# A HIGH POWER WINDOWLESS LIQUID LITHIUM TARGET FOR RIA

*C.B. Reed*[1], *J.A. Nolen*[2], *V.J. Novick*[1], *J.R. Specht*[2],
*P. Plotkin*[1], *Y. Momozaki*[1], *I.C. Gomes*[3]

[1] *Nuclear Engineering Division,*
[2] *Physics Division, Argonne National Laboratory,*
*9700 S. Cass Avenue, Argonne, Il. 60439 (cbreed@anl.gov)*
[3] *I.C.Gomes Consulting & Investment Inc*

**Introduction.** One of the challenges in the Rare Isotope Accelerator (RIA) project is to develop a target that withstands extreme thermal loads from the powerful ion beam bombardment. A liquid lithium, windowless target is considered to be the best candidate due to its preferable nuclear and thermal properties [1, 2, 3].

The objective of the present work is to demonstrate the stable formation of a liquid lithium jet simulating the windowless liquid lithium target in RIA while being heated by a 1 MeV electron beam. Details of justifications on using an electron beam as a thermal load are available elsewhere [3, 4, 5]. The maximum power density deposited within the jet was equivalent to that of a 200 kW, 400 MeV/u uranium beam. The experimental setup included a lithium loop, beam line, and an electron beam source and various instrumentation. The behavior of the liquid lithium jet was visually observed to confirm jet stability during heating. The temperatures and the background pressure were also monitored to evaluate the capability of the jet to handle an extreme thermal load without excessive vaporization.

**1. Experimental layout, setup, and procedure.** The experimental setup consisted of the lithium loop, beam line, and Dynamitron electron beam accelerator. The Dynamitron accelerator was connected to the loop with a beam line in which the electron beam was delivered to the liquid lithium jet [4]. The beam line was maintained under vacuum at $< 10^{-6}$ Torr using turbomolecular and diffusion pumps. There were two 5 degree bends in the beam line to prevent any lithium droplets or vapor from reaching to the Dynamitron accelerator in the event of lithium jet splashing or disruption. The beam line also had two steering electromagnets to control the beam path just before each bend. Gate valves were located at the each end of the beam line to isolate the Dynamitron accelerator and the lithium loop in case of emergencies or maintenance.

The lithium loop was mainly constructed from stainless steel. Construction materials for the loop were discussed elsewhere [3]. The loop had an Ar gas supply as well as a diffusion pump. This arrangement enables the loop to be under either Ar or vacuum, however, the loop was usually kept under vacuum. The nozzle with an opening size of 5 mm in width and 10 mm in depth was located in the vacuum chamber at the downstream of the electromagnetic (EM) flow meter. A free jet of liquid lithium simulating the windowless target was formed at the exit of the nozzle. Sixteen ceramic band heaters with total of 17.6 kW at 208 V were attached to the loop to control the temperature. These heaters were connected in five groups, forming five independent zones around the loop; each zone had its own programmable temperature controller. Each temperature controller had a

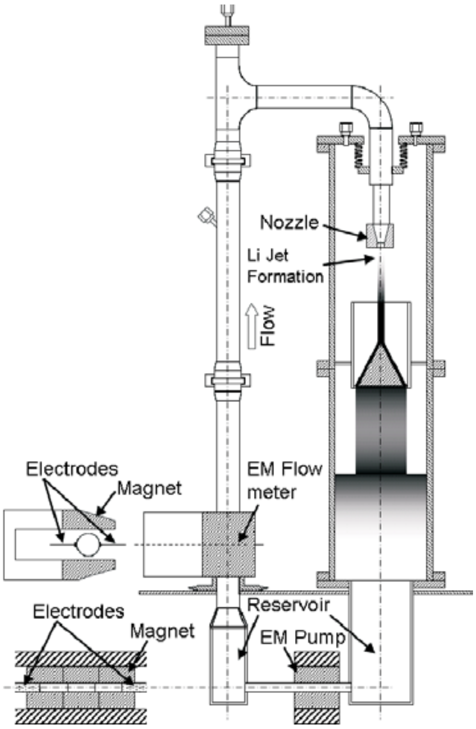

*Fig. 1.* Windowless lithium loop.

dedicated, type-K, TC to control the temperature of each zone. A DC EM pump located at the bottom of the loop was used to circulate the liquid lithium. The EM pump had a pair of permanent magnets (0.746 T) on the top and bottom of the pump ducts. The pump ducts were constructed from stainless steel and directly welded to the loop to minimize the potential of a leak. Two copper electrodes were brazed, one to each side of the pump and a programmable DC power supply (10 V × 1000 A) provided the DC current to the pump.

