Progress of Liquid Lithium Stripper for FRIB

T. Kanemura, J. Gao, M. LaVere, R. Madendorp, F. Marti, Y. Momozaki[1]

FRIB, Michigan State University, East Lansing, USA
[1]also at Argonne National Laboratory, Lemont, USA

MICHIGAN STATE UNIVERSITY

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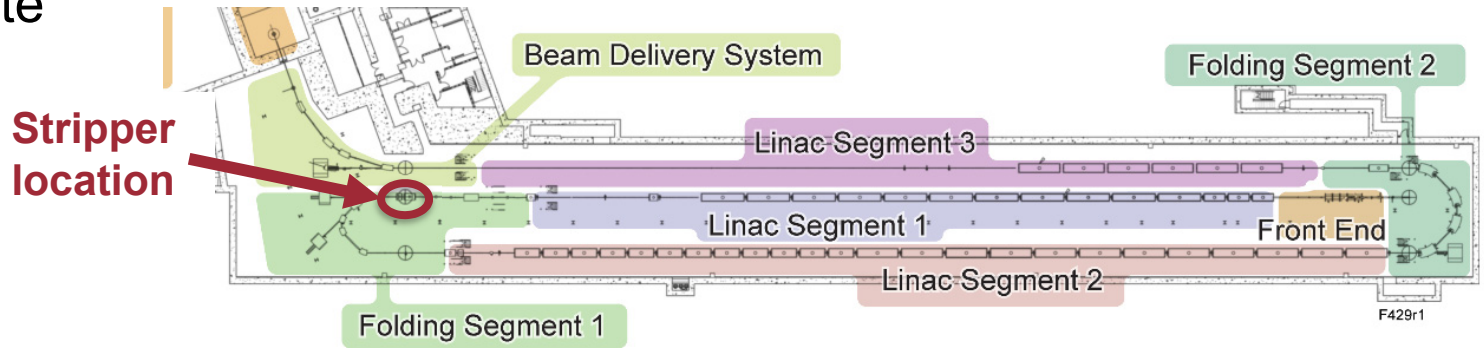
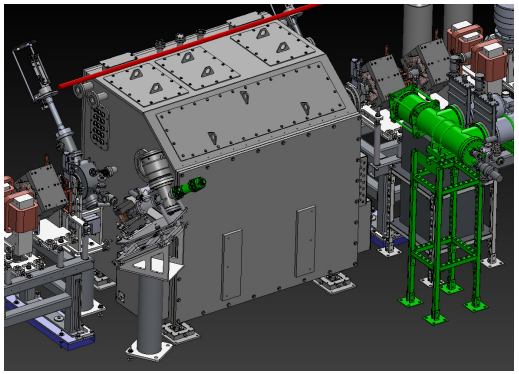
Scope of FRIB Charge Strippers

Design, Construct, Test, and Commission Carbon and Lithium Strippers for FRIB Driver Linac

- Carbon stripper (conventional stripper)
  - Solid carbon foils for low intensity beams: Commissioned with beam
- Lithium stripper: baseline choice
  - Thin liquid lithium film for high intensity beams: Commissioning at offline test site



Carbon stripper installed to beamline



Lithium stripper module designed to be installed to beamline

Lithium stripper module operational at offline test site

Lithium Charge Stripper Project Overview

- Prototype lithium stripper for feasibility demonstration: 2005 – 2013 [1,2]
  - Establishment of lithium film and thickness measurement at ANL: December 2010
  - Restoration of Low Energy Demonstration Accelerator (LEDA) proton source for lithium stripper test: 2013
  - Full (2X) power density test of lithium with proton beam at ANL: April 2013
- Fabrication of lithium stripper system 2013 – 2017
  - Liquid stripper lithium electromagnetic pump test: April 2017
  - Integrated controls test with Ar safety system: October 2017
  - Lithium charge stripper device assembled: December 2017
- Commissioning at offline test site: 2018 – 2020
  - Lithium circulated with the electromagnetic pump: August 2018
  - Continuous operation for an extended period: September 2018
  - Demonstration of nozzle and deflector replacement: November 2018
  - E-gun system offline test completed: March 2019
  - Unattended operation for an extended period: March 2019
  - Measurement of lithium film with electron gun system
- Online beam commissioning: 2020 –
  - Integrated test with beam in tunnel

