OAK RIDGE National Laboratory

Neutrons at ORNL and ESS: A Synergistic Program

Marcel Demarteau
Division Director
Physics Division

August 5, 2020

Workshop on
Theoretical Innovations for Future Experiments
Regarding Baryon Number Violation by Two Units

ORNL is managed by UT-Battelle, LLC for the US Department of Energy

U.S. DEPARTMENT OF ENERGY

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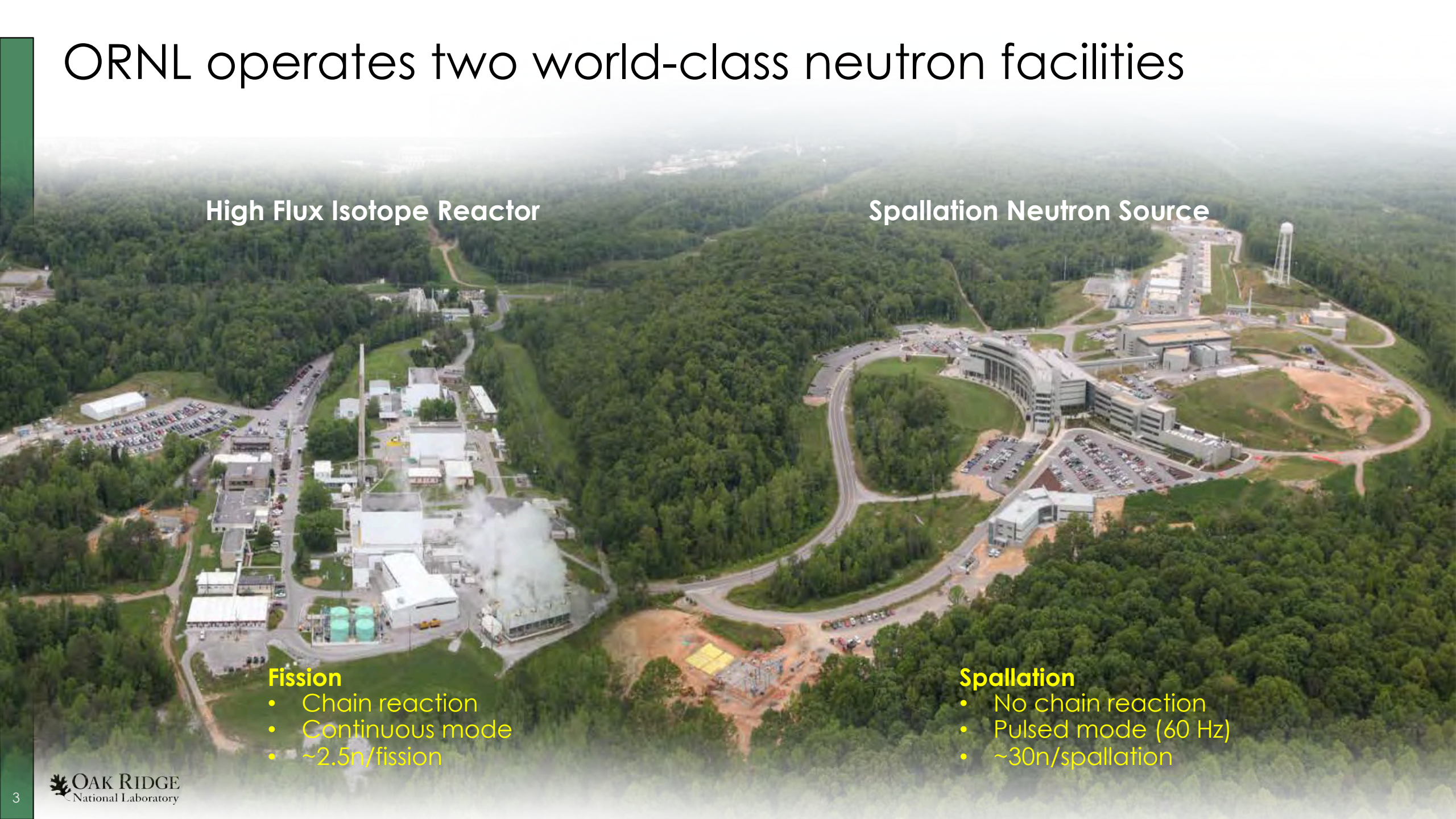
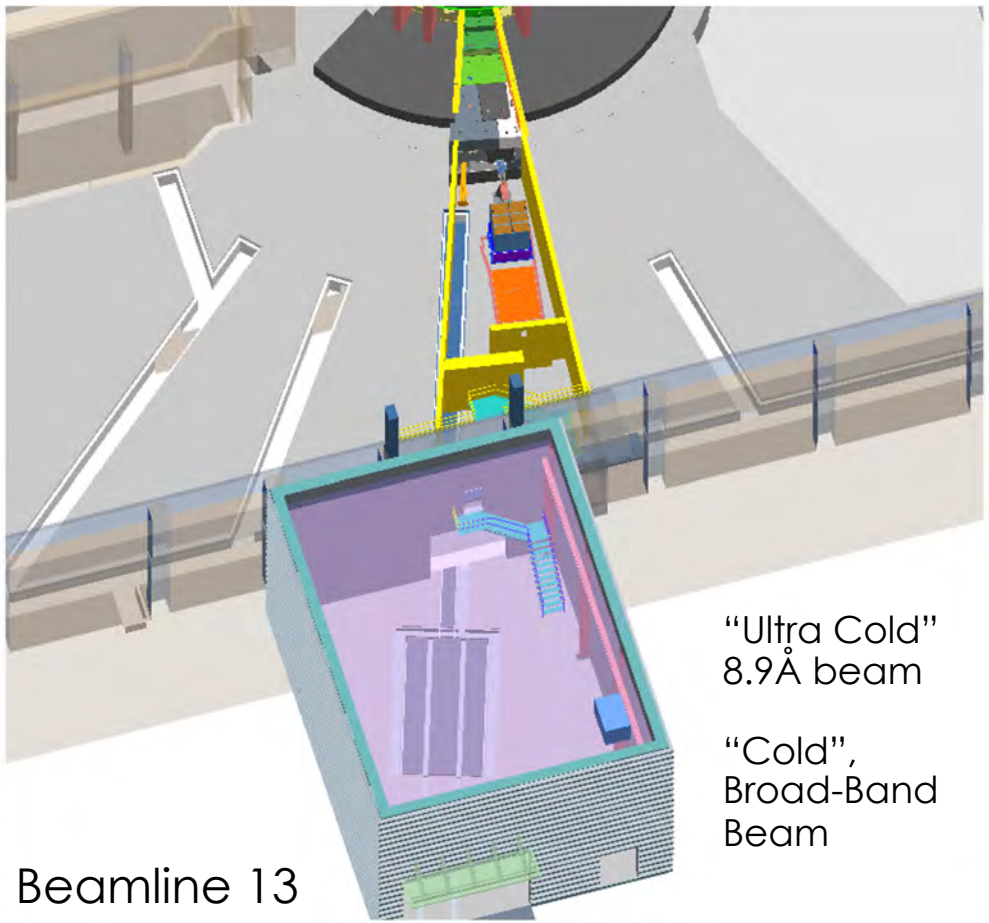
Outline

