5th High Power Targetry Workshop
20-23 May 2014 Fermi National Accelerator Laboratory

Spallation Neutron Sources Around the World

Bernie Riemer

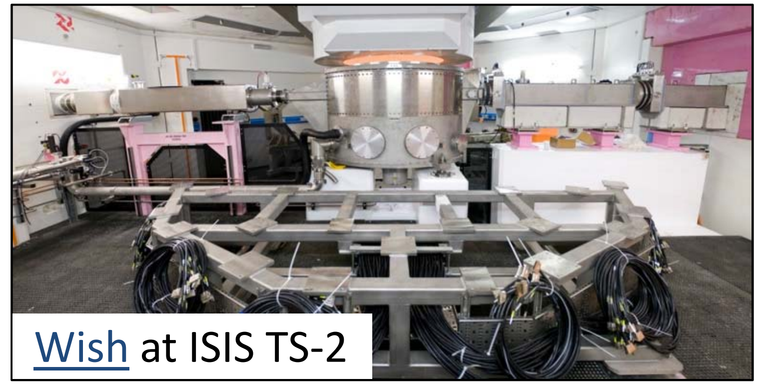
Thanks to others for the many shamelessly pilfered slides used herein …

U.S. DEPARTMENT OF ENERGY

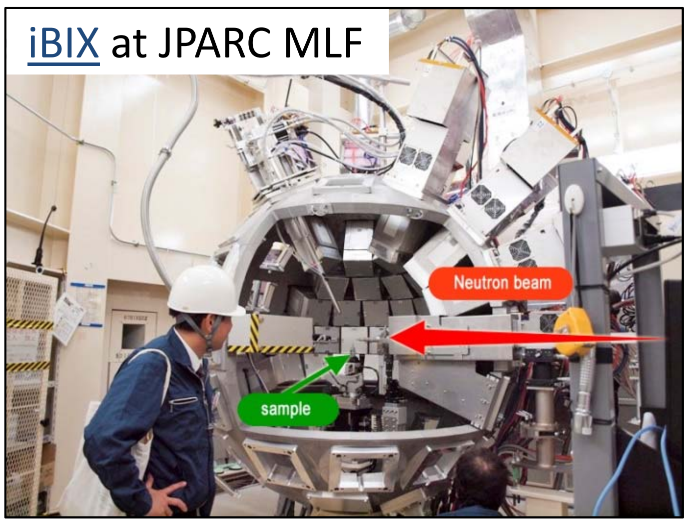
OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Spallation Neutron Source Facilities Serve *Neutron Science Programs*

- Neutron beams to suites of instruments
  - Elastic and inelastic scattering
  - Diffractometers and spectrometers
- Engineered structures, powders, liquids, crystals, bio-materials, proteins, chemistry …
- Neutron physics, imaging, SEE testing



Wish at ISIS TS-2



iBIX at JPARC MLF

Neutron Spin Echo at SNS

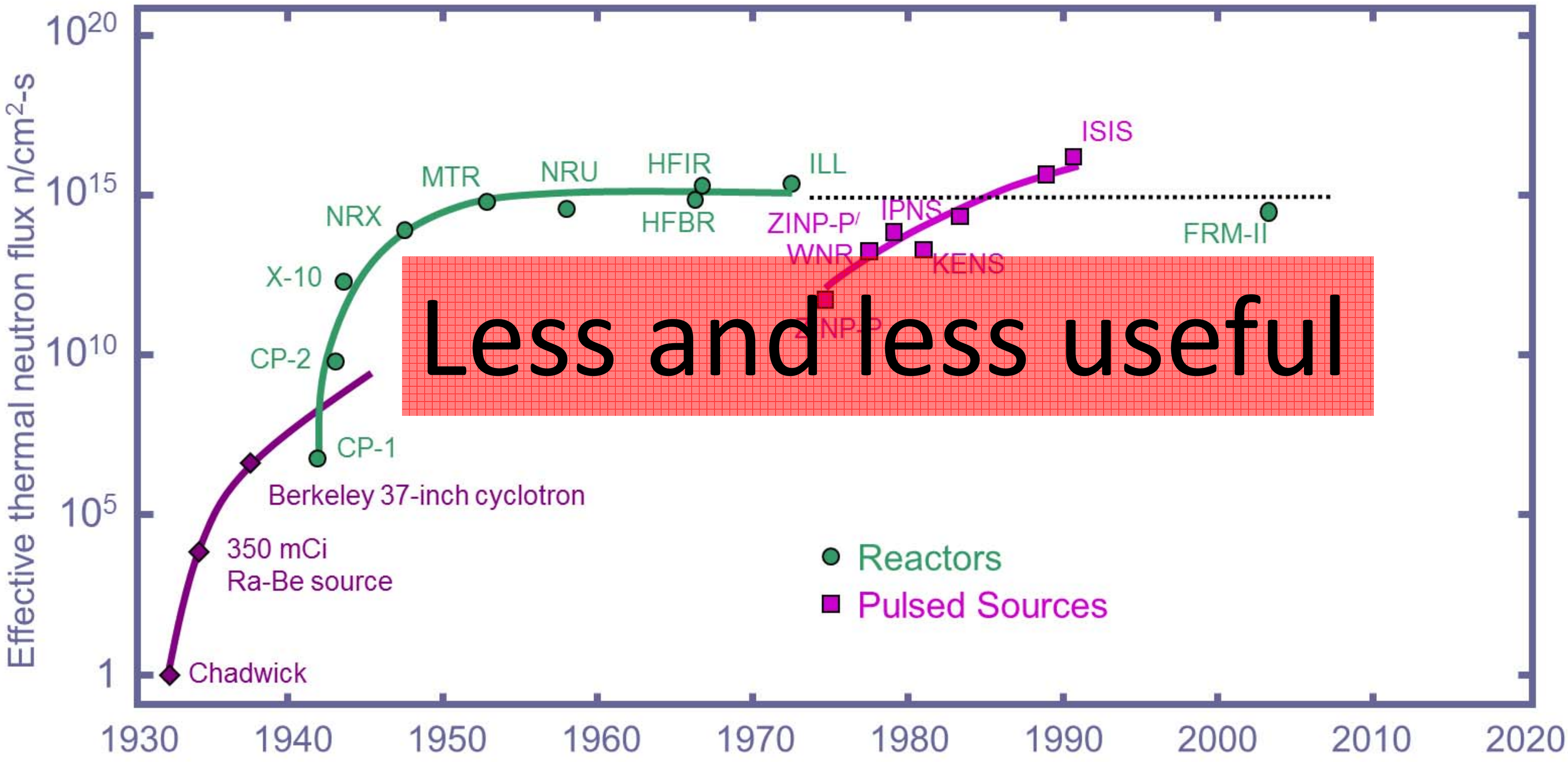
UCN at PSI

A few preliminary thoughts

- Expectations of funding bodies on neutron source facilities vary
  - What defines success?
    - Some measure of *science productivity*
- What defines neutron performance?
  - Total flux? Intensity? Peak brightness?
  - Preferred temporal characteristics?
  - *Instrument specific metrics have become the norm*
- Neutron sources: typically 3000 ~ 5000 neutron production hours per year
- Budget ups and downs

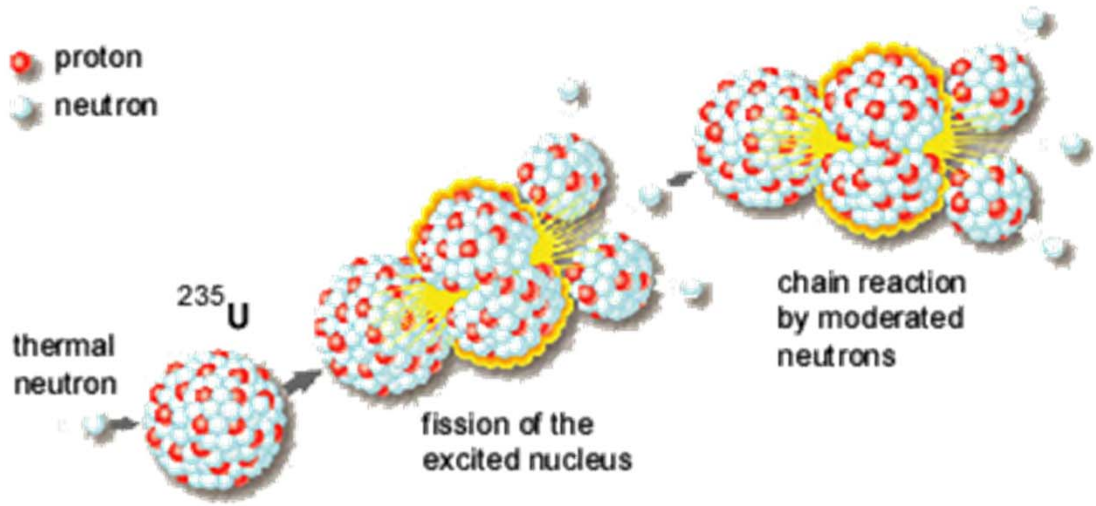
International Challenges

T. Broome
2006



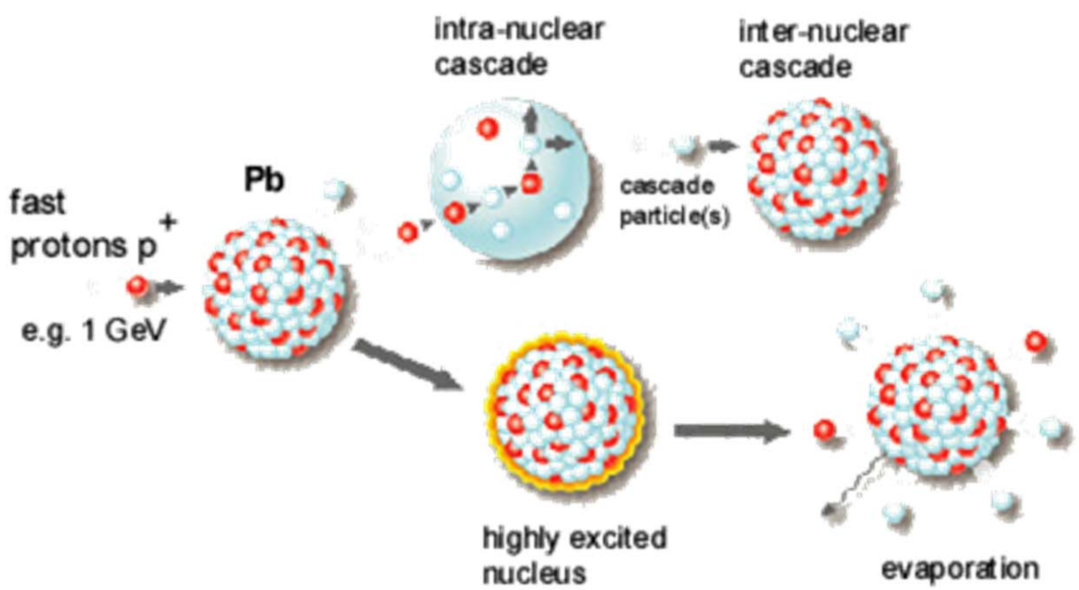
(Updated from *Neutron Scattering*, K. Skold and D. L. Price, eds., Academic Press, 1986)

Two popular ways to produce neutrons



Fission

- chain reaction
- continuous flow
- 1 neutron/fission
- 180 MeV/neutron



Spallation

- no chain reaction
- pulsed or continuous operation
- 40 neutrons/proton
- 30 MeV/neutron

Dealing with heating in spallation targets is a still a challenge

- Removal of steady state heating
  - Total power vs. volume power density
- Pulse effects
  - Thermal "shock", fatigue, cavitation damage

Of course, there's more to target design

- Target – source physics performance
- Required duty cycle, maintenance strategy, remote handling
- Radiation damage effects
- Facility safety, waste disposal

Spallation neutron sources

- Operating

- On the horizon

Low energy neutron sources

- Proton knock-out reaction sources – not spallation
  - For science, industry, development and education
- LENS (Indiana University)
- Tsinghua University
- Peking University
- Bilbao project - *in a deep sleep*

- UCANS
  - Union for Compact Accelerator-driven Neutron Sources

Rutherford Appleton Laboratory, Oxfordshire

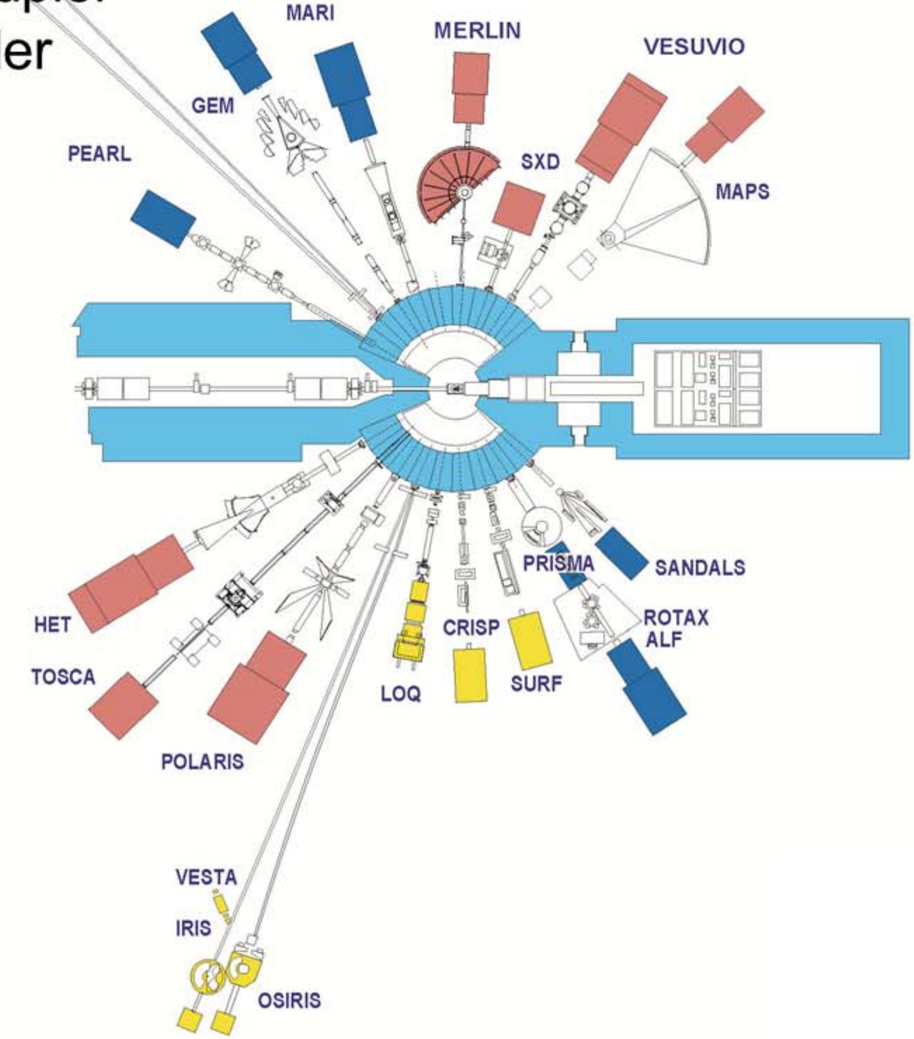
T. Broome

Existing Neutron Target Station (TS-1)

