Usage Report for Fiscal Year 2016

Project Title: Moderator design of RANS2 and investigating of radiation equivalent dose for neutron building

Name: Sheng Wang

Laboratory at RIKEN: Neutron Beam Technology Team

Description of the project

1. Introduction

The neutron is a fundamental particle with many unique properties, the excellent intrinsic attributes of neutrons make a wide range of objects to be imaged, ranging from massive structure to crystal structure. Neutron imaging is highly complementary to X-ray imaging.

Large scale neutron source facilities [1] are constructed mainly to accommodate academic scientific applications such as material science, life science and fundamental physics, however, the utilization rate of them is very low.

To compensate the shortcomings of large scale facilities, Compact accelerator-driven neutron sources (CANS) was constructed due to their modest cost and flexible use. The RIKEN accelerator-driven compact neutron source (RANS) [2] is such a state-of art CANS facilities. It has been developed for practical use in simple and convenient measurement. By using neutrons from Be (p, n) reaction, several measurements have already been successfully performed on RANS.

Optimized shielding design of RANS is a very important issue, not only due to the consideration of safety and cost, but also the compact size and light weight. Then the possibilities of detecting objects by using neutron imaging techniques in real operating environment for RANS, is promising for a range of industrial use and academic applications.

What's more, depending on the application fields and purpose, the neutron energy range for industrial use should be wide from cold neutron to fast neutron because the cold neutron is used to get great contrast between light element and heavy element while the fast neutron is used to penetrate large objects. So the flexible moderator design of RANS is essential to meet the various demands from industries.

In this study, based on an established configuration of compact neutron source facility RANS moderator with slab system (see Fig.1), wing system was designed for RANS (see Fig.2) to increase neutron utilization rate of RANS and to get a high intensity thermal flux as possible for neutron radiography. This study concentrates on the calculation of the moderator size optimization for two kinds of target configuration. The simulation work was done by a Monte Carlo code a particle and heavy ion transport code system (PHITS) [3].

In addition, equivalent dose distribution of the whole room was also calculated to evaluate the effectiveness of the existing shielding design.

2. Optimization of RANS moderator size

2.1 Optimization of slab system moderator.

Polyethylene was selected as moderator material for RANS due to its excellent property in moderating neutron [4]. According to the thermal neutron imaging requirements of RANS, the thermal neutron (1.0 meV to 0.5 eV) is what we need, and the fast neutron flux should be as small as possible to reduce the noise. Moderator has three parameters T1, T2 and T3 [5] that have to be optimized as shown in Fig. 1 to get the thermal neutron flux as high as possible. T1 is the thickness of vertical direction, T2 is the thickness of moderator in proton beam direction, and T3 is the thickness perpendicular to paper.

In this case, thermal neutron flux is checked at the detector which is put at 0.5 m away from the target center. Fig. 3 shows the thermal neutron flux with the variation of T1 and T2 under the condition of T3 = 20 cm. Fig. 3 indicates that under the condition of same T2, with the increase of T1, thermal neutron flux increases at first, then tends to be gentle. However, under the condition of same T1, thermal neutron flux first increases and then decreases, which means thermal neutron flux is more sensitive to T2. The maximum value is obtained when T1=14 cm, T2 =6 cm. Therefore, the optimal value of T1 and T2 are 14 cm and 6 cm respectively. At this time, the maximum thermal flux is 1.627E+05/ cm^2. Then T1 and T2 is set as 14 cm and 6 cm, the thickness of T3 is ranged from 10 cm to 18 cm to calculate the maximum thermal neutron flux. As shown in Fig.4, 1.628E+05 /cm^2 of maximum thermal neutron flux is got when T3=11 cm.