- ORNL User Facilities
- Physics Program
- Upgrades
- Snowmass Process
- Summary

ORNL operates two world-class neutron facilities



Fundamental Neutron Physics at the SNS

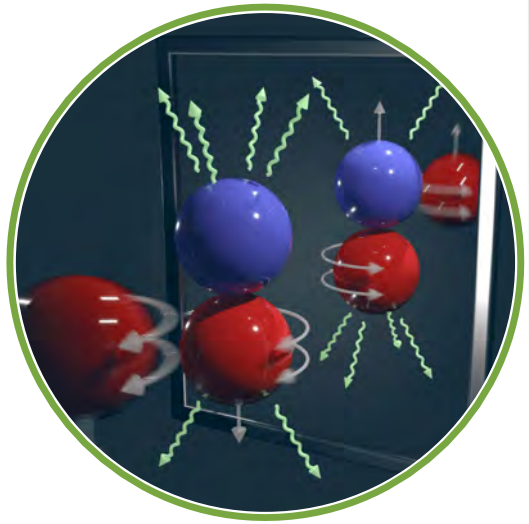


Fundamental Neutron Physics at the SNS

NPDGamma

$$\vec{n} + p \rightarrow d + \gamma$$

- First measurement of a weak-interaction term in the nucleon-nucleon potential.
- parity-odd asymmetry in the photon flux emitted from neutron capture



Nab

- Precision measurement of neutron beta-decay: the electron-neutrino correlation parameter, the Fierz interference term

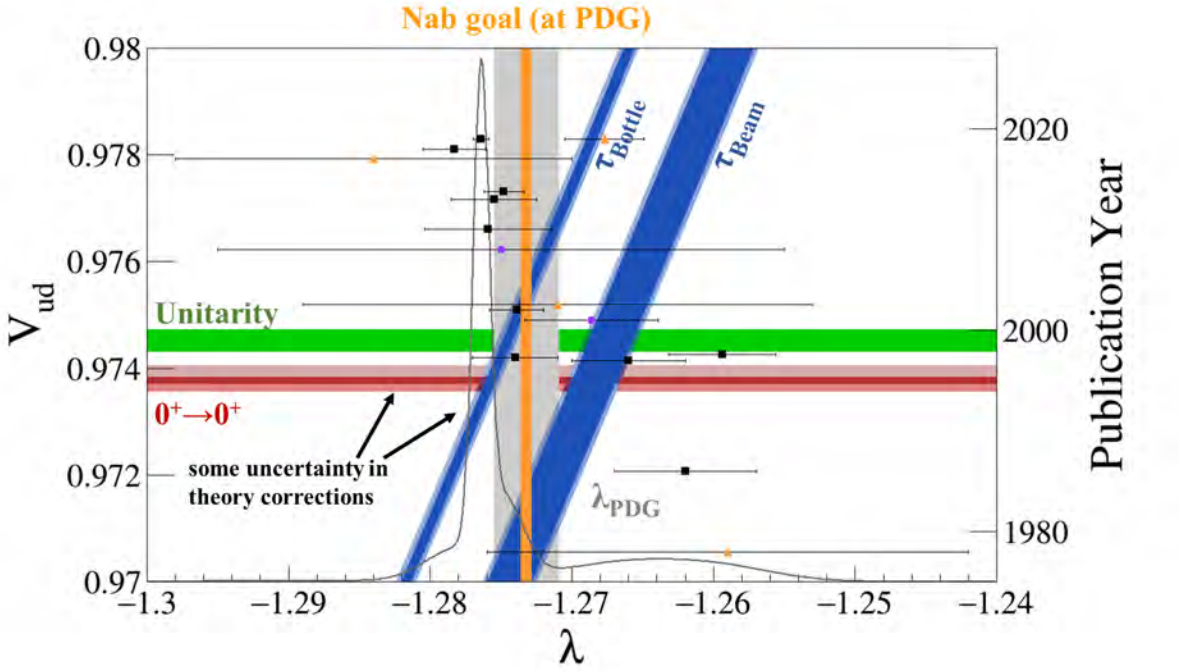
- Test of unitarity of CKM matrix; inform extensions of Standard Model

nEDM

- Most sensitive probe of the neutron Electric Dipole Moment
- Source of CP-violation
- Clean signature of new physics if $d_n > 10^{-32}$ e.cm

