The Materials Test Station: A Fast Spectrum Irradiation Facility

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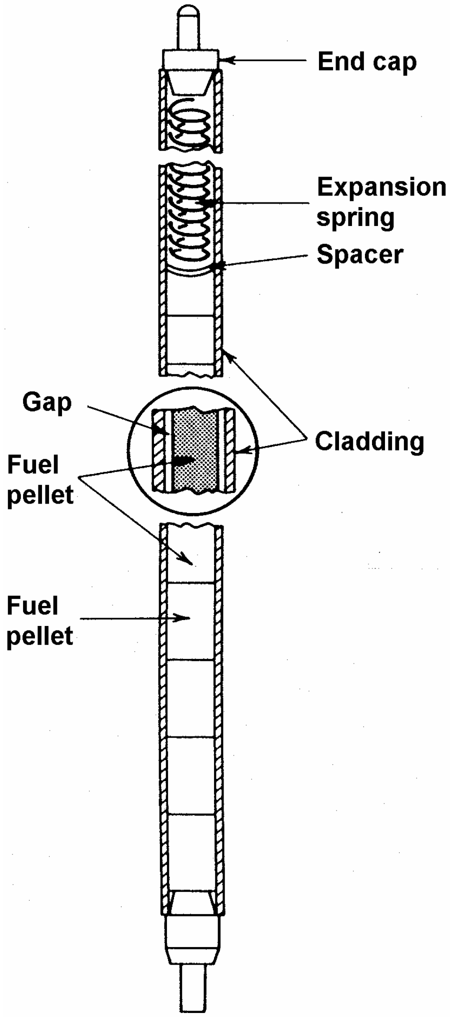
MTS Mission: Irradiate candidate transmutation fuels and materials for fast reactors

- Fuels containing the transuranics (Np, Pu, Am, Cm) are now being developed for transmutation in fast reactors
- Qualification is a long process (a decade or more)
- Irradiation testing in a prototypic environment is essential for fuel and cladding qualification
- Potential issues include
  - Need to achieve high burn-up (~20 a% or more)
  - Higher gas generation (especially He)

Irradiation testing in a thermal spectrum gives high fission rate but minimal clad damage, thereby missing any fuel-clad interaction failure mechanisms.



A readily accessible fast spectrum irradiation facility is needed to test transmutation fuels

- No facility in the USA today
- Access to facilities outside of the USA is limited
  - Phenix will close in 2009 (currently irradiating 4 US rodlets)
  - JOYO may irradiate a few US-produced rodlets in 2012
  - BOR-60 may be shut down in the 2010 - 2015 time frame
  - BN-600 may be an option in the future
- A new domestic fast reactor will take at least a decade to build and cost over $1B
- MTS is the only viable option for near-term domestic fast-spectrum irradiations

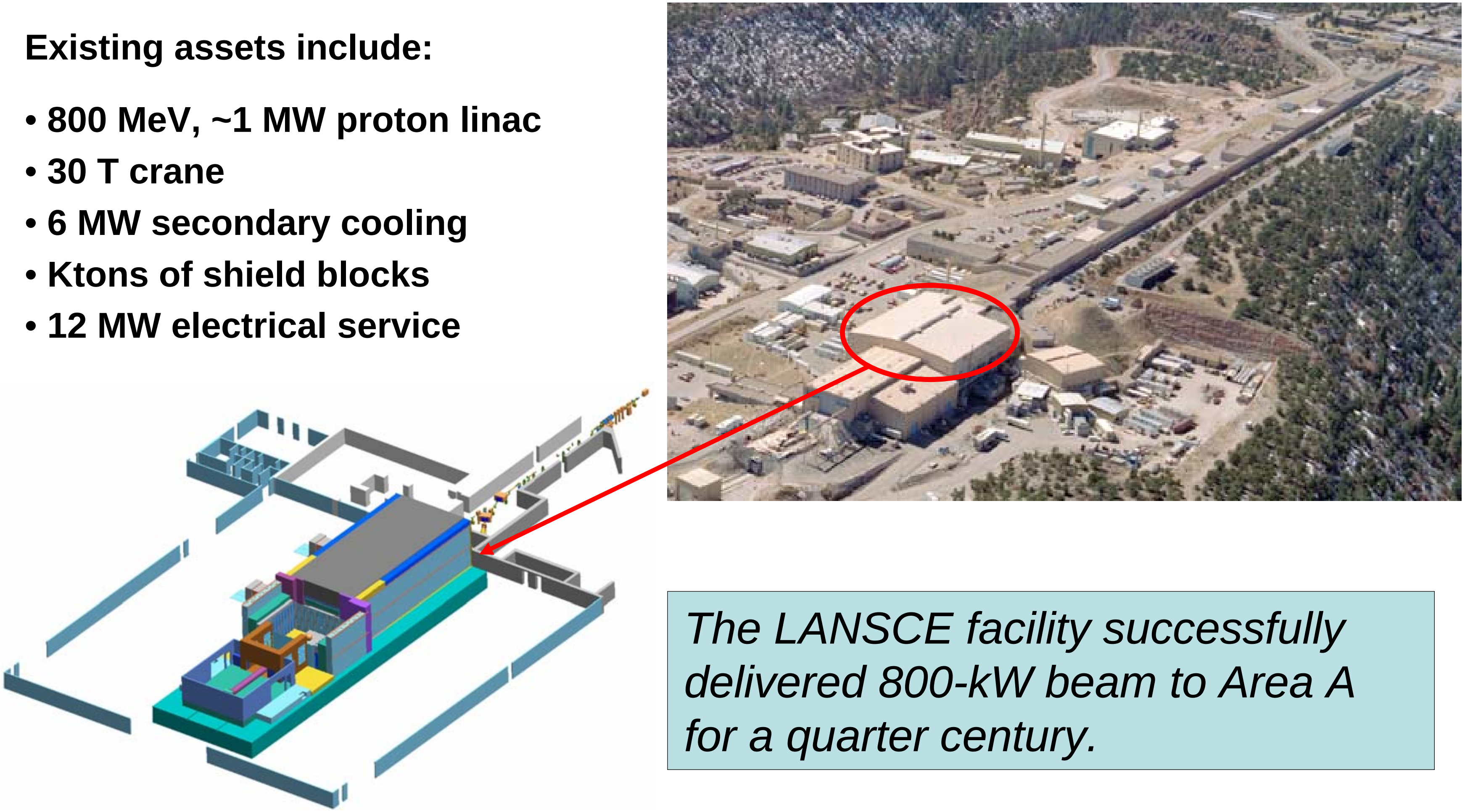
The MTS irradiation environment meets the programmatic objectives

Criterion	Design Requirement	Current Design
Neutron spectrum	Similar to that of a fast reactor	Meets requirement
Peak fast (>0.1 MeV) neutron flux	$\geq 1\times10^{15}$ n.cm^{-2}.s^{-1}	1.3×10^{15} n.cm^{-2}.s^{-1}
Irradiation volume	40 pellets in fast flux exceeding 1×10^{15} n.cm^{-2}.s^{-1}	Exceeds requirement by factor of 5
Irradiation temperature	Up to 550ºC clad surface temp	Meets requirement
Availability	≥3%/y burnup and ≥10 dpa/y in Fe in the peak flux region	3.5%/y burnup and 18 dpa/y in Fe
Prototypic fast reactor environment	Ability to accommodate liquid metal coolants	Meets requirement

MTS will be located in the 3,000 m² LANSCE "Area A" experiment hall

Existing assets include:

- **800 MeV, ~1 MW proton linac**
- **30 T crane**
- **6 MW secondary cooling**
- **Ktons of shield blocks**
- **12 MW electrical service**

