



August 29, 2026

Neutron User Facilities

2nd National Neutron Scattering School

Mark Lumsden

Neutron Scattering Division Director

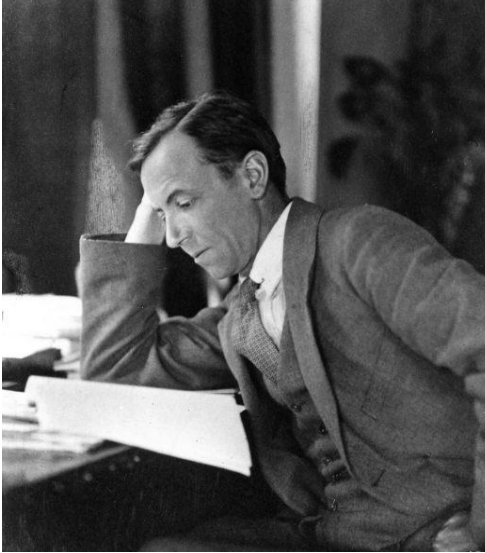


U.S. DEPARTMENT
of **ENERGY**

ORNL IS MANAGED BY UT-BATTELLE LLC
FOR THE US DEPARTMENT OF ENERGY



The first neutron source

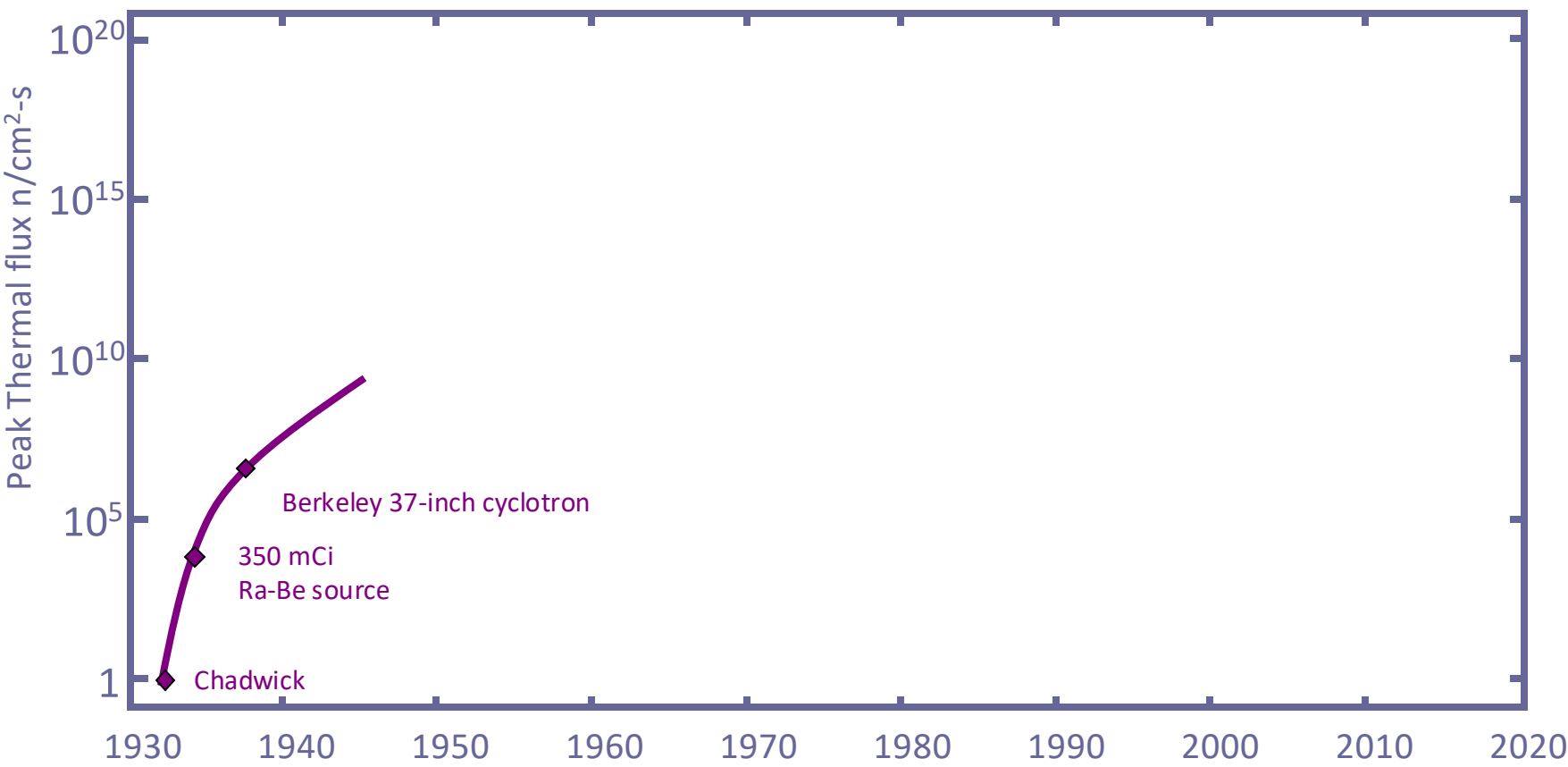


James Chadwick:
used Polonium as alpha emitter on Beryllium

1935 Nobel Prize in Physics for the
discovery of the neutron in 1932

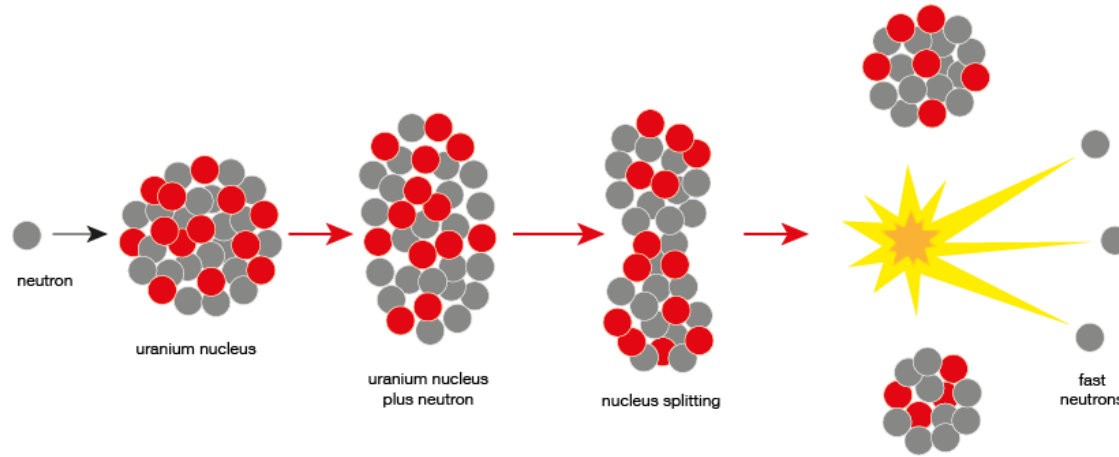


Evolution of neutron sources



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

Nuclear fission

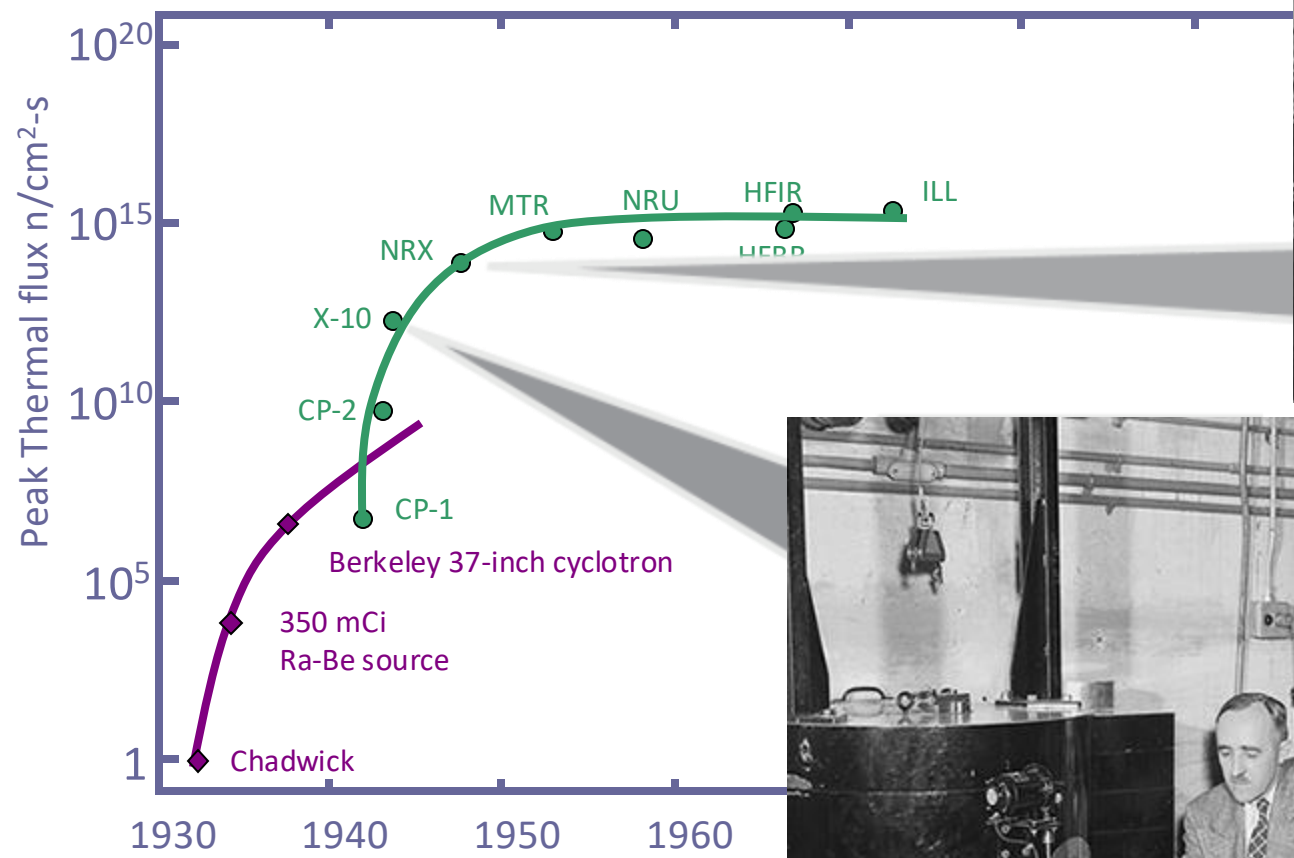


200 MeV/fission
 $2.35 - 1 = 1.35$ excess neutrons
 $\Rightarrow 150$ MeV/neutron



December 2, 1942

Evolution of neutron sources



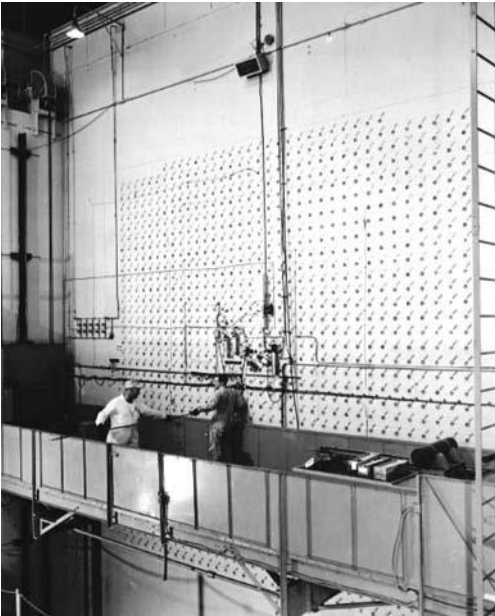
(Updated from *Neutron Scattering*, K. Sköld)