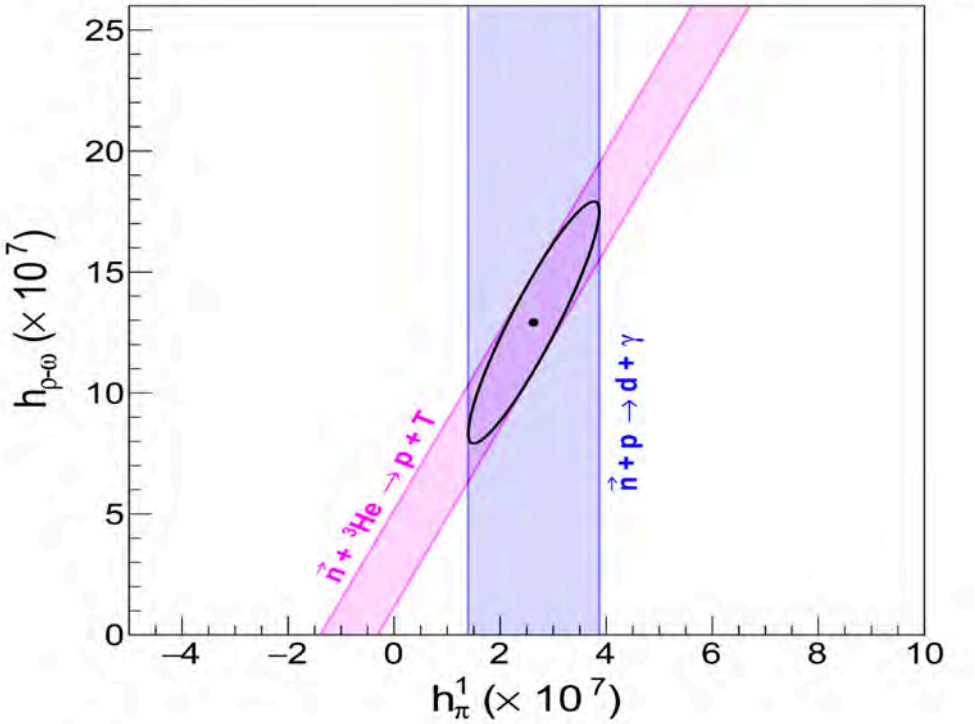
Fundamental Neutron Physics at the SNS

Nab



Goal: $\frac{\Delta a}{a} \approx 10^{-3}, \Delta b \approx 3 \cdot 10^{-3};\ \sigma(\lambda) = 3 \cdot 10^{-4}$

$\vec{n} + {}^3\mathrm{He} \rightarrow p + t$

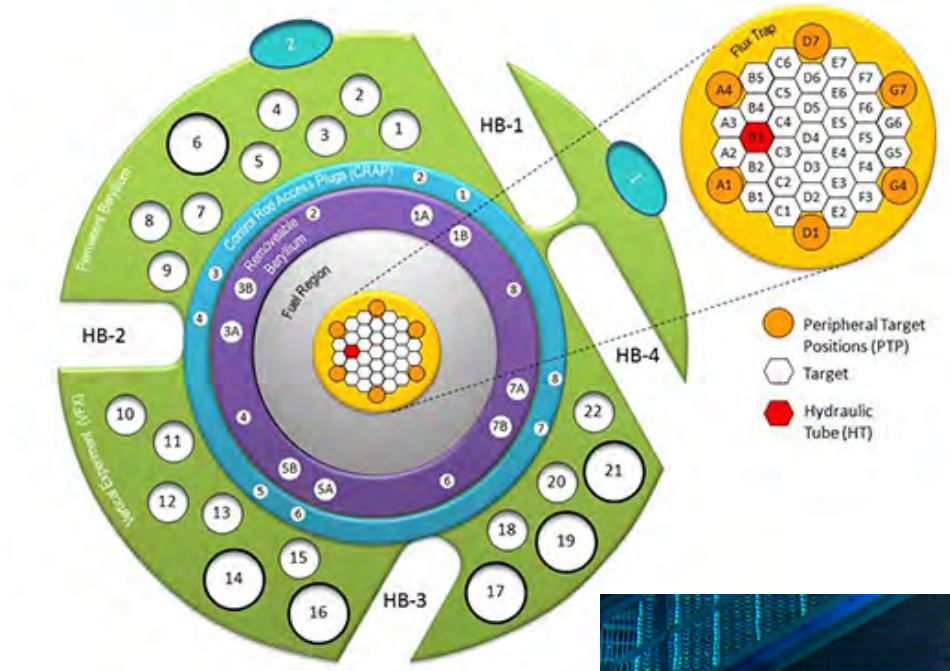


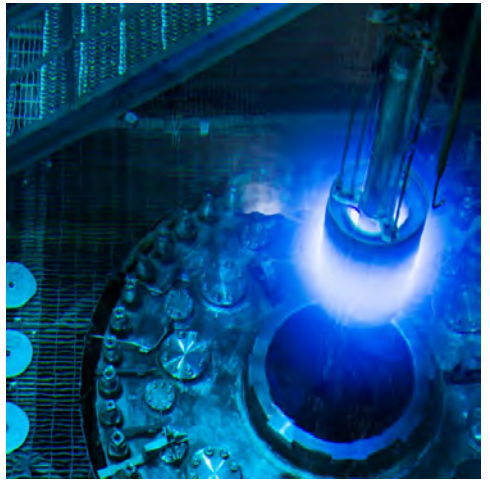
$A_{PV} = (1.58 \pm 0.97\ (stat.) \pm 0.24\ (syst.))\ 10^{-8}$

Most accurate parity violating asymmetry of the hadronic weak interaction
https://arxiv.org/pdf/2004.11535.pdf

HFIR: Driver For Multiple ORNL Science Missions

- High Flux Isotope Reactor (HFIR) is highest thermal flux in Western world – only Russia has a similar reactor
  - 2.1×10^{15} n/cm^2 s thermal
  - 1×10^{14} n/cm^2 s epithermal (< 1 MeV)
  - 4.7×10^{14} n/cm^2 s fast (> 1 MeV)
- The high thermal neutron flux that HFIR provides is necessary to produce many high specific activity isotopes
  - 79 target positions for isotope production and materials irradiation (37 in the flux trap)
  - In the US, HFIR required to produce ^{252}Cf and ^{238}Pu
- HFIR has the capacity for additional irradiations

