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Engineering and Design Activities at Los Alamos National Laboratory Supporting Commercial U.S. Production of ^{99}Mo without the Use of HEU

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^{99}Mo Topical Meeting

Boston, MA

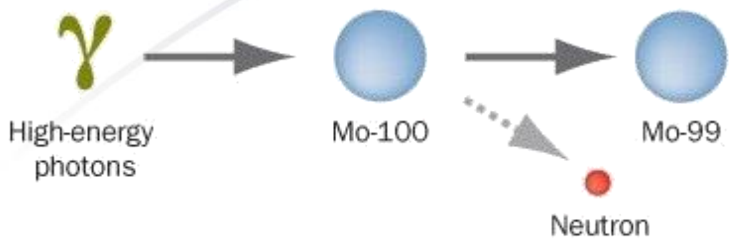
September 3, 2015

NNSA
National Nuclear Security Administration

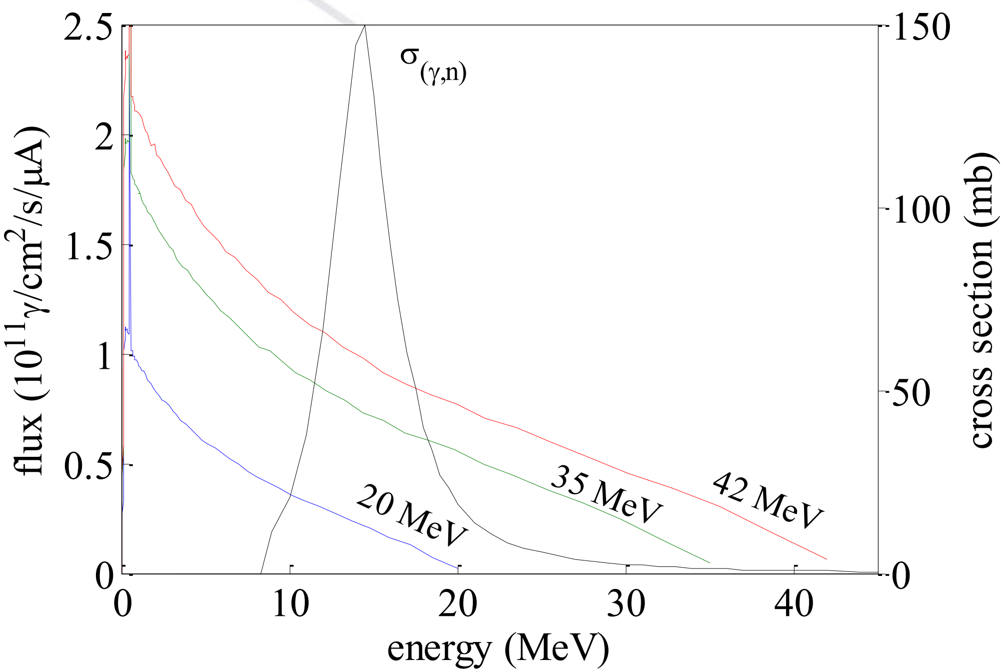
LANL Support for Domestic ^{99}Mo Production

- As part of the NNSA Material Management and Minimization (M^3) Program, LANL is supporting:
  - NorthStar Medical Radioisotopes with the electron accelerator production of ^{99}Mo from ^{100}Mo(γ,n)^{99}Mo.
  - Shine Medical Technologies with the production of fission product ^{99}Mo from a DT accelerator driven subcritical uranium salt solution.

NorthStar Electron Accelerator Production



- The NorthStar process uses an electron accelerator to create a high flux of bremsstrahlung photons in enriched ^{100}Mo targets to create ^{99}Mo through the photonuclear reaction $^{100}Mo(\gamma,n)^{99}Mo$.
  - Reaction threshold is 9 MeV.
  - Peak cross section is 150 mb at 14.5 MeV.
- We are exploring electron beams in the 35-42 MeV range.



