RICC Usage Report for Fiscal Year 2011

Project Title:

Simulation and design of a transportable and compact neutron source based radiography system for industrial applications

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1. Background

Investigation of inside structure as well as outside profile is important for many industrial applications. Concerning X-ray imaging systems, they have been applying not only to measure the outside profile but to investigate inside defects such as welding part, cast components and so on. However, X-ray imaging system has limit on penetration depth so that it is hard to measure large industrial components or structures. Neutron beam has advantages on penetration depth over X-ray. Furthermore, material information like strain or temperature that may be obtained by using pulsed neutron source will be quite useful in production engineering. Thus, neutron radiography is expected to be widely utilized in the production processes compared to X-ray CT systems, which are recently becoming popular method for product inspection on-site. Neutron radiography has a number of advantages over X-ray system. However, it requires very large accelerator systems.

For industrial radiography applications, we are planning to construct a compact neutron source using a small proton accelerator combined with a lithium or beryllium target. Primary applications of compact accelerator based neutron source are radiography of industrial components. By utilizing deep penetration depth of neutron beam, investigation of pores inside cast iron parts or other heavy materials are preferable application. Inspection of junction between composite material (carbon fiber structure and steel or aluminium) could be another good application taking advantage of neutron radiography. If transportable neutron source is possible, it can be applied to investigation of large industrial product like aircraft or ship or large scale structures like bridges, buildings.

Furthermore, neutron scattering research is performed primarily at large-scale facilities. However, history has shown that smaller scale neutron scattering facilities can play a useful role in education and innovation while performing valuable materials research.

Building a small-scale neutron source (proton energy about 7.0MeV and 0.7kW beam power) in RIBF Building inside RIKEN Wako Campus has been decided. A proton accelerator of has been ordered. A design of proton accelerator based compact neutron source for industrial and transportable use have been started. We use low energy nuclear reaction of Be(p,n) to produce neutron beam. For the purpose of transportable use, accelerator systems are more compactly designed since trailer can carry out approximately 3 to 5 m size and mass of several tons. To set up the small-scale neutron source, the first thing what we should do is to make a safe shielding design to make the radiation level lower than the one required by Japanese law and get a radiation safety certificate. In this paper, the work is focused on the radiation modelling of the small-scale neutron source.

Monte Carlo calculation is the basic and the most important tool for the compact neutron source design, as well as for the whole radiography system design. As known to all, Monte Carlo calculation is very time-consuming. The calculation cost almost has linear relationship with the particle number. At the same time, Monte Carlo code always has a perfect parallel efficiency. So running the parallel Monte Carlo calculation by using RIKEN Cluster (RICC) is very necessary for the success of this project.

2. Simulation modeling and methods

The target/moderator/reflector/shielding design for the 7.0 MeV small neutron source has been completed as indicated in Fig. 1. To make a compact size, a multi-layer shielding design is adopted to shield both of photon and neutron. Boracic acid resin is used to shield the neutron and lead to shield photon. A beryllium plate which has 5 cm diameter and 300 μm thickness was used for target. For reflection of neutron, graphite was adopted.

The layout of the small-scale neutron facility in RIBF Building on RIKEN Wako Campus is shown in Fig. 2. The facility is surrounded by the concrete with thickness of 1.5 meters. In front of the neutron beam, a Hazama concrete wall with thickness of 0.5 meter is put to shield both of neutron and photon. The radiation calculations of the whole domain with 6mx16mx30.05m have been carried our by Monte Carlo code (PHITS, ver. 2.24) with sample particle number 2.1E+9. The computational cost for one case is about 64 cores running 20 hours.

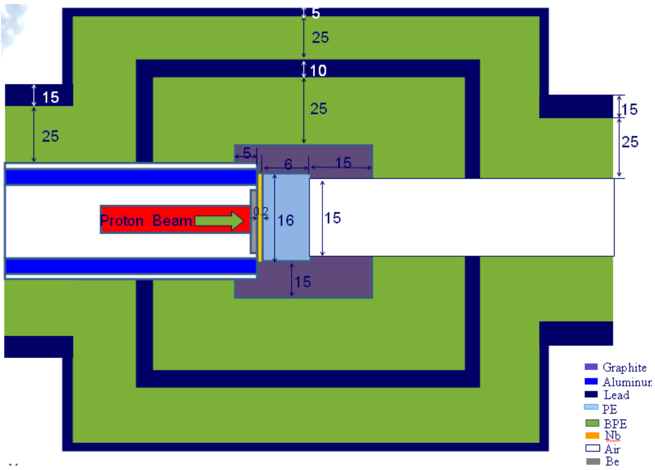


Fig.1. Geometrical design of target station for 7.0 MeV small scale neutron source

