Oak Ridge National Laboratory

Proton Power Upgrade and Second Target Station for the Spallation Neutron Source

Basic Energy Sciences Advisory Committee Meeting

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U.S. DEPARTMENT OF ENERGY

SNS update

Source is operating at 1.4 MW; the most power pulsed proton accelerator in the world

Mercury targets are operating reliably

2 new experiment stations under design; construction will bring total number of operating instruments to 21

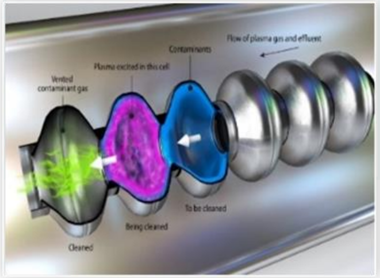
~850 experiments and 900 unique users per year

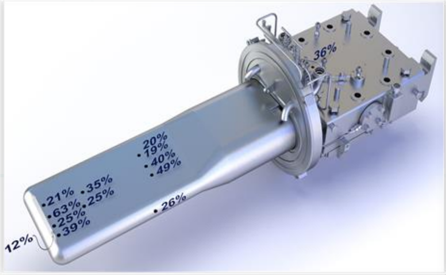
Goal of 4900 hours of neutron production in FY 2019

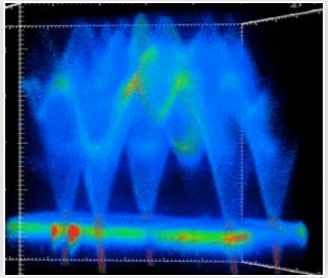
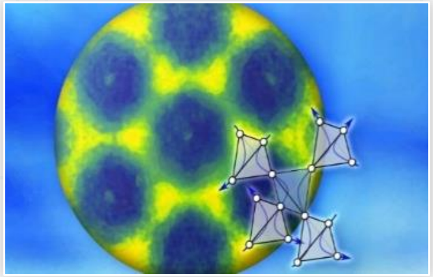
Scientific productivity and impact are growing

- 2018: 394 publications; 29% in journals with impact factor > 7

Emphasis on integration with ORNL computa-tional and software engineering capabilities



SNS upgrades will accelerate scientific progress and deliver wholly new capabilities

PPU project: Double the power of the existing accelerator structure

- First Target Station (FTS) is optimized for thermal neutrons
- Increases peak brightness of beams of pulsed neutrons
- Provides new science capabilities for atomic resolution and fast dynamics
- Provides a platform for STS

STS project: Build second target station with initial suite of beam lines

- Optimized for cold neutrons
- World-leading peak brightness
- Provides new science capabilities for measurements across broader ranges of temporal and length scales, real-time, and smaller samples

High-level status of SNS upgrade projects

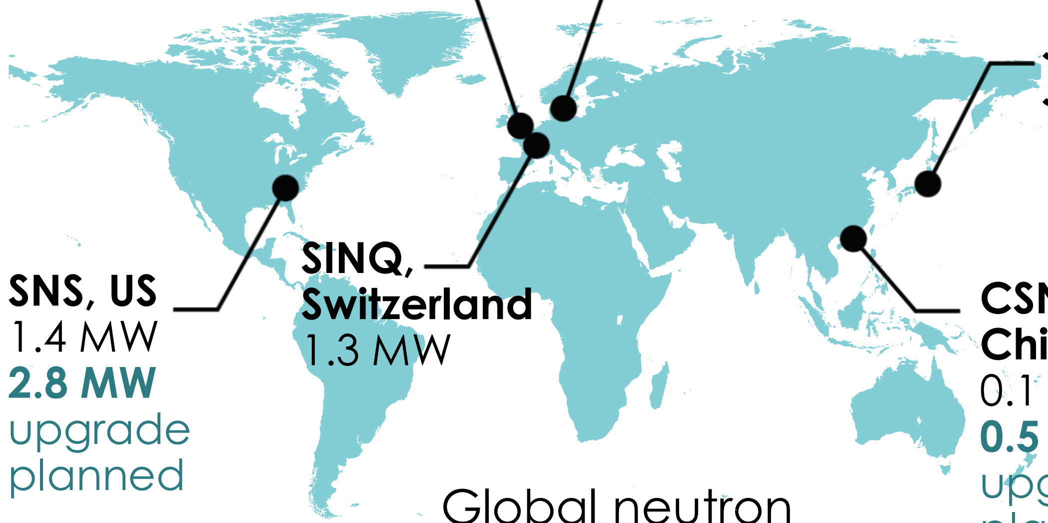
Proton Power Upgrade (PPU)