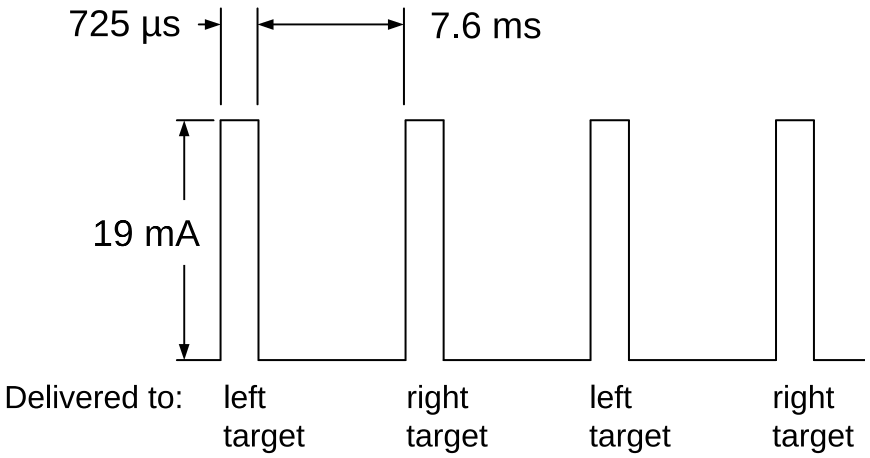


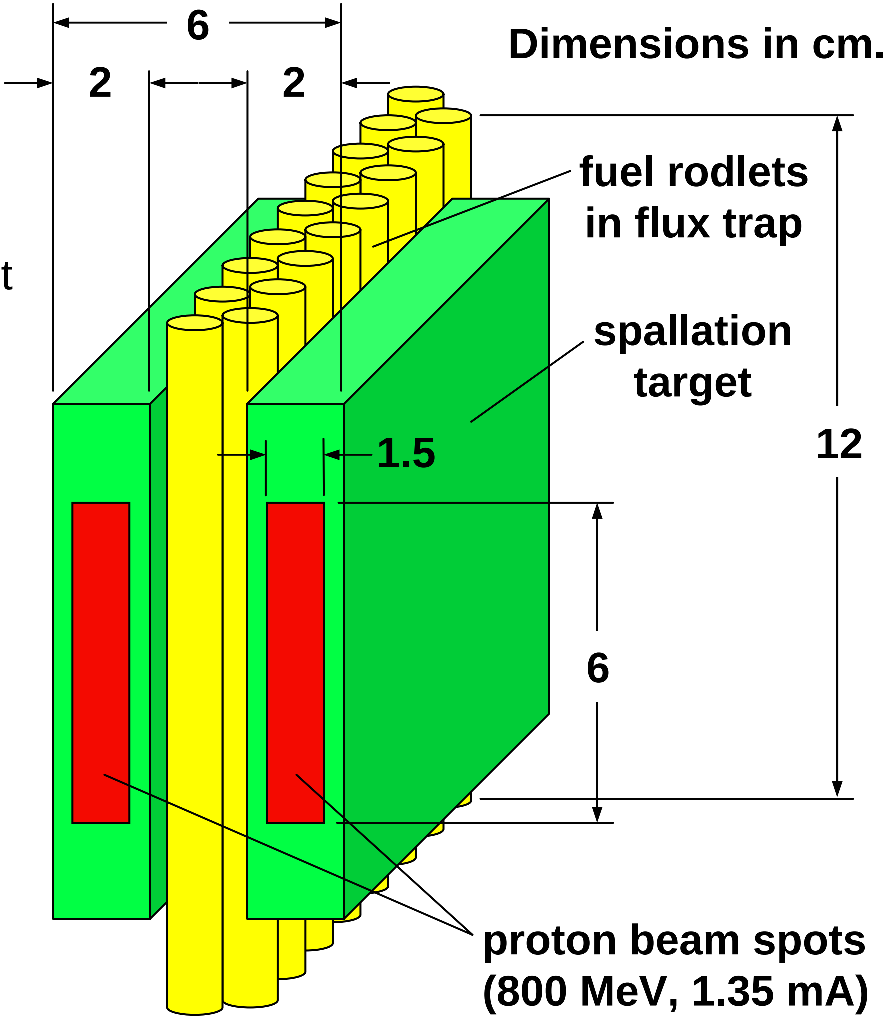
The LANSCE facility successfully delivered 800-kW beam to Area A for a quarter century.

The MTS target consists of two spallation target sections separated by a “flux trap”

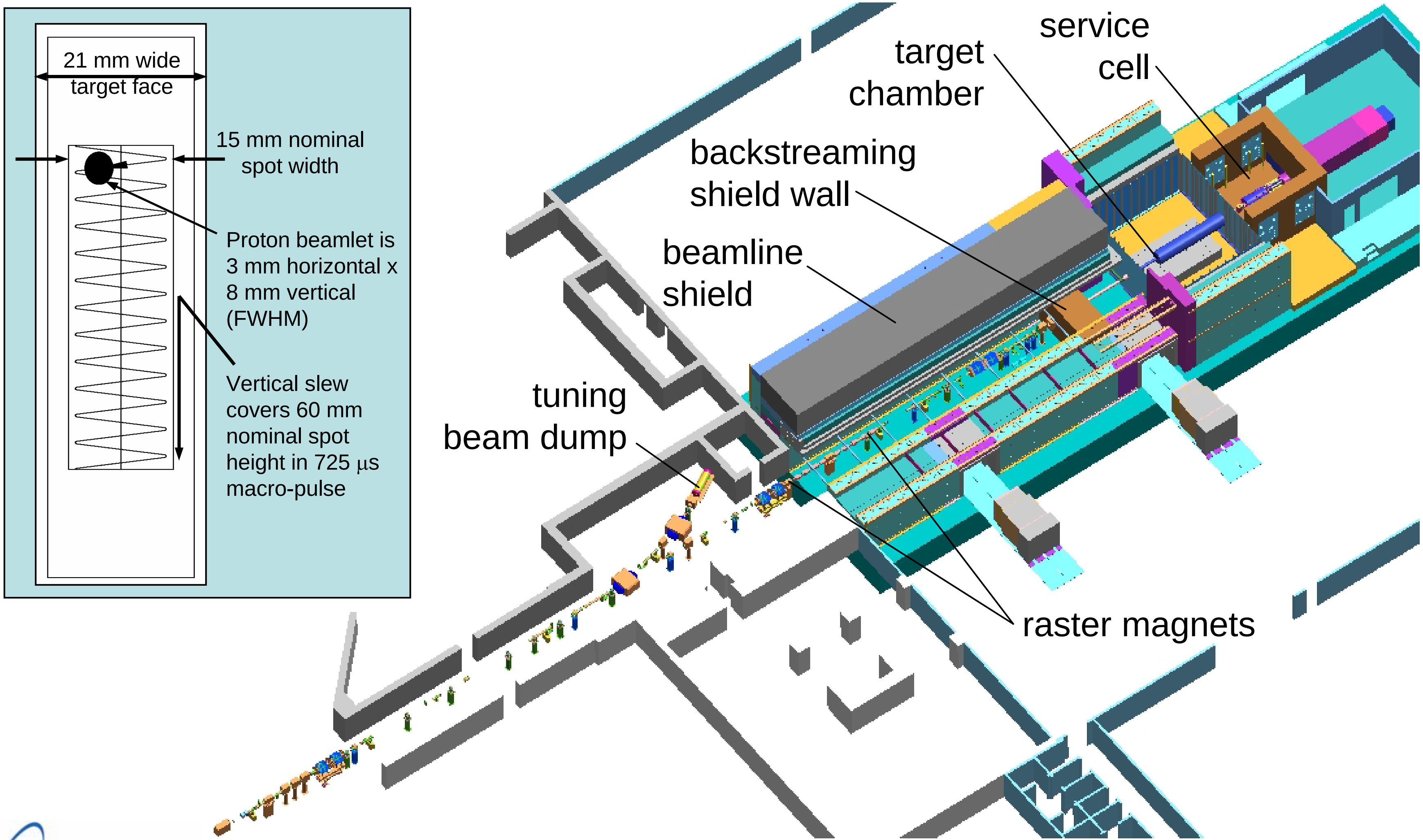
- Beam current will be 1.35 mA (after LANSCE Refurbishment)
- Availability is expected to be
  - 3000 hours per year in 2012-2014 during LANSCE refurbishment project
  - 4400 hours per year after LANSCE Refurbishment

Beam pulse structure:





The beam transport includes a raster system that yields nearly uniform current density on target