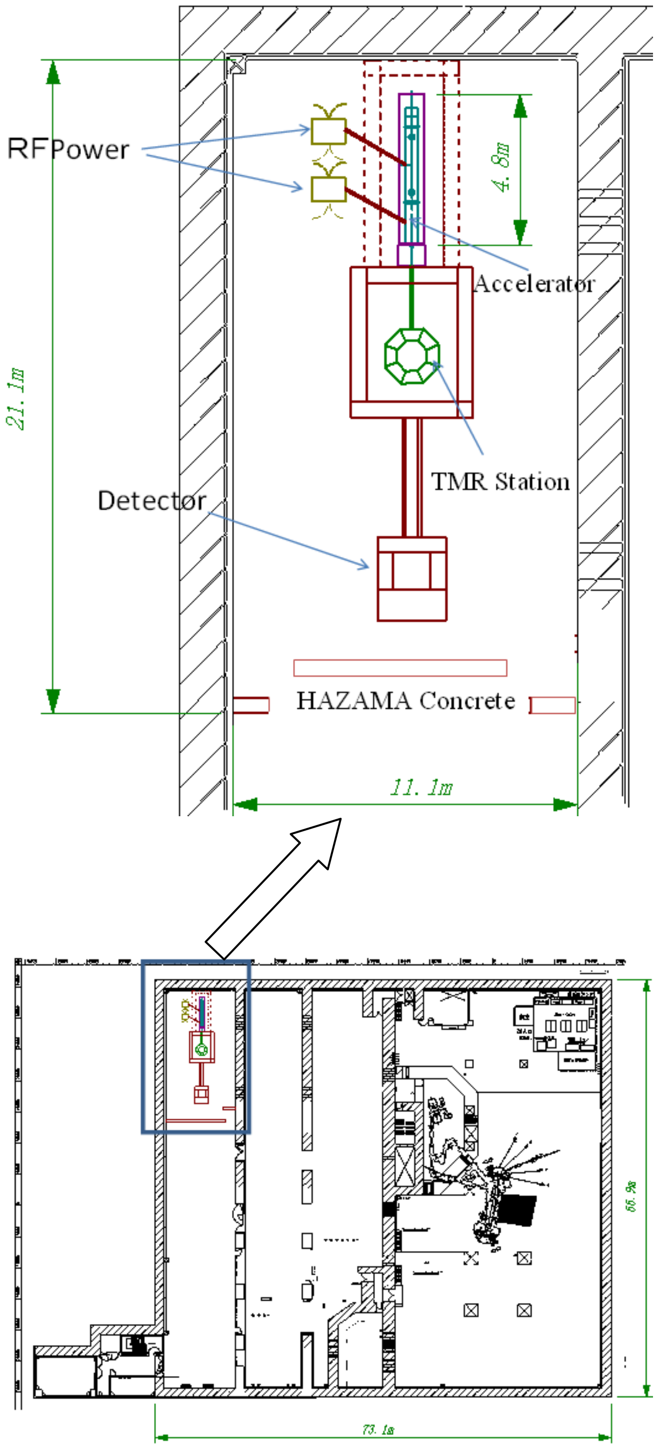


Fig.2. Layout of small-scale neutron source facility in RIBF Building on RIKEN Wako Campus

3. Radiation calculation result

To evaluate the multi-layer shielding design, the Monte Carlo calculation for the photon and neutron dose distribution was carried out around the target station. Figures 3-5 show the neutron, photon as well as the sum of neutron and photon equivalent dose distributions. From the calculation results, we can find that the multi-layer shielding design is very effective. In the bottom and top area outside of the target station, the photon equivalent dose is under the 10 μSv/h and the neutron equivalent dose is under the 1.0 μSv/h. This radiation level is quite acceptable for the area around the target station.

