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# Neutronics Analyses for the ORNL's Spallation Neutron Source Second Target Station

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**Abstract.** This paper presents an update of the status of the neutronics analyses performed for the Second Target Station (STS). The target station is driven with short (less than 1 micro second long) proton pulses at 15 Hz repetition rate and 700 kW proton beam power. The target will be optimized for high intensity and high resolution long wavelength neutron applications. The STS will accommodate 22 beamlines and will expand and complement the current national neutron scattering capabilities. The proton beam footprint as small as acceptable from the mechanical and heat removal aspects is planned to generate a compact-volume neutron production zone in the target, which is essential for tight coupling of the target and the moderators and for achieving high-intensity peak thermal and cold neutron fluxes. Present efforts to develop high fidelity engineering models for neutronics analyses with automatic CAD-to-MCNP conversion are described. Heating rates and radiation damage, which provide input in the engineering design are presented and the performance of the moderators is briefly addressed.

## 1. Introduction

The Spallation Neutron Source (SNS) and the High Flux Isotope Reactor (HFIR), two of the world-class neutron scattering facilities, are located at the Oak Ridge National Laboratory. The SNS and HFIR are funded by the U.S. Department of Energy, Office of Science, Office of Basic Energy Science, and are operated as user facilities, available to researchers from all over the world. Currently there are thirteen neutron scattering instruments in operation at the HFIR and twenty at the SNS First Target Station.

The SNS was designed from the beginning to allow addition of the Second Target Station (STS), and an upgrade of the accelerator power. At this time both advancements: the accelerator upgrade and the construction of the STS are in preparation.

Initially a stationary tungsten target was envisioned for the STS [1]; however, closer investigation of accident scenarios revealed that in the case of a loss of active cooling, decay heat alone could cause

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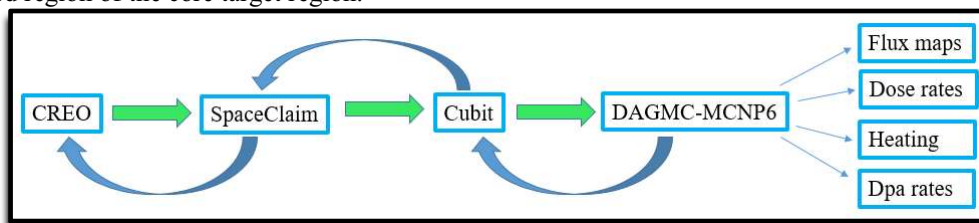
damage to the target and unacceptable consequences for the facility. For this reason, the current baseline STS design calls for a rotating tungsten target. The target station is driven with short (less than 1 micro second long) pulses of 1.3 *GeV* protons. Originally a 10 *Hz* pulse repetition rate and 467 *kW* beam power was proposed, while the current plan calls for a 15 *Hz* repetition rate and 700 *kW* beam power. The STS is optimized for high intensity and high resolution long wavelength neutron scattering applications. The proton beam footprint as small as acceptable from the mechanical and heat removal aspects is planned to generate a compact-volume neutron production zone in the target, which is essential for tight coupling of the target and the moderators and for achieving high-intensity peak thermal and cold neutron fluxes. The STS will accommodate 22 beamlines.

Recent neutronics analyses efforts were focused on transition to automatic conversion of computer-aided design (CAD) engineering models into high-fidelity models suitable for the analysis with Monte-Carlo (MC) radiation transport code MCNP6 [2].

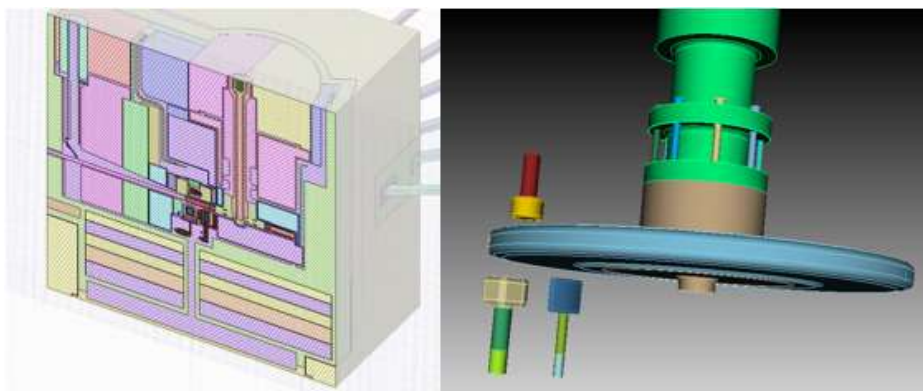
## 2. Conversion of CAD to MC models

Two tools for the automatic conversion of CAD to MC models were tested: SuperMC developed by the FDS Team, China [3, 4] and Direct Accelerated Geometry Monte Carlo (DAGMC) Toolkit integrated into MCNP6, which is developed at University of Wisconsin-Madison [5].