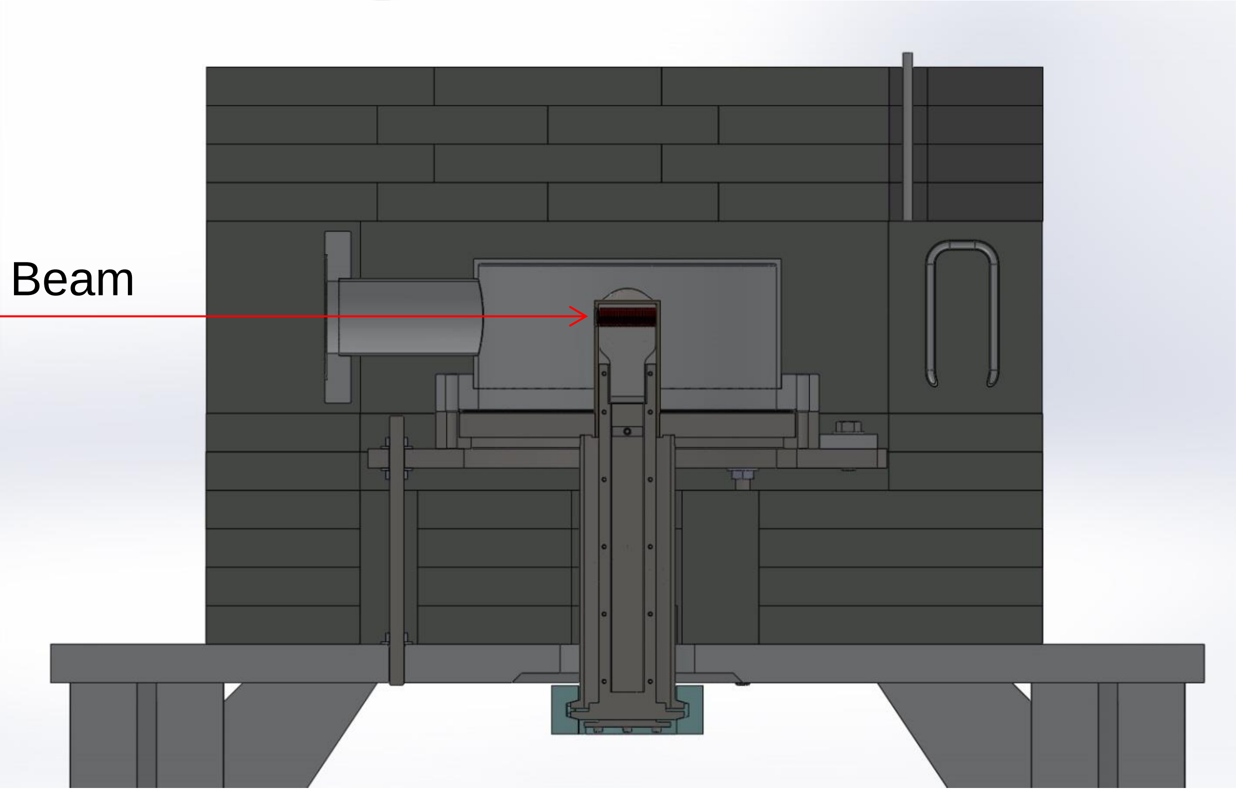
Average bremsstrahlung photon spectra produced with 20, 35, and 42 MeV electron beams in a Mo target compared to the photonuclear cross section of ^{100}Mo.

NorthStar Support Focus Areas

- Production and Thermal Tests at ANL
- Target Design and Testing
  - Target thermal performance
  - Production and radionuclide inventory
- Subsystem Development and Testing
  - Beam diagnostics
  - Target cooling system
  - Control systems
- Production Facility Design Support
  - Local target shielding
  - Beam line design
  - Target removal and conveyance