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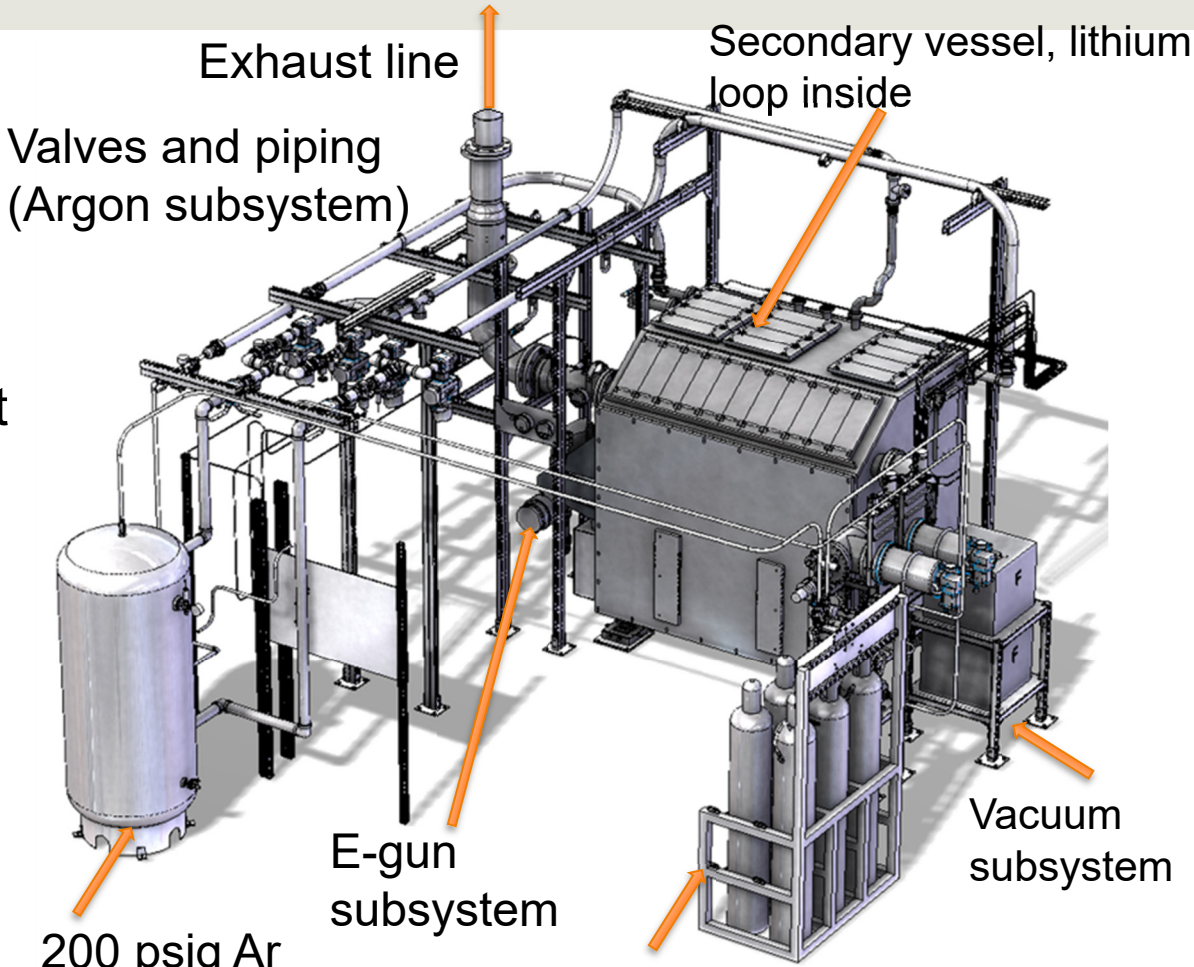
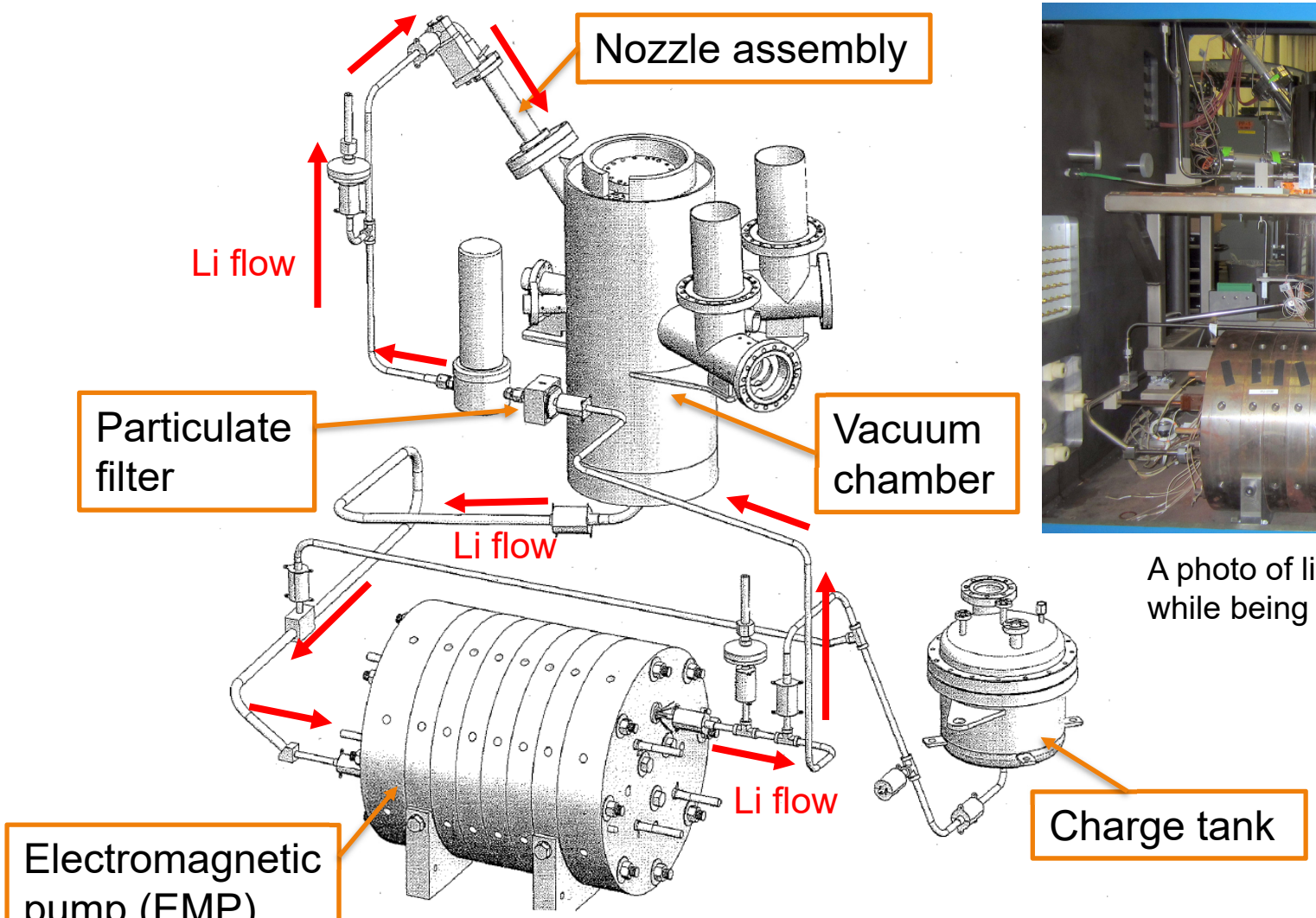
[1] Y. Momozaki et al., *J. Radioanal. Nucl. Chem.*, vol. 305, pp. 843-849, 2015.
[2] F. Marti *et al.*, in *Proc. 6th IPAC'15*, Richmond, VA, USA, May 2015, pp. 1339-1342.