- Critical Decision (CD)-0, CD-1 and CD-3a approved by DOE
- Partner Labs selected – FNAL, LBNL and J-Lab.
- Successful CD-3b review in June 2019
- Ready for CD-2 review at end of 2019
- Early power ramp-up to 1.7 MW proposed for 2022 with start of ramp-up to 2 MW in 2024
- Early project completion in 2024
- Most construction activities occur during regular scheduled maintenance periods

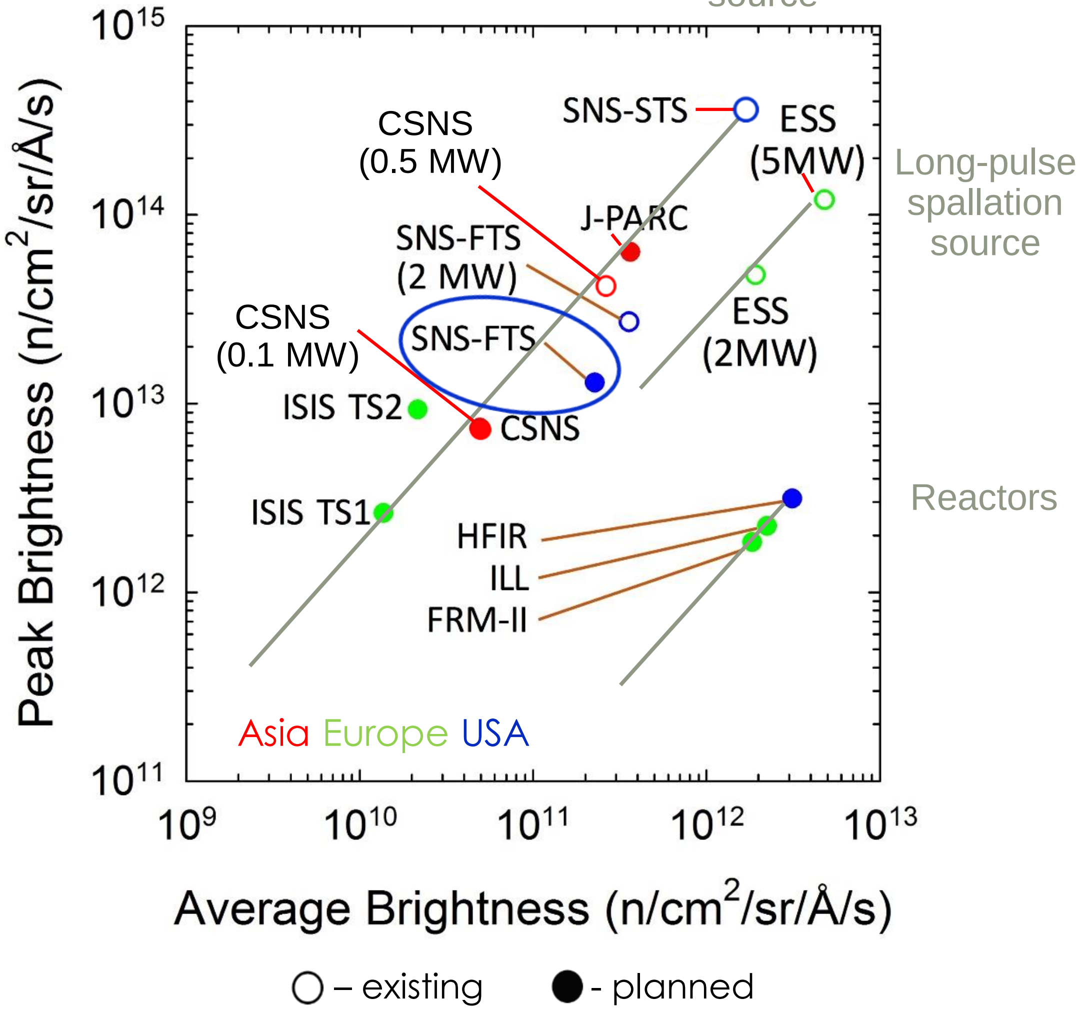
Second Target Station (STS)

