RICC Usage Report for Fiscal Year 2011

Project Title:

Simulation for radiography of neutron and X-ray as well as the shielding of radioactive rays

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Description of the project

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.

A design of 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 laboratory use, size of accelerator system need to be designed to fit 5 to 10 square meter laboratory space. 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. In this paper, moderator/reflector/shielding modelling for compact neutron source with low power level proton accelerator (energy about 3.5MeV and 0.3kW beam power) is carried out by Monte Carlo code (PHITS, ver. 2.24).

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

Neutron flux was simulated by PHITS (Particle and Heavy-Ion Transport code System, ver. 2.24) using RICC. The computational cost for one case is about 64 cores running 10 hours. Neutron source data was based on the experimental results by W. B. Howard et al.

. Figure 1 shows schematic diagram of moderator and parameter setting for the 3.5 MeV small neutron source. A beryllium plate which has 5 cm diameter was used for target. For reflection of neutron, graphite was adopted. A boric acid resin was used for neutron shielding. Water acts as cooling system and pre-moderator. Two detectors, which are located 2m and 5m far from the target, are put to detect the neutron flux. Concrete is put outside of the neutron source to shield neutron and photon radiation.

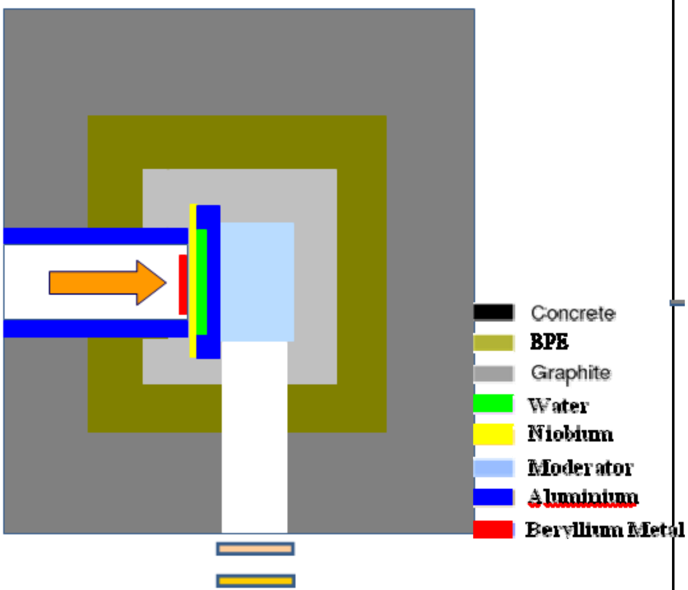

Fig.1. Slab design 3.5 MeV small scale neutron source

3. Result

3.1 Moderator design

To evaluate moderator performances, flux of thermal neutron at the point of 2 m and 5 m from the target was compared. Due to the excellent moderation effect, polyethylene is selected as moderator. To make an optimized design for moderator, three parameters T1, T2 and T3 as shown in Fig. 2 should be evaluated.

Figures 3 and 4 show the thermal neutron flux at 2 m with the variation of T1 and T2. From the two figures, we find that under same T1, with T2 increases, thermal neutron flux increases firstly, then decreases. Thermal neutron flux is sensitive to T1, for example, if T2 fixed at 12 cm, thermal neutron flux increases 14% when T1 is changed from 2 cm to -1.5 cm. Maximum thermal neutron flux may be obtained at T1=-1.5 cm and T2=12 cm.