LANL Designed NorthStar Target Testing at ANL

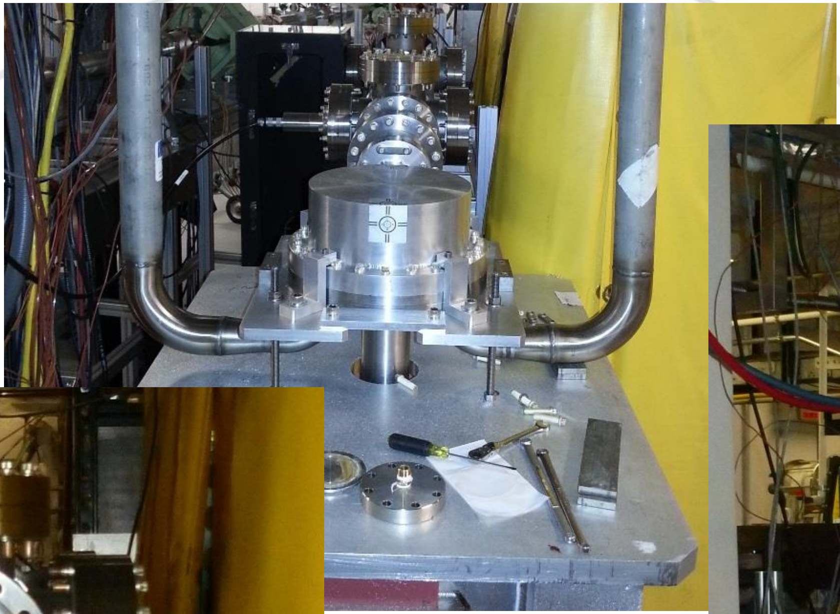
Target Side View

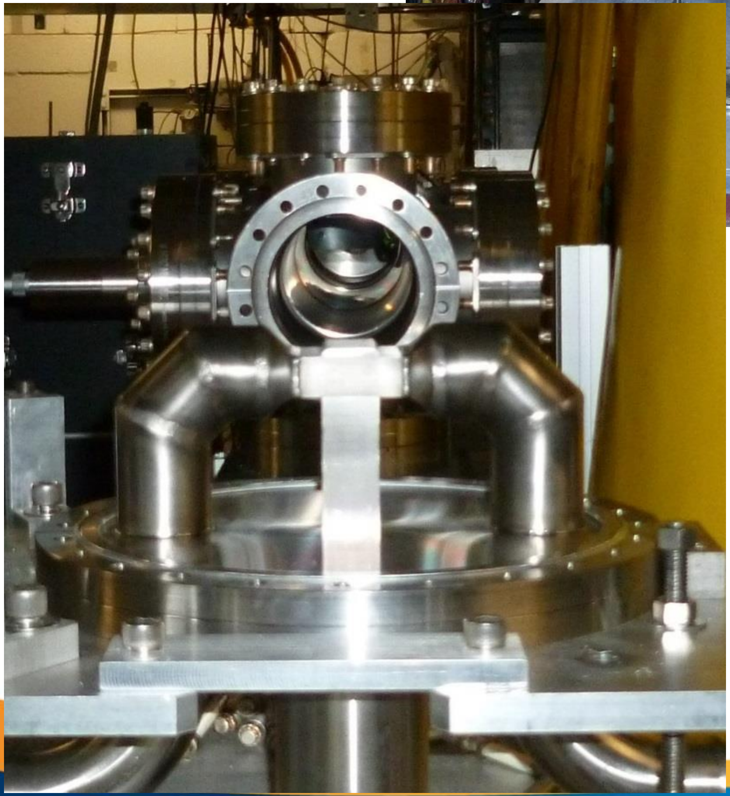


LANL designed single sided target for thermal and production tests

Target consisting of 25, 12 mm diameter, 1 mm thick disks with 1 mm cooling gaps

Thermal Test Target installed at ANL



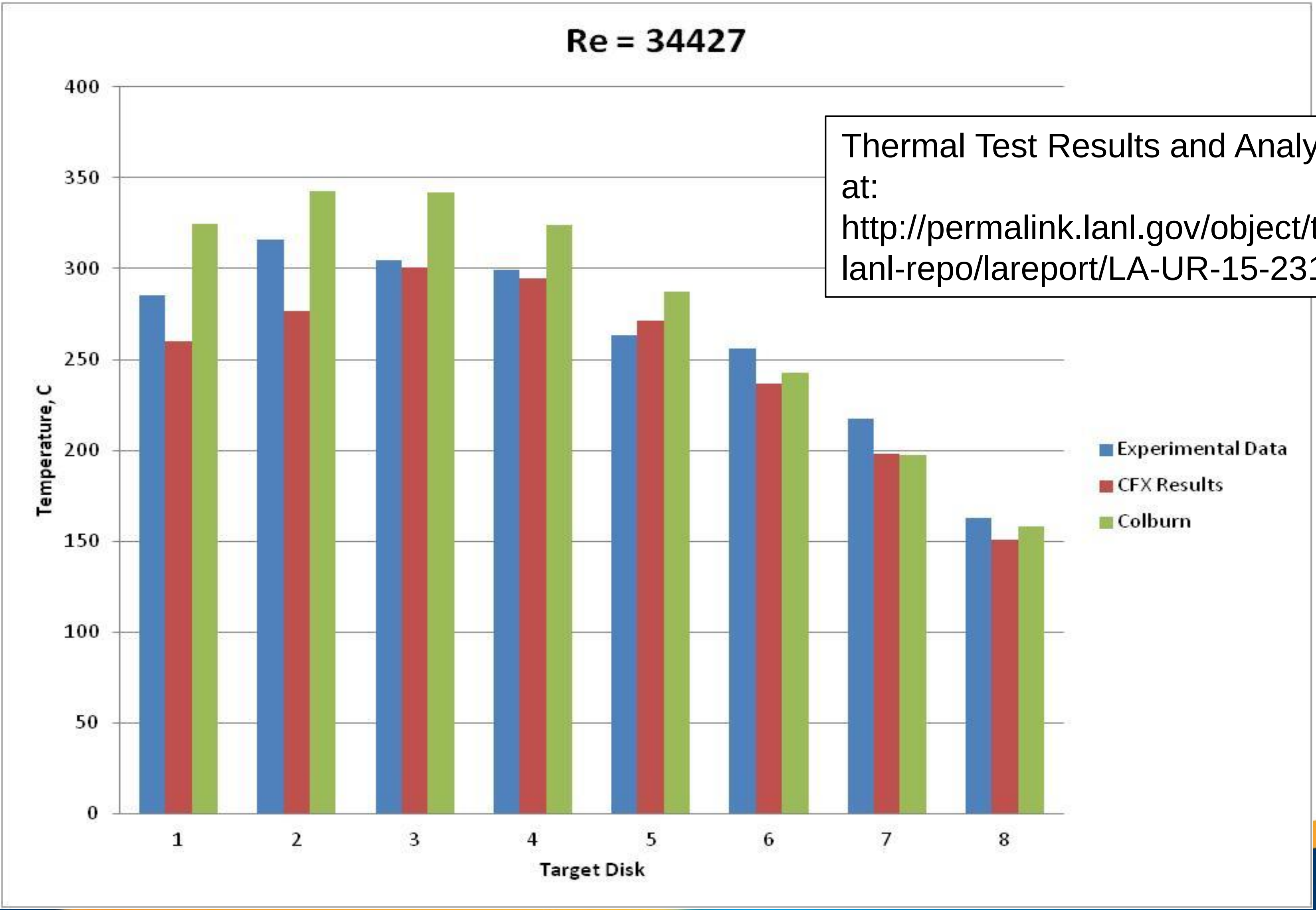


Scaled Accelerator Tests at ANL

Date	Test
April 2010	Water cooled target test using natural Mo targets, produced 236 µCi of ^{99}Mo.
May 2010	Water cooled target test using natural Mo targets, produced 377 µCi of ^{99}Mo.
July 2010	Water cooled production test using enriched ^{100}Mo targets, produced 10.5 mCi of ^{99}Mo.
April 2011	Once through gaseous helium cooled thermal test using natural Mo targets, 145 µCi of ^{99}Mo.
March 2012	Closed loop gaseous helium thermal test using natural Mo targets.
April 2014	Closed loop gaseous helium thermal test using natural Mo targets.
January 2015	35 and 42 MeV thermal tests at 13 kW and 7 kW, respectively. ~ 5 mm FWHM beam.
January 2015	Production Test 1: 42 MeV, 19 hours, 4.8 kW
March 2015	Production Test 2: 42 MeV, 19 hours, 7 kW
March 2015	Production Test 3: 42 MeV, 19 hours, 6 kW
May 2015	Production Test 4: 35 MeV