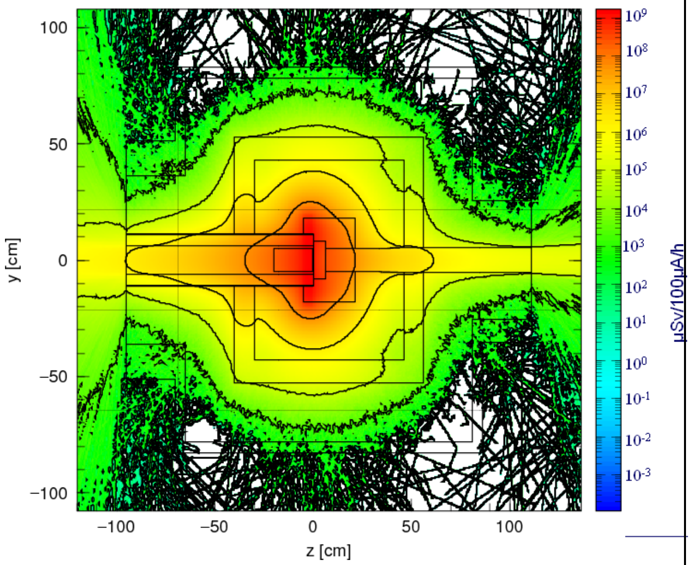


Fig.3. Neutron equivalent dose distribution around target station

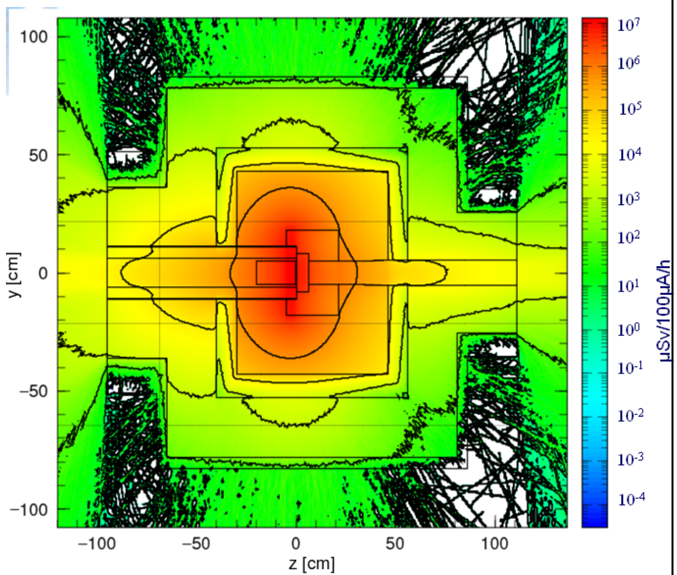


Fig.4. Photon equivalent dose distribution around target station

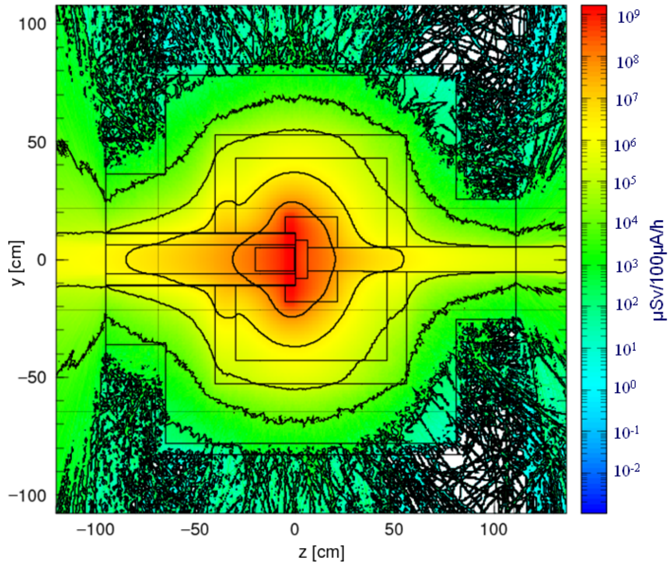
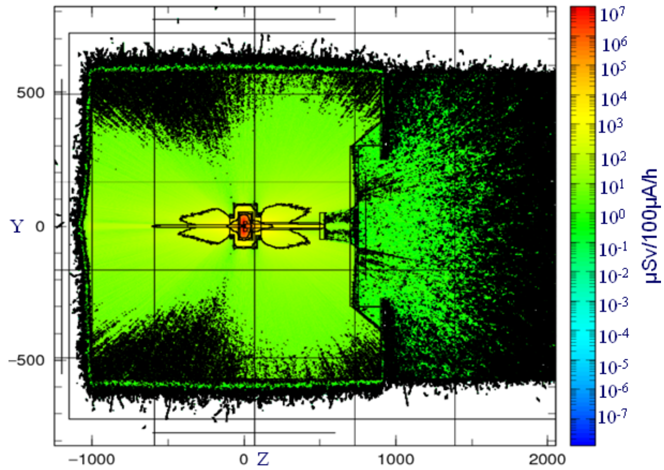


Fig.5. (Neutron+Photon) equivalent dose distribution around target station

The whole domain including the accelerator, target station, operation area and neighbouring rooms are simulated to check the radiation level. Figures 6-8 show the photon, neutron and the sum of photon and neutron equivalent dose distributions of top view for both two-dimension and one-dimension in the case of Y=0 and 300 cm. The results show Hazama concrete wall is very effective to shield both of photon and neutron. In the operation area, from the top view the radiation dose is lower than 1.25 μSv/h, which meets the requirement of Japanese law. In the neighbouring rooms, they are not suffered any radiation from the small-scale neutron source.