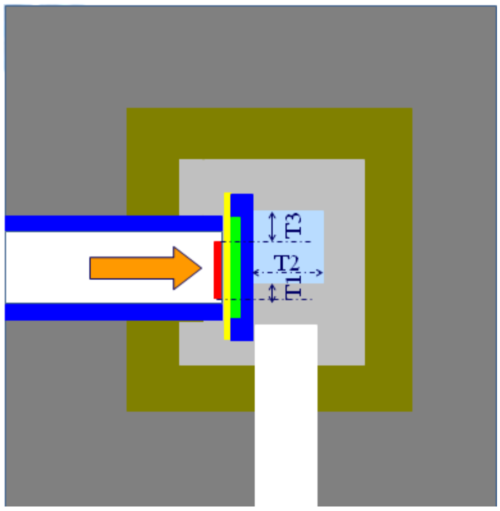

Fig.2. Three parameters for optimised design of moderator

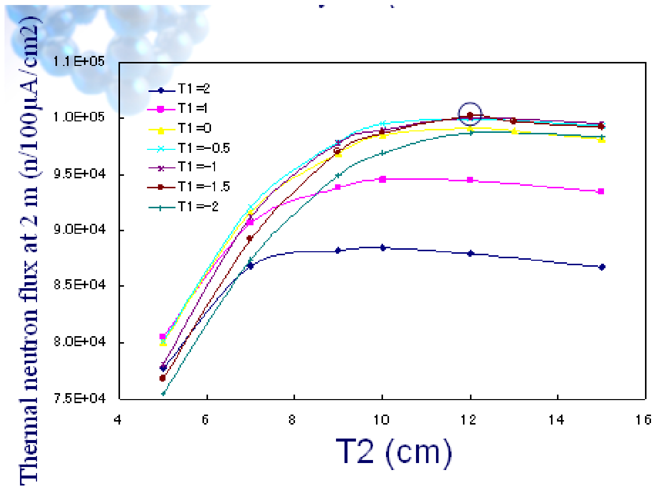

Fig. 3. Thermal neutron flux at 2m vs T2 under different T1

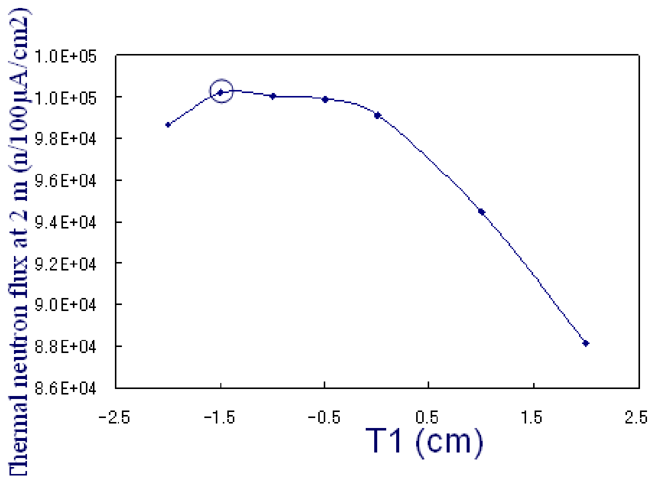

Fig. 4. Max. thermal neutron flux at 2m for each

Since what we need is thermal neutron and the fast neutron may cause activation and gamma generation, we want the ratio of fast neutron flux to thermal neutron flux as low as possible. Fig. 5 shows that the ratio decreases with the increase of T1. By considering thermal neutron flux together with ratio of fast neutron to thermal neutron, T1=-0.5 cm and T2=12 cm could be selected.

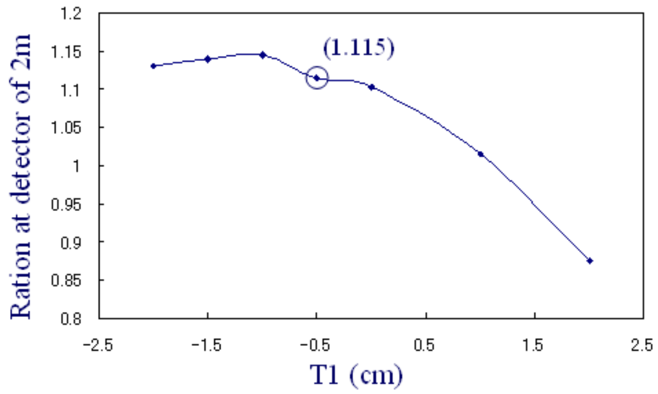

Fig. 5. Ratio of fast neutron flux to thermal neutron flux vs T1 (T2 fixed at 10 cm))

