High Power Liquid Lead-bismuth Targetry for Intense Fast Neutron Sources Using a Superconducting Electron Linac

M. Mamtimin, J. Diemer, T.L. Grimm, F.Y. Odeh, and V.N. Starovoitova
Niowave, Inc.

S.A. Maloy and K.A. Woloshun
Los Alamos National Laboratory

mayir@niowaveinc.com

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Outline

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- Uranium Target Assembly
- Hybrid Subcritical Testbed
- High Power Target
  - Physics
  - Target Material
- High Power Target Design
  - Stagnant LBE target
  - Forced flow LBE target
  - LBE + NU target
- Corrosion Studies
- Summary and Future Work

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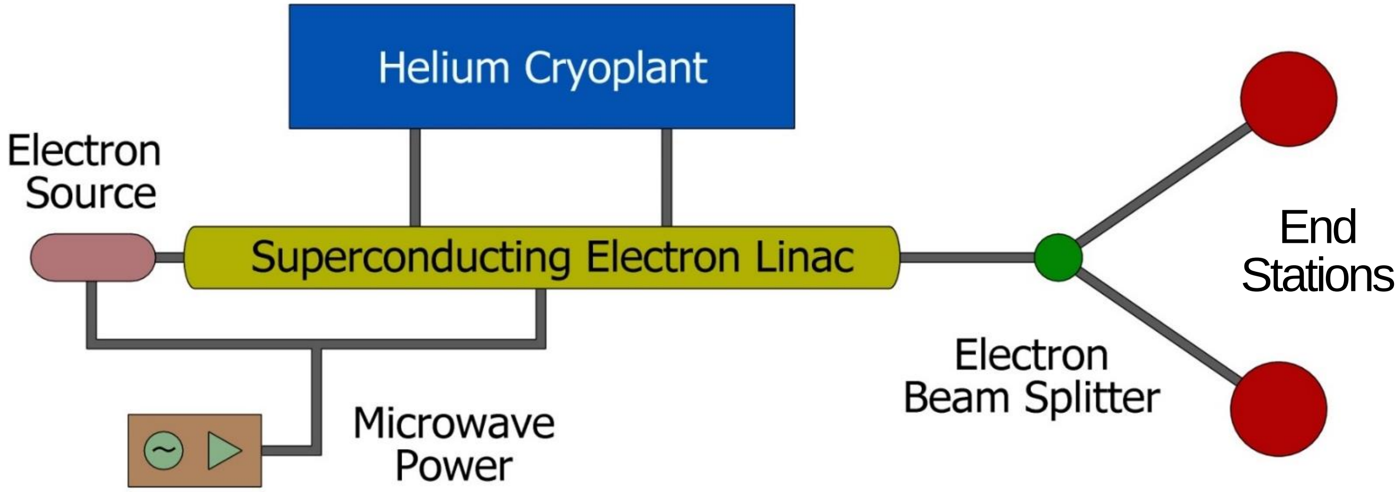
- Niowave is a world-wide leader in research, development, manufacturing and operation of superconducting electron linear accelerators.



Turn-key Systems
- Superconducting Linac
- Helium Cryoplant
- Microwave Power
- End Station
- Licensing

Beam Energy	~9 MeV
Average Beam Power	10-100 kW
Duty Cycle	10-100%
Closed-loop Cooling Capacity	40-110 W @ 4 K

Niowave's Commercial Markets

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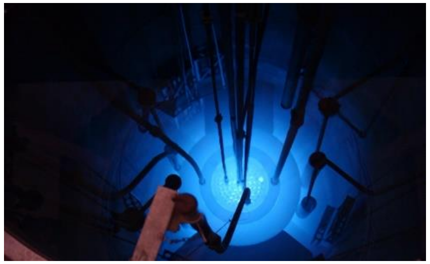
Superconducting Electron Linacs

< 9 MeV → **Sterilization & Advanced Manufacturing**
Eliminate dirty bomb material

9 MeV → **Radiography & Active Interrogation**
Cargo inspection for contraband and shielded nuclear bombs

> 9 MeV → **Medical & Industrial Radioisotopes**
Domestic supply without nuclear reactor or highly-enriched uranium

> 9 MeV → **Nuclear Energy Advanced Technologies**
Domestic fast neutron irradiation and advanced reactor development



Niowave's Subcritical Assembly

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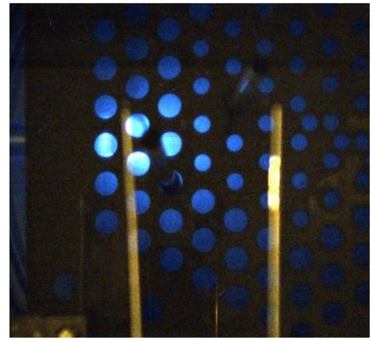
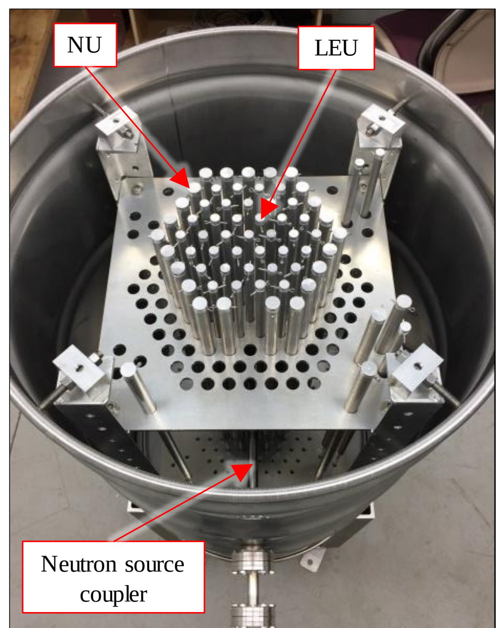
- Subcritical uranium target assembly (UTA)
- Water cooled pool type thermal assembly
- Low enriched uranium
- Driven by SEL and high power neutron target
- Licensed by NRC