2.2 Optimization of wing system moderator.

Two channels design of CANS can increase the utilization of neutron elaborately, at the same time, it can be used to investigate other method of neutron imaging. In this study, maximum thermal neutron flux of wing system is the optimization object. Thermal neutron flux is checked at the detector which is put at 2 m away from the target center. Fig.5 shows the thermal neutron flux with the variation of T1 and T2 under the condition of T3 = 20 cm. Fig.5 indicates that under the condition of same T2, with the increase of T1, thermal neutron flux increases at first, then tends to be gentle while under the condition of same T1, thermal neutron flux first increases and then decreases, which means thermal neutron flux is more sensitive to T2. The maximum value is obtained when T1=8 cm, T2 =15 cm. Therefore, the optimal value of T2 and T3 are 8 cm and 15 cm respectively. At this time, the maximum thermal flux is 5.79E+05/ cm^2. Then T1 and T2 is set as 8 cm and 15 cm, the thickness of T3 is ranged from 10 cm to 17 cm to calculate the maximum thermal neutron flux. As shown in Fig.4, 1.07E+06 /cm^2 of maximum thermal neutron flux is got when T3=12 cm.

Simulation results show that maximum thermal neutron flux of 1.628E+05 /cm^2 can be got when T1=14 cm, T2=6 cm, T3=11 cm for slab system, while maximum thermal neutron flux of 1.07E+06 /cm^2 can be got when T1=8 cm, T2=15 cm, T3=12 cm for wing system.

With this method, moderator for fast neutron imaging or cold thermal imaging can be also optimized to get maximum flux as possible in future research.

3. Simulation of equivalent dose distribution in neutron building

3.1 Configuration of the whole room

The laboratory room is located at the second floor. The thickness of western concrete wall and southern concrete wall are 60 cm, and the thickness of northern concrete wall is 90 cm. The right part of the room is operation area with maze structure. As shown in Fig.7 and Fig.8 are the top view and front view of radiation equivalent dose distribution for RANS room. Simulation results show that the highest radiation dose locates at the center of the target and the equivalent dose in the operating area is under 10μSv/h based on two beam holes, which means the existing shielding is good enough to protect operator from radiation exposure.

3.2 Simulation of radiation equivalent dose

To evaluate the radiation level of the laboratory room, Monte Carlo simulation code PHITS was used to calculate the equivalent dose. What's more, comparisons were made between RANS1 and RANS2 (see Fig.9 to Fig.13).

In this simulation, x axis is from the ground to the ceiling, along the RANS configuration is y axis, along the side extraction channel is y axis. From Fig. 9, it can be seen that from the ground to the ceiling, there are no much difference between one beam hole and two beam holes. However, radiation equivalent dose on the ground is a little lower when there are two beam holes because some of the neutron are extracted from the other side. Fig. 10 show the simulation results along the side extraction channel. Radiation equivalent dose of two beam holes from y=0.5 cm to y=380 cm is much higher than that of one beam hole. In other places, there are not much difference. As shown in Fig.11, equivalent dose of two beam holes from 7.5cm to 690cm is higher than that of one beam hole. But in the center of (x=0, y=0cm, z=100) neutron duct, equivalent dose of two beam holes is lower, that may because some of the neutrons go out from the other side. Fig. 12 show the equivalent dose along RANS configuration. Equivalent dose of two beam holes from 0 to 500 cm is lower from that of one beam hole. In other places, there are not much difference. Fig. 13 show the equivalent dose distribution along northern wall. Simulation results show that equivalent dose of two beam holes along z negative direction is lower than that of one beam hole, this may because there are more neutrons in z negative direction of one beam hole, when there are some neutrons extracting from the other side, the equivalent dose is decreased along z positive direction.

4. Conclusions

Monte Carlo simulation is one of the most accurate methods for shielding design. PHITS is such a Monte Carlo code which can transport nearly all particles over wide energy range. By using 32 node, 500 process on HOKUSAI system. Computing time is greatly reduced, which definitely accelerate the development of RANS2.

4. Schedule and prospect for the future

Within the fiscal year of 2017, the following two objectives have to be achieved with Monte Carlo simulation running on RICC. (1) Apr. 1, 2017-June 31, 2017: Complete the moderator design for RANS2; (2) July 1, 2017- Mar. 31, 2018: Complete the compact shielding design for RANS2.

