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Spallation neutron source target station design, development, and commissioning

J.R. Haines*, T.J. McManamy, T.A. Gabriel, R.E. Battle, K.K. Chipley, J.A. Crabtree, L.L. Jacobs, D.C. Lousteau, M.J. Rennich, B.W. Riemer

Oak Ridge National Laboratory, PO Box 2008, Oak Ridge, TN 37831-6476, USA

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ABSTRACT

The spallation neutron source target station is designed to safely, reliably, and efficiently convert a 1 GeV beam of protons to a high flux of about 1 meV neutrons that are available at 24 neutron scattering instrument beam lines. Research and development findings, design requirements, design description, initial checkout testing, and results from early operation with beam are discussed for each of the primary target subsystems, including the mercury target, neutron moderators and reflector, surrounding vessels and shielding, utilities, remote handling equipment, and instrumentation and controls. Future plans for the mercury target development program are also briefly discussed.

1. Introduction

The spallation neutron source (SNS) target station consists of the systems and equipment needed to safely convert the high-energy protons from the SNS accelerator to low-energy neutrons that are delivered to 24 neutron beam lines. Each sub-microsecond accelerator pulse sends a beam of 1 GeV protons to the target. The Target Station has been designed to accommodate up to 2×10^{14} protons per pulse (i.e., up to 2 MW for the nominal proton pulse repetition rate of 60 Hz). The protons produce neutrons through spallation reactions with the mercury target. The high-energy spallation neutrons are converted to low-energy neutrons through interactions with the SNS neutron moderator and reflector system. Approximately 5 m of iron and 1 m of heavy concrete shielding surround the target for biological shielding. The initial design layout was driven by a number of factors:

- safety,
- neutronic performance,
- remote handling and maintenance,
- experience at other spallation sources, and
- previous design studies.

Safety considerations led to the design philosophy of not relying on the target shell for protection of the public or workers because there was no database for mercury target containers. This led to the requirement to provide a vessel around the target container to hold the mercury, which could be released if the primary container suffered a breach. Furthermore, a separate window was required to segregate the target region from the accelerator. Yet another layer of protection was added to allow for failure of the vessel in a seismic event and collect any mercury released in the bulk shielding through a drain path to a shielded tank. The desire to separate the hydrogen system needed for cryogenic moderators from the mercury loop components to reduce the chances for a mercury release caused by a hydrogen release and ignition led to the hydrogen process systems being located above the target monolith and away from the mercury process loop. Finally, the design of the mercury process loop included the assumption that the inventory could be accidentally released from its normal containment, which led to a stainless steel lined cell with a safety credited collection basin at the lowest spot to collect any spills.

Neutronic performance considerations led to the set of three cryogenic hydrogen moderators and one ambient water moderator with a heavy water cooled beryllium reflector. The proton beam profile on the target was a compromise between performance and the desire to keep the peak current density low to improve target lifetime. This resulted in a beam profile “stretched” horizontally, similar to what was proposed for the European spallation source [1].

Remote handling considerations led to a desire to minimize the number of separate components that had to be replaced remotely and to group components with similar projected lifetimes together. Because the target was predicted to have a much shorter life than the moderators and reflectors, it was designed to be replaced

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* Corresponding author. Tel.: +1 865 574 0966; fax: +1 865 241 6909.
E-mail address: hainesjr@ornl.gov (J.R. Haines).

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separately within a week. All the moderators and a beryllium reflector were included in one assembly to be replaced as a unit. The outer radius of this reflector plug was set so that the peak damage on the water cooled shielding outside of this unit was below 10 dpa for a 40-year life at 2 MW (i.e., the projected lifetime of the facility). Because there was some concern that water cooled stainless steel with radiation damage levels between 2 dpa and 10 dpa could be susceptible to irradiation assisted stress corrosion cracking, this shielding was designed so that it could be replaced remotely, although the expectation is that it will last the lifetime of the facility. The core vessel, which included water cooled shielding near the midplane and a mercury collection region in the bottom, surrounded this latter shielding. This vessel was not designed for replacement, so its inner radius was set so that the lifetime damage was below 2 dpa. Based on embrittlement concerns, the proton beam window has a projected life of about 1 year at 2 MW, corresponding to a damage level of 10 dpa, so it was designed to be replaceable without removing the moderator reflector assemblies. All the mercury process loop components were designed to be maintained remotely in a target service bay (TSB) equipped with remote handling equipment.