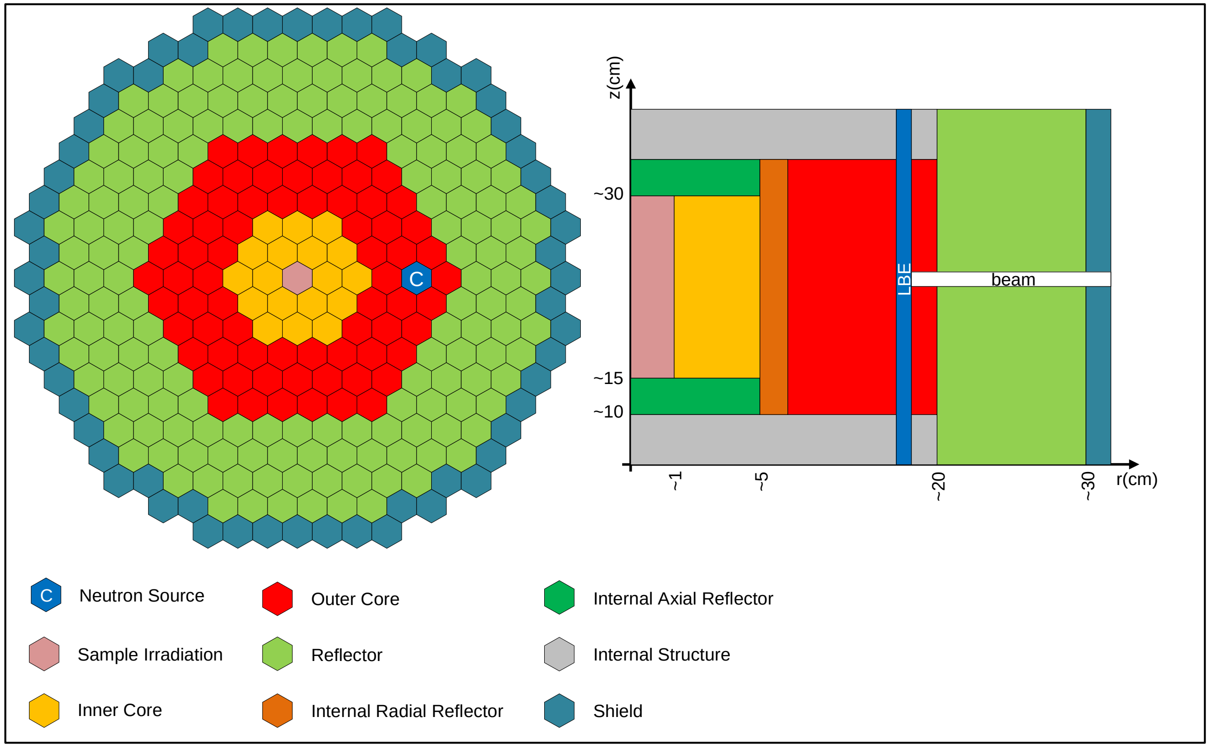
E-beam power	40 MeV, 530 kW
Neutron source	8.5×10^{14} n/s
LEU fuel loading	10 kgU
k_{eff}	0.95
Fission power	210 kW