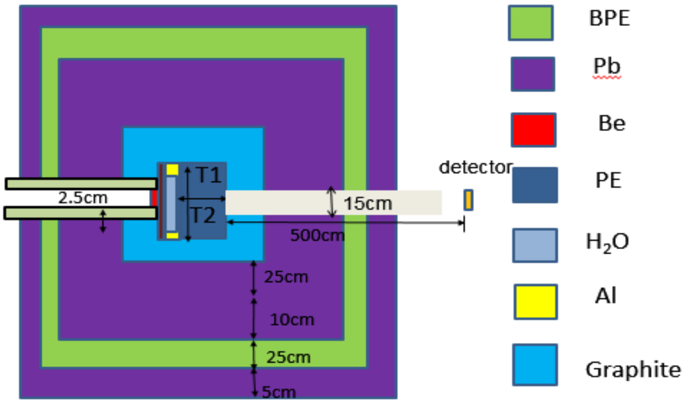

Fig.1 Slab system configuration of RANS

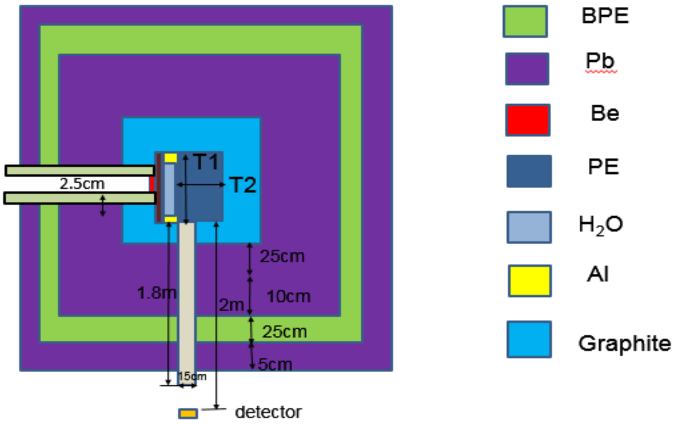

Fig.2 Wing system configuration of RANS

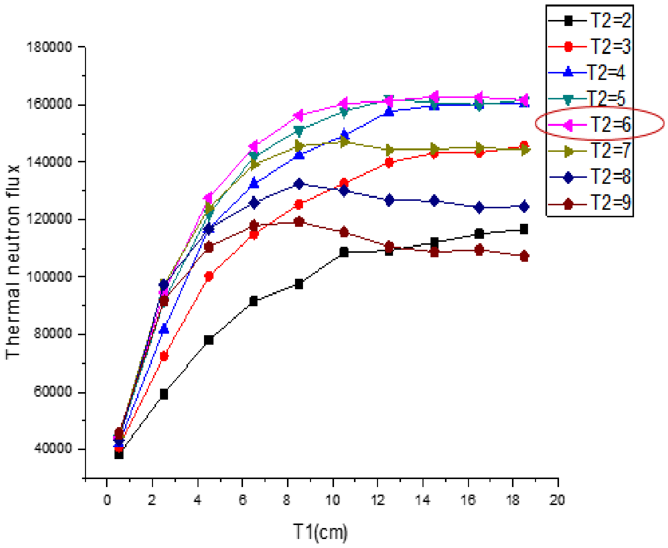

Fig.3 Optimization of T1, T2 for RANS moderator (slab system)