- CD-0 approved by DOE
- Design and implementation plan finalized following detailed studies and review panel evaluation in 2017
- Conceptual design packages completed
- Bottom-up cost-estimate by August 2019
- Preparing for CD-1 readiness review
- Early project completion in 2028
- Federal Project Director appointed, interim Director appointed, and active search for Director
- Construction has minimal impact on FTS operations

SNS upgrades will provide world-leading neutron capabilities to US researchers



Global neutron source competition: Spallation neutron sources



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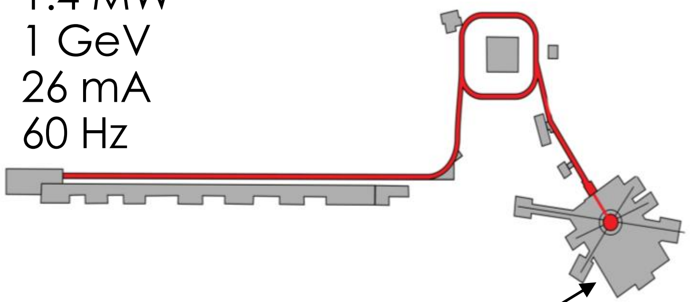
PPU and STS upgrades will ensure SNS remains the world's brightest accelerator-based neutron source

Today

- 900 users
- Materials at atomic resolution and fast dynamics

1.4 MW
1 GeV
26 mA
60 Hz

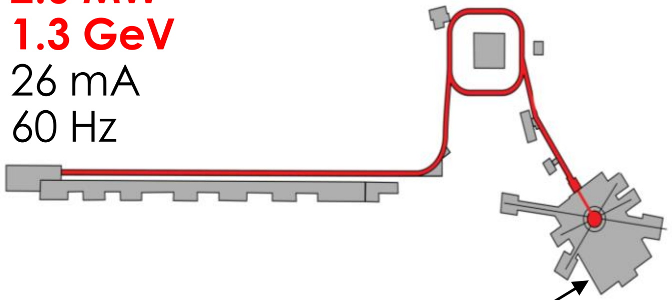


FTS
1.4 MW
60 Hz

2024 after PPU

- **1000+** users
- Enhanced capabilities

2.0 MW
1.3 GeV
26 mA
60 Hz