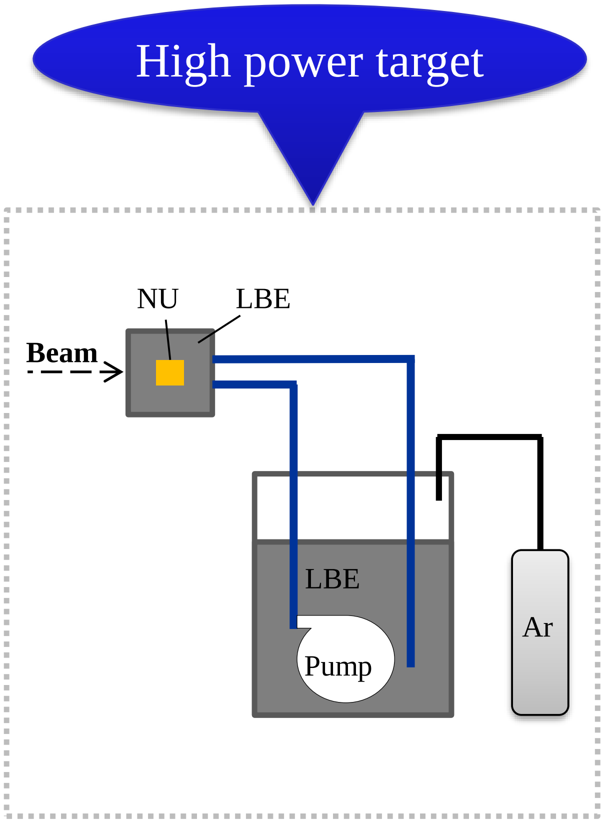




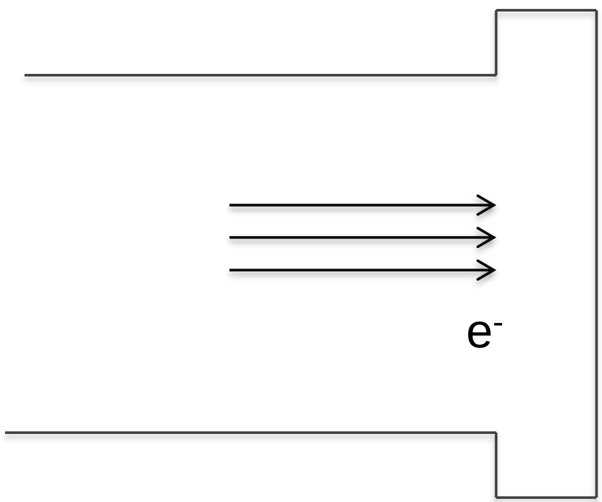
Hybrid Subcritical Testbed

- Nuclear Reactors
  - Domestic fast neutron irradiation facility
- Reactor Materials
  - Radiation and corrosion resistant materials
- Nuclear Fuel Cycle
  - Commercial closed-loop nuclear fuel cycle

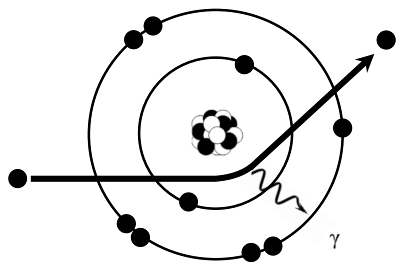




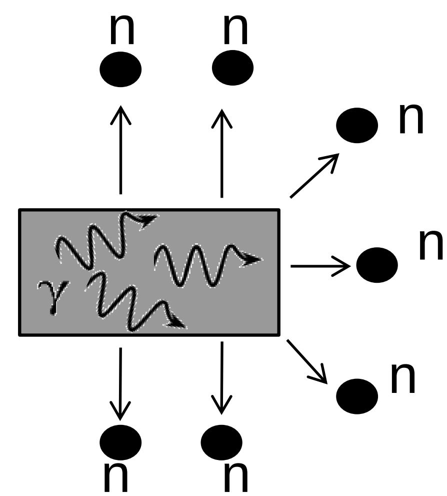
Photoneutron Production



Electrons are accelerated



Electrons brake and produce bremsstrahlung photons



Photons cause photonuclear reactions and liberate neutrons

Niowave's Superconducting Linear Electron Accelerator

High Power Neutron Target

Target Material

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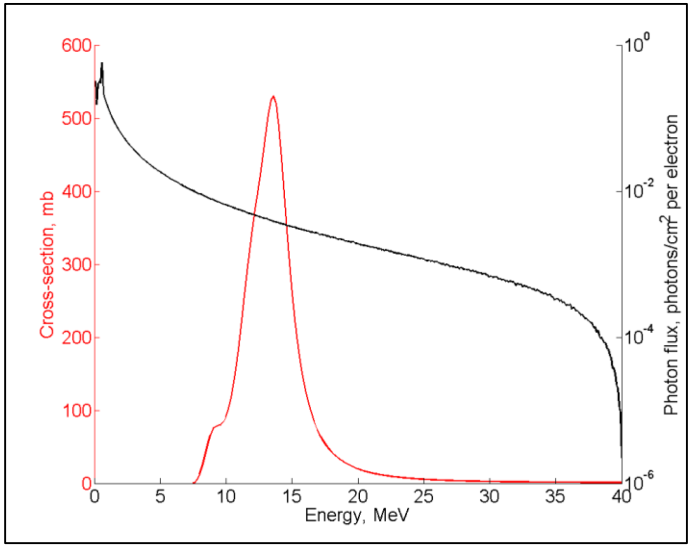
- High conversion efficiency (high Z)
- High melting point (if the converter is solid)
- If liquid, low melting point and good thermomechanical properties



Lead-bismuth eutectic (LBE):

- Z=82(45%),83(55%)
- T_{melt} = 124°C

Isotope	E_{th}(MeV)	Peak Value (mb)
^{2}H	2.22	2.5
^{9}Be	1.67	5
^{184}W	7.41	440
^{208}Pb	7.37	620
^{209}Bi	7.46	530

Target Design

- **Stagnant LBE**
  - Feasibility studies
  - Low power demonstration
- **Forced flow LBE**
  - Liquid metal pump
  - A fast neutron flux of 10^{14} n/cm^2/s
  - For small scale material studies (~ 10 mm^3)
- **LBE with uranium**
  - Low power prototype
  - Higher neutron production yield

