Niowave's Domestic Production of Mo-99 from Uranium to Start in 2015

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Outline

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- Superconducting Linacs and Their Applications
- Mo-99 Production with Linacs
  - Conceptual Design
  - Superconducting Electron Linac
  - Intense Neutron Source
  - Uranium Targets (LEU)
  - Mo-99 Production and Recovery
  - Uranium Target Recovery
- Licensing (NRC and State of Michigan)
- Niowave Facilities

Why Superconducting?

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- 10^6 lower surface resistance than copper
  - Most RF power goes to electron beam
  - CW/continuous operation at relatively high accelerating gradients >10 MV/m
- Large aperture resonant cavities
  - Improved wake-fields and higher order mode spectrum
  - Preserve high brightness beam at high average current (high power)

Superconducting Turnkey Electron Linacs

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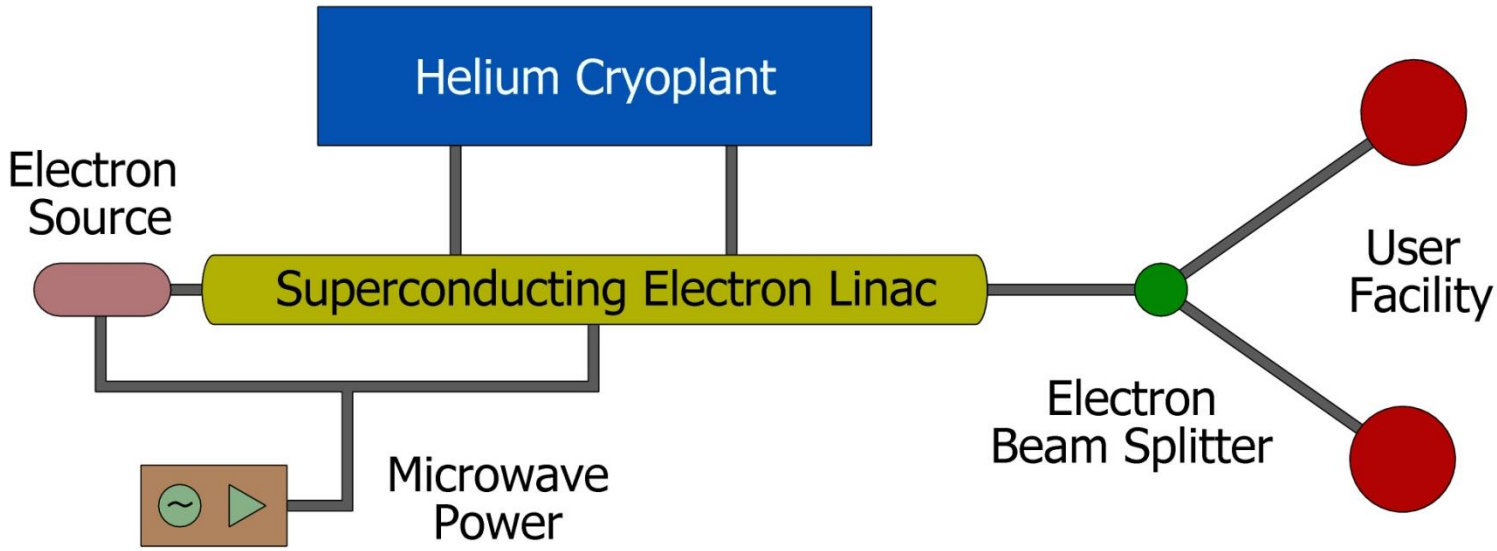

Turn-key Systems

- Superconducting Linac
- Helium Cryoplant
- Microwave Power
- Licensing

Electron Beam Energy	**0.5 – 80 MeV**
Electron Beam Power	**1 W – 400 kW**
Electron Bunch Length	**~5 ps**

Turnkey Linac Subsystems

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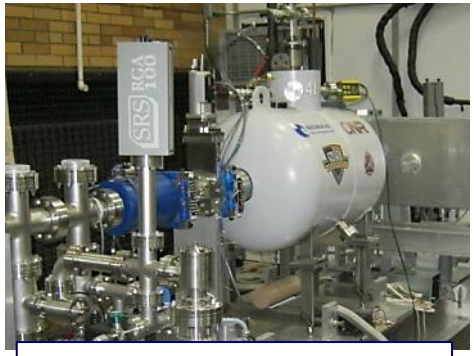
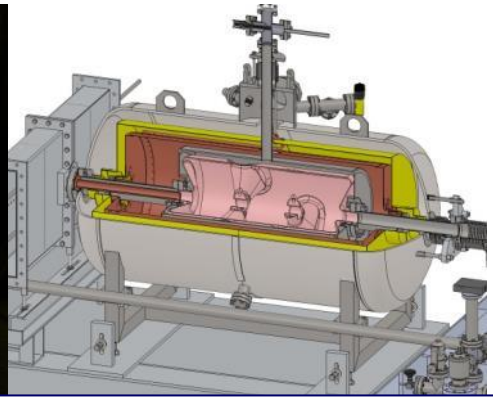