1994 Nobel Prize in Physics:
"for pioneering contributions to the development of neutron scattering techniques for studies of condensed matter"

Nuclear Reactor Power Drives Scientific Innovation

ORNL Graphite reactor
Critical on **Nov. 4, 1943**



Maximum power ~4 MW

Chalk River NRX Reactor
Critical on **July 22, 1947**



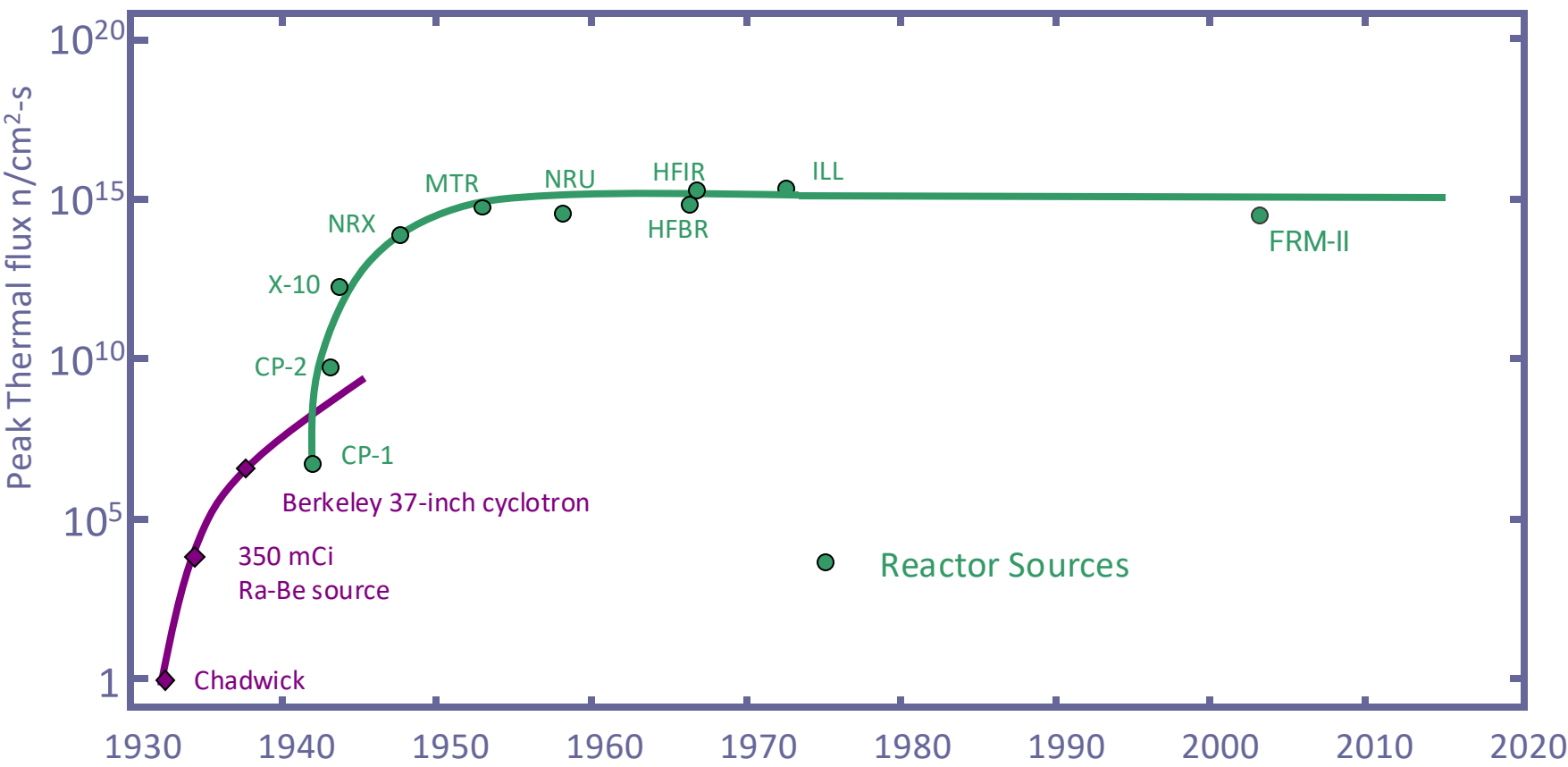
- maximum power 42 MW
- ***100-200 times more neutrons than Graphite Reactor!***

Chalk River NRU Reactor
Critical on **Nov. 3, 1957**



- Original design 200 MW with natural uranium
- Changed to 60 MW with high enriched Uranium
- Changed to 135 MW with low enriched Uranium

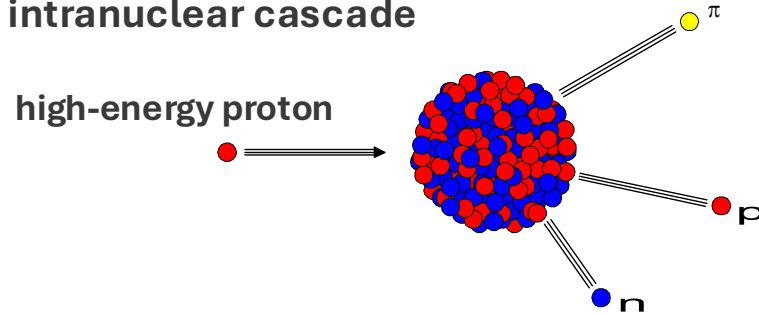
Evolution of neutron sources



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

Nuclear spallation

First stage: intranuclear cascade



1 GeV proton in:

250 MeV becomes mass (endothermic reaction)

30 neutrons freed

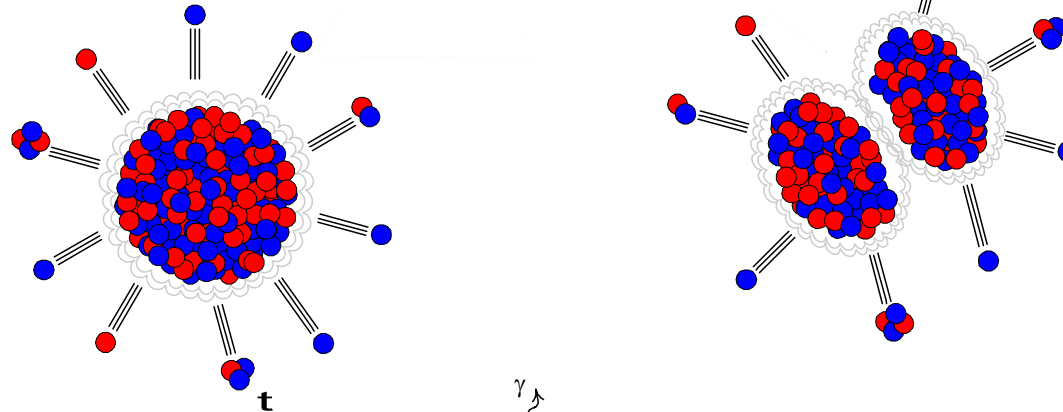
⇒ 25 MeV/neutron

6x more efficient than fission

Intermediate stage: pre-equilibrium

evaporation

fission



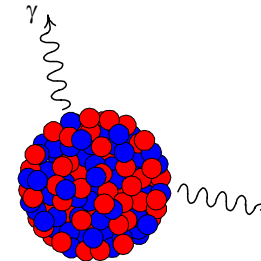
Reminder – fission:

200 MeV/fission

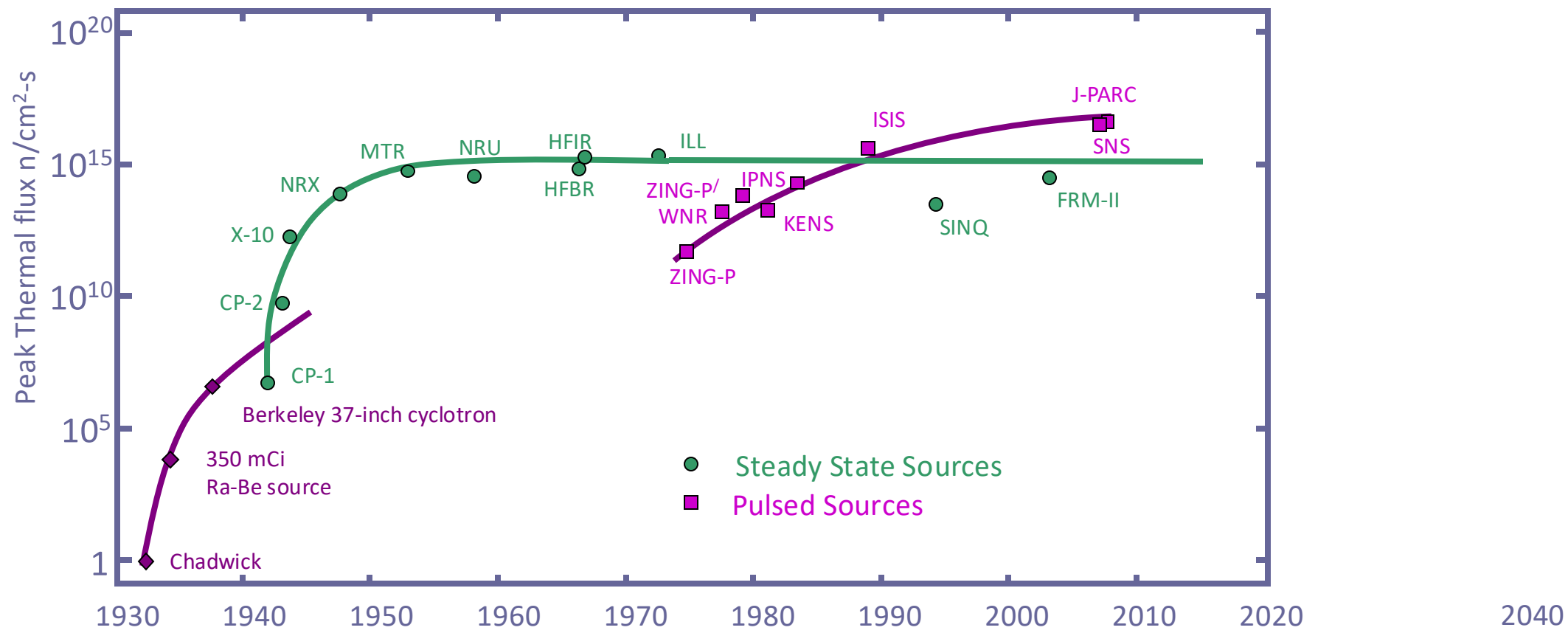
$2.35 - 1 = 1.35$ excess neutrons

⇒ 150 MeV/neutron

Final stage: residual de-excitation

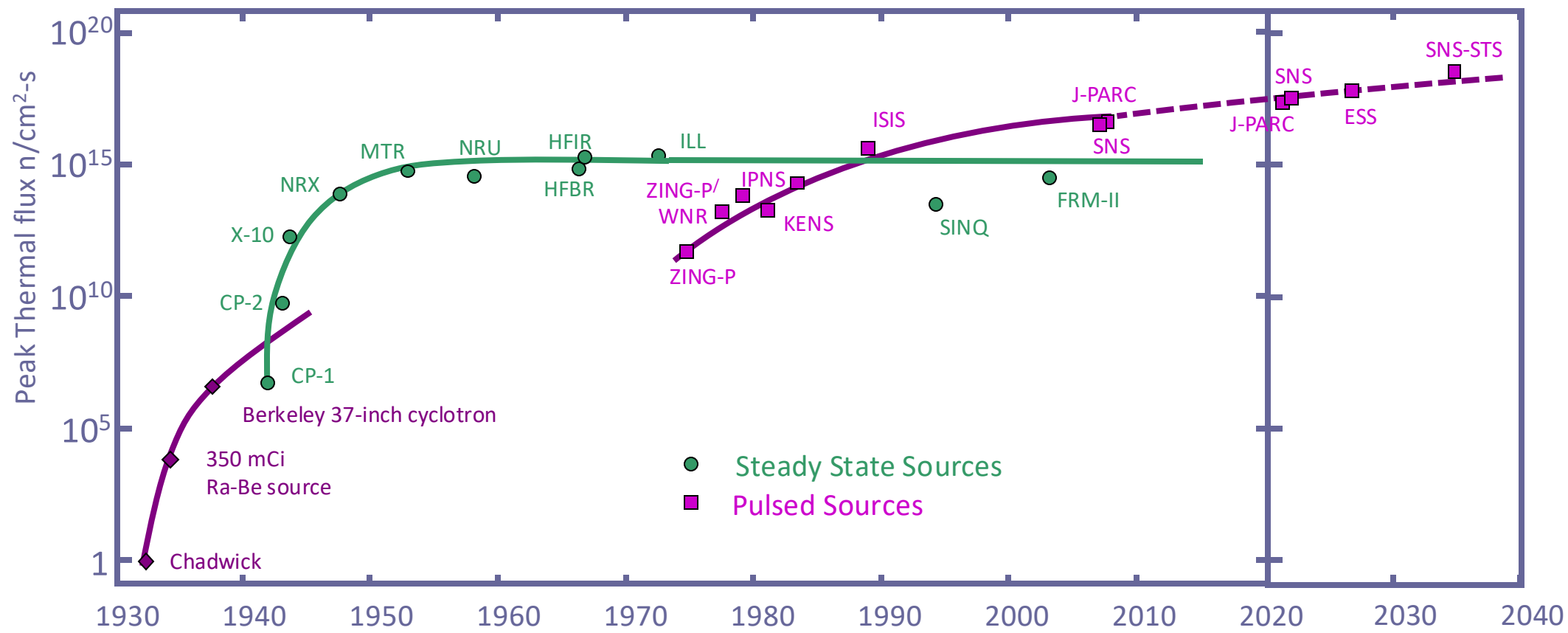


Evolution of neutron sources



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

Evolution of neutron sources



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

Institut Laue-Langevin (France): The First User Facility

➤ ILL founded 1967

- First experiments 1972
- International: France, Germany, UK

➤ A “Service Institute”

- Accessible to non-experts
- Support from an expert “local contact”
- Support for travel
- Access based on scientific merit
- Peer review of proposals
- Twice-yearly proposal rounds

➤ Until then, large-scale facilities were mainly for in-house expert users and their collaborators



User Facilities

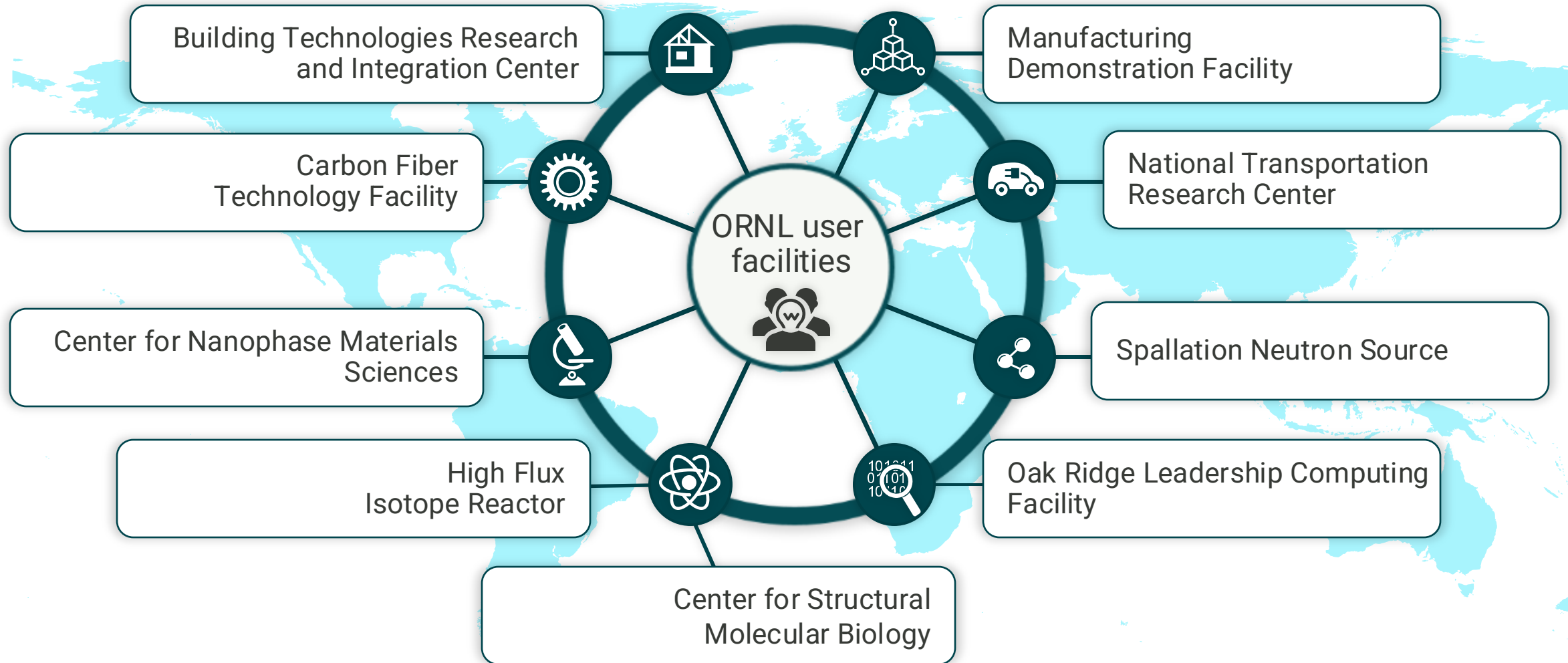
- Neutrons invented user facilities
 - Importance of technique
 - High cost
 - Small science
- Now a widespread business model in science
- Department of Energy Office of Science definition:
 - Open to all without regard to nationality or affiliation
 - Access based on merit review
 - Free to use if results are to be published
 - Facility allows safe and efficient work
 - Facility supports user organization to represent users and promote collaboration
 - Facility does not compete with private sector capability

Office of Science User Facilities List:

- Fermi accelerator complex (FermiLab)
- **Argonne Leadership Computing Facility (ANL)**
- **Advanced Light Source (LBNL)**
- **Advanced Photon Source (ANL)**
- Atmospheric Radiation Measurement user facility
- Accelerator Test Facility (BNL)
- Argonne Tandem Linac Accelerator System (ANL)
- Continuous Electron Beam Accelerator Facility (TJNAF)
- **Center for Functional Nanomaterials (BNL)**
- **Center for Integrated Nanotechnologies (LANL / SNL)**
- **Center for Nanoscale Materials (ANL)**
- **Center for Nanophase Materials Sciences (ORNL)**
- DIII-D National Fusion Facility (GA)
- Environmental Molecular Sciences Laboratory (PNNL)
- **Energy Sciences Network (LBNL)**
- Facility for Advanced Accelerator Experimental Tests (SLAC)
- Facility for Rare Isotope Beams (Michigan State)
- **High Flux Isotope Reactor (ORNL)**
- **National Synchrotron Light Source II (BNL)**
- **Neutron Sources**
- **Light Sources**
- **Nanoscience Centers**
- **Computing**
- Joint Genome Institute (LBNL)
- **Linac Coherent Light Source (SLAC)**
- **National Energy Research Scientific Computing Center (LBNL)**
- National Spherical Torus Experiment (Princeton)
- **Oak Ridge Leadership Computing Facility (ORNL)**
- Relativistic Heavy Ion Collider (BNL)
- **Spallation Neutron Source (ORNL)**
- **Stanford Synchrotron Radiation Light Source (SLAC)**
- **The Molecular Foundry (LBNL)**