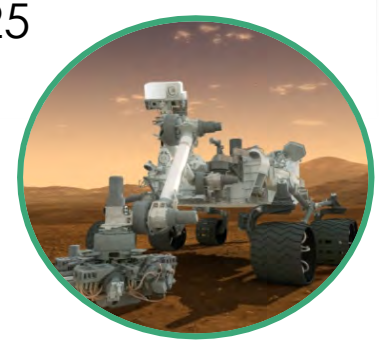




ORNL Radioisotope Key Thrusts at HFIR

Scientific Missions

- Sole US provider of ^{238}Pu
- Radioisotope power systems used in 26 space missions
- Leading major project to reestablish U.S. production capability
- Increase capacity from current 400 g/yr to 1500 g/yr of Pu-238 by 2025



Industry

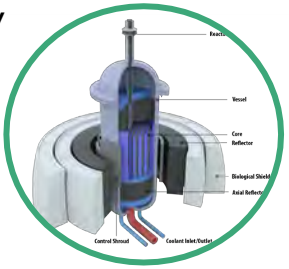
- Supplying majority of ^{252}Cf worldwide
- Oil and coal industry
- Nuclear reactor start-up sources
- Nuclear fuel rod examination
- Homeland security

Medical

- Producing and developing radioisotopes for theranostic and other uses:
  - ^{225}Ac, ^{227}Ac, ^{177}Lu, ^{89}Sr, $^{188}W/^{188}Re$, ^{223}Ra, ^{224}Ra, ^{212}Pb, ^{106}Ru, ^{195m}Pt
- Cancer treatment
- Only producer of new ^{227}Ac worldwide

Advanced R&D

- Research into new production methods of isotopes
- Leading the science behind accident-tolerant nuclear fuel technology
- Developing fuels for next-generation nuclear plants, Small Modular Reactors, and Nuclear Thermal Propulsion
- Super-heavy element discovery



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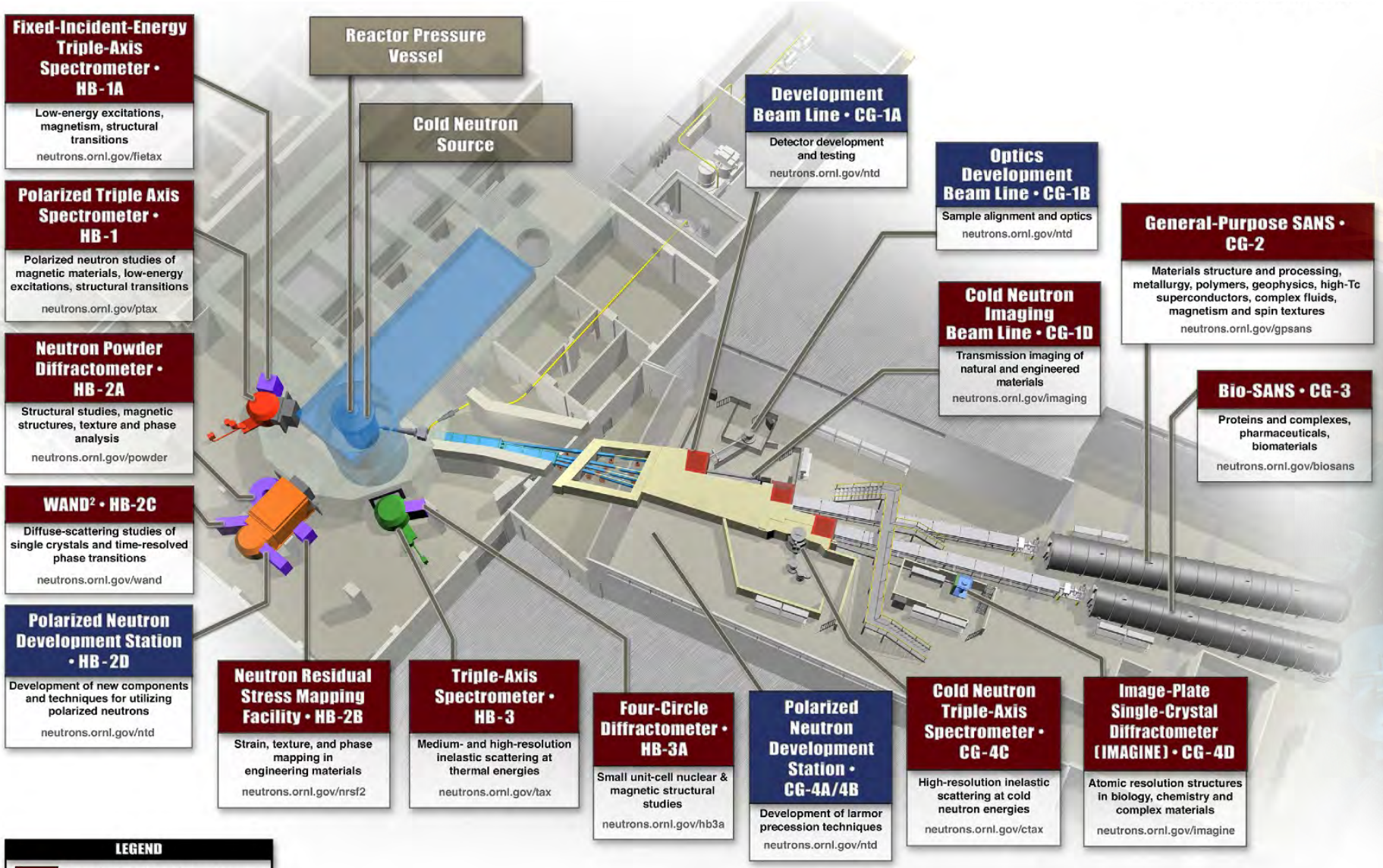
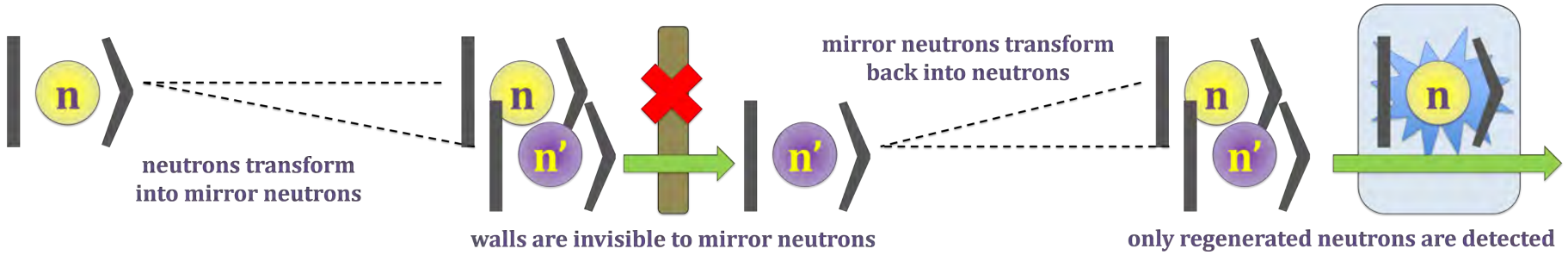
HFIR Neutron Scattering Instrument Layout



