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The ORNL Moderator Test Station Science Case

E. B. Iverson

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

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Neutron Technologies Division

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ACRONYMS

AIP	Accelerator Improvement Project
BTF	Beam Test Facility
CD	Critical Decision
FTS	First Target Station
HFIR	High Flux Isotope Reactor
HUNS	Hokkaido University Neutron Source
IRP	Inner Reflector Plug
LENS	Low Energy Neutron Source
MTS	Moderator Test Station
ORNL	Oak Ridge National Laboratory
SNS	Spallation Neutron Source
STS	Second Target Station

1. INTRODUCTION

Oak Ridge National Laboratory (ORNL) hosts two world-leading slow neutron sources, the Spallation Neutron Source (SNS) and the High Flux Isotope Reactor (HFIR), and is currently developing the technical design for a Second Target Station (STS) for the SNS. Upon completion of the STS project, ORNL will be uniquely positioned to optimize each of its three neutron sources, the SNS First Target Station (FTS), the STS, and HFIR, in a complementary way. [1]

Among the essential aspects of a re-imagined FTS and the current STS design are high-brightness parahydrogen moderators—moderators which are optimized for high per-unit-area neutron brightness rather than integrated-across-large-area neutron intensity. The high-brightness moderators proposed for the STS [2] will, for the brightness metric, significantly outperform the coupled moderators currently on the FTS for appropriately optimized neutron beamlines, provided the moderating hydrogen is converted to near-equilibrium levels of parahydrogen (approximately 99.8% at 20 K) [3, 2]. The original FTS moderators, by contrast, were conservatively designed to be relatively insensitive to the exact ortho:para ratio, with a consequent loss in performance. As a result, a redesign of the FTS moderators assuming fully converted parahydrogen could result in significant performance improvements on the FTS coupled moderators, and more consistent performance over time for all hydrogen moderators [4]. This "parahydrogen problem" is a long-standing challenge for the effective implementation of hydrogen cold moderators at high-power neutron sources. In addition, the development of new moderator concepts, whether based on previously unused materials, structured heterogeneous arrays, or even simply on changes in overall shape and size is significantly restricted at a large-scale production facility intended to use the resulting neutron beams. Accordingly, moderators for production neutron sources are often designed in a very conservative, low-risk fashion, even though this compromises the absolute neutronic performance. Advanced moderator concepts worthy of study include features that could not be tested without redesigning and redeploying the entire existing reflector, shielding, and neutron beamline installation, making such development efforts far more expensive than building a stand-alone test facility.

We are building a Moderator Test Station (MTS) at the SNS with which we will verify such performance gains and test new moderator concepts. These concepts include both high-brightness and large-volume parahydrogen moderators, as well as moderators with tailored ortho:para hydrogen levels, heterogeneous moderator concepts such as the convoluted moderator [5], pelletized moderators [6], moving moderators [7], and moderators made of materials like ammonia [8], ethane [9], and oxygen clathrates [10], which have not been widely tested let alone deployed at neutron source facilities.

We are adding to the SNS Beam Test Facility (BTF) a proton beam chopper similar to that already used in the SNS front end, various proton beam transport components, a neutron-producing target, a cryogenic moderator test stand, a reflector-shielding assembly, and a performance assessment neutron beamline. The MTS will provide the ability to:

1. validate STS moderator designs,
2. develop FTS moderator options,
3. benchmark scattering kernels for neutron moderating materials, and
4. explore new strategic directions for neutron beam production,

all in a prototypical "wing" moderator configuration more appropriate to deployment at production facilities than the current generation of test facilities, such as the Low Energy Neutron Source (LENS) [11] or the Hokkaido University Neutron Source (HUNS) [12]. While many of the moderator designs and options would be tested in a prototypical fashion, where the test moderator closely resembles that proposed for the production facility, we will also use the MTS to test, validate, and benchmark scattering kernels and simulation methods. Having reliable scattering kernels and simulation methods for new moderator materials and concepts will permit much more rapid, reproducible, and complete exploration of design phase space than a purely experimental approach.

In order for the MTS to optimally impact the strategic needs of ORNL's neutron source facilities, it should be functional within the next few years to validate STS moderator designs, and within the next five years in order to influence moderator options for IRP-7 and beyond. The work we describe below is well matched to that timescale, given that many of the ideas must progress through concept demonstration to safe, reliable high power operation in both physics and engineering respects. As shown in Figure 1 the validation of STS moderator designs could occur well before construction is complete, permitting response to unexpected results, and would precede the development phase for the seventh Inner Reflector Plug (IRP-7) for the First Target Station [13].

