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Development of High Powered Target Systems for the Spallation Neutron Source and the Muon Collider/Neutrino Factory

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Abstract. The purpose and requirements of the Spallation Neutron Source (SNS) and the target area of the Muon Collider/Neutrino Factory are presented. Parts of the technologies that are being utilized to design these facilities are discussed. Emphasis is given to the technology issues that present the greatest scientific challenges.

SPALLATION NEUTRON SOURCE

In many areas of physics, chemistry, biology, materials, and nuclear engineering, it is extremely valuable to have a very intense source of neutrons so that the structure and functionality of materials can be studied. Discussions on all the Spallation Neutron Sources under consideration or development are given in Refs. 1–3. One facility under construction at ORNL for this purpose is the Spallation Neutron Source (SNS). This facility will consist basically of three parts: 1) a high-energy (~1 GeV) and high-powered ($\lesssim$ 2 MW) proton accelerator (60 Hertz, <1.0 μs/pulse, <33 kJ/pulse), 2) a target/moderator/reflector/ shielding/shutter/utility [Target Systems (TS)] assembly, which converts part of the proton beam power to low-energy ($\lesssim$ 2eV) neutrons through spallation and delivers them to the third part, 3) the neutron scattering instruments. A picture showing the overall facility is given in Fig. 1. LBNL is responsible for the front end, which is currently being shipped to ORNL for installation; LANL/JLAB, the linac [parts of the Drift Tube Linac (DTL) and klystrons have been shipped to ORNL for installation]; BNL, the high-energy beam transport system and accumulator ring; ORNL, Target Systems and Conventional Facilities; and ANL, the neutron scattering instruments.



FIGURE 1. SNS configuration.

Accelerator Components

The SNS is composed of several sequential accelerator systems with a resultant proton energy of ~1.0 GeV delivered to the neutron production Hg target.

Beginning the process is a Cesium enhanced H- ion source, the Front End (FE) system. The next accelerator unit is the RFQ, which accelerates the H- beam to an energy of ~2.5 MeV. The last section of the FE system is the Medium Energy Beam Transport (MEBT). In the MEBT, the proper bunch structure of the beam is developed using buncher cavities to match the rotation frequency of the accumulator Ring.

After the front end, the H- beam enters the first of four distinct accelerating structures within the Linac. The first two parts are a DTL which accelerates the beam to ~87 MeV and a Coupled Cavity Linac (CCL) which accelerates the beam to ~187 MeV. The final two sections are Superconducting Radio Frequency (SRF) structures with a mechanical (relativistic) beta of 0.61 (~325 MeV) and 0.81 (~1.06 GeV).

At the injection region of the Ring, the H- beam traverses thin carbon foils that strip the two electrons from the H- beam and allow the resultant protons to be circulated and stored in the Ring. After ~1000 turns are accumulated in the Ring, a series of fast rise-time dipole elements (kickers) are triggered to extract the stored $\lesssim 2\text{x}10^{14}$ protons circulating in the Ring for delivery to the Hg target.

CP642, *High Intensity and High Brightness Hadron Beams: 20th ICFA Advanced Beam Dynamics Workshop on High Intensity and High Brightness Hadron Beams,* edited by W. Chou, Y. Mori, D. Neuffer, and J.-F. Ostiguy
2002 American Institute of Physics 0-7354-0097-0

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Scope and Requirements of Target Systems

The scope of TS is to provide low-energy neutrons from high-energy spallation reactions for short-pulsed neutron scattering instruments and to develop three-proton beam dumps, one for the linac and two for the storage ring (injection and extraction).

The first requirement for TS is to safely and reliably receive a proton beam in a flowing mercury target with the characteristics defined in the Introduction. As a second requirement, TS must be able to convert part of the proton beam power into short, high-intensity pulses of low-energy neutrons (both ambient and cold) which can be used by up to 24 neutron beam lines, and which meet the requirements of the neutron scattering instruments.

Building a TS for the SNS requires the development of a target, in this case a flowing-mercury target, which can give maximum neutron yield; a reflector/moderator assembly to trap, reflect, and thermalize (ambient and cryogenic temperatures) the neutrons; a vessel system to contain the reflector/moderator assembly and provide support and alignment for the start of the neutron guides; bulk shielding and shutter assemblies to shield the personnel from the neutrons and to allow the closing of the low energy neutron pathways so samples can be replaced in the neutron scattering instruments; utilities (light and heavy water, vacuum and He) to help with the cooling and functions of the various systems; remote handling to accommodate the change out of the target, inner reflector assembly, neutron guides and shutters, proton beam window, etc.; and Instruments and Controls for the majority of the subsystems mentioned above. Currently, the detailed design of the TS is almost complete and many procurements have been placed.

