A Three-Source Strategy for ORNL Neutron Sciences

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Revision: Draft version, July 26, 2020

Executive Summary

A vision is presented in which the three neutron sources at ORNL are designed to optimally play to their inherent key technical strengths:

- SNS First Target Station: high repetition rate, high resolution, focused bandwidth, thermal and epithermal neutrons
- SNS Second Target Station: high peak brightness of cold neutrons, large bandwidth, small beams
- HFIR: high time-integrated flux for both cold and thermal neutrons, polarized neutrons, focusing monochromators

All instruments should be placed at the source which maximizes their performance, thus maximizing the breadth and depth of scientific impact delivered by ORNL Neutron Sciences. The well-defined and complementary roles of the three facilities provide the diversity and flexibility needed to adapt the neutron scattering component of the national materials science toolkit to a rapidly changing world, while ensuring US leadership in neutron science for the decades to come.

A 3-source strategy is outlined, consisting of the steps required to reach this goal over a period of about 20 years:

1. Complete, upgrade and renew the instrument suite at the SNS First Target Station. Redesign and then replace the moderator-reflector plug to respond to expected changes at the Second Target Station and HFIR, replacing the coupled moderators with fully optimized high-brightness moderators and realigning the instrument suite to the key strengths of the FTS.
2. Build the SNS Second Target Station and its associated instrument suite, taking full advantage of the recent development of high-brightness parahydrogen moderators. In parallel, continue to design and construct more instruments, so as to fully populate all available beamports with world-leading instruments designed to take full advantage of the STS key strengths.
3. Strengthen and expand the HFIR instrument suite, incorporating major upgrades to the existing instruments, a rebuild of the cold source and a new thermal guide hall. The impact of the HFIR instrument suite has been held back by the design of the beam tubes. A redesign of the reflector vessel will allow the HFIR instrument suite to reach world-leading performance, while realigning its instrument suite to play to its key strengths.

A technically-limited timeline is presented for implementing this strategy, supported by critical R&D activities. Executing this strategy follows directly from the ongoing major facility upgrades; the Proton Power Upgrade, the SNS Second Target Station project, and the HFIR Beryllium Reflector Replacement project, as well as the study of a major HFIR upgrade, responding to a BESAC assessment (due July 31, 2020).

The 3-source vision and strategy take advantage of opportunities presented by the Second Target Station, as well as the experience of simultaneous operation of HFIR and SNS which has helped to identify key strengths, limitations, and opportunities of all three neutron sources within the global neutron landscape.

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1. Introduction and Background

The purpose of this document is to outline a vision and high-level strategy for ensuring maximal scientific impact from the ORNL neutron facilities, by fully exploiting their potential complementarity. It should be used as a guide when making decisions about the evolution of the HFIR and SNS facilities and their instrument suites, and should be reviewed regularly to ensure relevance and alignment. There are currently two neutron scattering facilities at ORNL:

The High-Flux Isotope Reactor (HFIR) is research reactor that has been operated since 1965. It currently runs at a thermal power of 85 MW, and houses 12 neutron scattering instruments in the user program; 7 on thermal beam tubes and 5 on cold guide positions. HFIR was primarily built for isotope production but had 4 horizontal beam tubes (HB1-HB4) incorporated into the design to extract thermal neutron beams. In 2004, a cold source was installed in HB4 together with a neutron guide system distributing neutrons into a new guide hall. At the same time, the HB2 beam tube was upgraded to increase the size of the beam tube and improve access and performance for the instruments on that beam tube.

Both the thermal beam tubes and the cold source provide a spectral neutron brightness which is world-leading, even higher than that of ILL, the currently world-leading neutron scattering facility in terms of scientific output. When ESS comes online and reaches its full design power of 5 MW it is expected to exceed the cold brightness of HFIR.