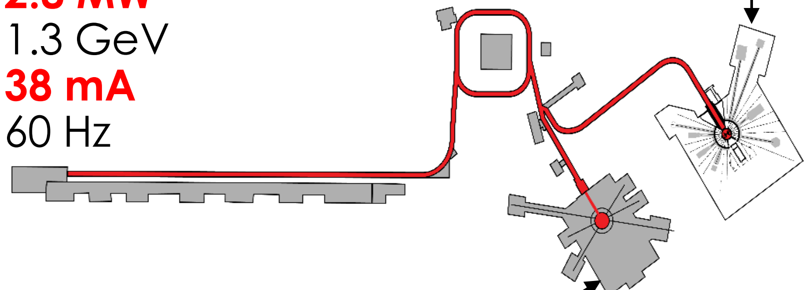
FTS
2 MW
60 Hz

2028 after STS

- **2000+** users
- Hierarchical materials, time-resolution and small samples

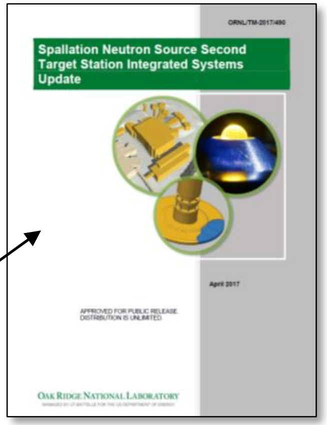
STS
0.7 MW
15 Hz

2.8 MW
1.3 GeV
38 mA
60 Hz

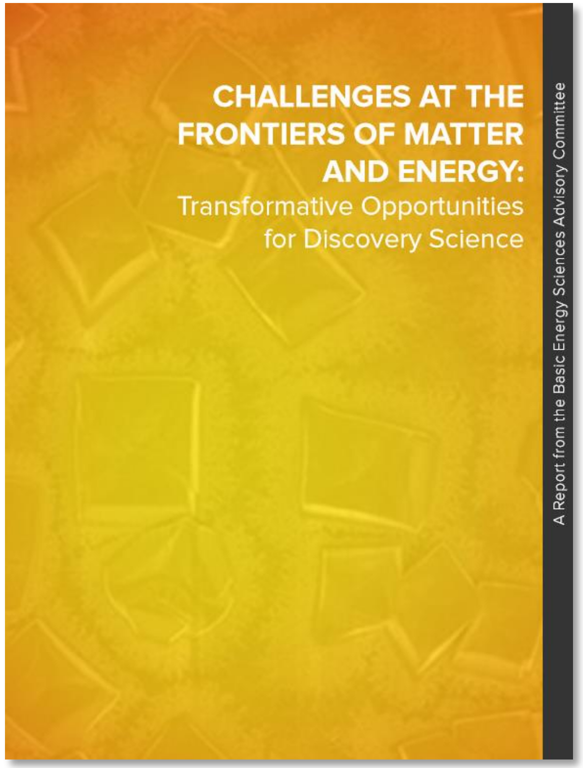


FTS
2 MW
45 pulses/sec

The choice of 15 Hz and 0.7 MW resulted from a detailed analysis of STS design (reviewed by a panel of experts in 2017) and optimizes performance of STS without impacting performance of FTS

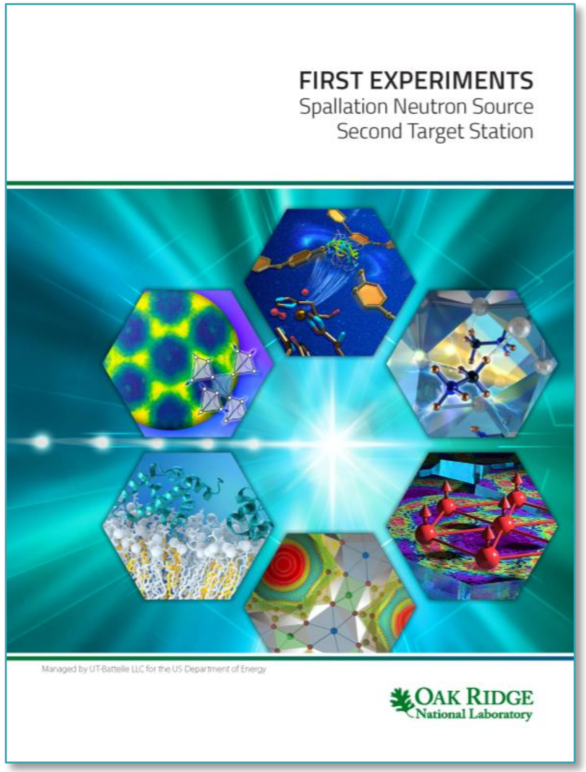


STS provides wholly new capabilities to the US user community



Beams of cold neutrons with higher peak brightness and broader ranges of neutron energies are required to meet challenges at the frontiers of matter and energy:

- Simultaneous measurement of hierarchical architectures across unprecedented ranges of length scales
- Time-resolved measurements of kinetic processes and beyond-equilibrium matter
- Characterization of smaller samples and matter under more extreme conditions