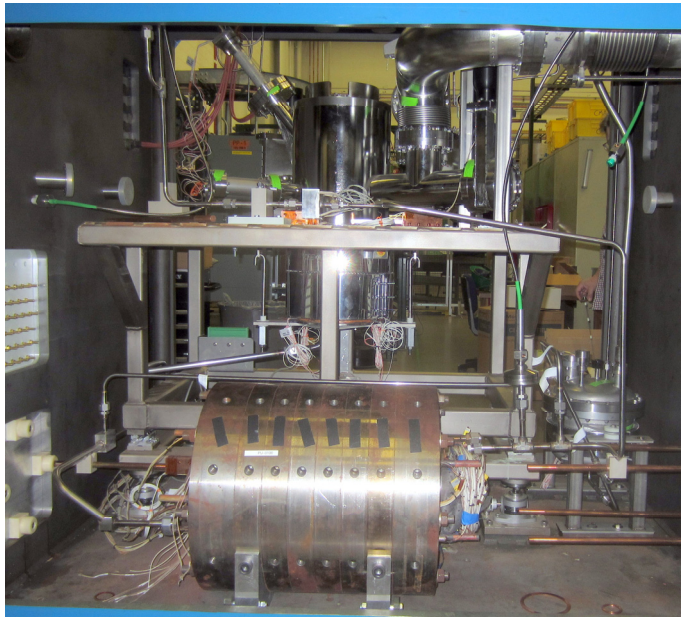
Lithium Stripper Module at Offline Test Site