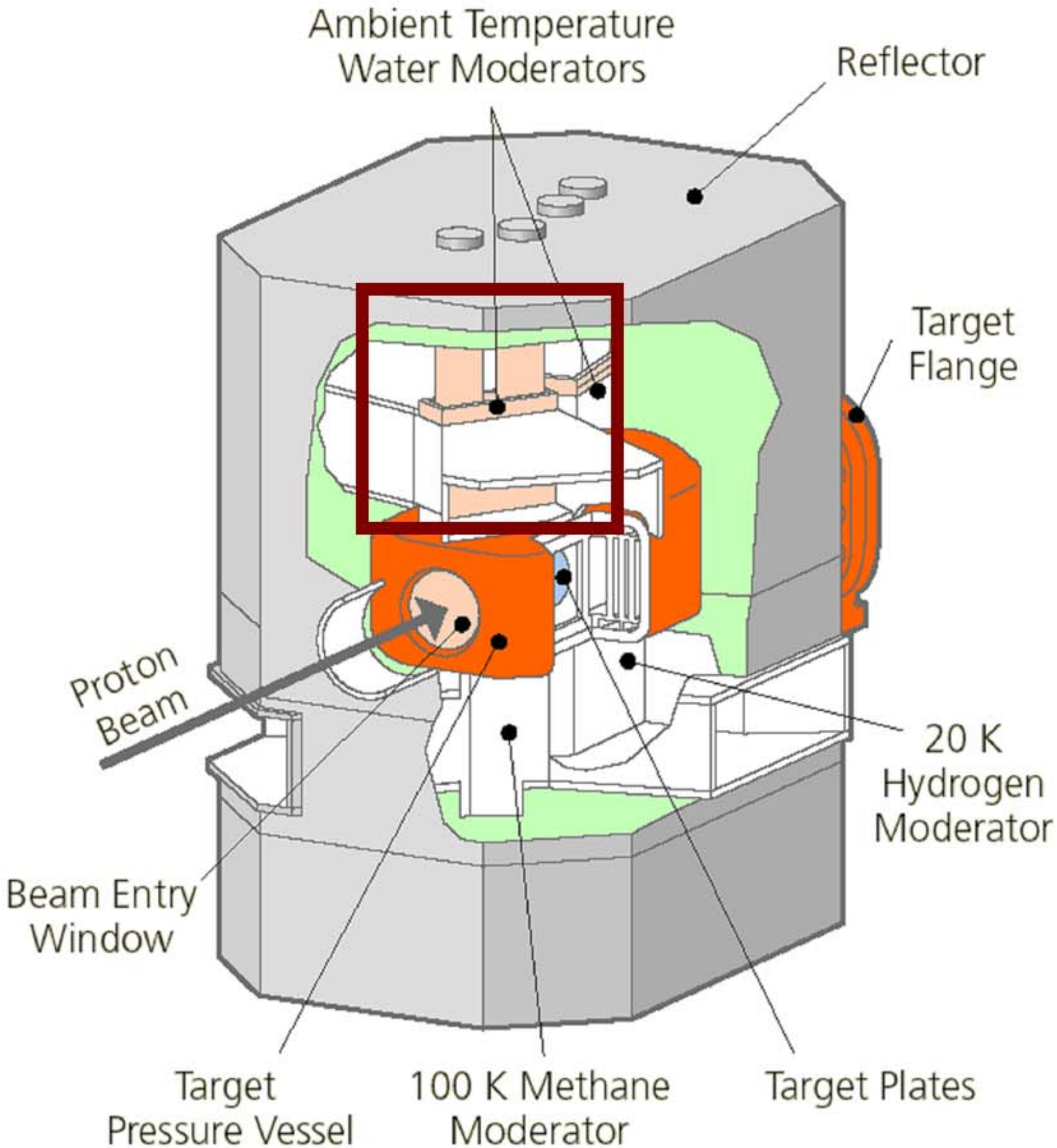
T. Broome

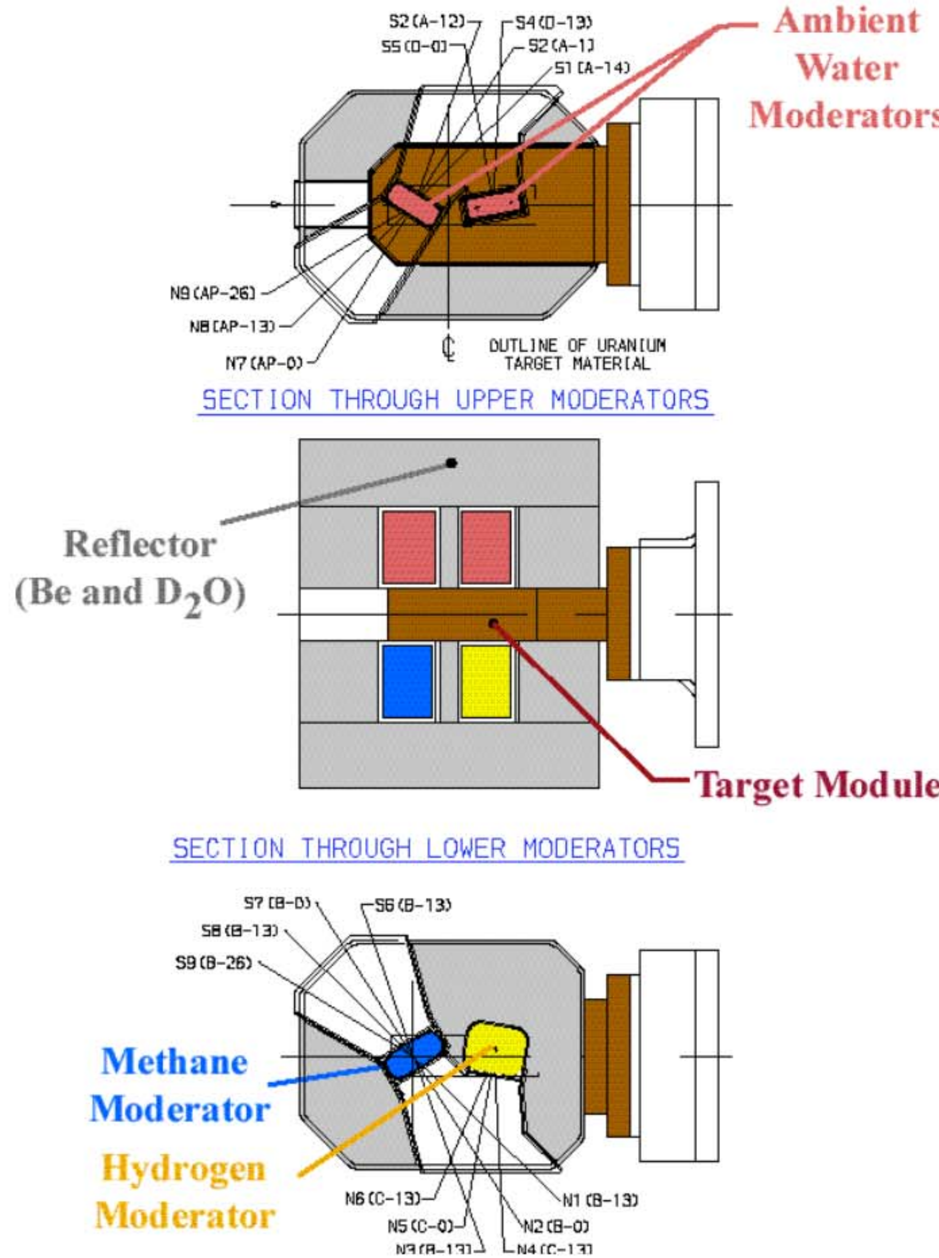
Running since 1984

- Tantalum clad Tungsten target D_2O cooled
- Moderators
  - H_2O 0.5 l Gd poison Boral decoupler
  - CH_4 0.5 l Gd poison Boral decoupler
  - H_2 0.8 l no poison Cd decoupler
- Beryllium (D_2O cooled) reflector
- 18 Neutron Beam Holes
- Integral Remote Handling Cell
- Horizontal target handling
- Dose rate at shield surface <0.75 mSv/h
- Beam shutters 2 m iron and concrete
  dose rate at sample positions ~ 10 mSv/h



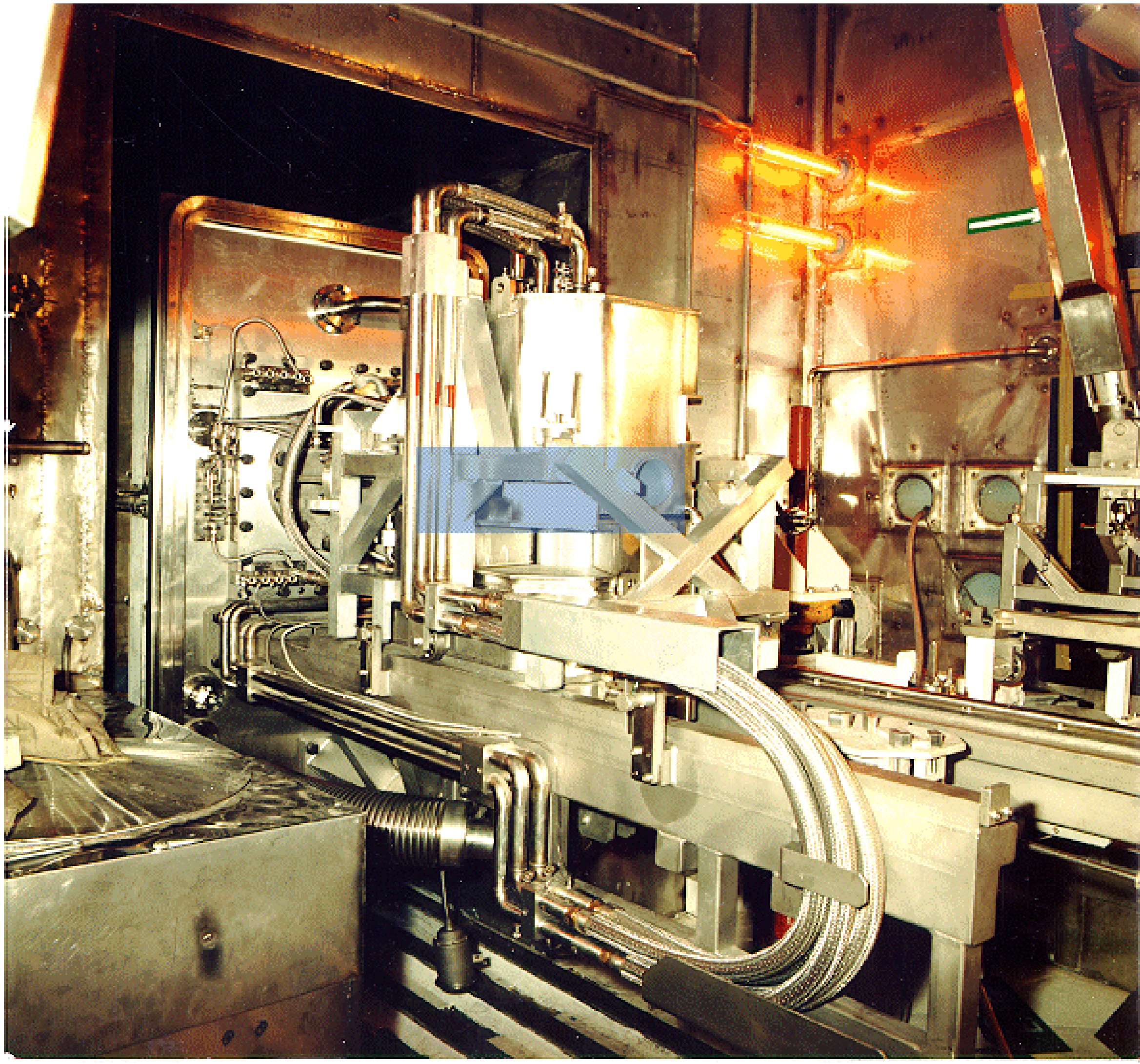
ISIS Target moderator and Reflector Assembly





kW class spallation neutron sources

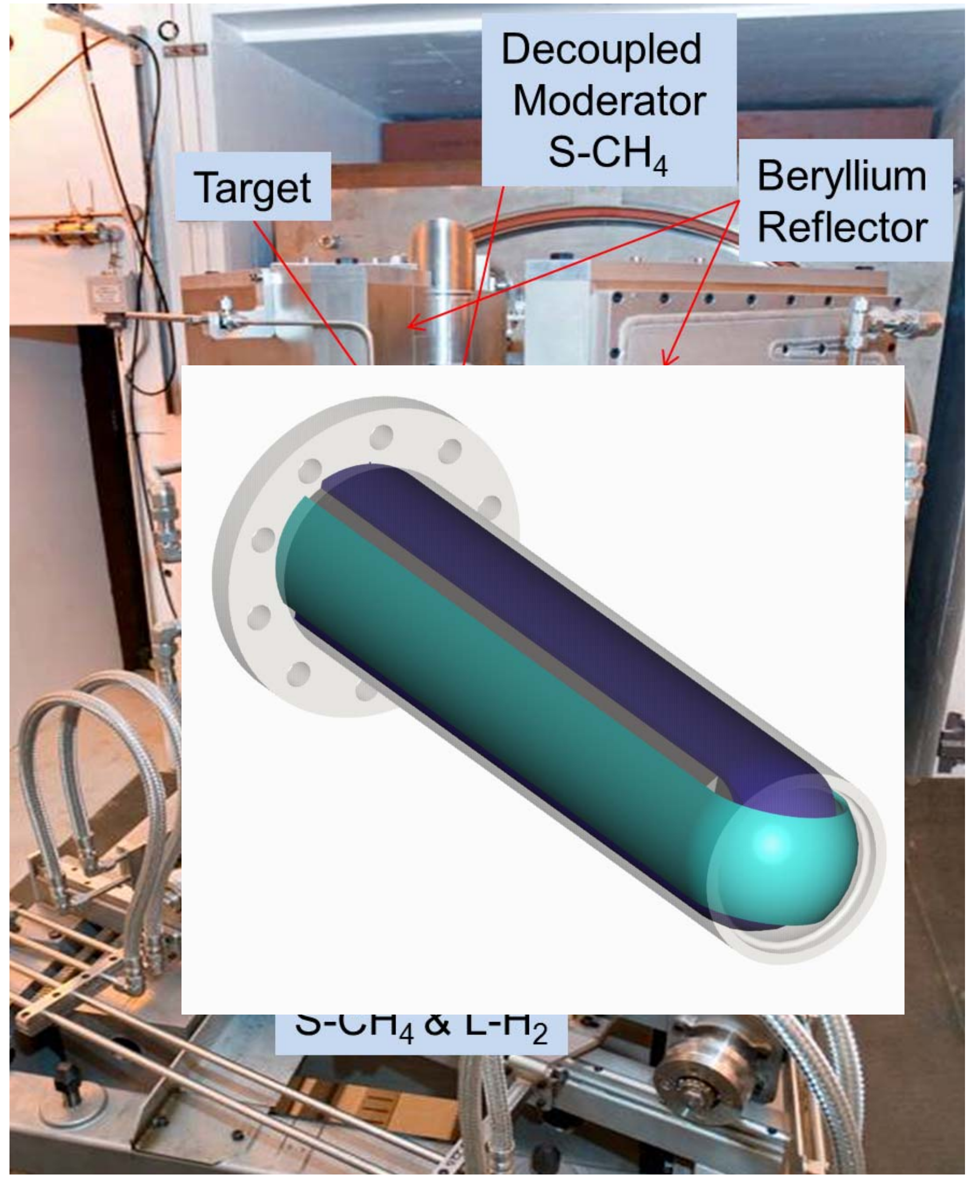
- ISIS TS-1 at RAL
  - 40 / 50 Hz, short-pulse (SP)
  - 800 MeV H^+
  - 160 kW
  - W plates target with Ta clad



