2003-288-N0 -- THIN-FILM LIQUID-LITHIUM STRIPPER FOR THE RIA DRIVER LINAC

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Purpose: The high-power heavy-ion beams to be produced by the Rare Isotope Accelerator (RIA) driver linac have large energy deposition density in solids and in many cases no solid materials would survive the full beam power. Multiple charge state operation of the linac using superconducting accelerators enhances the beam output power by more than a factor of 10 for uranium ions. Hence, more than one stripper could be employed to achieve even higher charge states for efficient acceleration for heavy ions at different energies [1], e.g. the high intensity uranium beam could pass through two 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 strippers for these applications for use with the 400-kW uranium beams of the driver linac. Successful development of these high power strippers is 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.

Liquid lithium target technology exists at Argonne and will play an important role in the RIA. One particular application of liquid lithium technology in RIA is the windowless thin-film strippers needed within the driver linac to increase the charge state for more efficient acceleration. This application will require a sheet of about 10 microns thickness of flowing liquid lithium. First designs had been developed earlier using a high pressure, high velocity jet-sheet for the stripper.

Approach: Since neither the required film thickness nor the required film speed for thin film strippers are known with great confidence at this time, one objective of the work is to establish the lithium film thickness vs. velocity operating window that can be reliably attained in the presence of a hard vacuum at roughly 230°C. An example window is shown in Figure 1. Some nozzle testing in water was carried out earlier, taking advantage of the rough equivalence in kinematic viscosity between lithium and water ($\nu \sim 9 \times 10^{7}$ m^2/s), thus the same Reynolds numbers were achieved for equal film thickness and velocity. Water is a good working fluid for nozzle testing, but its applicability to film flow in this case is limited. Based on preliminary analysis, the required lithium film thickness for very heavy ions approaches the limit where the surface tension will break the continuous flow and the continuous liquid surface turns into droplets. Since the surface tension of lithium is roughly 5 times higher than water, and water testing is not possible in a hard vacuum, some water work in partial vacuum conditions in needed before it is necessary to carry out the remainder of the work with lithium, or a working fluid that can simulate lithium in vacuum.

Although the use of a liquid metal as an electron stripper has potential advantages over gaseous or solid materials, there are technical issues that need to be resolved. If lithium (Li) is used as a working fluid, a preliminary investigation, from the viewpoint of nuclear physics, indicates that the optimum thickness of such a liquid stripper could be as little as ~10 μm, depending on the beam energy. To provide consistent stripping characteristics, the shape, especially, the thickness of the film must be kept constant and stable. In addition, to avoid excessive vaporization of the liquid, the mass flow rate of the jet must be high enough to remove the thermal energy deposited in the film from the beam without a significant temperature rise. Therefore, producing a very thin, stable film jet with a high flow rate in a vacuum environment is a key element in the development of a liquid stripper [2].

Technical Progress and Results: A study was performed to investigate the factors controlling the stability of jets under the conditions expected in the RIA stripper environment. It was assumed that a thin film stripper could be modeled to first order as a two-dimensional jet, and an approach was developed for mapping the regions of instability using the Weber number, *We*, and the Reynolds number, *Re*, which are ratios of the inertia forces to the surface tension forces and of the inertia forces to the viscous forces, respectively. Conducting experiments to measure the intact length to assess the feasibility of the liquid stripper is therefore only necessary in certain regions of the *We*-*Re* plane, see Figure 2. A comparison of two other candidate thin film liquid metal working fluids, Ga and Hg, that have low enough vapor pressures to permit testing under vacuum, and are somewhat easier to handle than liquid lithium was carried out. The main conclusion was that the driving pressure necessary to produce a thin film of Hg via the mechanism of a small diameter round jet impinging on an angled flat surface was 43 times higher than that needed for Li, while Ga required 7 times higher driving pressure than that required for Li.

System designs were developed for two approaches to nozzle and thin film testing; once-through and closed loop systems, see Figure 3. The closed loop system could conceivably be designed to be near final configuration, however this approach implicitly assumes that a suitable pump is available, requiring little development time. The once-through, or blow down approach allows the flexibility of developing both the pump and the stripper nozzle in parallel.

Based on the above considerations, next steps for developing a thin film liquid lithium stripper are twofold: 1) a detailed analysis of the film instability using linear stability theory to obtain a stability diagram for lithium. This diagram will provide the range of design parameters, such as nozzle width and film velocity, that are potentially capable of producing a stable, smooth film, and 2) experimentally testing nozzles fabricated within the design range to measure the actual intact length of the film jet and to confirm that the intact length of the film is sufficient to be used as a stripper.