January 2015 Thermal Test

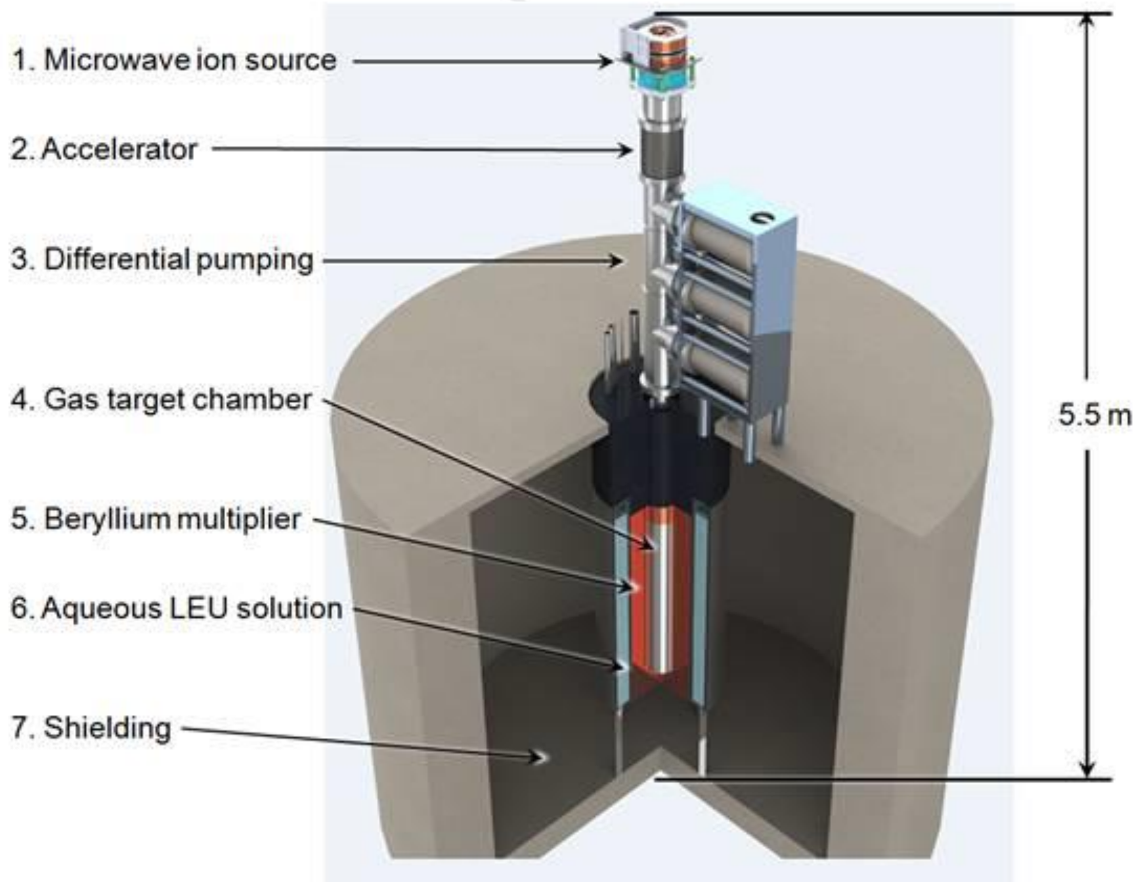
Target Thermocouple Data from the January 2015 Thermal Test 35 MeV, 13 kW beam, 290 psi inlet, 97 g/sec



Thermal Test Results and Analysis available at: http://permalink.lanl.gov/object/tr?what=info:lanl-repo/lareport/LA-UR-15-23134

SHINE Medical Technologies Production Overview

SHINE Medical Technologies will produce fission product ^{99}Mo in a subcritical accelerator driven low enriched uranium salt solution



SHINE Support Activities

- Thermal hydraulics modeling
- Dynamic system simulation
  - System dynamics and reactivity modeling
- Gas nozzle design for the accelerator target
- Irradiations and separations chemistry
  - Measurement and control of the total uranium concentration
- Evaluation of the tritium recycle loop and associated systems (in partnership with SRNL)
- Zr Clad DU target fabrication
  - For the ANL photoneutron target for the mini-SHINE experiment.

