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

Baolong Ma[1,2], Mingfei Yan[2], Quanxu Jiang[1], Makoto Teshigawara[3], Yasuo Wakabayashi[2], Yutaka Yamagata[2], Yujiro Ikeda[3,2], Yoshie Otake[2,1], and Sheng Wang[1,2] *

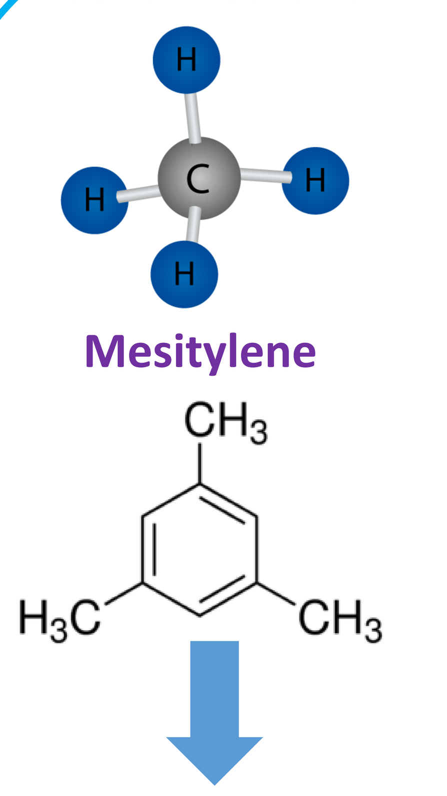
Xi'an, China
24th, May-28th, May, 2021

[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

Background

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.

Optimization Study of Cold Moderator



Applied on

RIKEN Accelerator-driven Neutron Source (RANS)

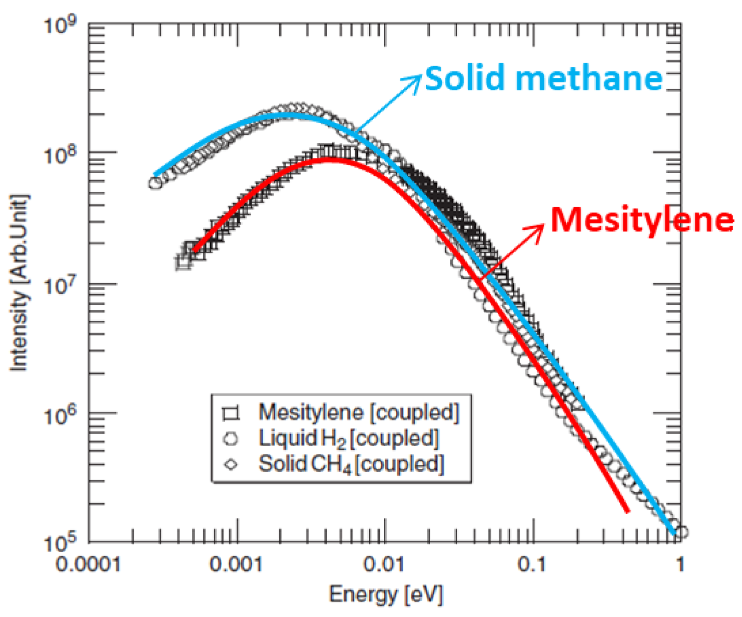


Fig.1 measured neutron spectra of mesitylene and solid methane[1]

Solid methane:
- Best cold neutron moderator from neutronic point of view.
- hard to handle, explosive, poor irradiation resistance

Mesitylene:
- Non-explosive, easy to handle, good irradiation resistance
- Acceptable performance