Stagnant LBE Target

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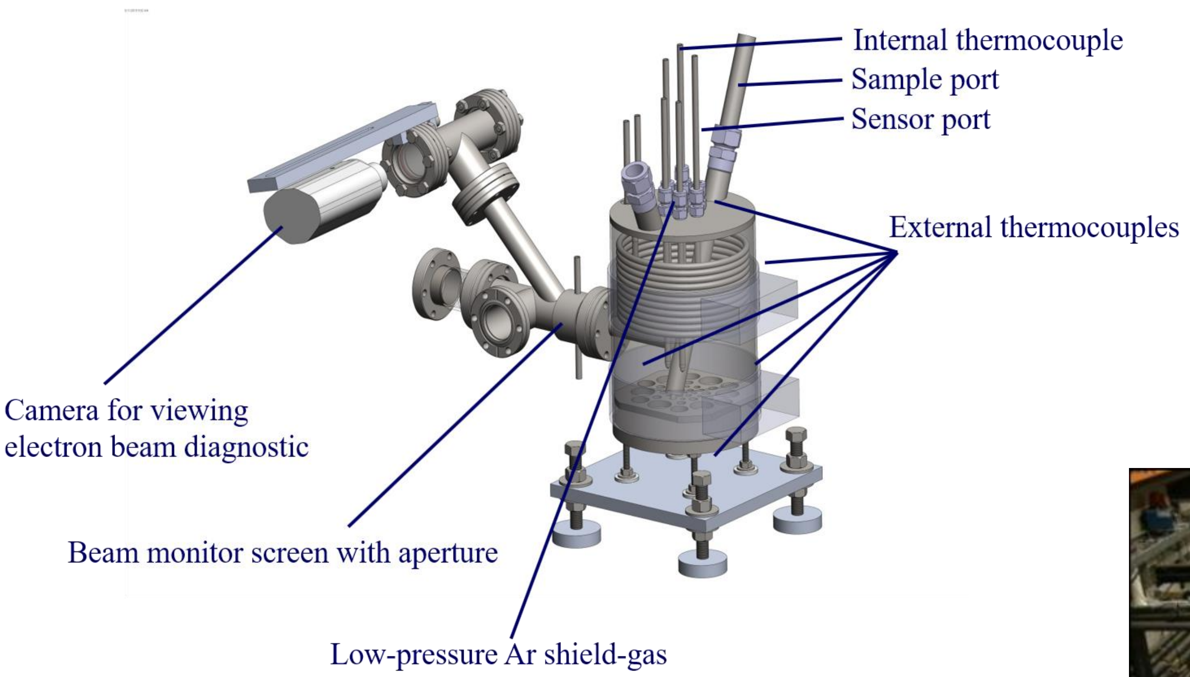
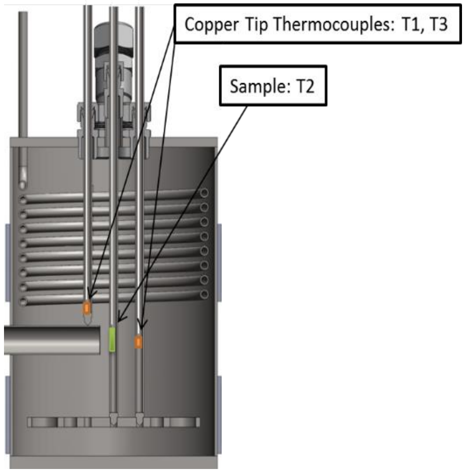
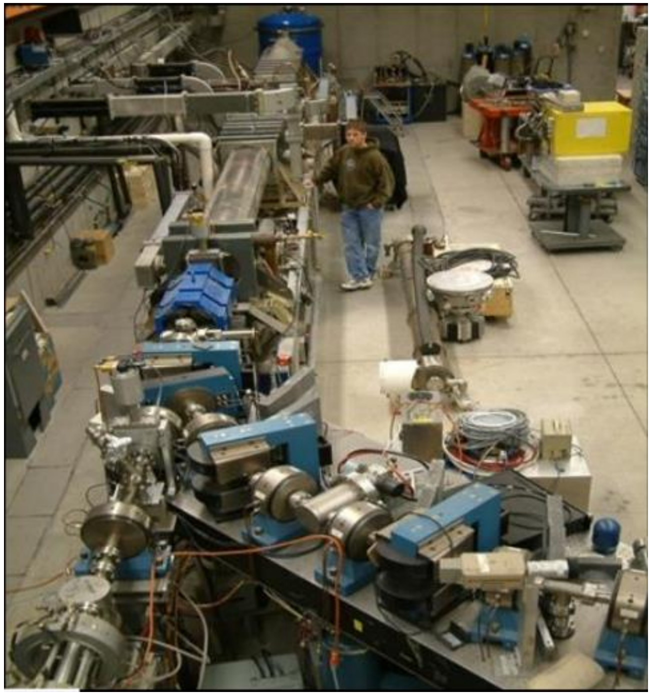




E_e, MeV	Power, W	Average Flux, #/cm^2/s	Peak Flux, #/cm^2/s
10	500	1.63E+08	8.30E+08
20	1200	1.02E+11	3.10E+11
35	1600	2.97E+11	7.50E+11