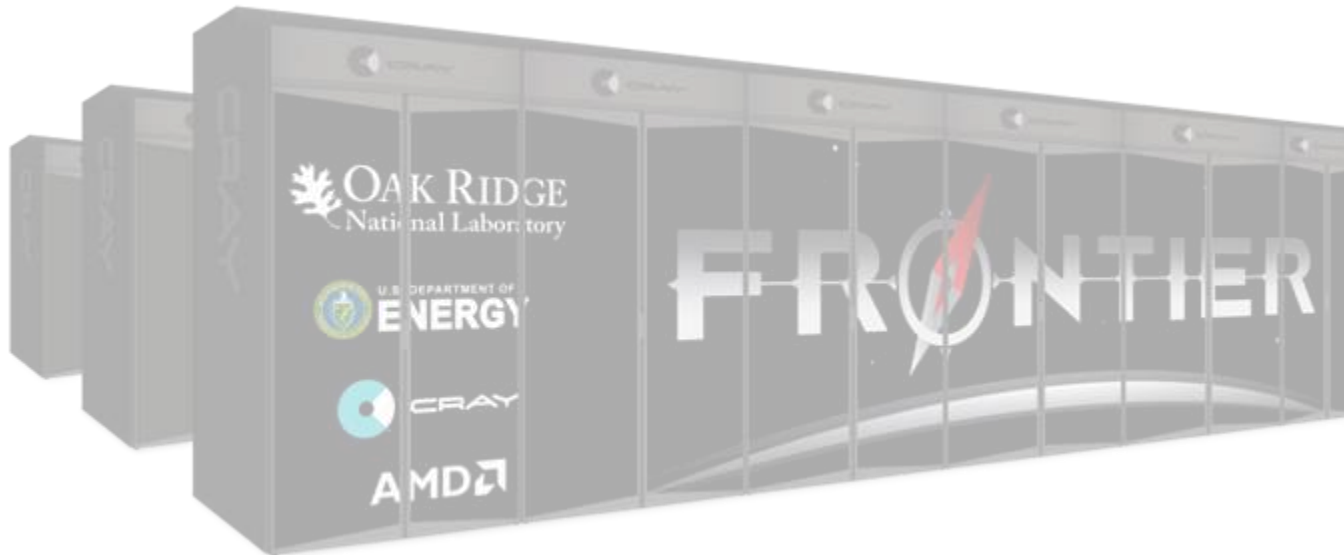
28 Office of Science User Facilities

Oak Ridge National Laboratory User Facilities



Oak Ridge Leadership Computing Facility (OLCF)

- Computing and Computational Sciences Directorate (CCSD) houses the Oak Ridge Leadership Computing Facility, home to **Frontier**
- Provides expertise in data science, modeling and simulation for grand challenge science. Advances the state-of-the-art in artificial intelligence, data science and quantum information science
- Researchers can apply for time at leadership computing facilities through several allocation programs that cater to a range of scientific disciplines and HPC experience levels
- Since 2006, the Oak Ridge Leadership Computing Facility has deployed four supercomputers that debuted as fastest in the world, including Summit in 2018 and Frontier in 2022 - the **first exascale machine in the world**.



DOE Exascale Computing Initiative (2016-2024) produced three systems exceeding an ExaFlop/s performance



Rank	System	Cores	Rmax (PFlop/s)	Rpeak (PFlop/s)	Power (kW)
1	LineShine - LingKun, LX2 304C 1.55GHz, LingQi, Kylin OS, Shenzhen Cloud Computing Center Co., Ltd. National Supercomputing Centre in Shenzhen (NSCS) China	13,789,440	2,198.40	2,735.82	42,220
2	El Capitan - HPE Cray EX255a, AMD 4th Gen EPYC 24C 1.8GHz, AMD Instinct MI300A, Slingshot-11, TOSS, HPE DOE/NNSA/LLNL United States	11,340,000	1,809.00	2,821.10	29,685
3	Frontier - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE Cray OS, HPE DOE/SC/Oak Ridge National Laboratory United States	9,066,176	1,353.00	2,055.72	24,607
4	Aurora - HPE Cray EX - Intel Exascale Compute Blade, Xeon CPU Max 9470 52C 2.4GHz, Intel Data Center GPU Max, Slingshot-11, Intel DOE/SC/Argonne National Laboratory United States	9,264,128	1,012.00	1,980.01	38,698
5	JUPITER Booster - BullSequana XH3000, GH Superchip 72C 3GHz, NVIDIA GH200 Superchip, Quad-Rail NVIDIA InfiniBand NDR200, RedHat Enterprise Linux, Bull EuroHPC/FZJ Germany	4,801,344	1,000.00	1,226.28	15,794
6	HPC7 - HPE Cray EX255a, AMD 4th Gen EPYC 24C 1.8GHz, AMD Instinct MI300A, Slingshot-11, RHEL 9, HPE Eni S.p.A. Italy	3,461,472	571.50	861.13	8,735
7	Eagle - Microsoft NDv5, Xeon Platinum 8480C 48C 2GHz, NVIDIA H100, NVIDIA Infiniband NDR, Microsoft Azure Microsoft Azure United States	2,073,600	561.20	846.84	

Center for Nanophase Materials Sciences

A user facility for nanoscale and quantum materials



- **Broad spectrum of imaging capabilities**

- scanning transmission electron microscopy (now down to 4.5 K) emphasizing electron energy loss spectroscopy
- scanning probe microscopy; He-ion microscopy
- atom probe tomography
- mass spectrometry-based chemical imaging

- The Center for Nanophase Materials Sciences (CNMS) at ORNL offers the user community access to state-of-the-art equipment for a broad range of nanoscience research, including nanomaterials synthesis, nanofabrication, imaging/microscopy/characterization, and theory/modeling/simulation.
- Access is obtained through a peer-reviewed proposal with no charge for users who intend to publish their results in the open literature.
- CNMS also acts as gateway for the nanoscience community to benefit from ORNL's neutron sources ([SNS and HFIR](#)) and computational resources.

Center for Structural Molecular Biology

Deuteration access through SNS/HFIR User Program



- **Biological H/D labeling** of cells, proteins, nucleic acids, lipids, uniform, selective labeling
- **Biomolecule purification** and characterization
- **Chemical deuteration** in collaboration with the CNMS
- **Supporting capabilities:** protein crystallography, SAXS

- The Center for Structural Molecular Biology (CSMB) at ORNL is an open access user program dedicated to advancing instrumentation and methods for determining the three-dimensional structures of biomacromolecules and their assemblies as well as hierarchical structures and biomimetic systems.
- The centerpiece of the CSMB is a SANS instrument at HFIR dedicated to studying biological samples (Bio-SANS).
- CSMB also operates a Bio-Deuteration Laboratory for cloning, protein expression, purification, and characterization of H/D-labeled biological macromolecules. When deuterium labeling is combined with SANS experimentation, data analysis and visualization, models of complex systems can be constructed that are not obtainable using other techniques.

ORNL operates two advanced neutron scattering user facilities

High Flux Isotope Reactor - 1965



- 85 MW steady state neutron source.
- Peak thermal flux of 2.5×10^{15} neutrons/cm²/s
- Neutron scattering, isotopes, materials irradiation
- Isotopes: Cf-252, Pu-238, Ac-227, Ni-63
- 12 instruments for neutron scattering & imaging