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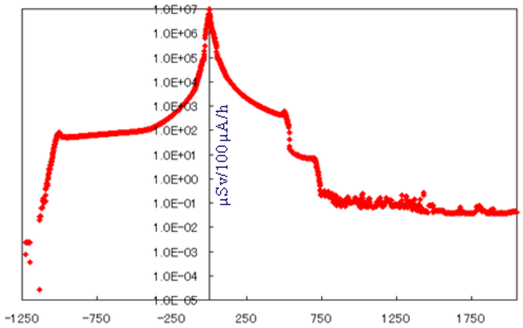

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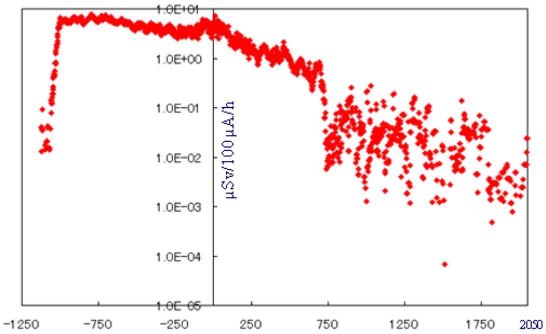

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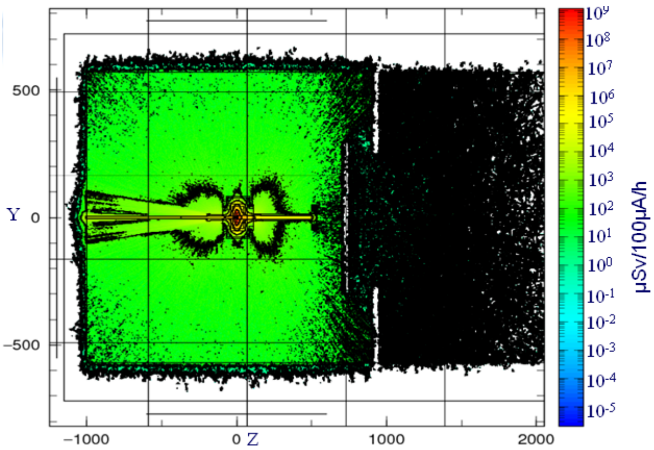
Fig. 6 Photon equivalent dose distribution for whole domain: (a) two dimensional distribution of top view; (b) Y=0 (c) Y=300 cm



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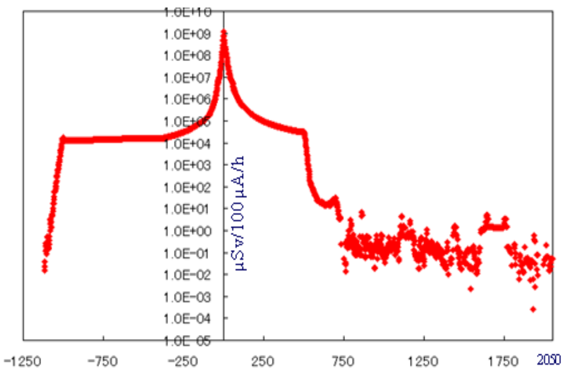

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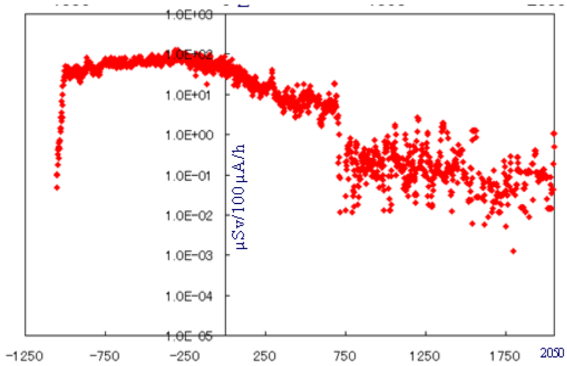

