Transformative Hadron Beamlines Workshop
21-23 July 2014 Brookhaven National Laboratory

SNS Target R&D

Presented by

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U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

SNS – running since 2006

- Mission is focused on neutron science
- 1.4 MW on target, 1 GeV, linac & accumulator ring, μs pulses to target at 60 Hz

The master plan is for two short-pulse target stations at SNS

First target station

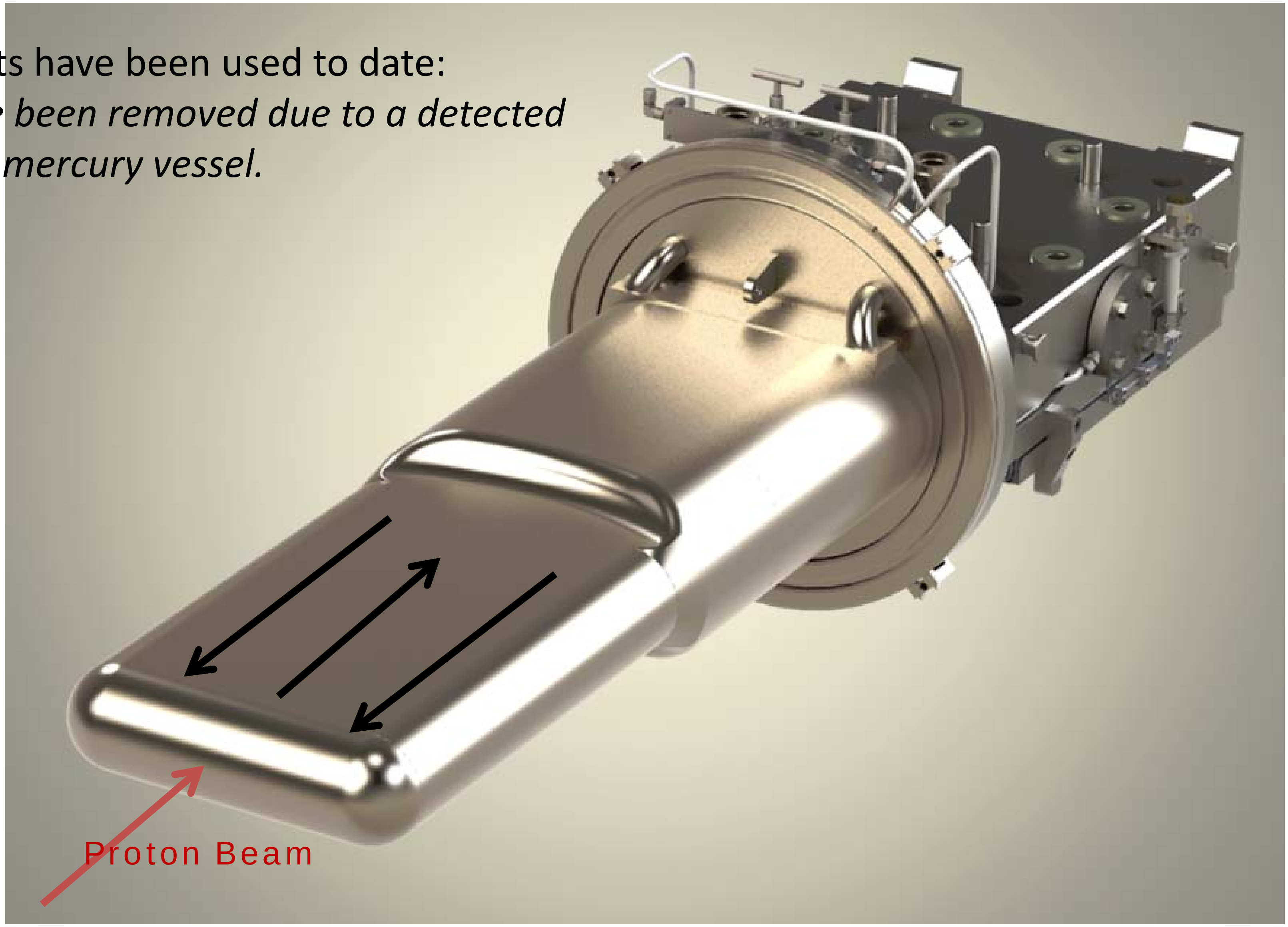
- Mercury was chosen as the target material since high power was a priority:
  - Steady state power handling allows MW-class operation
  - R&D basis at the time of the decision was tenuous for what has been achieved
- Rotating target was rejected due to suspected seal issues
  - These issues have since been resolved
  - QA program would have to be very stringent for long lifetime

Second target station

- 500 kW power level, short pulse, tungsten plates
- Complement to the FTS/HFIR instrument suite
- High brightness moderators is the emphasis

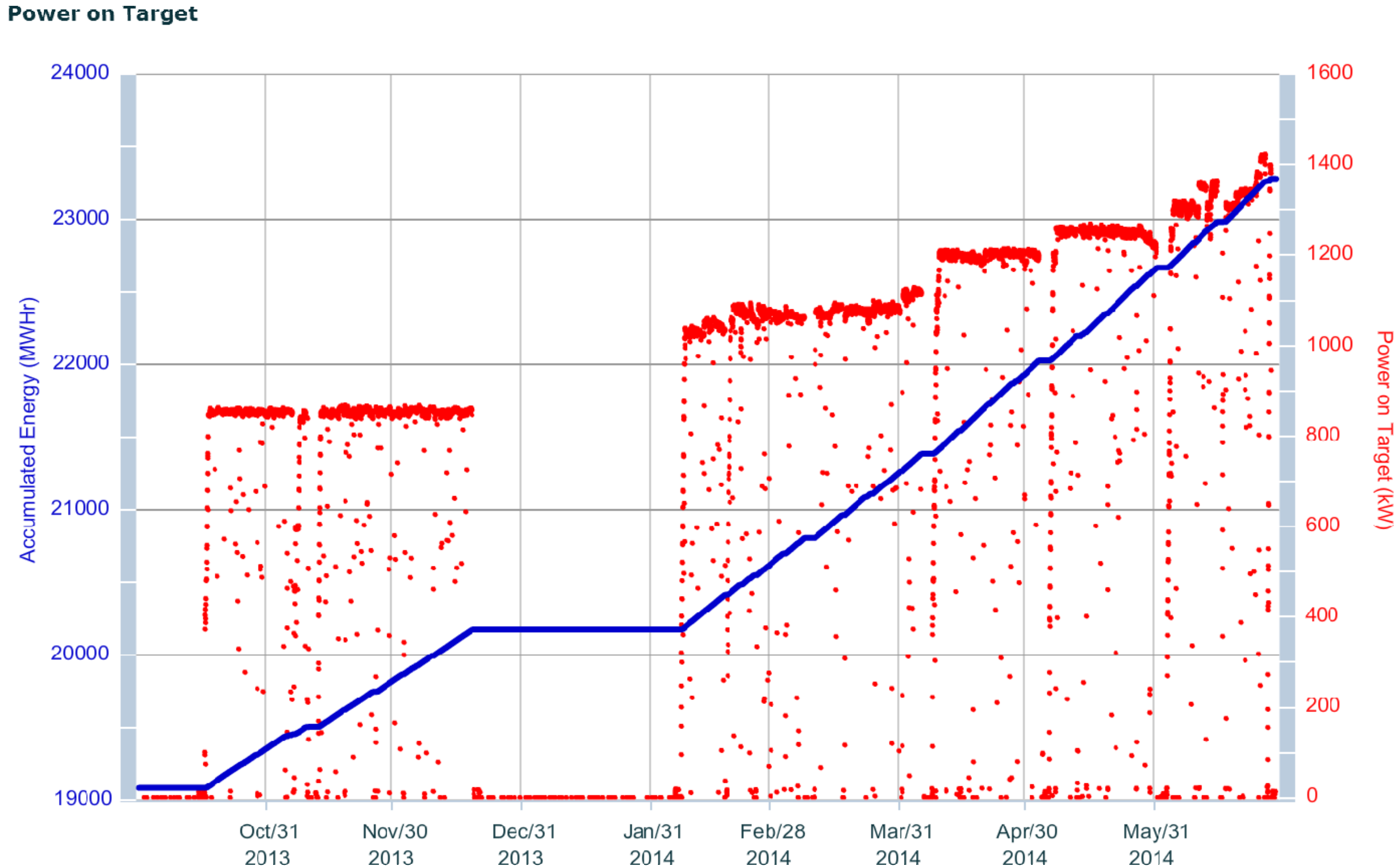
First target station SNS target module for mercury containment.

