping in mind that the initial creation of charge can be of the order of 10^6 to 10^7 ions per incoming radioactive ion, it is clear that even a small fraction of that amount will usually dominate the extracted ion number. The charge fraction extracted depends critically on the purity of the gas, the outgassing rates, the time the ions spend in the gas catcher, and is typically larger for the full-scale RIA gas catcher test device than the smaller scale CPT gas catcher. Typical numbers are 1000 total ions extracted per incoming radioactive ion and so the best beam properties (which correspond to below 10^9 total ions extracted per second) can only be expected for incoming ion number below 10^6 radioactive ions per second or so. Rough mass selectivity can be implemented in the ion cooler itself and was demonstrated at the CPT system but that can result at most in a gain of a factor of 20 or so in total throughput if high transmission is to be maintained.

The requirement initially defined for the RIA gas catcher is to be able to handle an incoming ion number of 10^9 per second which implies that delivered beam emittance will be increased at these currents. A typical requirement for the following isobar separation will then have to be able to yield a mass resolution of at least 10000 (required to resolve typical isobaric contamination) with an input emittance of up to 10π - 20π mm-mrad at 60 keV. The large energy-compensation isobar separator design proposed by Portillo,

et al., would fulfill these requirements but at a large cost in real estate and funds. It is however a near optimal combination if dealing with flythrough magnetic separation and any competing approach must use a different approach if trying to alleviate the cost and space constraints.

An alternative approach using mass selective recentering in an ion trap has been tested. A cylindrical Penning trap located in a compact high homogeneity normal conducting 1 Tesla magnet was built and injected with ion bunches from the CPT gas catcher. The main contamination, that from stable molecules with same mass number as the radioactive ions, was removed easily. The resolution reached with the 1 Tesla magnetic field was up to 3000 with a storage time of 350 ms, independently of the initial emittance of the incoming beam. The product of resolution and interaction times that can be obtained with such a device scales with the square of the magnetic field and we expect that such an approach would yield a resolution of 10,000 with an interaction time of 20 ms for a cylindrical Penning trap in a 7 Tesla superconducting magnet. Such a magnet is available and a suitable Penning trap is being constructed and will be injected with ions from the CPT gas catcher to confirm the viability of this approach.

Specific Accomplishments: None.