The preliminary design of a low flow, high-pressure pump, needed to overcome the pressure drop in the thin film nozzle, was also completed, see Figure 4. Preliminary drawings were produced, magnet field profiles were calculated, and magnet vendors were contacted for feedback on magnet design issues and cost estimates. Concerns over plugging of small diameter nozzle orifices opened up investigations of alternative methods for generating the thin film and the possibility of employing mechanical pumps that have been used previously on larger lithium systems.

To determine the intact length, the thickness, and the uniformity of the film jet, reliable diagnostic methods must be developed. Thin foils can be corroded and jets might experience instabilities that can compromise their functionality. Low energy electron beams can be used to detect any change in thickness enabling a continuous on-line monitoring of the thin film being monitored. The small energy deposition of the electron beam would not interfere with the main use of the material film and would allow monitoring at the same spot as an accelerator heavy ion beam strikes the jet.

The MCNPX Monte Carlo transport code was used to simulate the interaction of electron beams with a lithium film. The spatial and energy distribution of the scattered electron beam was scored in a plate placed at 30cm, in the beam direction, from the stripper. The radial mesh size on the plate varies from 0.01cm to 3cm and an azimuthal symmetry was assumed for the tally set up. The electrons were counted as they crossed the plane defining the plate. No interaction between the scattered beam and the collecting plate material was considered. The radial step for the segments varied from 0.1mm for the most inner segments to 3-cm for the most outer segments. For each segment, the total number of electrons crossing the annular region was scored. The total thickness of the lithium film was assumed to vary from 9 μm to 12 μm. The beam diameter was considered to be 0.1cm. Results of these calculations, made of a low energy electron beam as a diagnostic tool for on-line monitoring of thickness variations of thin jets, indicate that variations in lithium jet thicknesses at the micron level can easily be detected, see Figure 5.

Specific Accomplishments: The citations listed below document in more detail the work done under this topic. References 03-1, 03-2 and 03-3 were refereed.

[03-1] C.B. Reed, *et al.,* "Engineering and Safety Issues of Lithium Targets and Film Strippers," accepted for publication in the Proceedings of the Sixth International Topical Meeting on Nuclear Applications of Accelerator Technology, AccApp'03, San Diego, California (June 1-5, 2003).

[03-2] C.B. Reed, *et al*., "A 20 kW Beam-On-Target Test of a High-Power Liquid Lithium Target for RIA," presented at Radioactive Nuclear Beams 6, Argonne National Laboratory, Argonne, Illinois (September 22-26, 2003) and accepted for publication in *Nuclear Physics A*.

[03-3] I. C. Gomes, J.A. Nolen, C.B. Reed, “The Use of Electron Beams in RIA R&D,” presented at Radioactive Nuclear Beams 6, Argonne National Laboratory, Argonne, Illinois (September 22-26, 2003) and accepted for publication in *Nuclear Physics A*.

[03-4] C.B. Reed, *et al*., “Thick and Thin Liquid Lithium Targets,” presented at DOE Nuclear Physics Division RIA: R&D Workshop, Bethesda, Maryland (August 26-28, 2003).

General References

[1] K.W. Shepard, “The RIA Driver Linac,” Proceedings, XXI International LINAC Conference, Gyeongju, Korea (August 19-23, 2002).

[2] J. Nolen, "The U.S. Rare Isotope Accelerator Project," Proceedings, XXI International LINAC Conference, Gyeongju, Korea, p. 29-33, (August 19-23, 2002) [http://accelconf.web.cern.ch/accelco nf/l02/PAPERS/MO302.PDF](http://accelconf.web.cern.ch/accelconf/l02/PAPERS/MO302.PDF).