Currently most of the work at SNS is performed with DAGMC. The CAD design starts in CREO [6]; in the next step the model is imported in SpaceClaim [7] where geometry checks and cleanups are performed. In the next step, the model is transferred in Cubit [8] as an ACIS file and additional checks of the geometry are performed, followed by imprinting and merging of surfaces and assigning materials to the volumes. Then the faceting is performed and the model is exported in the h5m file format. Finally, the “make\_watertight” and “check\_watertight” tools of the DAGMC toolkit are applied to assure the watertightness of the model. Several iterations may be required to develop acceptable MC model. A flowchart of the CAD to MC model conversion is shown in figure 1. The model developed with the automatic conversion is shown in Fig.2. The model is a 3 x 3 x 3 m cube intended to bound the actively cooled region of the core target region.



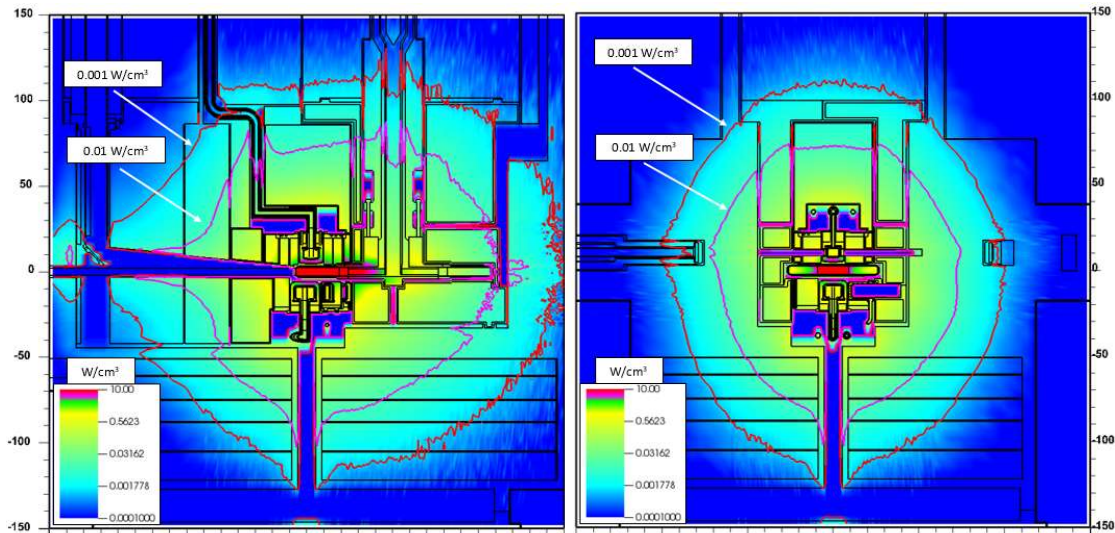
**Figure 1.** Flowchart of the CAD to MC model conversion.



**Figure 2.** Vertical section through the MCNP6 model (left); detail of the rotating target and the moderators (right).

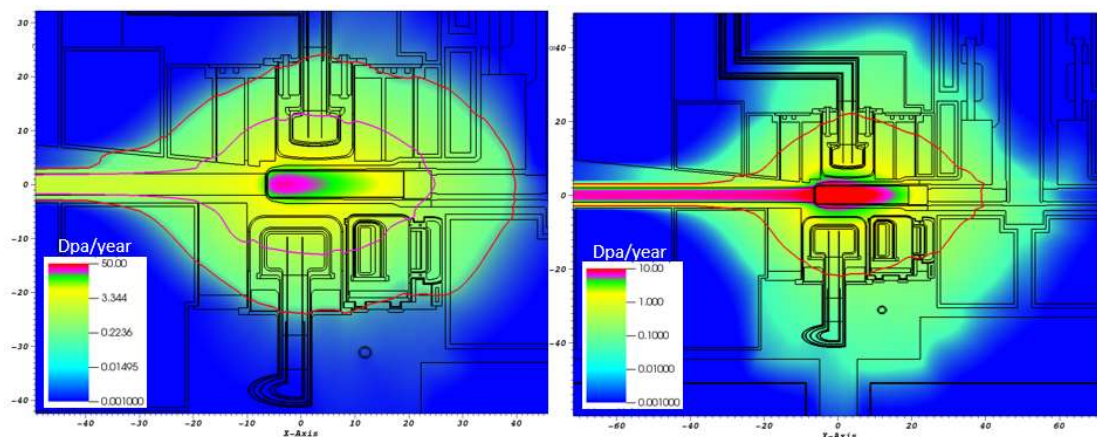
### 3. Results

Using model developed as described in the previous section heating rates and maps of displacements-per atom were calculated. Figure 3 shows heating rates around the rotating target. The isoline marking