Nine targets have been used to date:
Three have been removed due to a detected leak in the mercury vessel.



First target station has performed reliably up to design parameters.

Recently we had our first target module exceed 4000 MW-hr and sustain the 1.4 MW design power level for 1 day



Nine targets have been used to date.

R&D requirements for SNS First Target Station to 2MW+

- Minor changes to mercury vessel to handle steady-state power – no R&D
- Cavitation damage erosion (CDE) may become a limiter
  - PIE has shown major damage, but no target failures have been blamed on CDE
  - Reliable gas injection/recovery system needs development (collaboration with JPARC)
  - Test facility for prototypic energy deposition is not currently available
- Moderator enhancements – brightness for 1 of 3 Hydrogen Moderators
- Lifetime extension to higher radiation damage levels beyond 10 dpa

PIE: disk-shaped specimens routinely removed from the target module by each cutter

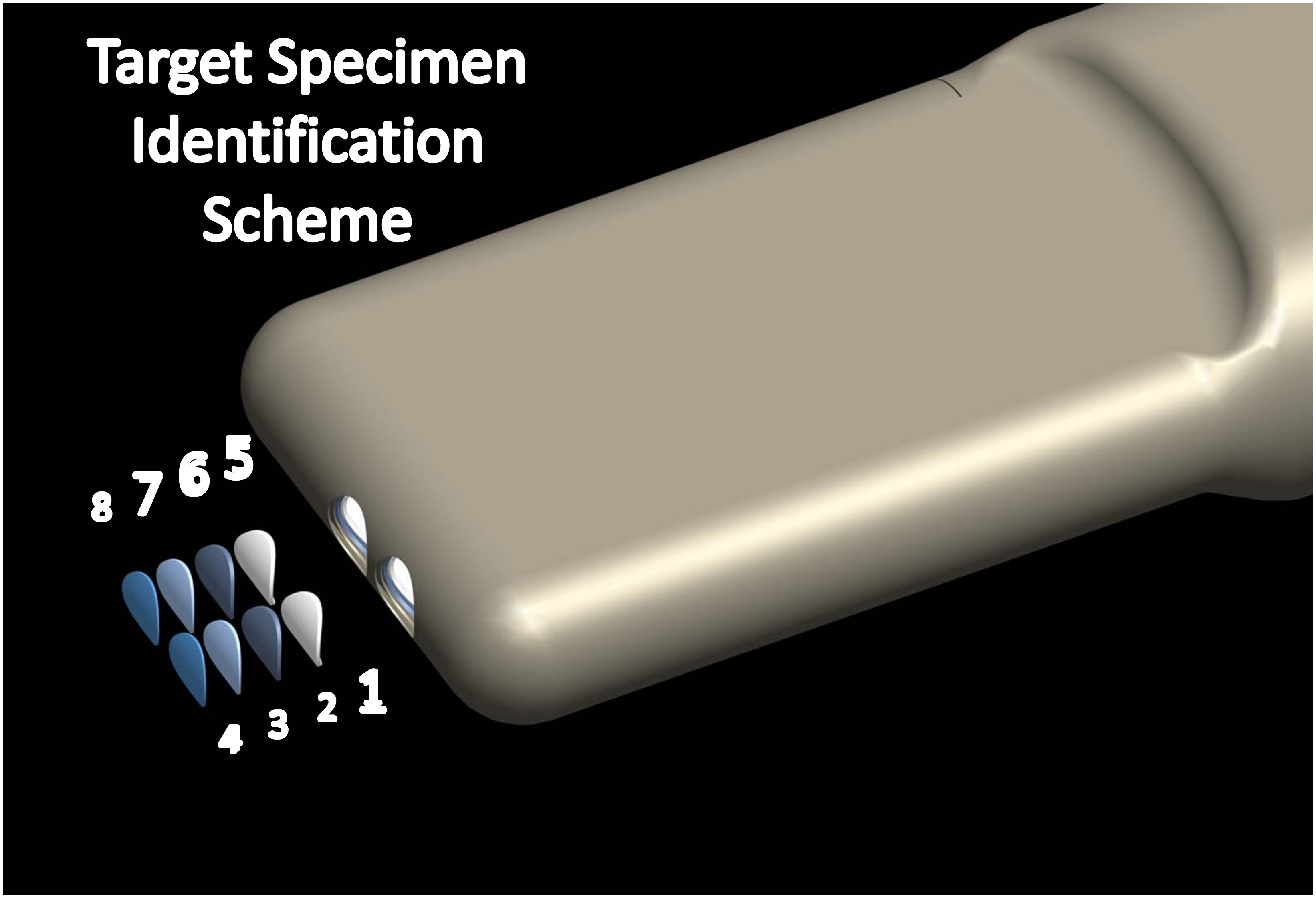
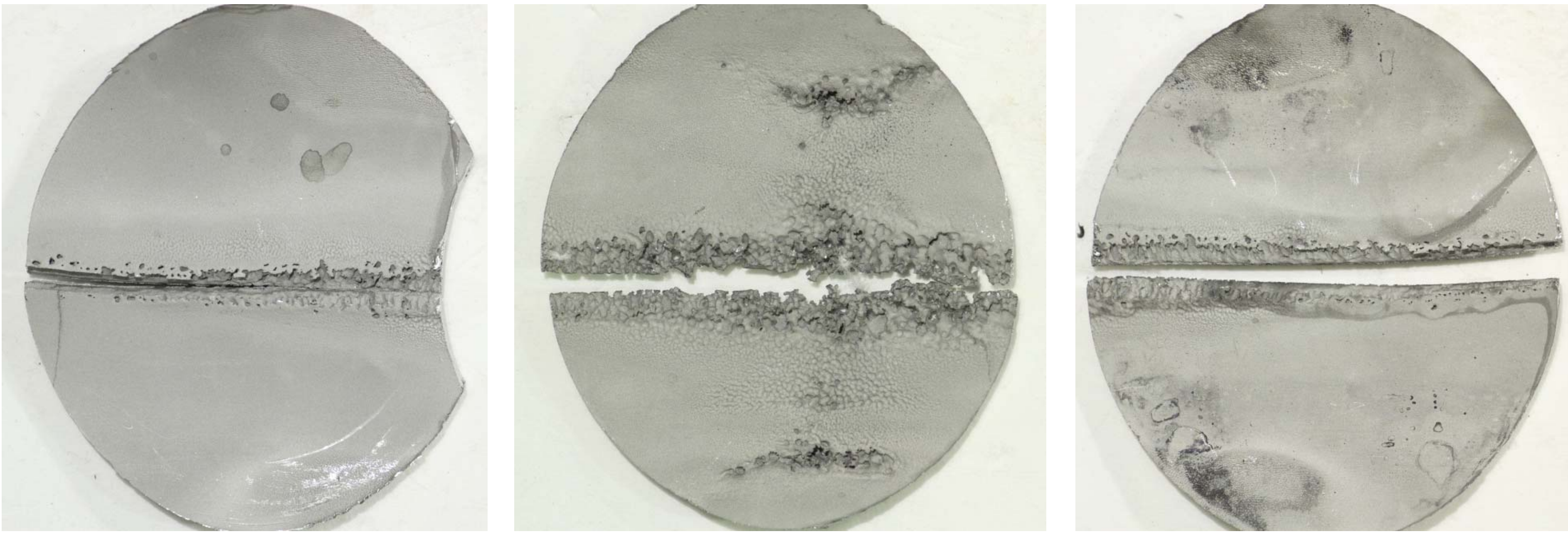