Target Development R&D

Five areas have been defined as needing R&D to develop a successful Target Systems[4]. These are (1) steady-state power handling, (2) remote handling and operation, (3) radiation damage, (4) material compatibility, and (5) thermal shock. All of the issues have been addressed or solved except for the erosion through cavitation induced pitting brought on by the thermal shock of the beam. After testing at the WNR in 2001, pitting (both large and small) was detected. Additional tests are planned in 2002 to assess possible solutions based on geometry, mitigation methods, and materials.

MUON COLLIDER/NEUTRINO FACTORY: DEVELOPMENT OF THE TARGET AREA, REMOTE HANDLING, AND GRAPHITE TARGET FOR THE μ/ν

The development of a high-intensity source of muons that can be used for collider experiments or for the production of high-energy neutrinos opens the door for a broad range of physics experiments. A large effort is underway in this country to develop such a source. The concept is to use a high-intensity proton beam (~24 GeV, ~1MW, ~15 hz) incident on a Hg jet or graphite target to produce pions which decay to give the muons. These muons will be magnetically captured and then accelerated in a collider ring or in a "race track" system. The "race track" itself can be pointed at a detector located many hundred kilometers away. This part of the paper describes some of the target remote handling needs, which are necessary at such a facility, and also on some of the R&D that is underway on the graphite target.

Remote Handling Associated with the Target Area

Facility design concepts have been developed for graphite and mercury target systems based on the requirements to operate and maintain these different targets. A picture of a possible layout of the target

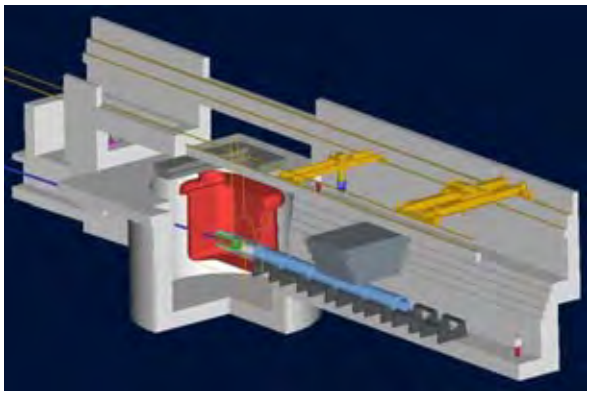


FIGURE. 2. Layout of the target area, decay channel, nuclear shielding, and remote handling for the muon/neutrino factory.

area, decay channel, nuclear shielding, and remote handling devices is given in Fig. 2. Both systems have highly activated components that must be replaced periodically using remote handling equipment and tools. For the case of a graphite target, overhead access was the preferred approach and the hot cell was located above the target area. For the mercury target, overhead access combined with below-grade access

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was necessary in order to maintain the mechanical components of the system, i.e., pumps, valves, and mercury storage. A more detailed writeup can be found in Refs. 5 and 6.

Graphite Rod Test at the Lansce-WNR and ORNL

Graphite rods were instrumented with fiber optic strain gages to measure the dynamic response from the LANSCE 800 MeV proton beam pulses. The energy deposition produced by the protons in the graphite is similar to that anticipated at a Mu/Nu facility. Structural analysis simulations of the response were performed with the finite element code, ABAQUS/ Explicit.[7] The predicted and measured strains at the mid length location compare favorably.

Sublimation of the radiatively cooled graphite target is a limiting feature of the target's lifetime. Tests have been carried out in a vacuum environment to determine the useful lifetime at about 2000ºC. The data, which is in reasonable agreement with theoretical data, indicates that the lifetime is short, but acceptable. This experiment is described in detail in Ref. 8. Tests are also underway to determine the lifetime in a 1 atm He environment, which should increase the lifetime.

Neutronics and Shielding

Substantial analysis based on the MARS code [9] simulations have been carried out [10] which includes pi/mu production and collection, energy deposition and residual dose levels, shielding and component lifetimes. The optimized system would provide 0.37 captured muons per proton at 36 meters from the tilted mercury jet impacted by 24-GeV protons. If a graphite target had been used, this number would be reduced by about a factor of two. Peak energy deposition and dynamic heat loads in the superconducting coils of a 20-T hybrid solenoid are kept below the tolerable limits via carefully designed shielding made of water-cooled tungsten-carbide balls. With the current setup, the anticipated lifetime of main components exceeds 15 years. The inner shielding is very radioactive, with residual dose rate up to 1 kSv/hr. This will require remote control and robotics for the inner parts of the system. This dose drops by two orders of magnitude after several weeks. The residual dose outside the cryostat is significantly lower, of the order of 100 mSv/hr.

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