RF electron guns

Solid-state and tetrode RF amplifiers (up to 60 kW)



Superconducting cavities and cryomodules

High-power couplers

Commercial 4 K refrigerators (rugged piston-based systems, 100 W cryogenic capacity)

Frequency & Temperature

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- Superconducting linacs have inherent losses due to the time varying fields

frequency

superconducting transition temperature

$$R_{BCS} \propto f^2 \exp\left(-\frac{T_c}{T}\right)$$

operating temperature

- For commercial electron linacs the minimum costs for a system occur around:
  - 300-350 MHz (multi-spoke structures)
  - 4.5 K (>1 atmosphere liquid helium)

Superconducting Accelerating Cavities

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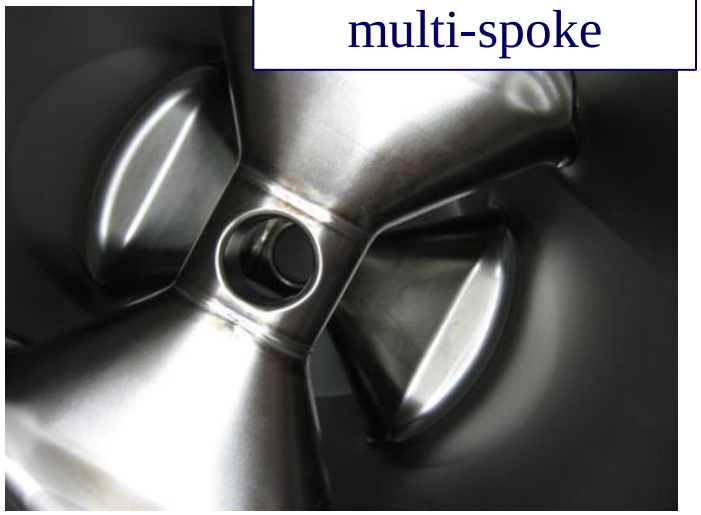
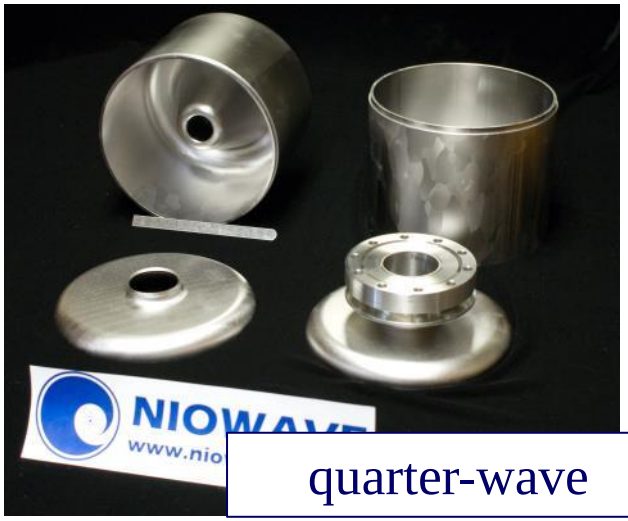
multi-cell elliptical

multi-spoke





quarter-wave

photonic bandgap

Variety of new SRF cavity shapes are allowing compact, low-frequency acceleration with high average beam power.

Superconducting Multi-Spoke Cavities

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- Advantages for low frequency, high current linacs
  - **Mechanical stability** (stable against microphonics)
  - **Compact geometry** for improved real-estate gradient and low-frequency operation at 4 K
  - **Improved higher-order-mode (HOM) spectrum** and damping