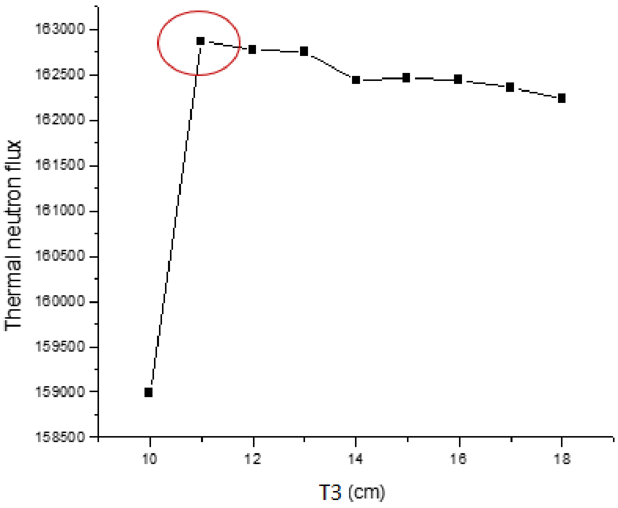

Fig.4 Optimization of T3 for RANS moderator (slab system)

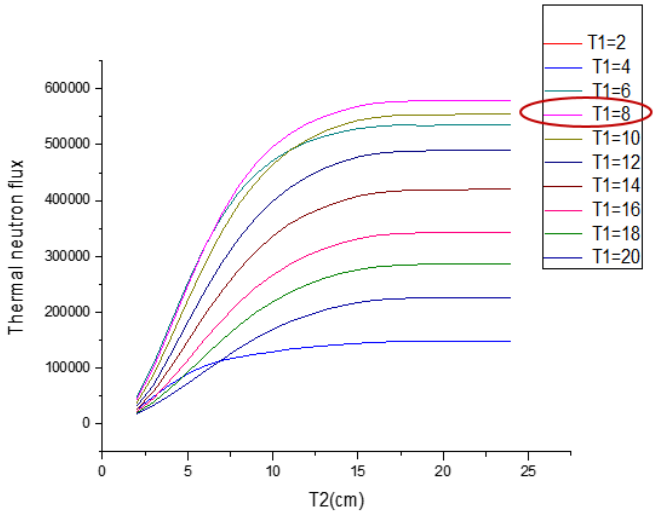

Fig.5 Optimization of T1, T2 for RANS moderator (wing system)

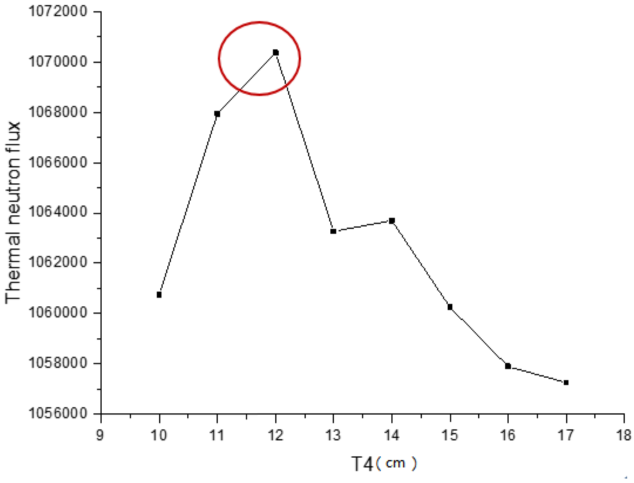

Fig.6 Optimization of T3 for RANS moderator (wing system)

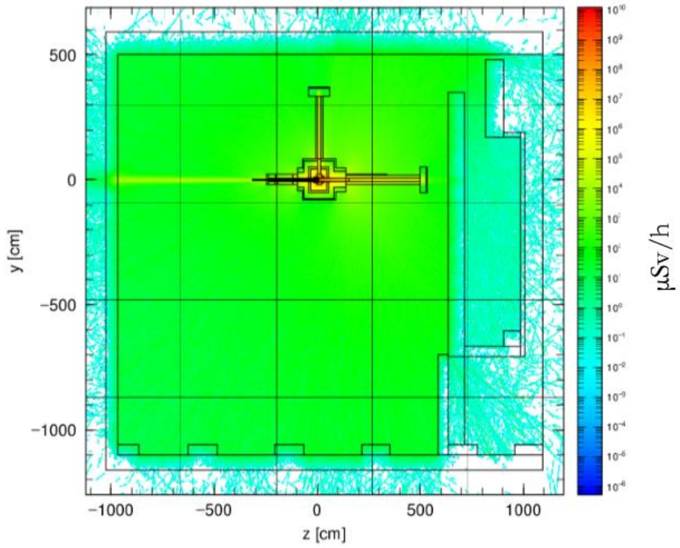

Fig.7 Top view of radiation distribution (Z=0)