T. Broome, ISIS

kW class spallation neutron sources

- ISIS TS-1 at RAL
  - 40 / 50 Hz, SP 800 MeV H^+
  - 160 kW
  - W target with Ta clad
- ISIS TS-2 at RAL
  - 10 Hz, SP 800 MeV H^+
  - 32 kW
  - Monolithic W rod target
    - with Ta clad



L. Jones, ISIS

ISIS Operations

- Total of 3200 hr of beam on targets in 2012-13 run cycles
- 642 mAh at 800 MeV
  - 500+ MW·h
- > 419 publications

Beam Statistics 2012-13

For the period of this report and during scheduled operating cycles, ISIS delivered a total of 642mA.hrs of user proton beam to the muon and neutron targets.

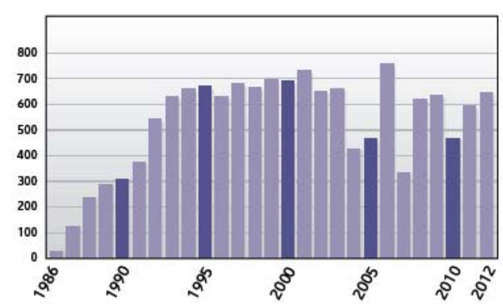
Cycle	12/1	12/2	12/3	12/4	12/5
	15 May – 15 Jun 2013	10 Jul – 10 Aug 2013	1 Oct – 1 Nov 2013	20 Nov – 21 Dec 2013	19 Feb – 29 Mar 2013
Beam on target (hr)	557	501	660	658	795
Total beam current delivery for both targets (mA-hr)	109.2	102.9	136.8	125.9	167.3
Averaged beam current per hour (µA) for targets 1 and 2 combined	170.0	182.5	198.6	193.4	193.6

ISIS operational statistics for year 2012-2013.

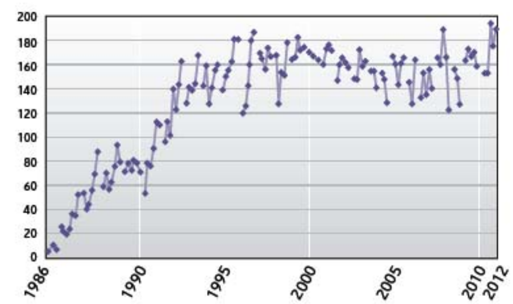
Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Total scheduled days[1]	156	165	106	119	190	86	163	156	116	138	145
Total integrated current (mAh)	612	647	409	445	738	317	612	630	459	583	642
Average beam current (for beam on target) (µA)	178	177	177	178	179	176	177	208	197	194	203

Year-on-year ISIS performance summary for the past 10 years.

[1] This is the total days available from the accelerator, before instrument calibration and commissioning time, and instrument and accelerator down-time, are taken into account. The days available for the user programme are therefore less than this figure – 120 days were delivered to the user programme in 12/13, averaged across the fully-scheduled instruments.



The ISIS integrated beam current year-on-year



Average ISIS beam current per cycle.

ISIS TS-1 upgrade

- In December 2014, TS-1 will have its 30 year anniversary
- Upgrades are being contemplated

Expectations

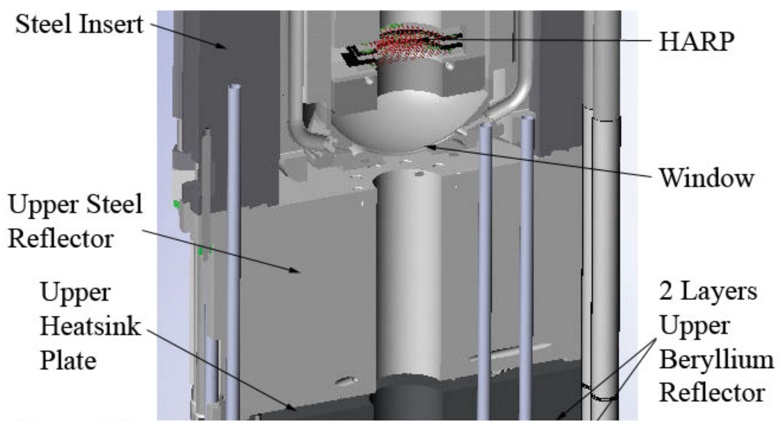
M. Fletcher

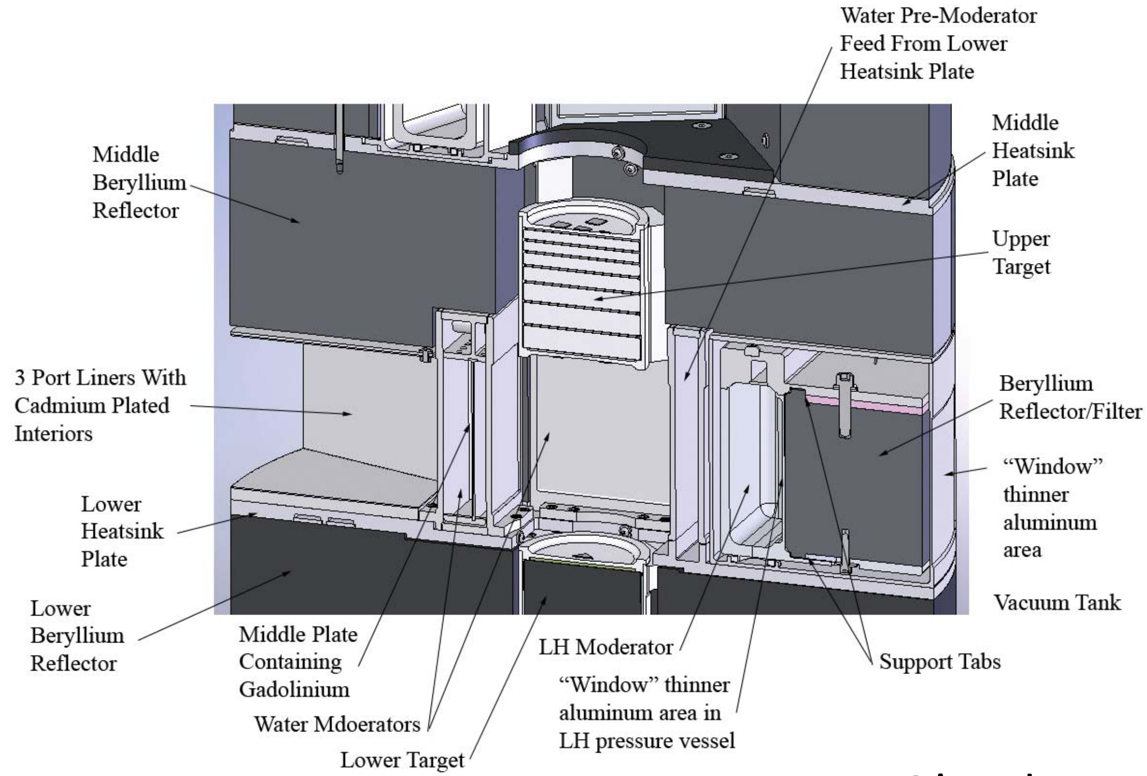
- Average factor two gain in performance minimum
- Possibility of higher but localised / specialised gains
- Proton power as it is, but benefits / consequences understood of increasing to max of 500kW
- Risk level on implementation low
- Re-configuring instruments not in the scope
  - Filters (to limit saturation should this occur) in scope
- Upgradability built in (probably moderator tweaks)
  - Development moderator considered

Science & Technology Facilities Council

kW class spallation neutron sources

- ISIS TS-1 at RAL
  - 40 / 50 Hz, SP 800 MeV H^+
  - 160 kW
  - W target with Ta clad
- ISIS TS-2 at RAL
  - 10 Hz, SP 800 MeV H^+
  - 32 kW
  - W target with Ta clad
- Lujan Center at LANSCE
  - 20 Hz, SP 800 MeV H^+
  - 100 kW
  - W disks target with Ta clad
  - Vertical beam injection



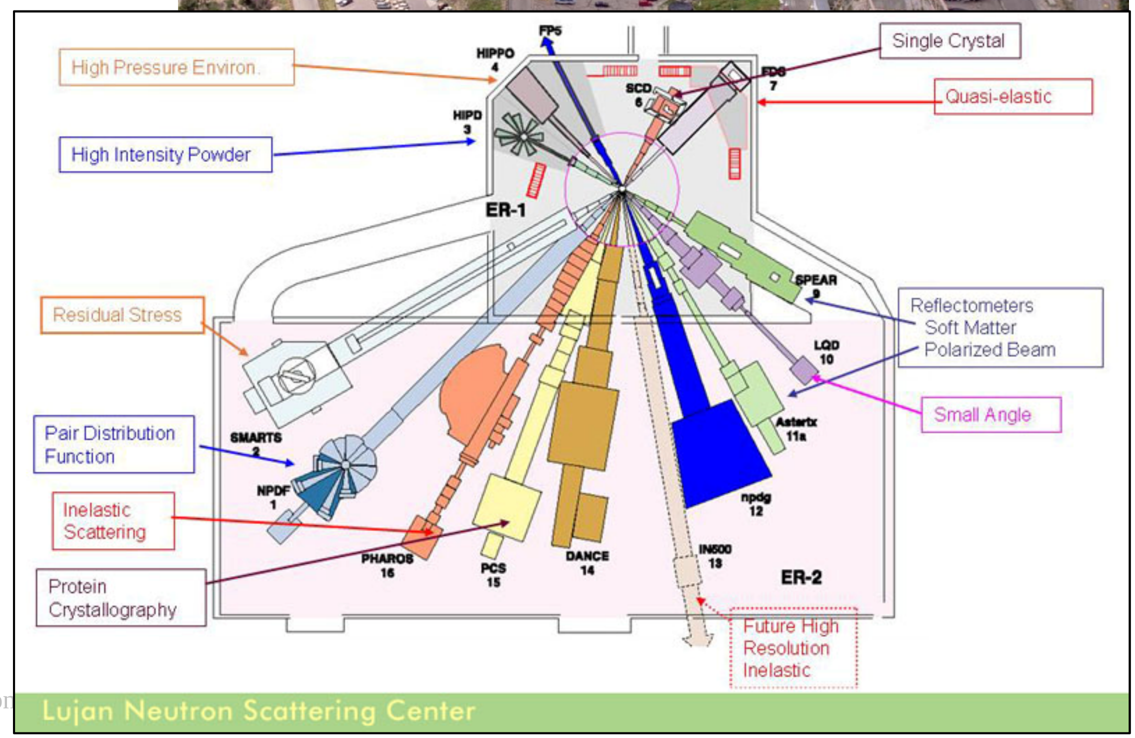


J. O'Toole, LANL

Lujan Neutron Scattering Center at LANSCE

Running since 1985

- Operated ~900 hr in 2012
  - Beam is shared between several experimental facilities
- Proposed cessation of funding for the Lujan Neutron Scattering Center operations from the DOE's Office of Science Basic Energy Sciences – FY15
  - NNSA mission continues



kW class spallation neutron sources

- ISIS TS-1 at RAL
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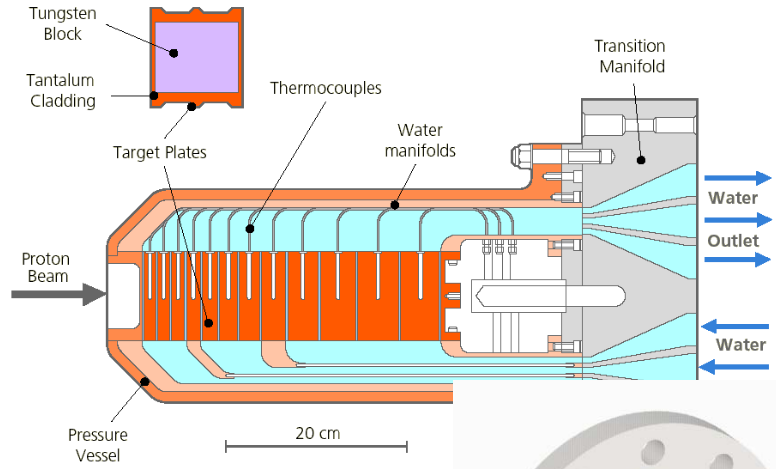
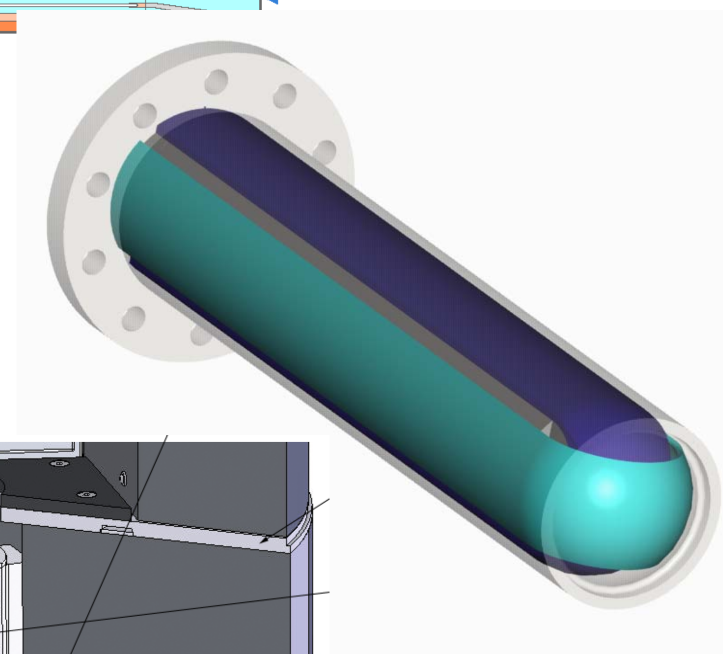
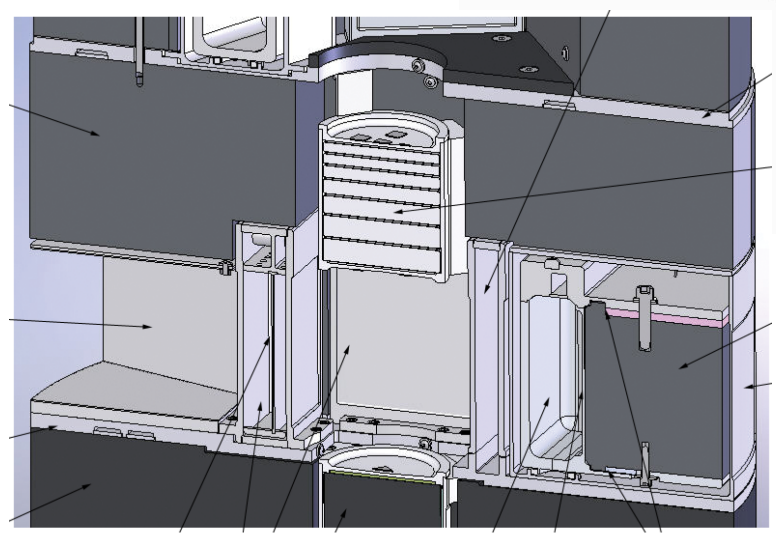
  - 160 kW
  - W target with Ta clad
- ISIS TS-2 at RAL
  - 10 Hz, SP 800 MeV H^+
  - 32 kW
  - W target with Ta clad
- Lujan LANSCE at LANL
  - 20 Hz, SP 800 MeV H^+
  - 100 kW
  - W target with Ta clad