Figure Credit: K. Gawne

Cavitation damage is clear on an internal wall – lifetime of vessel is unclear

- Target 8 mercury vessel beam entrance inner wall
- Outer containment wall holds up much better



- "Jet-flow" target design should reduce this damage
  - Mitigation by flow – no gas injection
  - First JFT is already installed

Figure Credit: D. McClintock

ORNL target test facility hydraulically prototypic for mercury & gas testing

- No energy deposition
- Gas circulating system
- Gas injection location effectiveness
- Target R&D was halted with early success
- Now picking up some momentum with push toward higher power

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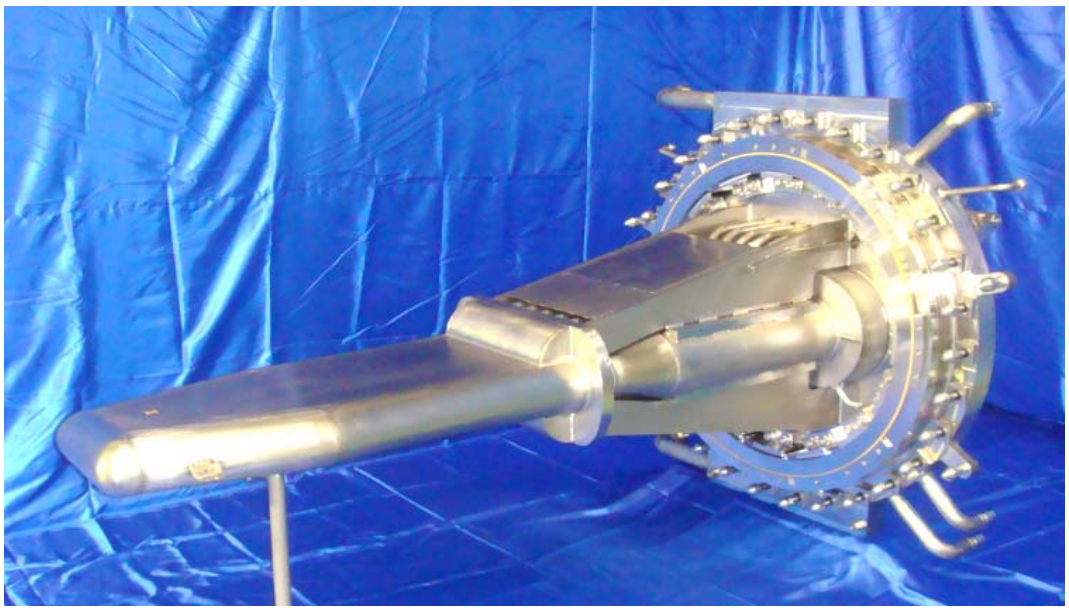
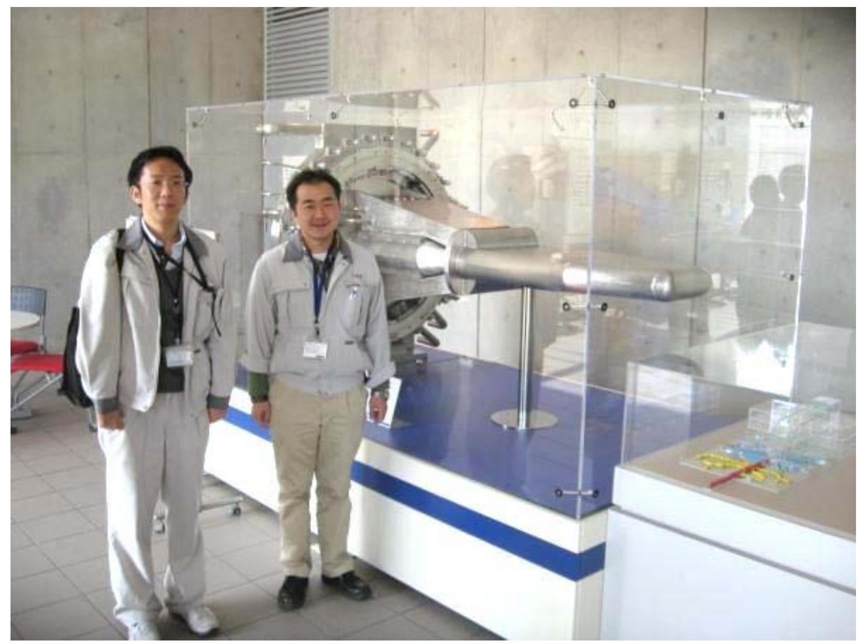
Collaborations with J-PARC on cavitation damage mitigation with gas are ongoing