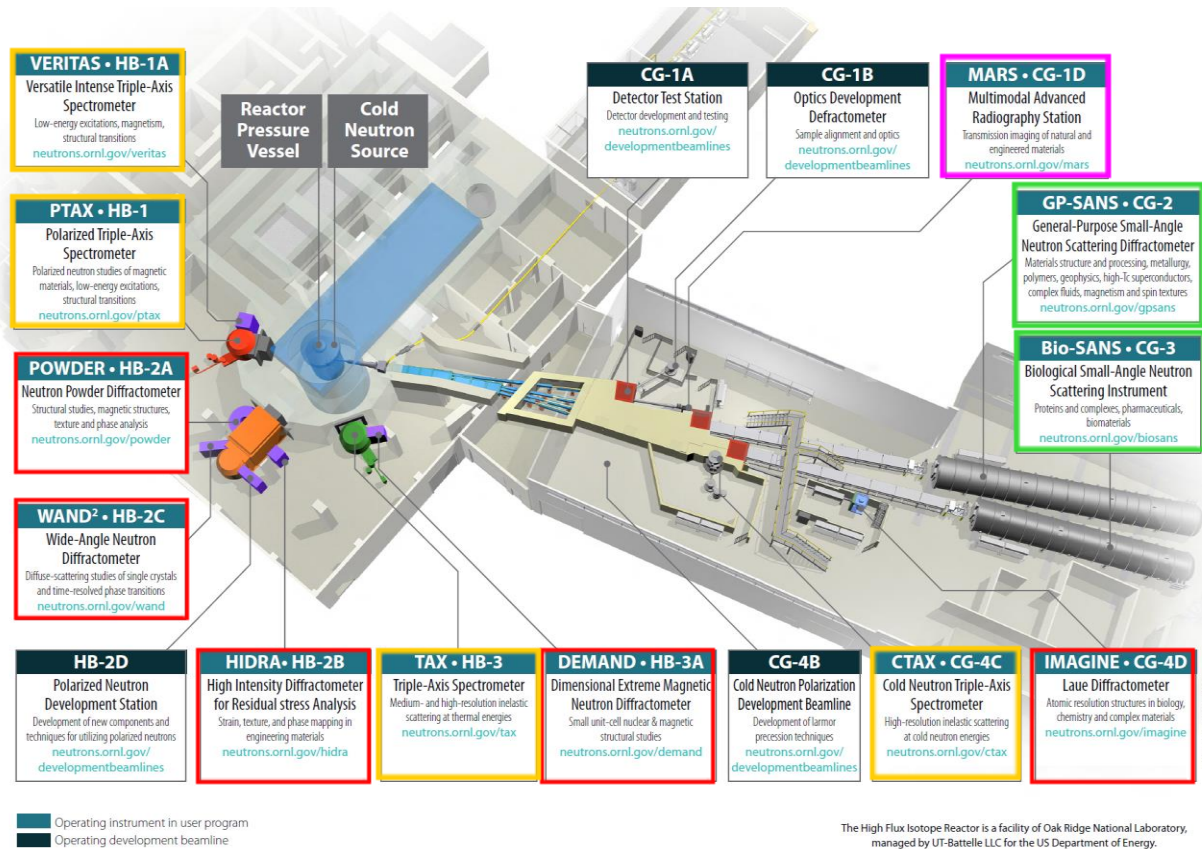
Spallation Neutron Source - 2006



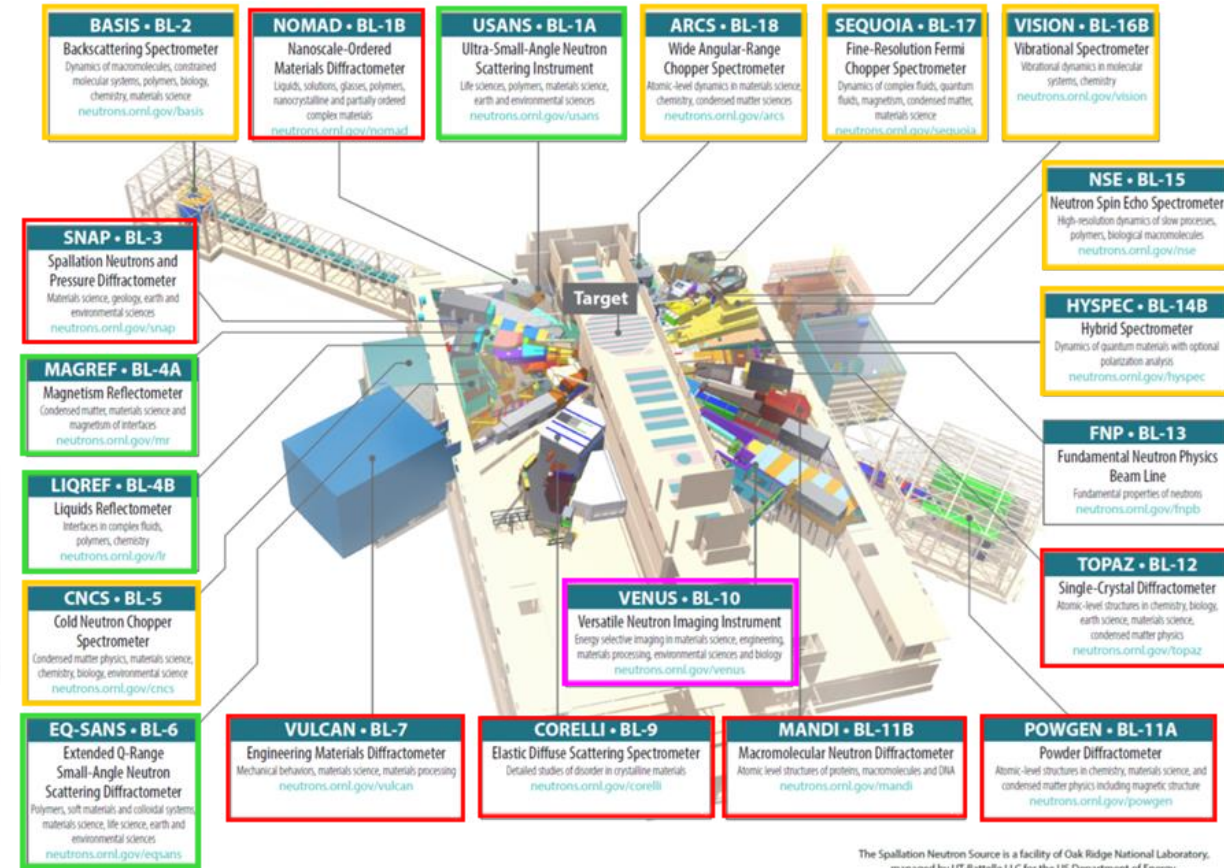
- 2 MW operating power
- Worlds highest power proton accelerator
 - 1.3 GeV protons: 30 kJ/proton pulse
- 60 Hz pulsed neutron source (695 ns pulse width)
- 19 instruments for neutron scattering & imaging

Instruments at HFIR and SNS

HFIR (12 instruments)



SNS (19 instruments)



Diffraction (elastic scattering) (12 instruments)

Spectroscopy (inelastic scattering) (11 instruments)

SANS & Reflectometry (elastic scattering) (6 instruments)

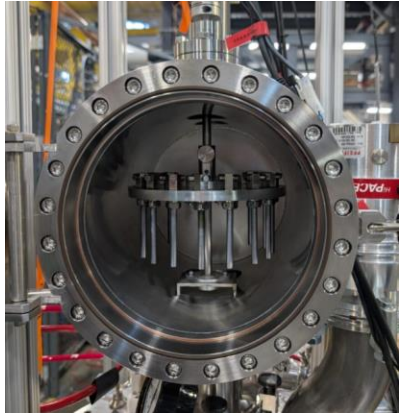
Neutron Imaging (2 instruments)

Sample Environment and Complementary Facilities



- Experiments are increasingly complex – few ‘routine’ measurements. This requires increasingly complex sample environments.
- Complementary laboratory facilities are needed for sample preparation (including deuteration) and characterization

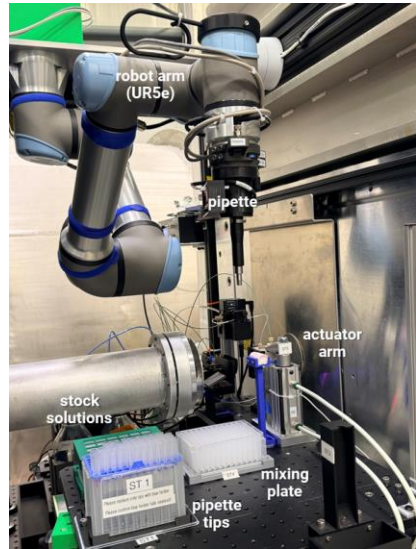
Increased integration of automation and robotics



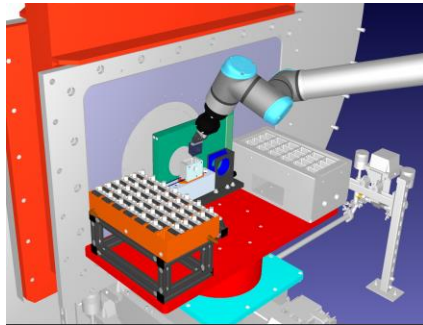
High Temp. 13 sample changer



POWDER: Dry dilution fridge +
14 sample changer
(base temp ~ 10 mK)



Bio-SANS automated
liquid handling



GP-SANS Robotic Sample Changer



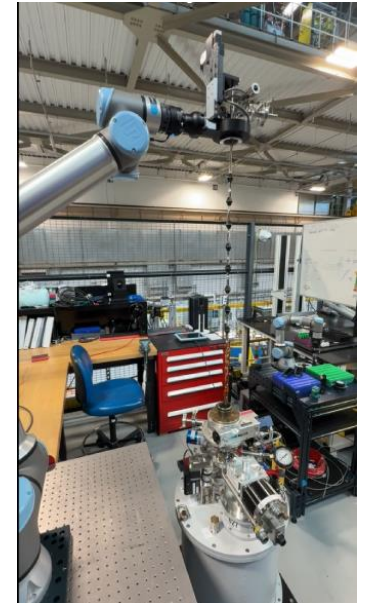
100 mm top loader / 23
sample changer for BASIS



MARS 7-axis sample changing robot



Robotic banjo cell
cleaning robots

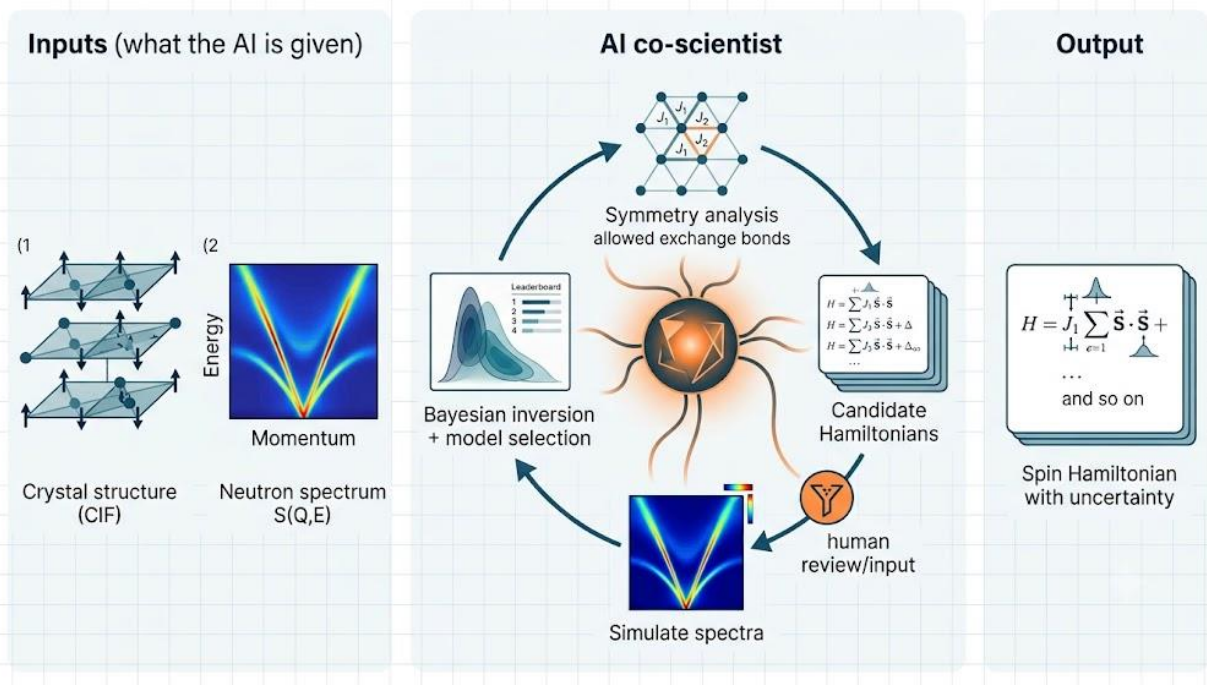


MAGREF Stick changing robot

Genesis Mission:

National initiative to build the world's most powerful scientific platform to accelerate discovery science, strengthen national security, and drive energy innovation

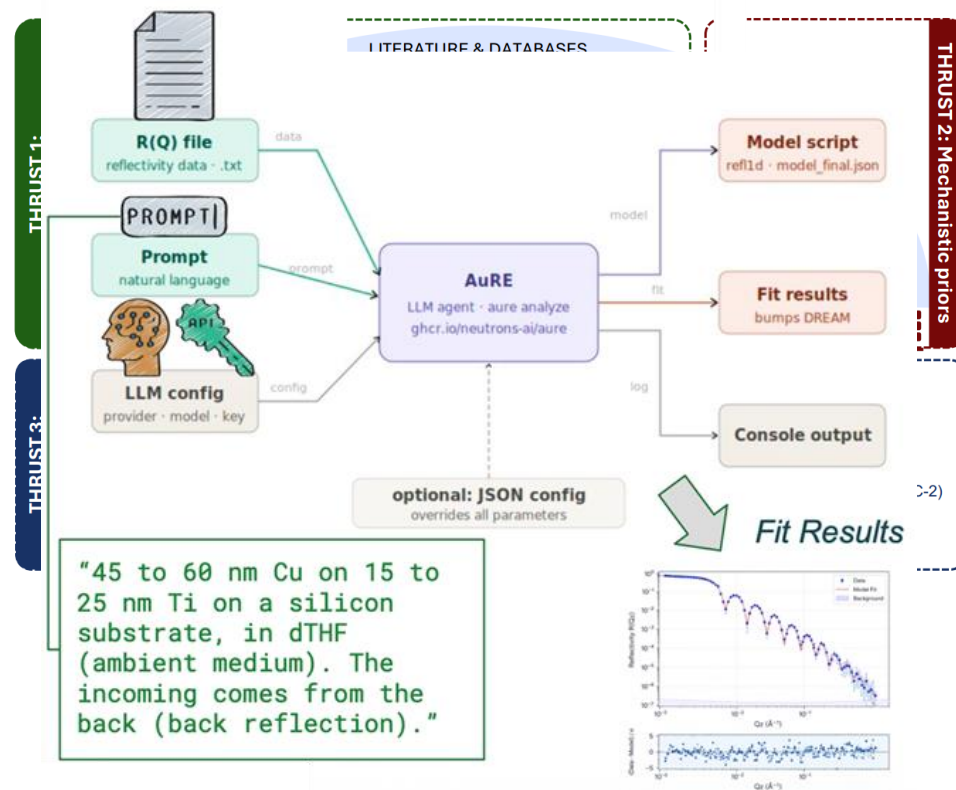
MAIQMag: Multimodal AI for 2D Quantum Magnets



