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A plan for neutron radiography facility using a compact accelerator at RIKEN

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ABSTRACT

We are planning to construct a thermal neutron source consists of a small proton accelerator and a beryllium target. The aim of this instrument is for industrial radiography applications. 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. Not only the penetration depth of neutron beam compared with X-ray, but material information like strain or temperature that may be obtained by using pulsed neutron source will be quite useful in production engineering. We present the design parameters and the estimated performance of this neutron source.

1. Introduction

Investigation of inside structure as well as outside profile is important for industrial applications. Concerning the 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 radiography has a number of advantages over X-ray systems, but compact neutron source that can be situated in the laboratory scale must be developed. We have started a preliminary design of accelerator based compact neutron source for industrial and transportable use.

2. Accelerator systems and applications

Although spallation neutron source has high energy efficiency, it requires very large accelerator systems. We are planning to use low energy nuclear reaction of Be(p,n) or Li(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. Table 1 shows possible accelerator systems, which specifications are estimated by authors. Figure 1 shows an image of LINAC based neutron source for laboratory use.

Table 1. Possible accelerator systems (Specifications are estimated by authors)

Accelerator type	Acceleration energy (MeV)	Beam current (pulse peak)	Expected dimension and mass
LINAC	3.9	100µA(7mA)	4m 2 ton
LINAC	7	100µ□(7mA)	5m 3 ton
LINAC	11	100µ□□8mA)	6m 4 ton
Cyclotron	18	100µA	2m 15 ton
LINAC	2.5	10mA	3m 3 ton

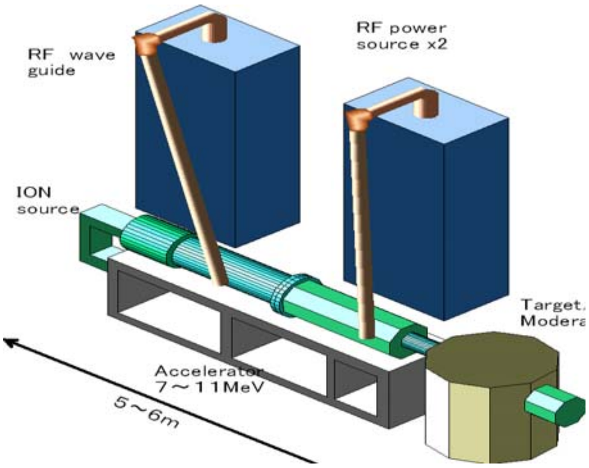

Figure 1. An image of LINAC based neutron source for laboratory use

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 aluminum) 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.

3. Preliminary design of target and moderator

3.1. Thermal properties

Thermal properties of target are one limiting factor of compact neutron source. Heat removal of target is simulated using finite element software (COMSOL Multiphysics 3.5a). Long term average condition and short pulsed conditions are simulated. Figure 2 shows simulation results of temperature variation on the target. Short-term temperature changes due to pulsed proton beam. Temperature rose up to 550 (K) after 500 micro seconds of 15 mA 7 MeV beam irradiation at 2x2 cm area of beryllium (0.5 mm) and aluminum (2 mm). Long term heat removal is simulated with 15 L/min cooling water on aluminum side.

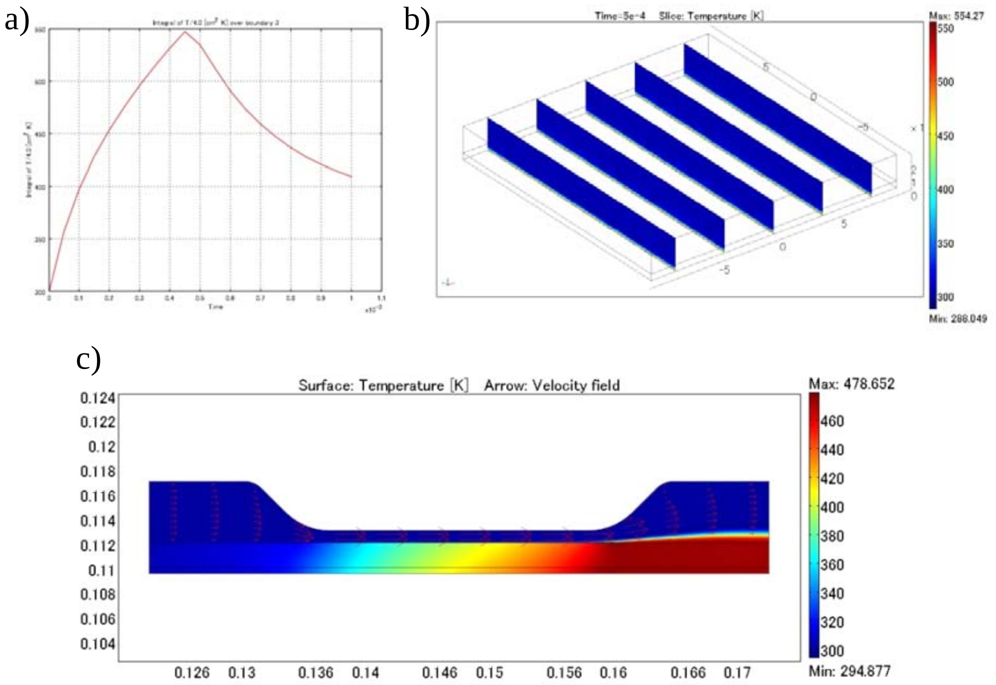

Figure 2. Temperature variation on the target, a) temperature profile according to the time, b) 3D temperature profile on target, c) cross section of target