Thermal Hydraulic Modeling

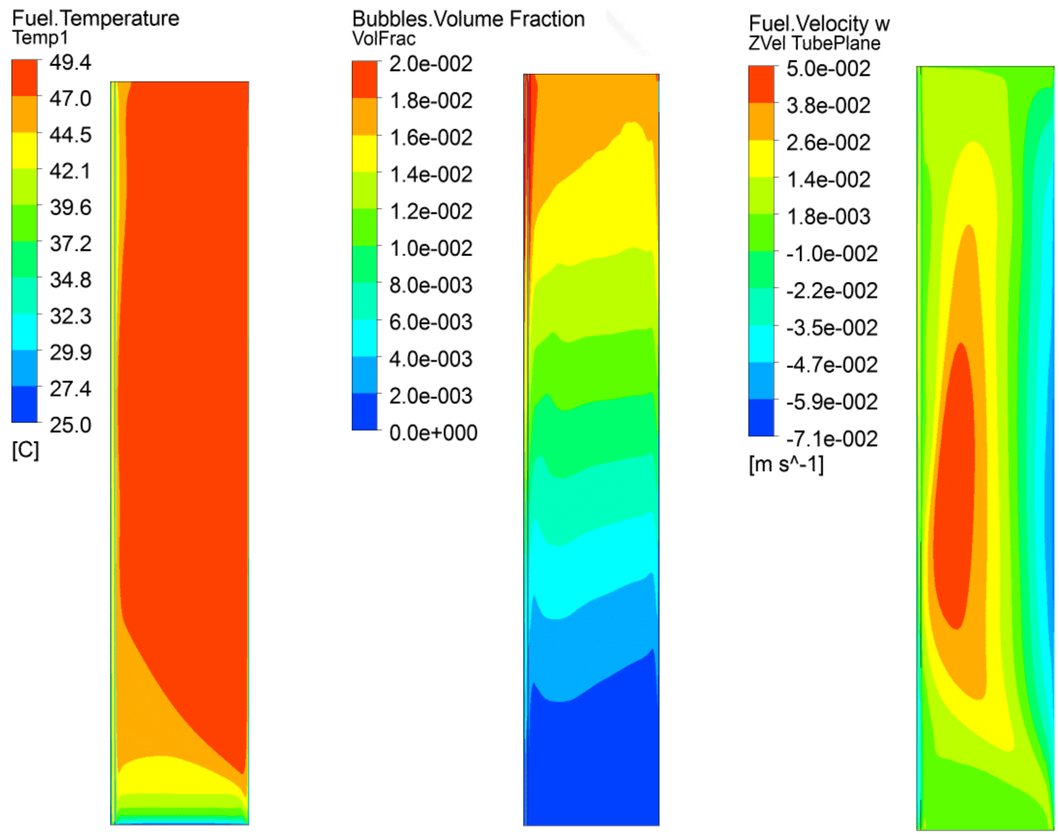
Fluid dynamics model developed to calculate steady state temperature and void fraction profiles for an externally cooled fuel solution vessel.

Computational fluid dynamics calculations performed in Ansys FLUENT.

- Heat transfer by natural convection enhanced by bubble generation
- Non-uniform volumetric heat and bubble generation profiles
- Temperature-dependent fuel and gas properties

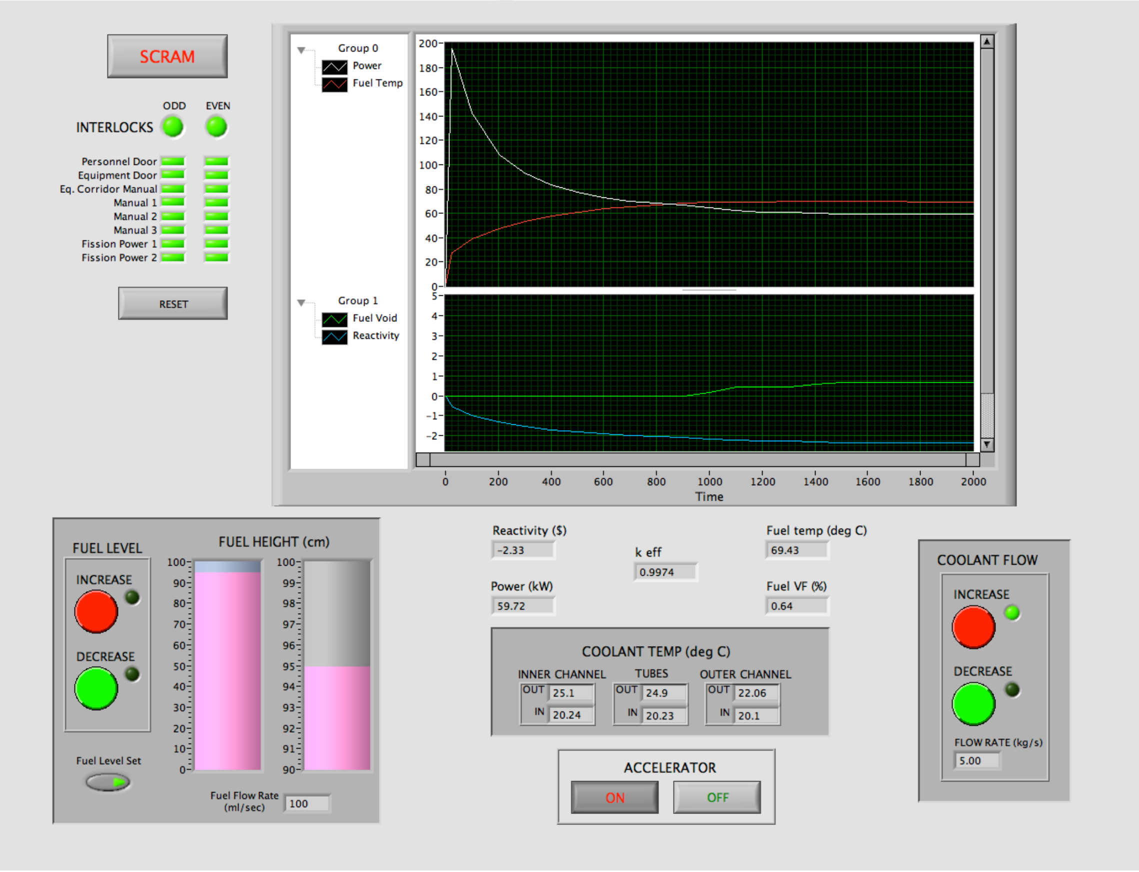
Currently iterating with reaction simulations to obtain steady-state solutions for various conditions.

- Results will be used to improve heat transfer calculations in system model.