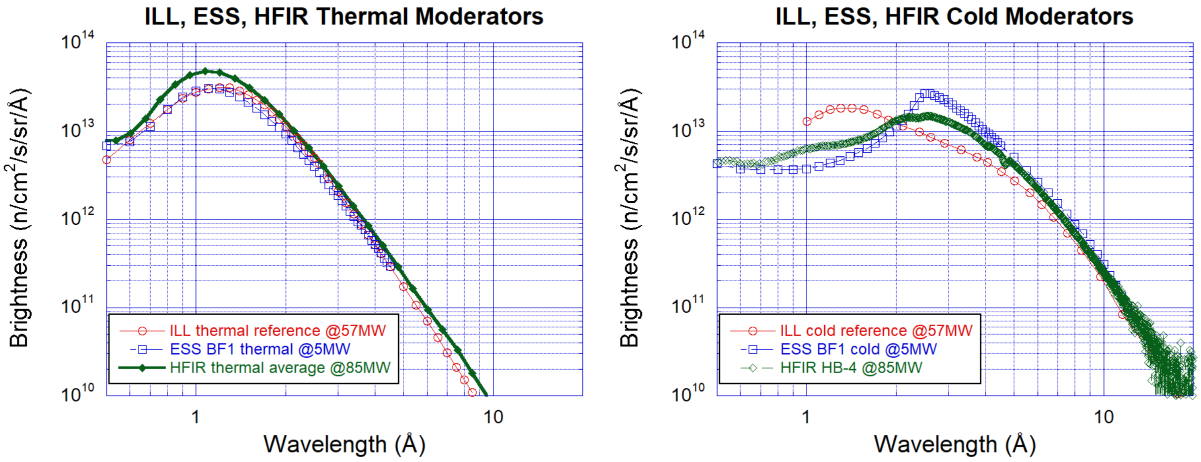

Figure 1. *Thermal and cold neutron spectral brightness at ILL, ESS and HFIR.*

The Spallation Neutron Source (SNS) came online in 2006. Its technical design was established in the 1990s as the first of a pair of next-generation MW-class pulsed spallation neutron sources – the other is in Japan (J-PARC). It is the highest-power spallation neutron source in the world and provides correspondingly world-class performance for its instrument suite. The SNS capabilities have increased dramatically since first coming online. The initial suite of 3 instruments has been expanded to 18 instruments for materials science, as well as a fundamental physics beamline. The accelerator power has increased from an initial level of below 100 kW to a steady 1.4 MW today, together with an increase in the reliability of the accelerator, reaching 95% availability averaged over the last cycle. The instrument performance has also greatly improved with the most impactful changes relating to improvements to instrument control, data acquisition and reduction software, sample environment equipment, and increases to detector coverage.

2. Current Strengths and Limitations

While both HFIR and SNS are scientifically highly productive, with about 500 publications annually, many of them in high-impact journals, the accumulated operational experience now allows a more thorough analysis of their relative strengths and limitations. This will allow us to establish a vision for better exploiting their complementary capabilities and to outline a strategy for achieving that vision.

High-Flux Isotope Reactor (HFIR)

Reactor-based neutron sources offer a number of technical advantages for neutron instrumentation. When combined with the world-leading time-average flux of the HFIR thermal and cold neutron sources, this leads to a number of technical areas in which the instruments there can excel:

- Monochromatic beams: focusing crystal optics can extract high-intensity, well-defined monochromatic beams. The resulting instrument designs provide focused information in particular volumes of reciprocal space and energy very quickly. This is particularly useful for parametric studies, e.g. as a function of temperature, humidity, chemical composition or strain.
- Polarized beams: the key neutron beam properties of sensitivity to magnetism and being able to extract quantitative cross-sectional information are best exploited using neutron polarization and analysis. This technique is inherently flux-hungry, requiring the highest source brightness. It is also technically challenging and much more straightforward to implement on monochromatic instruments.
- Kinetics: the very high count rates achievable within focused volumes of reciprocal space mean that measurements can be taken very quickly, allowing the study of rapidly-changing systems, such as those under flow or undergoing chemical reactions. Reactor-based facilities offer very stable beams allowing reliable single-shot experiments, and their more open design gives quick and flexible access to the sample area, allowing complex in-situ sample environments.
- Compact and cost-effective instrumentation: compared to spallation, nuclear fission produces lower energy particles which are easier to shield. As a result, the instruments can be more open and hence accessible, as they require less shielding. They are also considerably less costly, both due to the relaxed shielding requirements and their generally more straightforward detector technologies.

These inherent advantages are, however, compromised by particular design features of the HFIR beam tubes and associated infrastructure. Though significant performance improvements to the HFIR instrument suite have been implemented over the years, some serious challenges remain for both thermal and cold neutron instruments:

- Thermal neutrons: all 7 thermal instruments are situated in the beam room using HB1-HB3. The beam room is cramped, noisy, has very limited floor loading capacity and a high background of both fast and slow neutrons, as well as gamma radiation. In addition, most of the space for instruments does not allow for the installation of polished floors for air pads, due to trenches below the floor for reactor utilities and the need to move out the HB1 and HB3 monochromator drums for replacement of the Be reflector. The only monochromator turret which allows for a flexible selection of the incident neutron energy with an air pad system is on HB2, but is restricted to a single take-off angle due to space limitations. The net result is an instrument suite which is severely restricted in its performance and therefore generally does not reach world-leading levels of flux, resolution, background, flexibility or sample-environment capabilities.