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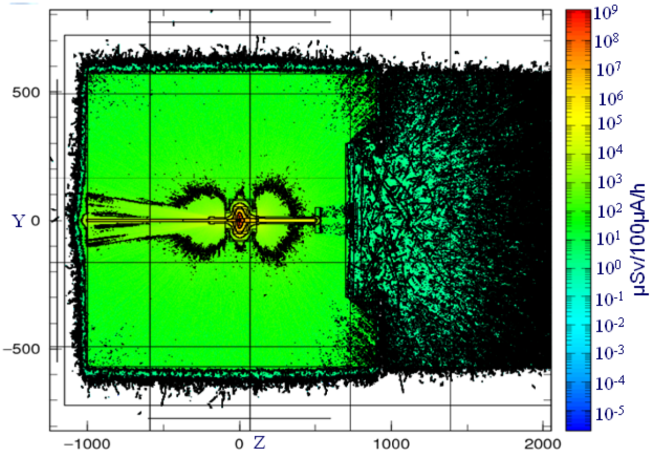
Fig. 7 Neutron equivalent dose distribution for whole domain: (a) two dimensional distribution of top view; (b) Y=0 (c) Y=300 cm



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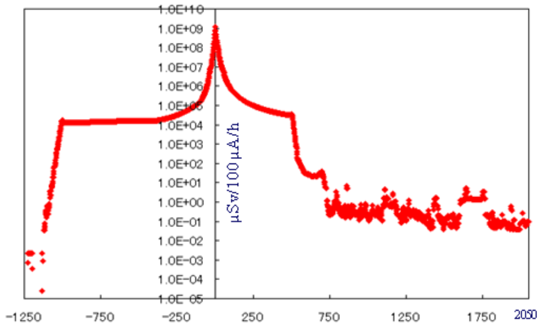

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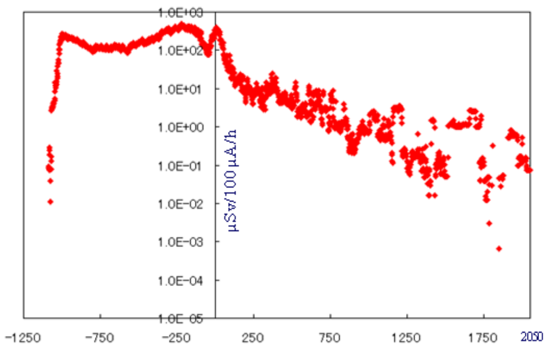
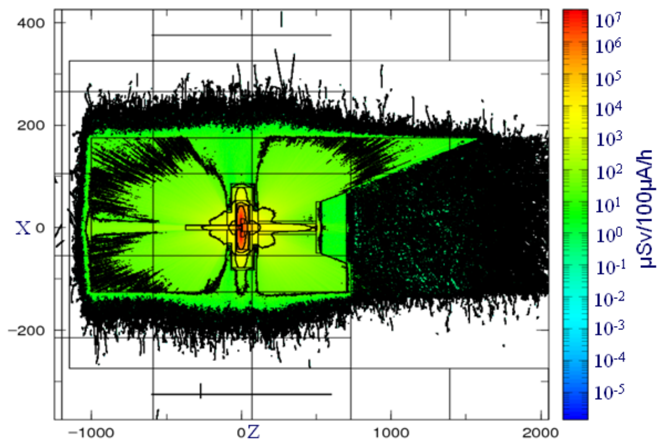


(c)

Fig. 8 (Neutron+Photon) equivalent dose distribution for whole domain: (a) two dimensional distribution of top view; (b) Y=0 (c) Y=300 cm

Figures 9-11 show the photon, neutron and the sum of photon and neutron equivalent dose distributions of side view for both two-dimension and one-dimension in the case of X=70 cm and 100 cm. The results show that behind Hazama concrete wall, the radiation level is very low. In the neighbouring rooms of upstairs and downstairs, they are not suffered any radiation from the small-scale neutron source.



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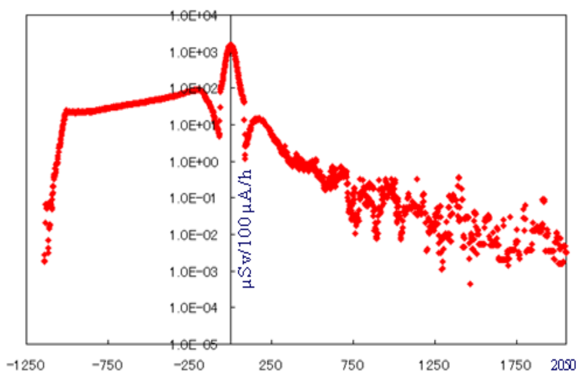