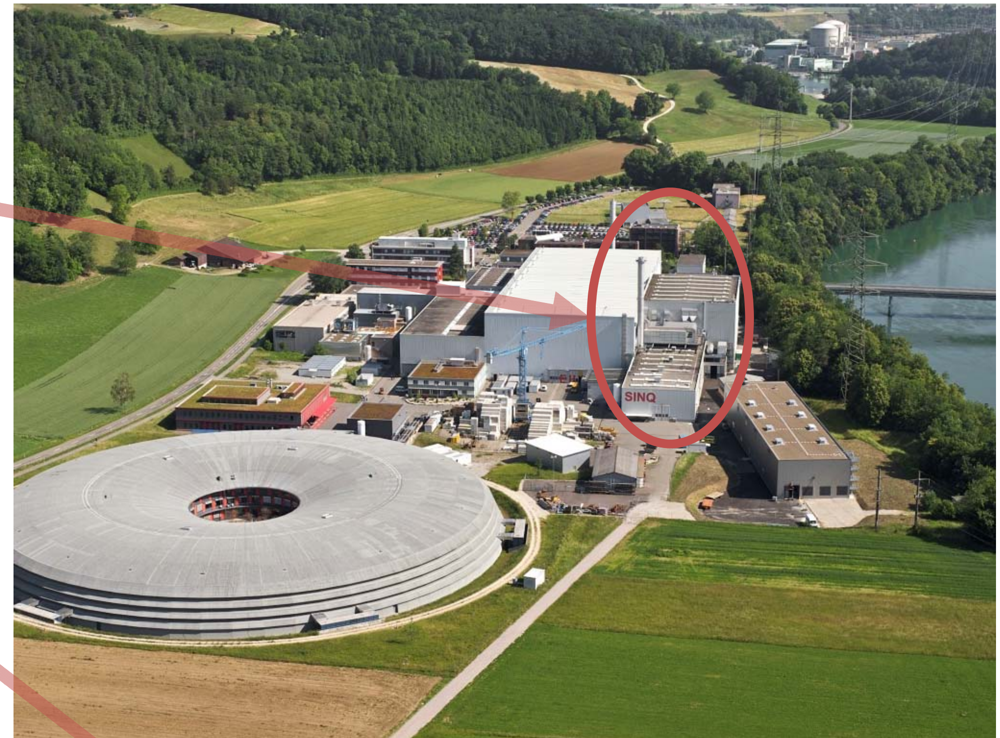






MW class spallation neutron sources

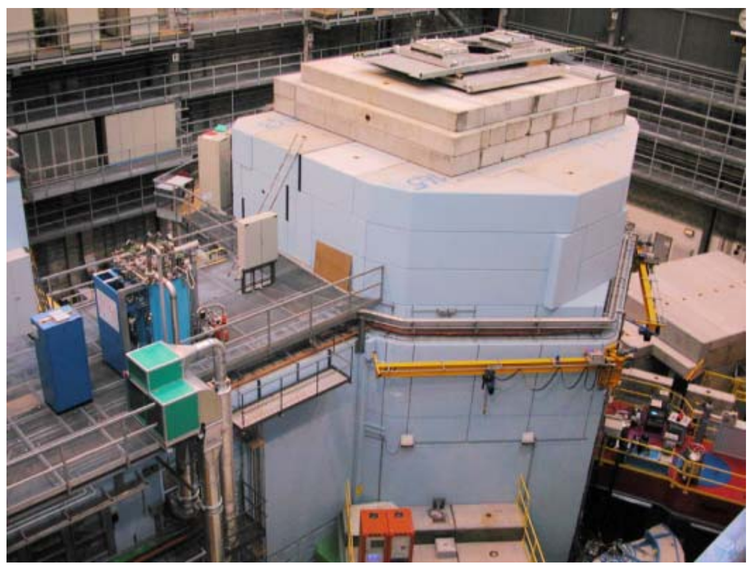
- SINQ at PSI
  - Continuous beam, 570 MeV H^+
- SNS at the ORNL
  - 60 Hz, short-pulse, 1 GeV H^+
- JSNS at MLF / JPARC
  - 25 Hz, short-pulse, 3 GeV H^+



PSI: Swiss Spallation Neutron Source SINQ

- Solid lead in Zircaloy tube array target
- Water-cooled, stationary SS316L vessel, AlMg3 safety hull
- Vertical beam injection, from below
- MEGAPIE experiment: molten lead-bismuth

Pb / Zircaloy target

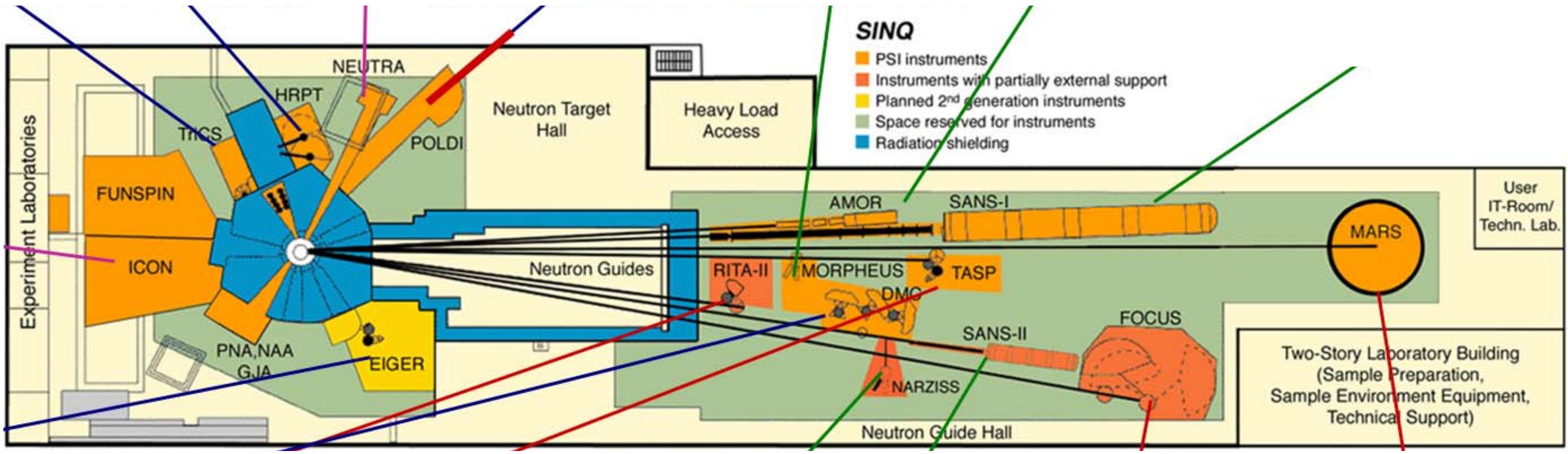


Target bulk shielding

W. Wagner, PSI

SINQ Instrument Suite

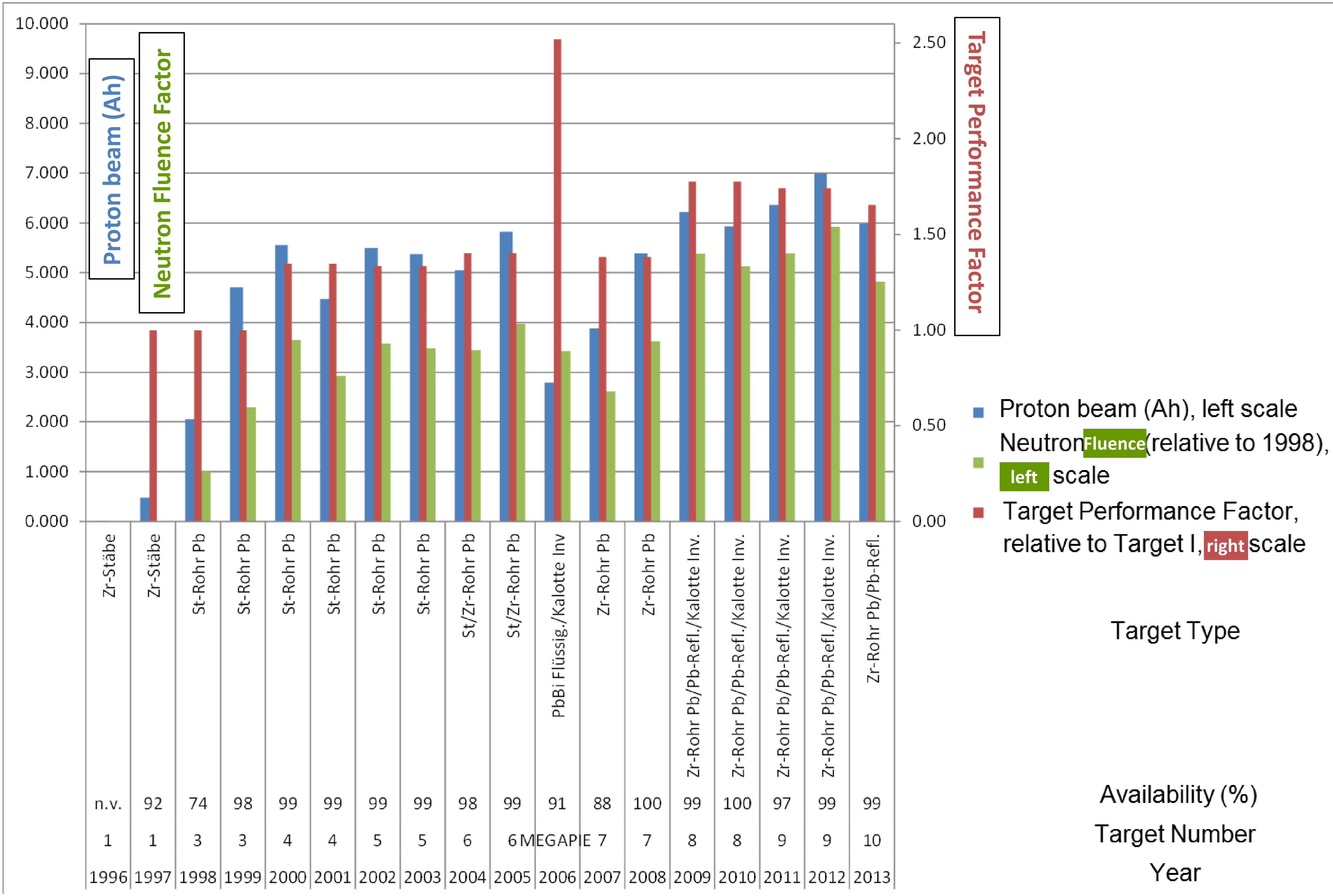
M. Wohlmuther, Feb. 2014



PAUL SCHERRER INSTITUT PSI

SINQ History

M. Wohlmuther, Feb. 2014



The SINQ upgrade project

M. Wohlmuther, Feb. 2014

On 01.01.2014 the "SINQ Upgrade Project" has officially been started. Joint project of Departments "Neutron and Muons" (NUM) and Large Research Facilities (GFA).