ORNL (NSD) led

Principal investigators: Mark Lumsden & Daniel Pajerowski

ISAAC: Integrated Scientific Agentic AI for Catalysis



SLAC led

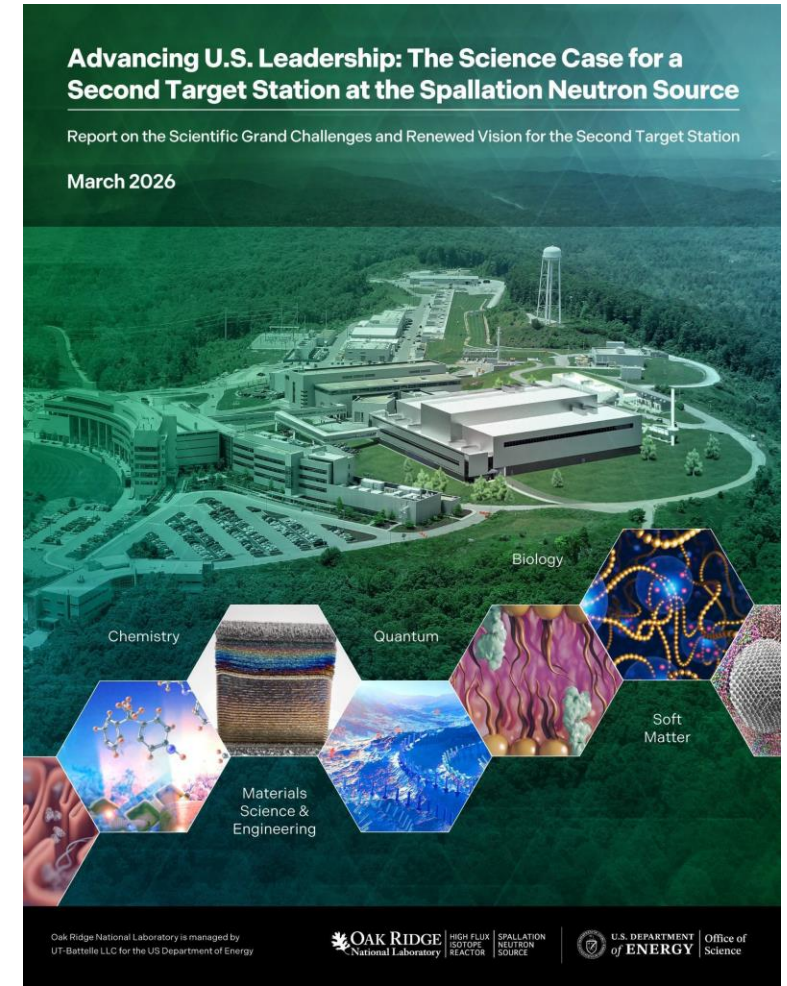
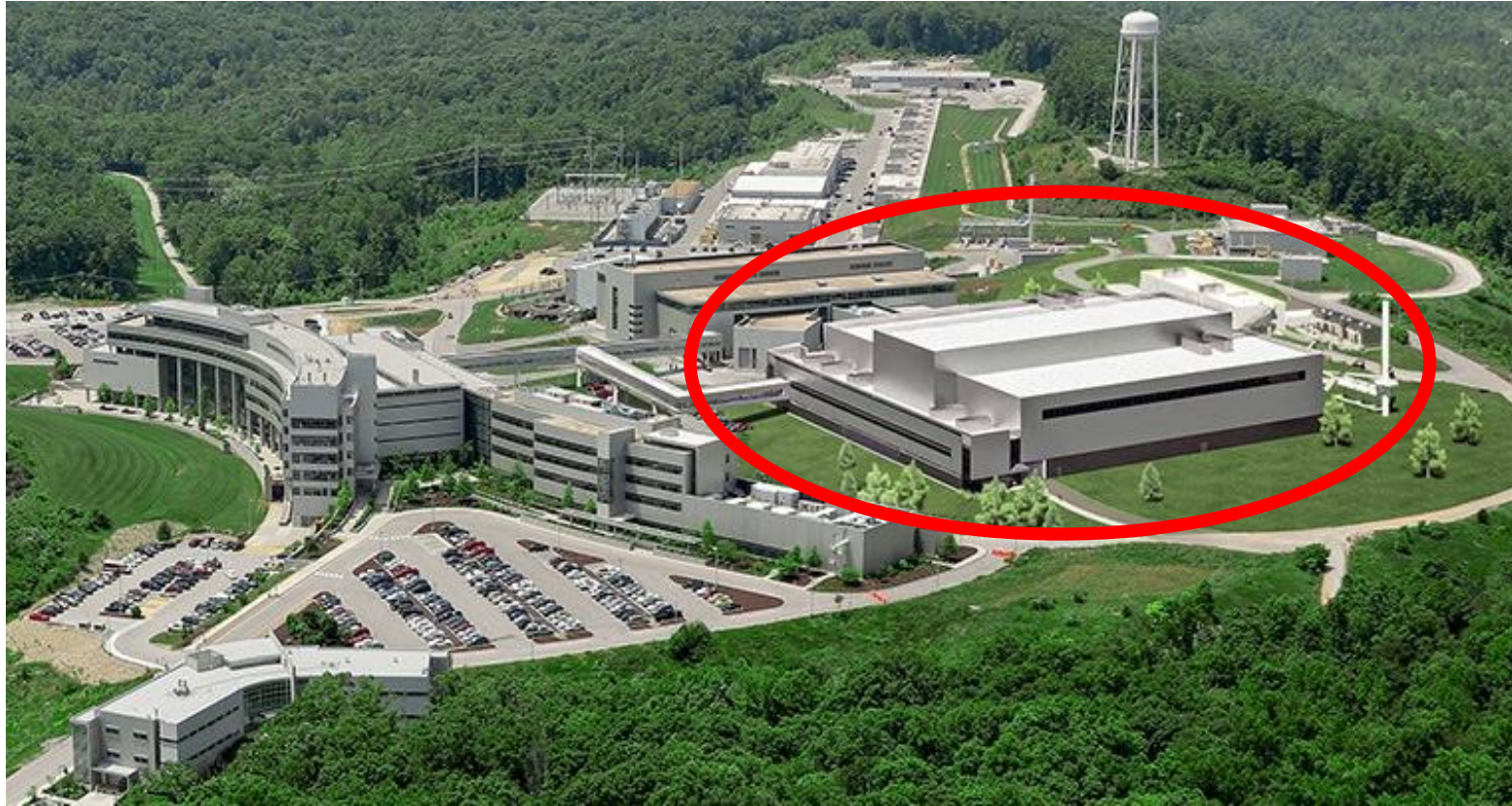
Principal investigators: Dimosthenis Sokaras
ORNL co-I: Mathieu Doucet

Becoming a neutron scattering user at SNS or HFIR

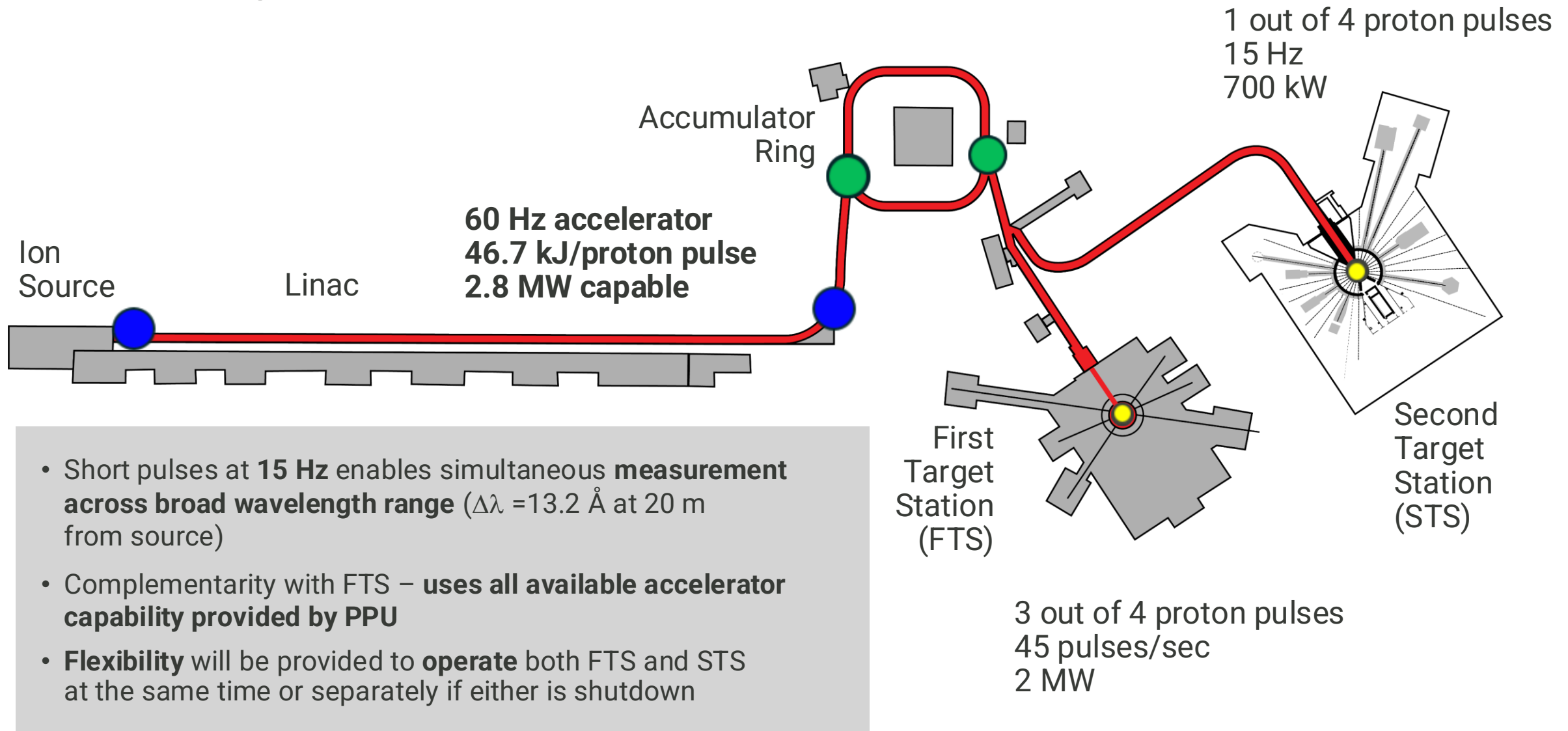
- Prospective users should submit a proposal to one of our biannual proposal calls
- 2027-A GU proposal call for HFIR submissions only is open now and will close on Sept. 23, 2026.
- 1500+ General User proposals requesting beam time are received annually
- ***New users should contact an instrument scientist for feedback on their experimental plan before submitting***
- More information and tips on submitting a proposal can be found at <https://neutrons.ornl.gov/users>