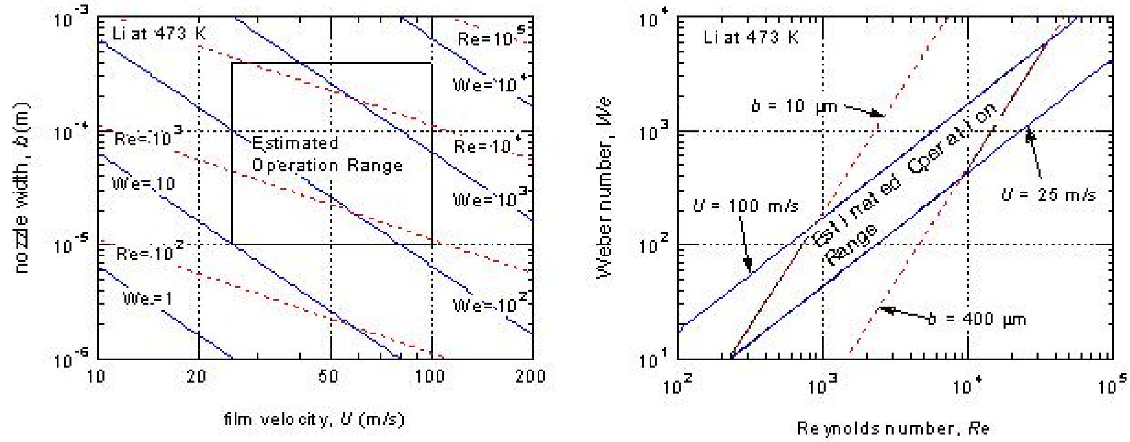


Fig. 1. Estimated range of operation for Li.