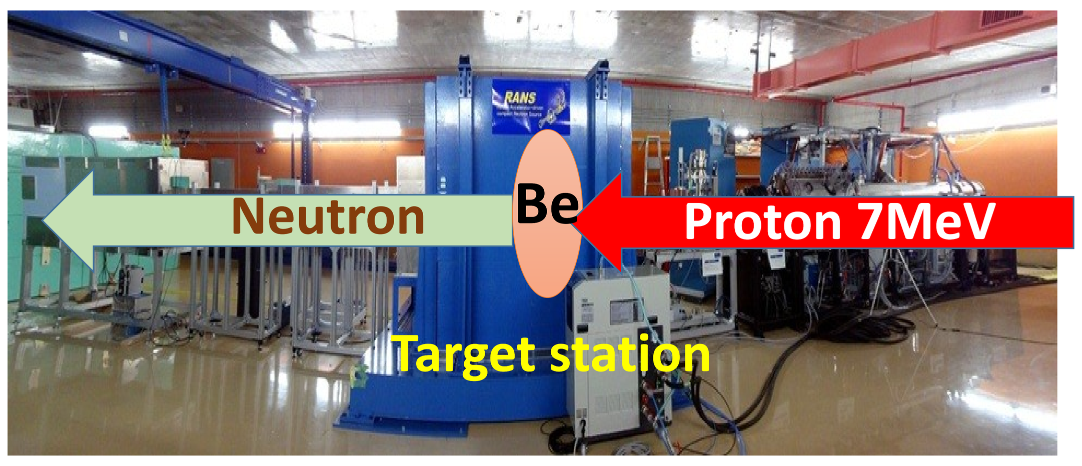


Fig. 2 RANS configuration

TMR of RANS

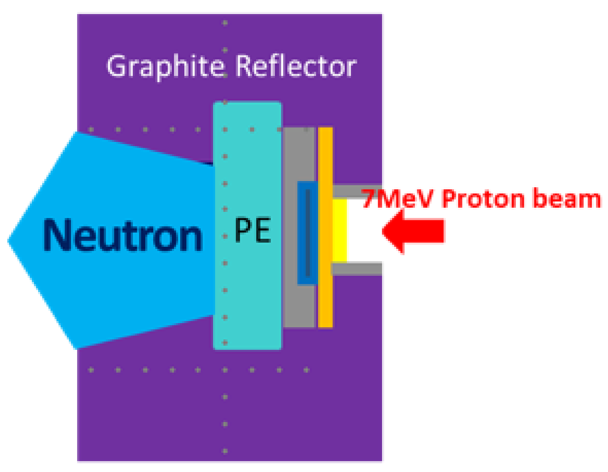


Fig. 3 TMR of RANS

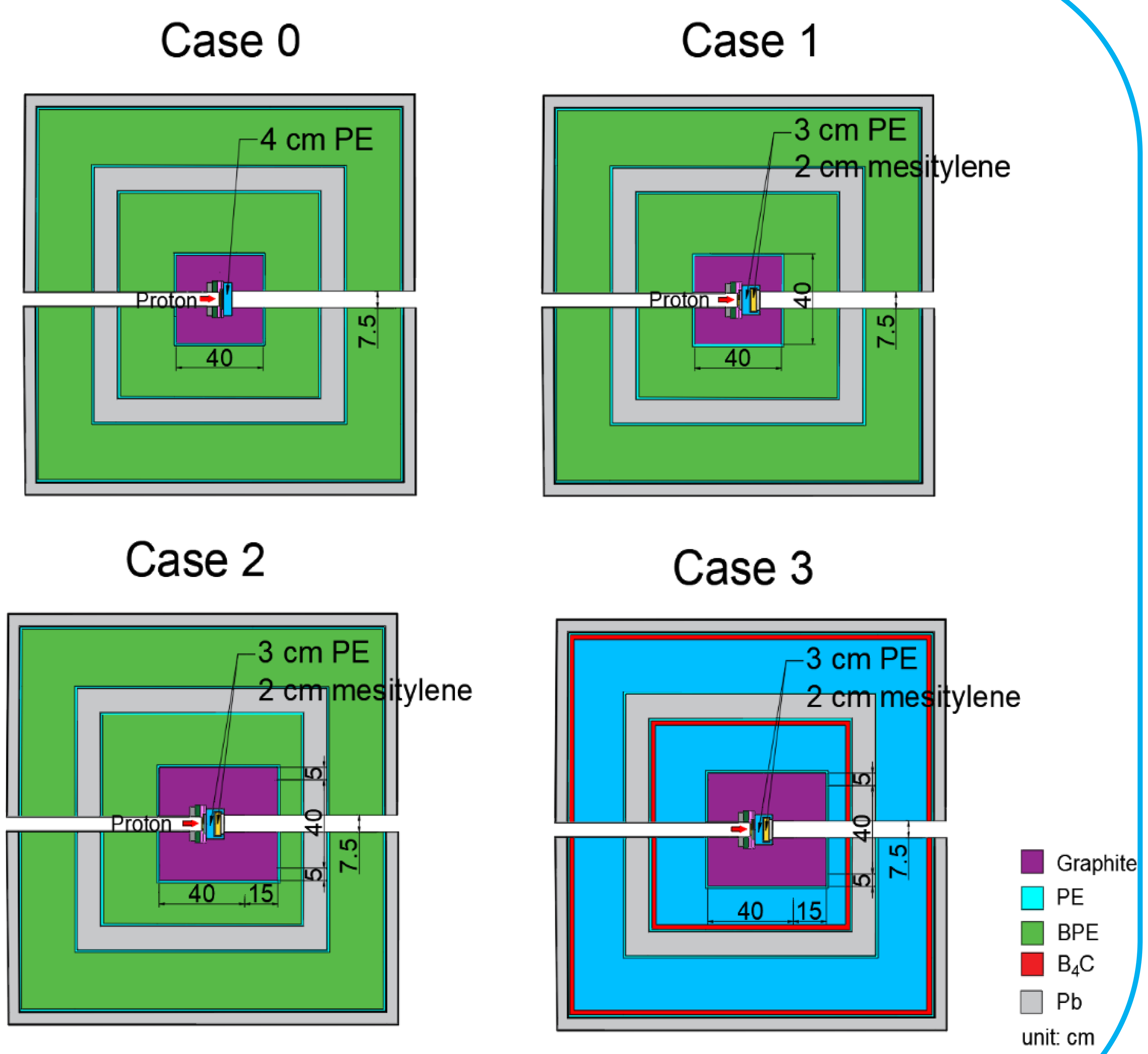