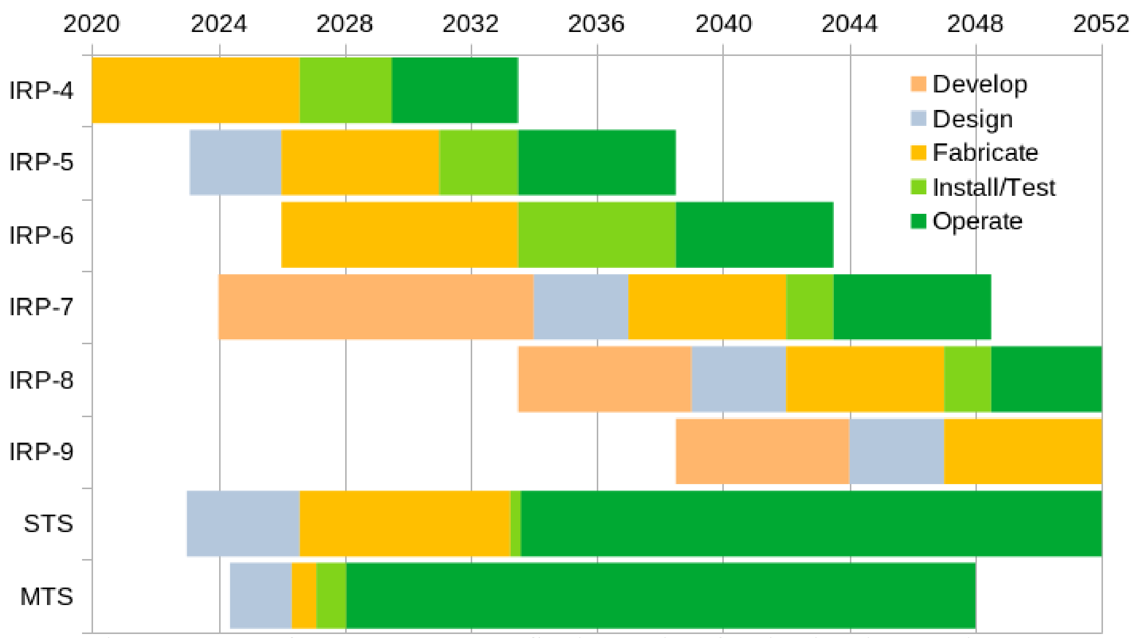

Figure 1. Notional schedule for Moderator Test Station design, fabrication, installation, and operation in relation to the ongoing operation of the First Target Station as documented in the Inner Reflector Plug Management Plan and the proposed commissioning of the Second Target Station.

2. MODERATOR TEST PLAN

While there are any number of neutron moderator concepts which would benefit from testing at the MTS, a number of specific moderators stand out as being of high interest to SNS in the short–medium term, representing an initial series of test moderators to be studied upon MTS completion.

2.1 STS MODERATOR VALIDATION

The STS Cylindrical Moderator concept is a high-brightness parahydrogen moderator serving the majority of the neutron beamlines in the STS [2]. Key to the successful exploitation of the Cylindrical Moderator is a very low orthohydrogen content in the liquid hydrogen material making up the moderator. This low orthohydrogen content fundamentally changes the nature of the moderator as a neutron source—the moderator becomes brighter at the edges (rather than in the center of the viewed region), and becomes a volumetric source, benefiting from significantly greater axial extent than when the orthohydrogen content rises beyond a few percent. Unfortunately, currently available neutron scattering cross section are based on evaluations which are not particularly reliable with respect to the ortho:para mix present during the measurement of the neutron scattering cross sections upon which the libraries were based [14]. As a result, the tolerance for higher orthohydrogen levels is not well understood. We will measure the brightness and brightness distribution across a prototype of the STS Cylindrical Moderator and compare it with the brightness distribution across more conventional hydrogen moderators, both as a function of viewable moderator area and as a function of parahydrogen purity. This will allow us to understand the technical requirements of a hydrogen catalyst system intended to drive relaxation to lower orthohydrogen levels, and maximize the Cylindrical Moderator effectiveness. Similarly, the STS Tube Moderator concept, also a high-brightness configuration, relies on low orthohydrogen contamination to deliver its performance advantages [15]. Work at the MTS will identify satisfactorily low levels of orthohydrogen contamination in the Cylindrical and Tube Moderator systems, such that they provide the order of magnitude increases in time-averaged and peak brightness over the FTS coupled moderator anticipated without unnecessarily oversizing the liquid hydrogen catalysis systems and needlessly increasing the hydrogen inventory and system complexity. [16]

The fundamental features of the MTS that make characterizing the Cylindrical and Tube Moderator sensitivity to orthohydrogen level, and other aspects of high-brightness moderator performance, possible are:

1. The MTS will provide a wing moderator test configuration, unlike the HUNS or LENS moderator test facilities. The brighter edges associated with both concepts are only evident in a wing configuration—as is used at production-scale neutron facilities—rather than the slab configuration used at other moderator test facilities.