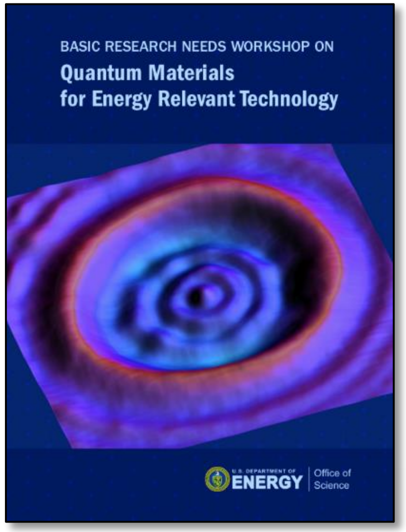


The US user community has developed a set of “first experiments” that demonstrate the transformative capabilities of STS

More intense beams to characterize smaller samples and matter under more extreme conditions

Quantum Materials for Energy Relevant Technology, 2016

"Quantum materials may enable fundamentally new approaches to computation, such as quantum or neuromorphic computing, to progress from fantasy to reality"



STS instrument capabilities

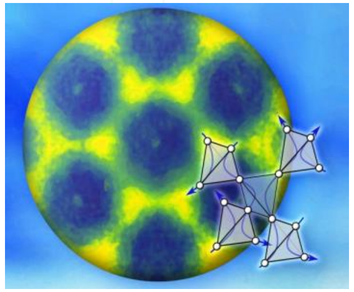
Intense beams will enable measurements on samples 2 orders of magnitude smaller, allowing:

- Characterization earlier in the materials discovery cycle
- Dramatic broadening in application of inelastic neutron scattering to characterize QSLs and broader family of organic magnets (metal-insulators, superconductors, etc.)
- More extreme sample environments
- Multimodal instruments

Wen et al. *Nature Partner Journals* (2019)

Quantum spin liquids (QSLs)

- Entanglement in QSLs can result in topologically protected quasi-particles linked to unconventional super-conductivity and may be useful for advancing quantum computing
- Neutron scattering can provide unique insight into quantum materials such as candidate QSLs, but current capabilities impose limits on sample size

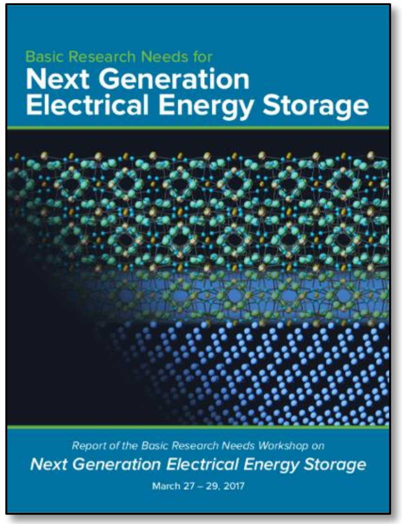


Fractionalized excitations in candidate QSLs result in characteristic diffuse inelastic neutron scattering
[Plumb et al., *Nature Physics* (2019)]

Time-resolved measurements of kinetic processes and beyond-equilibrium matter

Next Generation Electrical Energy Storage, 2017

"Can we characterize the chemical and material reactions and behaviors that comprise dynamic interfaces?"



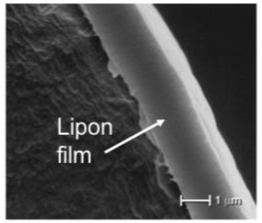
STS instrument capabilities

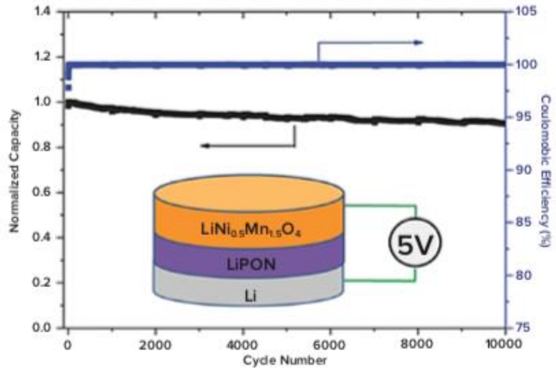
Up to 2 orders of magnitude improvement in time resolution, allowing:

- A real-time (seconds), in situ, in operando view of changes in SEI morphology across broad range of length scales
- Redox and mass transport viewed in real time
- Real-time observation of heterostructures using Li isotope contrast techniques
- Effect of applying static or dynamic loads of variation in electrical current or temperature on structure of moving interfaces

Dynamics of solid-electrolyte interphase (SEIs)

- SEI formation is central to Li+ battery performance but not understood; effective in situ experimental techniques needed
- Today's neutron instruments lack time resolution necessary to capture SEI dynamics



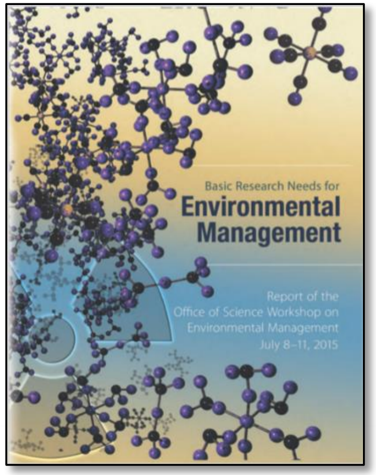


Studying lithium phosphate oxynitride (LIPON): Neutrons are deeply penetrating, sensitive to Li, and do not change the chemistry
[Han et al., *Nature Energy* (2019)]

Simultaneous measurement of hierarchical architectures across unprecedented ranges of length scales

Environmental Management, 2015

"Predicting the behavior of high-level wastes and developing methods for their characterization and treatment requires an understanding of multiscale complexity and heterogeneity"



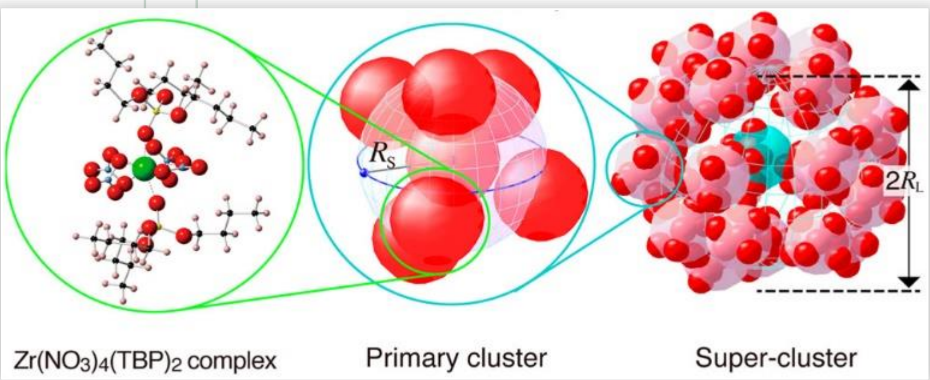
STS instrument capabilities

Coverage of all necessary length scales (<1 Å to >100 nm) in a single shot and in real time, allowing:

- Correlation of hierarchical structure with experimental variables (e.g., temperature, concentration, pH)
- Correlation of hierarchical structure with performance
- Understanding interplay of different processes across length scales
- Development of more efficient separations processes

Understanding complex structured fluids

- Complex structured fluids are central to a wide variety of nuclear waste extraction systems (e.g., PUREX)
- Today, no single technique can cover all relevant length scales



Neutron scattering can see all components of complex systems without changing their chemistry
[Motokawa et al., *ACS Central Science* (2019)]

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Summary

SNS is operating at high power levels and is having a tremendous impact on international science

PPU project will double accelerator power capability, increase neutron brightness at FTS, and provide a platform for STS

STS project will provide beams of cold (long-wavelength) neutrons with world's highest peak brightness and with broad ranges of neutron energies

SNS upgrades will deliver wholly new and world-leading capabilities to US researchers

The US user community has created a set of "first experiments" to demonstrate the transformative capabilities of STS over a broad variety of scientific areas