ANSYS Thermal Analysis

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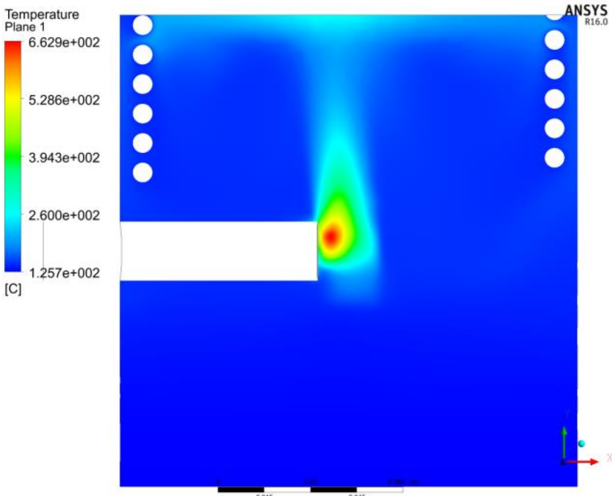
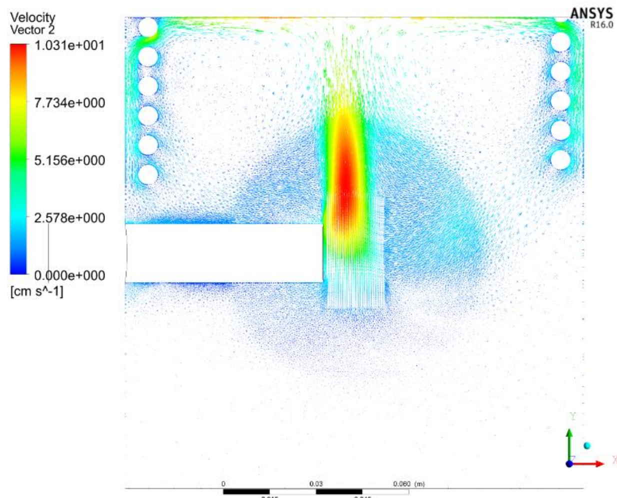
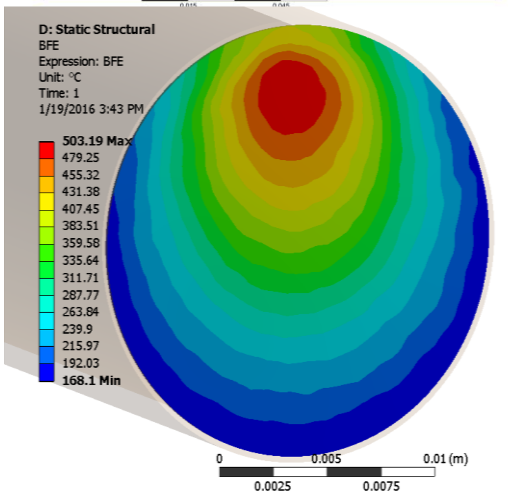
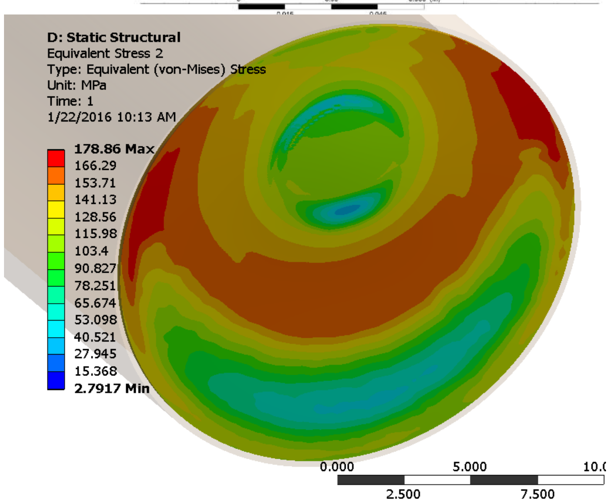
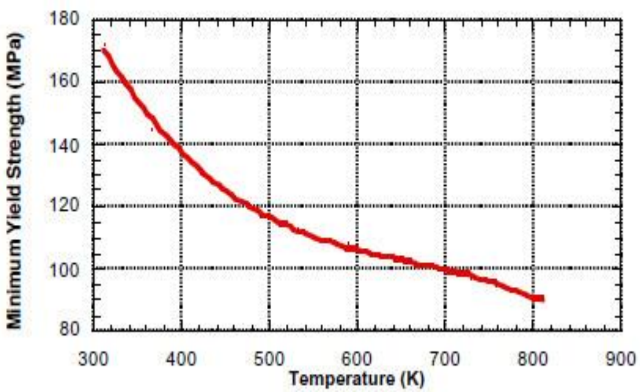




<u>At 40 MeV 5 kW:</u>
Max LBE T= 663 °C;
Flow Rate = 15 cm/s
Max SS T = 503 C
Max SS Y = 179 MPa