2. The MTS will provide a large test volume permitting the deployment of full-sized Cylindrical Moderators and Tube Moderators designed for fully converted parahydrogen. Such a moderator is two to three times larger (along the emitted beam direction) than moderators with significant orthohydrogen content or moderators made from thermalizing materials like liquid methane or water.

In addition, the MTS will offer diagnostic capabilities recently developed as part of the Proton Power Upgrade project [16] to monitor the level of parahydrogen purity in the liquid hydrogen moderating material. This real-time monitoring capability is not presently available at any operating neutron source other than SNS, either production facility or test facility.

2.2 NEW MODERATOR DEVELOPMENT

2.2.1 Intermediate-Temperature Moderators

The long term three-source strategy [1] for ORNL neutron sources involves optimizing the moderators on the First Target Station for high resolution, focused bandwidth, and high repetition rate. Such an optimization will combine with rolling upgrades to the scattering instrument suite intended to exploit new instrument techniques, explore new areas of science, and leverage tighter optimization of the FTS moderators made possible by the availability of an STS emphasizing high brightness and low neutron energies. One such upgrade to the FTS moderator suite would be to add an intermediate temperature high-resolution moderator, either replacing the existing ambient water moderator or (after STS commissioning) one of the coupled hydrogen moderators. In fact, original considerations for the SNS FTS moderator suite included several concepts for providing "liquid methane"–like performance despite operational challenges from liquid methane at high source power [17, 18, 19]. Recent studies have indicated that either ammonia [8] or ethane [9] might provide the desired performance enhancements:

1. A lower energy transition from "slowing-down" to "thermalized" behavior, which retains the high peak intensity from a water moderator at 1 Å but with dramatically sharper pulse widths.
2. A higher hydrogen density than liquid water, which results in sharper pulses at high neutron energies, and sharper rise times at all neutron energies.
3. Enhanced low-energy neutron intensity compared to ambient water, which results from lowered thermalization temperature.

In conjunction with performance studies of these moderator materials, we would also need to demonstrate the postulated enhanced radiation resistance of ammonia, ethane, or mixes of various hydrocarbons relative to the often-used liquid methane, before they could be considered viable options on a production-scale neutron source facility. A significant advantage of performing these studies at MTS, with a lower intrinsic level of radiation damage to the moderator material, is that the performance of radiation-damaged material can be studied separately from the performance of fresh material. As the radiation damage effects on moderating materials arise from radiolysis and recombination effects [20, 21], those effects can be imposed on the moderating material separately from the primary neutron source we use to characterize the moderator performance, for example using ultraviolet lasers to ionize the moderating material.

Depending on the figure-of-merit chosen for comparison, such an intermediate temperature moderator might represent gains of two to three in instrument effectiveness relative to current versions of either liquid water or liquid hydrogen moderators.

The essential features of the MTS that make characterizing intermediate moderator materials possible are:

1. Easy access to the moderator installation volume for the replacement of cryogenic cooling and flow systems with ones suited to different materials and operating temperatures.
2. Broad control over the geometry of the test moderator to enable independent optimization of geometry, temperature, material, and poisoning.
3. Low radiation damage from the source itself, permitting independent study of moderating material performance and the compromise of that performance by radiolysis.

2.2.2 Directionally-Enhanced Moderators

The SNS moderator development effort has already demonstrated a concept for a directionally-enhanced moderator, the Convoluted Moderator, that enhances the brightness of a delivered neutron beam *in a chosen direction* by a factor of two or more relative to a conventional monolithic block moderator [5]. The specific convoluted moderator tested would not directly be suitable for deployment at high-power neutron sources like the SNS FTS, but implementations have been proposed that may provide the same performance benefits while permitting satisfactory cryogenic cooling and radiation tolerance, and would be suitable for deployment at a high-powered source. Obviously, such implementations would need extensive prototypical testing, both neutronically and thermomechanically, before deployment at the production facility would be acceptable. We should anticipate multiple development-test cycles before eventual deployment.

The fundamental characteristics of the MTS that make characterizing the Directionally-Enhanced Moderators possible are:

1. Easy access to a large-volume area in which the test moderator resides, so that larger or more mechanically complicated designs can be tested.
2. Time and access to iterate the thermomechanical cooling concepts, high-precision cryogenic positioning and pointing linkages, and diagnostic sensors that will be required for effective production deployment.
3. Low radiation damage and heating from the source itself, permitting independent study of moderator concept performance and the compromise of that performance by engineering necessity.