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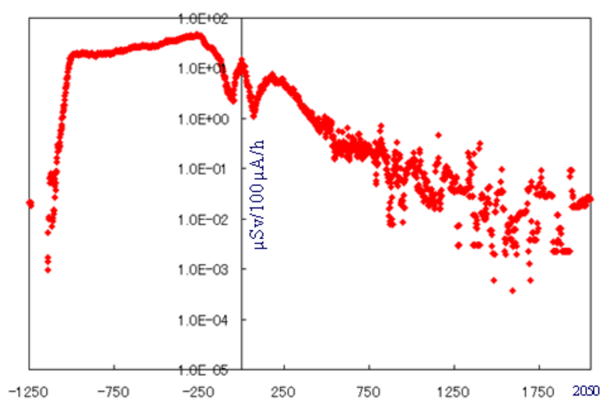

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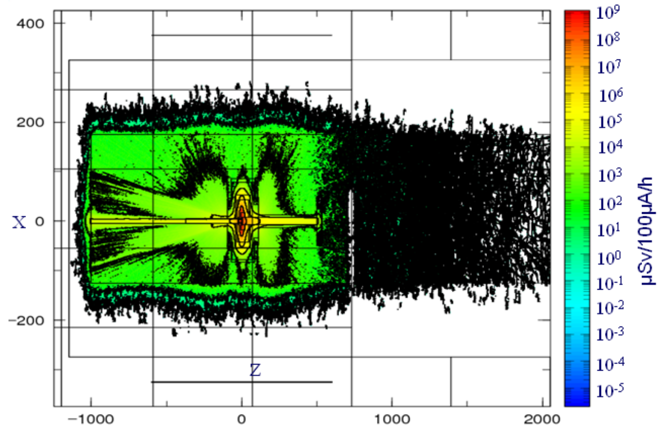
Fig. 9 Photon equivalent dose distribution for whole domain: (a) two dimensional distribution of side view; (b) X=70 cm; (c) X=100 cm



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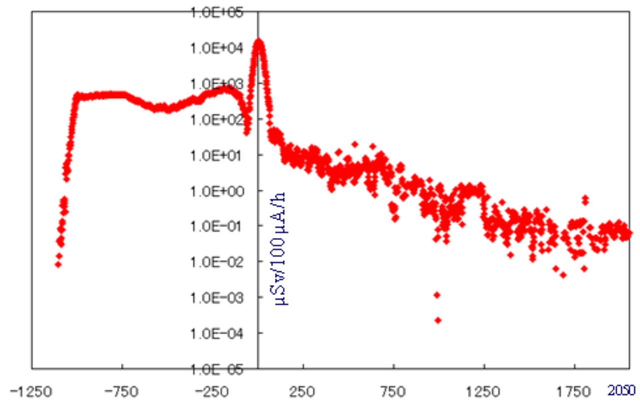

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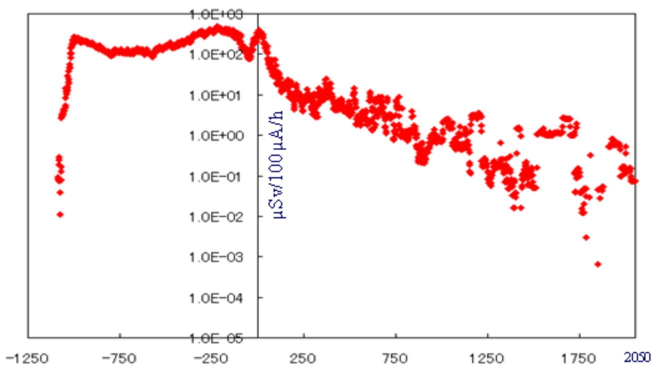

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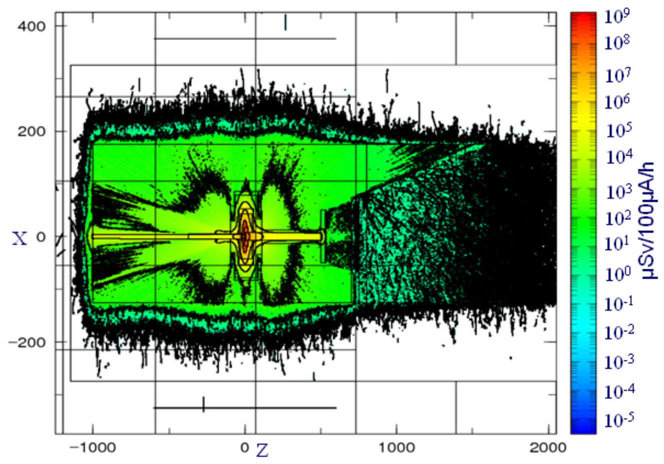
Fig. 10 Neutron equivalent dose distribution for whole domain: (a) two dimensional distribution of side view; (b) X=70 cm; (c) X=100 cm