ONR Revolutionary Research . . . Relevant Results

Joint Technology Office High Energy Lasers

NPS Praestantia per Scientiam 1909

Los Alamos National Laboratory

Old Dominion University

RF Power Sources

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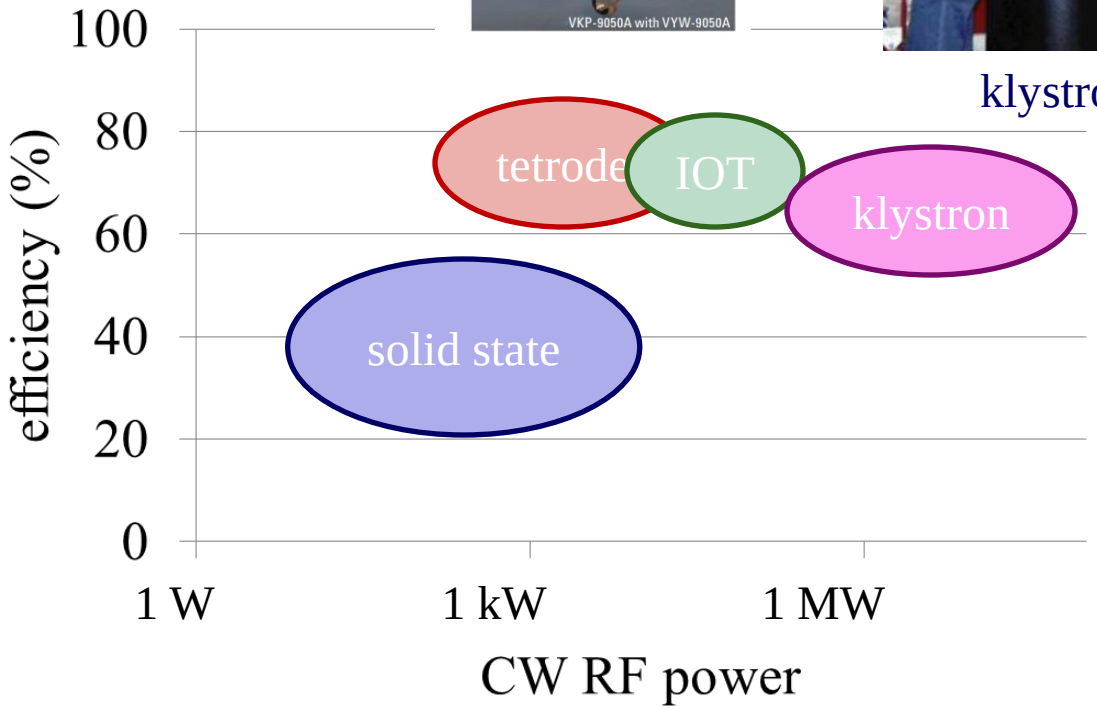
- Solid-state supplies to 5 kW
- Tetrode amplifer to 60 kW
- IOTs to 90 kW
- Klystrons to >1 MW

inductive output tube

klystron

tetrode

solid-state



Commercial 4 K Refrigerators

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- Cryo-cooler to 5 W
  - 4.5 K operation
  - 5 kW electrical power
- Commercial refrigerator to 110 W
  - 4.5 K operation (slightly above 1 atm)
  - total electrical power 100 kW
  - higher capacity units available

compressor

5 W cryocooler

110 W refrigerator

2 & 10 MeV Injectors

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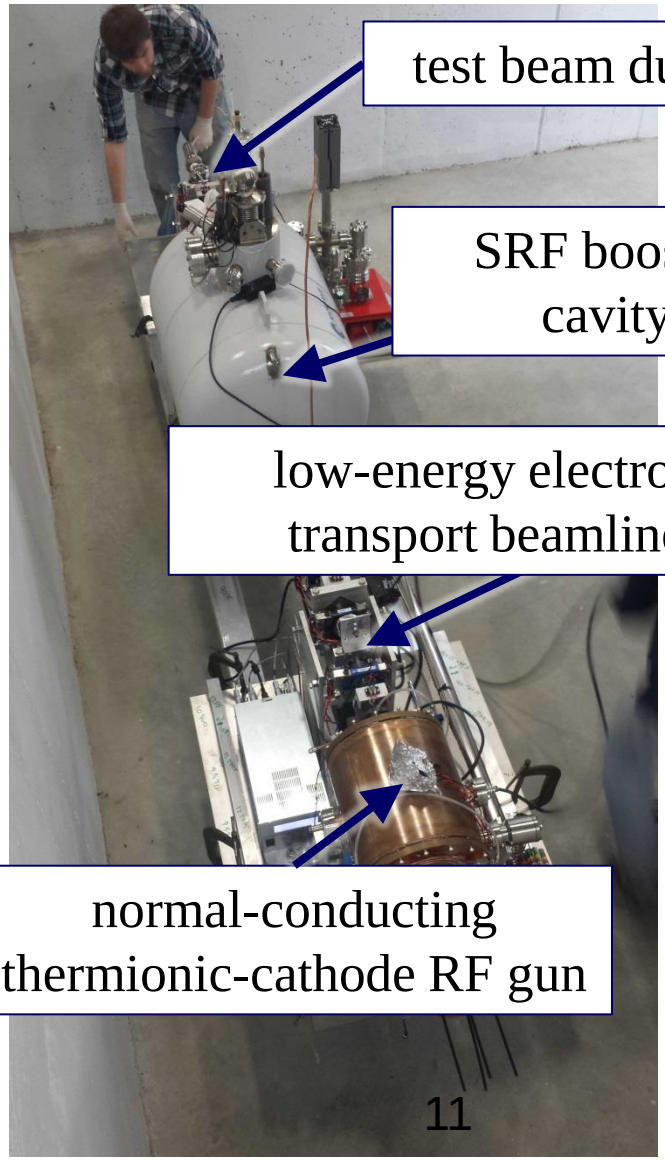

