Optimization Study of Moderation System and Shielding Design for Compact Accelerator-driven Neutron Sources

Baolong Ma[1,2] , Mingfei Yan[2], Xuquan Jiang[1], Makoto Teshigawara[3],Yujiro Ikeda[3,1], Yoshie Otake[2,1], and Sheng Wang[1,2] *

[1] *Department of Nuclear Science and Technology, School of Energy and Power Engineering, Xi'an Jiaotong University, Xi'an, Shaanxi, 710049, China*

[2] *RIKEN Center for Advanced Photonics, RIKEN, Wako, Saitama, 351-0198, Japan*

[3] *J-PARC Center, Japan Atomic Energy Agency, Naka-gun, Ibaraki, 319-1195, Japan*

Neutron has important applications in both science and engineering. The scarcity of neutron beam has become a severe problem in neutron applications. Compact accelerator-driven neutron source (CANS) is complementary to large neutron source because of its high flexibility, short construction period. However, because the neutron beam intensity, especially the cold neutron intensity of CANS is lower than that of the large neutron source, it is difficult to carry out the low energy neutron scattering experiments on CANS. The optimization of the moderating system for CANS has become urgent. If the CANS could be designed further compact and realized transportable, the nondestructive inspections of special equipment such as roads, bridges, pipes, nuclear power facilities, aircraft, rocket, and other facilities can be easily realized on site. Therefore, the demand for light-weight and compact shielding optimization design has become one of the key topics for CANS.

Firstly, we adopted mesitylene as the cold moderator and systematically optimized the structure of the pre-moderator, reflector and target station structure. The optimized results showed that the moderating system of mesitylene had the same cold neutron intensity and nearly twice thermal neutron intensity as much as that of solid methane. The developed moderating system has been successfully applied on RIKEN Accelerator-driven Neutron Source (RANS).

Secondly, we developed a multi-objective shielding optimization method NSGA-MC. By coupling a multi-objective genetic algorithm and the Monte Carlo code, NSGA-MC can obtain a set of non-dominated optimal solutions. The application of NSGA-MC on RANS target station showed that the optimized shielding structure can reduce the shield weight by at least 60% without sacrificing the shielding performance. Compared with weighting method, NSGA-MC could provide diverse optimal solutions and largely save calculation time.

Finally, to experimentally prove the validity of NSGA-MC, two multilayer shielding structures of PE/B_4C/Pb and PE/B_4C/Pb/PE/B_4C/Pb were optimized by NSGA-MC with two objectives of minimized dose rate and shield weight. Three solutions on the Pareto optimal front and a non-optimized shielding structure based on the existing RANS target station were selected to be tested on RANS. The experimental results and simulation results agreed well with each other. The results show that the shielding effect and weight of the optimized shielding structure are greatly improved compared with the non-optimized shielding structure. Better shielding performance can be achieved by adopting a finer shielding structure.

The optimization design of moderation system provides guidance for other CANS which need to design or upgrade cold neutron moderation systems. The developed multi-objective optimization method, NSGA-MC, has laid a strong foundation for the application of light and compact radiation source devices such as transportable neutron sources, nuclear submarine, and space reactor.