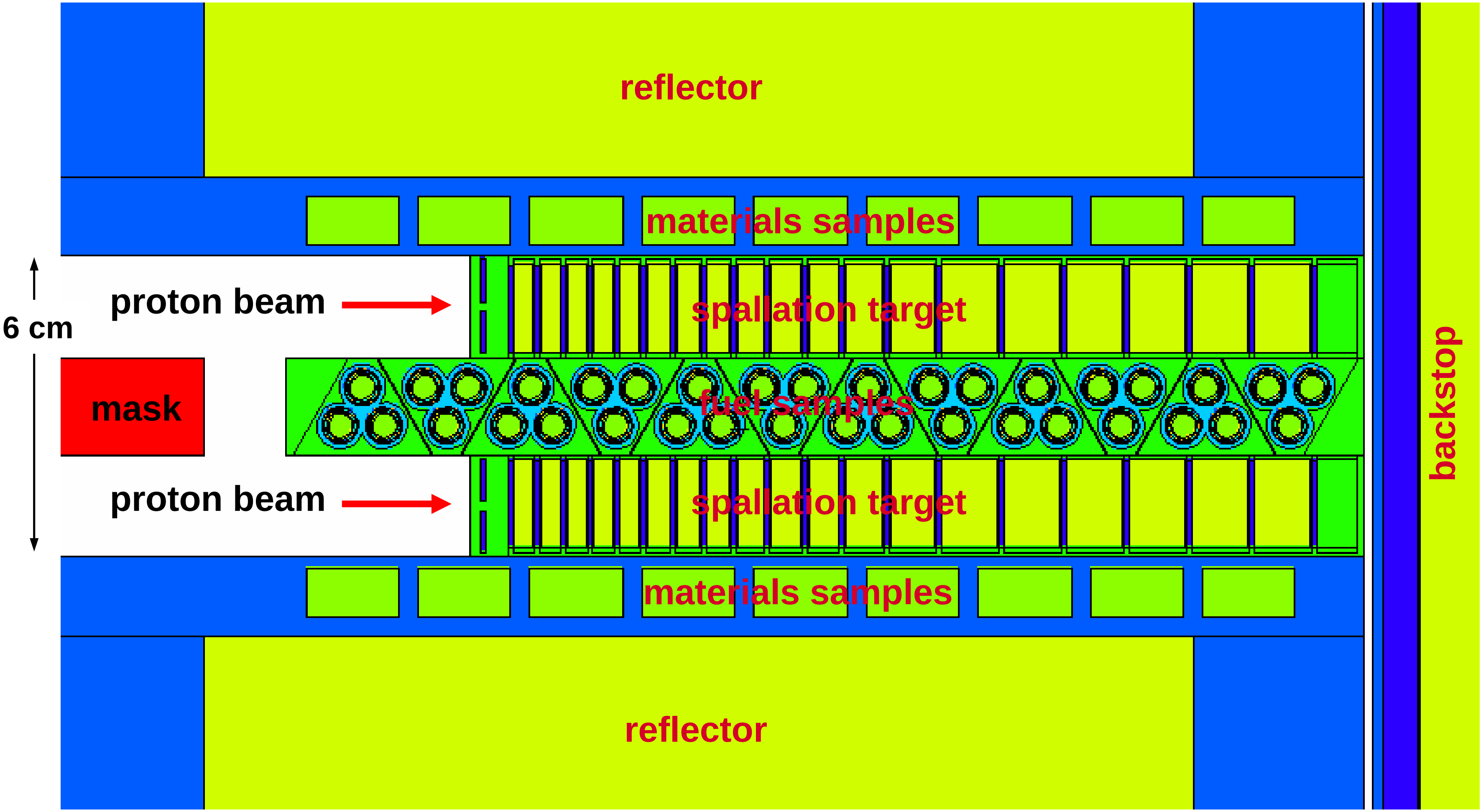
21 mm wide target face

15 mm nominal spot width

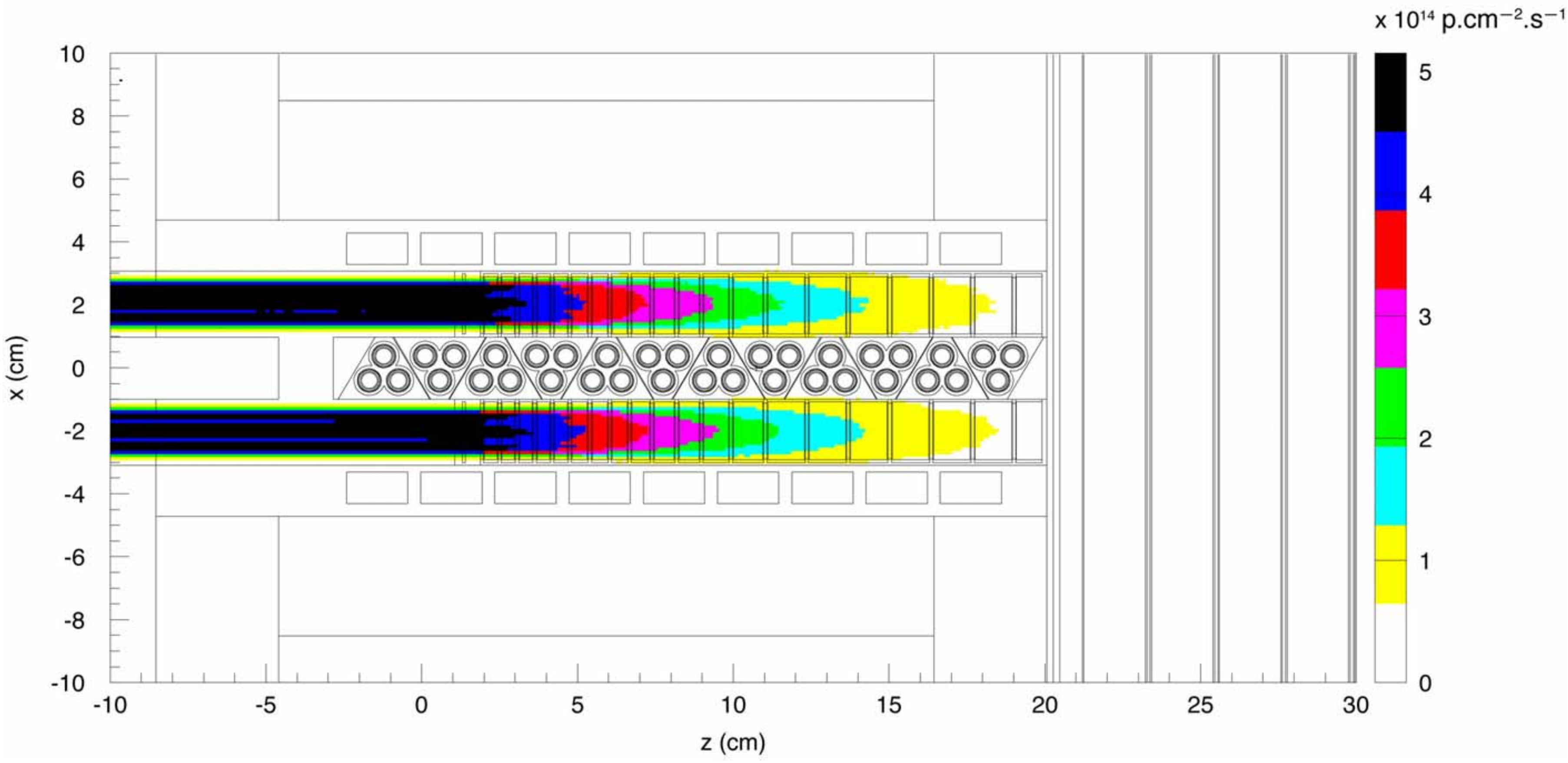
Proton beamlet is 3 mm horizontal x 8 mm vertical (FWHM)