- Lithium loop
  - Completely enclosed by the secondary vessel
- Secondary vessel
  - Serves as a safety component, filled with inert argon, to prevent lithium-air reaction in case lithium leaks.
- Argon subsystem
  - Serves as a safety function, e.g. in case loss of vacuum is detected in the Li vacuum chamber, it is backfilled with argon
- Vacuum subsystem
- Electron gun (E-gun) diagnostics subsystem



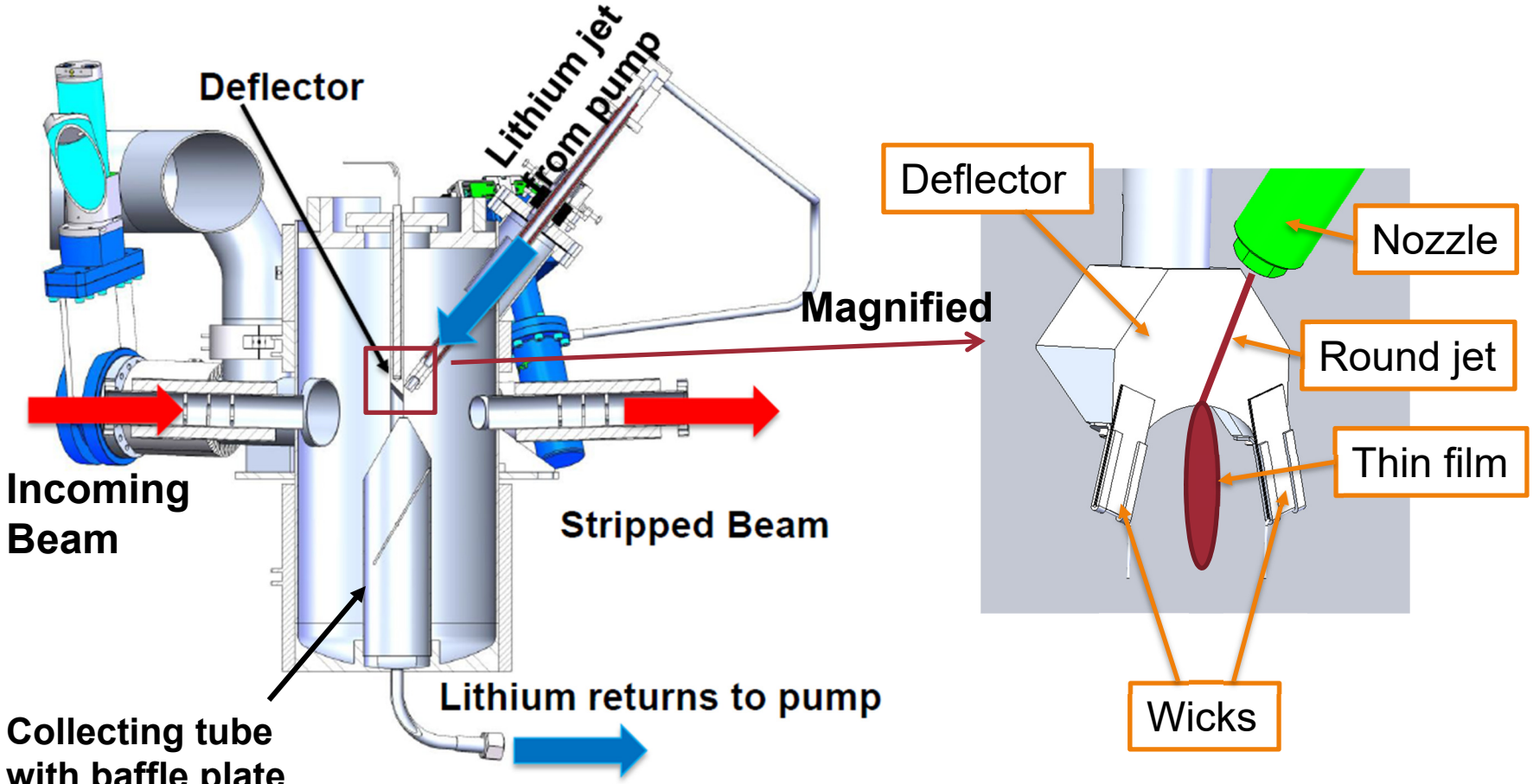
Lithium Loop Configuration





A photo of lithium loop taken while being assembled

Lithium Film is Formed by Hitting Round Jet on Deflector in the Vacuum Chamber



This film formation scheme was established at ANL:
Y. Momozaki et al., *JINST* 4 (2009) P04005.
Y. Momozaki et al., *J. Radioanal. Nucl. Chem.*, vol. 305, pp. 843-849, 2015.