Simulator for Accelerator-Driven System

- Implemented in LabVIEW
- Functional controls
- Strict operational sequencing and protocols enforced
- Data displays derived from DSS model
- Aids in human factors engineering of controls design
- With companion "Instructor's Screen" may be used for operator training in start-up, normal and off-normal events

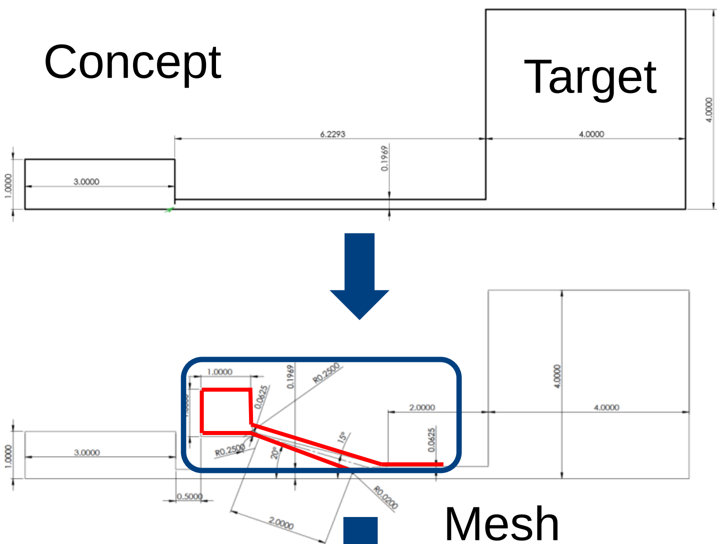


Tritium Nozzle Design

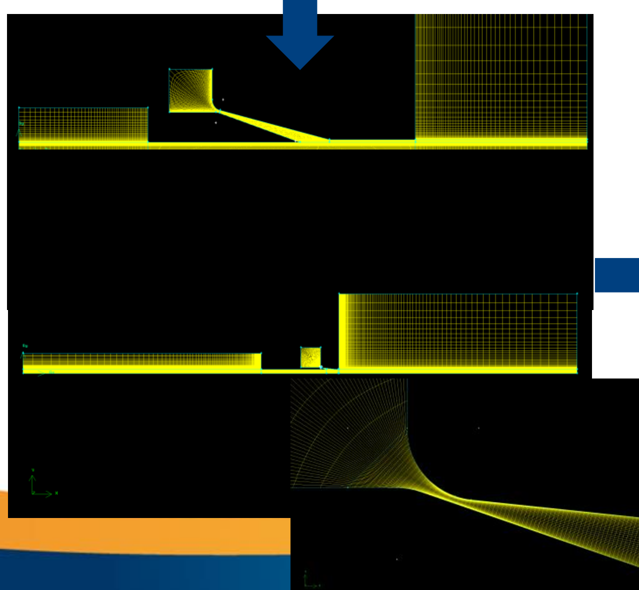
Purpose is to reduce the leakage of gas from the target to the accelerator vacuum

Concept

Target



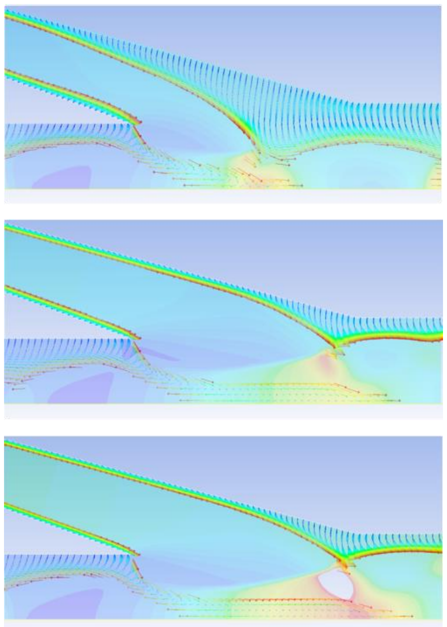
Mesh

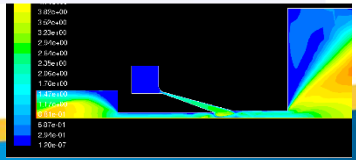


Gasses:

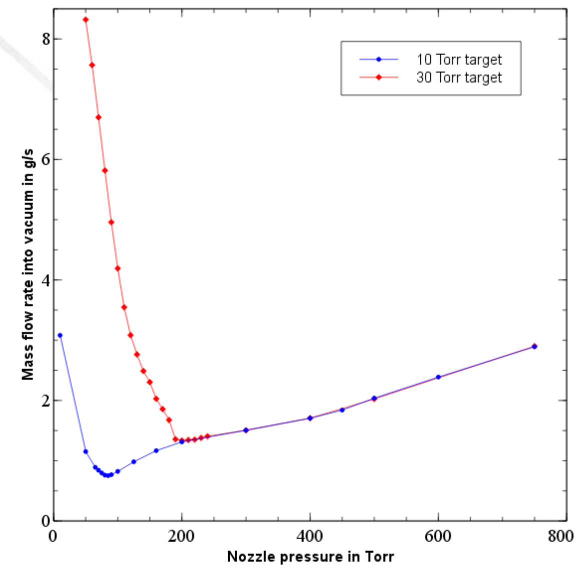
- Hydrogen
- Deuterium

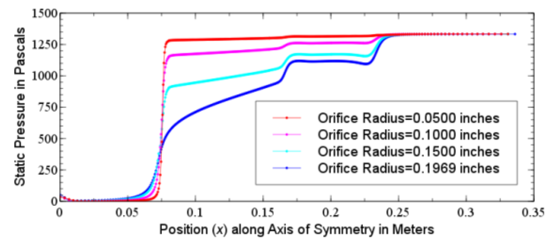
CFD



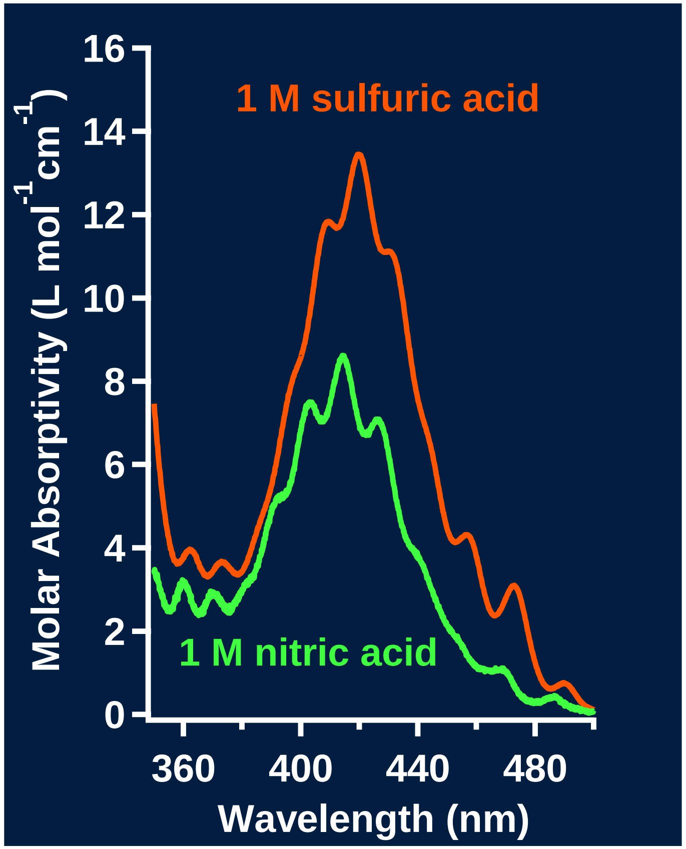


Nozzle Characterization

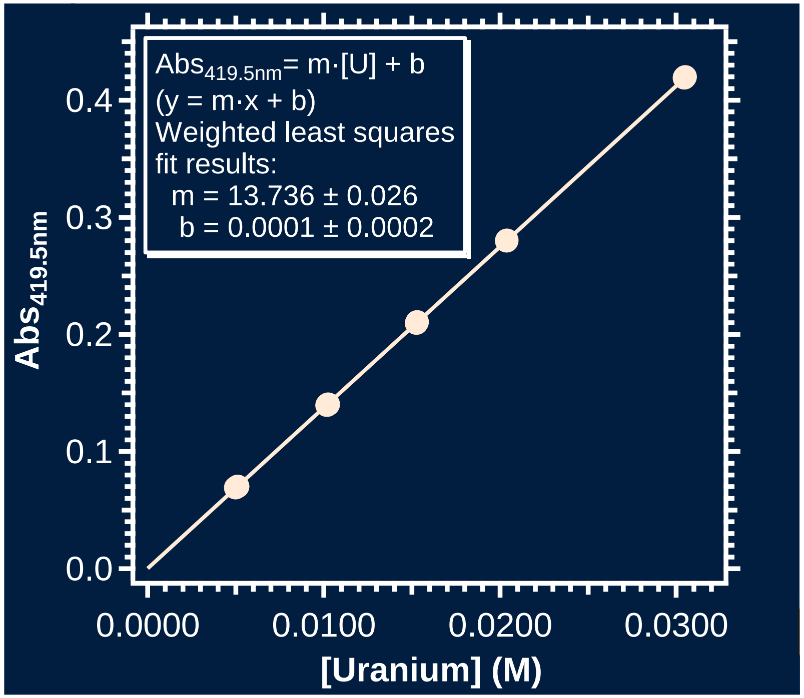




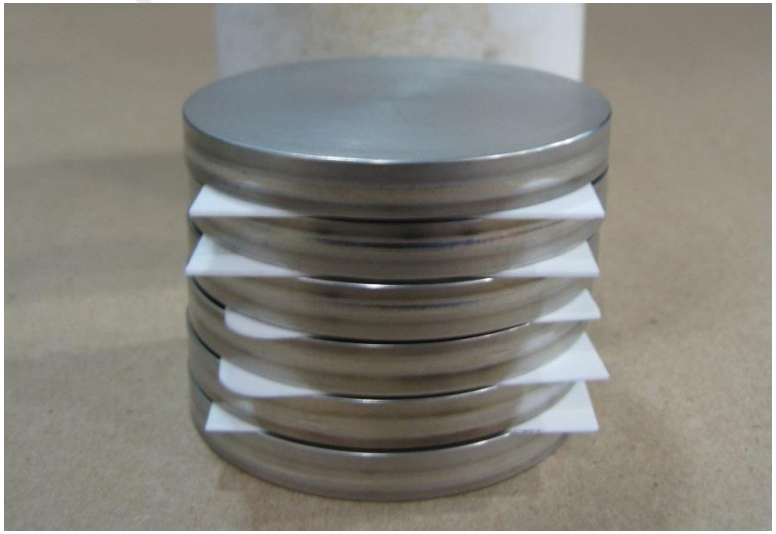
Uranium Concentration Measurement



- Uranyl absorption spectroscopy – can be applied to uranium concentration measurement in solution
- A small aliquot of sample (*e.g.* 100 μL) diluted in excess of 1 M H_2SO_4 (2000 μL)
- λ_{max} (peak max, nm) and ε (molar absorptivity) vary with chemical composition