**2. Instrumentation.** The applied voltage was monitored across the pump. The pump current was also monitored by means of measuring the voltage drop across a shunt resistor connected in series with the power supply. The loop was also equipped with a DC EM flow meter downstream of the EM pump. The EM flow meter consisted of a 0.086 T permanent magnet and 1 inch schedule 40 stainless steel piping with two electrodes. The flow rate was obtained by measuring the voltage across these two electrodes of the flow meter. The flow meter calibration was determined by transferring a previous calibration of the flow meter performed in Na to the presently used Li. However, since the magnetic field created by the flow meter magnet disturbed beam focusing, the magnet was removed and the flow meter was not used during beam-on-target experiments. Using the flow meter, the volumetric flow rate of lithium and the jet velocity at the nozzle were determined as a function of the pump current.

The loop had 20, type-K monitoring TCs attached at various locations including on the EM pump ducts, EM pump magnets, and the EM flow meter magnet. One of these monitoring TCs was inserted into the lithium jet during the experiments [4]. All monitoring TCs were connected to a chart recorder for data collection. The pressures at the various locations of the loop were monitored by pressure transducers and thermocouple gauges. The pressure data and the voltages across the EM pump, flow meter, and the shunt resistor connected in series with the power supply were monitored by a data acquisition DAQ card attached to a PC, which also collected temperature data from the chart recorder via a General Purpose Interface Bus (GPIB). Data acquisition was controlled by the LabVIEW program.

Since the high level of X-rays during the experiments did not permit direct visual observation of the lithium jet, a remotely controlled digital camcorder was employed to record and monitor visual images of the lithium jet through a viewport attached to the loop near the nozzle. Two types of window material were used; quartz and sapphire. Of the two, sapphire has better IR transmission. Depending on the beam power, the quartz window showed brown discoloration from X-ray irradiation. To shield the camcorder from direct X-ray exposure, the visual images were reflected at right angles using a mirror located near the viewport, allowing several lead bricks to be placed between the camcorder and the loop where the X-rays were generated by electron beam bombardment on the lithium jet (or surrounding stainless structures in case of miss-steering of the beam). This optical setup was replaced with an IR camera, gold plated mirror, and telescope to observe IR images of the lithium jet for measuring the surface temperature distribution of the jet.

**3. Experimental procedure.** A typical experiment started by heating the loop to around 220°C. After all temperatures along the loop were stabilized, the pump current was increased slowly. The lithium jet was usually formed when the pump current reached around 50 A. The formation of the jet was confirmed visually through the viewport. After the jet flow was established, the Dynamitron accelerator was turned on for electron beam irradiation at low power. The beam spot appeared as a white-blue dot on the lithium jet. The spot diameter was controlled via a focusing coil about 1 m from the target. A beam diameter of 1 to 1.5 mm was used during the high power tests. The location of the beam spot relative to the jet was carefully adjusted by changing the current to the two steering magnets. Once the location of the beam spot was set, a digital camcorder started recording visual images and the beam power was increased to the desired level. The temperatures, pressure, and other voltage signals including the pump current and voltage were recorded every one second during the experiment (see Fig. 2). The recorded visual images as well as temperatures, pressure, and voltages form the basis of the present work.

**4. Results.** Preliminary experiments were conducted at low beam powers to ensure the stability of the lithium jet during beam irradiation. After confirming the stable operation of the jet with low power beams, a series of experiments at increased beam powers up to 20 kW was performed. Since there was no heat exchanger in the loop, deposited thermal energy accumulated within the loop, increasing the bulk lithium temperature. Such temperature increases limited continuous operation of the loop at high beam power. Therefore, the duration of each run at high beam power was typically limited to a few minutes.

