THE NATIONAL SPALLATION NEUTRON SOURCE (NSNS) PROJECT

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Abstract

The need and justification for new sources and instrumentation in neutron science have been firmly established by numerous assessments since the early 1970s by the scientific community and the U.S. Department of Energy (DOE). In their 1996 budget, the DOE Office of Energy Research asked ORNL to lead the R&D and conceptual design effort for a next-generation spallation neutron source to be used for neutron scattering. To accomplish this, the NSNS collaboration involving five national laboratories (ANL, BNL, LANL, LBNL, and ORNL) has been formed. The NSNS reference design is for a 1-GeV linac and accumulator ring which delivers 1-MW proton beams in microsecond pulses to a mercury target; neutrons are produced by the spallation reaction, moderated, and guided into an experimental hall for neutron scattering. The design includes the necessary flexibility to upgrade the source in stages to significantly higher powers in the future and to expand the experimental capabilities. This paper describes the origins of NSNS, the current funding status, progress on the technical design, user community input and intended uses, and future prospects.

1.0 INTRODUCTION

The National Spallation Neutron Source (NSNS) is an accelerator-based facility that produces pulsed beams of neutrons by bombarding a mercury target with intense beams of 1-GeV protons. It is being designed to meet the needs of the neutron-scattering community in the United States well into the next century. The need and scientific justification for a more intense source of neutrons to keep pace with the burgeoning use of neutrons in science and technology have been well established in numerous assessments by the National Research Council and the U.S. Department of Energy (DOE) since the 1970s.[1]

Many advances in our society are driven by new technologies, and most of these new technologies depend on the development of new materials such as high-strength ceramics and composites, magnetic and electro-optic materials, or new high-transition- temperature superconductors. The approach to developing many of these materials requires understanding their interactions at the atomic level and relating these interactions to macroscopic properties. This usually requires the use of large facilities such as synchrotron radiation sources and neutron sources. Neutrons have several unique advantages for determining the structure and dynamics of a wide range of materials. This is why the demand for neutrons has increased so rapidly and has spread to so many fields of science in the last twenty years, and why there is a need for the NSNS.

2.0 ORGANIZING FOR THE CONCEPTUAL DESIGN

DOE provided $8 million in FY 1996 and FY 1997 to Oak Ridge National Laboratory (ORNL) to initiate the conceptual design and R&D for a next-generation spallation neutron source, the NSNS. Organizing to perform the conceptual design was a challenge. A design was needed in a short period of time and with limited funds. To accomplish this, ORNL formed a collaboration involving five DOE National Laboratories, Argonne National Laboratory (ANL), Brookhaven National Laboratory (BNL), Ernest Orlando Lawrence Berkeley National Laboratory (LBNL), Los Alamos National Laboratory (LANL), and ORNL. This approach assembles the best available expertise and latest technologies, utilizes the experience gained from all the laboratories in designing facilities and operating user facilities, leverages DOE resources, and allows ORNL to tailor the final staff at NSNS to user operations.

3.0 FUNCTIONAL REQUIREMENTS FOR NSNS

The functional requirements for the NSNS have been set by the scientific community and DOE through distillation of the many assessments and events dating from the 1970s that have firmly established the need and justification for a new neutron source.[1] From these studies and a recent NSNS User's Workshop on Performance Metrics and Instrumentation Needs held in Oak Ridge, October 31–November 1, 1996, the requirements the

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*Managed by Lockheed Martin Energy Research Corporation for the U.S. Department of Energy under Contract No. E-AC05-96OR22464.

0-7803-4376-X/98/$10.00

community would like designed into the NSNS are basically the following:

- Short pulse (~1 microsecond) operation
- Initial operation at ~1 megawatt beam power
- A flexible initial design capable of being upgraded "to significantly higher power" in the future
- One target station initially at 30–60 Hz repetition rate, and provisions for a second at 10–20 Hz
- Rapid completion, high reliability, and high availability to the users
- A flexible design that preserves a long pulse (1 millisecond) mode of operation

4.0 ACCELERATOR REFERENCE DESIGN

To address the needs expressed by the neutron community, the NSNS team examined the relative merits of several technology options, including a full-energy linac plus accumulator ring vs a lower-energy linac and a rapid cycling synchrotron.

The NSNS team concluded that a full-energy linac injecting into an accumulator ring was the best combination of technologies for the accelerator system. The relatively modest cost for upgrading the 1-MW accumulator-ring scenario to 2 MW, and the flexibility of this option for additional upgrades to significantly higher powers and long-pulse operation in the future were the primary reasons. A liquid-mercury target rather than a solid target was chosen initially because this appeared the best option to accommodate higher power upgrades in the future, but as design activities have progressed, we now conclude this is the superior choice even at 1-MW power levels. A 60-Hz target was selected for the initial experiment system to accommodate the majority of recommendations from the User's Workshop, although there was a clear need expressed for both high- and low-frequency targets in the near future.