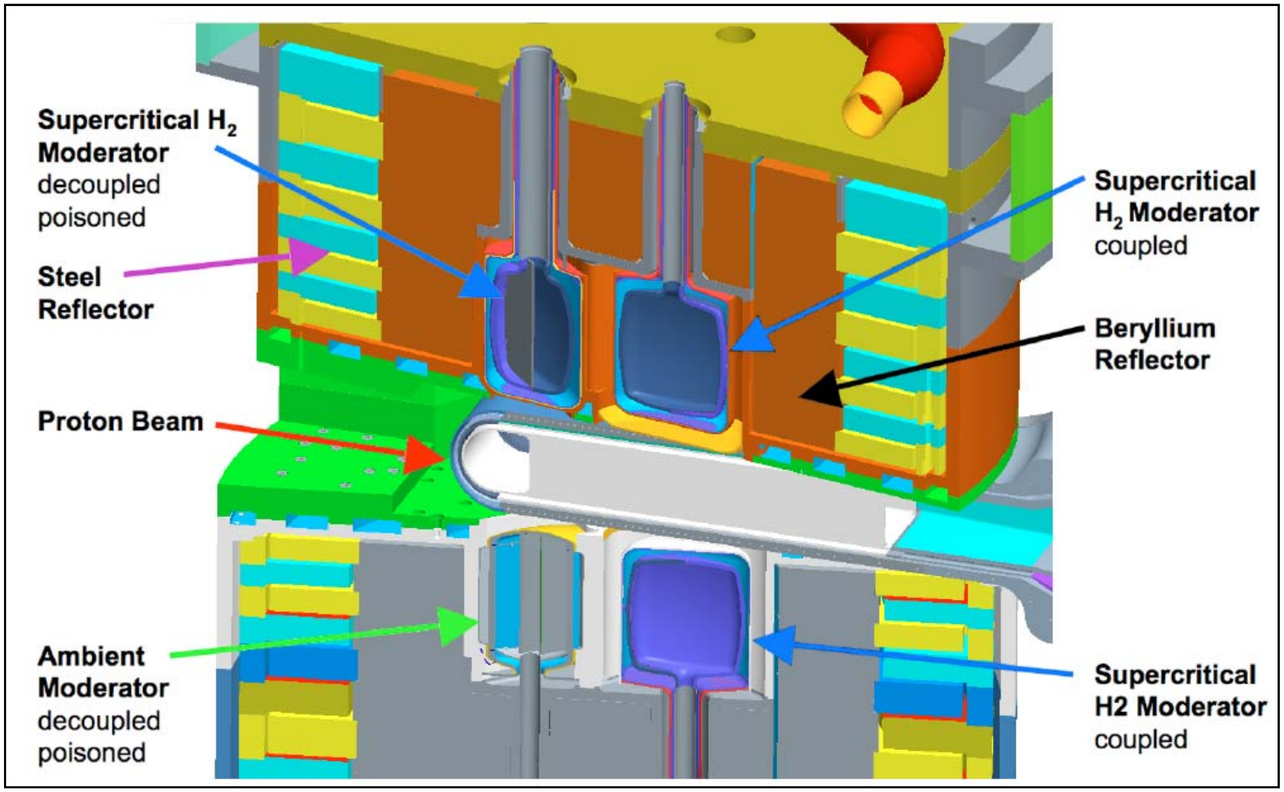
- 3 GeV RCS, μs pulses to target at 25 Hz
- Mercury, stationary SS316L vessel
- Gas injection already implemented





Some internal R&D funding has become available to restart moderator design effort

- Upstream moderators are decoupled and poisoned
- Downstream are coupled, not large; no ortho→para catalyst
  - Next generation IRP to improve and enlarge top downstream moderator; catalyst equipment to be added



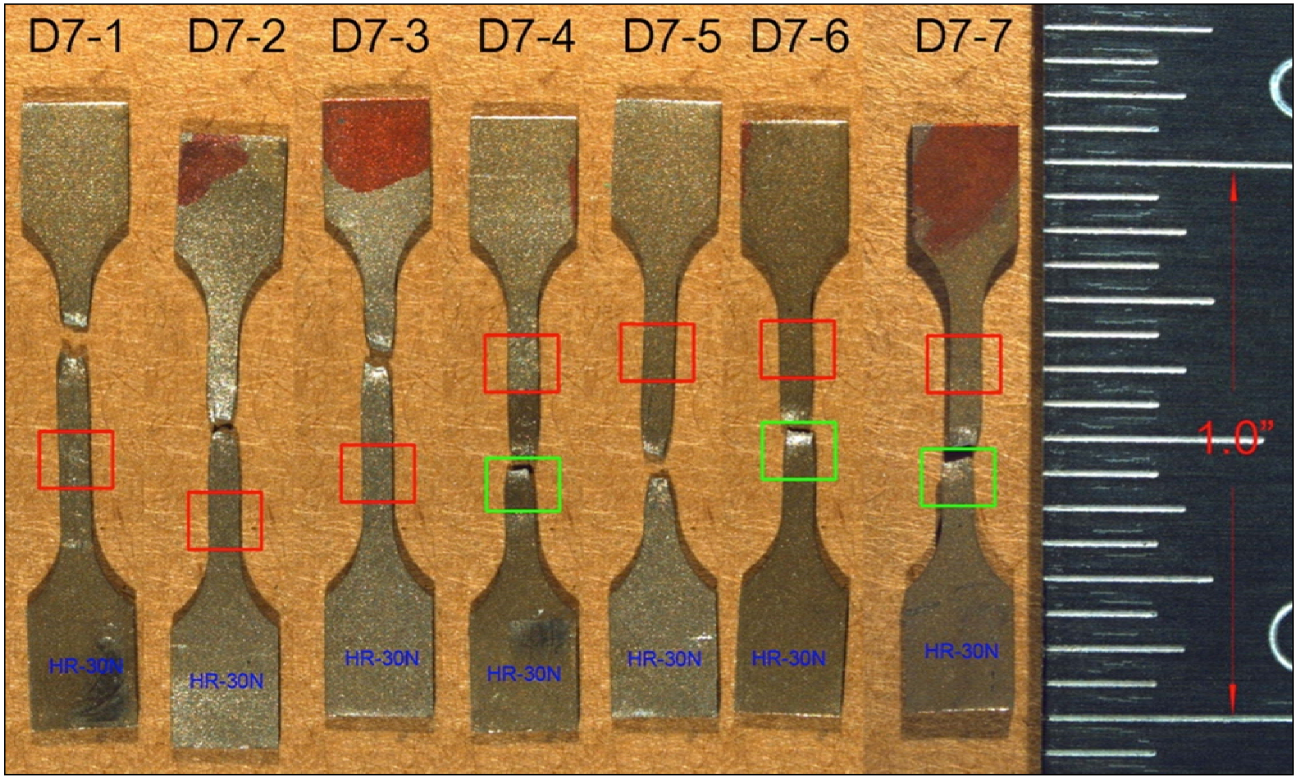
Lifetime limits at the SNS are based on different considerations

- AISI 316L and Inconel 718
  - Limit Basis: Maximum dpa
  - Concern: Loss off fracture toughness and ductility
- Aluminum PBW
  - Limit Basis: He concentration
  - Concern: Grain boundary embrittlement by He
- Inner reflector plug (aluminum)
  - Limit Basis: Burnup of gadolinium coating on the moderator poison plates
  - Concern: Loss of resolution and performance of instruments serviced

	Material	Lifetime Limit
Target	316L	10 dpa
PBW	Inconel 718	15 dpa
	AL 6061-T651	2,000 appm-He
RID	316L	10 dpa
IRP	Gadolinium	32,000 MW-hr

Figure Credit: D. McClintock

PIE program is starting to pick up momentum: goal is to extend the target module lifetime