At 40 MeV 5 kW:
SS window stress is above yield

Liquid Metal Pump

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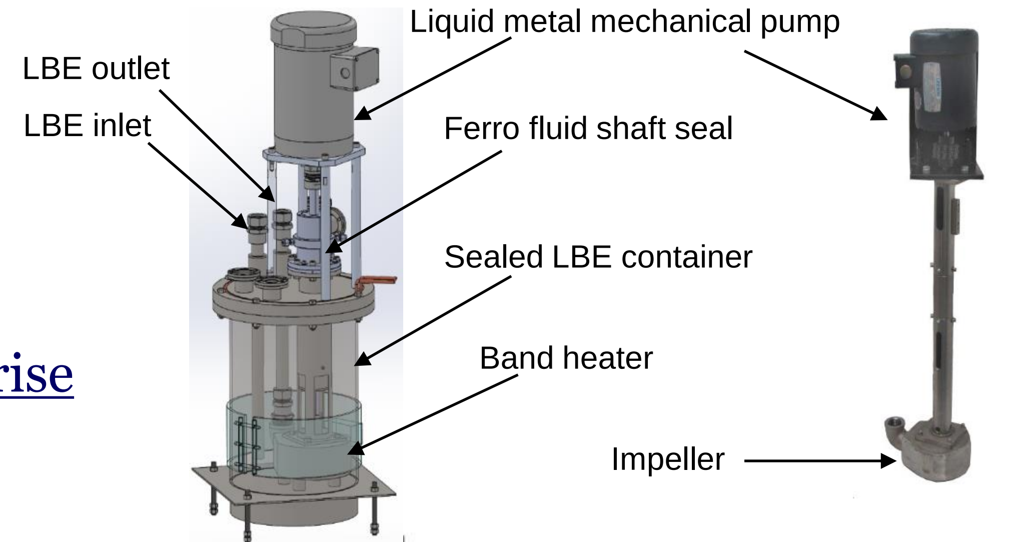
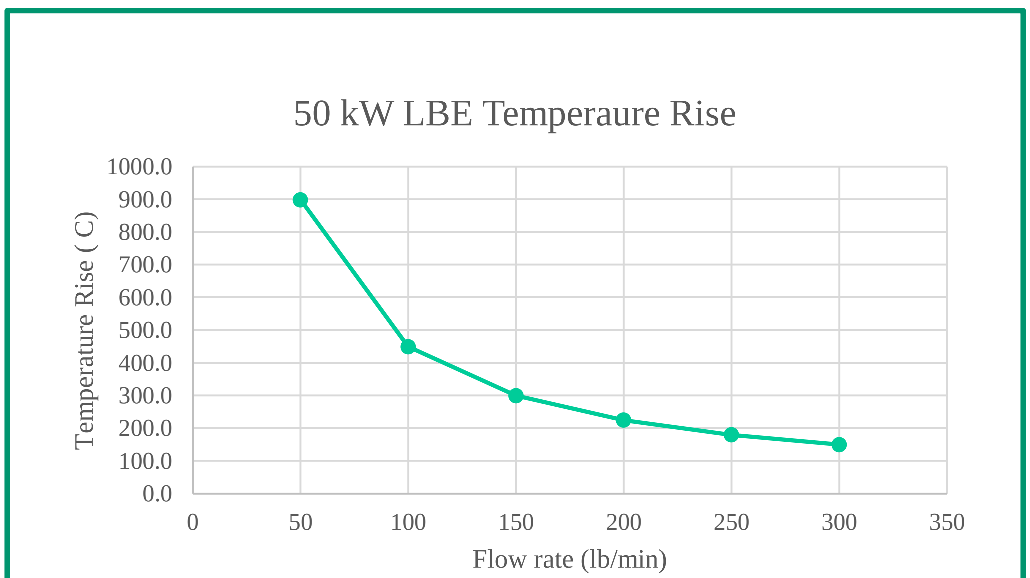
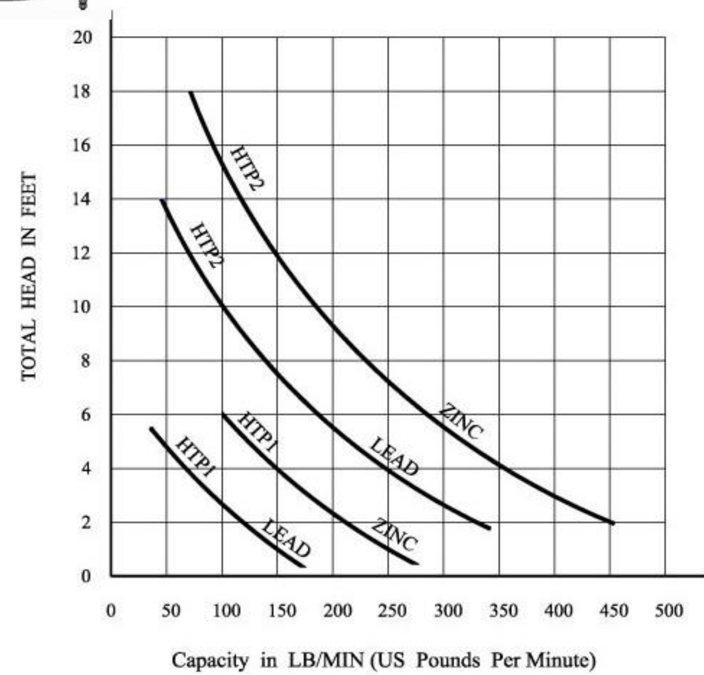
- Better heat removal
- Higher power operation
- Minimum LBE temperature rise