Vertical slew covers 60 mm nominal spot height in 725 µs macro-pulse

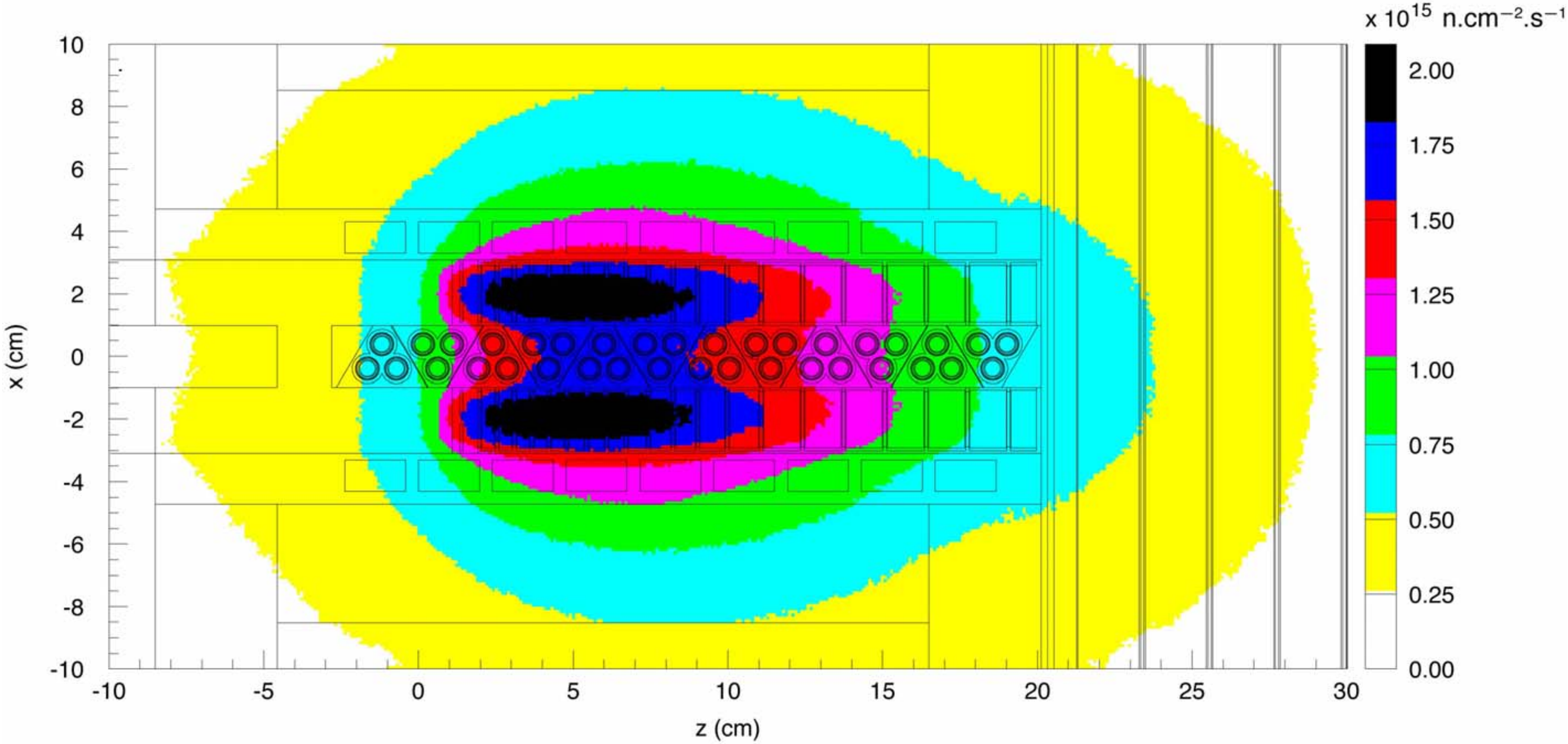
Horizontal cut through the MTS target assembly at beam centerline



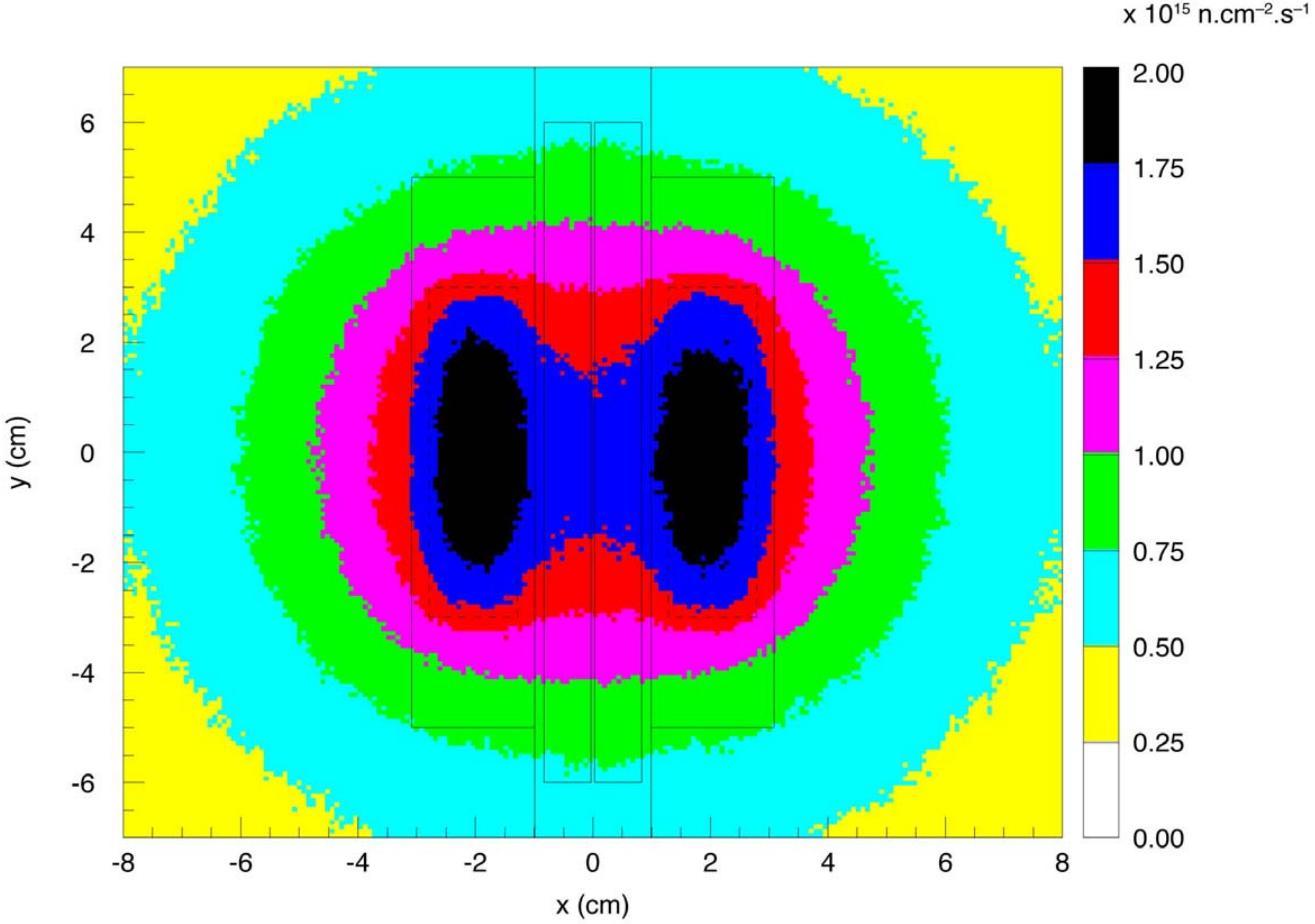
Spatial distribution of the proton flux shows low proton contamination in the irradiation regions