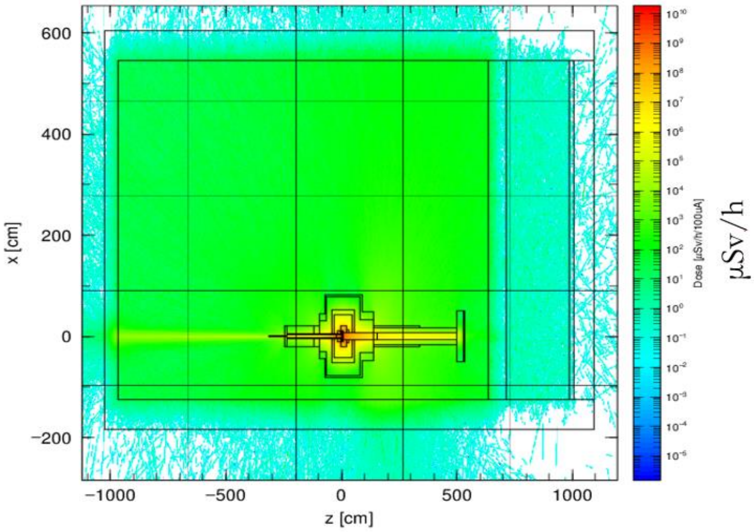

Fig.8 Front view of radiation dstribution(X=0)

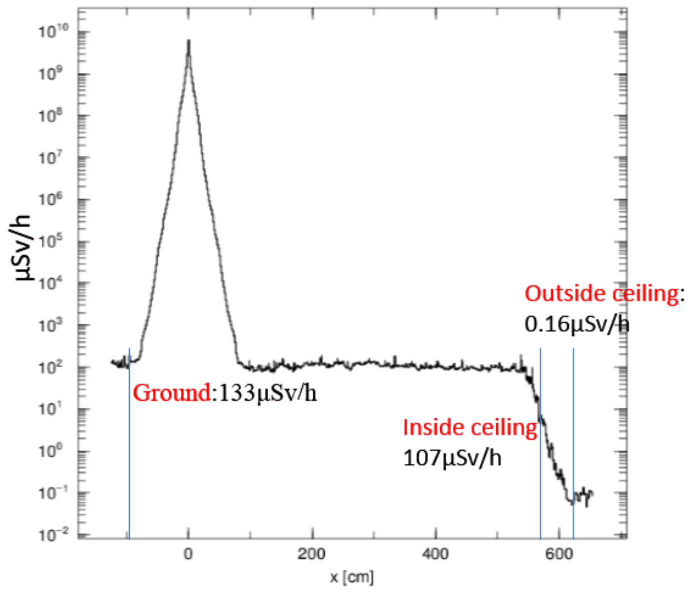

Fig.9 (a) Radiation equivalent distribution of RANS1 (y=0, z=0)

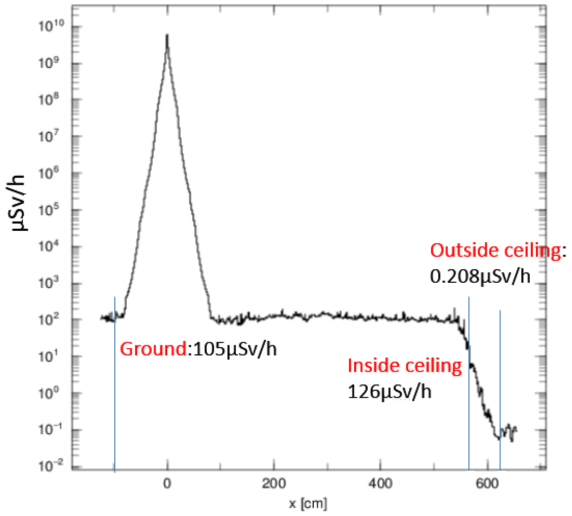

Fig.9 (b) Radiation equivalent distribution of RANS2 (y=0, z=0)