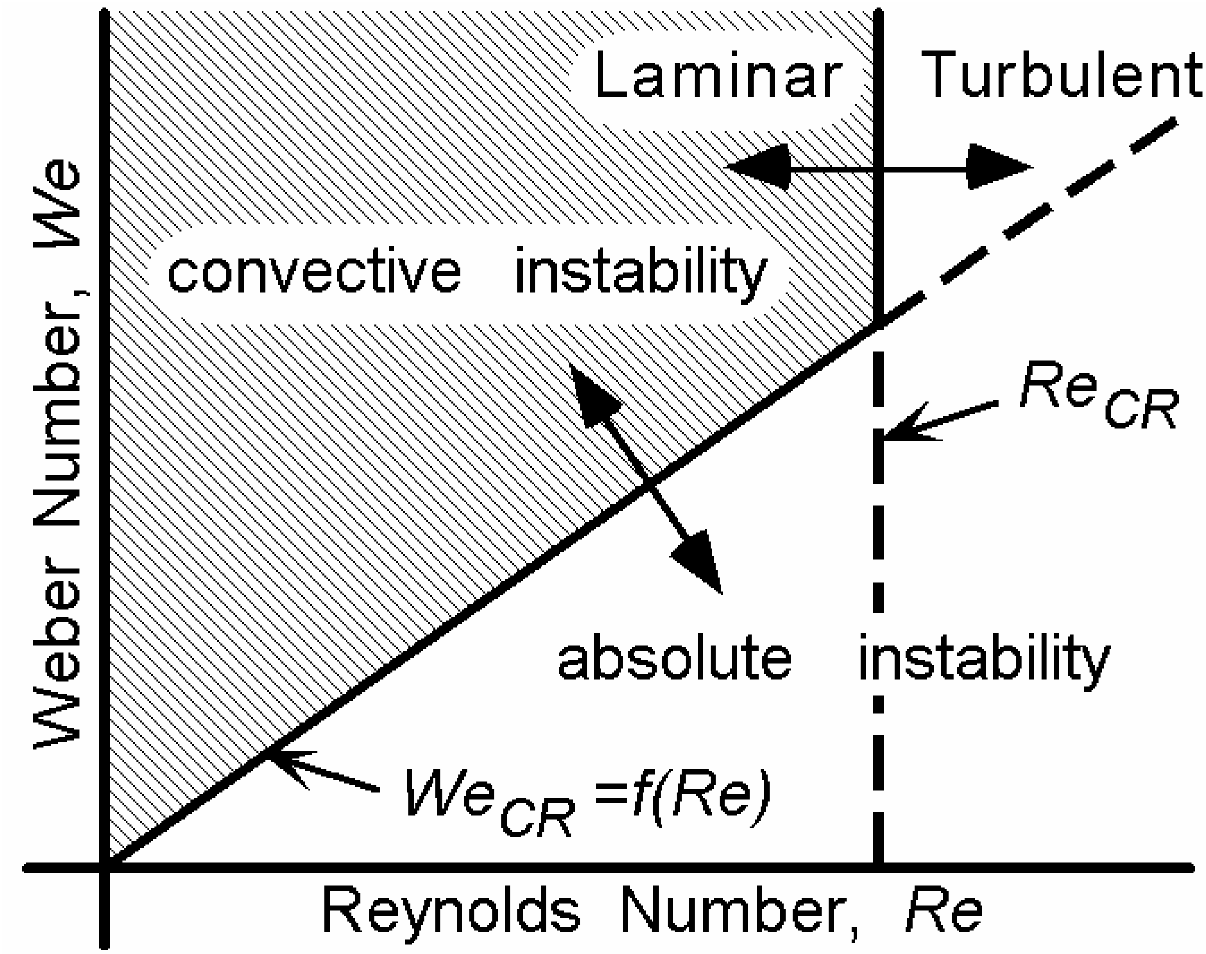
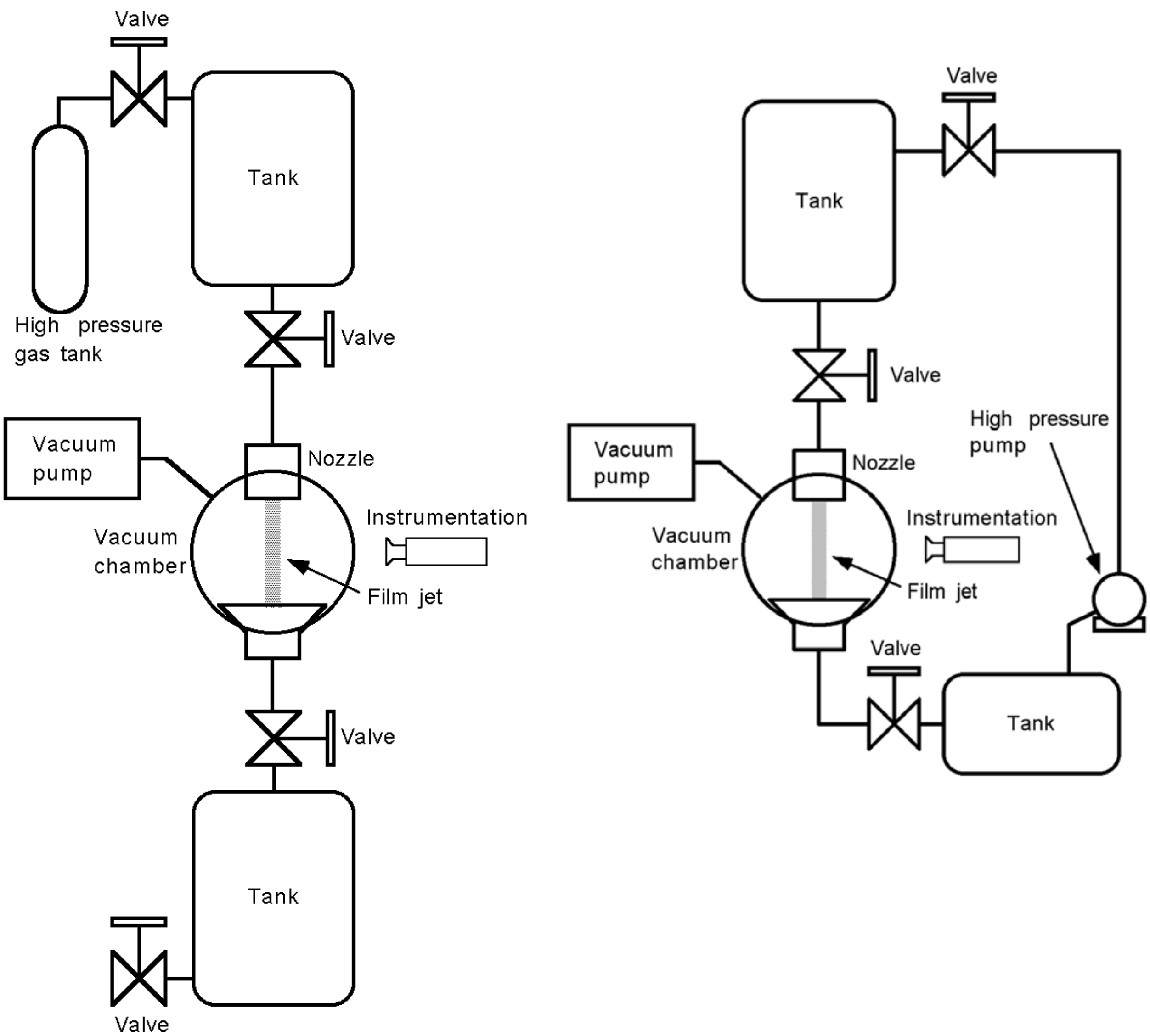