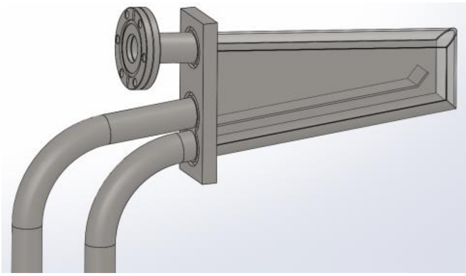


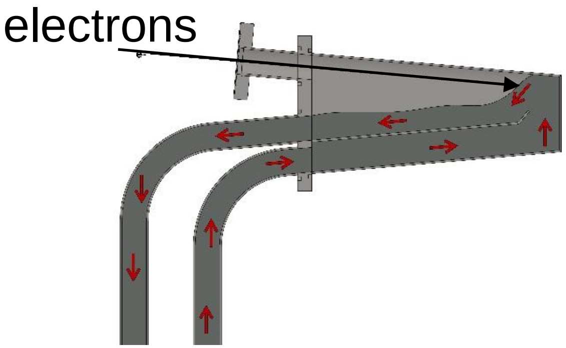


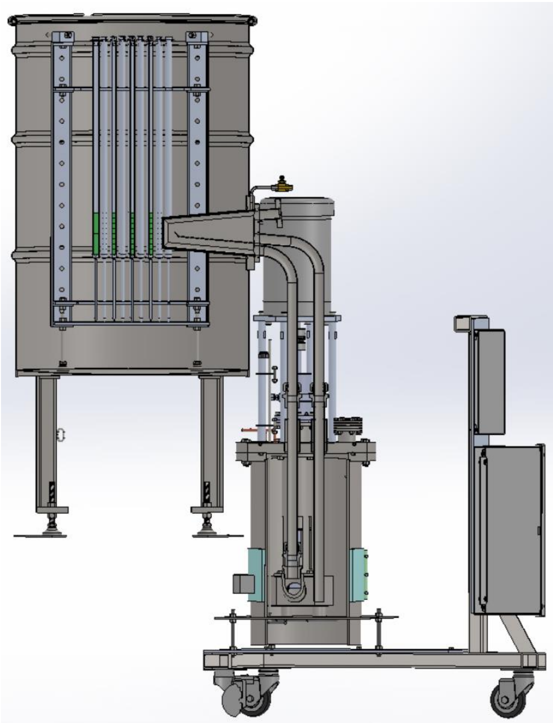


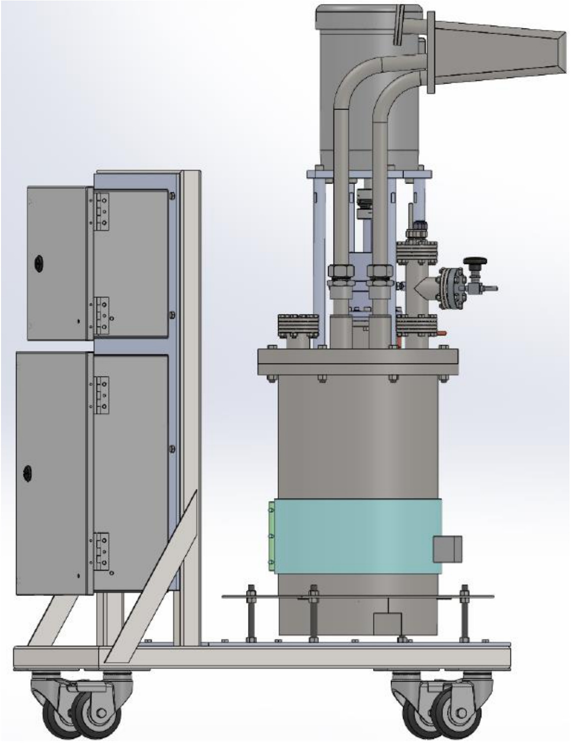
Windowless LBE Target

- Eliminates thin SS window
- High power operation
- Allows better coupling
- Versatile:
  - Neutron source
  - Xray source
  - Positron target

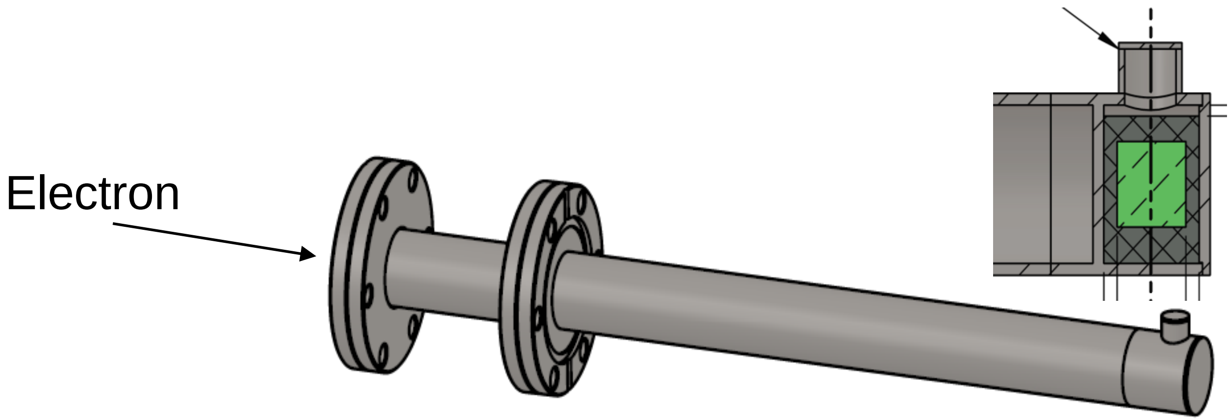








LBE with Uranium



- Higher neutron production due to (γ,xn) and (γ,f) reactions
- Gram quantities of uranium will increase peak neutron flux by a factor of 4