2.2.3 Pelletized Moderators

The concept of a pelletized moderator, first proposed by Lucas in 1995 [22], has been successfully deployed at the IBR-2 reactor [6]. Such a moderator uses millimeter-scale pellets of solid cold moderating material cooled by liquid hydrogen or helium rather than a monolithic block of such material. Good moderator materials typically have very poor heat conduction, making the removal of large amounts of radiation deposited heat problematic. Solid moderating materials enable far better performance in some ways than liquid hydrogen with its relatively low hydrogen density, but suffer from radiation damage which degrades performance and eventually results in rapid radical recombination [21, 23], in turn resulting in rapid temperature and pressure excursions. Some of these excursions have resulted in moderator vessel ruptures [20, 24]. Using pellets as the moderating material eases both problems, by permitting better temperature control of the bulk material, better overall heat removal by mass transfer, and geometric limitation of the "burping" phenomenon by limiting the mass of material involved in a given warming event. Pelletized moderator systems would enable significantly higher resolution neutron beams across all energies, by enabling the use of these higher hydrogen density materials (such as solid methane and ammonia) with true thermalization capability and at lower moderator temperatures at high power sources like the FTS and STS. Depending on the figure-of-merit appropriate to the application, a pelletized moderator, with lower temperature and more stable operation, could provide factors of two to four more low-energy neutron brightness for high resolution cold moderators, as well as factors of two to three better intrinsic resolution at intermediate neutron energies through lowering the neutron thermalization temperature.

The fundamental characteristics of the MTS that make characterizing pelletized moderators possible are:

1. Easy access to the moderator volume for delivery of externally manufactured pellets through pneumatic, gravity, or conveyor systems.
2. Easy replacement of cryogenic services based on a static cold bar with circulating cooling cryogens.
3. Low radiation damage and heating from the source itself, allowing us to separate moderating performance from cooling strategy.

2.2.4 Slush Moderators

While a pelletized moderator involves a bed of solid pieces of moderating material, there are additional possibilities for moderators in the form of sub-cooled liquids or "slushes." [25] Such moderators might expand the temperature range in which different materials may be employed, and may offer better thermophysical and radiation resistance properties needed at high power production facilities than conventional solid materials.

The fundamental characteristics of the MTS that make characterizing slush moderators possible are:

1. Easy access to the moderator volume for delivery of externally fabricated slush or for *in situ* production of slush.
2. Low radiation damage and heating from the source itself, allowing us to separate moderating performance from cooling strategy.

2.2.5 Moving Moderators

Moderator concepts involving rapidly moving moderator materials have been proposed [7, 26] that would shift the mean energy of a cooled, high phase space density neutron spectrum higher, without broadening the narrow energy distribution associated with the lower temperature, producing an intense narrow-band neutron energy spectrum. While such a source would have excellent performance over a narrow energy range, it would have significantly reduced performance outside that energy range, which may be an acceptable tradeoff in certain circumstances.

The fundamental characteristics of the MTS that make characterizing moving moderators possible are:

1. Easy access to a large-volume area in which the test moderator resides, so that mechanically complicated designs, including turbomachinery, can be tested.
2. Low radiation damage and heating from the source itself, enabling us to more easily test such a design prior to investing in making it practical at a high power production facility.

2.2.6 High Brightness Moderators

The high brightness moderator concepts being developed for the STS described above will also be strong candidates for inclusion in the moderator suite of the FTS as the FTS is redesigned to optimize its performance within the ORNL three-source context once STS is operating.

The fundamental features of the MTS that make characterizing high brightness moderators in general, as well as their sensitivity to orthohydrogen level, are:

1. The MTS will provide a wing moderator test configuration, unlike the HUNS or LENS moderator test facilities. The brighter edges associated with both concepts are only evident in a wing configuration—as is used at production-scale neutron facilities—rather than the slab configuration used at other moderator test facilities.

2. The MTS will provide a large test volume permitting the deployment of larger moderators designed for fully converted parahydrogen. Such a moderator is two to three times larger (along the emitted beam direction) than moderators with significant orthohydrogen content or moderators made from thermalizing materials like liquid methane or water.

In addition, the MTS will offer diagnostic capabilities currently being developed as part of the Proton Power Upgrade project to monitor the level of parahydrogen purity in the liquid hydrogen moderating material. This real-time monitoring capability is not presently available at any operating neutron source, either production facility or test facility.

2.2.7 Very Cold Neutron Moderators

The scientific case for the deployment of Very Cold Neutron Moderators (moderators producing neutrons below 0.3 meV energy) at neutron source facilities has been made at a variety of workshops over the past few decades [27]. While a variety of technical concepts have been proposed, many of those concepts can not, with currently available cross section libraries, be modeled with sufficient reliability to be shown to be effective relative to conventional cold moderators. The MTS would offer an alternative mechanism to study Very Cold Neutron Moderator concepts prior to the full development of scattering kernel libraries and low-energy transport methods as well as a testbed for validating those libraries and methods prior to their use designing a production-scale deployment. Such a moderator might represent a new capability, for which there is no current baseline for comparison, but could certainly be expected to be an order of magnitude more effective for the generation of very low energy neutrons than the current generation of cold moderators (e.g., 20 K hydrogen).