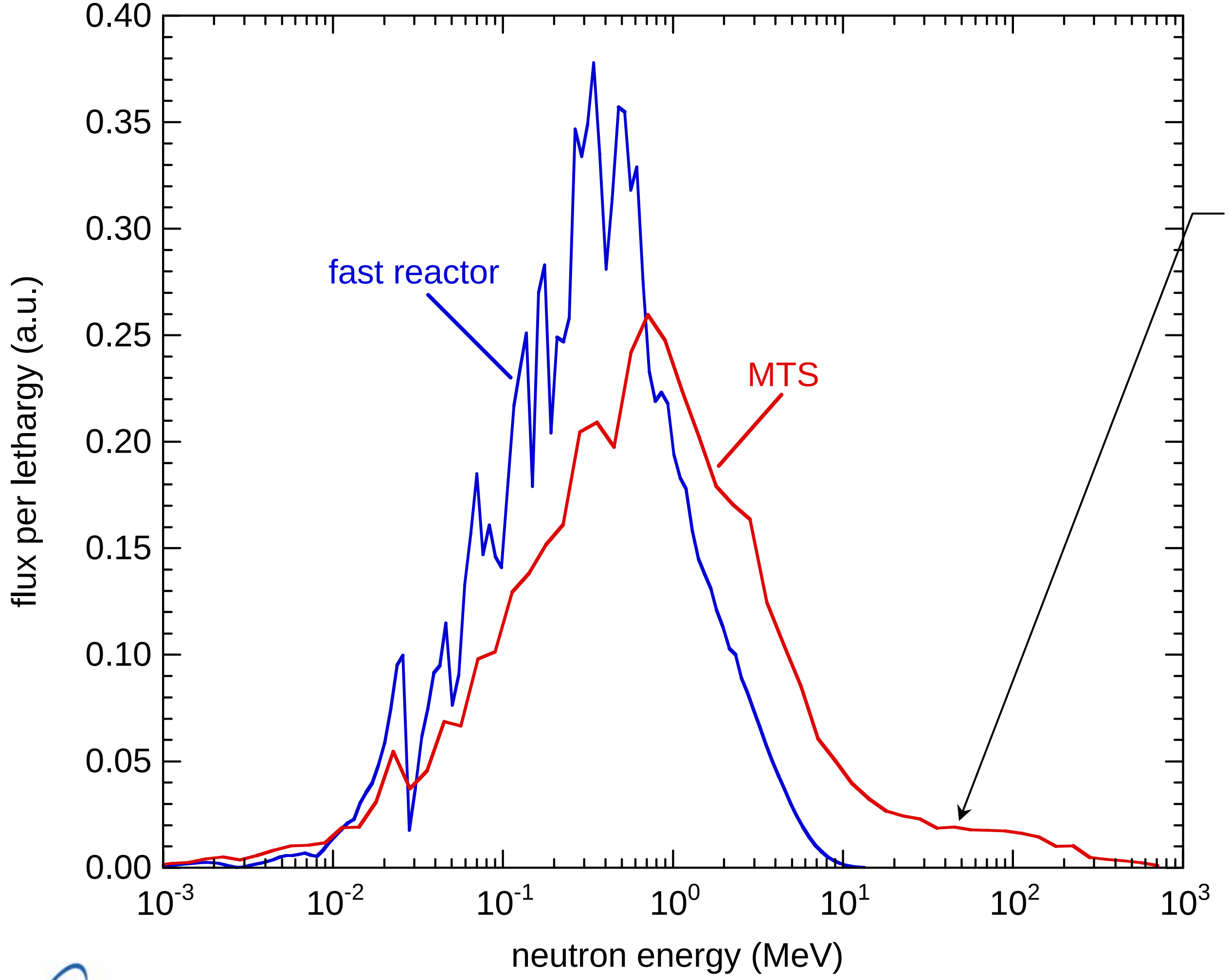
Spatial distribution of the neutron flux shows uniformity over the dimensions of a fuel pellet



Neutron flux distribution, vertical cut showing low gradient in the vertical dimension



MTS neutron spectrum is similar to that of a fast reactor with the addition of a high-energy tail

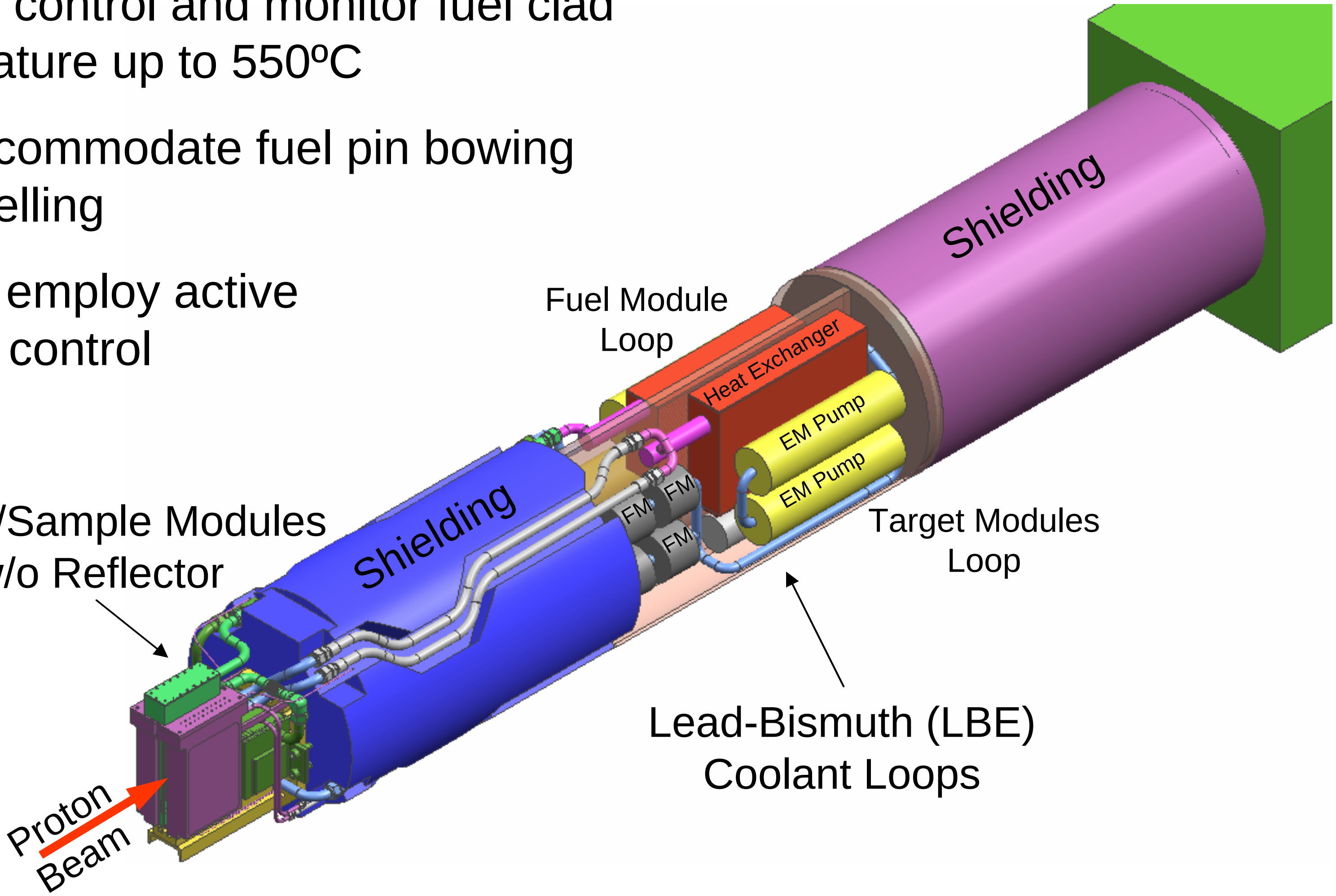


6% of neutron flux is >10 MeV

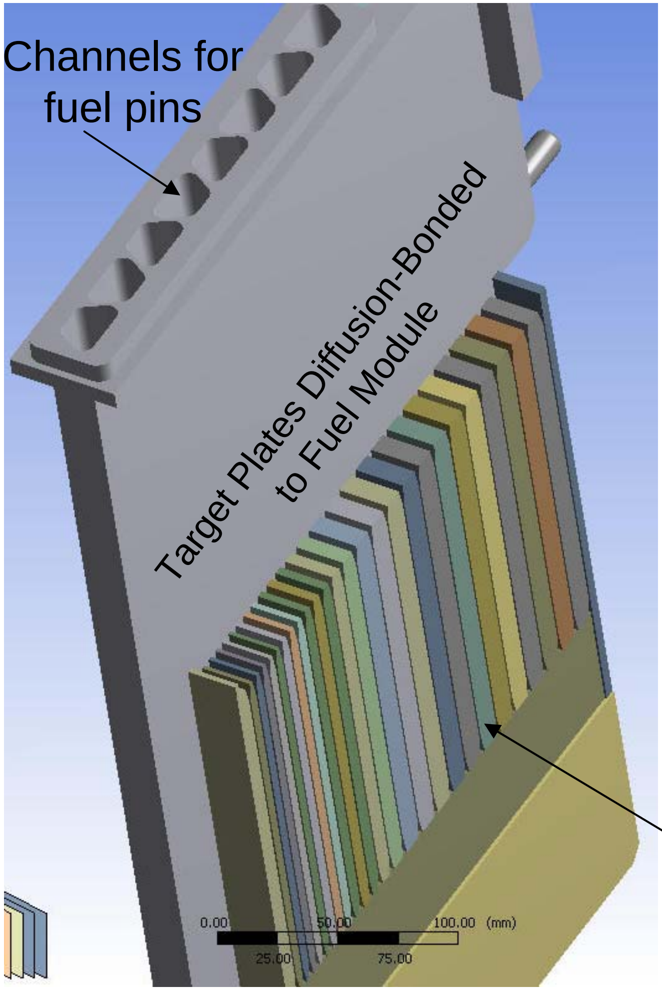
- **Effect on fuel is minimal**
- **Effect on cladding from additional He generation**
  - **Embrittlement**
  - **Creep rupture**