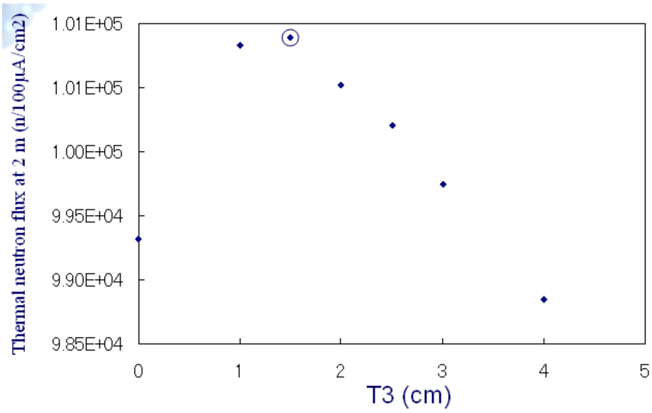

Fig. 6. Thermal neutron flux vs T3

Thermal neutron flux is not sensitive to T3. For example, when T3 increases from 1.5 cm to 4 cm, the thermal neutron flux only decreases about 2%. The highest thermal neutron flux is obtained in the case of T3=1.5 cm.

Finally, the optimized size for moderator may be: T1= -0.5 cm, T2= 12 cm and T3= 1.5 cm.

3.2 Reflector design

There are totally five parameters for optimized design of the reflector, i.e. R1, R2, R3, and R4 shown in Fig. 7 and R5, the thickness of reflector in perpendicular direction.

Figure 8 shows the effects of the R1, R2, R3, R4, and R5 to the thermal neutron flux. It indicates that with increase of reflector thickness, thermal neutron flux increase, but thermal neutron flux is only very sensitive to R4.

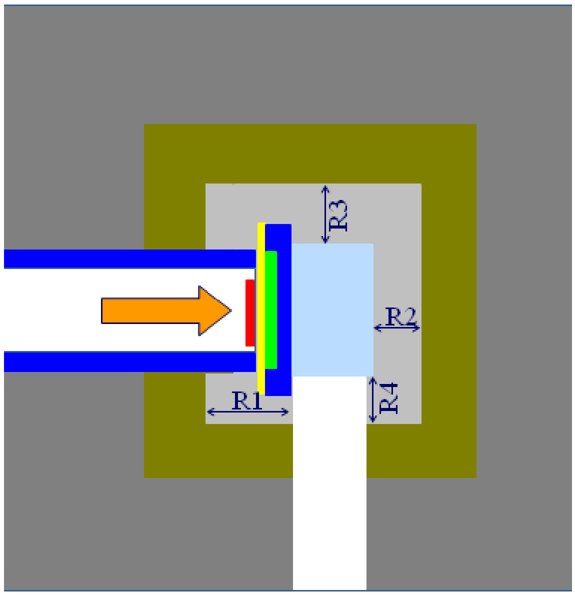

Fig. 7. Optimized design for reflector

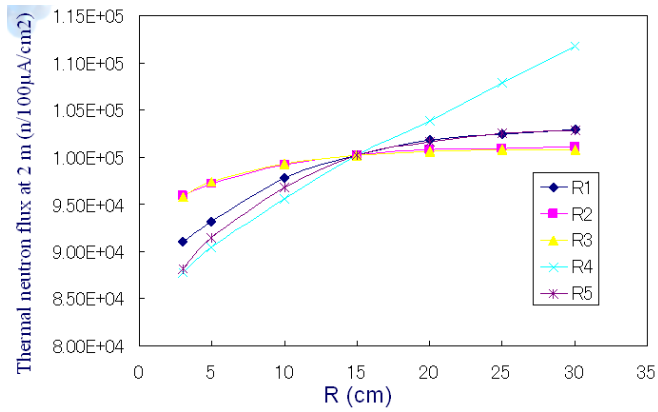

Fig. 8. Thermal neutron flux vs R1, R2, R3, R4 and R5

After considering the situation on-the-spot and the effect of each side thickness of reflector to thermal neutron flux, an appropriate reflector design may be: R1=13 cm, R2=5 cm, R3=5 cm, R4=20 cm and R5=9 cm.