We are ready to continue progress with PPU and STS upgrades

Discussion

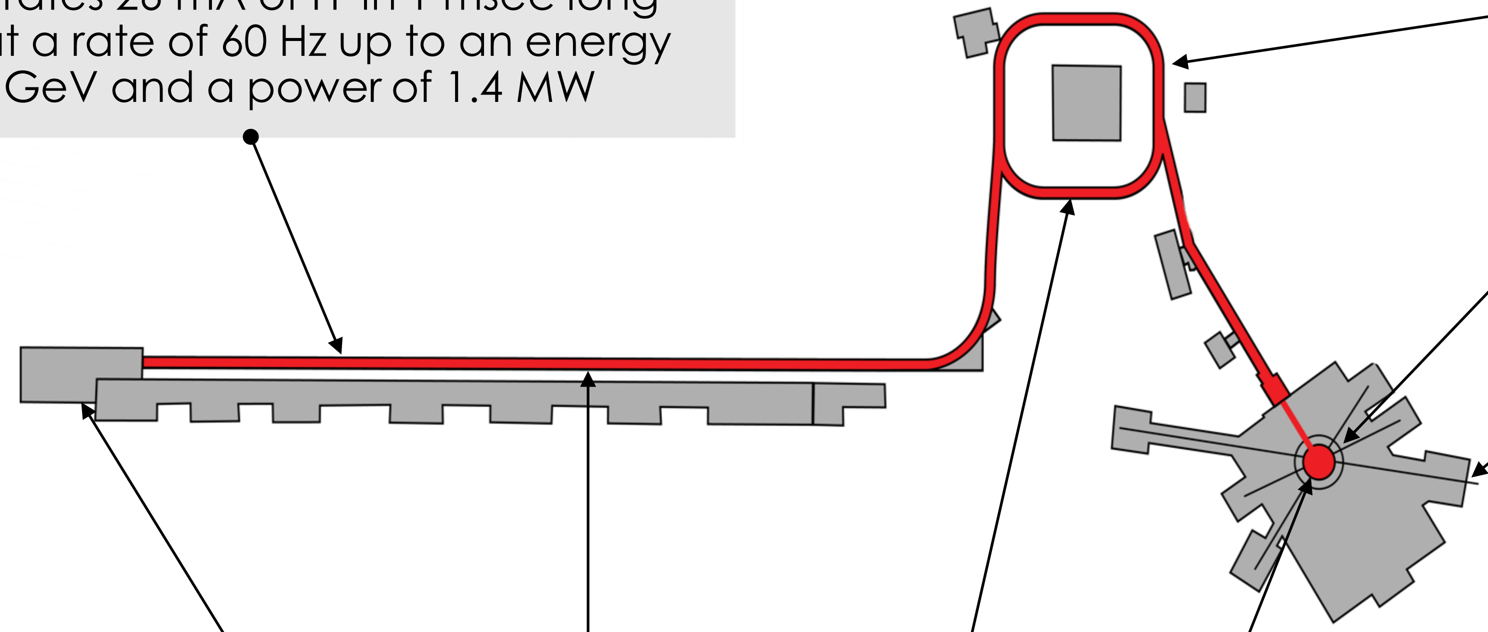
PPU and STS upgrades will ensure SNS remains the world's brightest accelerator-based neutron source

Accelerates 26 mA of H^- in 1 msec long pulses at a rate of 60 Hz up to an energy of 1 GeV and a power of 1.4 MW

Compresses proton pulse to < 1 μsec to increase brightness and improve time-resolution

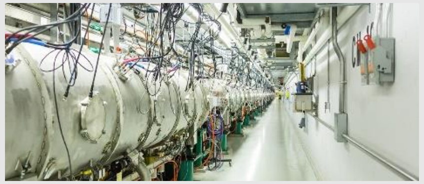
Provides the highest peak brightness pulses of thermal neutrons in the world

Optimized for studying materials with atomic resolution and fast dynamics

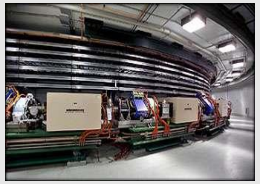


Front-end systems

Linac



Accumulator ring



Hg Target