The use of Pb-Bi as a fuel and target coolant provides prototypic reactor environment

- Easy to control and monitor fuel clad temperature up to 550ºC
- Can accommodate fuel pin bowing and swelling
- We will employ active oxygen control

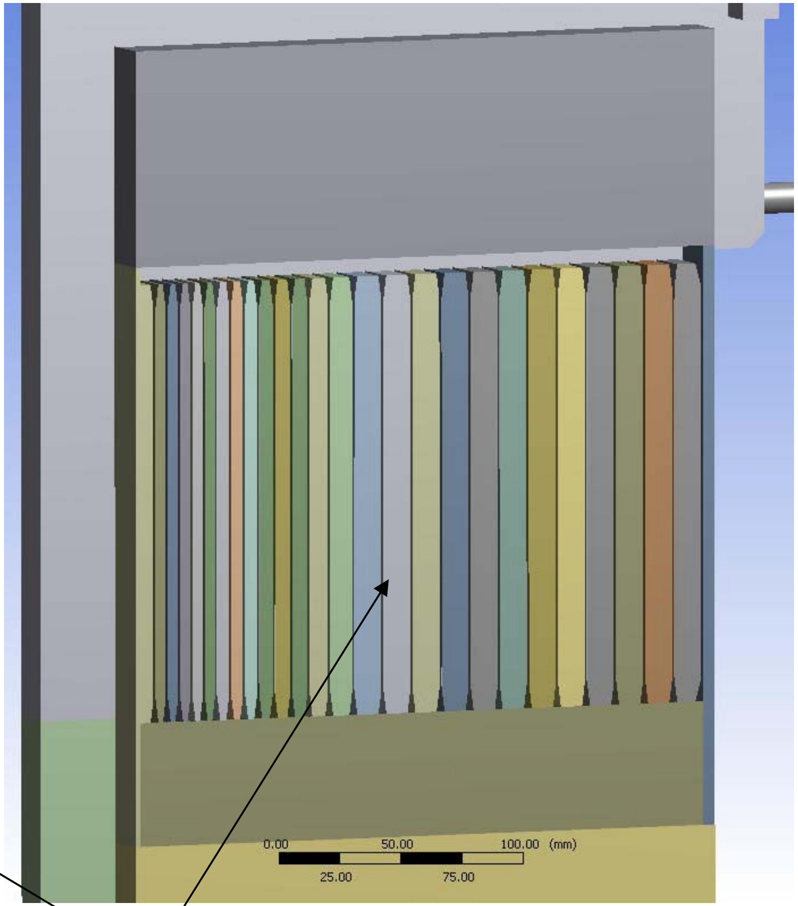


Targets consist of tungsten plates cooled by flowing Pb-Bi in 1-mm-wide gaps between plates