- Cold neutrons: The small size of the cold source which can be accommodated within HB4 severely limits the neutron flux of the instruments viewing it. This problem is exacerbated by the design of the beam tube which does not allow neutron guides to extract a large beam divergence, in part due to the presence of a collimator which is a feature of the reactor safety envelope, currently restricting the start of the neutron guides to 6 m from the cold source. As a result, the only instruments in the guide hall which are adequately served are the two SANS instruments. The other three instruments in the cold guide hall have a performance which can be more than an order of magnitude below their counterparts at ILL.

<u>Spallation Neutron Source (SNS)</u>

The key feature of short-pulse spallation sources is their very high peak neutron brightness. As the highest-power spallation source in the world, SNS provides the highest peak brightness, particularly for high-resolution and short-wavelength applications. Its key technical strengths can be summarized as follows:

- High peak brightness: for thermal and epithermal neutrons the peak brightness is the highest in the world. For many instruments using the time-of-flight technique, peak brightness is the key factor determining instrument performance. Many of the instruments at SNS are therefore world-leading in performance.
- High resolution: the short neutron pulses arising from the design of the decoupled and poisoned moderators translates directly into high resolution in both reciprocal space and energy.
- Focused bandwidth: With a repetition rate of 60 Hz, the high peak brightness is combined with a measurement bandwidth which, though large compared to reactor-based instruments, is intentionally narrower than any other pulsed spallation source, in order to deliver data in the specific volume of reciprocal and energy space where it is needed.

When SNS was being designed, the concept was that of a stand-alone facility, covering as broad a range of neutron beam applications, as can reasonably be accommodated at a single pulsed spallation source. The complementarity with the HFIR neutron beam instruments was thus not fully exploited. SNS was seen as a modern flagship facility which would outperform the much older HFIR neutron source and instruments in most significant aspects. The perspective on some of these aspects has evolved as operational experience has progressed. The areas which are seen as open for improvement are as follows:

- The original design requirement to serve the widest possible range of neutron applications has resulted in compromises in moderator brightness, particularly for the cold coupled moderators. It should be noted here that the key technological breakthrough for the Second Target Station is in the performance of its cold coupled moderators.
- With a design which was finalized in the 1990s, SNS represents the state-of-the-art at that time. Since then, significant advances have been made not just in moderators but also in critical instrument technologies. The expected lifetime of an instrument is typically 20 years before it is eclipsed by technological change and evolving scientific trends, though it can be extended by 10 years or so by a major upgrade. Given that the first instruments are now 15 years old, parts of the instrument suite are no longer fully state-of-the-art.
- Most, but not all, of the beamports have now been populated with instruments. Projects are underway or are being prepared to build instruments on two of the five remaining available beamports.
- A few instruments still have sizeable gaps in their detector coverage or other well-identified paths for significant upgrades.

3. Major Neutron Facility Projects

Five major projects are in progress to advance the neutron science capabilities at ORNL. If executed strategically, these projects will move the capabilities toward the integrated 3-source vision outlined in the next section.

Proton Power Upgrade (PPU) Project

This project will allow a doubling of the accelerator power at SNS, by increasing both the current and the energy of the proton beam, while retaining the 60 Hz repetition rate. On project completion in 2024, it will deliver 2 MW to the SNS. Once the Second Target Station (STS) has been completed, currently foreseen for 2031, the PPU upgrade will allow one pulse in four to be diverted to the STS, delivering 2 MW to the First Target Station (FTS) and 0.7 MW to the STS.

SNS Second Target Station (STS) Project

The STS project will deliver a 15 Hz spallation source, optimized for cold neutrons and coupled moderators, and implementing the latest developments in moderator and instrument technology. This is expected to result in order-of-magnitude increases in peak brightness compared to the FTS moderators, directly translating into order-of-magnitude improvements in instrument performance. Instruments which stand to gain most significantly are those using cold neutrons and requiring moderate to coarse resolution. The STS is expected to deliver first neutrons in 2031 and will ramp up its instrument suite over time in a similar way to what was achieved at the FTS. It will be designed to house 22 instruments and is expected to reach that number by the early 2040s.