Primary objective

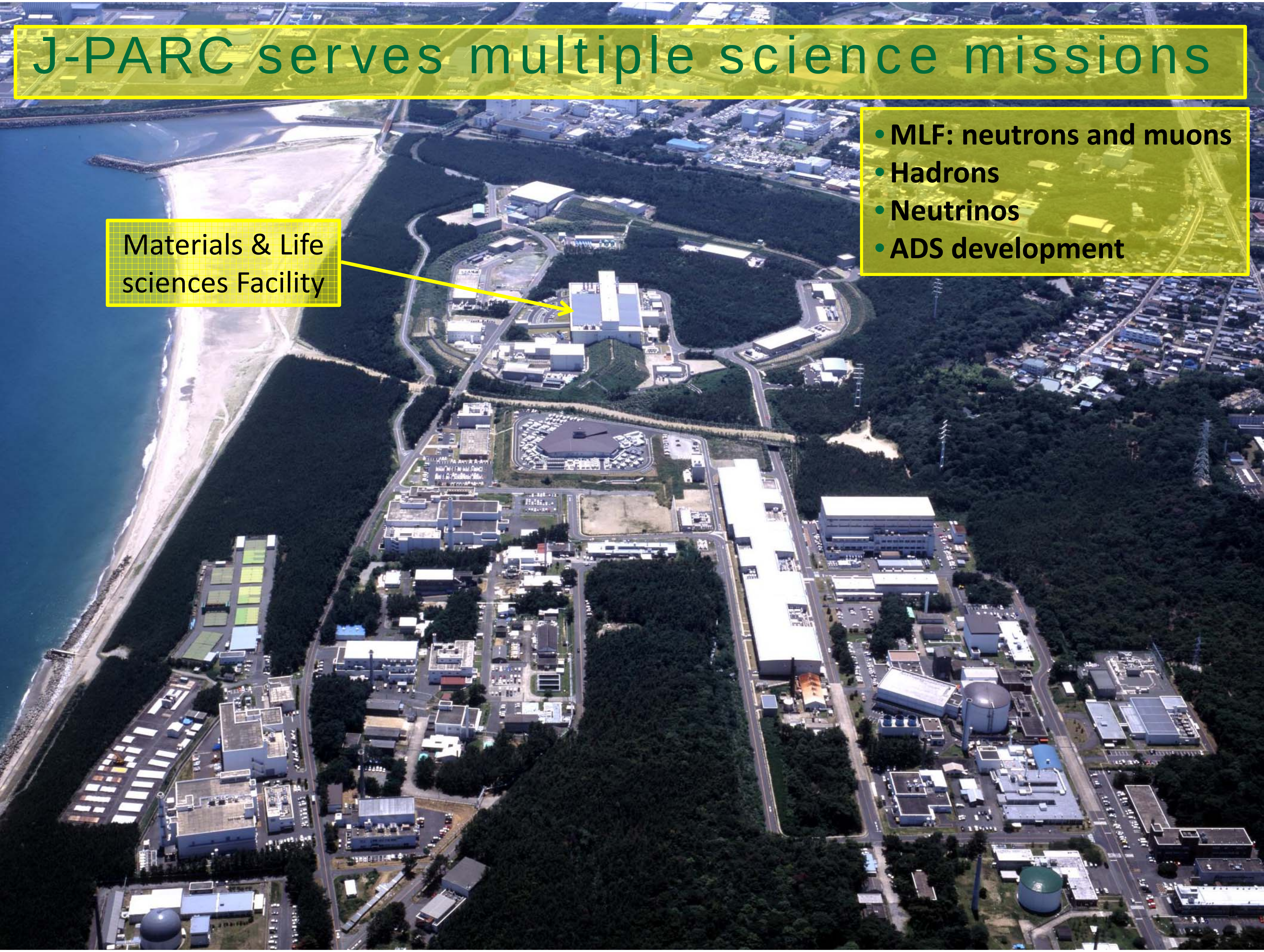
- Significant increase of the SINQ instrument performance*
- Study of (all) integral parts of SINQ for their "upgrade potential"
  - Proton beam
  - Target
  - Moderator inserts (D_2 source, H_2O scatterer)
  - Neutron guides
  - Shielding
  - Instruments (background, detectors, disposition in neutron hall …)

Major milestone

Conceptual Design Report in 2016/2017 (engineering feedback will be included)

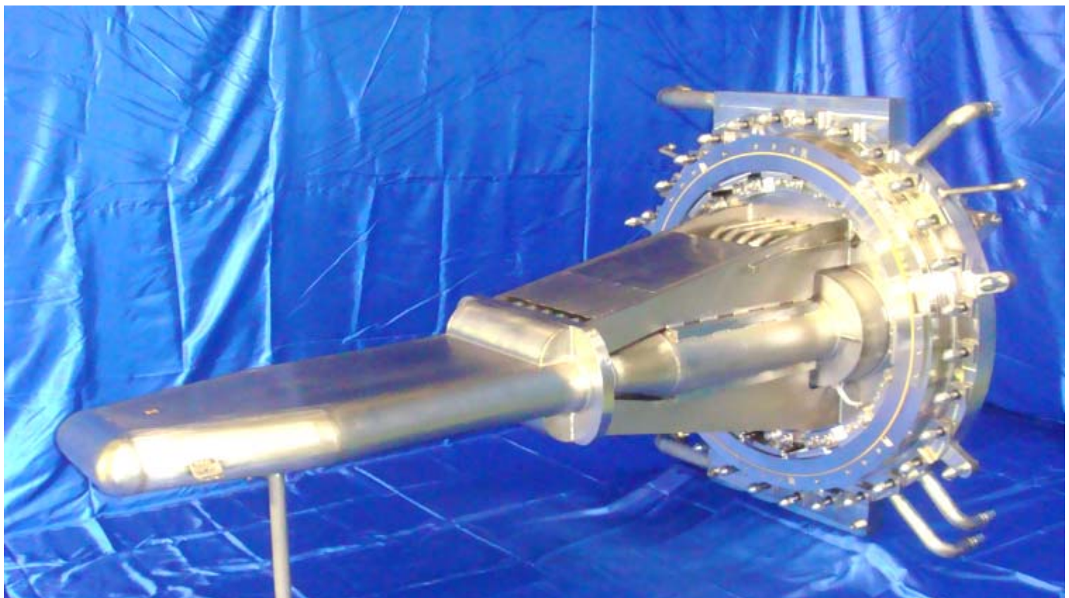
* **Definition of Performance**: **not solely neutron flux** at sample position; Performance will be optimized by **complex Figure of Merit** (FoM) for the different instruments: **low background instruments, maximal signal/noise ratio, maximum neutron flux in correct wavelength band etc…**

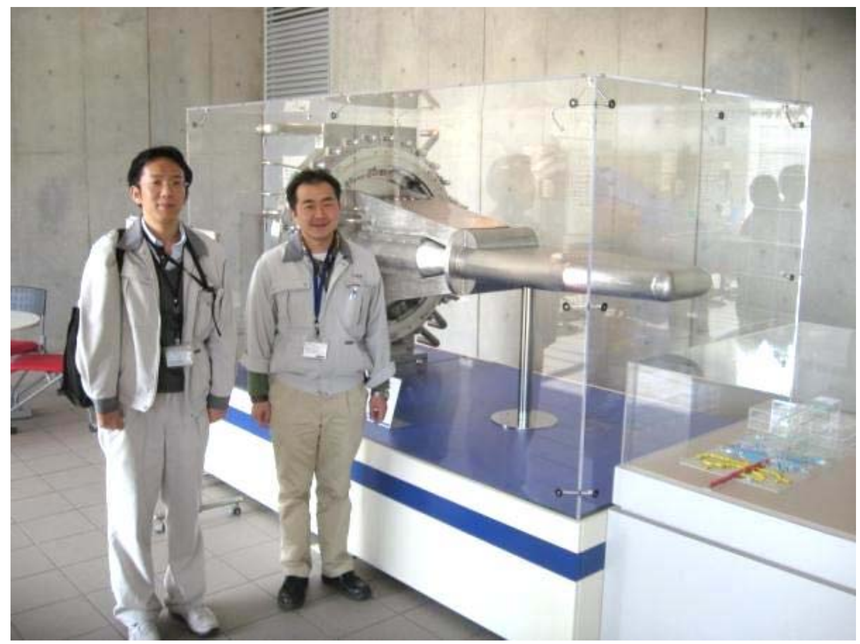
J-PARC serves multiple science missions



MLF neutron source at J-PARC - JSNS

- 3 GeV RCS, μs pulses to target at 25 Hz
- Mercury, stationary SS316L vessel
- Ca. 20 tons of mercury, circulates at 11 liters/sec
- Magnetic pump, HX, storage tank all on target trolley

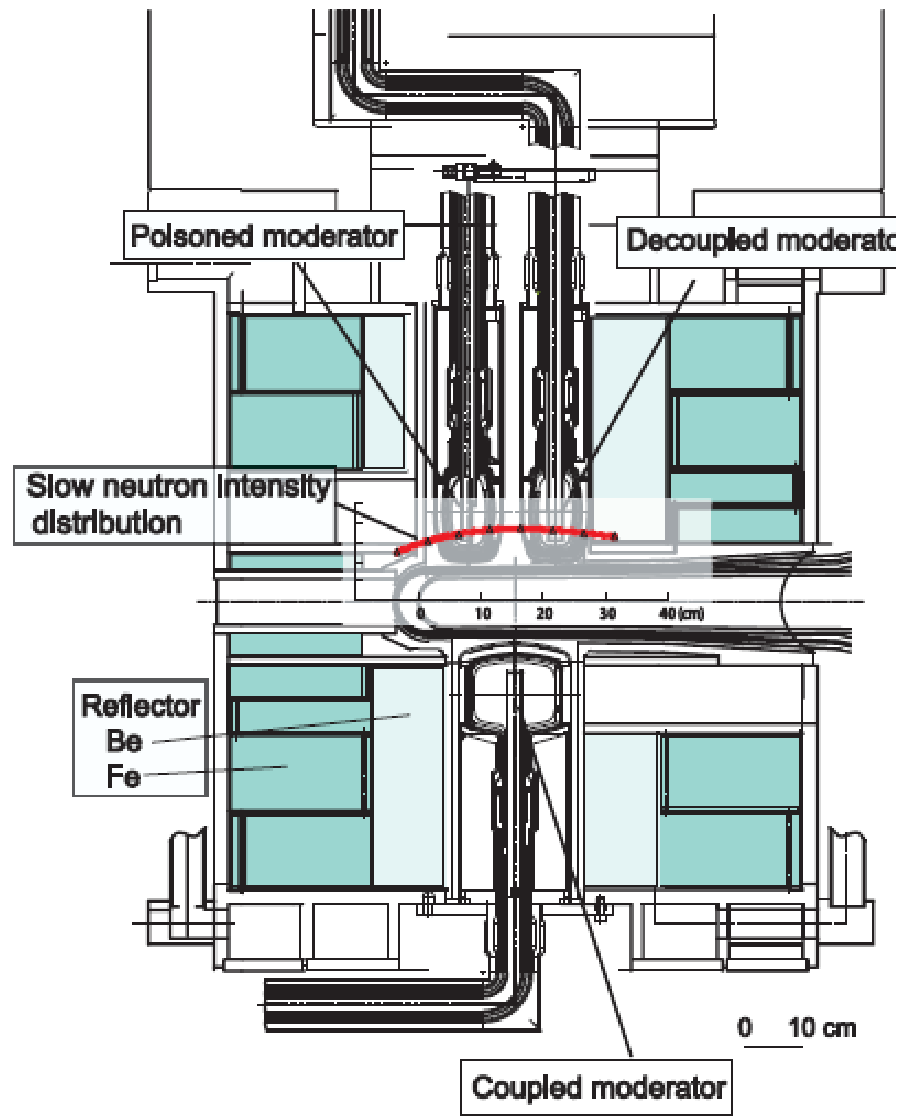




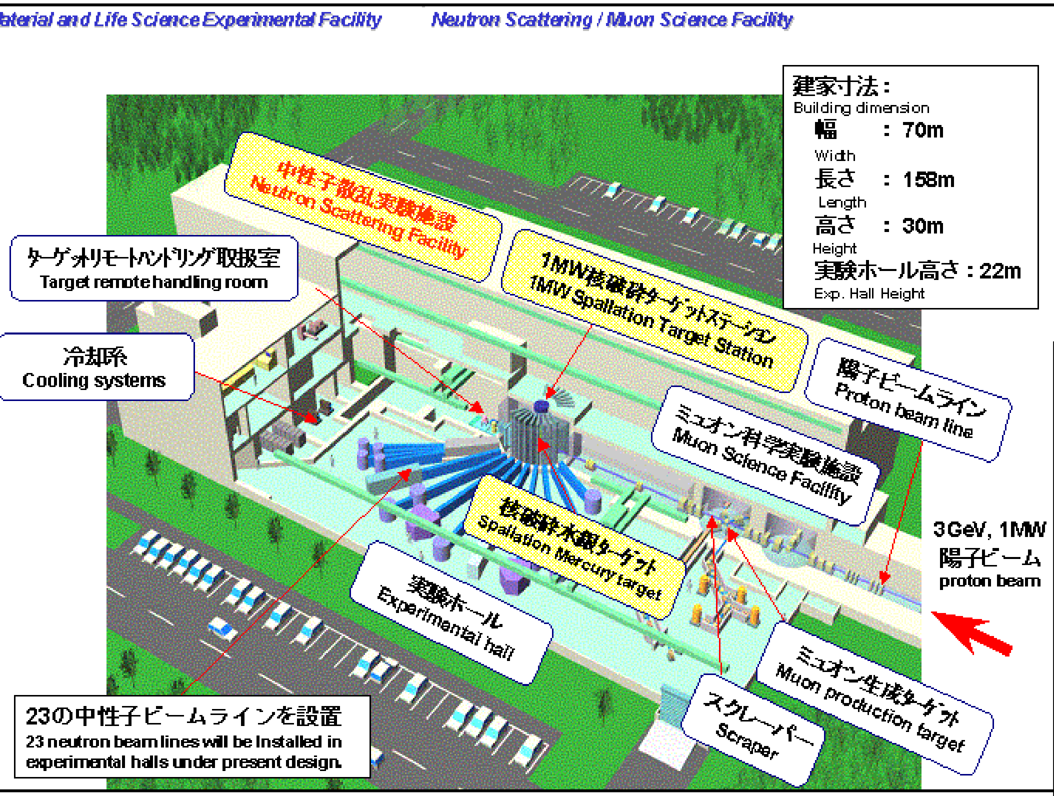
JSNS features 3 liquid hydrogen moderators

- Large, coupled
  - High time-integrated and pulse-peak intensities
  - Requires LH_2 ortho→para catalyst
- Decoupled
  - Unique Ag-In-Cd de-coupler
    - will be replaced by Au-In-Cd
  - Sharply cuts neutron pulse tail for improved resolution
- Decoupled & poisoned
  - Cd poison plate
- Moderators can be replaced independently of reflector plug