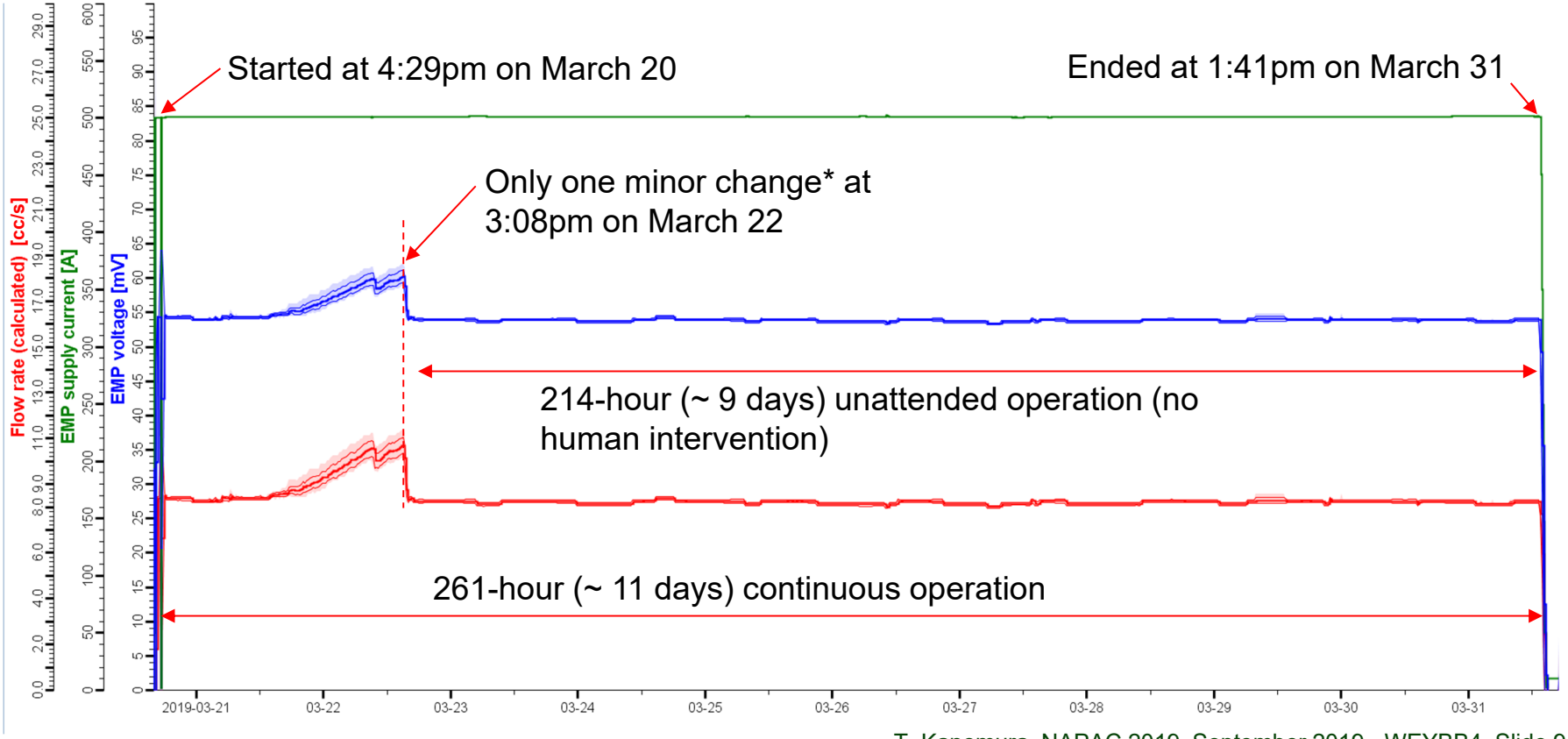
Commissioning at Offline Test Site In Progress

- Lithium loading into the charge tank: May 2018
- Lithium charging of the loop: August 2018
- Lithium circulation with the electromagnetic pump: August 2018
- Continuous operation for an extended period: September 2018
- Demonstration of nozzle and deflector replacement: November 2018
- Unattended operation for an extended period: March 2019
- E-gun subsystem offline test completed: March 2019 [1]
- E-gun subsystem integration to the module completed: June 2019
- E-gun subsystem re-commissioned: July 2019