HFIR Beryllium Reflector Replacement (HBRR) Project

The Be reflector around the HFIR core needs to be replaced every 20 years due to radiation damage. The next replacement is scheduled to take place in 2024. This is being used as an opportunity to upgrade the guide system for the cold instruments, resulting in significant performance improvements and the creation of a new position for a neutron spin-echo instrument.

HFIR Futures Project

A Laboratory Directed Research and Development (LDRD) proposal is currently being evaluated for a 2-3-year study of a lifetime extension and upgrade to HFIR, including a replaced pressure vessel, modified reflector geometry, an upgraded cold source and a thermal neutron guide hall. If successful, this would show the way forward for a very significant performance enhancement for neutron scattering, as well as several new instruments. Such an upgrade could address the central performance limitations for the current HFIR instrument suite, and open up a world-leading position for both thermal and cold neutron instruments at reactor-based facilities.

Instrument Upgrades and New Instrument Builds

The last few remaining slots at SNS are being filled, with projects for an imaging instrument currently ongoing and a high-throughput powder diffractometer preparing to launch. There is also an ongoing rolling program of Instrument Improvement Projects; modernizing old instruments, implementing new developments, and sometimes adding capabilities which were identified but omitted from the scope of instrument construction projects for various reasons. The laboratory is also developing and plans to incorporate advanced data handling including real-time data reduction and comparisons to predictions, and machine learning and autonomy to increase the productivity of the experimenters.

These ongoing projects are integral parts of the 3-source strategy, as will be seen below. They allow each facility to continue its path towards optimization using the currently foreseen resources.

4. The 3-Source Strategy

After more than a decade of parallel operational experience of the instrument suites at HFIR and SNS, many details of their relative technical strengths and limitations are now becoming apparent. With the advent of the STS with its strong and clearly identified science case and technical vision, it is now timely to re-evaluate the roles that HFIR and SNS-FTS should play and how those roles should change over time in order to maximize overall impact and associated coverage of scientific areas. This will be accomplished by playing to the strengths of each facility in providing capability at the facility where it performs best, thus providing access to as wide and varied a user community as possible, and addressing the scientific questions that have the highest priority and impact.

Vision

The three neutron sources at ORNL will occupy complementary parameter spaces in their source characteristics. The dimensions constituting this parameter space include neutron energy, resolution and bandwidth in both time- and length-scales, and polarization. Each instrument installed at the three neutron sources will be placed at the source which maximizes its performance. All instruments will be world-leading in their field, both in terms of technical performance and scientific output. All available beamports will be filled at the two SNS target stations, and a significant number of new instrument made available at HFIR, fully leveraging the infrastructure investments, and providing greatly increased user access to neutron science.

The parameter spaces spanned by neutron energy, resolution and bandwidth, and the areas optimally occupied by the three neutron sources within those parameter spaces are sketched in Fig. 2.