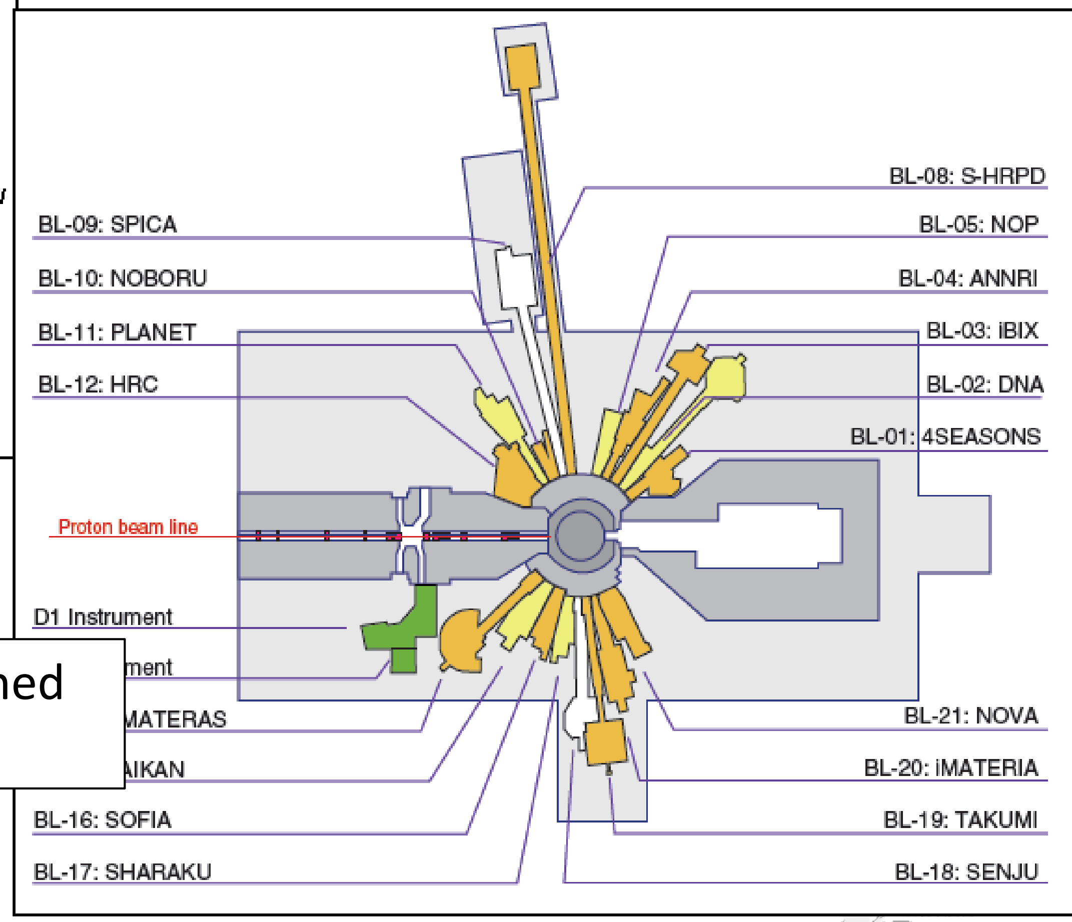
JAEA-Technology 2011-035



MLF neutron and muon sources



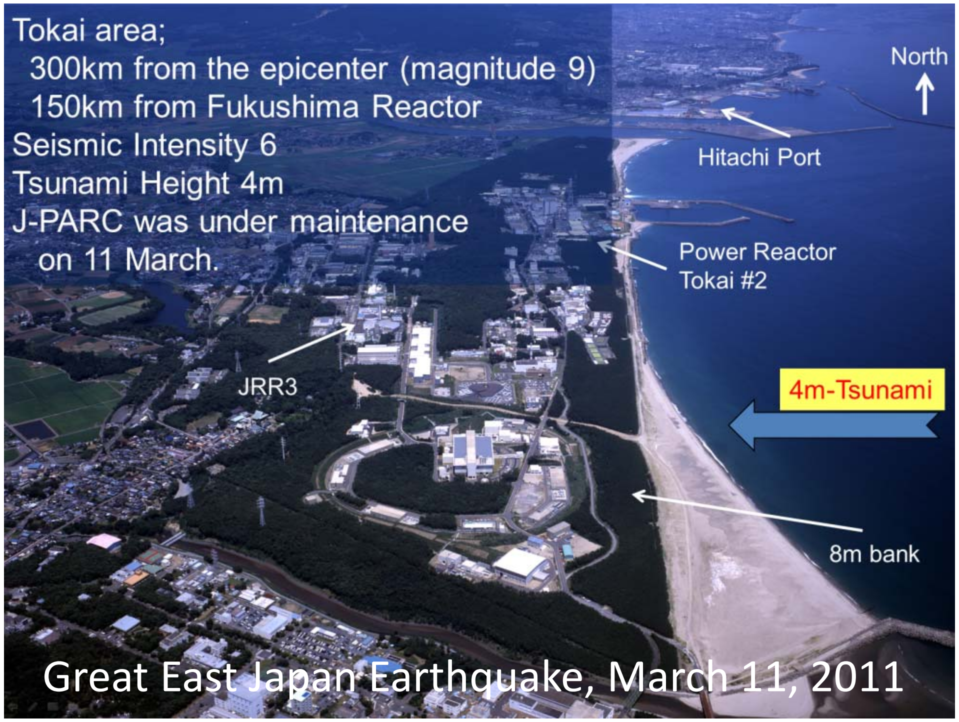
Running since 2008



- 20 / 23 neutron beam lines occupied or assigned
- Time for a second target station!

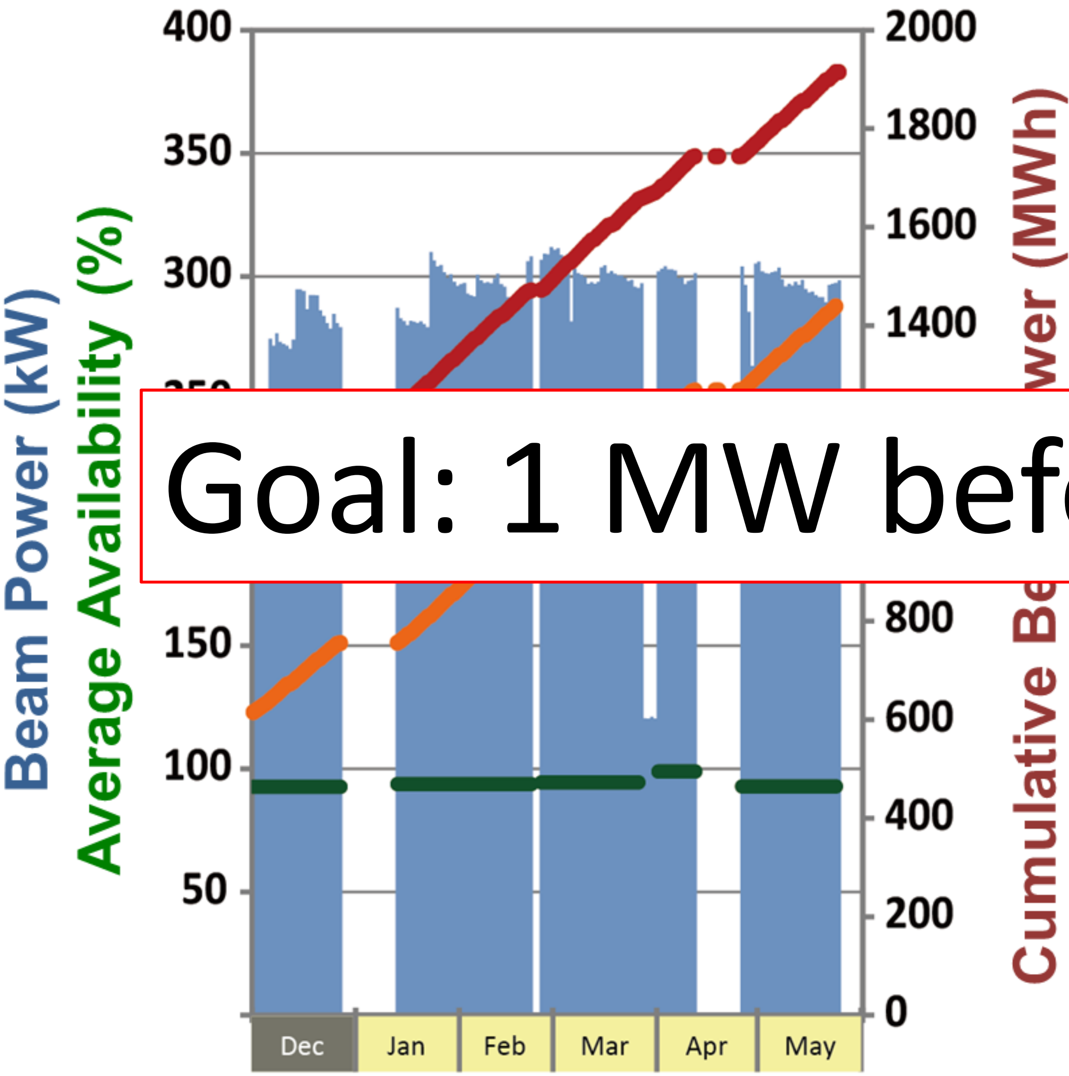
A couple of unfortunate events at J-PARC have held up neutron production

- Great East Japan Earthquake, March 2011
  - Phenomenal recovery
  - Operations resumed in < 1 year
- Hadron facility accident May 2013
  - Beam extraction malfunction caused 5 ms extraction, vs. intended 2 s
    - Gold target partly vaporized
    - Spread of contamination
  - Safety review of incident and all of operations at J-PARC
  - Operations resumed in February 2014



Operational history in 2013

- 300 kW steady operation with injecting gas micro-bubbles since Dec. 2012
- 187 days beam delivery with high availability of 93.8% for JFY 2012.
- 36.5-day operation for 2013A with an availability of 94% until the radioactive materials leak accident occurred at Hadron Facility in May



May 25. to end of July, 2013;
Unscheduled shutdown due to accident
- Cooperation to the investigations of causes of the accident.

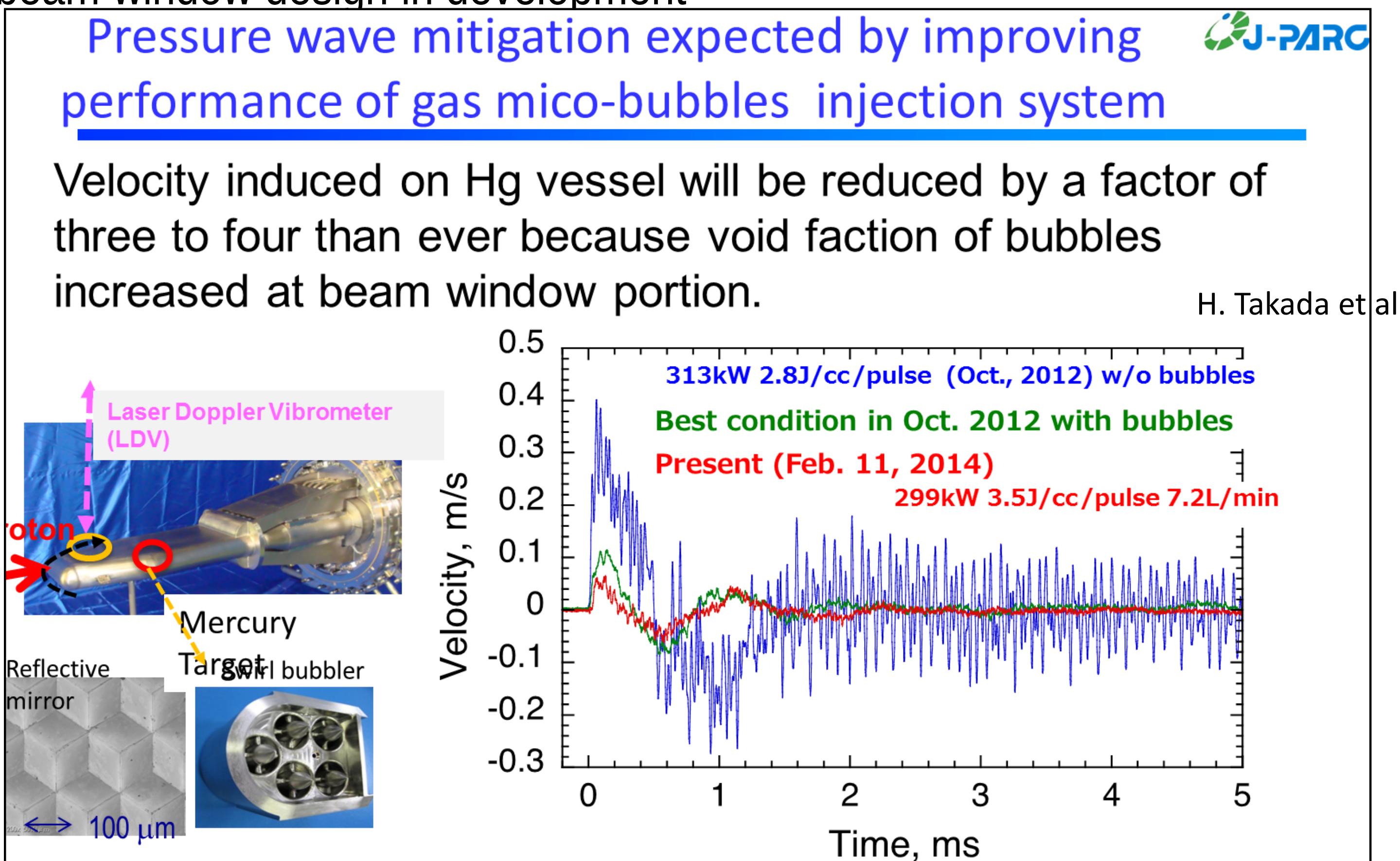
and replacing components

Goal: 1 MW before Spring 2016

- **Jan. 17: The 400 MeV Linac energy upgrade successfully achieved**
- Feb. 17: User program resumes today!

J-PARC is aggressively working mitigation of target pitting damage

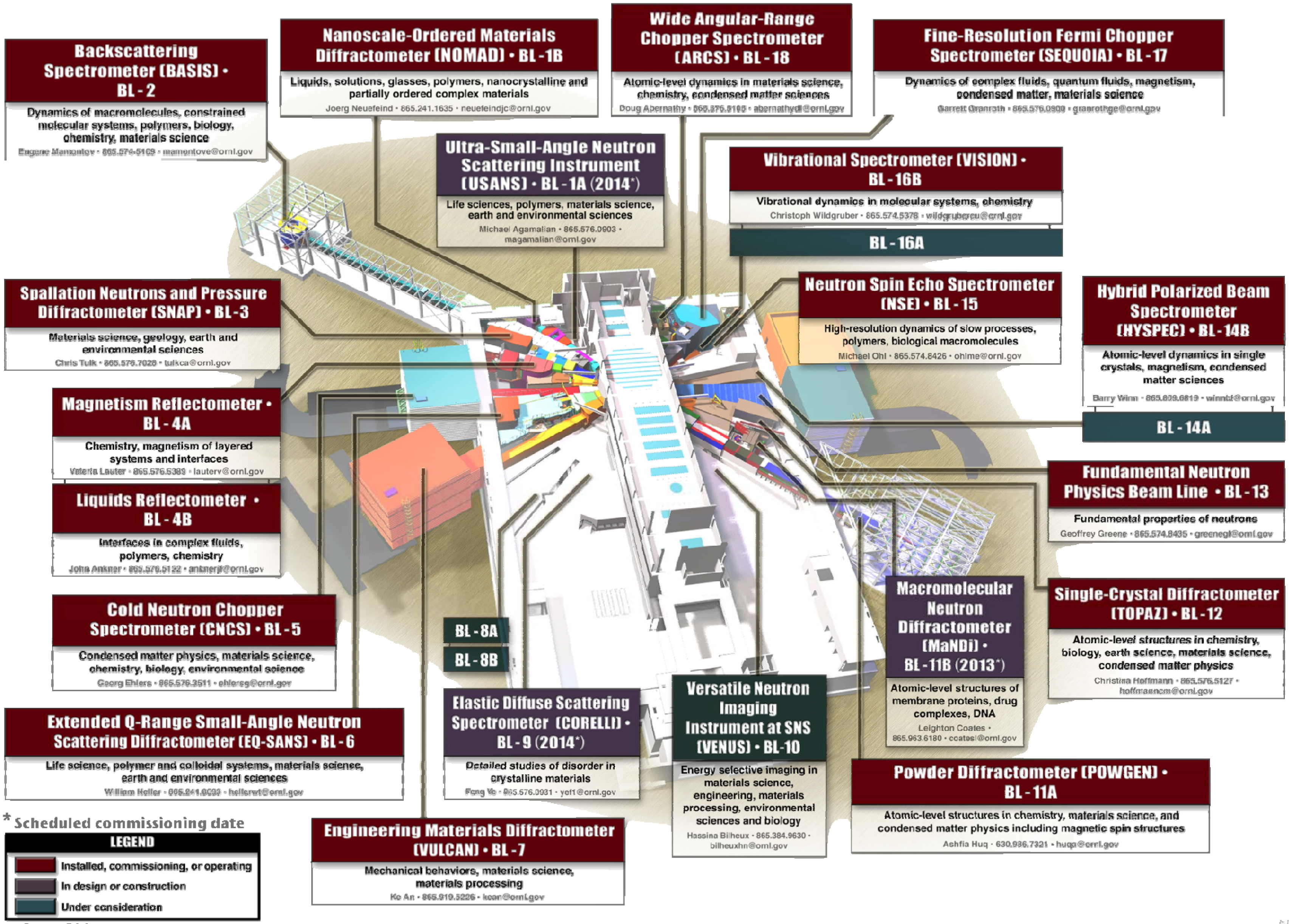
- Bubbler system operational
  - Substantial suppression of target vibration associated with cavitation
- New octupole magnet flattens beam on target & reduces energy density in mercury
- Target post irradiation examination is pending
- Double-wall beam window design in development