3.3 Shielding design

Figure 9 shows the shielding design for the 3.5 MeV small scale neutron source. Based on this design, radiation calculations have been carried out. Figure 10, 11 and 12 display the radiation distribution of photon, neutron and the sum of photon and neutron, respectively. According to the radiation regulation and actual situation of the 3.5 MeV small scale neutron source facility, the current shielding design is acceptable.

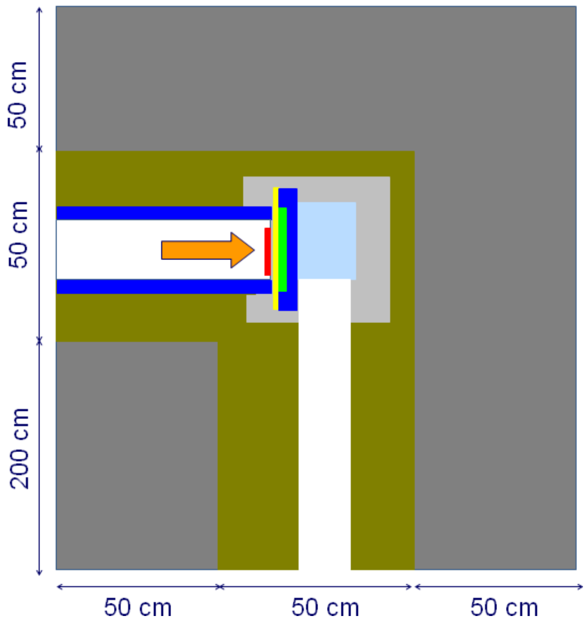

Fig. 9 Shielding design

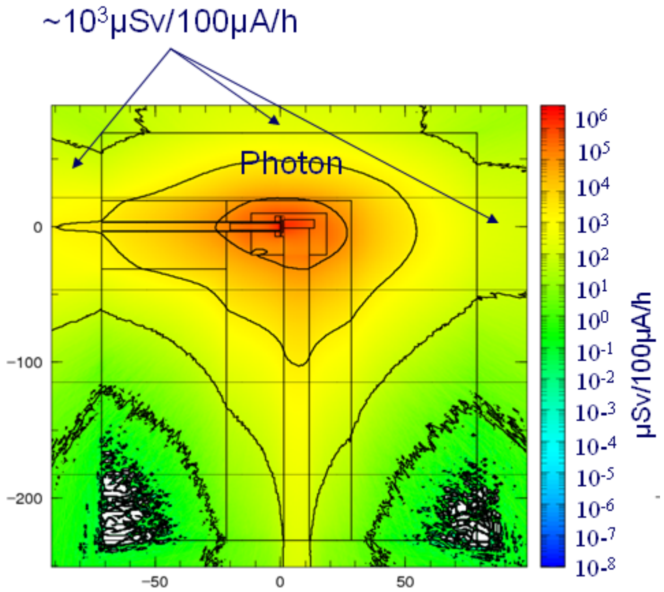

Fig. 10 Photon radiation distribution

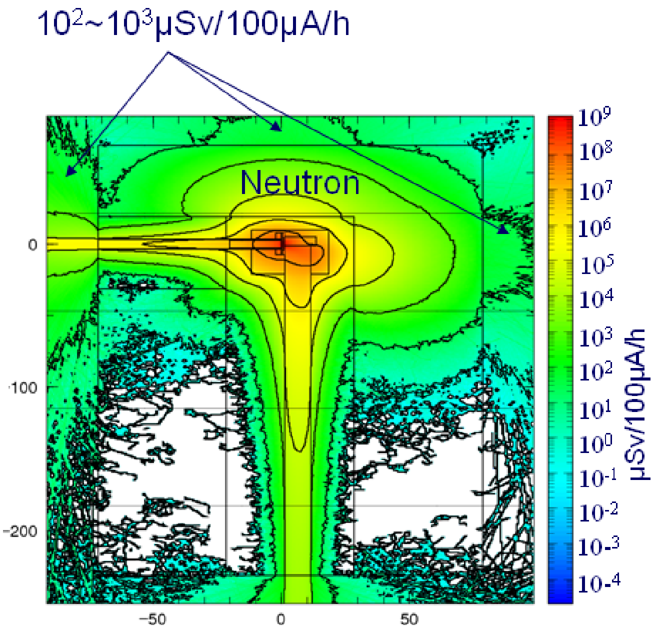

Fig. 11 Neutron radiation distribution

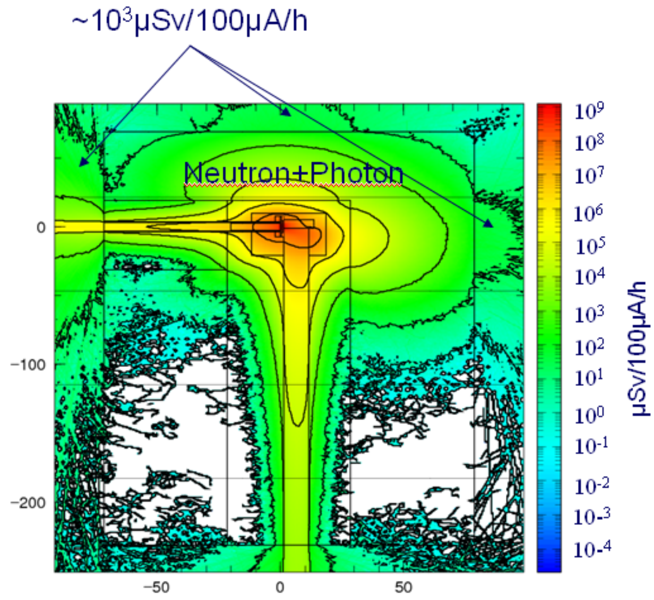

Fig. 12 Total radiation distribution

4. Conclusion

A small scale neutron source based on low power level proton accelerator (energy about 3.5MeV and 0.3kW beam power) was designed.

Polyethylene was adopted for material of moderator due to its excellent moderation effect. Optimized design of the moderator was carried out: (1) under same T1, with T2 increases, thermal neutron flux increases firstly, then decreases; (2) Thermal neutron flux is sensitive to T1 and T1 with somewhat minus value may have higher thermal neutron flux; (3) maximum thermal neutron flux was obtained at T1=-1.5 cm, T2=12 cm; (4) thermal neutron flux is not sensitive to T3; (5) by considering thermal neutron flux and the ratio of fast neutron flux to thermal neutron flux, optimized size of moderator may be: T1= -0.5 cm, T2= 12 cm, T3= 1.5 cm.