Future of neutron scattering: Addition of the SNS Second Target Station (STS) will provide next generation capabilities



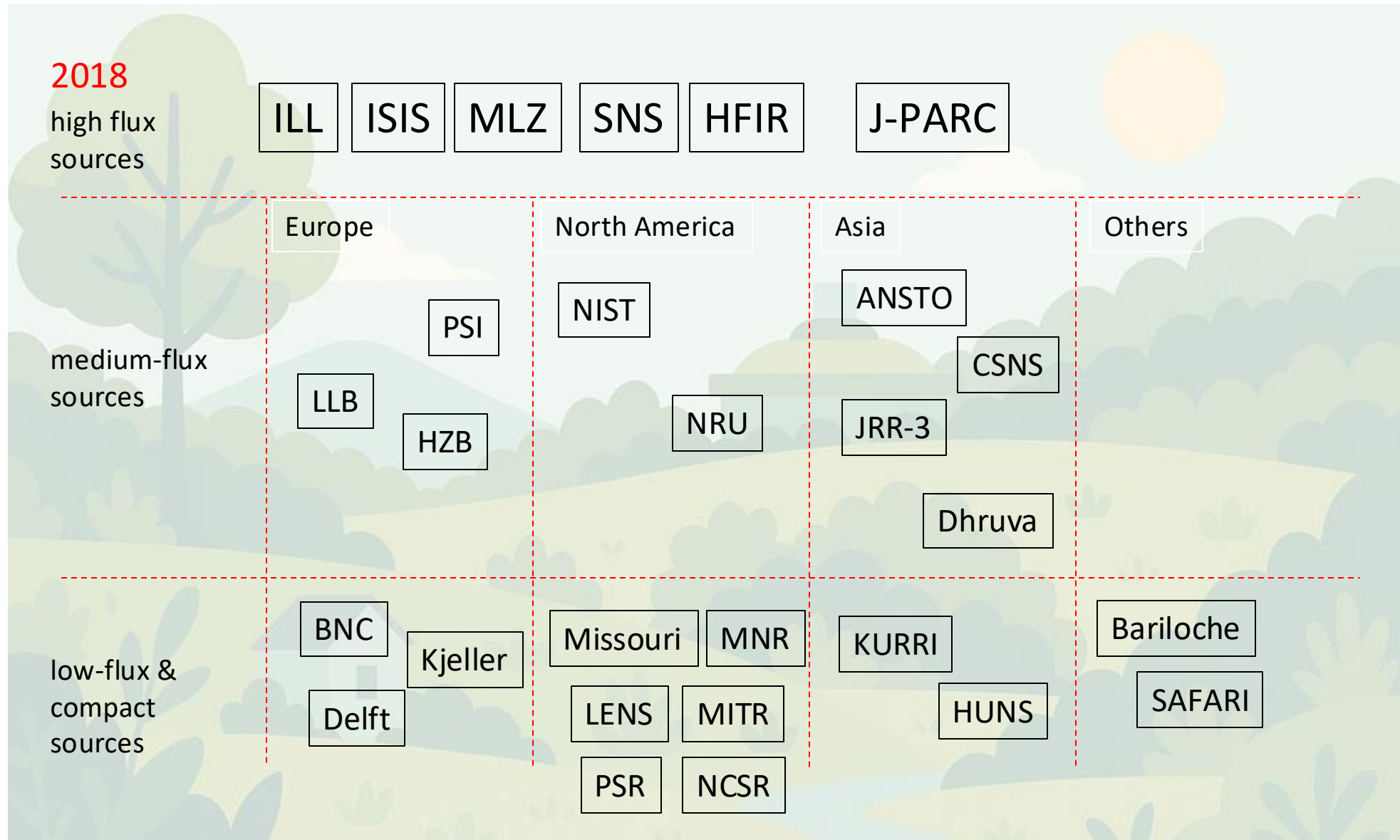
One out of 4 pulses from the 60 Hz accelerator will be used to feed the Second Target Station



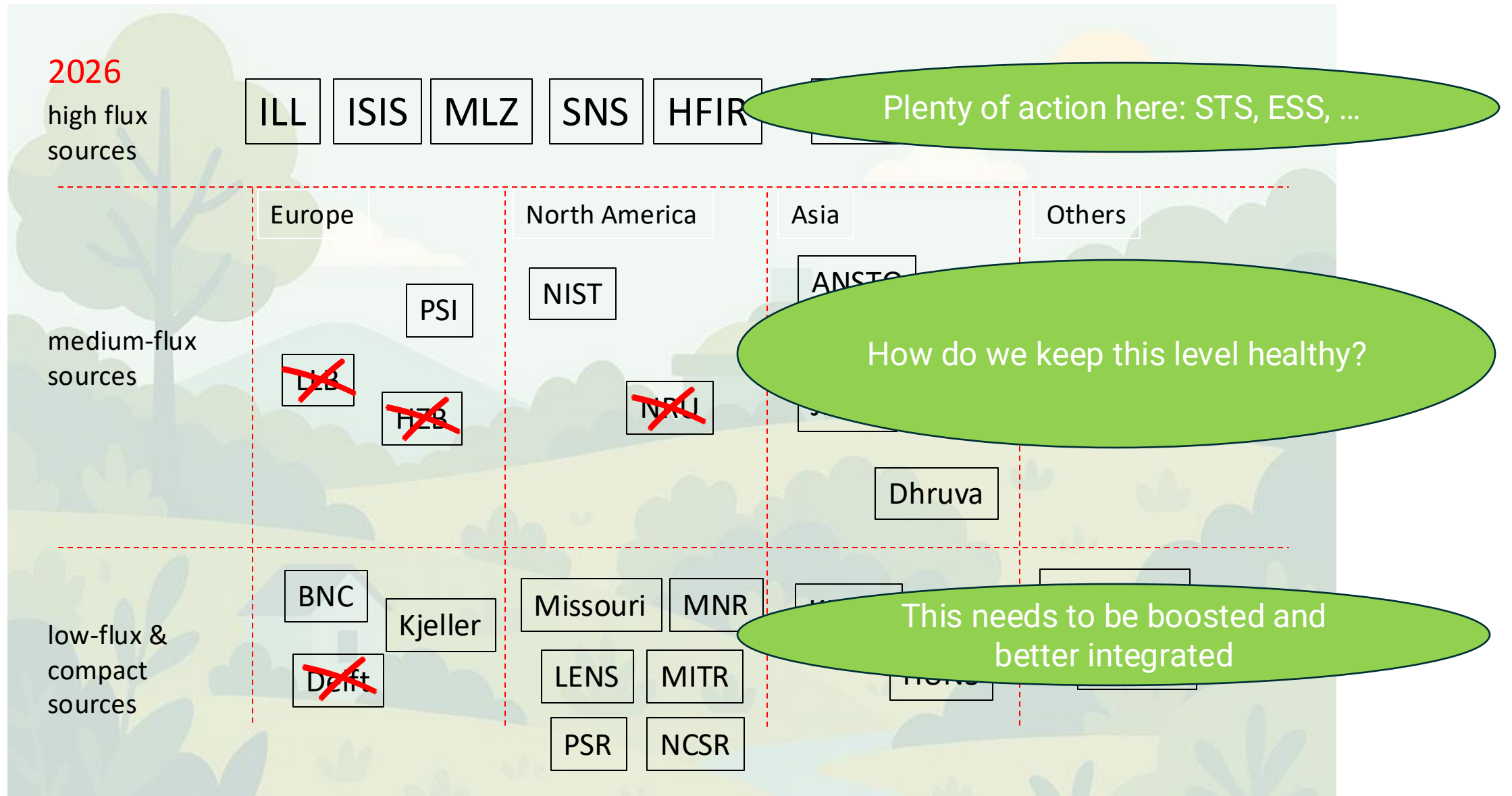
Neutron User Facilities Worldwide



Neutron Facility Ecosystem



Neutron Facility Ecosystem



Developing a national neutron roadmap is essential and urgent.

- Build and grow the neutron community
- Develop new capabilities and capacity
- Ensuring the community is ready to use new facilities like STS

High Flux Isotope Reactor (HFIR)



Operates at 85 MW and provides highest steady-state neutron fluxes

**12 instruments
in user program**

Spallation Neutron Source (SNS)



Most powerful pulsed neutron source in the world

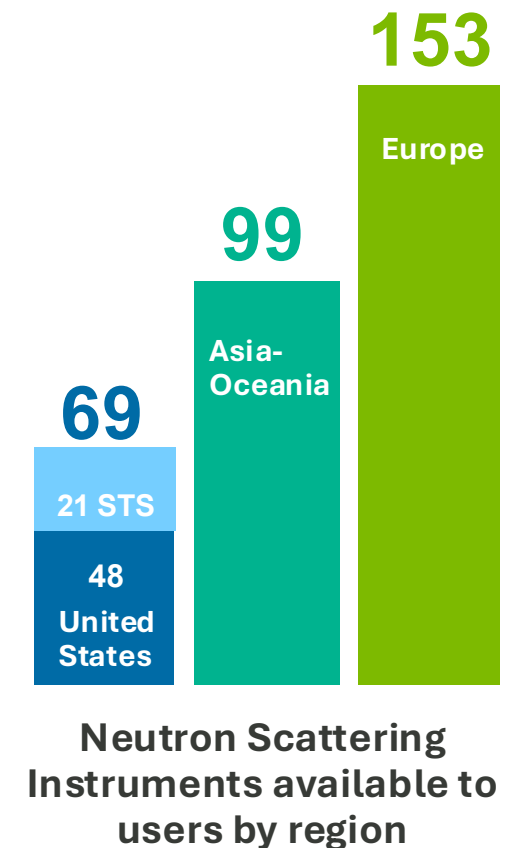
**19 instruments
in user program**

NIST Center for Neutron Research (NCNR)