A schematic representation of the accelerator system layout and experiment building for the first 1-MW phase of NSNS is shown in Fig. 1.

4.1 Accelerator Reference Design

The performance parameters for the NSNS accelerator system reference design are listed in abbreviated form in Table 1. The first column of parameters are for the initial stage of the NSNS that would operate at a power of 1 MW.

The second column shows those parameters that would be changed for the NSNS to operate at the upgraded power of 2 MW. As mentioned in Table 1, the NSNS is designed so that the upgrade to 2 MW mainly requires increasing the ion source current to 70 milliamps and boosting the rf power to the existing linac structure to accelerate the additional beam, and this can all be accomplished quite economically.

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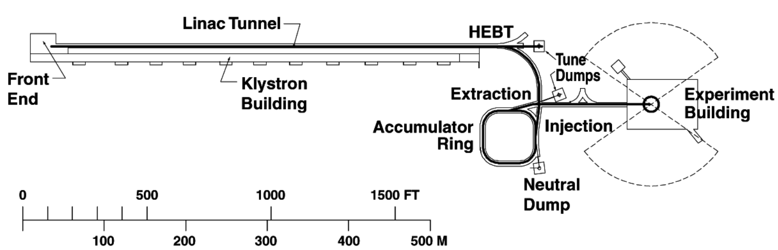

Fig. 1. Schematic representation of the accelerator system layout and experiment building for the first 1-MW phase of NSNS.

Table 1. National Spallation Neutron Source Performance Parameters

	Initial 1.0 MW	Upgrade to 2.0 MW
Pulse repetition rate	60 Hz	
Peak ion source H^- current	35 mA	70 mA
RFQ capture-bunching factor	>80%	
Linac length	493 m	
Linac capture-acceleration efficiency	100%	
Linac duty factor	6.2%	
Linac final beam energy	1.0 GeV	
Accumlator ring circumference	220.7 m	
Ring controlled injection loss	<10%	
Ring orbit rotation time	841 ns	
Pulse length at ring injection	546 ns	
Kicker gap at ring injection	295 ns	
Ring filling fraction	65%	
Number of injected turns	1225	
Ring filling time	1.03 ms	
Protons per pulse on target	1.04×10^{14}	2.08×10^{14}
Protons per second on target	6.3×10^{15}	1.25×10^{16}
Time average beam current on target	1.0 mA	2.0 mA
Beam power on target	1.0 MW	2.0 MW

LBNL has responsibility to design, develop, construct, and integrate the front-end system as a fully operational part of the NSNS accelerator system. The primary function of the front-end system is to produce a beam of H^- ions to be injected into the linac at 2.5 MeV. The ion source technology selected by LBNL to accomplish this is an rf-driven, rather than filament-operated, multi-cusp volume source, chosen primarily because of its stable, low-noise, and high-efficiency operation. This technology has been developed over many years and requires no major breakthroughs to achieve the performance goals.

LANL is responsible for the linac. The linac consists of a drift-tube linac (DTL) that accelerates beam from 2.5 to 20 MeV, a cavity-coupled drift-tube linac (CCDTL) that further accelerates beam to 95 MeV, and a cavity-coupled linac (CCL) that accelerates beam to 1.0 GeV. The DTL operates at an rf frequency of 402.5 MHz while the CCDTL and CCL operate at 805 MHz. Careful beam matching, large aperture-to-beam size ratios, and equipartitioning will greatly reduce the problem of beam halo. The linac and front end provide chopped beams suitable for injection into the accumulator ring.

The particular parameters chosen for the linac are the result of substantial experience with design, construction, and operation of the Los Alamos Neutron Science Center (LANSCE) linac, the Ground-Test Accelerator (GTA), and studies for the APT-linac design. The studies done for the European Spallation Source (ESS) accelerator systems have also been considered.

BNL is responsible for the high-energy beam transport (HEBT) from the linac to the ring, the accumulator ring, and the ring-to-target-beam-transport (RTBT) system. The HEBT system provides the beam transport between the linac and the accumulator ring. The accumulator ring is a simple FODO lattice with four-fold symmetry responsible for accumulating beam pulses from the linac, and bunching them into intense short pulses which are delivered to the target. Pulses of H^- ions from the linac are stripped in a carbon foil and injected into the accumulator ring as protons. The ring accumulates about 1200, 1.0-GeV pulses of about 1-msec length from the linac, overlaps these into a single pulse about 0.5 μsec in length, and ejects them onto the mercury target as intense proton pulses where neutrons are produced by the spallation reaction, and transports it to the neutron target.