The fundamental characteristics of the MTS that make characterizing the Very Cold Neutron Moderators possible are:

1. Easy access to a large volume in which the test moderator resides, so that larger quantities of moderating material (the capture cross section of hydrogen limits its utility for very cold neutron production) can be tested.

2. Easy replacement of cryogenic services with ones suitable for very low temperature operation.

3. Low radiation damage and heating from the source itself, reducing cryogenic heat loads.

2.2.8 Supercritical Hydrogen

During commissioning of the SNS FTS, there were operational difficulties associated with manufacturing errors on one of the coupled liquid hydrogen moderators. These moderators are designed to operate with hydrogen at roughly 20 K and 13 bar, above the critical pressure, so that boiling cannot happen. The manufacturing error resulted in a large stagnation zone within the Bottom Downstream moderator, which we believe may have resulted in hydrogen temperatures exceeding the critical temperature of 33 K by a substantial margin. A remedial solution was found to correct the flow maldistribution, resulting in the design performance. However, before the repair was accomplished, performance measurements on a beamline viewing that moderator appeared to suggest dramatically different performance from hydrogen at roughly 50-80 K and 13 bar undergoing pulsed heating. If that apparent performance could be replicated and verified, it might result in a strongly peaked (in neutron energy) distribution, resulting in factors of 3–5 higher brightness at specific energies, and 2–3 lower brightness at other energies. While such a moderator would not be suited to broad spectrum applications such as time-of-flight powder diffraction, it would be extremely useful for direct geometry inelastic instruments, or other applications involving specific neutron energies and focused bandwidth. Testing such a moderator would require the ability to operate a high pressure (13 bar) hydrogen loop over a broad temperature range (at least 20–100 K). A conceptual design has not yet been developed, but it may further require circulating hydrogen in order to maintain an appropriate temperature distribution.

The fundamental characteristics of the MTS that make characterizing supercritical hydrogen moderators possible are:

1. Easy access to a large-volume area in which the test moderator resides, so that pressure vessels suitable for the appropriate pressure can be safely used.
2. The freedom to test many pressure, temperature, and flow configurations without requiring rapid return to general production use.
3. Low radiation damage and heating from the source itself, permitting independent study of moderator concept performance and the requirements of large scale heat removal.

2.3 SCATTERING KERNEL VALIDATION

Some of the moderator concepts described above come about via new implementations of relatively well-understood materials deployed in innovative configurations, but most of them involve materials for which neutron scattering kernels are not readily available or have not been sufficiently proven to accurately describe the moderating capabilities of the material. We anticipate using the MTS to validate neutron scattering kernels and their implementation in neutron transport codes. Scattering kernel validation would be accomplished by neutron die-away and neutron leakage measurements, [28, 29] which are virtually identical to our standard moderator characterization measurements. [30, 5, 31, 8]

The fundamental characteristics of the MTS that support validating scattering kernels include:

1. Easy access to a large-volume area in which the test moderator resides, so that a wide variety of moderator sizes can be studies, facilitating a more complete validation of the scattering kernels.
2. The freedom to test many pressure, temperature, and flow configurations in a variety of geometries without requiring rapid return to general production use.
3. Rigorous control of a well-defined geometry in which to implement a variety of test moderators.

2.4 OPERATIONAL MODERATOR DIAGNOSTICS

2.4.1 Stable FTS Moderators

Since early days in SNS operations, it has been apparent that the FTS liquid hydrogen moderators display a certain level of non-linearity in performance. As proton beam power increases, the spectral distribution of neutrons coming from the moderators changes, with the brightness at longer wavelengths (e.g., 5 Å) going down by roughly 20% per megaWatt of proton beam power—that is, the time-averaged 5 Å brightness at 1.0 MW is only 800 times that what it is at 1 kW. This diminishing return could be explained by, for example, an uncontrolled, variable orthohydrogen contamination, by flow maldistribution resulting in temperature variation resulting in density variation, or by entrained gas resulting in density variation. Without detailed diagnostics not practical within the high powered production moderator, and the flexibility to widely vary operating temperature, pressure, flow, and flow distribution conditions without needing to maintain high reliability production operation, untangling these possible effects (as well as those not yet hypothesized), is proving very difficult. In the MTS, we would seek to design an instrumented test moderator vessel capable of variable temperature, pressure, flow, and heating conditions on arbitrary mixtures of ortho and parahydrogen. With such a capability, we would attempt to unravel the many different potential causes of moderator non-linearity to isolate the cause of the behavior in the production SNS FTS system.