Parameter	2 MeV	10 MeV
cathode type	thermionic	thermionic
NCRF electron gun energy	100 keV	100 keV
SRF booster cavity energy	2 MeV	10 MeV
bunch repetition rate (gun, booster frequency)	350 MHz	350 MHz
transverse normalized rms emittance	3-5 mm mrad	3-5 mm mrad
bunch length @ 2 MeV	2-5 ps	2-5 ps
average beam current	2 mA	1-2 mA

Commercial Uses of Superconducting Electron Linacs

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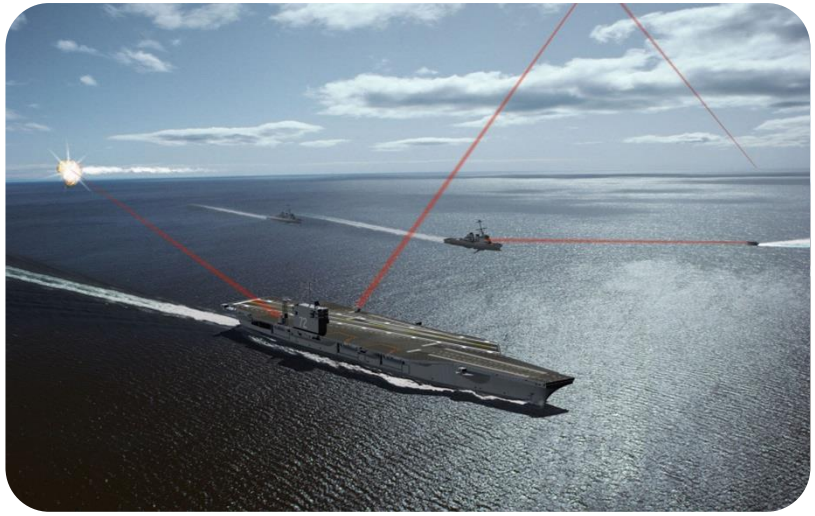
High Power X-Ray Sources

Radioisotope Production



Free Electron Lasers

High Flux Neutron Sources

Intense Neutron Source [1]

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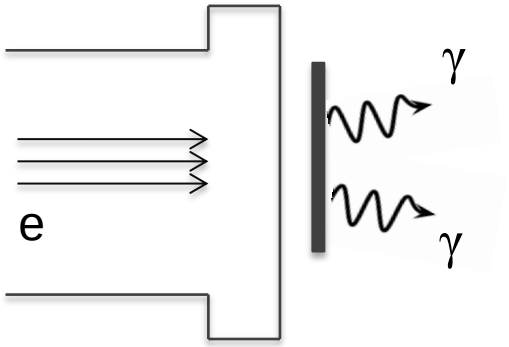
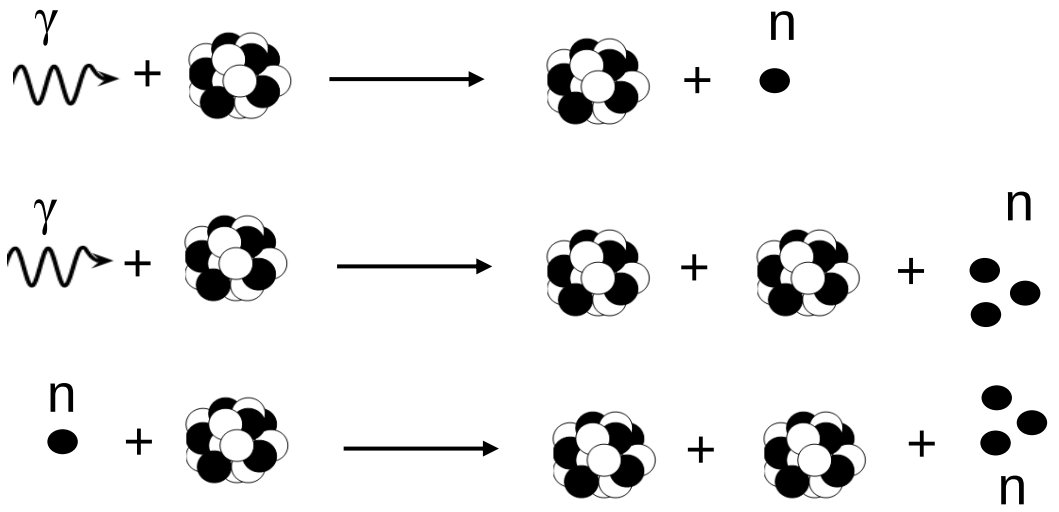


Electrons are accelerated

Electrons brake and produce photons



Neutrons are generated by:

a) (γ,n) reactions
b) Photo-fission
c) Neutron-induced fission

Intense Neutron Source [2]