SNS – running since 2006

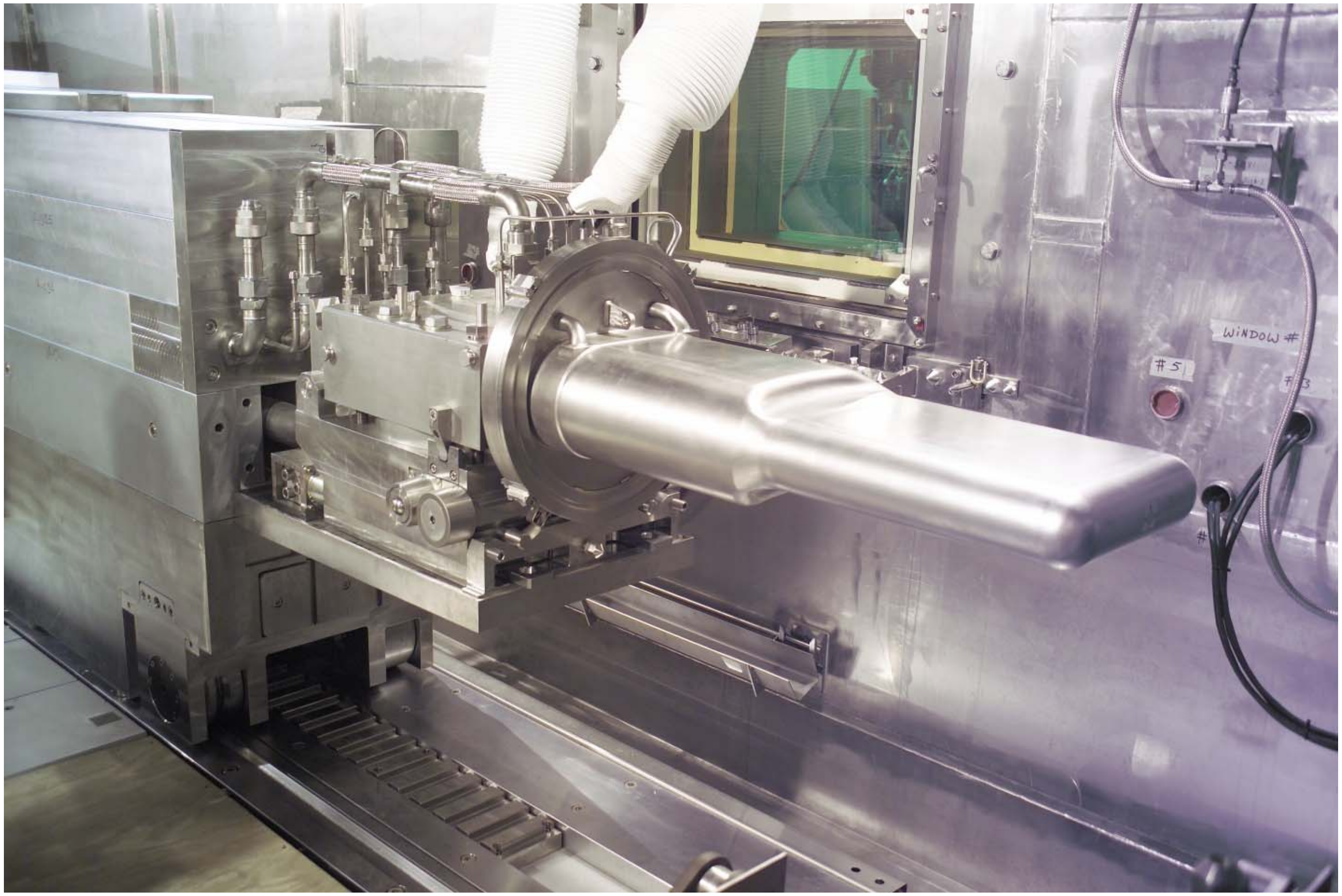
- Mission is focused on neutron science
- 1.4 MW accelerator, 1 GeV, linac & accumulator ring, μs pulses to target at 60 Hz

20 out of 24 beam-lines built or assigned
Neutron production schedule ~5000 h/y



SNS mercury target

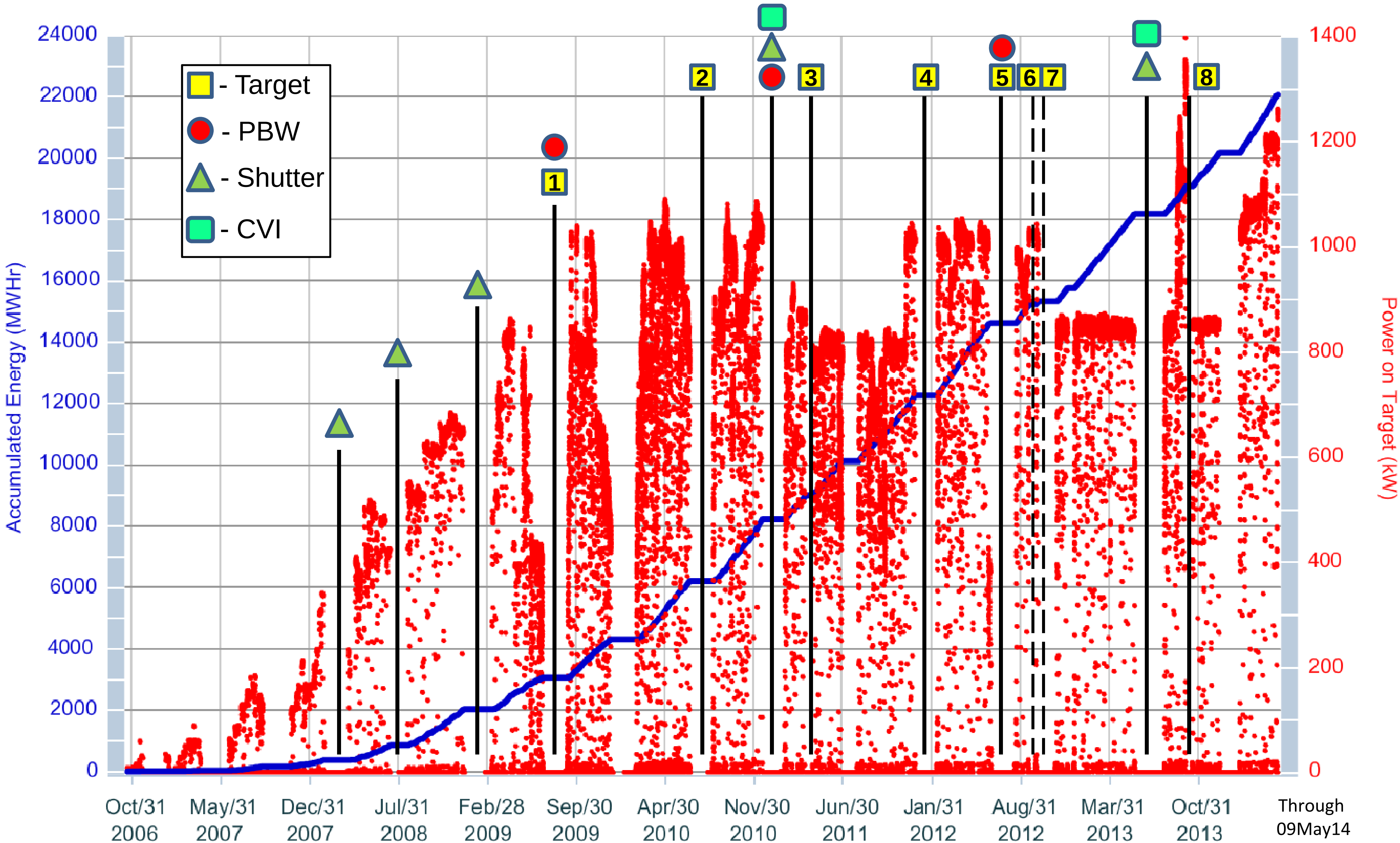
- More than 20 tons of mercury circulating through a SS 316L target module



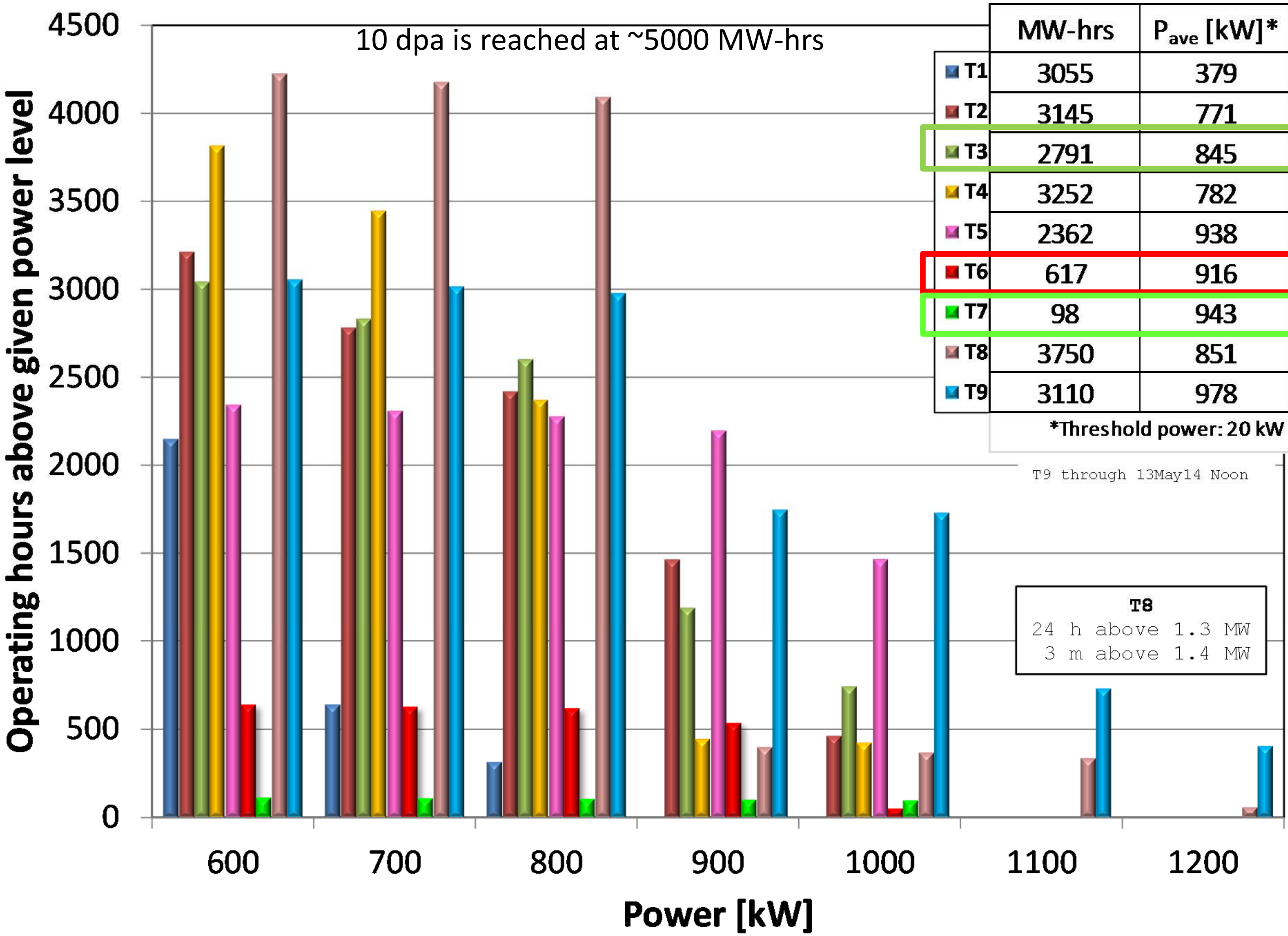
- The target module is a *replaceable* component
  - Administrative radiation damage limit is 10 dpa

