Monte Carlo Simulation of the Cold Neutron Guide for the HANARO Cold Neutron Triple-Axis Spectrometer

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1. Introduction

The Cold Neutron Research Facility (CNRF) project carried out by Korea Atomic Energy Research Institute (KAERI) is an effort to bring cold neutron instrumentation to Korea's only large scale research reactor, HANARO, located in Daejeon. As part of the CNRF project, a cold neutron triple-axis spectrometer (Cold-TAS) is being developed along with other five: 40 m long and 12 m long small angle neutron scattering instruments (40m-SANS and 12m-SANS), disk-chopper time-of-flight spectrometer (DC-ToF), Bio-Reflectometer (Bio-REF) and the reflectometer with vertical sample geometry (REF-V).

For those cold neutron instruments, the performance of an individual instrument depends not only on its design but also on the guide that feeds cold neutrons to the instrument. Therefore, the quality of the neutron flux at an instrument position has to be checked with the specification of the instrument. As for the Cold-TAS, since the instrument requires a tall beam and a high flux of short wavelength neutrons, it was tentatively decided that it would use the cold guide 4 (CG4). [1] The detailed specification of the guide is listed in Table 1. Checking the neutron flux of the guide at the instrument position is the obvious next step.

Since it is not practical to wait until the cold neutron source (CNS) and guides are built to measure the flux actually, computer simulation of the neutron optical component has progressed greatly in recent years. This paper reports the results of a computer-aided simulation of a neutron guide devoted to the Cold-TAS. It was found that the guide provides large enough neutron flux to the instrument. Other qualities of the neutron beam such as the uniformity and the availability of short wave neutrons were also observed and found to be adequate for the planned instrument.

Table 1. The Default Moderator and CG4 Parameters

Moderator Width × Height	7 cm × 15 cm
Moderator 1 Temperature	125 K
Moderator 1 Neutron Flux	4.81×10^{13} n/s cm^2
Moderator 2 Temperature	26.3 K
Moderator 2 Neutron Flux	7.65×10^{12} n/s cm^2
Moderator-Guide Distance	183.3 cm
Guide Declination Angle	-1.91°
Supermirror Quality	m = 2
Guide Width × Height	5 cm × 15 cm
Length, In-pile Guide	4.809 m
Curvature, Curved Guide	2500 m
Length, Curved Guide	31.679 m
Length, Straight Guide	40.960 m

2. Methods and Results

Currently there are two principally used Monte Carlo simulators for neutron instrumentation, McSTAS and Vitess. [2,3] Both are known to give similar results for the same instrument. For the present work, Vitess has been utilized to model CG4. The modeling of the neutron guide starts with the cold neutron source, which is called "the moderator" in the simulation package. The neutron spectrum and flux from the source are of the critical importance for successful simulation. For example, the thermal neutron spectrum in a research reactor is often modeled to follow a Maxwell-Boltzmann distribution. The real spectrum, however, diverges from this simple description. To do a realistic simulation, the fit parameters of the MCNP results for the HANARO cold neutron source were used to describe the moderator. Table 1 shows the moderator parameters. [4]

The CG4, like other cold neutron guides planned in the CNRF, consists of three guides: the in-pile guide, the curved guide and the straight guide. The in-pile guide usually designates the portion of the guide that is imbedded inside the neutron beam tube of the research reactor and has to withstand intense radiation. Here the term is used to define the portion of the guide that has not started to curve yet. The curved guide follows the in-pile guide. The curvature provides a filter of fast

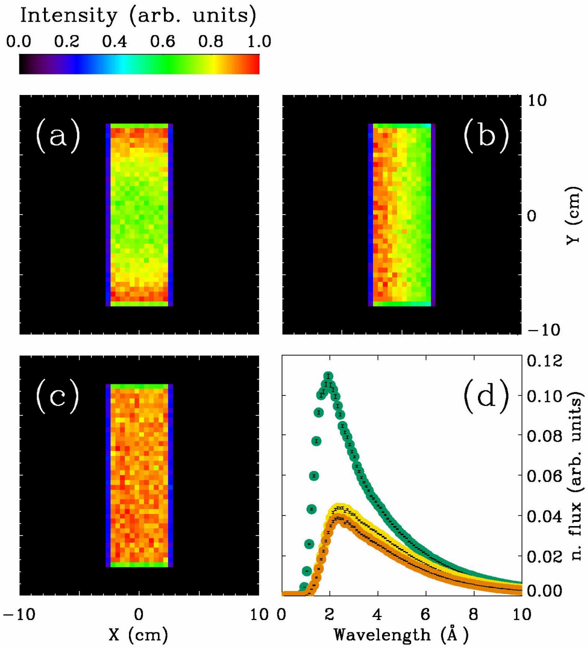

Figure 1. Neutron Flux Distribution

neutrons and unwanted high energy thermal neutrons. The desired cutoff wavelength, which is determined by the curvature, is different for different instruments. A side effect of the curved guide is an asymmetric beam distribution over the area of the guide. Lastly, there is a straight guide that makes the beam uniform and provides enough distances between the guides so that the instruments has as much room as possible.