The fundamental characteristics of the MTS that make studying hydrogen moderator non-linearity possible are:

1. Easy access to the moderator volume for rapid changes of moderator configuration.
2. Open space around the moderator for significant diagnostic sensors.
3. Operational flexibility made possible by not serving a production neutron beam facility.
4. Low radiation damage and heating from the source itself, allowing us to deliberately control orthohydrogen levels, hydrogen pressure, temperature, and flow distributions, and provide external heating in the absence of source-related heating.

3. ADDITIONAL USES

The Moderator Test Station is designed and optimized for the characterization of test moderators in support of moderator development. The scattering kernels associated with those test moderator materials are also useful for reactor physics studies and development, [32, 33, 29] and we might envision using MTS in support of that sort of scattering kernel testing and validation as well as that directly associated with neutron source facility development. The MTS may also prove useful for additional applications, including detector testing, neutron polarization and optical component testing, or data acquisition system testing. While nearly any such testing might also be done at SNS [34] or HFIR, [35] with their vastly more intense beams, the nature of those highly over-subscribed user facilities may preclude timely access, and their optimization for scattering purposes may provide minimal access for larger test systems.

4. MTS DESCRIPTION

The Moderator Test Station will receive up to 75 W (time-averaged) of 2.5 MeV proton beam from the BTF, defocused to a beam spot of 80 mm diameter. The beam will obliquely impact a lithium-7 target such that the beam spot on target is an ellipse of 80 mm by 309 mm, comparable to the extended neutron production region of a stopping length target at a spallation source. This target will be adjacent to a test moderator assembly, which will position a variety of test moderators within an evacuated environment in a wing configuration relative to a single neutron beamline, used to characterize the neutron beam emitted from the face of the moderator. The evacuated moderator environment will also form the first portion of the neutron beamline, with instrumentation lines, gas lines, cryogenic lines, etc., coming down along the edges of the neutron flight path (much like the cold source at HFIR). The neutron beamline will characterize the neutron beam emitted from the moderator surface using a variety of detector and analyzer configurations, including time-focused crystal analyzer detectors [11, 31, 30, 36], pixelated in-beam detectors, and a variety of collimators. A summary of system parameters appears in Table 1.

Table 1. Moderator Test Station parameters and reference information

Proton Energy	2.5	MeV
Peak Current	50	mA
Beamspot Width	80	mm
Beamspot Height	80	mm
Beam Angle to Target	75	degrees
Beamspot Width on Target	80	mm
Beamspot Height on Target	309	mm
Productive Lithium Path Length	70	μm
Required Lithium Thickness	18	μm
Nominal Lithium Thickness	30	μm
Proton Energy Entering Backing Aluminum	1.3	MeV
Proton Range in Backing Aluminum	21	μm
Primary Neutron Yield	9.4×10^9	n/μC
Maximum Primary Neutron Energy	0.78	MeV
Operational Scenario I		
Maximum Frequency	60	Hz
Maximum Pulse Length	10	μs
Maximum Proton Power	75	W
Primary Neutron Intensity	2.8×10^{10}	n/s
Operational Scenario II		
Maximum Frequency	30	Hz
Maximum Pulse Length	1	μs
Maximum Proton Power	3.75	W
Primary Neutron Intensity	1.4×10^9	n/s

Figure 2 shows a simplified preliminary layout of the Moderator Test Station, including the target-moderator-reflector assembly, a primary neutron beamline, and two scattered neutron beamlines, each fed by a crystal analyzer array.

Figure 3 shows the location for the MTS within the BTF area. The BTF is shown “straightened” from its original configuration, and the MTS is scaled such that the primary neutron flight path is roughly 4.5 m long. This would be compatible with operation at the full 60 Hz from a frame overlap perspective, although there may be circumstances in which 30 Hz operation would be preferable.