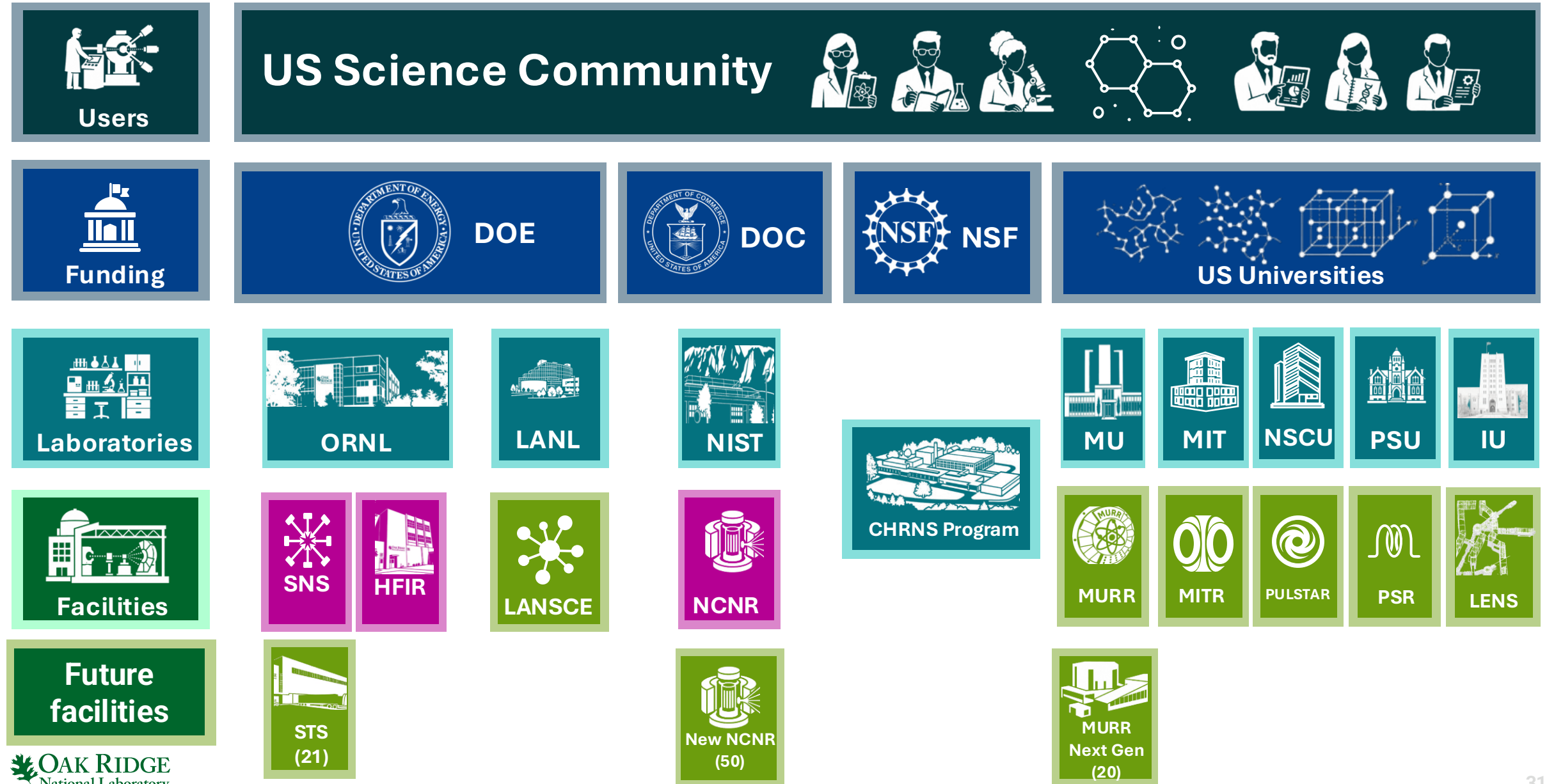
20 MW reactor

**17 instruments
in user program**



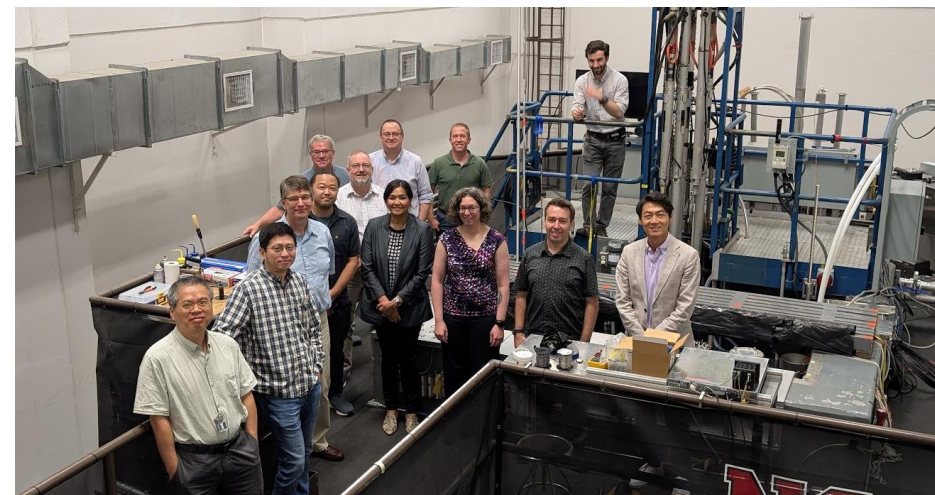
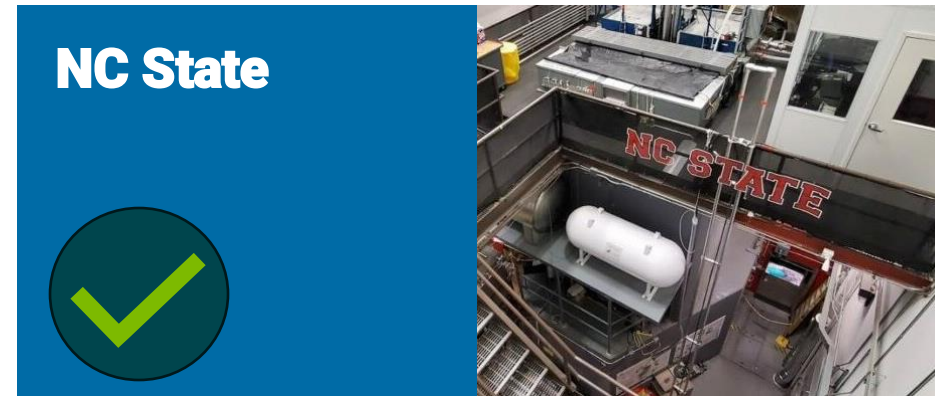
Distribution of neutron sources in the US

(Magenta designates facilities with open user program) (University reactors >1 MW)



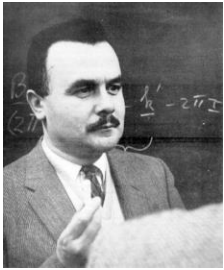
Ongoing discussions with US Universities with neutron scattering capabilities

Find a route to sustainable growth of capabilities and work force through strategic utilization of regional sources



Students – essential in growing the user community and training next generation neutron scientists.

- Brockhouse and Shull recognized this!



Bert Brockhouse

Chalk River
Laboratories



McMaster University
(1962)

McMaster Nuclear
Reactor
(5 MW - 1959)



Oak Ridge National
Laboratory



MIT (1955)



Cliff Shull



MIT Nuclear Research
Reactor
(5 MW 1958-1974
6 MW 1974 – present)

Legacy of training students

Students of Bertram Brockhouse

Bill Kamitakahara
Developed the NCNR
user program

Eric Svensson
Chalk River – pioneering
work on liquid He



Sow-Hsin
Chen
Professor
MIT

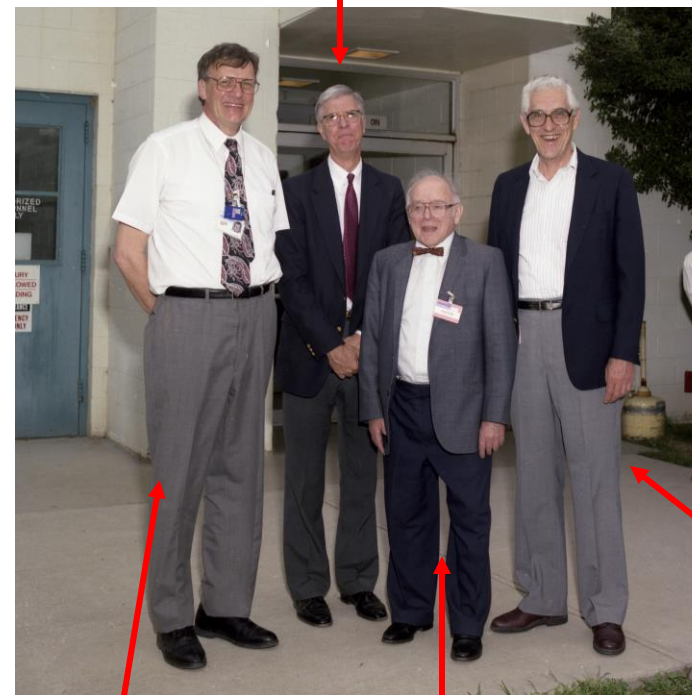
Michael Rowe
Director of NIST
Center for Neutron
Research

Brockhouse

John Copley
Built DCS spectrometer
at NCNR

Students of Clifford Shull

Herb Mook
Pioneering work on superconductors and
metals. Former director of neutron
scattering at HFIR



Stephen Spooner
HFIR – materials science
and residual stress

Shull



David Moncton
Former director of
APS and the SNS
project

Ralph Moon
Development of neutron
polarization analysis.
Former director of
neutron scattering at HFIR

Graduate Student Opportunities

Program details: <https://education.ornl.gov/gro/>

ORNL offers graduate students the opportunity to pursue collaborative research projects with scientists at HFIR and SNS.

The program is open to graduate students from US-based universities admitted to PhD candidate programs. Students are required to apply jointly with their PhD supervisor and an ORNL Neutron Sciences staff member who also will serve as the student's scientific mentor.

Positions are awarded to work for periods between 3 and 12 months. The students' salary and benefits are paid by their university while ORNL covers the costs for allowable travel and local living expenses.



Bottom Line

- Neutron scattering invented the User Facility
 - A large and diverse user community can access facilities which are scientifically essential, but unaffordable to university groups or industry
- It continues to evolve
 - Couple beamtime access with ancillary capabilities: deuteration, sample environment.
 - Increased focus on robotics, automation, and autonomous experimentation,
 - Complex data requires advanced data analysis and modeling methods. AI integration can be transformative.
- Neutron science relies on healthy ecosystem of neutron facilities
 - We are working towards a national neutron roadmap
- Students are critical to the growth of the neutron user community

Questions?