Fig. 1 shows the history of measured temperatures at the nozzle and the splash shield, and background pressure taken at the highest beam power of 20 kW. The pump current was kept at 200 A at which the estimated jet velocity was about 1.8 m/s. The beam power was increased quickly (20 kW over $\sim$ 30 seconds) to minimize the temperature rise in the system. As a result, a steady beam power of 20 kW was achieved for about 55 seconds. A steady, 55 seconds of electron beam irradiation at 20 kW resulted in a temperature rise of $\sim$ 30°C in bulk lithium temperature. The observed increase in pressure was only $\sim$ 0.3 mTorr (from 0.8 to 1.1 mTorr) during the experiment. It must be noted that

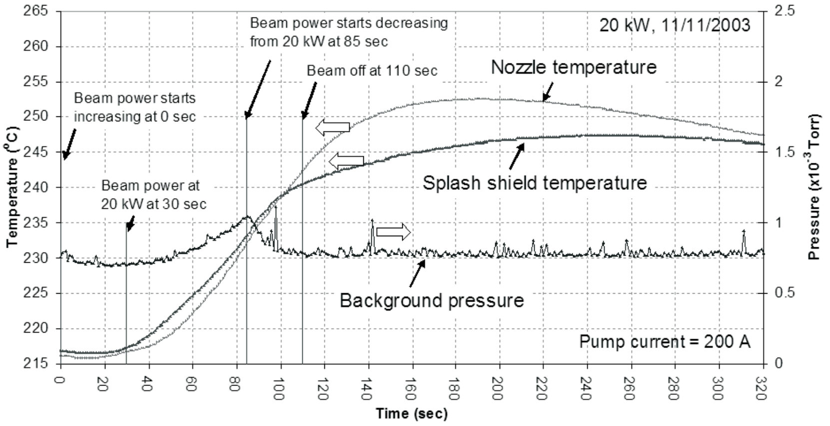

*Fig. 2.* History of measured temperatures and pressure.

because some beam energy was emitted as X-rays and absorbed by surrounding structures, temperatures kept increasing even after the beam was shut off, while energy stored in the surrounding structures was released. The observed increase in the background pressure was as high as ∼ 0.9 mTorr (from 0.5 to 1.4 mTorr) during the experiment.

Video images showed stable operation of the liquid lithium jet under an extreme thermal load of 20 kW. All other images recorded at various beam powers showed similar results, confirming stable flow of the jets under thermal loads up to 20 kW. For the beam diameter used in this experiment, the total power deposited in the 1 cm thick lithium jet and the power density in the jet are equivalent to those of a 200 kW, 400 MeV/u uranium beam in RIA.

**5. Summary and conclusions.** Experiments were performed to demonstrate the stable formation of a liquid lithium jet that simulates the windowless liquid lithium target under a thermal load similar to that of RIA using a 1 MeV electron beam. Stable jet formation under beam powers up to 20 kW were confirmed at a jet velocity as low as 1.8 m/s. A 55 second beam irradiation at 20 kW resulted in a temperature rise of only ∼ 30°C in bulk lithium temperature and a background pressure rise of only ∼ 0.3 mTorr.

## REFERENCES

1. J.A. Nolen, C.B. Reed, A. Hassanein, and I.C. Gomes. Liquid-lithium cooling for 100-kW ISOL and fragmentation targets. *Nucl. Phys. A*, vol. 701 (2002), pp. 312c–322c.
2. J.A. Nolen. Overview of the U.S. Rare Isotope Accelerator Proposal. *Nucl. Phys. A*, vol. 734 (2004), pp. 661–668.
3. C.B. Reed, J.A. Nolen, J.R. Specht, and V.J. Novick. Engineering and Safety Issues of Lithium Targets and Film Strippers. In *Proc. Sixth International Meeting on Nuclear Applications of Accelerator Technology (AccApp'03)*, (San Diego, CA, June 1–5, 2003), pp. 556–559.
4. C.B Reed, J.A. Nolen, J.R. Specht, V.J. Novick, and P. Plotkin. A 20 kW Beam-on-Target Test of a High-Power Liquid Lithium Target for RIA. *Nucl. Phys. A*, vol. 746 (2004), pp. 161c–165c.
5. I.C. Gomes, J.A. Nolen, and C.B. Reed. The Use of Electron Beams in RIA R&D. *Nucl. Phys. A*, vol. 746 (2004), pp. 453c–456c.