4.2 Target Systems

ORNL has primary responsibility for the target systems. The NSNS target systems include two major elements: the neutron source system, which provides neutrons for the scattering instruments, and a set of three beam dumps for the accelerator systems.

The function of the neutron source system is to convert a 60-Hz short pulse (<1 μs), high-energy (17 kJ/pulse), high-average-power (1 MW), 1.0 GeV proton beam into intense, short (~tens of μs) neutron pulses optimized for use by 18 neutron beam lines. Pulse rates of less than 60 Hz are acceptable as long as the nominal 17 kJ/pulse is not exceeded. In addition to the proton beam target itself, the target systems include neutron moderators, reflectors, shielding, utilities, and maintenance systems.

A cross-sectional view of this neutron source system is shown in Fig. 2. The proton beam target will be liquid mercury flowing inside an austenitic stainless steel container. Two ambient temperature water moderators will be located under the target, and two cryogenic hydrogen moderators above the target. Each one of the 18 beam tubes view one of these four moderators. The moderators will be surrounded by a beryllium reflector cooled with heavy water.

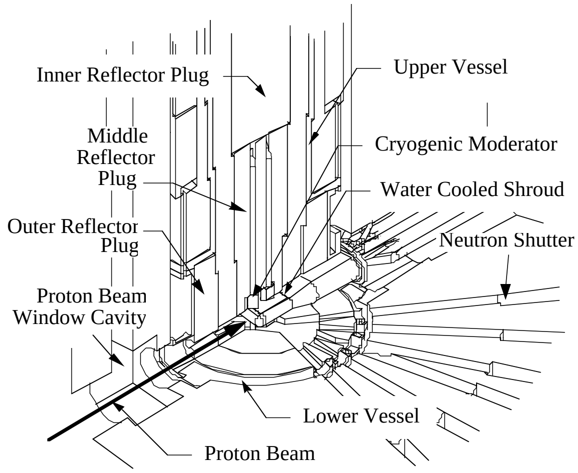

Fig. 2. Cross-sectional view of target station.

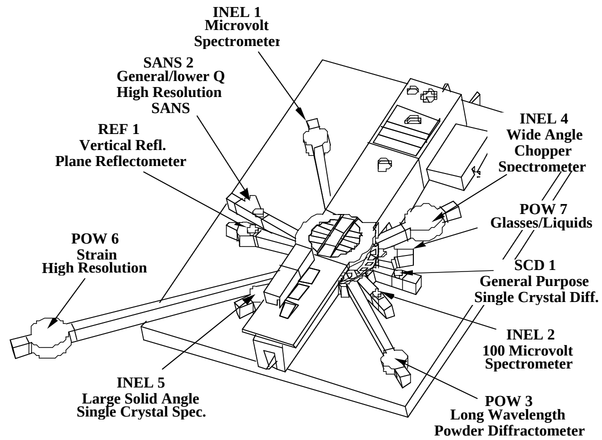

Fig. 3. Layout of experimental hall showing neutron beam lines and initial instrument set.

5.0 FACILITIES FOR SCIENTIFIC EXPERIMENTS

The purpose of the NSNS is to provide neutron beams for DOE and the scientific community. ANL and ORNL are jointly responsible for the instrumentation and experiment facilities.

The plan for staged upgrades of NSNS provides for an initial suite of state-of-the-art instruments and facilities that will grow as user needs evolve. The 1-MW first stage of operations will begin with construction of the target operating at 60 Hz with a reference design set of about 10 neutron-scattering instruments. The broad user community has been involved in the selection of these instruments. Based on recommendations from the NSNS User's Workshop, a layout of this reference set of instruments on NSNS neutron beams was developed and is shown schematically in Fig. 3. This layout was used in determining the size, shape, and other characteristics of the experiment hall shown on the facility footprint in Fig. 1.

6.0 FUTURE UPGRADES

Because of the reference design of NSNS, it is anticipated that the facility will be capable of operating at 2 MW in a short period and at modest cost. This would offer additional flexibility for the design and development of new instrumentation and a second low- frequency (10–20 Hz) target and experiment building. The suggested second stage of power upgrade would require building a second ion source, RFQ, MEBT, and DTL, and "funneling" of beam from two front-end systems operating at 70 mA into the linac. The initial accumulator ring is designed for maximum of 2 x 10^{14} particles per pulse, corresponding to 2 MW of beam power. A second ring would be built to accommodate the increased beam storage. While present plans have been carried only to the 4-MW level, the flexible nature of the baseline configuration and the potential of the planned site allow one to consider a variety of additional and alternate upgrade scenarios.

REFERENCES

1. DOE Basic Energy Sciences Advisory Committee (BESAC) Panel on Neutron Sources, Walter Kohn, Chairman, Michael Rowe, Vice-Chairman, *Neutron Sources for America's Future*, U.S. DOE Office of Energy Research, January 1993 and references therein.