Fig. 4 Optimization of cold moderator

Optimization Results & Conclusions

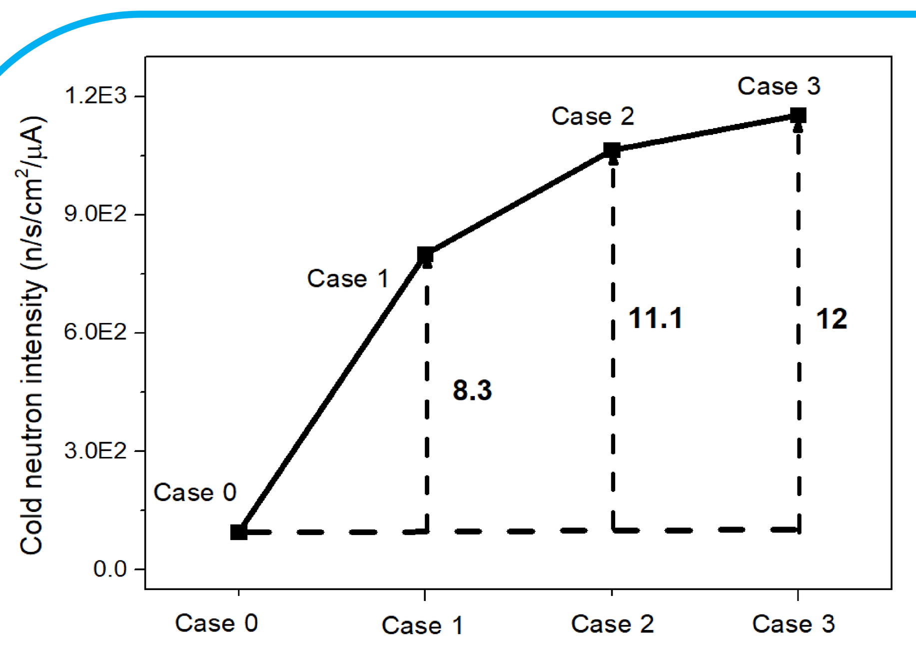


Fig. 5 Integrated cold neutron intensities within [0.1 meV, 10 meV] of case 0-case 3.