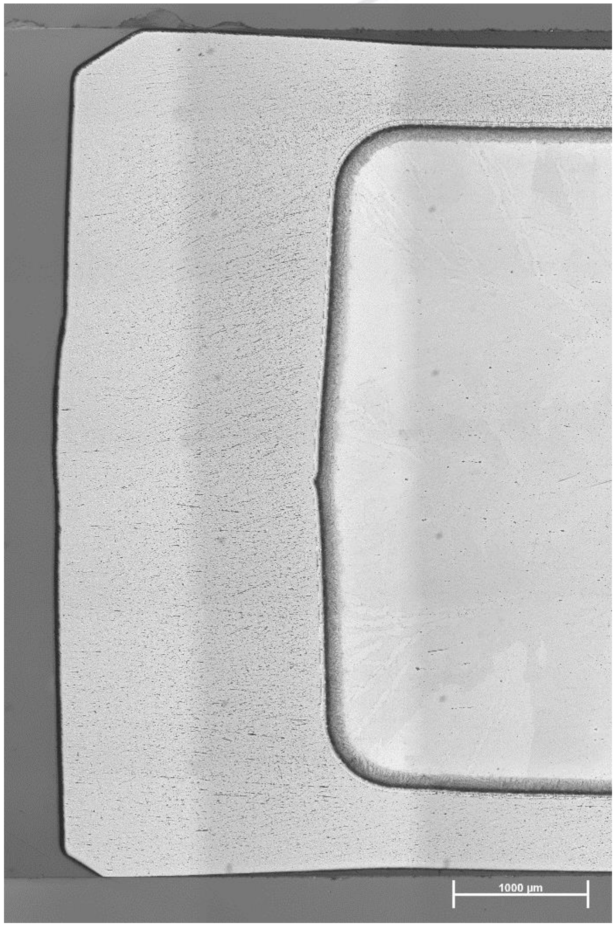
Fabrication of Zr clad DU Disks

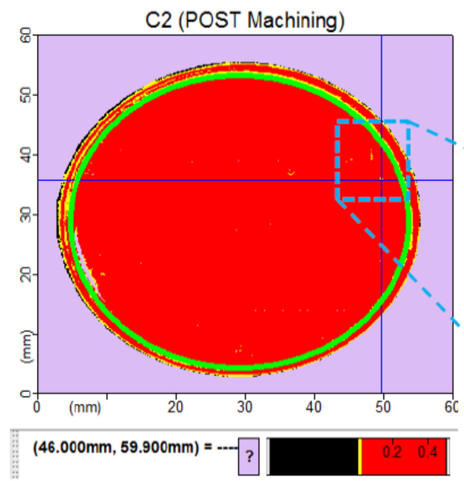


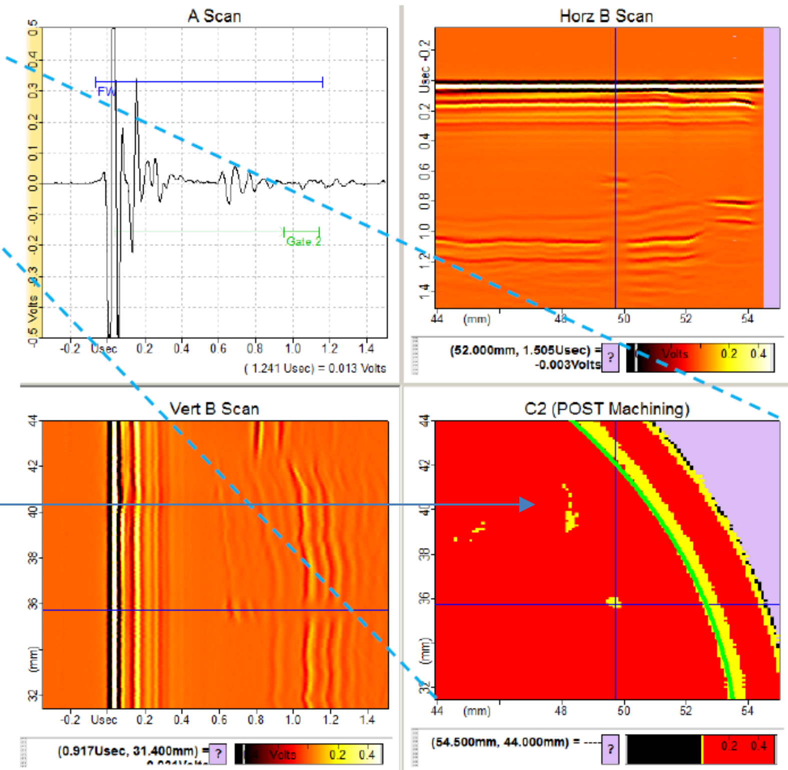
Completed thick disks

The Zr cladding was ebeam welded and then the cans were HIP bonded to create good thermal contact between the DU and Zr.

Characterization of the Zr Clad DU Disks







Assembly C2 – Post Machining

- Very small disbonded region observed near rim in upper right quadrant
- No appreciable difference noted from pre-machined sample

Optical Image of a sectioned test piece

Ultrasonic test results of the final machined component.

Summary

- LANL is partnering closely with NNSA and the other National Laboratories to help develop the commercial domestic production of ^{99}Mo without the use of HEU.
- Under the M^3 ^{99}Mo Program, we are currently supporting NorthStar Medical Radioisotopes and SHINE Medical Technologies.
- Leveraging the unique capabilities of the National Laboratories to facilitate the domestic production of ^{99}Mo.