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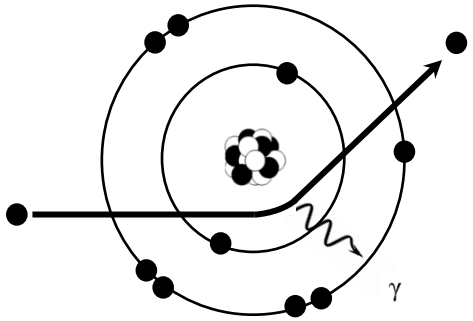
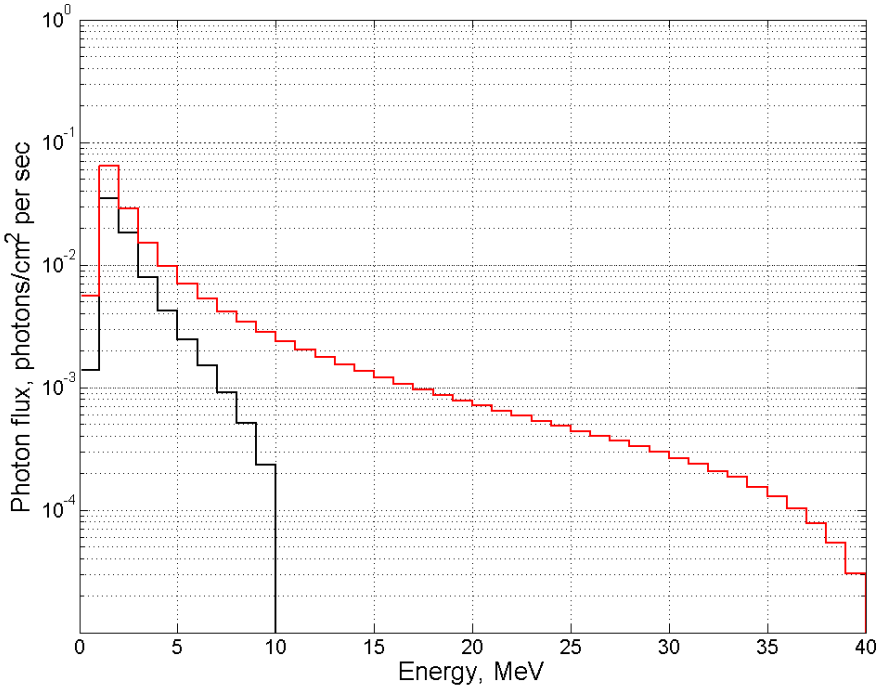
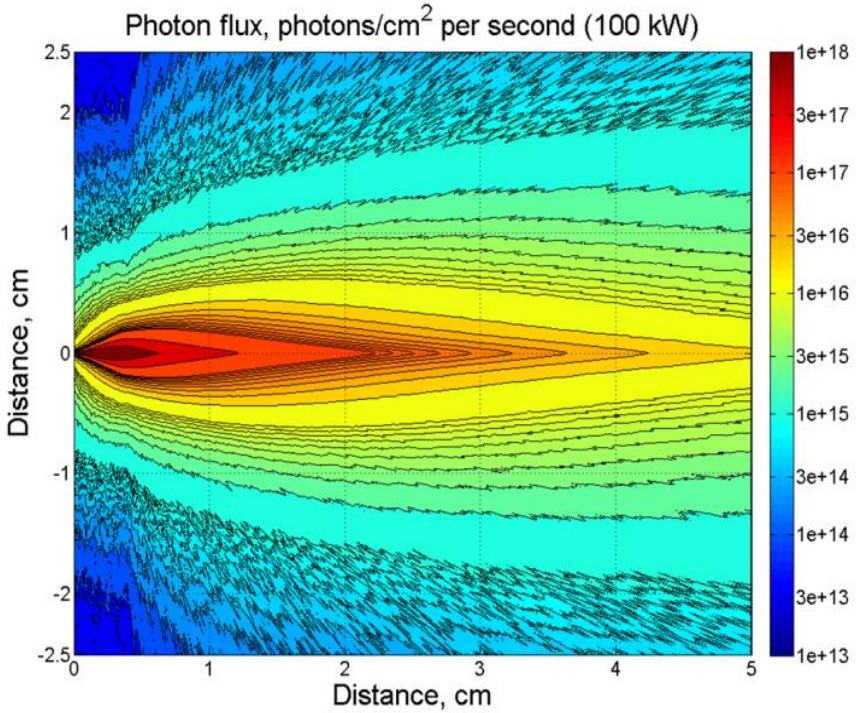
Breaking radiation (bremsstrahlung photons):







Intense Neutron Source [3]