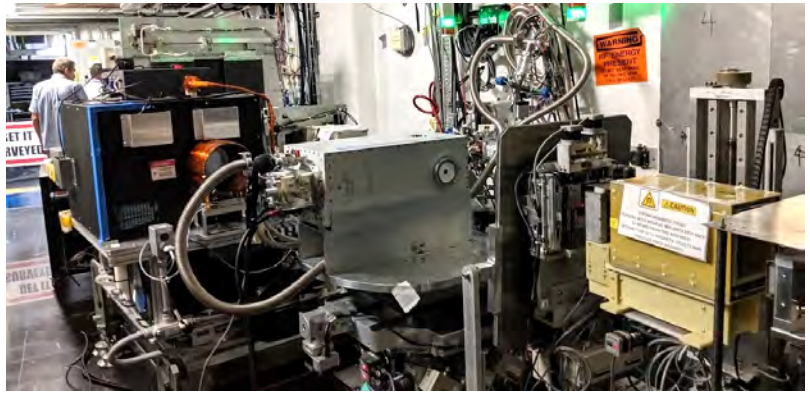
HFIR user program at 12 neutron scattering instruments.

Mirror neutron oscillations at HFIR: $n \rightarrow n' \rightarrow n$

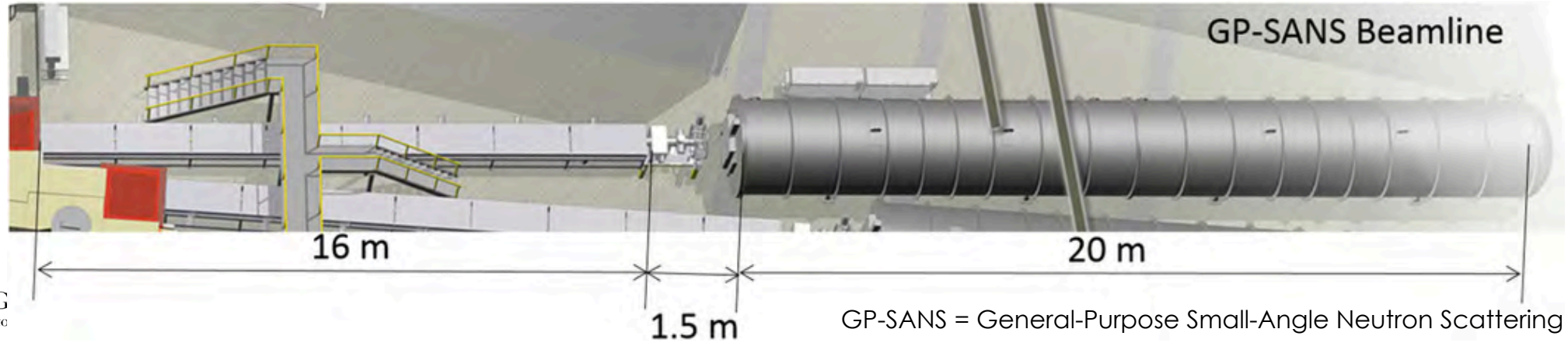


- Probe dark matter candidates; baryon # violation
- Searches for $n \rightarrow n' \rightarrow n$, $n \rightarrow n' \rightarrow \bar{n}$ possible
- Exploring options at HFIR (GP-SANS)
  - Implications for future $n \rightarrow \bar{n}$ development