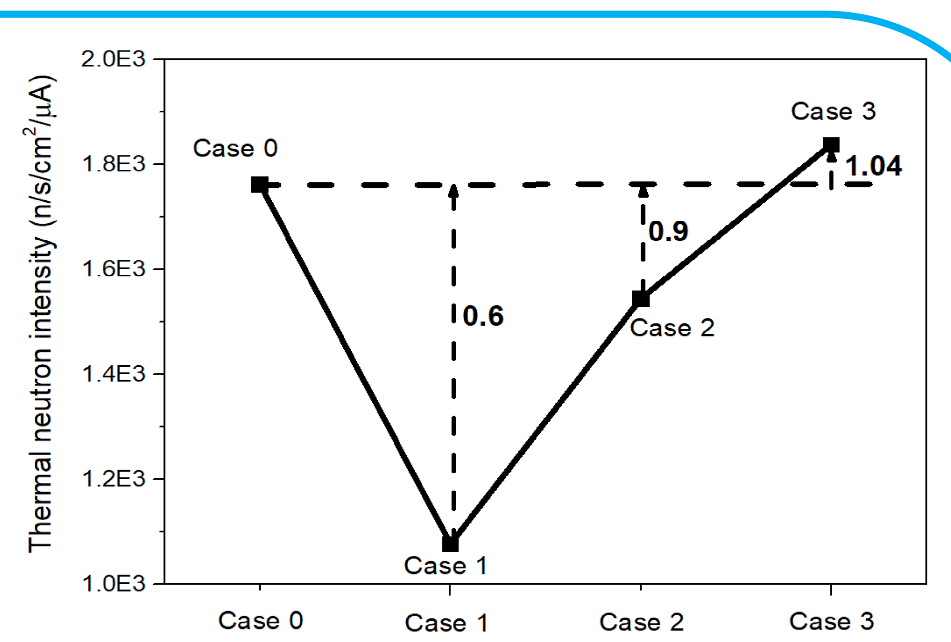


Fig.6 Integrated thermal neutron intensities within [0.1 meV, 10 meV] of case 0-case 3.

1. 11 times higher cold neutron intensity can be achieved compared with current RANS conditions, without sacrificing thermal neutron intensity.
2. Comparing the optimized RANS cold moderator configuration with a methane-based cold neutron source, LENS, it was shown that comparable cold neutron intensities could be provided for cold neutron users with mesitylene [2].
3. Even for low-power CANS, the cold moderator material of mesitylene will produce an attractive performance in applications.

Multi-objective Optimization Shielding Design

NSGA-II: Non-dominated Sorting Genetic Algorithm-II
MCNP: Monte Carlo N Particle Transport Cde
} **NSGA-MC** [3]