In most cases, guides tend to branch to feed neutrons to a diverse set of instrument. As for the CG4, the entire guide is devoted to a single instrument. Therefore, the width and the height of the guide do not change from its initial value. The guide uses supermirror to reflect neutrons. The quality of the supermirror is also conserved at m = 2 from the in-pile guide to the straight guide.

Figure 1 (a-c) shows the neutron flux distributed over guide sections (a) at the end of the in-pile guide, (b) at the end of the curved guide and (c) at the end of the straight guide. It is clearly visible in Figure 1 (a, b) that the neutron flux distribution is not homogeneous before the neutrons go through the long straight guide. The short in-pile guide allows only a small number of bounces by neutrons, hence the inhomogeneity. Meanwhile the curved guide, due to its geometry, causes more bounces at the "outer"-side mirrors and causes concentration of neutron flux near them. Only after several bounces in the straight guide, the beam distribution can become homogeneous. The minimum distance of the straight guide to achieve this can also be determined by simulation. This aspect is illustrated in Figure 2. From the most asymmetric dark blue curve, which represents the flux distribution over the guide width at the end of the curved guide, each colored curve (blue, green, red and yellow) corresponds to the flux distribution with additional straight guide of 10 m. It turns out that with only 10 m straight guide, the beam is already evenly distributed over the width of the guide. The total neutron flux decreases gradually over the straight guide as shown in the inset of Figure 2. Overall, about 17 % is lost in the 40 m long straight guide.

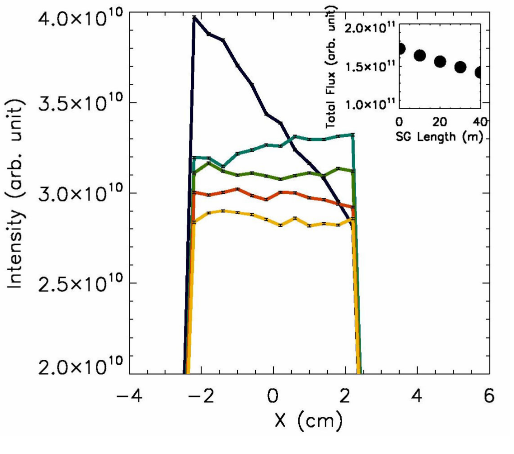

Figure 2. Neutron Flux Change by the Straight Guide

Due to the curved guide, neutron spectrum changes from the original spectrum at the beam tube. At CG4, the curvature is set to 2,500 m, to avoid loss of too much intensity of the short wavelength neutrons. Note that a triple-axis spectrometer, even a cold neutron one, requires an ample flux at 2 Å. Figure 1 (d) shows that the spectral peak moves only slightly at the end of the guide. Green circles represent the neutron spectrum at the end of the in-pile guide, yellow circles at the end of the curved guide and orange circles at the end of the straight guide. It seems the defined curvature for CG4 is good enough to preserve high energy neutrons to the instrument, therefore making the guides suitable for the cold neutron triple-axis spectrometer.

3. Conclusion

Monte Carlo simulation tools for neutron beam instrumentation like Vitess provides a powerful method to investigate the quality of instrument on the drawing board and to aid the designing process. I have shown that the presently designed cold neutron guide CG4 is adequate for the planned HANARO cold neutron triple-axis spectrometer in terms of neutron flux. The only drawback of the current design seems to be the lengthy straight guide. However, with the limited space between the instruments there does not seem to be an alternative to the current specification.

Acknowledgements

The present work has been carried out as part of the Cold Neutron Instrumentation project (Project Manager, Chang-Hee Lee), a sub-project of the CNRF project (Project Manager, Hak-Rho Kim), which is supported by the ministry of science and technology (MOST) through the Nuclear R&D Fund. The author thanks both project managers for financial support and Sang-Jin Cho and Baek-Seok Seong for helpful advices and discussions.

REFERENCES

[1] B. S. Seong, S. J. Cho, D. G. Whang, C. H. Lee and Y. J. Kim, Basic Concept of the Neutron Guide System at HANARO, Proceedings of the International Symposium on Research Reactor and Neutron Science – In Commemoration of the 10th Anniversary of HANARO, 518 (2005)
[2] K. Lefmann and K. Nielsen, McStas, a General Software Package for Neutron Ray-tracing Simulations, Neutron News **10**, 20, (1999).
[3] K. Lieutenant, G. Zsigmond, S. Manoshin, M. Fromme, H. N. Bordallo, D. Champion, J. Peters and F. Mezei, Neutron instrument simulation and optimization using the software package VITESS, Proceedings of SPIE **5536**, 134 (2004)
[4] J. Y. So, private communications