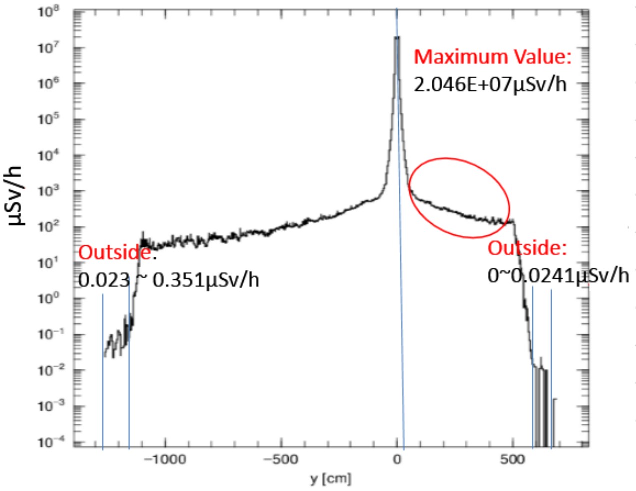

Fig.11 (a) Radiation equivalent distribution of RANS1 (x=0, z=100 cm)

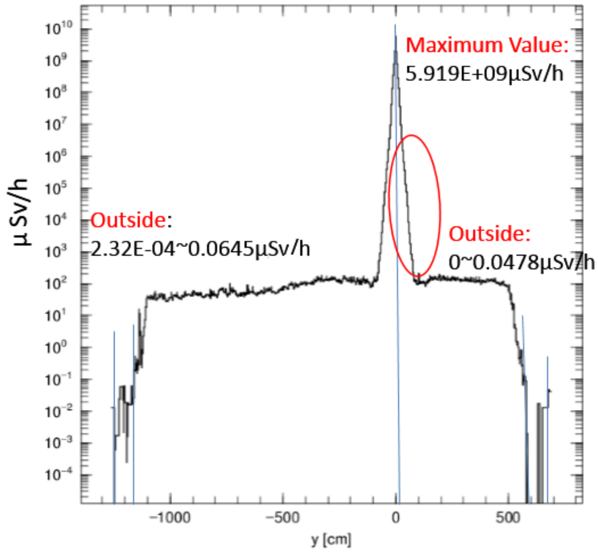

Fig.10 (a) Radiation equivalent distribution of RANS2 (x=0, z=8.25 cm)

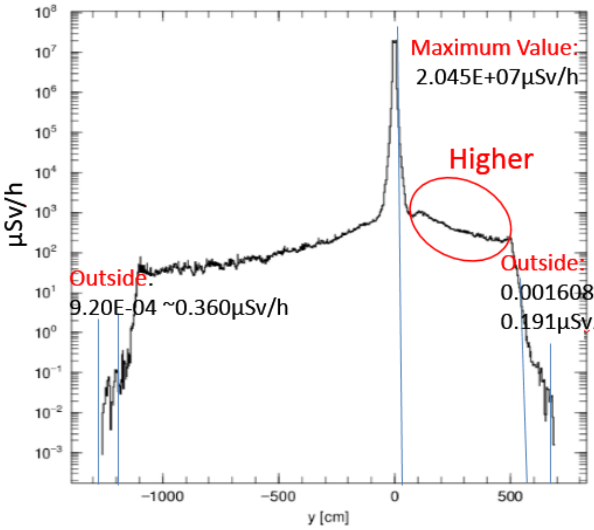

Fig.11 (b) Radiation equivalent distribution of RANS2 (x=0, z=100 cm)