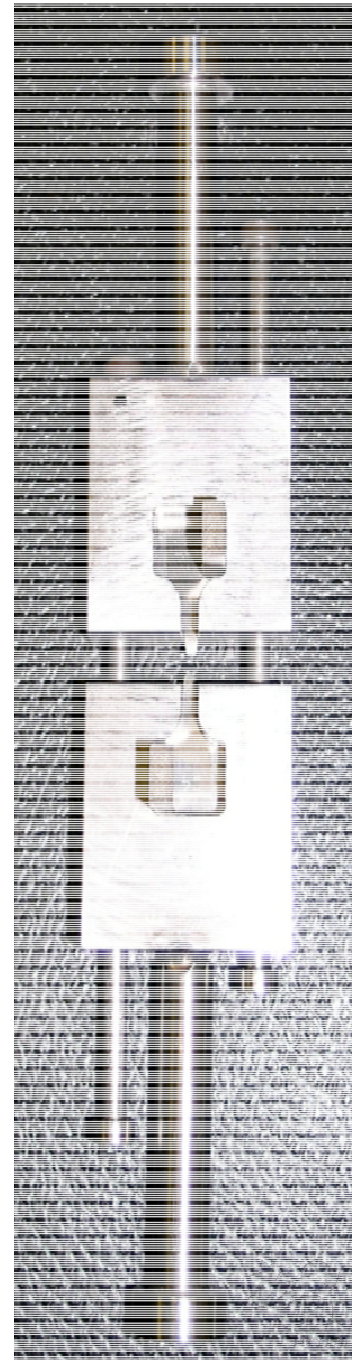
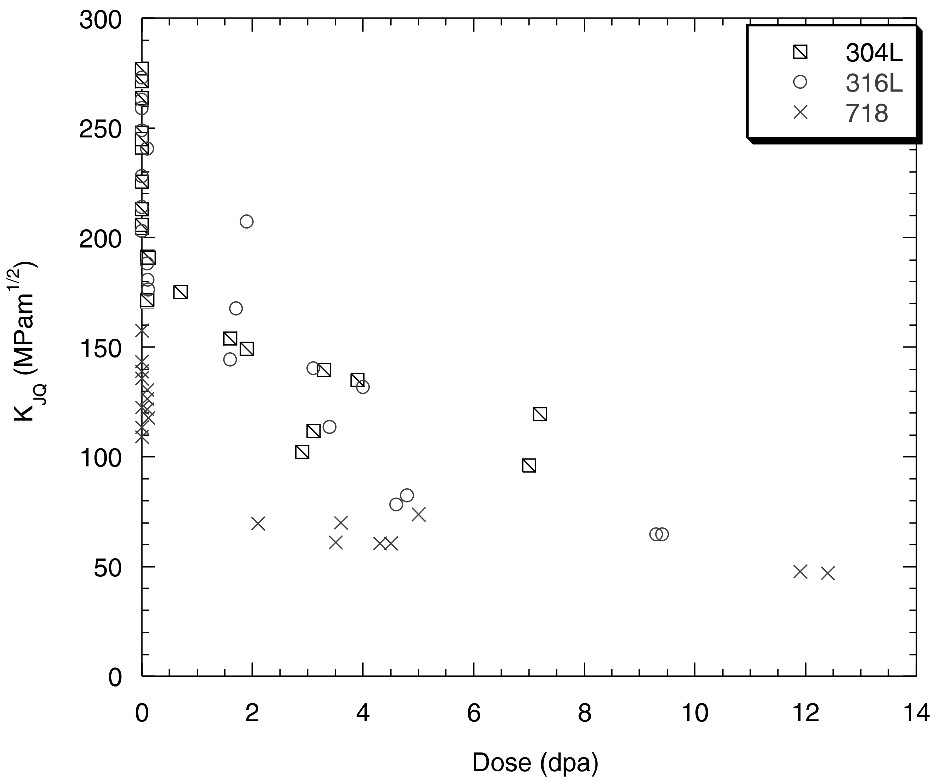


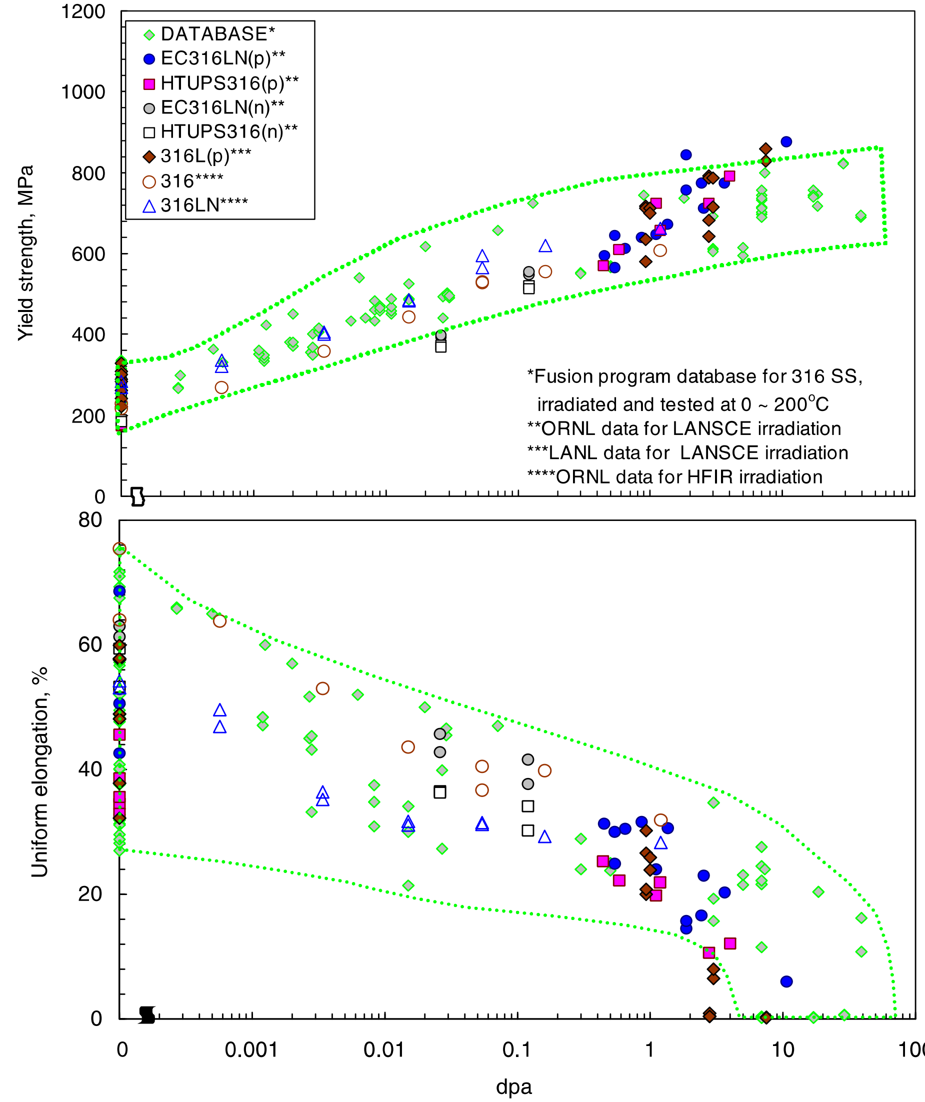
Figure Credit: D. McClintock & B. Vevera

316L – Target and RID Windows

- 316L and similar alloys have a long history in nuclear applications
- Numerous 316L studies have been published on radiation-induced changes including irradiations in spallation spectrums



From: S. Maloy et al., *J. Nucl. Mater* 296(2001) 119-128.



From: L.K. Mansur and J.R. Haines, *J. Nucl. Mater.* 356 (2006) 1-15.