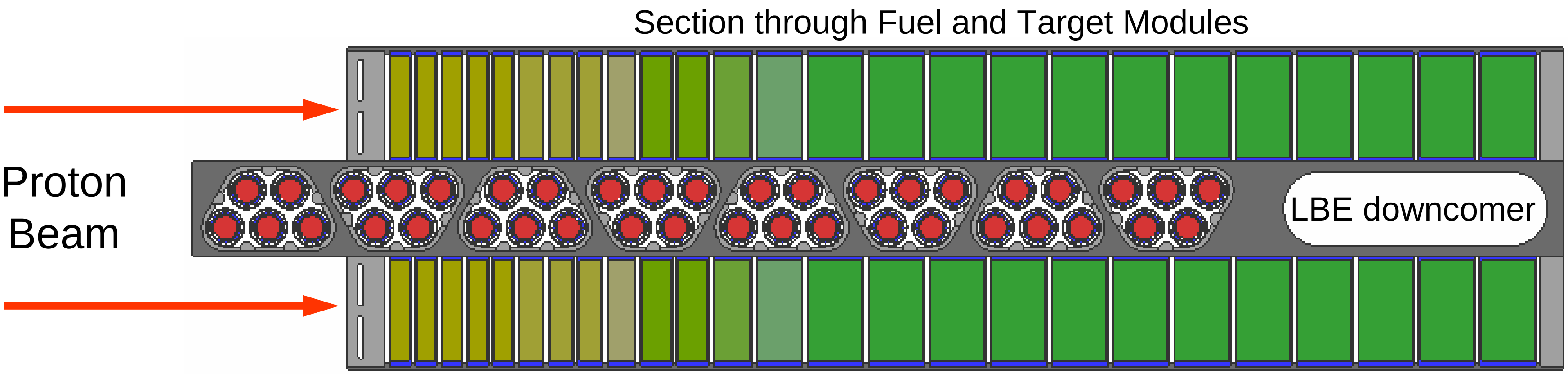
Channels for fuel pins

Target Plates Diffusion-Bonded to Fuel Module

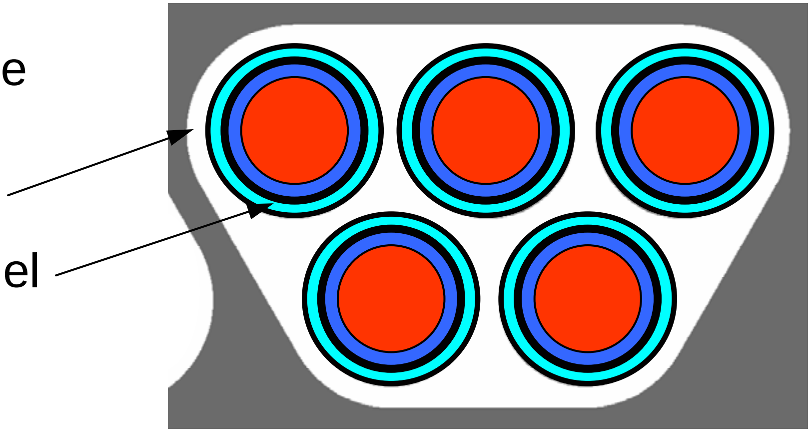


Tungsten target plates with 1-mm-wide coolant gaps

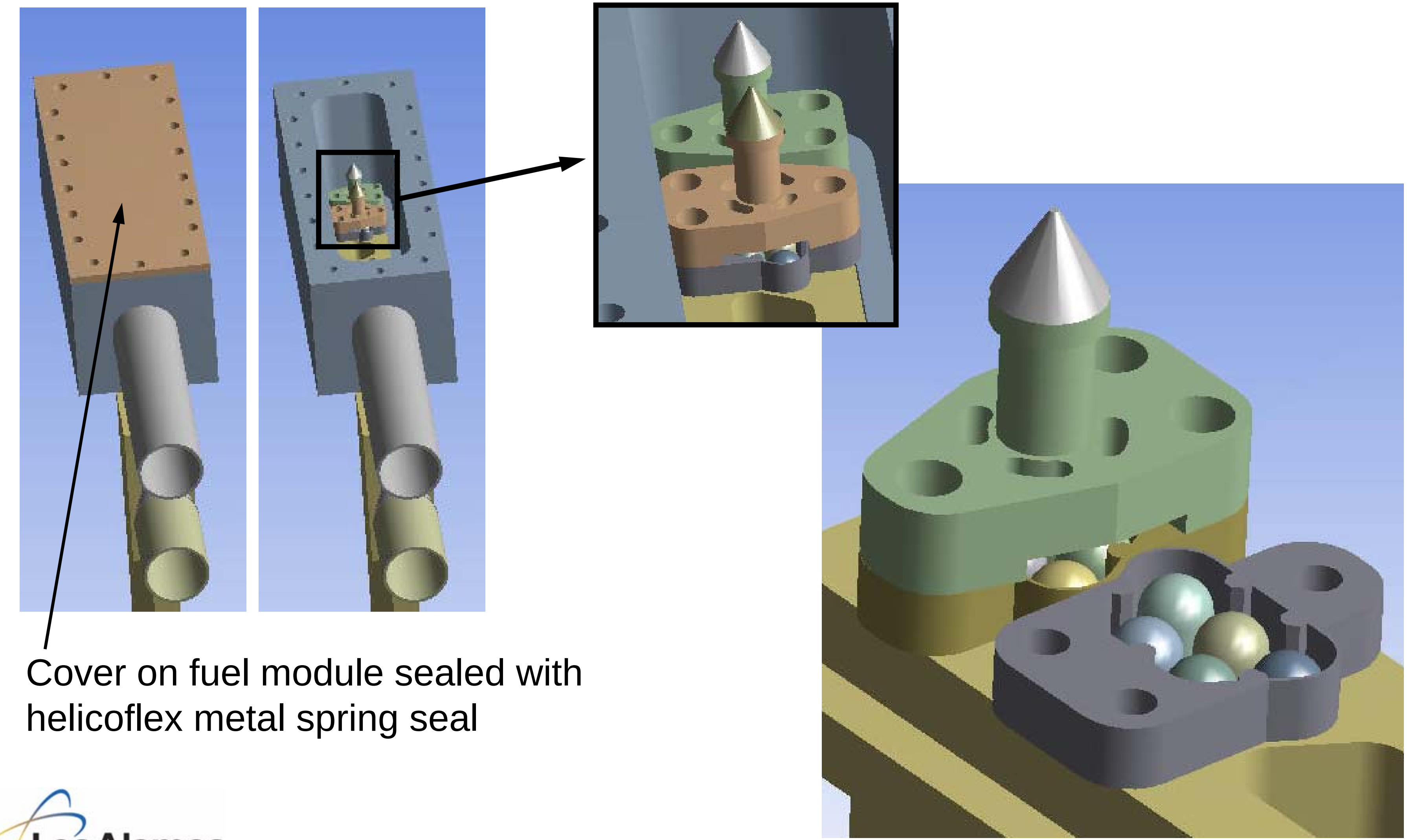
Fuel module holds 40 rodlets in 5-pin bundles, cooled by flowing LBE axially along pin bundles



- Pins are wire-wrapped (not shown) to provide pin-to-pin spacing and enhance turbulent heat transfer
- 1-mm LBE coolant gaps between pins
- 0.25-mm static sodium layer around fuel pin

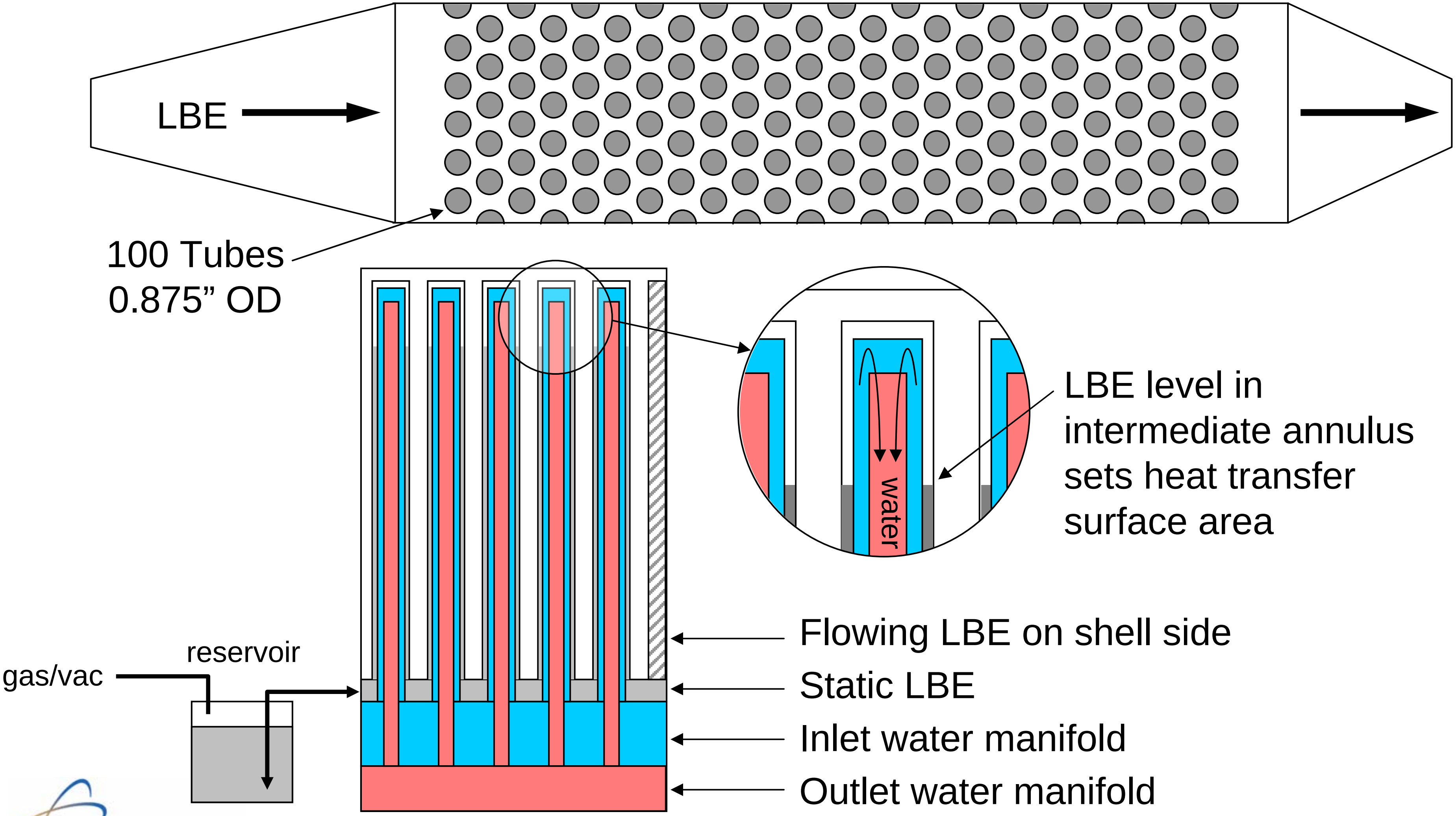


Fuel basket enables insertion & removal of 5-pin fuel sub-assemblies (based on EBR-II design)



Cover on fuel module sealed with helicoflex metal spring seal

LBE temperature is controlled with variable-area, double-walled shell-and-tube heat exchanger