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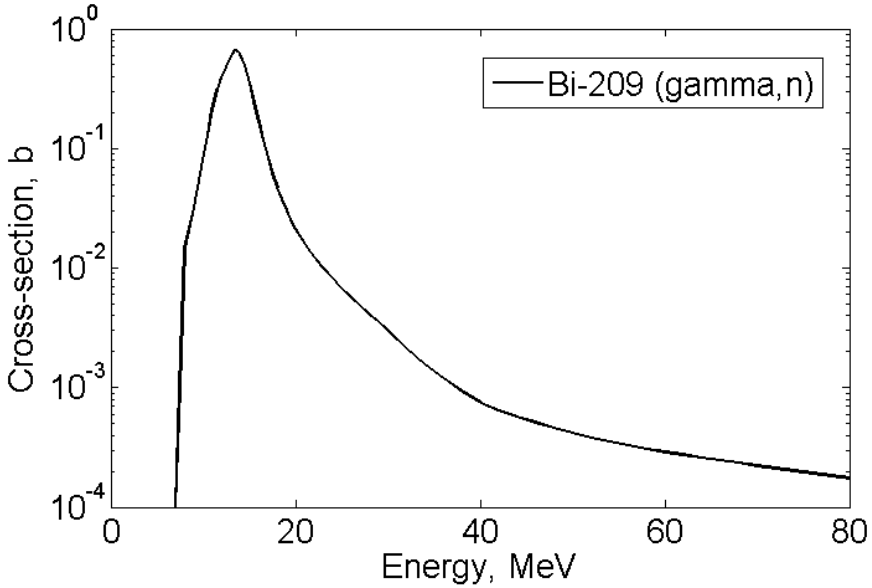
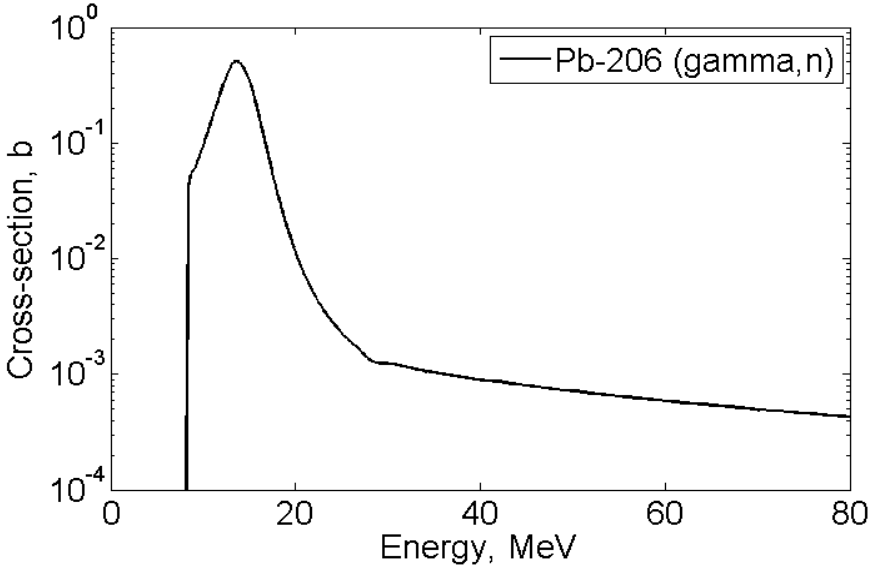
Lead-Bismuth Eutectic (PbBi):

- High conversion efficiency (Z=82,83)
- Low melting point (124°C)
- High boiling point
- (1670 °C)





Intense Neutron Source [4]