**Figure 3.** Heating rates around the rotating target: at left is the vertical section along the proton beam direction and on the right is vertical section perpendicular to the proton beam direction.

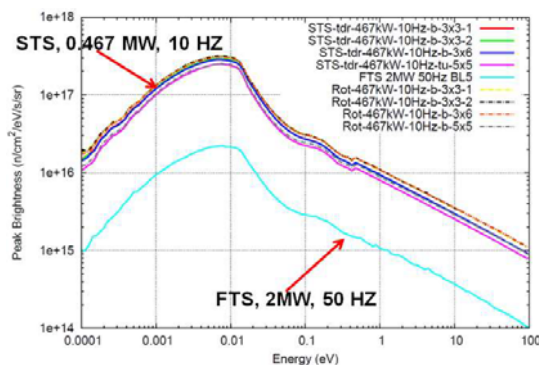
$0.001 \text{ W/cm}^3$  bounds the volume within which active cooling is typically required while the  $0.01 \text{ W/cm}^3$  isoline defines the boundary of components requiring contact cooling. Figure 4 depicts displacement per atom (*dpa*) rates around the rotating target in aluminum and stainless steel; values shown are valid only for the static components. The *dpa/year* rates were calculated assuming 5000 hours of operation per year. The *dpa* rates can be used for determining the lifetime of certain components. This information is required for operational planning and making decisions regarding the segmentation of core components. The high fidelity model also provides integrated heat loads in the core components. This information will be used to size cooling water flows, pipe sizes and cooling channels.



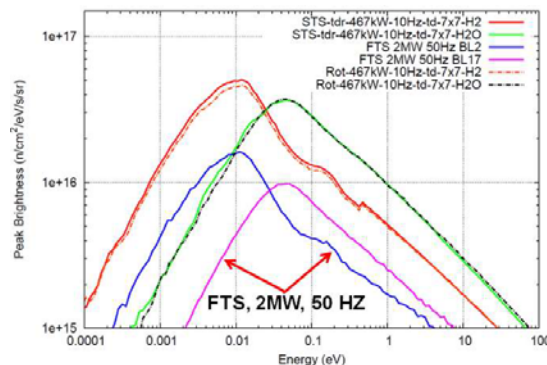
**Figure 4** Radiation damage rates in *dpa/year* around the rotating target: in aluminum (at left) and in stainless steel (on the right). The pink isoline marks  $1.0 \text{ dpa/year}$  level (Al only), and the red isoline mark  $0.25 \text{ dpa/year}$  level.



The performance of the moderators has so far been calculated only with the simplified MC models, which allow application of the optimization procedures, but do not account for engineering details such as rounded moderator shapes and domes, and cooling pipe connections. The results therefore represent expected performance in optimal configuration. The coupled para-H<sub>2</sub> moderator peak brightness for the STS is about 10 to 14 times higher than the brightness for the FTS coupled moderators in the range below 10 meV (see figure 5). STS decoupled moderators are not optimally placed, but still exhibit gains in brightness by a factor of ~3 and ~4 for the para-H<sub>2</sub> and H<sub>2</sub>O moderator faces at energies below ~1 eV, relative to the brightness of the FTS decoupled para-H<sub>2</sub> and water moderators (see figure 6). More discussion of moderators is provided in references [9] and [10].



**Figure 5.** Coupled para-H<sub>2</sub> moderators; peak brightness versus neutron energy, for the stationary STS (STS-tdr), rotating STS (Rot), and first target station (FTS).



**Figure 6.** Decoupled para-H<sub>2</sub> moderator and ambient temperature H<sub>2</sub>O moderator; peak brightness versus neutron energy, for the stationary STS (STS-tdr), rotating STS (Rot), and first target station (FTS).

#### 4. Conclusions

Current work on neutronics analysis for the SNS STS was briefly reviewed with emphasis on newly adopted automatic conversion of CAD models to MC models with DAGMC toolkit which allows efficient creation of detailed MC models. First results obtained with detailed MC model were presented.

#### Acknowledgments

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