PIE is also planned this year on Inconel 718 proton beam window

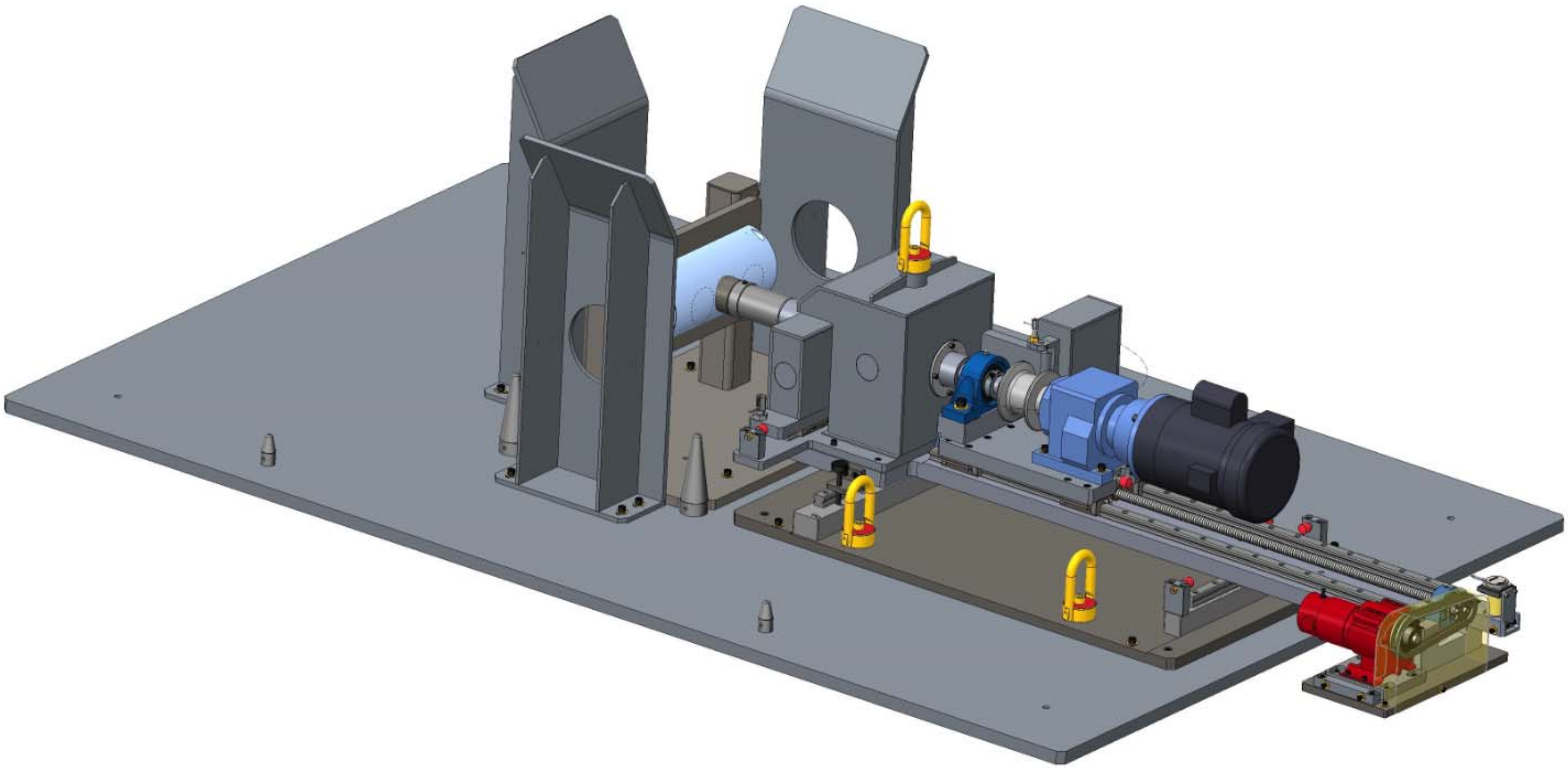
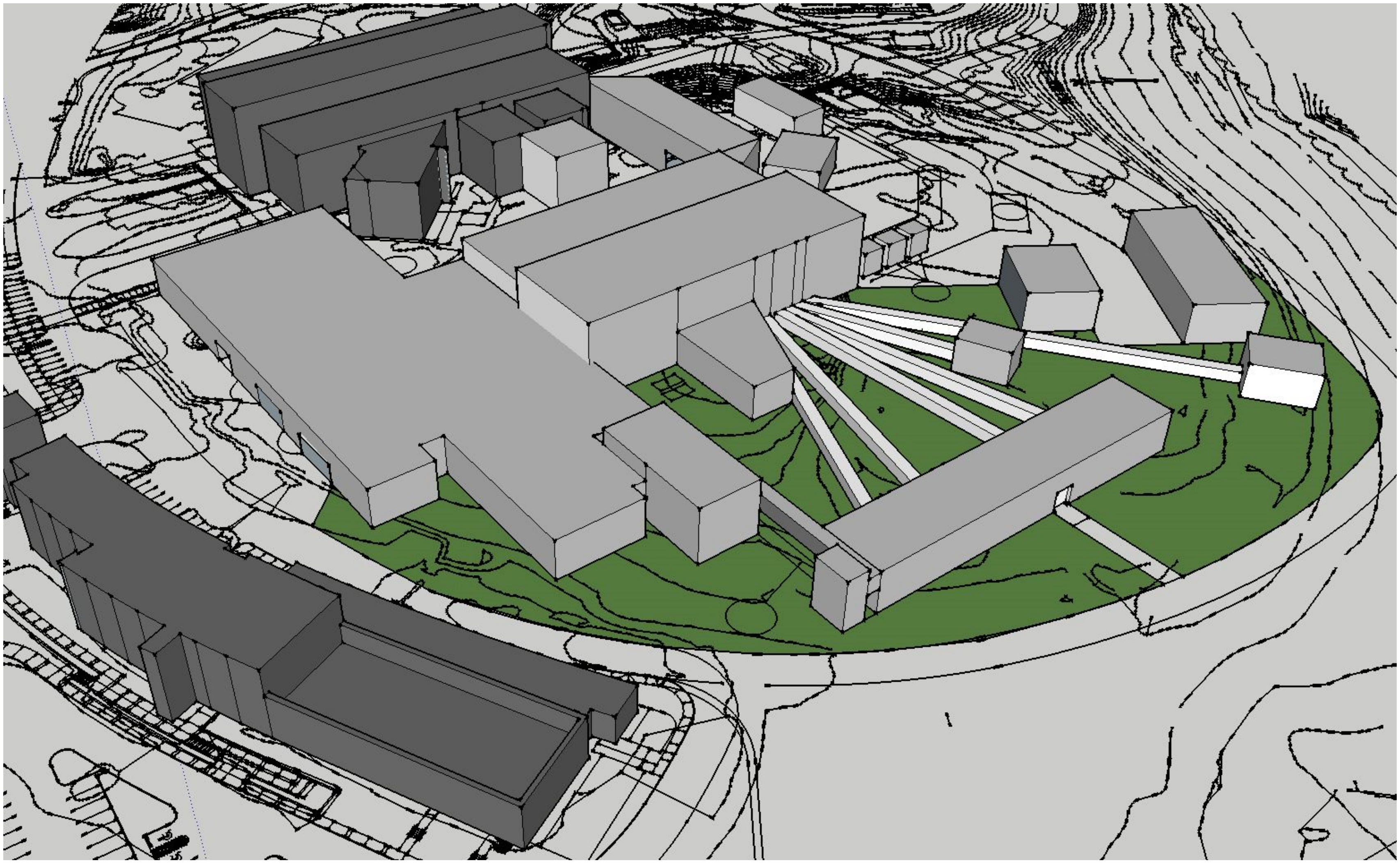