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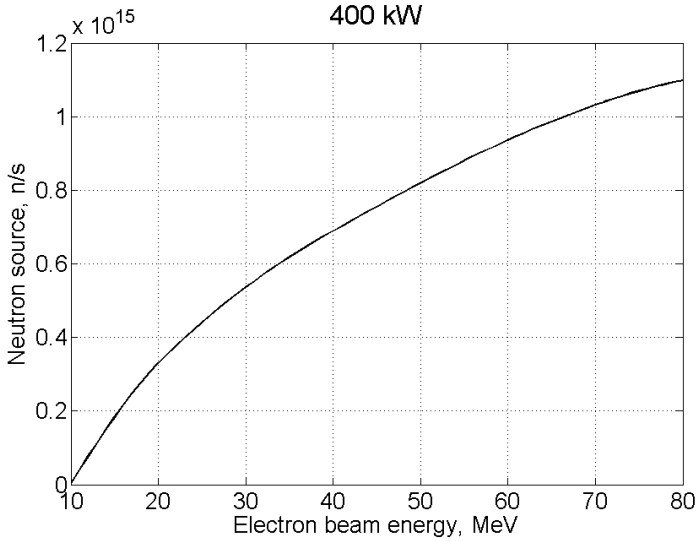
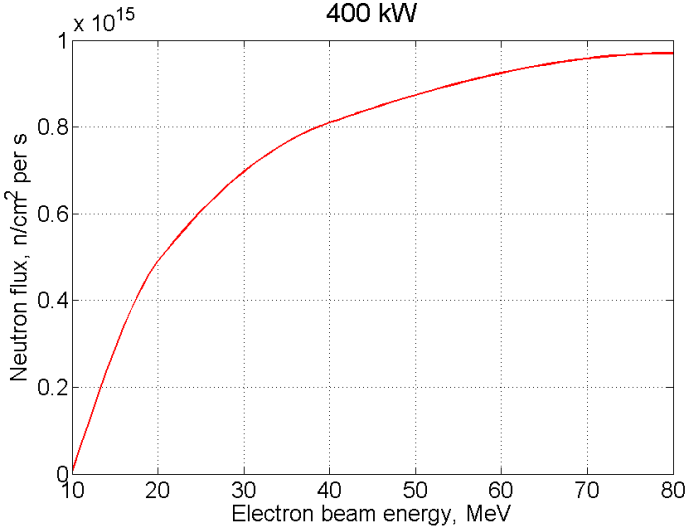
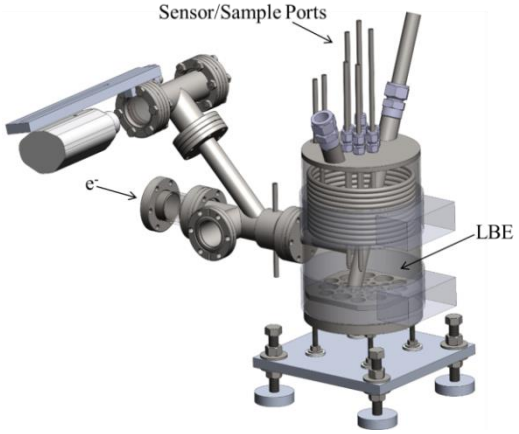
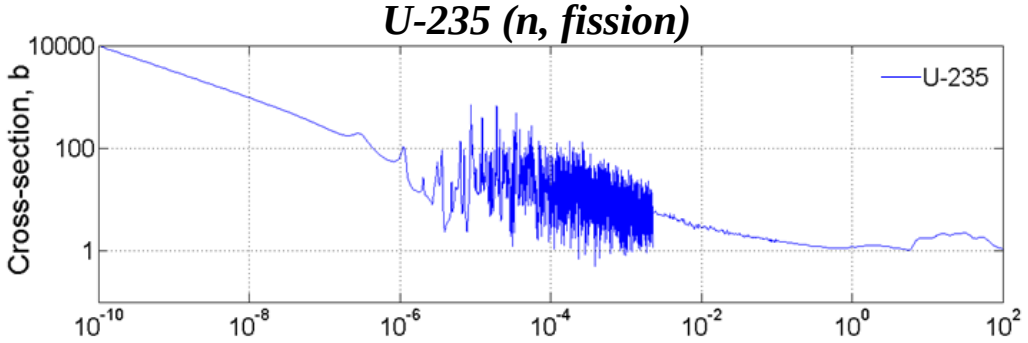
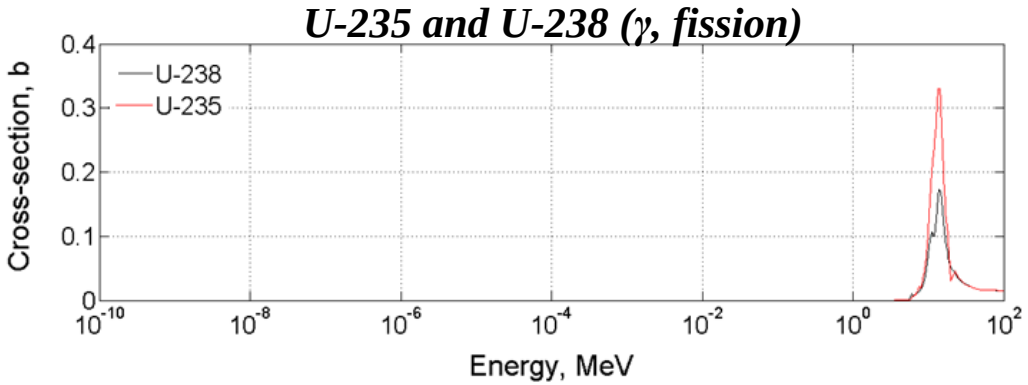
PbBi source intensity & flux:











Mo-99 Production

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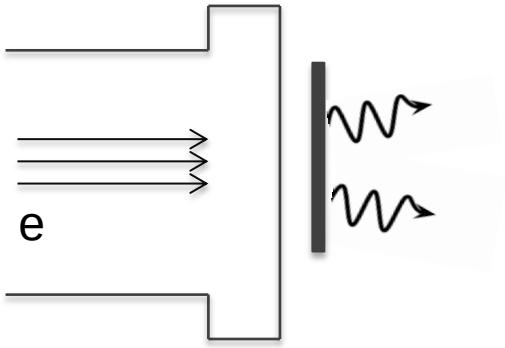

