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# Design-oriented study on target station for spallation neutron source at KOMAC

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**Abstract**

A neutron-production target system, composed of targets, moderators, reflectors, and shielding, has been conceptually designed for the future MW-class spallation neutron source based on a high-intensity proton accelerator at KOMAC. For targetry, we tentatively adopted a fixed-metal target concept; tantalum-clad tungsten plates in a water-cooled target shroud made of stainless steel. In the thermal analysis and stress calculations using ANSYS, the von Mises stress was found to exceed the yield stress of SS316L at the edges of the structure for a 500-kW proton beam on target. Relatively high stress at edges seems to be a stress concentration that could be reduced by minor design modifications. Preliminary calculation results for a conservative design of target shielding show that radiation dose after the outermost shielding could be lower than 10 μSv/h in a 500-kW operation condition, implying that the design could be optimized to reduce construction costs without loss of shielding performance.

**Keywords** Targetry · Moderator · Reflector · Shielding · Spallation neutron source

## 1 Introduction

A spallation neutron source is a research facility that produces neutrons using high-energy proton accelerators. These neutrons are used in a broad range of disciplines including physics, material science, biology, and chemistry. Recently, the impact of high-energy particles on semiconductor devices becomes a serious issue in related industries as semiconductor process becomes unprecedentedly fine; on-board devices in aerospace and satellite industries, mission-critical devices in automotive, financial, and medical industries require the evaluation of radiation effects for a high level of reliability.

A proton linear accelerator was developed in 2012, and KOMAC was established in Gyeongju for research and development of accelerator and beam utilization. It is a high-power pulsed machine designed to accelerate a 100-MeV proton beam up to 160 kW at 60 Hz [1]. The goal is the development of accelerator-related techniques to improve national capability towards the future MW-class spallation neutron source in Korea. In this endeavor, we are studying a neutron-production target system, conventionally composed of targets, moderators, reflectors, and shielding, for the production of spallation neutrons. Here, we present the conceptual design of the neutron-production target system and its preliminary analysis results.

## 2 Project planning of Korea Spallation Neutron Source

The construction of Korea Spallation Neutron Source (K-SNS) would be a huge research and development project, and the progress is bit tardy in technical and political decision-making. In 2022, the direction of main accelerator development has been discussed in three consecutive committees; a rapid-cycling synchrotron fed by an injector linac was suggested as options for facility upgrade in the distant future. The proton energy was set in consideration of applications in deep space and national security as well as basic science. In Fig. 1, the artist's drawing of Korea spallation neutron source on the KOMAC site (440,000 $m^2$) is presented, while buildings on the right side are already constructed at the half of the site for the operation of the

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**Fig. 1** Artist's drawing of Korea Spallation Neutron Source at KOMAC. The facility includes an injector linac, rapid-cycling synchrotron, high-power target station, and proton and neutron beam lines for beam utilization. Buildings on the right side of the picture are already constructed at the site for the operation of the 100-MeV proton linear accelerator

100-MeV linear accelerator by the proton engineering frontier project (PEFP) from 2002 to 2012.

## 3 Target station

Target station is an essential part of a spallation neutron source facility to produce neutrons and protect personnels against hazardous radiations. Spallation neutron source facilities established in the early twenty-first century have almost the same structure of target station, only target assemblies are clearly different depending on beam parameters. There are three major types of spallation targetry in the world; fixed metal, liquid metal, and rotating metal targets.

A fixed-metal target is the most common type of targets employed in a wide range of energy and beam power. Generally, solid tungsten is used, but other materials such as beryllium, copper, tantalum or lead can be considered. Fixed-metal target is deemed capable for sub-MW target systems up to a few hundred kW, where the upper limit is determined by beam parameters and target design. RAL-ISIS (0.8 GeV, 192 kW) [2] and IHEP-CSNS (1.6 GeV, 500 kW) [3] are operating facilities with fixed-metal targets.

A liquid-metal target is developed for MW-class neutron factories at the dawn of the twenty-first century. In the system, eutectic alloy or liquid mercury circulating target chamber behaves as coolant as well as target material. The two flagship neutron facilities, ORNL-SNS (1.3 GeV, 2 MW) [4] and J-PARC-MLF (3.0 GeV, 1 MW) [5], are operating liquid-metal target systems.

A rotating-metal target is the most advanced targetry for the next-generation neutron source. Rotational frequency is comparable with the repetition rate of its driver accelerator, allowing incident beam energy to be spread across target blades. It has an extended life compared to the other types by reducing thermal density and radioactivity in target materials. ESS (2.0 GeV, 5 MW) [6] and STS project of SNS (1.3 GeV, 700 kW) [7] are developing rotating target systems.