3.2. Neutronic properties

Neutron flux is simulated by PHITS (Particle and Heavy-Ion Transport code System, ver. 2.08). Be is used for target and light water is used on the moderator as shown in figure 5. Table 2 shows input parameters for simulation. To simplify parametric sweep, inlet and outlet diameter of output duct (D_{in} and D_{out}) are proportional to the diameter of moderator (B). To verify optimum condition of neutron flux, thickness and diameter of moderator (A and B) are swept and flux of thermal neutron at the point of 2 m and 5 m away from the Be target is compared. Neutron source data is based on paper by Gibbons et al. [4].

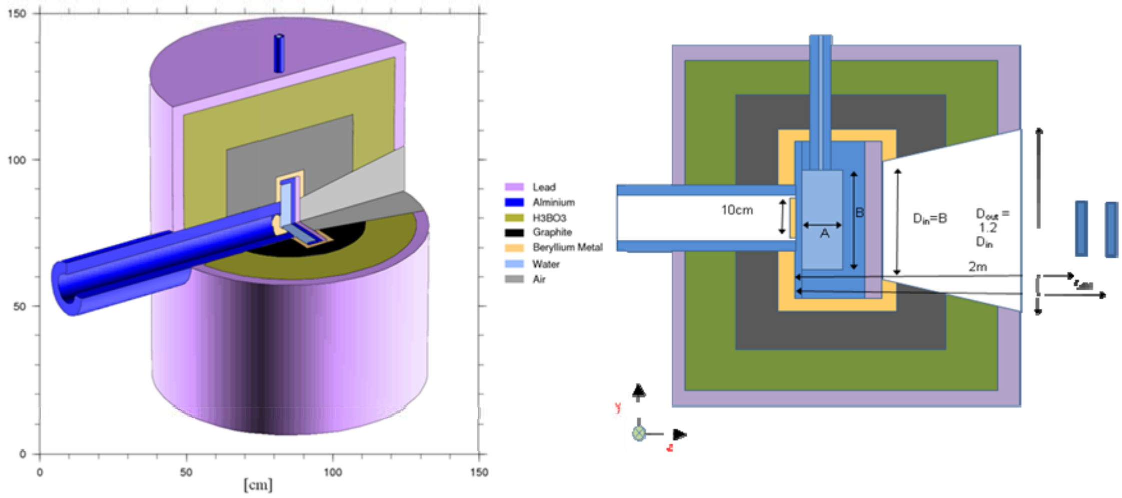

Figure 3. 3D view and parameters setting of compact accelerator system

Table 2. Input parameters for simulation

E_p [MeV]	5.42	Thickness of Be reflector [cm]	2
Radius of beam [cm]	1	Radius of graphite [cm]	30
Thickness of target [cm]	0.2	Height of graphite [cm]	80
Radius of target [cm]	5	Radius of boric acid resin reflector [cm]	50
Housing thickness of moderator [cm]	2	Height of boric acid resin reflector [cm]	120
Radius of duct inside [cm]	6		
Thickness of duct [cm]	5	Radius of gamma shield [cm]	55
Duct length [m]	1	Height of gamma shield [cm]	130

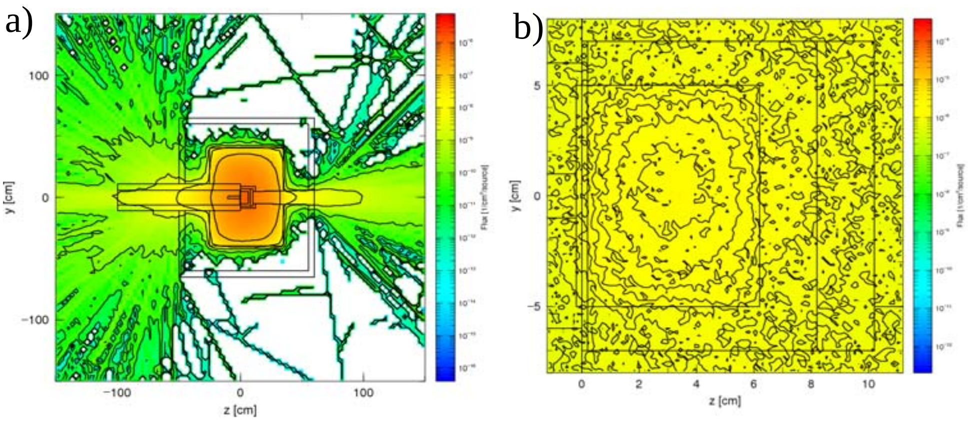

Figure 4. Flux distribution of thermal neutron, a) entire area of system, b) distribution around moderator