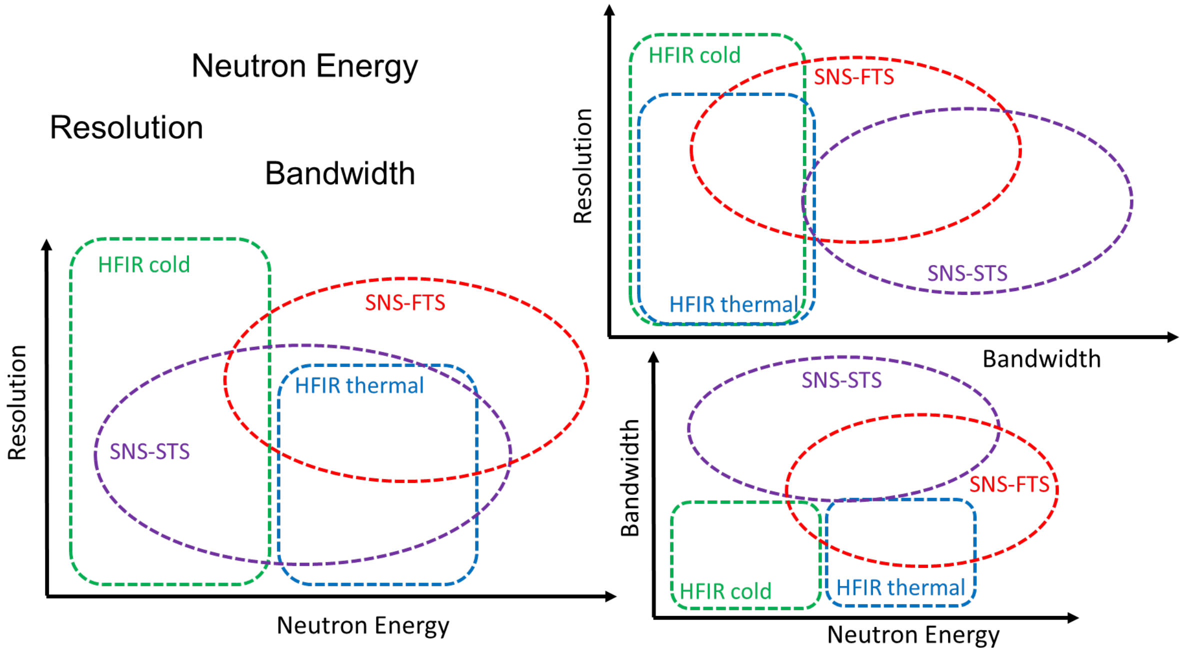

Figure 2 *Areas occupied by the three neutron sources within the parameter spaces spanned by neutron energy, resolution and bandwidth. The figure illustrates the technical strengths of the three sources.*

As can be seen in Fig. 2, the complementarity between the different neutron sources appears quite differently depending on which parameter space it is viewed in, but it is clear that there are well-defined and distinct areas for each source. HFIR is shown as two separate areas, due to the quite different energy and resolution options for the cold and thermal instruments. The two pulsed sources provide an intrinsically larger bandwidth than HFIR, with STS best positioned for the largest bandwidths, and FTS better covering higher energies and higher resolution. Similar parameter spaces could be drawn up covering other aspects such as polarization, measurement time, beam size and signal-to-noise ratios.

For the purpose of showing the optimal placement of instruments at the three sources, we choose the energy-resolution space. A sketch of the optimal distribution of instrument types installed at the three facilities is given in Fig. 3 for this parameter space.

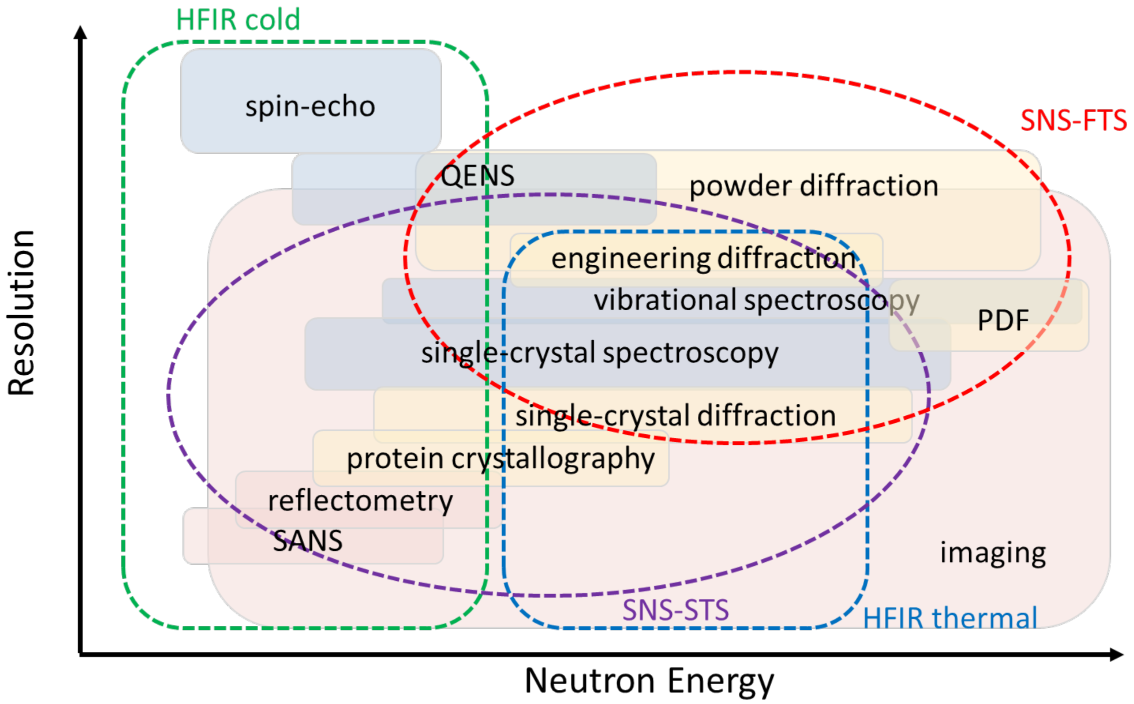

Figure 3 *Optimal instrument placement at the three neutron sources, in the parameter space spanned by neutron energy and resolution. The figure indicates the requirements of the different instrument types, which sometimes results in a placement which is different to where they are today.*