For K-SNS, we designed target station accommodating tantalum-clad tungsten targets, cryogenic moderators, reflectors, and other ancillary components for accepting a 500-kW proton beam from an accelerator. The conceptual modeling of the target station is shown in Fig. 2. The main concept of the target station was adopted from operating facilities, SNS [8], J-PARC [9], and CSNS [10].

### 3.1 Target

For target assembly, we tentatively adopted a fixed-metal target concept as in ISIS [11] and CSNS [10], and we imitated

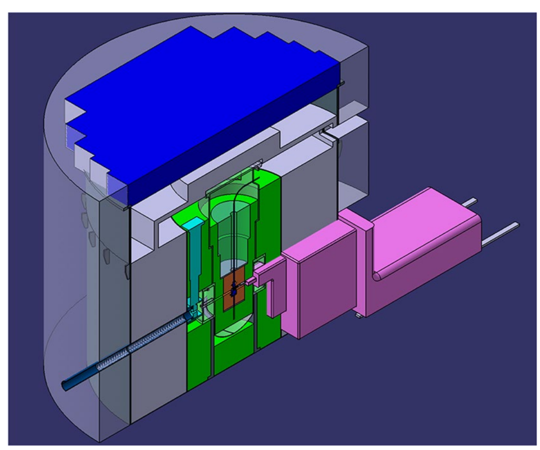

**Fig. 2** Preliminary design of target station that accommodates tantalum-clad tungsten targets, cryogenic moderators, reflectors, and other ancillary components for admitting a 500-kW proton beam from an accelerator. The major concept has been adopted from other neutron facilities such as SNS and J-PARC

the design of the second target station project at SNS [8]. It has 19 tantalum-clad tungsten plates in water-cooled target shroud made of stainless steel (SS316L). It is expected that only 0.1% of incident energy be deposited in the 2-mm thick steel window of the target shroud. The weight of the target plates is 22.4 kg and the total weight including the target shroud is 58.8 kg. The present target model and its thermal analysis results are shown in Fig. 3.

Thermal analysis of the target design was done using ANSYS CFX 19.2; the single-phase analysis was done with the $k$–$\epsilon$ model by setting coolant temperature and reference pressure to 43 °C and 3.5 bar. The maximum temperature was observed in the middle of an 18th target plate that shows the highest surface temperature as well. The average temperature and velocity of fluid between target plates were 46 °C and 9.9 m/s, respectively. Material properties of tungsten and stainless steel were obtained from ITER material properties handbook [12], while tantalum properties were adopted from ANSYS database, for von Mises stress calculations. Stress calculations showed that the maximum stress exceeds the yield stress of steel at the edges of shroud abutting on target plates. Relatively high stress at the edges of the target structure seems to be a stress concentration, so some fillets could be added to internal edges to reduce the stress concentration. Also, thick target plates that show immoderate temperature and stress could be sliced into thinner plates for relieving thermal stress. On the other hand, the maximum temperature of the window of the target shroud was 49 °C and von Mises stress was 66 MPa, which is below the yield stress of stainless steel. Maximum deformations due to thermal expansion lie between 0.1 and 0.2 mm, and they were found at the front window and the side of the target shroud.

### 3.2 Moderator, reflector and shielding

Two moderators are considered in the station design; an upper moderator for high resolution and a lower moderator for high flux configurations delivering neutrons to 18 beamlines. Room-temperature and cryogenic moderators could be installed inside the station, while the size and position of moderators should be optimized according to neutronic calculations. Depending on neutron science program and strategy, including the programs in the neutron science facility of HANARO which is a 30-MW research reactor, neutron instruments and moderator configurations need to be coordinated.