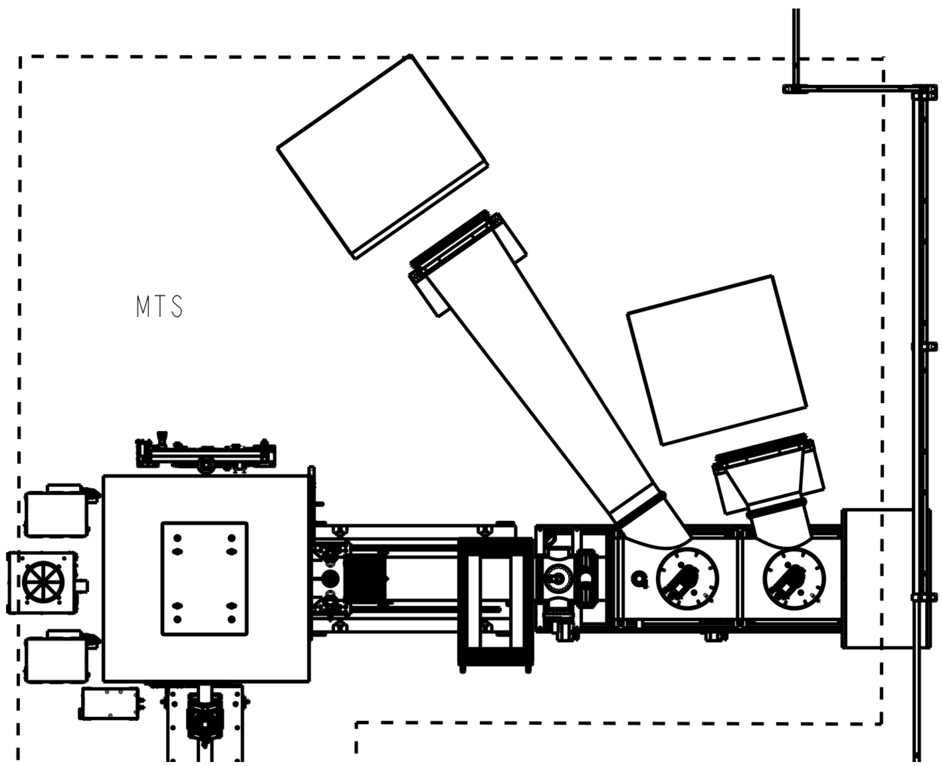

Figure 2. Layout of the Moderator Test Station. The target-moderator-reflector assembly is in the upper left corner, with a primary neutron beamline coming off to the right, feeding two analyzer crystal arrays and two scattered neutron beamlines.

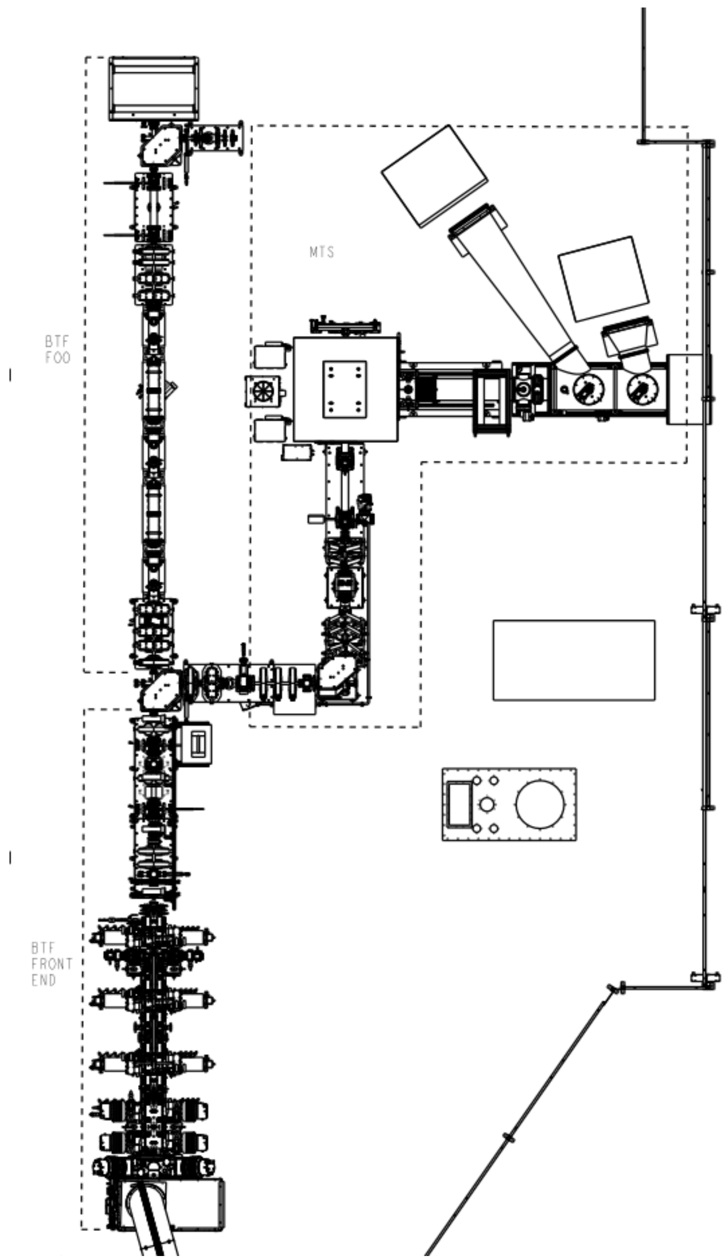

Figure 3. MTS at the BTF. With a primary neutron flight path of roughly 4.5 m, the MTS would be compatible with 60 Hz operation.