Power on target & accumulated energy

Major Remote Handling Component Replacements



Target lifetime and power levels are improving – still room for more

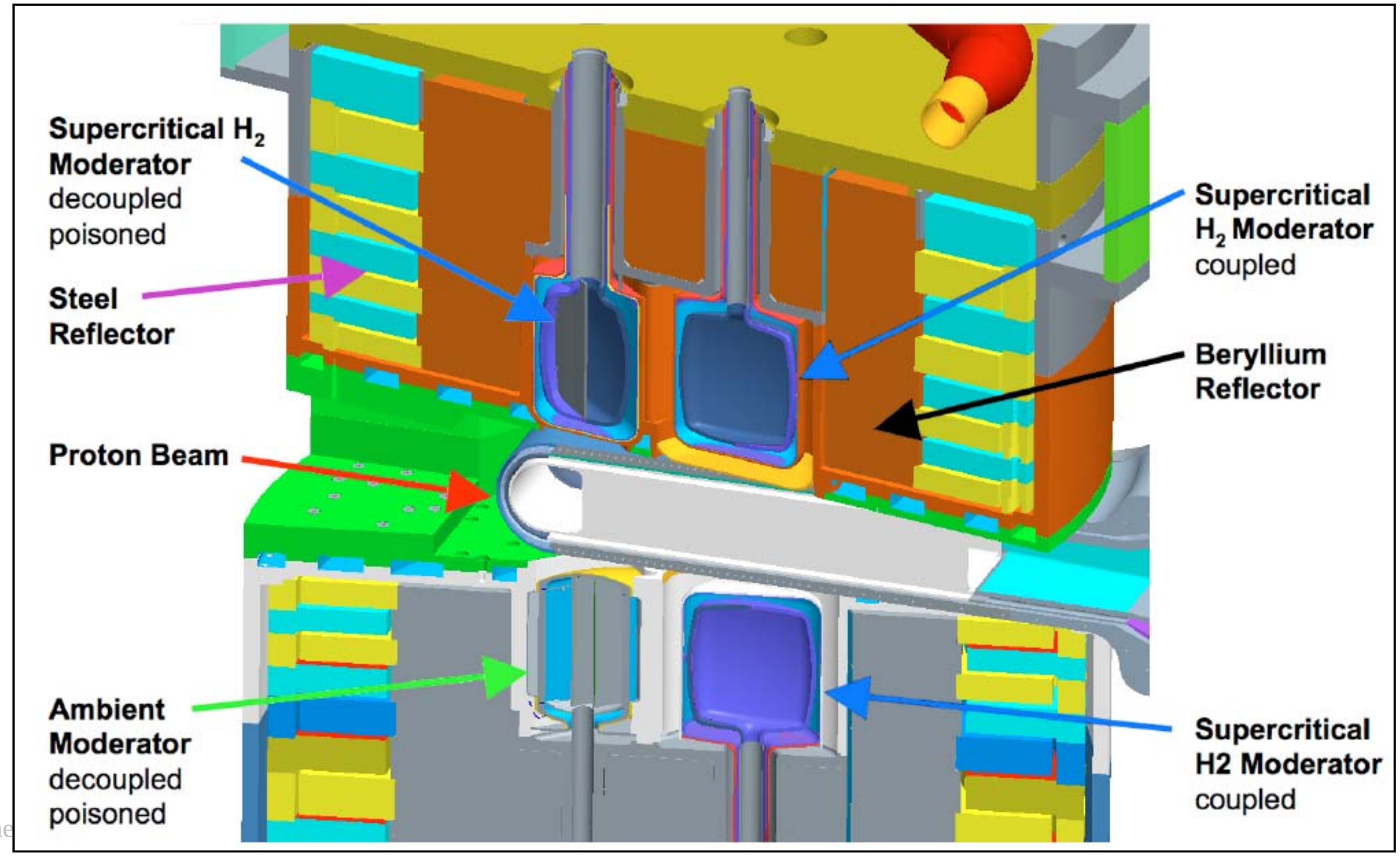


	MW-hrs	P_{ave} [kW]*	
T1	3055	379	
T2	3145	771	
T3	2791	845	Cavitation / inclusions?
T4	3252	782	
T5	2362	938	
T6	617	916	Weld defect
T7	98	943	Weld defect
T8	3750	851	
T9	3110	978	

*Threshold power: 20 kW

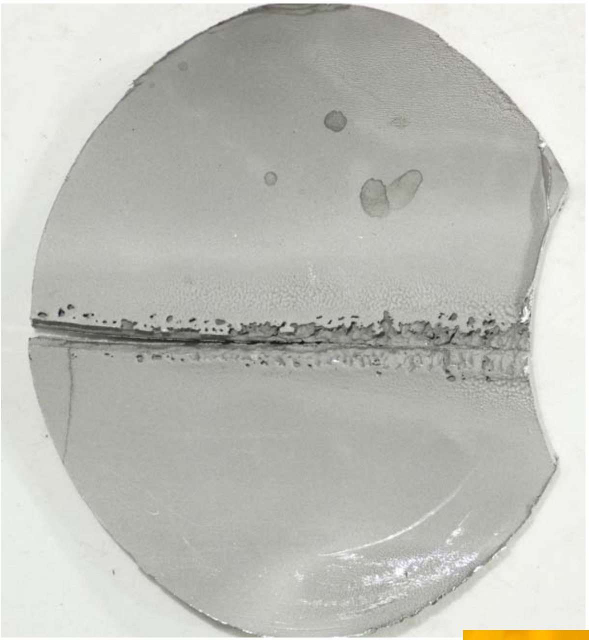
SNS has 3 liquid hydrogen moderators and 1 water moderator

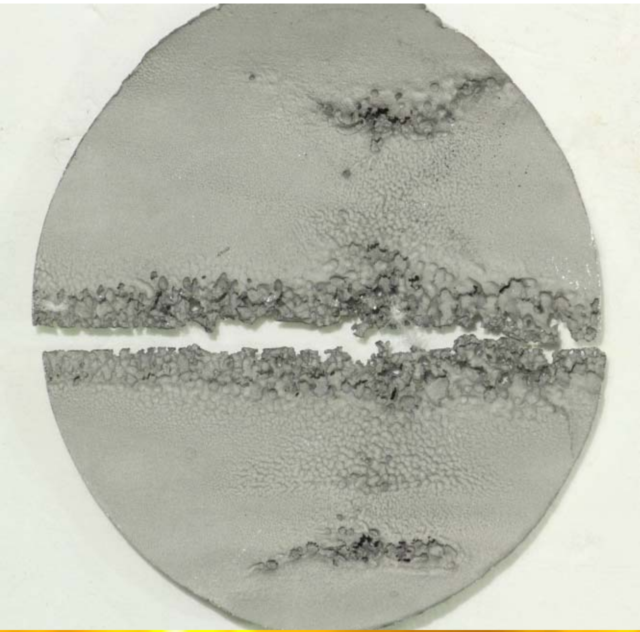
- Upstream moderators are decoupled and poisoned
- Downstream are coupled, not large; no ortho→para catalyst
  - Disadvantage vs. JSNS
  - Next generation IRP to improve and enlarge top downstream moderator; catalyst equipment to be added



Target pitting damage is being monitored with PIE program

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





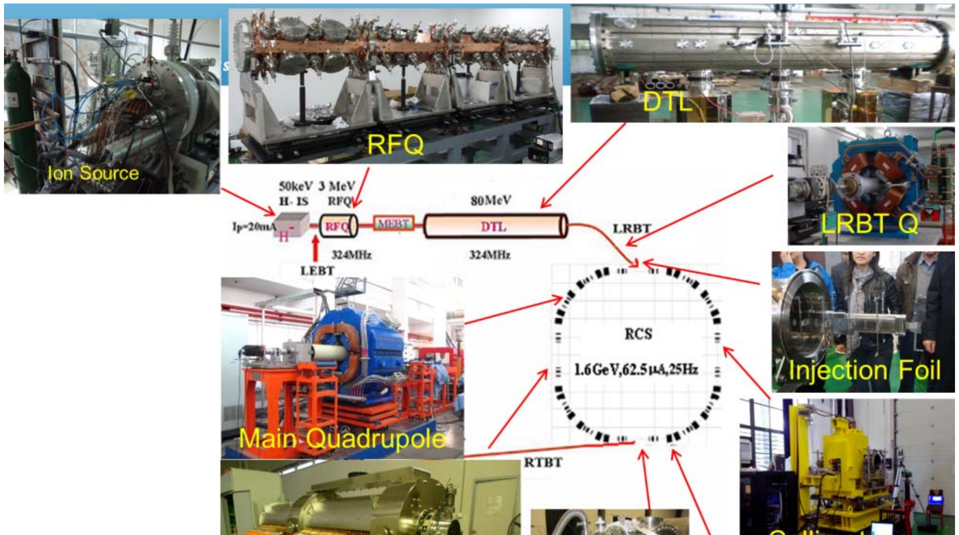
- "Jet-flow" target design should reduce this damage
  - Mitigation by flow – no gas injection
  - First unit set for installation this summer

Final words on SNS

- Upcoming IRP replacement in 2016 will be largest remote handling operation to date
- Fusion Materials Irradiation Test Stand (FMITS) about to have 30% design review
- Second Target Station Technical Design Study (TDR) is in preparation
  - Up to 500 kW, 10 Hz, short-pulse, solid tungsten target – water-cooled
  - Related accelerator upgrades will provide 2 MW to FTS

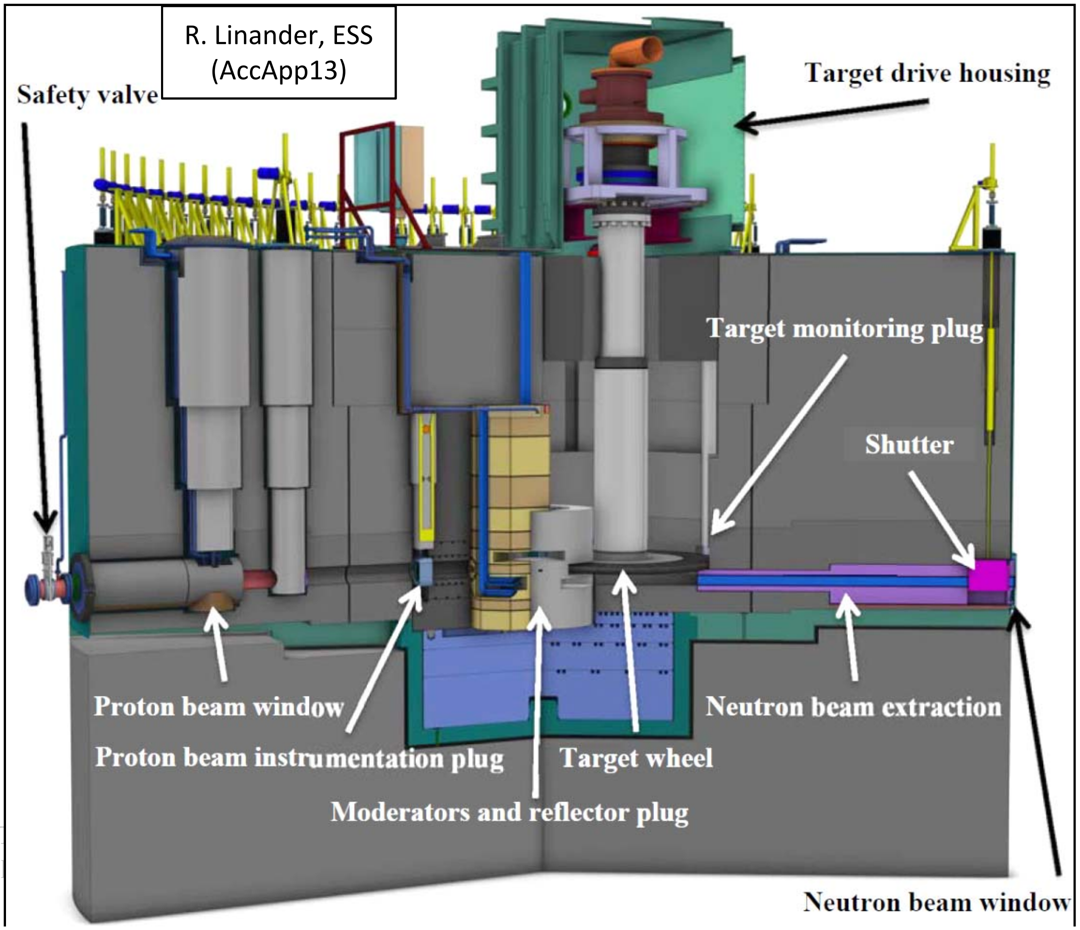
CSNS has taken off Operational in 2018

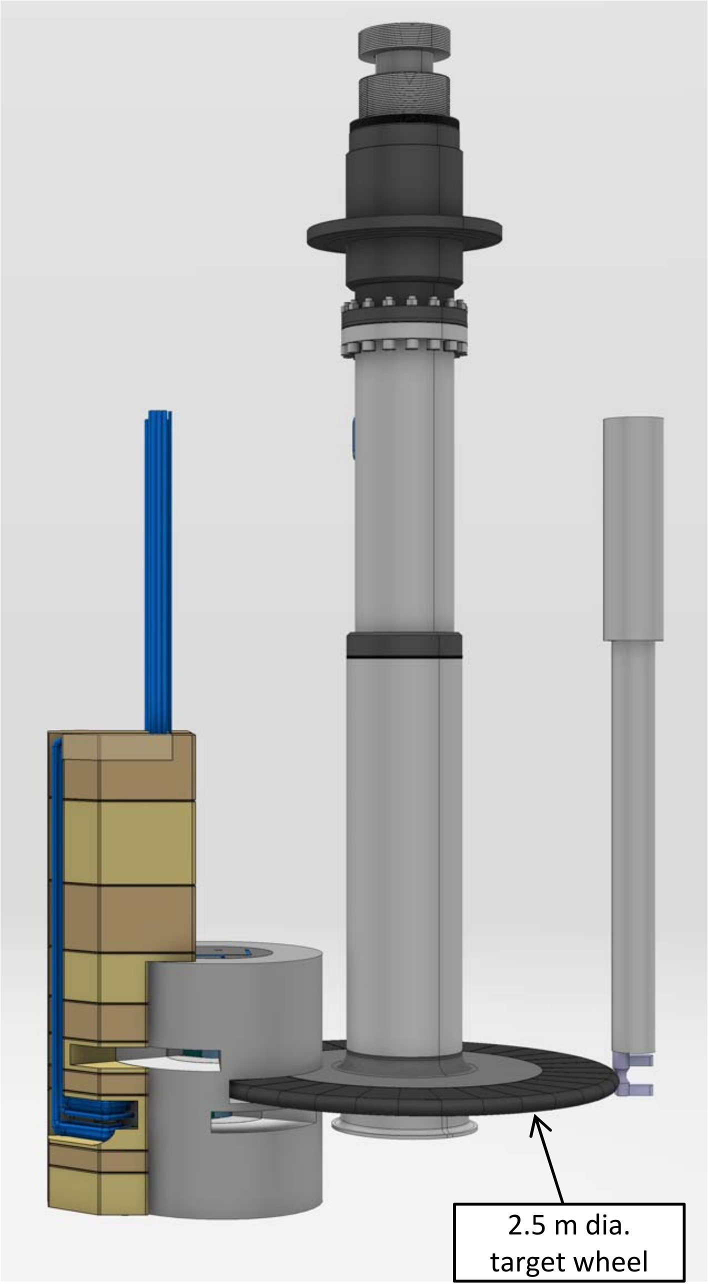
25 Hz, SP, 100–200–500 kW, 1.6 GeV
Ta clad W plates target



ESS is gaining momentum

- 5 MW of 2.5 GeV protons
- 14 Hz, long-pulse (2.86 ms)
- Rotating target of tungsten blocks – cooled by helium
- More from Yong Joong Lee





It's harder to talk only about targets

- Overall <u>source</u> performance is what matters
  - How well does the source provide the desired beams for science instruments?
- Integrated approaches to source design around specific instrument performance metrics, utilizing optimization techniques, can show new paths to high-performance
  - TS-2 at ISIS
- When isn't higher target power the right direction for higher performance?
  - Spallation sources
  - Other high-power target applications