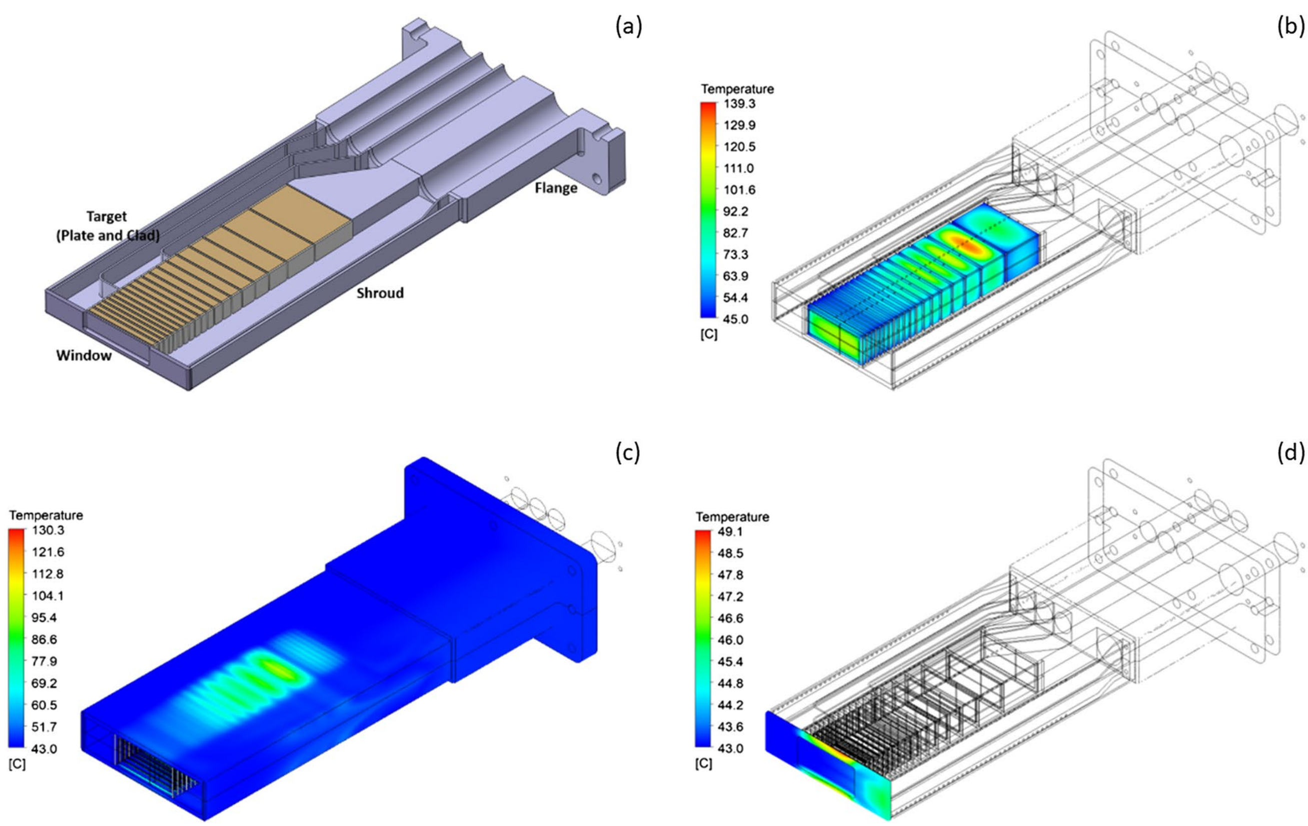


**Fig. 3** **a** A 3-dimensional modeling of targetry and its temperature distribution on **b** tungsten blocks, **c** stainless steel shroud, and **d** front window for a 500-kW proton beam on target. In the analysis, the single-phase analysis was done with the $k$–$\epsilon$ model by setting coolant temperature and reference pressure to 43 °C and 3.5 bar

The moderators are surrounded by a beryllium reflector and shielding. A reflector is mostly made of pure beryllium; it is considered a good neutron scatterer for high-power neutron sources because of neutron cross-sections and good thermal conductivity of 200 W/m K. The diameter and height of the reflector are 0.8 m and 1.0 m, giving the total weight around 900 kg. The disadvantage of beryllium is that the number of manufacturers is very limited so manufacturing-cost is extremely high. In 2022, the cost estimation of a beryllium reflector was 13 million KRW/kg. After neutronic calculations and optimizations of target-moderator-reflector (TMR) assembly, cheaper metals could replace part of the reflector body to release the price burden. The present model of TMR assembly adopted core vessel system that incorporates moderators, reflectors and ancillary components for active cooling, while the target is technically attached to the target trolley (Fig. 4). The diameter and height of a core vessel are about 3 m and 6.5 m with the total weight of 168 tons, and it is supposed to be replaceable for the maintenance of the target system.

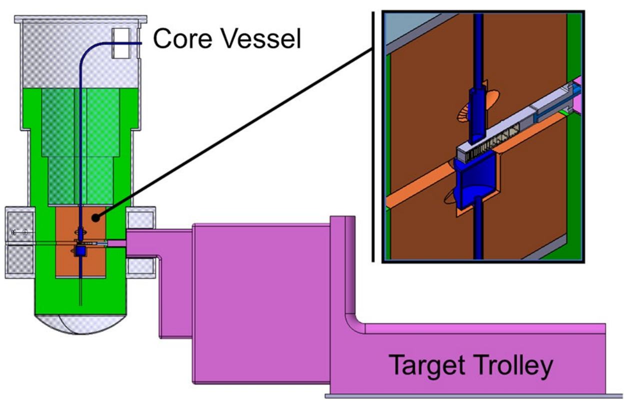


**Fig. 4** Present model of core vessel incorporates moderators, reflectors and ancillary components for active cooling. The diameter and height of a core vessel are about 3 m and 6.5 m with a total weight of 168 tons, and it is supposed to be replaceable for the maintenance of target system