First experimental search conducted at SNS



HFIR ➡

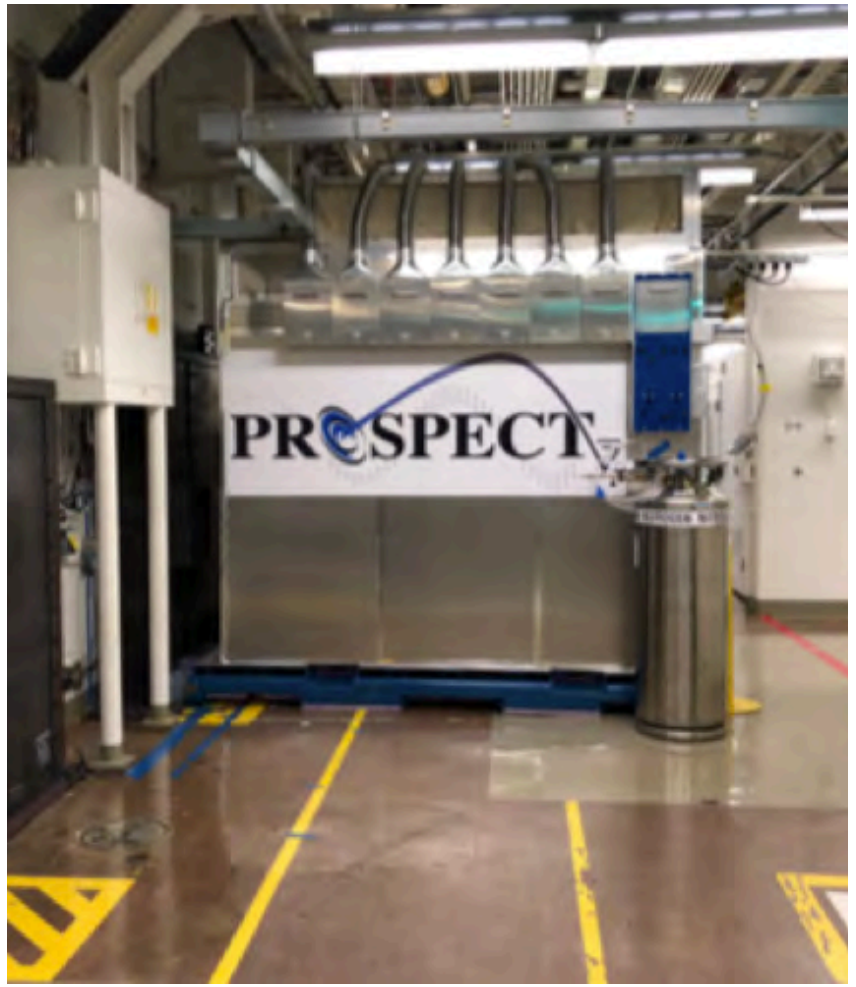


GP-SANS = General-Purpose Small-Angle Neutron Scattering Diffractometer

Neutrons and Neutrinos !

Akimov et al. Science
Vol 357 (6356), Sept. 2017

In addition a strong and growing neutrino program at both facilities



J. Ashenfelter et al., Phys. Rev. Lett.
122 (2019) 251801

Second Target Station and Upgraded HFIR

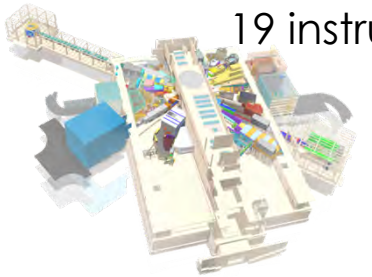
- Both facilities to be upgraded

SNS Upgrade Plans

Today

Future

24 instrument positions
19 instruments built



First Target Station

1.4 MW

Accelerator

Now

24 instrument positions
21 instruments built

First Target Station (FTS)

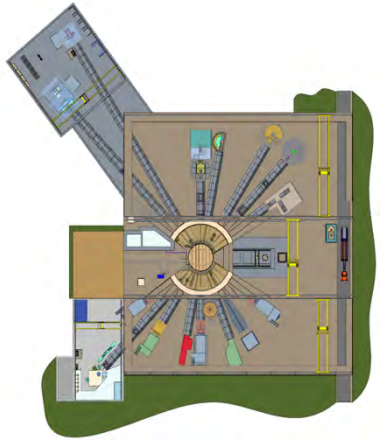
2 MW

Accelerator
2.8 MW capable

Proton Power Upgrade (PPU)

22 instrument slots,
8 initial instruments

Second Target Station (STS)