5. SCOPE OF WORK

We envision the Moderator Test Station effort to add four major components to the Beam Test Facility:

1. an extended proton beamline, including a proton chopper, transport, and focusing;
2. a target and reflector assembly (the “target” will actually be contiguous with the accelerator vacuum);
3. a moderator system, with the mounting apparatus for a test moderator, gas handling system, and cryogenics, including a single test vessel to contain hydrogen and similar cryogenic materials;
4. a neutron beamline to characterize the performance of the moderator under test.

A very preliminary cost estimate for the various components has been developed, and indicates a design and construction cost of less than $9,000k, with operating costs, including staff, of around $1,000k per year. The MTS project will be managed as an Accelerator Improvement Project (AIP) within the Neutron Technologies Division.

Operation of the MTS itself would involve fractional time from a number of staff, likely to aggregate to around one to one-and-a-half full time equivalent per year, primarily from neutronics staff. We envision an operational tempo that would support several test moderator runs per year. Based on experience with our test program to date, individual moderator assemblies for test would run anywhere from $20k to $50k each, depending on complexity, although many of the tests being run would reuse test assemblies. In addition, of course, the operation of the MTS would necessitate operation of the BTF itself to drive the neutron production. Table 2 summarizes our current cost estimates.

Table 2. Notional cost estimates for design, construction, and operation of the Moderator Test Station

Project Management	$0.5M	FY 2024-2026
Design	$2.4M	FY 2024-2026
Procurement	$3.0M	FY 2025-2027
Installation	$1.1M	FY 2025-2027
Total Project Cost	$7.0M	FY -
Contingency	$2.0M	FY -
Total Project Budget	$9.0M	FY -
Test assemblies and consumables	$200k per year	FY 2028+
Staff	$450k per year	FY 2028+

5.1 UPGRADE PATHS

Many of the advanced moderator concepts described above would not be fully realized as part of the MTS project, but would instead be implemented from ongoing operating funds or from dedicated upgrade projects. The project as such includes a single moderator test vessel, for example, while many such vessels would be needed for a full test program, enabling geometric studies as well as studies of different moderating materials which might require different vessel materials, cooling strategies, etc. We would envision most upgrade paths, minor or major, to feature different moderator types, materials, or systems, as we intend to provide a fully developed neutron beam characterization system from first commissioning.

One potential upgrade path for the facility (as opposed to for additional moderators) would entail a second neutron beam, offering a different viewing angle (furthering the study of directional moderators as described above), as well as offering additional possibilities for beam characterization. The initial characterization beamline will likely require sequential measurement of the emission time distributions and the transverse brightness distributions. A second beamline would permit concurrent evaluation of both distributions, improving the speed and quality of a measurement campaign, but would also permit the installation of high speed chopper for measuring energy-dependent emission time distributions via a different mechanism—this different mechanism would permit cross calibration of the measurement resolution in wavelength regions where the two techniques overlap, and would permit measurements at relatively closely spaced wavelengths beyond 5 Å, as distinct from our crystal analyzer techniques, which provide relatively few measurements at long wavelengths, but go to far shorter wavelengths (and more closely spaced sampling) than any chopper system could permit.

The moderator systems we envision to be implemented as part of eventual operational developments or formal facility upgrades would include:

1. Moderators composed of ammonia or other materials providing toxic or caustic hazards not present in the initial facility implementation. The moderator system as initially implemented will permit use of polyethylene and other stable solids, water, hydrogen, and hydrocarbons (e.g., methane, etc.).
2. Liquid moderator materials in flowing loops. While MTS will not deposit sufficient energy that flowing the moderator material will be necessary for cooling purposes, many moderator concepts to be implemented at production facilities do involve flowing loops, and their study at MTS will involve additional infrastructure. Such flowing loops would certainly include conventional liquids (e.g., liquid methane at 100 K), but could also include slurries, slushes, and extrusions. [25]
3. Pelletized moderators—that is, moderators composed of a packed bed of solid pieces of moderating material, typically filled via gravitational or pneumatic means from outside the moderator region. Such studies would also involve some significant level of infrastructure outside the cryostat vessel to support the fabrication and delivery of said pellets, as well as a flowing coolant system to control their temperature.
4. Moving moderator assemblies. In contrast to flowing liquids or slushes, as described above, some moderator concepts involve high-speed movement of solid assemblies, [7], which would require modification or replacement of the cryostat vessel and additional safety considerations.

6. SUMMARY

The Moderator Test Station at the Spallation Neutron Source will facilitate improved operation of Oak Ridge National Laboratory's suite of three slow neutron sources, support production scale deployment of advanced moderator concepts offering significant factors of improvement in performance, and advance the understanding of slow neutron production dramatically for future applications. The potential gains could range from tens of percent in effective reliable beam-time to factors of four to eight in useful neutron brightness, supporting ORNL's mission in neutron related sciences and status as a world-leading facility. We will deliver this capability at a design and construction cost of less than $9.0M, and annual operating cost of approximately $1M thereafter.

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