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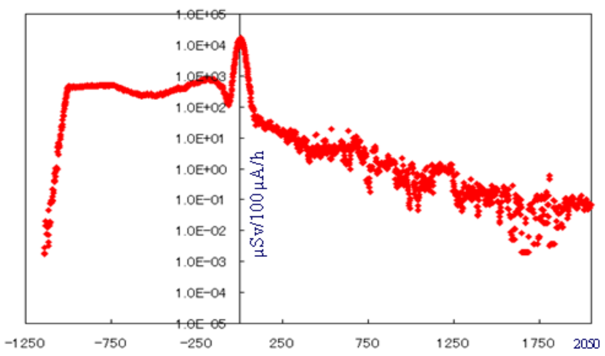

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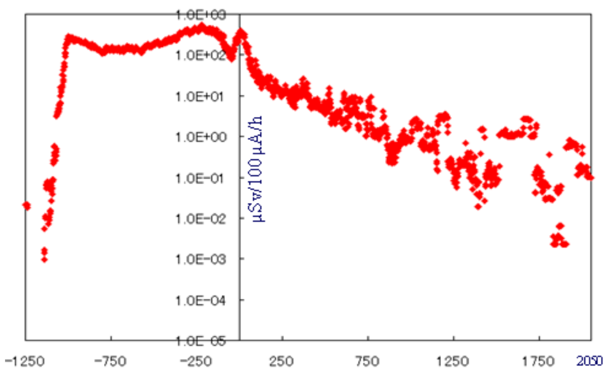

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Fig. 11 Neutron+Photon equivalent dose distribution for whole domain: (a) two dimensional distribution of side view; (b) X=70 cm; (c) X=100 cm

Figures 12-14 show the photon, neutron and the sum of photon and neutron equivalent dose distributions of side view for both two-dimension and one-dimension in the case of Z=0 cm from bottom to top of the target station. They indicate that outside of the target station, the radiation level is acceptable.

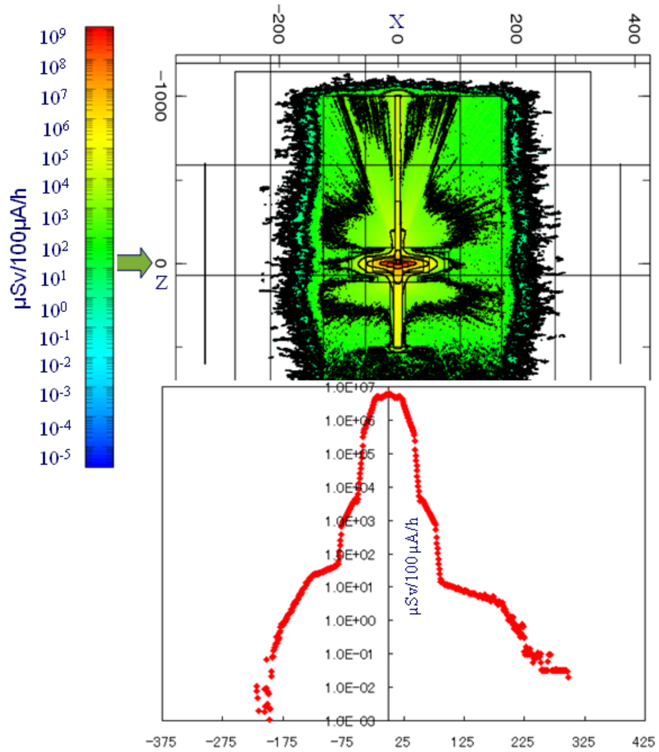

Fig. 12 Photon equivalent dose distribution for whole domain: (a) two dimensional distribution of side view; (b) Z=0 cm