STS Upgrade

Passed CD-2/3 review July 14-17,2020

CD-1 review June 2020

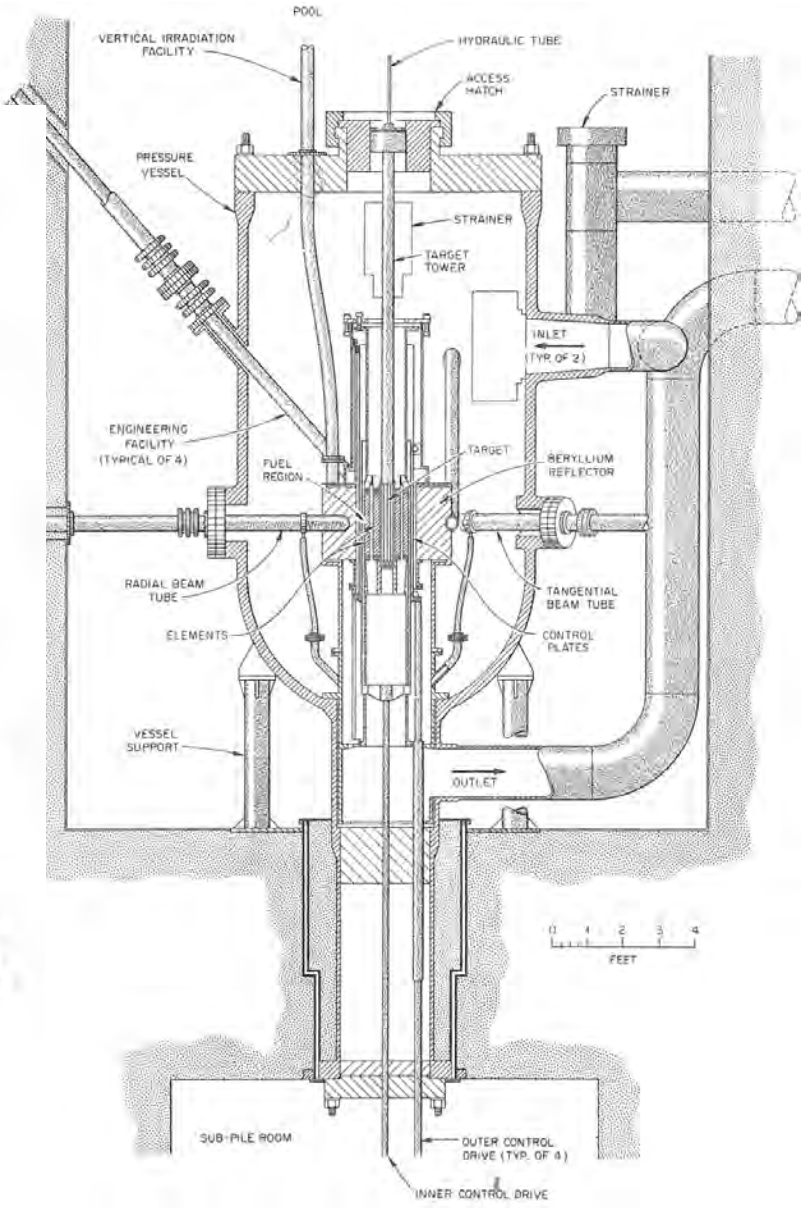
HFIR Upgrade Plans

- Charge from the Office of Science to the neutron subcommittee of the Basic Energy Science Advisory Committee (BESAC), (March 3, 2019):
  - **Assess the scientific justification for a domestic high-performance reactor-based research facility**
- Presentation and recommendation on July 30, 2020 *
- Three options considered
  - **Option 2:** Replace the pressure vessel of HFIR. If possible, coordinate this replacement with the conversion of HFIR to LEU fuel so that a single shutdown would accomplish both objectives.
  - **Recommendation: Pursue this approach immediately with the goal that the fuel conversion and pressure vessel replacement be performed during the same shutdown. The significant risk of HFIR failure will be removed, and important capabilities will result.**

* https://science.osti.gov/bes/besac/Meetings/Meeting-Presentations/202007

HFIR Upgrade: Pressure Vessel Replacement to provide significant enhancements

- **New pressure vessel**:
  - Operating at 100 MW (instead of 85 MW)
  - Extending life of HFIR by 50 years
- **D_2O reflector:**
  - Significant performance gain
- **Second guide hall at HB-2**:
  - ~10 instruments at much lower background
- **Upgraded cold source:**
  - ~50% higher brightness for neutron at $\lambda > 2$ Å



ORNL Response

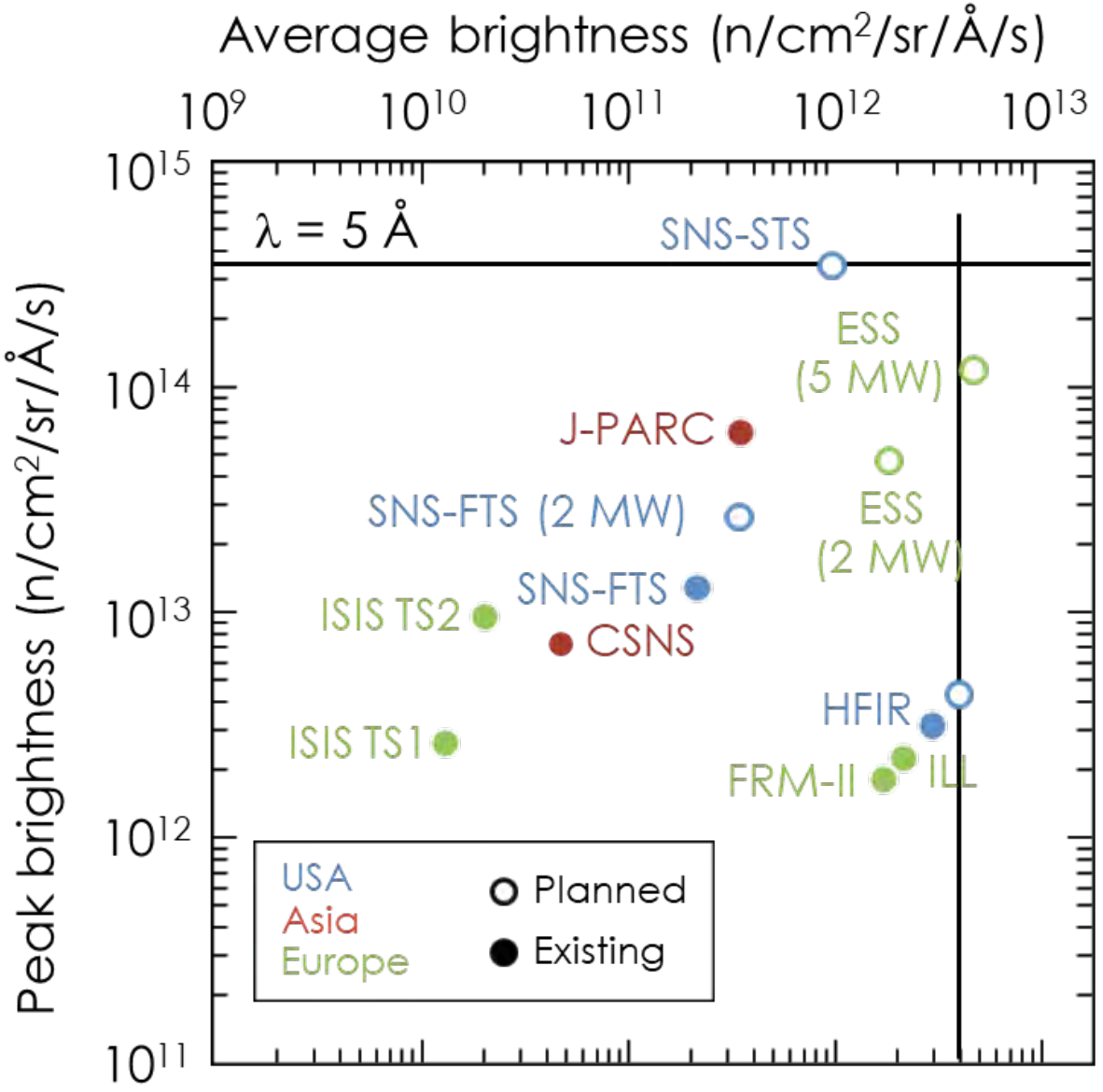
- ORNL has setup a working group to brainstorm ideas and concepts for upgrades or features of HFIR that will benefit a fundamental physics program.

- All options are being considered. Next calendar year ideas and concepts will be ranked in preparation of a presentation to BES with recommendations and a plan towards CD-0.

- Physics Division Points of Contacts:
  - Leah Broussard for neutrons (broussardlj@ornl.gov)
  - Jason Newby for neutrinos (newbyrj@ornl.gov)

Future Facilities

- ORNL facilities will be very complementary to the ESS and will enable development of new ideas and projects in support of future deployment at the ESS.