Applied in the shielding design of RANS target station

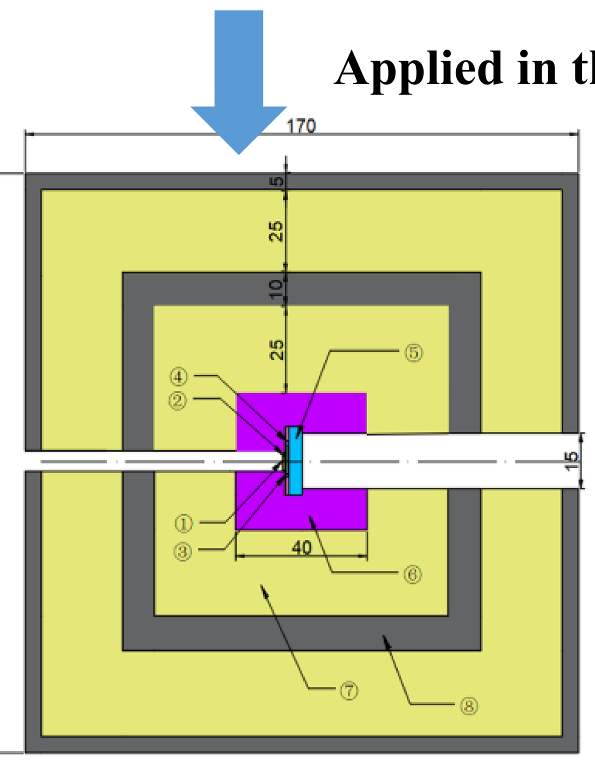


Fig. 7 Calculation model

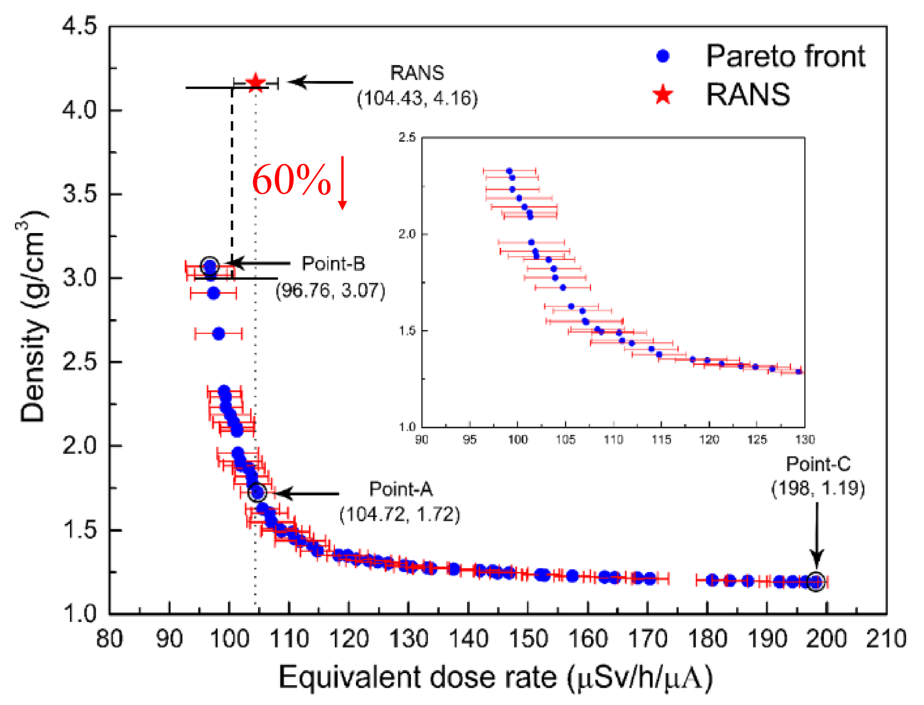


Fig. 8 Calculation model [3]

Results &Conclusions

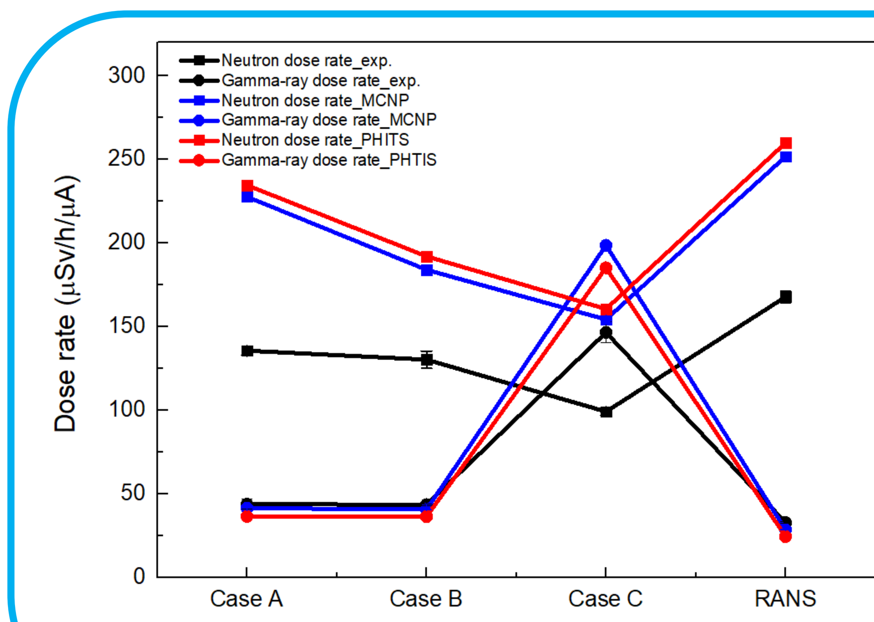


Fig. 12 Experimental and simulation results

- Tendency agreed well between simulation results and experimental results;
- The difference can be explained by benchmark study for deep penetration shielding problems in Monte Carlo simulation;
- NSGA-MC has been proved to be effective.