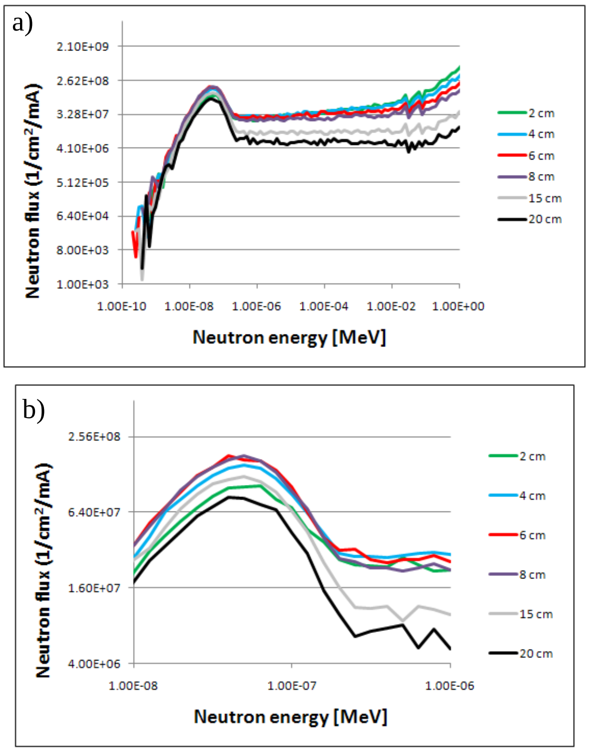

Figure 5.Neutron energy distribution on the start point of neutron output duct, a) total energy distribution, b) distribution of thermal neutron

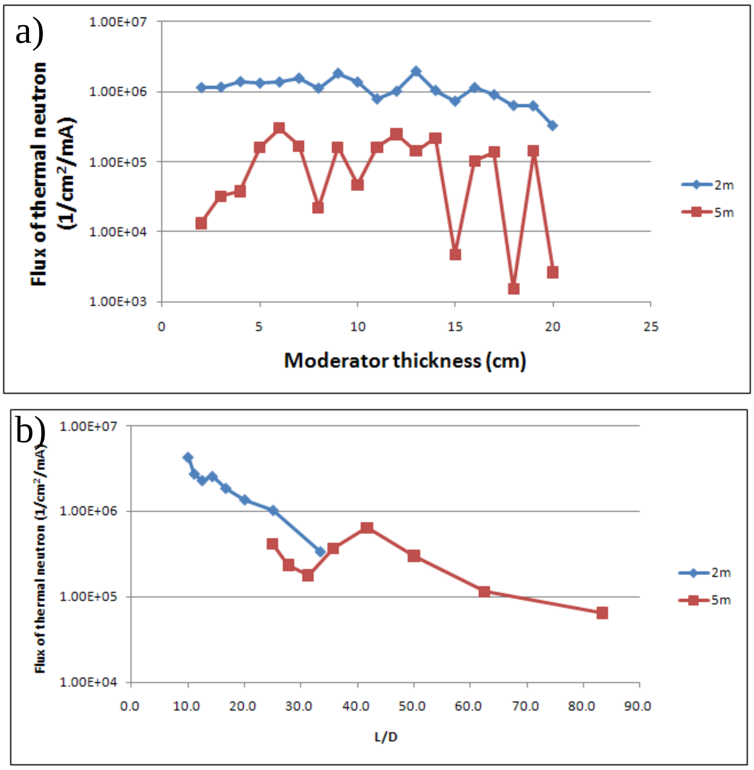

Figure 6. Flux of thermal neutron according to the moderator thickness and L/D.

Figure 4 and figure 5 shows flux distributions of thermal neutron and neutron energy distribution on the neutron output duct. Figure 6 shows flux of thermal neutron according to the moderator thickness and L/D at the point of 2 m and 5 m. In the figure 5 (b) and figure 6 (a), maximum flux is achieved when thickness of moderator (parameter A) is 6 cm. Based on these results, parameter A is fixed and parameter B is swept to verify L/D characteristics. In the figure 6 (b) shows that maximum flux on the 5 m distance is 6.37×10^5 [1/cm^2/mA] when L/D is 41.7.

4. Conclusion and future prospects

A plan for compact neutron source based on accelerator is discussed. Temperature rose up to 550 (K) at the condition of 15 mA and 7 MeV. Neutron flux was 6.37×10^5 [1/cm^2/mA] at the 5.4 MeV. Based on thermal and neutronic property analysis, 7 MeV, 0.1 mA average current system seems to be feasible. There are still many parameters, which are not well discussed. Further analysis and consideration will be necessary before construction.

5. References

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