The 3-source strategy is a means to arrive at this vision. It serves to maximize the scientific impact of ORNL Neutron Sciences by deliberately designing in complementary source capabilities at the three facilities and designing and installing instruments which are optimized for those properties. The benefits include:

- Maximizing the coverage and integration of scientific areas across the directorate.
- Maximizing the performance of the instruments. Averaged over the facility, we expect improvements in performance by more than an order of magnitude.
- Providing access to the largest possible user community for a given funding level, addressing the highest-priority scientific questions.
- Ensuring long-term leadership in the global neutron landscape, in the context of emerging facilities such as the European Spallation Source.

The strategy consists in implementing the following three elements:

Upgrade, Expand and Renew the SNS-FTS

- Key strengths: high repetition rate, high resolution, focused bandwidth, thermal and epithermal neutrons.
- Instruments which play naturally to these key strengths include chopper spectrometers, vibrational spectroscopy, small-bandwidth QENS and high-resolution powder diffraction.
- Implementation near-term: The remaining instrument positions at SNS should be filled quickly. Existing instruments in need of detector coverage completion and/or upgrades which extend capability should also be prioritized. Given the age of the SNS, it is now timely to initiate a rolling program of instrument replacements as older instruments become obsolete. The balance between building new instruments on available beamports and upgrading existing instruments should be informed by scientific impact on a case-by-case basis, as outlined in the existing Science Productivity Process. In addition, a rolling program of instrument concept development and selection should be initiated, in parallel with reviews of the existing instruments to identify instruments for replacement.
- Implementation long-term: The composition of the instrument suite and moderators needs to evolve to respond to changes at STS and HFIR. There is no need for significant change to the mercury target, other than what is currently foreseen within the PPU project. However, the design of the inner reflector plug needs to be re-evaluated and new moderators should be installed to benefit from progress since SNS was first designed and enhance complementarity with the STS. These could incorporate low-dimensional para-hydrogen moderators, both decoupled and poisoned, as well as liquid ammonia, but no coupled moderators and possibly no water. R&D for evaluating and optimizing moderators is required. Once implemented, some instruments should be closed down as a result; both those eclipsed by new instruments at STS and those better served at HFIR. They should be replaced by new instruments, designed to take full advantage of the new design and capabilities. Some existing instruments may benefit from being upgraded to adapt to the new moderator properties. The process for development and selection of instrument concepts for the upgraded FTS should be combined with the process established for the STS instruments.
- Timeline: The near-term implementation process needs to start immediately and proceed as quickly as funding allows. R&D for replacement moderators at FTS should ramp up in parallel, starting now. The timescale from idea to implementation is more than 10 years, due to the immaturity of some of the high-potential concepts, and the stringent performance, safety and reliability requirements that will need to be satisfied. The upgrade to the SNS-FTS should be implemented as soon as funding allows after STS has started operating.
- Constraints: minimize disruption to SNS operations.

Build the SNS-STS and Complete its Instrument Suite

- Key strengths: high peak brightness of cold neutrons, large bandwidth, small beams.
- A range of instrument concepts are in the process of being developed to turn these theoretical strengths into reality; cold chopper and indirect-geometry spectrometers, simultaneous SANS and powder diffraction, reflectometry, single-crystal diffraction and extreme environments are all technical areas which are well suited to take full advantage the STS key strengths.
- Implementation: A credible and robust project plan for STS has been established and is currently going through its CD-1 approval. A process has been developed for determining the 5-8 instruments to be included within the construction project. In parallel with the execution of the construction project, a rolling program of instrument concept development and selection should be developed and executed, so that instruments can continue to be installed after project completion on the 22 available beamports. This should be combined with the equivalent process for instrument renewal on SNS-FTS. Given the
- Timeline: The STS is currently expected to come on-line with its initial instrument suite in around 2031 and will reach full capacity in around 2040.