[1] J. Gao, et al., paper MOPLO02, this conference

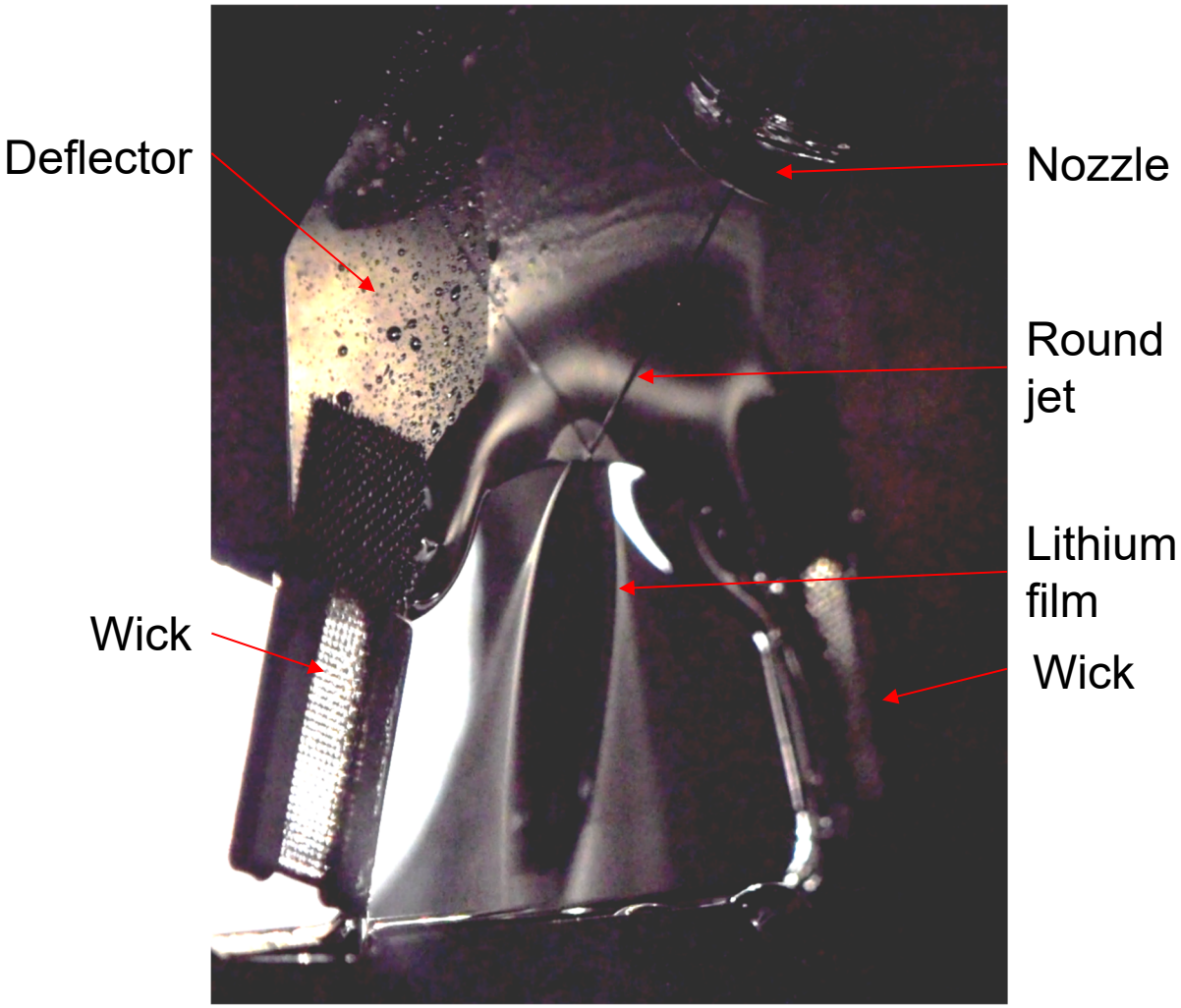
Successful Unattended Operation for More Than 10 Days: Reliable Operation Proved

- Operation parameter
  - EMP supply current: 500 A (discharge pressure: 135 psi)
  - EMP voltage: 54 mV (Flow rate: 8.2 cc/s)
  - Vacuum pressure: ~1e−7 Torr
  - Total operating period: 261 hours (~ 11 days)



Liquid Lithium Film Produced

- Flow parameters
  - EMP discharge pressure: 135 psi
  - Jet speed: 61 m/s (EMP discharge pressure of 135 psi)
  - Vacuum pressure: 1 x 10^{-7} Torr.