Corrosion Studies

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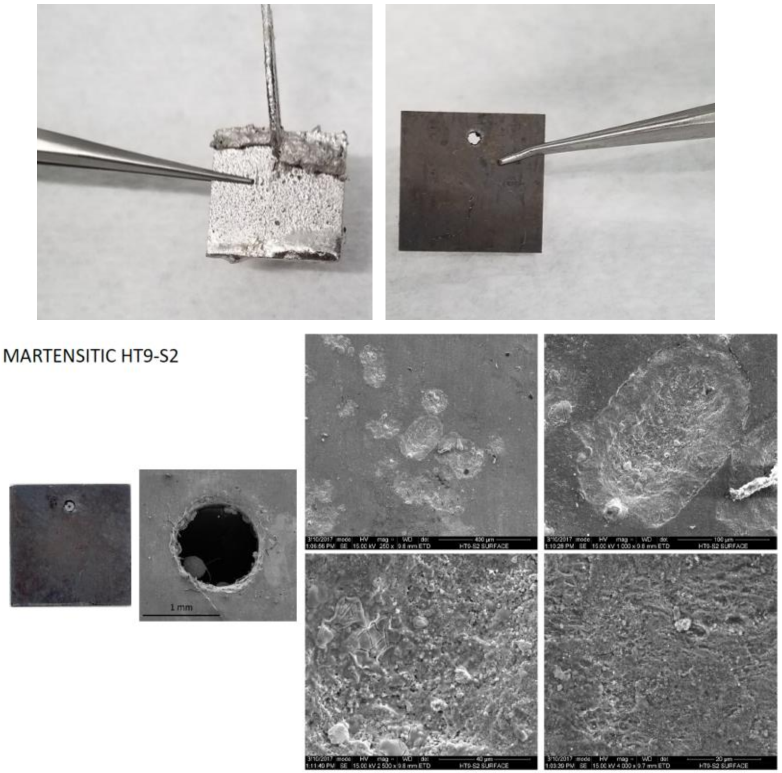
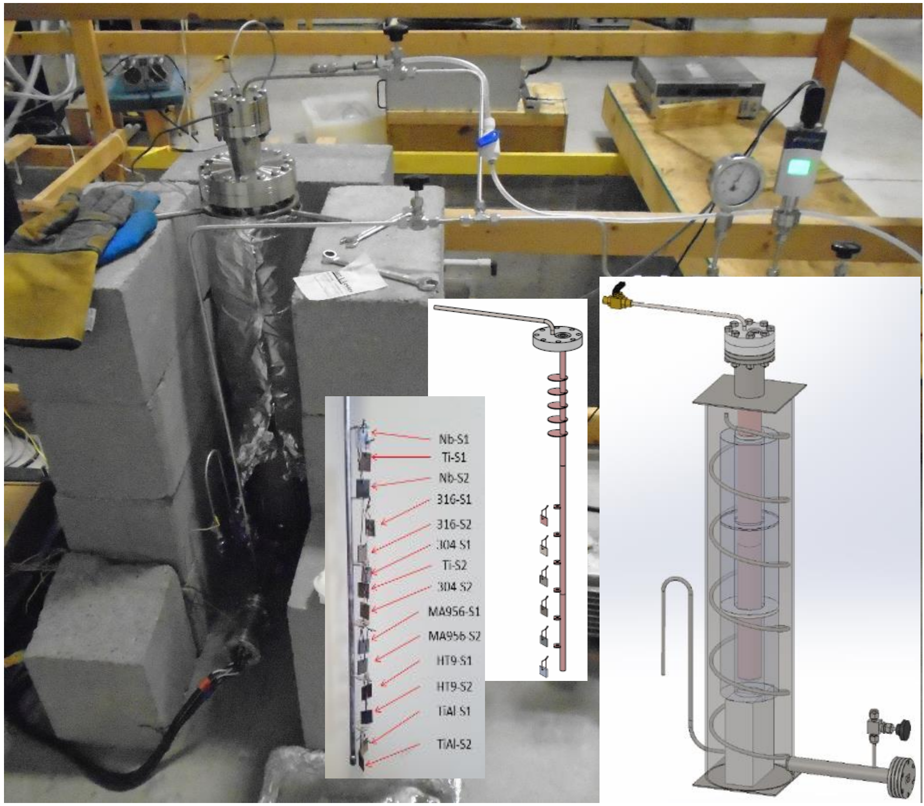
- LBE is corrosive:
    - Corrosion studies in up to 700 C LBE
    - Bimetal structures for high temperature components
    - Forced flow corrosion test station (erosion and corrosion)





Summary

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- Liquid metal based target development
- Various high power neutron targets were designed, built, and tested
- Radiation damage, corrosion, and erosion issues are being addressed
- Versatility can be leveraged towards nuclear energy community and basic nuclear physics research