Upgrade HFIR and Build a Thermal Neutron Guide Hall

- Key strengths: high time-integrated flux for both cold and thermal neutrons, polarized neutrons, focusing monochromators, cost-effective instruments.
- Instruments which would directly benefit from these strengths include: white-beam imaging, 3-axis spectrometers with backend multiplexing and/or polarization analysis, SANS, chemical crystallography, residual stress, single crystal diffraction (optionally with polarized neutrons), macromolecular crystallography with dynamic nuclear polarization, thermal chopper spectroscopy, cold-neutron particle physics.
- Implementation: The existing HBRR program needs to go ahead and will result in significant improvements to all the instruments in the cold guide hall. Constraints in the design of the HB4 beam tube, however, do not permit full illumination of the guides, limiting the impact of the improvements. A major upgrade to HFIR should be undertaken incorporating the following features: (a) An upgraded HB4 beam tube incorporating a larger cold source with close-proximity guides, requiring modifications to the Be reflector and reactor vessel. (b) A thermal guide hall on HB2 feeding a suite of high-performance instruments. (c) R&D in polarized neutron and polarized proton technologies and implementation on the new and upgraded instruments. A full study should be performed of the possible instrument suite, which needs to be done at the same time as the cold source, beam tube and guide systems are designed. Most instruments will need end-of-guide positions and need to be optimized in conjunction with the common guide system, rather than as a rolling program of instrument concept developments as for SNS-FTS and STS.
- Timeline: This should take place as soon as possible. The HFIR instrument suite is ripe for upgrade.
- Constraints: Minimize disruption to the various programs which depend on HFIR operation, such as the neutron user program, materials irradiation and isotope production. Site geography is a major constraint; expansion of the cold guide hall is constrained by existing reactor facilities nearby.

A possible timeline for these activities is shown schematically in Fig. 4.

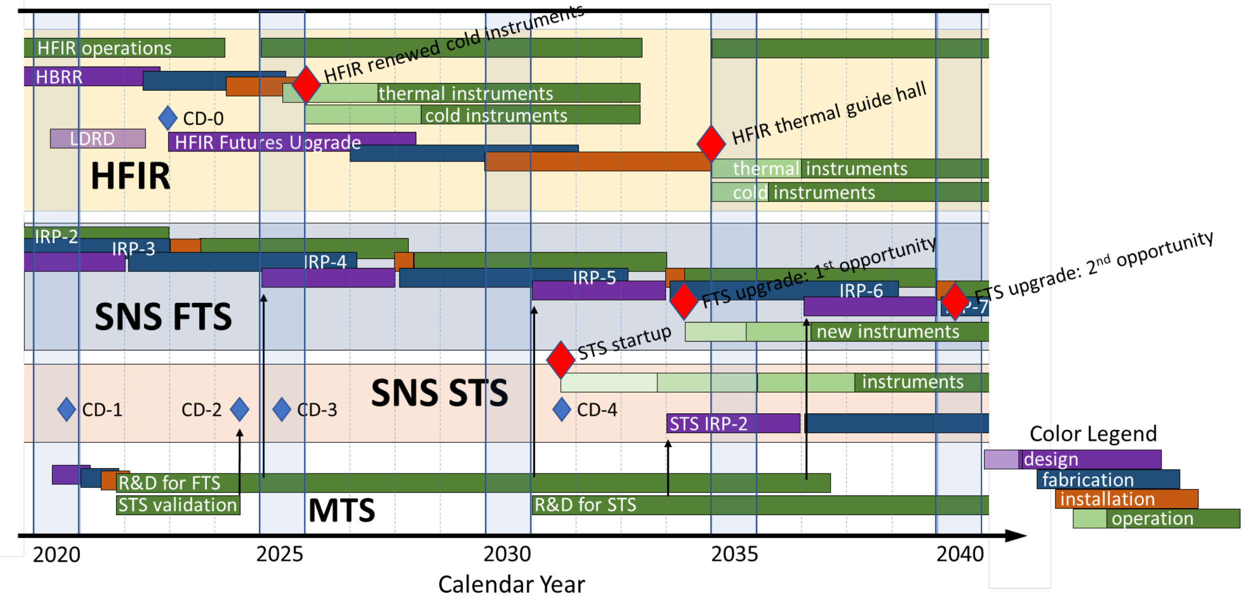

Figure 4 *Timeline for implementation of the 3-source strategy. The timescale for the regular replacements of the Inner Reflector Plug (IRP) for the FTS and STS is shown. A Moderator Test Station (MTS) is needed to support the validation and development of moderators for both target stations.*

The timeline shown here is assumed to be constrained by technical limitations, rather than funding. A number of high-level milestones are highlighted in red:

- Entry into the user program of the first cold instruments at HFIR as part of the HBRR program.
- Entry into the user program of the first thermal instruments in the new thermal guide hall, as part of the HFIR Futures project.
- Two first opportunities for installation of an upgraded moderator system for the SNS-FTS. This would need to be preceded by R&D at a Moderator Test Station (MTS), and timed to coincide with the commissioning of new instruments viewing the new moderators.
- Entry into the user program of the first instruments at the SNS Second Target Station, followed by a gradual ramp-up in the number of instruments.