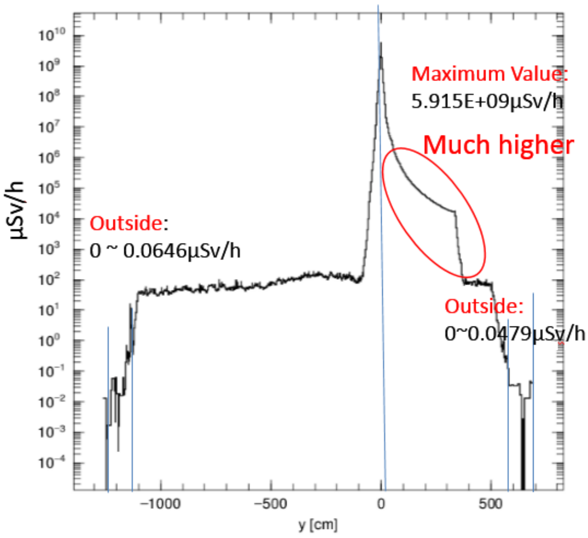

Fig.10 (b) Radiation equivalent distribution of RANS1 (x=0, z=8.25 cm)

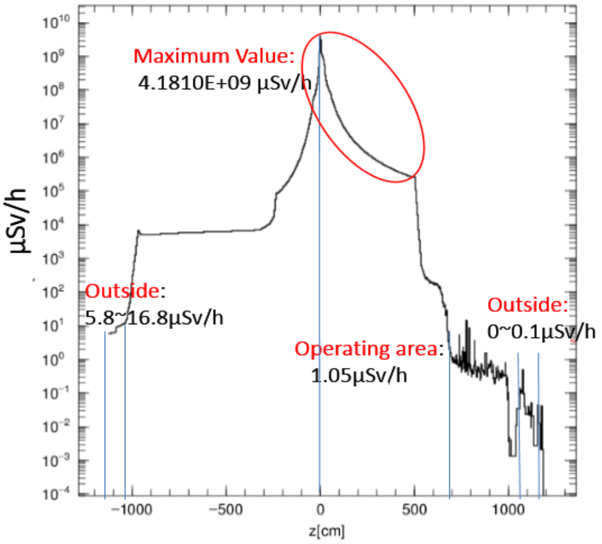

Fig.12 (a) Radiation equivalent distribution of RANS1 (x=0, y=0)

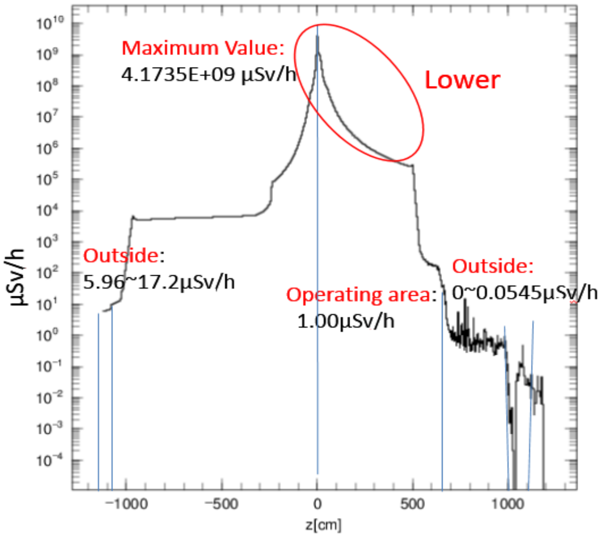

Fig.12 (b) Radiation equivalent distribution of RANS2 (x=0, y=0)