Fig. 2. Schematic Representation of Stability Diagram for a Jet in Vacuum.



a) Once-through system

b) Closed loop system

Fig. 3. Schematics of once-through and closed loop systems for development of stripper jet.

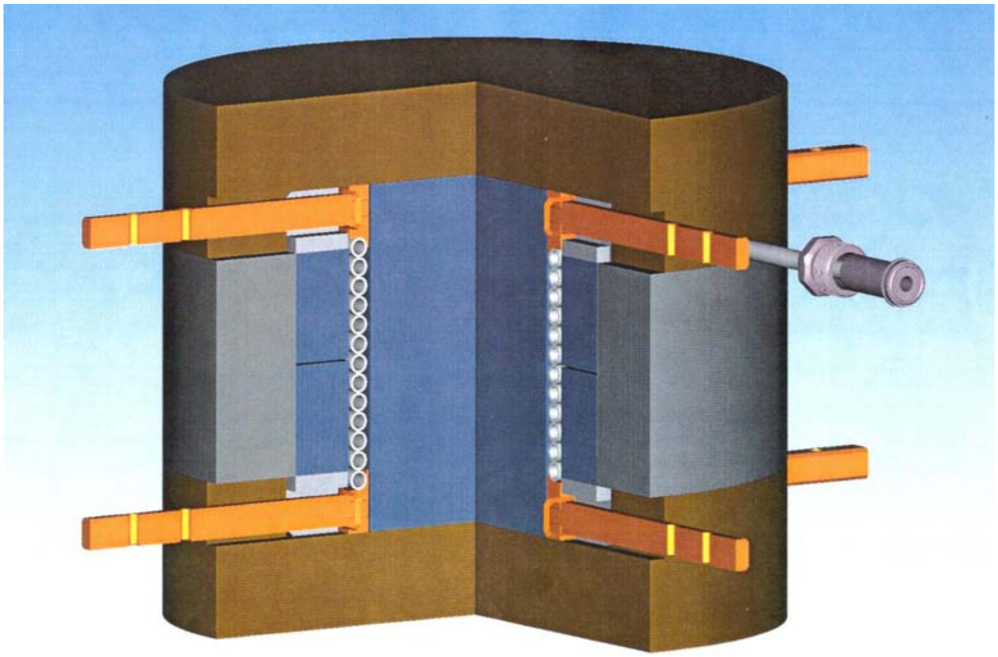


Fig. 4. High pressure Li pump for thin film stripper, after APS design.

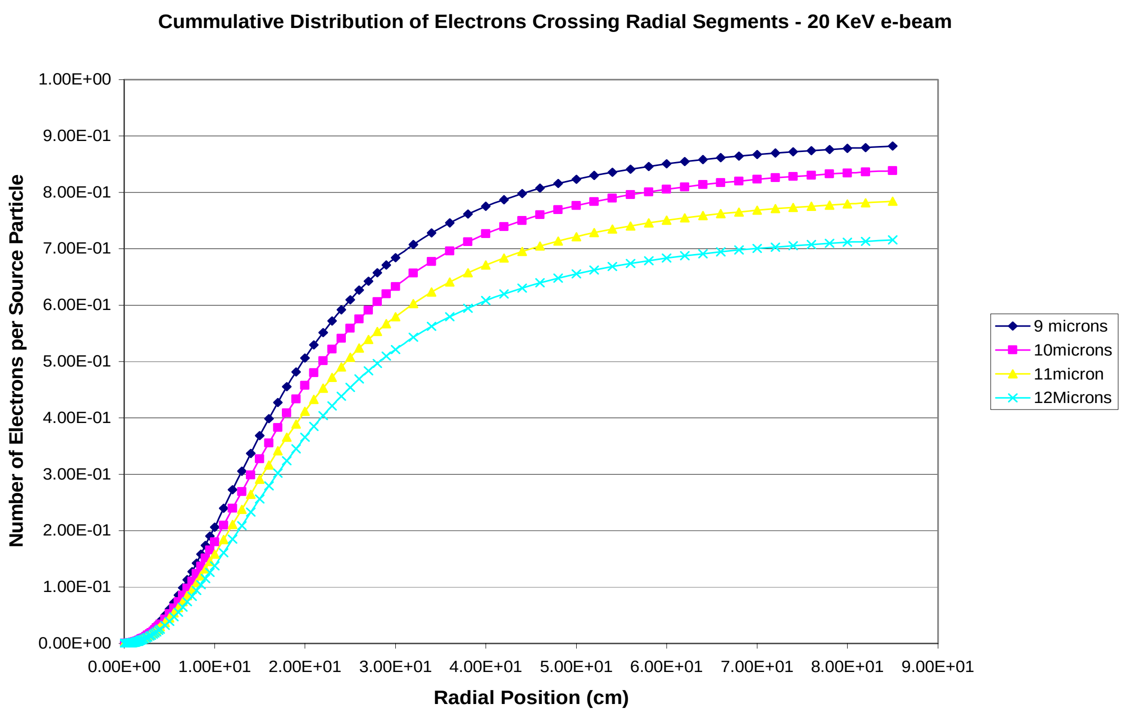


Fig. 5. A 20-KeV electron beam on a lithium film with 9 μm to 12 μm thickness. Plot shows cumulative charge collection on a plate placed 30-cm from the lithium film as a function of the radial position on the plate.