Full implementation of the 3-source strategy will take at least 20 years. It needs to be supported by ongoing programs for instrument upgrades and the development of new instrument concepts for all three neutron sources, as well as critical R&D activities at a Moderator Test Station to provide the needed new capability for FTS.

5. Context

The proposed 3-source strategy needs to be seen within the wider contexts of needs and trends in materials science and data tools, as well as the evolving US and international neutron landscape. The cornerstone of this wider picture is the continuing important of materials science in driving a dynamic and competitive economy which is able to respond to the grand challenges faced both today and in the future. Neutron scattering is just one of many tools in the materials science toolkit. To ensure US leadership in materials science it is essential that this toolkit covers not only the needed diversity and provides world-leading quality of insight, but also that it is responsive to changing societal, economic and technological needs.

Implementing the 3-source strategy ensures that the neutron scattering component of the national materials science toolkit rises to this challenge. By providing 3 neutron sources with distinctly complementary capabilities, each world-leading in its field, ORNL positions neutron scattering in the US to deliver the broadest and most impactful range of capabilities, while the diversity of the 3 sources ensures the responsiveness which is needed in a rapidly changing world.

The 3-source strategy should not be seen as an exclusive plan. Important and parallel efforts need to be pursued to push neutron scattering capabilities to continue to evolve and improve. These include improving the productivity of scientists by advanced software, better and wider ranges of sample environment equipment, continuing to improve availability, R&D to improve critical neutron technologies such as detectors and polarization, as well as method developments to expand the range of instrument capabilities. Key among these areas are state-of-the-art data handling, integration of real-time data reduction and modeling/simulation, machine learning to recognize patterns and compare to predictions, guiding experimentation even to the extent of autonomy. The urgency of these approaches is reinforced by the immediate need to provide more remote and autonomous experiment capability, as we prepare for a post-COVID-19 society.

The global neutron landscape is evolving and requires a clearly-articulated US strategy to defend and consolidate its position where it is world-leading, and to push forward where it is not.
Reactor-based neutron scattering in the US mainly takes place at HFIR, and at the NIST Center for Neutron Research, a medium-flux research reactor. The field has been led by European facilities over the last decades, with the ILL in Grenoble, France leading the way. Over the last few years, a number of small and medium-flux research reactors have closed down in Europe, and the future of the ILL beyond 2030 is not assured. Outside Europe, a modern medium-flux research reactor is now operating in Australia, another is under construction in Argentina, the JRR-3 reactor in Japan has been shut down since the Fukushima incident, and the CARR research reactor in China and the PIK reactor in Russia are slowly taking shape. No significant leaps forward in research reactors are expected in Asia or elsewhere outside the US in the near or medium term. This landscape provides an opportunity for HFIR to take a leading position world-wide.

Spallation neutron sources will slowly approach the time-average flux of high-flux reactors over the years, but will generally remain about an order of magnitude below. J-PARC in Japan is planning on building a second target station in the 15-20 years’ timescale, with a design anticipated to be similar to that of SNS-STS. The ISIS facility in the UK, which pioneered pulsed-source neutron scattering in the 1990s will remain competitive, while CSNS in China is rapidly ramping up to ISIS-level capability and plans to upgrade further. The main competitor to SNS is the European Spallation Source (ESS) in Lund, Sweden, which is expected to reach 2 MW operation in 2025 and 5 MW in 2030. By that time, it will be the highest-performance neutron facility in Europe, targeting many of the same key science cases as STS, and approaching a similar level of performance. Similarly to STS, the bulk of the ESS instrument suite is focused on cold neutrons, large-bandwidth, medium-resolution applications. This provides an opportunity for SNS-FTS to provide unrivalled performance in high-resolution, smaller bandwidth applications at thermal to epithermal energies. An upgraded HFIR with a new thermal instrument suite will be world-leading in thermal neutron instrumentation, and applications that require narrow bandwidth. Implementation of the 3-source strategy thus ensures US leadership in neutron scattering for the foreseeable future.