01-222R1(C) -- LIQUID LITHIUM STRIPPER FILMS AND WINDOWLESS TARGET

Principal Investigators: Jerry Nolen, Physics
James Specht, Physics
Claude Reed, Technology Development
Vince Novick, Technology Development

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Purpose: The high-power heavy-ion beams to be produced by the RIA driver linac have large energy deposition density in solids and in many cases no solid materials would survive the full beam power. The high intensity uranium beam will pass through 2 stripper foils, at 9.3 MeV/u and 85 MeV/u, and then through a thick production target at 400 MeV/u. The purpose of this work is to develop targets for these applications for use with the 400-kW uranium beams of the driver linac. Related necessary work is to measure the charge state distribution and associated energy and angular straggling of uranium beams after passing through stripper foils of various thicknesses. Such data do not currently exist at the level of accuracy necessary to evaluate the level of beam halo and losses in the driver linac following the strippers. These studies must be done over about 3 orders of magnitude of dynamic range since in the driver linac a charge state carrying even below 1% of the total beam power can still correspond to over a kilowatt of beam power. The magnitude of this problem has strong implications on the details of the driver linac design to appropriately mitigate issues related to accelerator component activation. These high power target and stripper issues are of great importance to RIA, as well as, to other radioactive beam facilities being planned around the world, especially at RIKEN in Japan and GSI in Germany.

Approach: We are applying liquid lithium technology to solve the high-power target problems described above. Windowless targets are being developed for the production of radioactive ions via fragmentation and the thin-film strippers (also windowless) needed within the driver linac to increase the charge state for more efficient acceleration. The first application requires a jet of about 3 cm thickness of flowing liquid lithium while the strippers will be sheets of about 5 microns and 200 microns in thickness. This technology seems to be ideally suited to this general RIA problem, but a completely windowless liquid lithium target system has not been previously demonstrated. Designs have been developed for both systems with a rectangular stainless steel nozzle for the windowless target and a novel slit aperture with an expanding jet for the stripper. Loops for both the thick and thin targets will include liquid lithium pumps adapted to the required flow rates and pressures. The measurements of the charge-state distributions and energy straggling from the stripper foils will have to be done at accelerator facilities that can currently provide uranium beams at the two required energies. Plans are underway for measurements at Texas A&M for the

9 MeV/u uranium beam and at either the MSU NSCL facility or GSI for the 85 MeV/u energy.

The lithium loop development at ANL is utilizing the existing ALEX facility and expertise of the Technology Development Division. In addition to the PI's listed above, the project has the technical support of Bob Haglund (TD) and an undergraduate student, Perry Plotkin. All design drawings for these projects have been done by Harold Russell of the TD design group. The measurements of the stripper foil characteristics will involve collaborators at the respective nuclear physics facilties, Al Zeller and others at the NSCL, Dave Youngblood and Henry Clark at Texas A&M, and Mauricio Portillo and the FRS group at GSI.

Technical Progress and Results: The HEIGHTS simulation package was used to analyze both double window Be-Li targets as well as free Li jet to beam energy deposition for a future high-power nuclear physics fragmentation accelerator. An adjustable thickness Li/Be hybrid target is being developed for use at the NSCL. The lithium serves as a part of the target as well as the coolant. Up to 1 kW of beam power is dissipated in the target and is carried away by the recirculating liquid lithium loop. It is designed for high power beams in the mass range from oxygen to calcium. Tapered beryllium windows combined with a uniform thickness lithium channel gives an overall target thickness ranging from 0.7 g/cm^2 to 3 g/cm^2, which is adjusted by moving the target vertically. Three-dimensional thermal calculations of the temperature profiles in the entrance and exit regions of the target have been carried out using the HEIGHTS simulation package. Calculations were performed for a ^{48}Ca beam at 160 MeV/u and 0.5 particle microampres at the thin end of the target (1-mm beryllium windows and 5-mm lithium thickness) and for an ^{16}O beam at 200 MeV/u and 1.0 particle microamperes at the thick end (7-mm beryllium windows and 5-mm lithium). The results show that the temperature rise at the target entrance and exit are reasonable. A mechanical design of the hybrid target based on these thermal calculations was completed early in FY2002 and reported at the International Conference on Electromagnetic Isotope Separators [1]. The liquid lithium pump has been constructed at Argonne and the other hardware is currently being fabricated at the NSCL.

The mechanical design of the loop for the high-power thick windowless target was also completed early in FY2002 and it was also reported at the EMIS conference [2]. This loop was constructed at Argonne and commissioned in the TD ALEX facility, with first operation in August. The first tests were with a 5-mm by 10-mm rectangular nozzle which performed well up to full pump current of 800 amperes, correspponding to a linear flow velocity of 12 m/s.