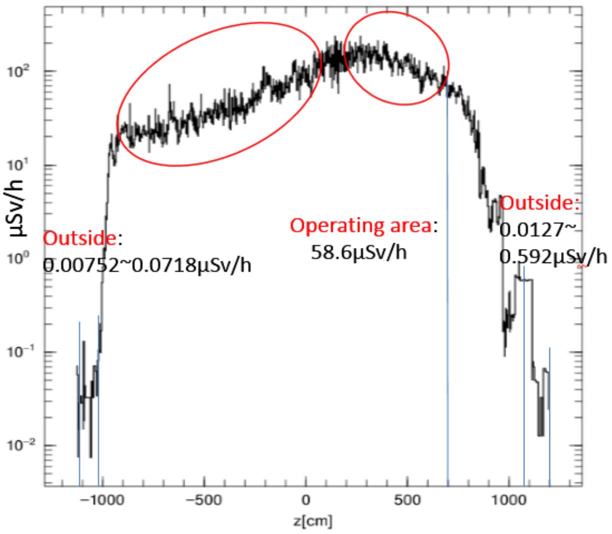

Fig.13 (a) Radiation equivalent distribution of RANS1 (x=0, y=490 cm)

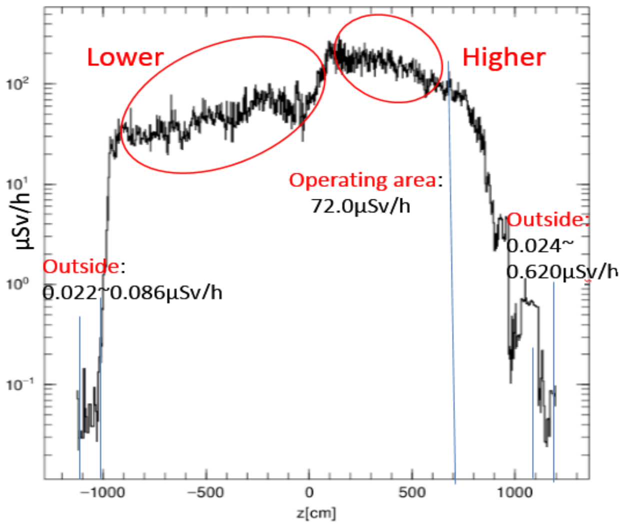

Fig.13 (b) Radiation equivalent distribution of RANS1 (x=0, y=490 cm)

References

[1] Filges D, Goldenbaum F. Handbook of Spallation Research[J]. 2010.

[2] 大竹, 淑恵. Non-Destructive Visualization Technique for the RIKEN Compact Neutron Source RANS[J]. 色材協会誌 = Journal of the Japan Society of Colour Material, 2015, 88.

[3] Sihver L. PHITS -, a particle and heavy ion transport code system[J]. 2006.

[4] Yoshiaki KIYANAGI. Neutronics of Rectangular Parallelepiped Polyethylene Moderator in Wing Geometry for Accelerator Based Thermal Neutron Source[J]. Journal of Nuclear Science and Technology, 1984, 21(11):814-823.

[5] Wang S, Otake Y, Yamagata Y, et al. Simulation and Design of a Simple and Easy-to-use Small-scale Neutron Source at Kyoto University ☆[J]. Physics Procedia, 2014, 60:310-319

Usage Report for Fiscal Year 2016

Fiscal Year 2016 List of Publications Resulting from the Use of the supercomputer

[Proceedings, etc.]

1. Shielding design of proton linac for CANS, S. Wang, B. Ma, Y. Otake, et al.
2. Target System Design for Transportable Neutron Source, S. Wang, X. Li, Y. Otake, et al.
3. Optimized design of moderator for wing system plus slab system of CANS, S. Wang, B. L. Ma, Y. Otake, et al.

[Oral presentation at an international symposium]

1. Shielding design of proton linac for CANS, S. Wang, B. Ma, Y. Otake, et al, 9th International Youth Nuclear Congress, 24-30, July, 2016, Hangzhou.
2. Target System Design for Transportable Neutron Source, S. Wang, X. Li, Y. Otake, et al, 9th International Youth Nuclear Congress, 24-30, July, 2016, Hangzhou.
3. Optimized design of moderator for wing system plus slab system of CANS, S. Wang, B. L. Ma, Y. Otake, et al, 6th International Meeting of Union for Compact Accelerator-driven Neutron source, 25-28, October, 2016, Xi’an.