Experience at other spallation facilities and design studies also influenced the design. The large shielding cart used for moving the target from the operating position to a hot cell was adopted from the ISIS design [2]. The selection of Inconel-718 for the proton beam window material was based on the experience at ISIS and the Los Alamos Neutron Science Center (LANSCE). A vacuum sealing concept using inflatable sections and differential vacuum pumping that was developed at the Paul Scherrer Institut for use in high radiation zones was adopted for the proton beam window and target. The concept for vertical insertion and removal of the reflector/moderator plug is similar to that proposed by Los Alamos National Laboratory (LANL) for a 1 MW target station [3]. Nearly all systems benefited from design reviews by experts from similar facilities who were willing to share their experience.

Fig. 1.1 shows a simplified model of the target building and some of the neutron scattering instruments. The building is approximately 60 m by 200 m with a basement region for utility systems, an instrument floor as shown in the figure, and an upper level where the hydrogen system components are located. An external building houses the helium compressors used for the moderator refrigeration system. The central region of the target building contains the target monolith, target service bay (TSB), and an enclosed central high bay region with a 50-t crane.

Fig. 1.2 shows a projection made from the computer aided design model of the target monolith including all major components. This model was used for design, interference checking, and developing the installation plans. The major elements of the SNS Target Station, which are discussed in subsequent sections of this paper, include

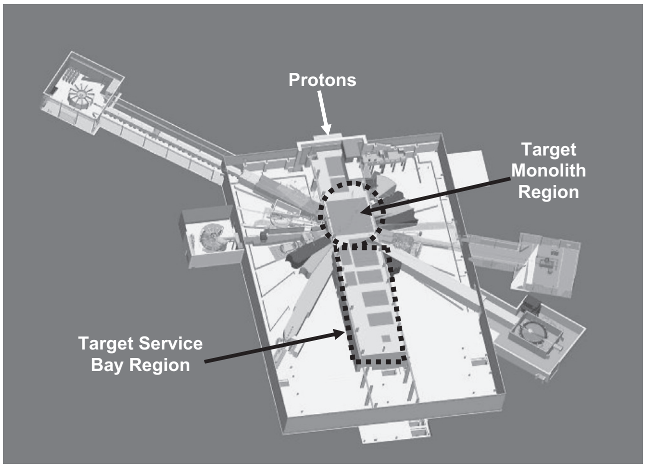

Fig. 1.1. Spallation neutron source target building instrument floor.

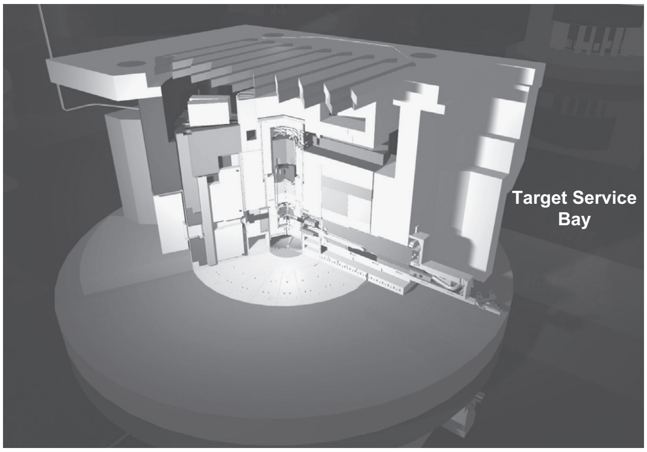

Fig. 1.2. Target monolith engineering model.

- mercury target and associated process loop;
- neutron reflector and moderator systems, including three hydrogen moderators and their associated cryogenic systems and one ambient water moderator;
- core vessel and proton beam window that enclose the actively cooled portions of the target station and separate it from the accelerator environment;
- bulk shielding within a 5 m radius surrounding the target (referred to as the target monolith), including 18 shutters for neutron beams with provisions for 6 shutters to contain two beam lines and an associated hydraulic drive system;
- utility systems, including heavy and light water, vacuum systems, helium and nitrogen systems;
- remote handling systems; and
- instrumentation and controls.

2. Mercury target

The primary function of the SNS target is to produce neutrons through nuclear spallation driven by the interaction of the high-energy proton beam with the target material. Mercury, rather than water cooled solid heavy metal, was selected as the target material for SNS primarily because of its potential for increased power handling capability and greatly reduced waste stream. Another significant advantage is that no active cooling for the mercury is required after shutdown because the decay heat is distributed over a large mass. Mercury was also selected as the reference liquid target material because it (1) is a liquid at room temperature, (2) has good heat transport properties, and (3) has high atomic number and mass density resulting in high neutron yield and source brightness.

The mercury target is part of a system that comprises

- mercury;
- a vessel (referred to as the target module) for containing the mercury in the region where the proton beam strikes;
- a process loop for circulating, cooling, and storing the mercury;
- a carriage that moves the target module between its operating and maintenance positions;
- vacuum, water, nitrogen, and helium utility systems; and
- shielding.