In addition, calculations were made for the nozzle design to guide future improvements in thickness and flow stability. The first experimental nozzle was machined as a continuous transition from a 22-mm diameter circle at the entrance to a 5-mm by 10-mm rectangular shape at the exit. Simulations of the flow exiting this nozzle explained the shape transitions near the nozzle exit. Calculations were made for a nozzle with the exit region changed to have a 5-mm long straight-sided section. The calculations and further experiments confirmed that this nozzle produced a larger rectangular cross section for the first few millimeters beyond the exit. A similar nozzle with a larger aspect ratio, 2.5 mm by 20 mm, showed that thicker targets can be made without increasing the volume flow-rate requirements.

A next step in the development is to add a heat exchanger for evaluation of the performance at high beam power. Simulations have been done by a consultant, Itacil Gomes, to show that a 1-MeV 40-kW electron beam can be used for this demonstration. Another next step is to install the thick windowless target at an appropriate nuclear physics facility to demonstrate the target uniformity and stability with real ion beams. Such a test will also be a crucial demonstration that the lithium target technology can be safely operated in a typical nuclear physics accelerator laboratory environment. This test is being planned for Texas A&M during 2003. Their 65-MeV proton and 130-MeV deuteron beams have the appropriate energy and range for use with the 1-cm and 2-cm thick lithium targets. Plans are underway for setting up this test at Texas A&M. We have requested funding from the DOE to support this continued work.

Visits to Texas A&M, NSCL, and GSI were made to initiate collaborations to carry out the stripper foil charge-state and energy straggling measurements. All three facilities have appropriate beams and instrumentation for carrying out these measurements. There are also interested collaborators at each institution. Foils of lithium, beryllium, carbon, sodium, and aluminum will be compared. It is possible that the best material for the stripper at 85 MeV/u will be liquid sodium rather than liquid lithium.

One of the remaining challenging problems is the demonstration that high velocity, thin lithium film, ~5 microns, can be produced in a vacuum appropriate for use at an accelerator. Preliminary concepts were evaluated during the past year. Various slit geometries and types of nozzles were tried with high-pressure water, first in air and recently in partial vacuum. To-date the most promising technique is to use a high-velocity, small circular jet at grazing incidence on a stainless steel plate. The tests with various nozzles have led to a very nice film produced from a 0.25-mm sapphire orifice with a water velocity of 33 m/s. A thickness estimated to be as low as 2 microns has been obtained in a partial vacuum of 70 Torr. The water pressure was 15 atmospheres. This preliminary success with water gives incentive for implementing a lithium system.

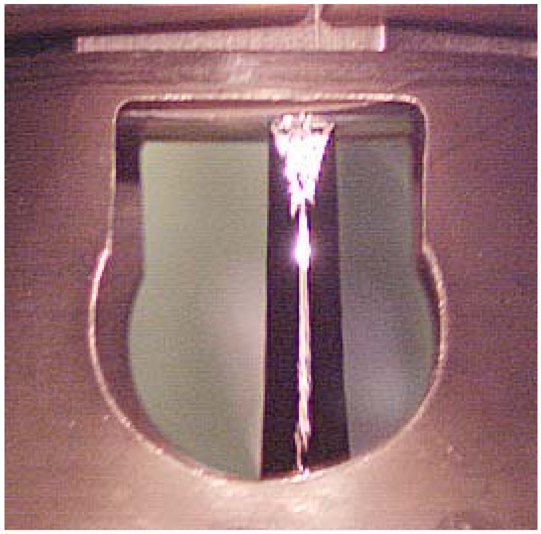
Specific Accomplishments: The references listed below contain material done during FY2002 under this topic. References 1, 2, and 4 were refereed, and reference 3 was an unrefereed invited paper.

[1] J.A. Nolen, *et al.,* “An Adjustable Thickness Li/Be Target for Fragmentation of 3-kW Heavy Ion Beams,” The 14th International Conference on Electromagnetic Isotope Separators and Techniques Related to their Applications (EMIS-14), May 6-10, 2002, Victoria, Canada, to be published in *Nucl. Instr. Meth. B*.

[2] J.A. Nolen, *et al.,* “Development of Windowless Liquid Lithium Targets for Fragmentation and Fission of 400-kW Uranium Beams,” *ibid.*

[3] J.A. Nolen, The U.S. Rare Isotope Accelerator Project," Proc. XXI International Linac Conference, August 19-23, 2002.

[4] C.B. Reed, *et al.,* "Engineering and Safety Issues for the Operation of Liquid Lithium Targets in a Nuclear Physics Laboratory," *American Nuclear Society Transactions*, **87**:516 (2002).



Photograph through the vacuum window of the first test of the 5-mm by 10-mm prototype windowless liquid lithium target. The lithium stream is 5-mm wide in this view. The bright triangular spot at the top is a very flat region.

Photograph of a ~5-micron thick water film moving at ~33 m/s in air. The initial water jet, above the plate is 0.25-mm diameter. The thin film area is ~1-cm in diameter.