Reflector is also an important part for the design of small scale neutron source. The effect of each side thickness of reflector to thermal neutron flux was evaluated: (1) with increase of reflector thickness at each side, thermal neutron flux increase, but thermal neutron flux is only very sensitive to reflector thickness at neutron beam direction; (2) by considering the on-the-spot situation as well as the influence of each side thickness of reflector to thermal neutron flux, an appropriate reflector design may be: R1=13cm, R2=5cm, R3=5cm, R4=20cm, R5=9cm.

According to the simulation results, the current shielding design for both of neutron and gamma is enough.

The construction-based simulation for the small scale neutron source with 3.5 MeV proton accelerator has almost been finished, and it is under construction now. After construction, the research-based modelling will start.

5. Schedule and prospect for the future

The next step within fiscal year 2012 will focus on the research-based evaluation by using PHITS code run on RICC, such as the moderator shape design, the neutron beam intensity evaluation for different application background, and et al.

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 moderator/reflector/shield design for the purpose of the construction of the small scale neutron source with 3.5 MeV proton accelerator has almost been finished. It is under construction now and will be finished after April. After completing the construction, the simulation for the purpose of research will start, such as the shape design of moderator, the intensity of neutron beam evaluation according to different application purposes, and et al. The next usage term will focus on the 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.