Physics Division Vision

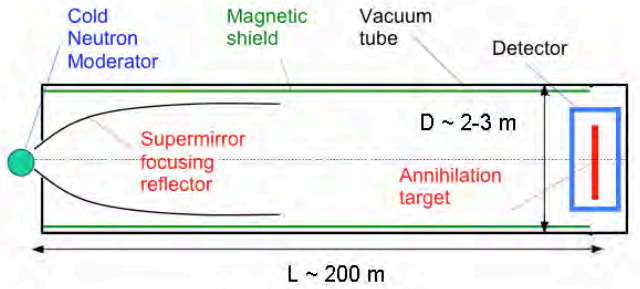
Neutrino Program

- Expand CEvNS program at the SNS using different targets; normalize flux with D_2O detector; 1 ton LAr detector
- Use Neutrino Alley as a test bed for new detector developments
- Fundamental measurements of neutrino properties
- Search for new interactions, dark matter
- Large-scale detector at STS

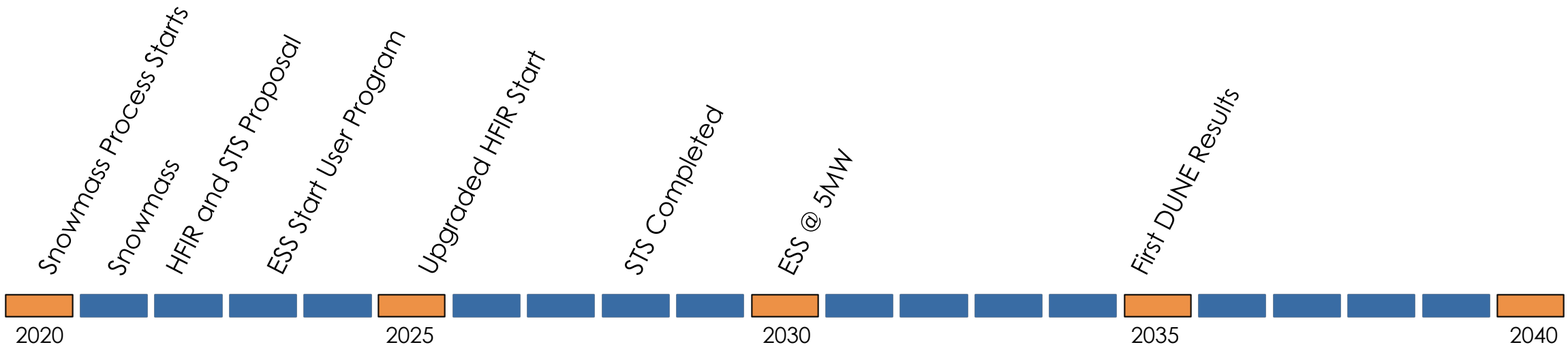
Facilities

Neutron Program

- Continue current high-impact program at FTS
- Execute current proposals at HFIR
- Develop program for upgraded HFIR and STS
- Create test bed for new detector developments
- Build a long-term fundamental neutron physics program (FnPB at HFIR)

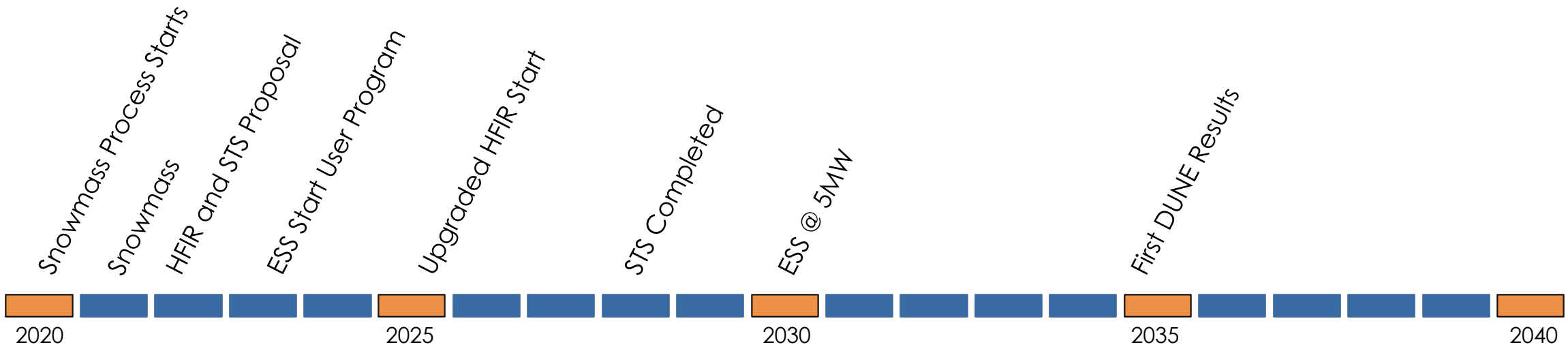


Fundamental n/ν Physics Program



- Baryon number violation could help explain the matter antimatter asymmetry.
- n-nbar oscillations a fundamental process that needs to be studied
- ORNL provides a unique, mutually beneficial, window of opportunity to develop a strong fundamental neutron physics program.
- ORNL program has complementary timeline with respect to the ESS program and the physics program is nicely complementary with the neutrino program (and they both use the same facilities).

Fundamental n/ν Physics Program



- **Particle Physics is global and the P5 process is an important step to advocate and propose a compelling, complementary fundamental physics program.**
- **The LOI is the first step; follow-up longer physics paper meshes will with the ORNL-HFIR timeline for a fundamental physics program.**

Summary

- Unique opportunity to jointly develop a compelling neutron fundamental physics program. Great synergies exist.
- ORNL invites the international community to participate in the formulation and execution of its program at the STS and HFIR.
  - A future workshop is being discussed
- The first step is to submit a compelling research program to the Snowmass process.
- We very much look forward towards a collaborative effort to establish an international project at the ESS for fundamental neutron physics.