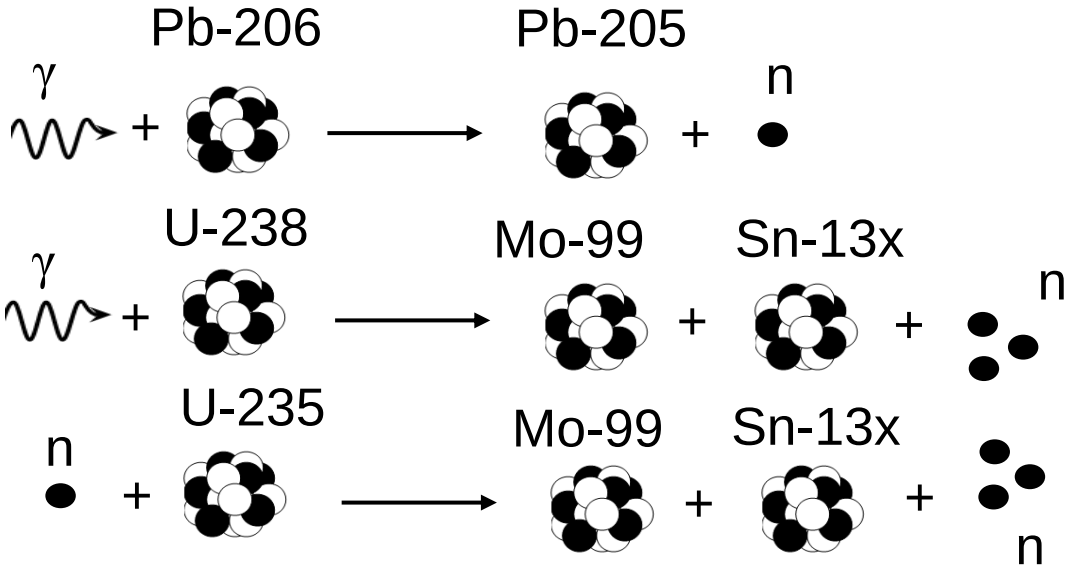

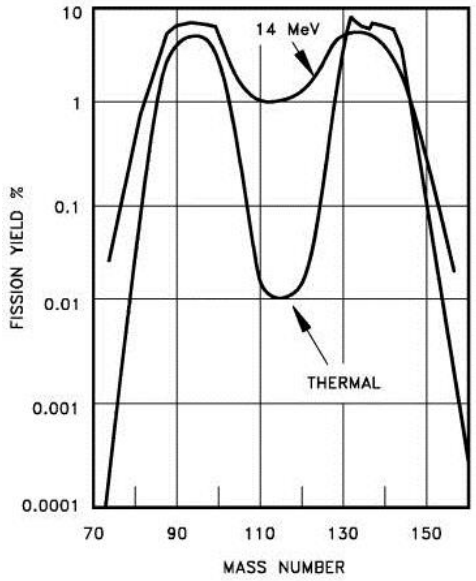

- Time of irradiation – 1 week
- Mo-99 activity per rod – 0.1 kCi
- Total Mo-99 produced – 9 kCi/week

Niowave Facilities [1]

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- **60,000 square feet**
  - Engineering & design
  - Machine shop
  - Fabrication & welding
  - Chemistry facility
  - Class 100 Cleanroom
  - Cryogenic test lab
  - Two operating 100 W cryoplants
- **Test Facilities (2)**
  - 3 megawatts power available at both
  - Licensed to operate up to 40 MeV and 100 kW

Lansing, Michigan Headquarters

Niowave Facilities [2]

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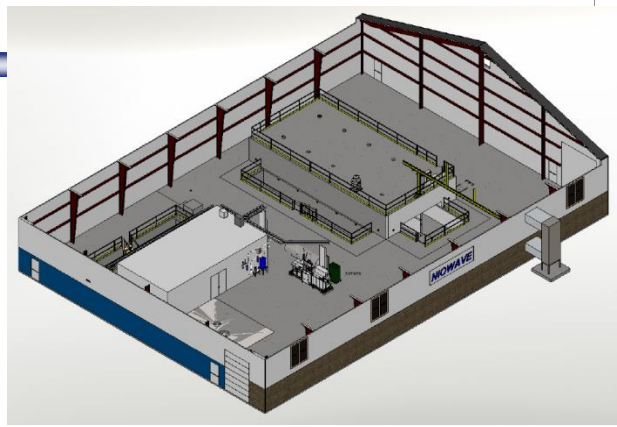

- Headquarters test facility
  - Prototype and commission
  - 40 MeV superconducting electron linac
- 2012 Dedication of test facility at headquarters
  - Keynote speakers: Senator Carl Levin, Senator Debbie Stabenow, Rear Admiral Matthew Klunder and MSU Provost Kim Wilcox

Headquarters Test Facility

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The high-power test facility at Niowave headquarters allows parallel development on multiple superconducting linacs

- 3 MW electrical power available
- three below-grade trenches for source and cavity testing
- two shielded tunnels for beam operation up to 40 MeV, 100 kW

Niowave Airport Facility

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- Production & processing facility
  - Occupancy Jan 2015
  - 24/7 operation
  - Isotopes, x-rays, etc.
- Lansing International Airport
  - Foreign Trade Zone

Summary

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- First domestic production of Mo-99 from U
  - Planned for Summer 2015
- Large scale Mo-99 production & distribution
  - Planned for 2016-17