Experimental verification for NSGA-MC on RANS

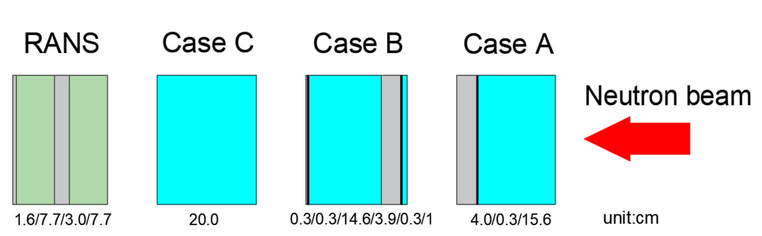


Fig. 9 Shielding Configuration of case A、case B、case C、RANS

Fig. 10 Experimental environment

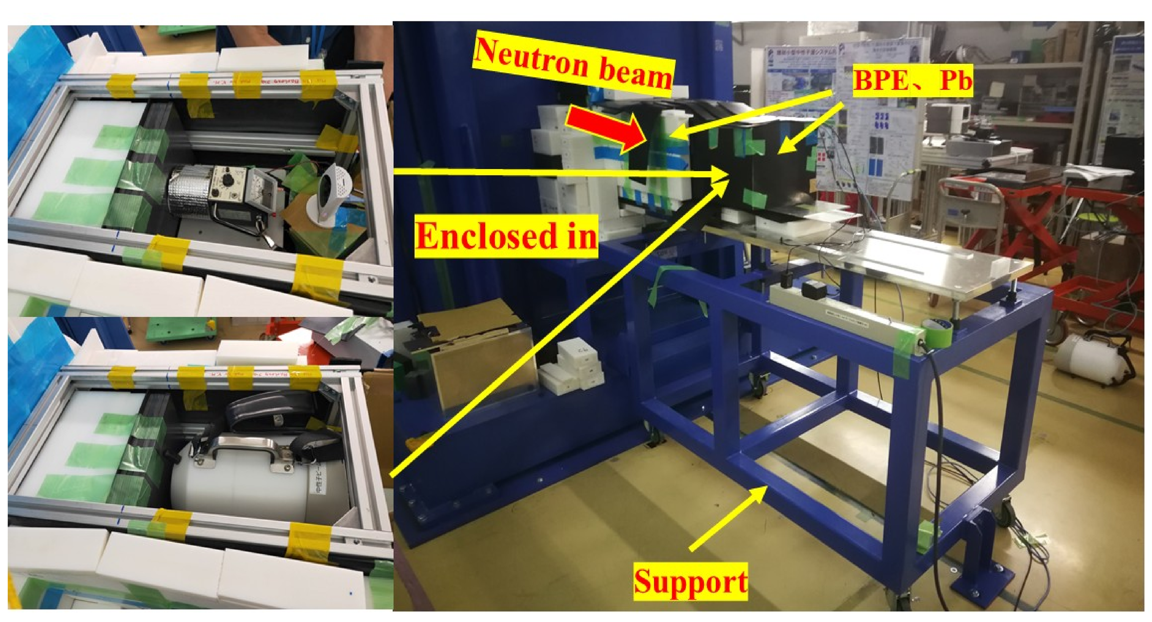


Fig. 11 Experimental setup

Reference

[1] Kiyanagi Y. Experimental studies on neutronic performance of various cold-neutron moderators for the pulsed neutron sources. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 2006, 562(2): 561-564.
[2] Ma B, Teshigawara M, Wakabayashi Y, et al. Optimization of a slab geometry type cold neutron moderator for RIKEN accelerator-driven compact neutron source [J]. Nuclear Inst & Methods in Physics Research A, 2021, 995: 165079.
[3] Ma B, Song L, Yan M, et al. Multi-objective optimization shielding design for compact accelerator-driven neutron sources by application of NSGA-II and MCNP. IEEE Transactions on Nuclear Science, 2020, 68(2): 110-117.