LBE level in intermediate annulus sets heat transfer surface area

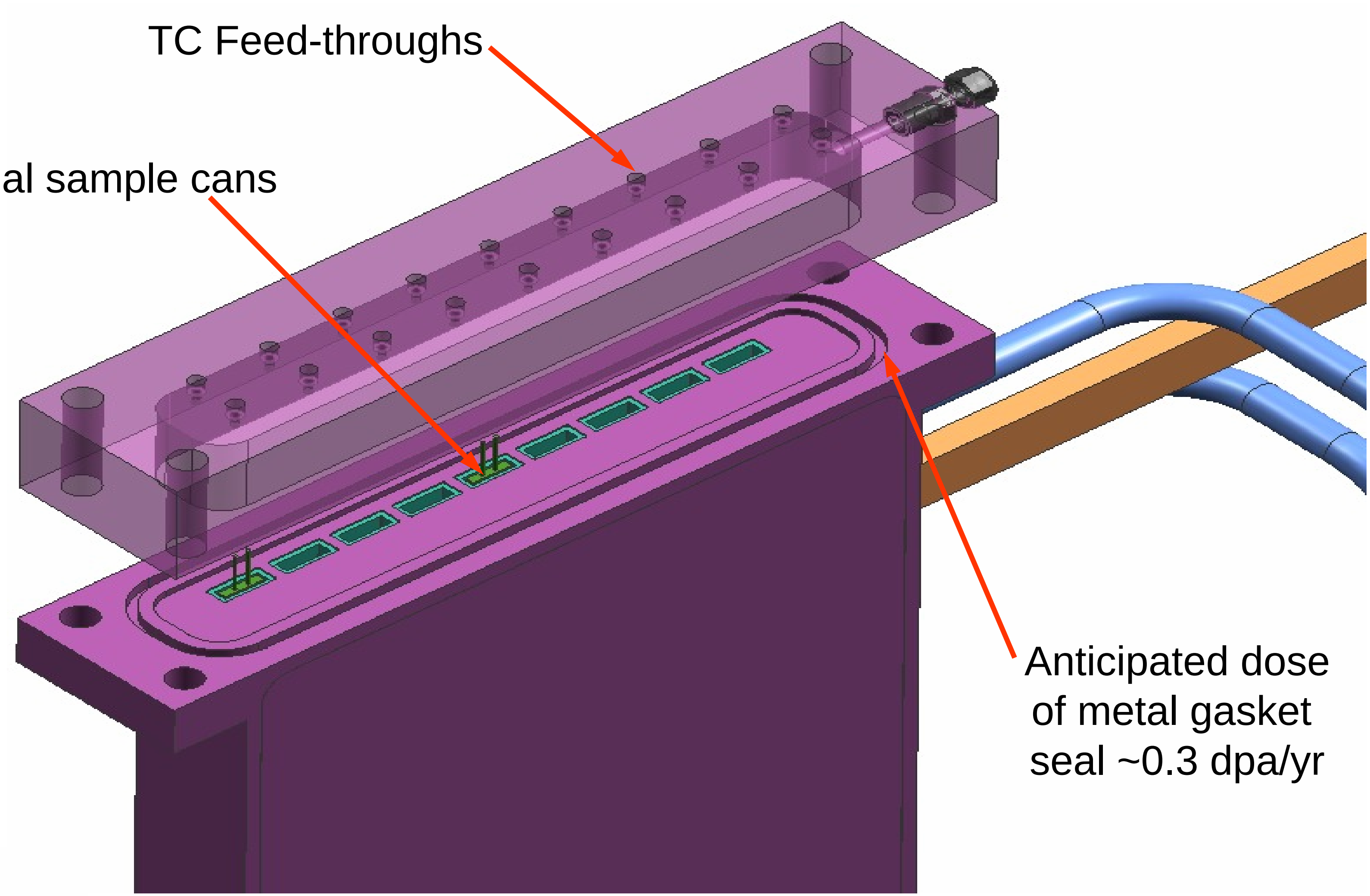
Flowing LBE on shell side

Static LBE

Inlet water manifold

Outlet water manifold

Removable cover plate on materials sample module provides easy access to sample cans



TC Feed-throughs

Material sample cans

Anticipated dose of metal gasket seal ~0.3 dpa/yr

The target front face will be subjected to 75 μA/cm^2 current density for 4400 hrs per year

- Target front face is HT9-clad tantalum

	displacements (dpa/y)		He production (appm/y)		He/dpa (appm/dpa)	
	Ta	Fe	Ta	Fe	Ta	Fe
neutrons	3.6	10.8	38	90		
protons	36.8	12.1	4760	3190		
total	40.4	22.9	4800	3280	119	144

MTS proton fluence on target = 7.4×10^{21} protons/cm^2 per year
This compares to:
MEGAPIE (Pb-Bi, T91 front face) = 1.9×10^{21} protons/cm^2
ISIS (D2O-cooled Ta-clad W, SS316 front face) = 3.2×10^{21} protons/cm^2

Pending DOE approval, MTS will operate as a non-nuclear facility

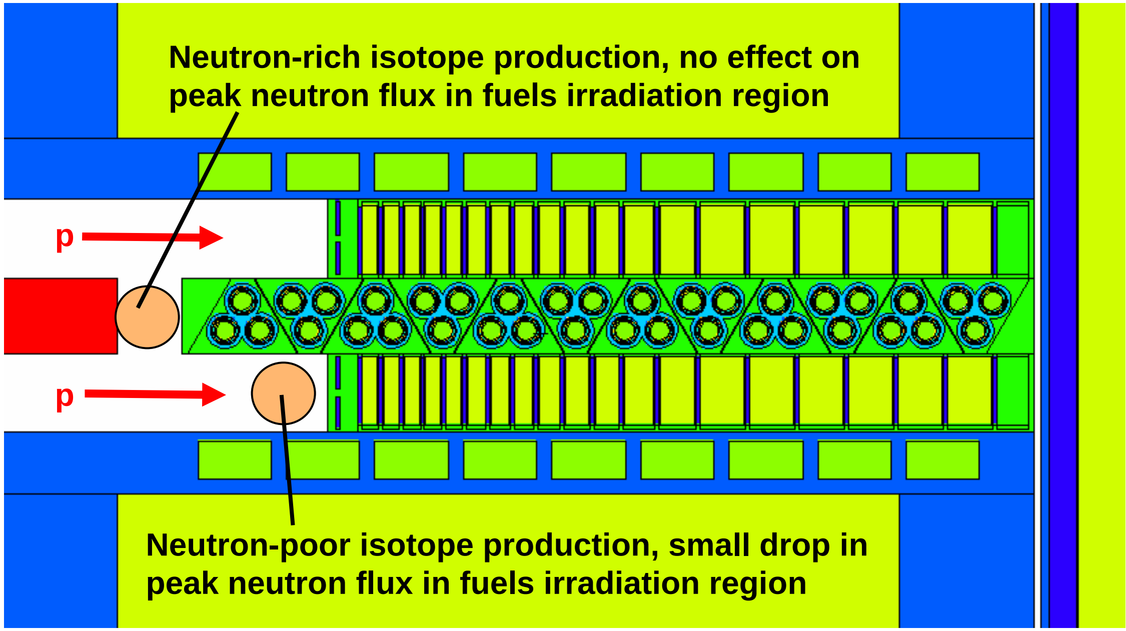
- The MTS is deeply subcritical
  - Only 4% of neutrons are generated by low-energy (<10 MeV) neutron-induced fission reactions
  - Fissile inventory is less than 1 kg
- SNS operates as a non-nuclear facility under the Department of Energy (DOE) Accelerator Safety Order
- Accelerator targets are exempt from classification as a nuclear facility so long as there is “no potential for criticality”

Our approach to safety is equivalent to that of a nuclear facility

- “Credited controls” replace safety-significant or safety-class components
- Given an initiating event and the simultaneous failure of the first-line credited control, the dose at the site boundary must be well below 0.25 Sv
  - Example design basis accident:
    Assume the loss of site power (initiating event) and, simultaneously, one Pb-Bi target coolant EM pump fails (failure of a credited control)
    ⇒ this accident should not exceed 0.03 Sv at the site boundary

We are currently evaluating an expanded mission scope to include isotope production

- Long-lived radioisotopes (e.g., Si-32, Sr-89) can be produced in the MTS in a straightforward manner
- Rapid retrieval systems would allow the production of short-lived radioisotopes



Neutron-rich isotope production, no effect on peak neutron flux in fuels irradiation region

Neutron-poor isotope production, small drop in peak neutron flux in fuels irradiation region

Project completion is expected near the end of 2011

- Approval of Mission Need by DOE expected this month
- Conceptual design will be completed by end of 2007
- Cleanout of Area A is estimated to take one year
- The total fabrication/installation process is estimated to take three years
- Start of operation is scheduled for the end of 2011
- MTS Total Cost range is $58M - $90M
- Operating cost is estimated to be $6M - $12M per year

Summary

- MTS provides a fast neutron spectrum that meets programmatic requirements for transmutation fuel testing
- Use of Pb-Bi liquid metal coolant meets experimenters' needs for elevated irradiation temperature
- An innovative Pb-Bi primary heat exchanger design should accommodate beam trips without large temperature transients
- MTS will produce valuable irradiation data for the development of transmutation fuels starting in 2012