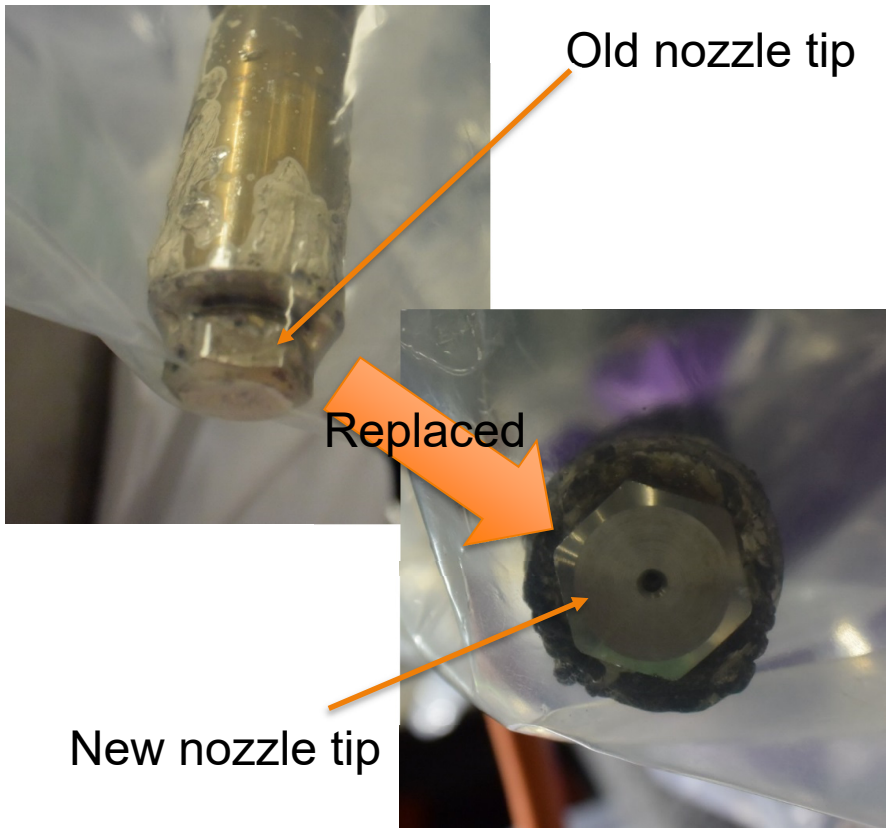


Lithium Stripper Maintenance Plan Getting Matured

- During the offline test period, one of our main focuses is to develop detailed lithium stripper maintenance plan, especially maintenance works requiring lithium handling in terms of ESH and QA aspects
- To handle lithium safely, we have practiced the following safety controls:
  - Make sure lithium is solid at room temperature before any maintenance works
    - » Because lithium is not pyrophoric at room temperature
  - Keep away from any water source
    - » Because lithium is reactive with water generating hydrogen
  - Keep away from any heat source
    - » Because reactivity of lithium increases with temperature
  - Only trained personnel allowed to perform maintenance
    - » Because untrained workers might jeopardize the safe works.
  - Wear proper PPE to eliminate possible contacts with lithium
    - » Because lithium is caustic (lithium burns the skin)
- To keep lithium uncontaminated (machine protection), we handle lithium under an inert argon environment using a glove bag monitoring an oxygen concentration (< 0.2 vol.%).

Lithium Stripper Maintenance Plan Getting Matured

- Lithium handling maintenance works conducted so far are
  - Lithium loading
  - Connection of the lithium filled electromagnetic pump to the plumbing
  - Replacement of nozzle and deflector that had been used with lithium
  - Replacement of lithium pressure sensors
  - Replacement of vacuum chamber viewports
  - Installation of electron beamline gate valve to the vacuum chamber
- Every work was done safely
- Those procedures will be combined into “lithium stripper maintenance manual”



Summary and Path Forward

- Since the FRIB chose liquid lithium as its baseline charge stripping media, we have strived for establishing the liquid lithium stripper.
- We have so far constructed the lithium stripper module at an offline test site and been commissioning the module accumulating operational experience and developing maintenance plan and procedures.
- The next step is to characterize the lithium film stability with the electron gun subsystem. In 2020, we plan to bring the lithium stripper into the accelerator tunnel and commission it with ion beams.