Figure Credit: S. Parson

Second target station planning is underway: TDR will be issued in FY15

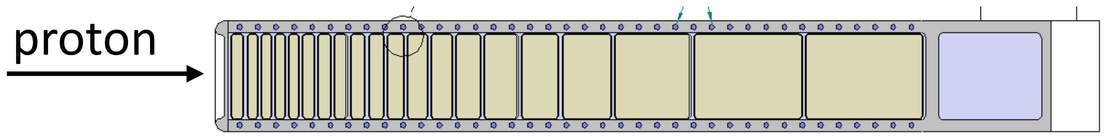


Emphasis will be laid on *total* optimization of the neutron source

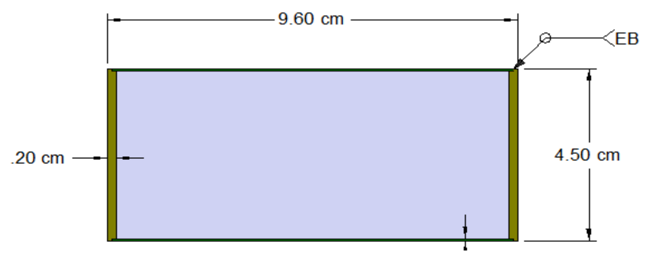
Figure Credit: K. Herwig

SNS Second Target Station Concept –
Optimized for Highest Neutron Peak Brightness at Long Wavelengths

- 2.8 MW accelerator complex, 1.3 GeV protons, 60 Hz, pulse-stealing mode
  - FTS – 2+ MW (5/6 pulses)
  - STS – 467 kW (1/6 pulses)

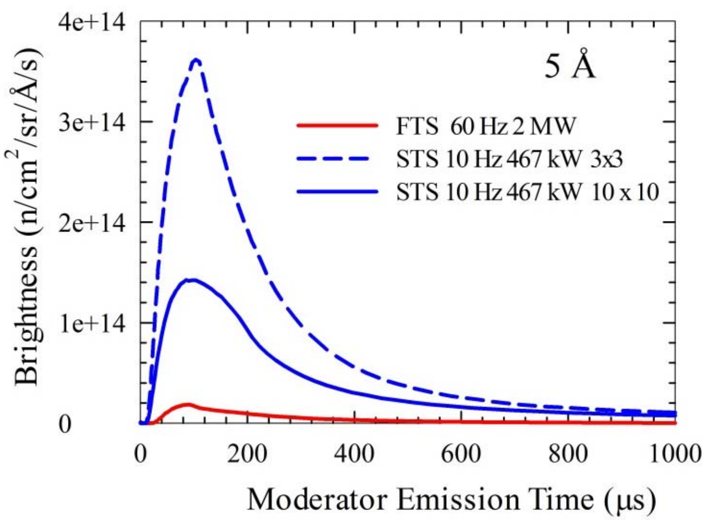


- Compact, high-performing target
  - 30 cm^2 proton beam cross-section (140 cm^2 at FTS)
  - Solid Tungsten/Ta clad



Cross-section

- Compact, high-brightness moderators
  - Gains of 2 – 3 compared to large moderators
- 22 instrument end stations
  - ≈ 11 deg separation
  - Instrument length, 15 m ≤ L ≤ 120 m

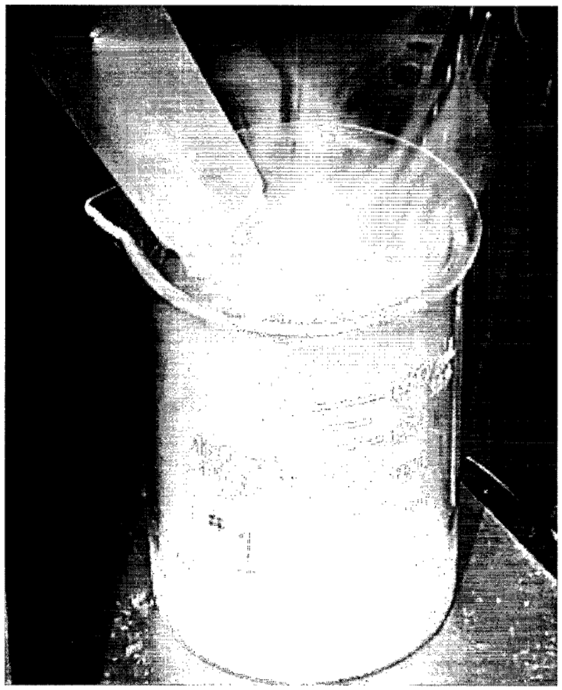


R&D Directions for Second Target Station

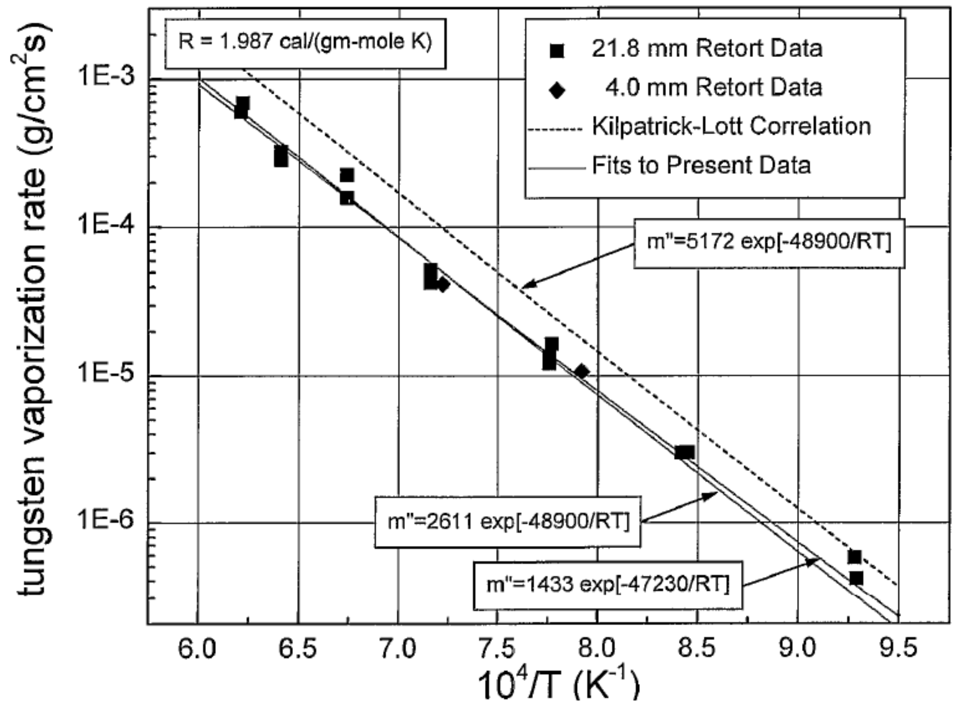
- Mitigation of the safety issue for tungsten-steam interaction
  - Experimental research on steam interaction with Ta clad (lower corrosion in Ta)
  - Experiment to determine required Ta thickness
  - Investigation of other cladding materials
  - Fabrication research to determine joining process
- Thermal-hydraulic experiments to confirm CFD
- Moderator performance enhancements/advanced design