Shielding is composed of inner iron and outer heavy-concrete blocks. The total diameter is 12.8 m, and the total weight is estimated to be 7400 tons. All shielding blocks should be designed in a modular manner; those blocks could be assembled and disassembled in maintenance. Every beamline has its beam shutter so that it can be individually opened or closed during beam time. Heavy shielding is to maintain radiation dose level below 10 $\mu$Sv/h after the outermost shielding in the full-power operation of a neutron source. Neutronic calculations were partially done using MCNPX with the Bertini physics model for the described shielding geometry, and radiation dose was calculated using F4 tally and AP dose conversion coefficients in ICRP-116 [13]. Preliminary results show that radiation dose after the outermost shielding could be lower than 10 μSv/h in a 500-kW operation condition (Fig. 5). The present shielding design is quite conservative, so we expect that the design could be optimized to reduce construction costs without loss of shielding performance. Also, radiation damage, lifetime and radioactivity of the targetry induced by an intense proton beam need to be evaluated later.

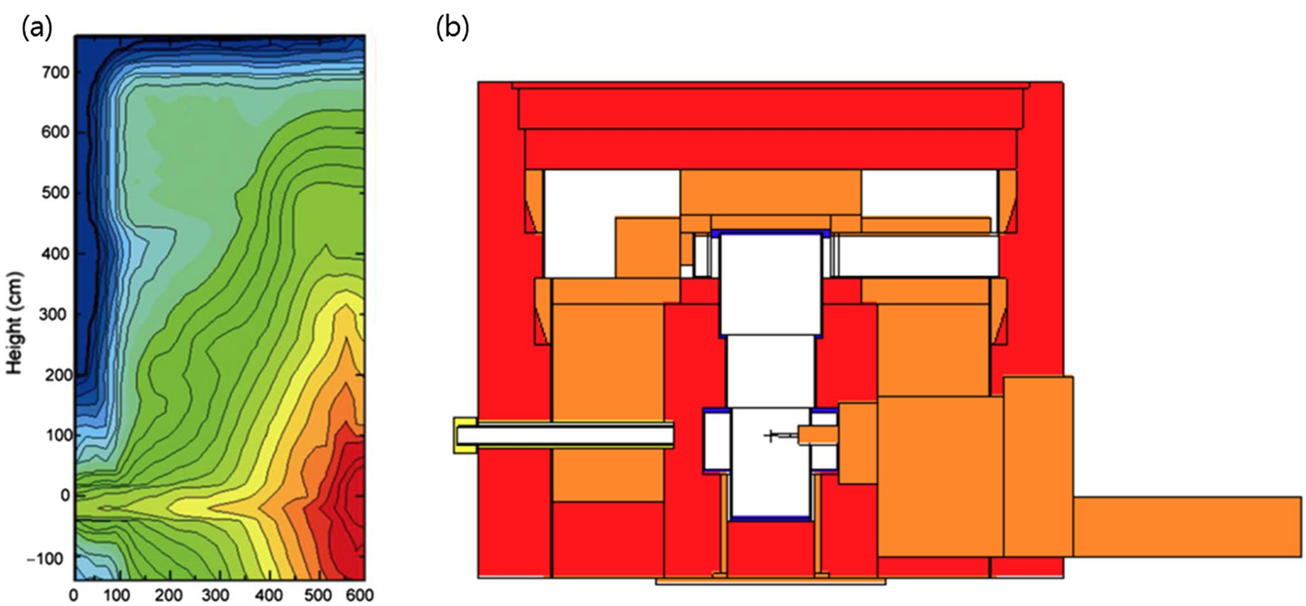


**Fig. 5** **a** Preliminary result of radiation dose map calculated for **b** the geometry of shielding modeled in MCNPX. Preliminary calculations show that radiation dose after the outermost shielding could be lower than 10 μSv/h

## 4 Summary

Neutron science is essential in most advanced science and technology fields: physics, chemistry, biology, material science, batteries, aerospace, and semiconductor industries. For the next-generation neutron source that inherits the neutron science program in Korea, we are planning a project for a spallation neutron source based on a high-power proton accelerator at KOMAC. In this effort to develop a master plan for the project, we made a conceptual design of the target station in the light of neutron facilities over the world. Fixed-metal targetry was designed, simulated and evaluated in terms of finite element analysis using ANSYS. Also shielding blocks surrounding the core vessel were designed, and radiation shielding analysis was done with MCNPX calculations. The presented design and simulation results are very preliminary, further design study and extensive calculations are inevitable. In the near future, the technical design of an accelerator, high-power targetry and target station will be required and core technologies in the critical path should be secured for the successful launch of the project.

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