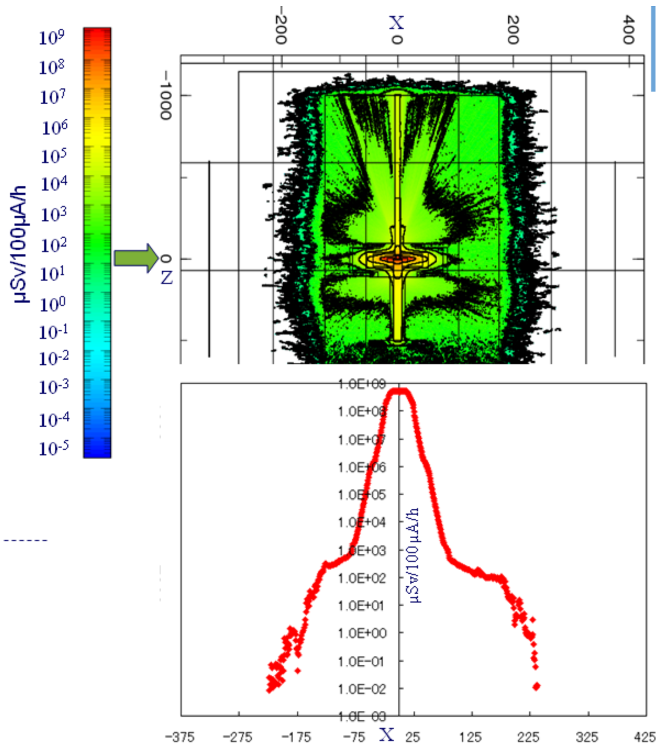

Fig. 13 Neutron equivalent dose distribution for whole domain: (a) two dimensional distribution of side view; (b) Z=0 cm

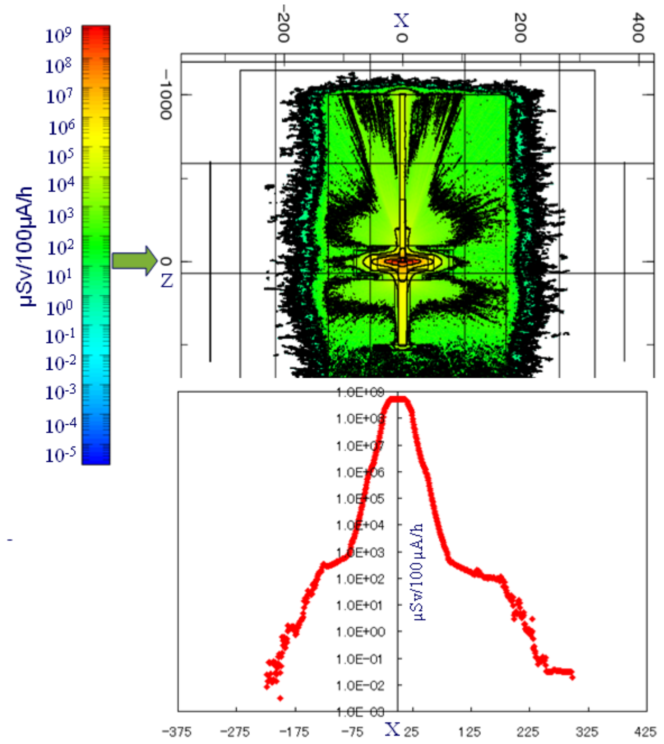

Fig. 14 Neutron+Photon equivalent dose distribution for whole domain: (a) two dimensional distribution of side view; (b) Z=0 cm

4. Conclusion

The shielding design for the small-scale neutron source facility (energy about 7.0 MeV and 0.7kW beam power) to be built up on RIKEN Wako Campus has been completed and the radiation level

will begin.

evaluations have been carried out with PHITS code run on RICC. The radiation calculation results indicate that the current shielding design can meet the requirement of Japanese law.

5. Schedule and prospect for the future

The next step within fiscal year 2012 will focus on the detailed and optimized design of target/moderator/reflector by using PHITS code run on RICC. Many calculations with heavy computational load have to be carried out.

6. If you wish to extend your account, provide usage situation (how far you have achieved, what calculation you have completed and what is yet to be done) and what you will do specifically in the next usage term.

Up to now, the shielding design for the purpose of getting certificate of radiation permission for the construction of the small scale neutron source with 7.0 MeV proton accelerator has been finished. From now on, the optimized design and detailed simulations for TMR will start. TMR modelling will be completed before July. The neutron beam is scheduled to be flown out around August. After that neutron research-based simulation by using RICC

Fiscal Year 2011 List of Publications Resulting from the Use of RICC

[Publication]

1. Design and simulation of simple and easy-to-use compact neutron source-shielding and neutron beam calculation by PHITS code, Sheng Wang, Yutaka Yamagata, Jungmyoung Ju, Shin-ya Morita, Yoshie Otake and Katsuya Hirota, The Second Meeting of The Union for Compact Accelerator-Driven Neutron Sources, Indiana University, Bloomington, U.S.A., July 5-8, 2011.

2. Moderator/reflector/collimator/shielding assembly design and simulation for simple and easy-to-use compact neutron source, Sheng Wang, Yutaka Yamagata, Jungmyoung Ju, Katsuya Hirota, Shin-ya Morita, Yoshie Otake, Hirohiko M. Shimizu, and Yoshiaki Kiyanagi, 1st Asia-Oceania Conference on Neutron Scattering, Tsukuba, Japan, Nov. 20-24, 2011.