STS Safety Issue: Tungsten-Oxide Aerosol Generation

- **Review tantalum oxidation in steam and evaluate if the clad could be a CEC to reduce accident release dose levels and if a test program would be useful**



Photograph of Tungsten-Oxide Aerosol exiting a condenser

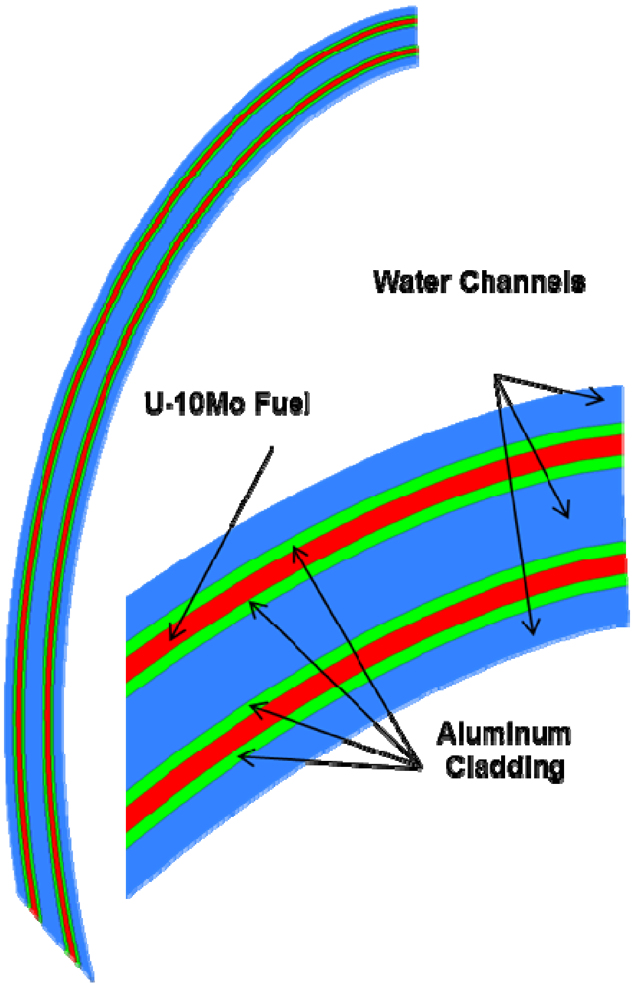


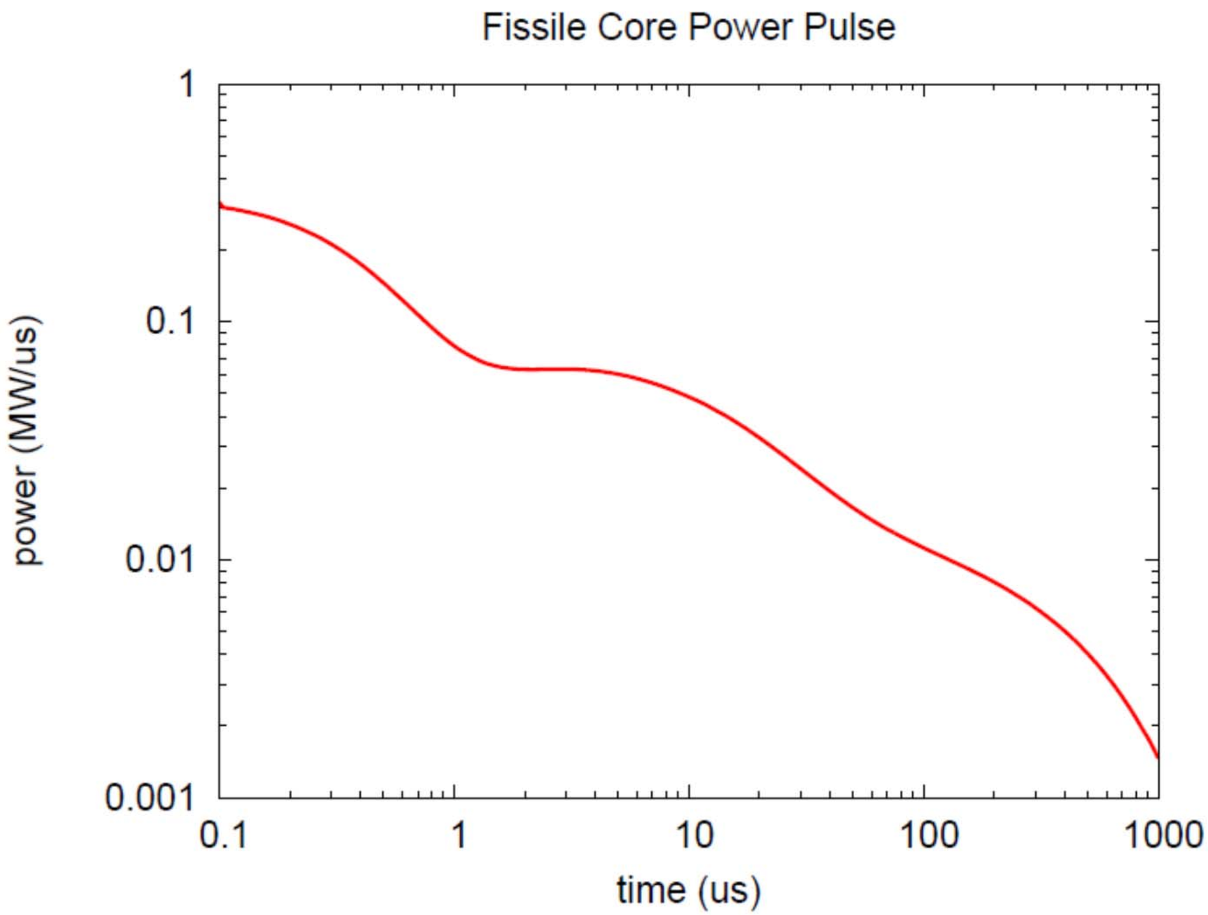
Tungsten-metal vaporization rates in 100% steam vs. temperature

Figure Credit: T. McManamy

G.A. Greene, C.C Finfrock, Generation, transport and deposition of tungsten-oxide aerosols at 1000 °C in flowing air/steam mixtures

ADS option was considered for STS – analysis on fuel elements of blanket





High duty cycle for SNS/STS leads to high temperatures, and significant materials issues arise requiring too much R&D

SNS R&D Summary

- SNS First Target Station
  - Lifetime reliability and extension
  - Higher power enhancements
- SNS Second Target Station
  - Safety case
  - Performance optimization
- Potential uses for right-sized beam
  - Cavitation damage mitigation mechanism (geometry/flow/focus?)
  - Irradiation effects on tungsten/tantalum joining