Usage Report for Fiscal Year 2017

Project Title:

Accelerator-driven compact neutron source development

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Laboratory at RIKEN: Neutron Beam Technology Team

1. Introduction

This project includes three parts:

① Monte Carlo Simulation of Thermal Neutron Radiography for Liquid Film Samples;

Inspection of liquid film is an important work of engine fuel movement investigation for the aerospace engine. Thermal neutron photography can effectively detect the situation of liquid film and Monte Carlo method, e.g. MCNP, can effectively simulate the neutron transport problem. The results obtained by simulations on different liquid film samples and source intensity situations, were of great significance to the design of the actual neutron imaging system.

② Monte Carlo Simulation of Backscattering Neutron Imaging for Defective Bridge;

The bridges defections will happen after years of serving. There are several bridges occurring accidents every year and increases continually. Considering the structure of the bridge, the detector can't be set under the bridge. Thus, backscattering image technology can be used in this field.

There are several attempts try to detect bridge detection, such as ultrasonic detector, concrete protection covers thickness instrument and crack width detector. There are some limitations among these methods, e.g. operating difficulty, destroying of the bridge and time consuming. Therefore, a non-destructive testing method should be used.

2. Usage status of the system and calculation method

All the calculations are performed on HOKUSAI system by using PHITS or MCNP6 code.

3. Calculation model, results and conclusions

3.1 Monte Carlo Simulation of Thermal Neutron Radiography for Liquid Film Samples;

3.1.1 Calculation model

Fig.1 The simulation model

The simulation model of thermal neutron image system is simplified into four parts: neutron source, moderator, sample and detector as shown in Fig. 1. The deuterium and deuterium neutron source, with 150 keV, is used in the problem and the fast neutron with 2.5MeV is generated. The appropriate thermal neutron beam is obtained by the optimized moderator. There are two types of moderator structures, cylinder and hollow cylinder. The moderator material is polyethylene. The liquid film in the sample is distributed between two hollow stainless-steel shaft interlayers. Detector is set as an array with 200×200 cells. The resolution of the detector is 1mm. The neutron energy detected by the thermal neutron detector is set to 1.0-9 ~ 5.0-7MeV.

3.1.2 Calculation results

The process of numerical simulation is divided into neutron moderation and neutron photography. Neutron is detected after moderation, and the feature of neutron beam is shown in the Fig. 2, Fig.3, Fig.4.

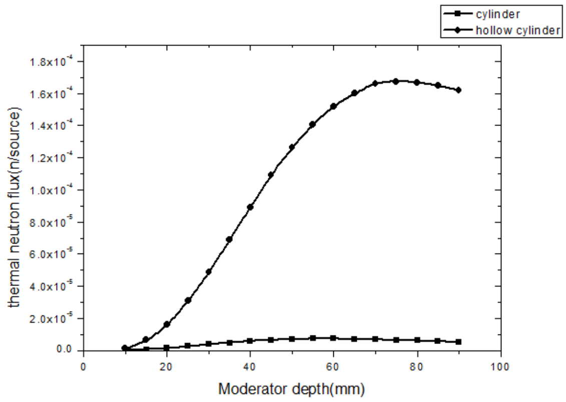
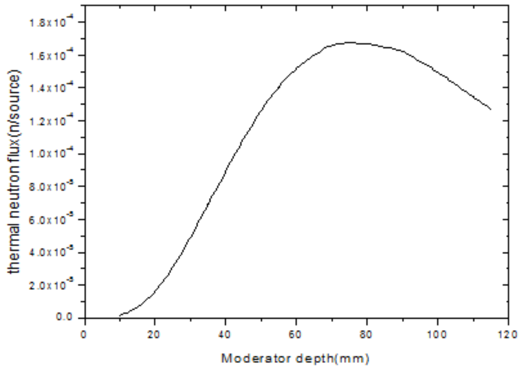


Fig.2 The curves of the thermal neutron flux vs. moderator depth



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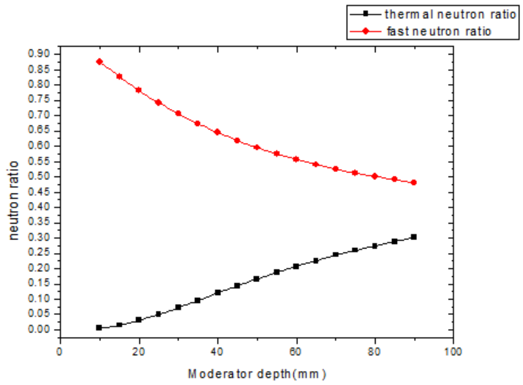

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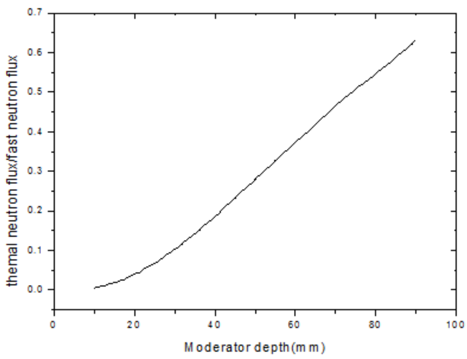


(c)

Fig.3 The curves of (a) The thermal neutron flux vs. moderator depth; (b) Neutron ratio vs. moderator depth; (c) Thermal fast neutron ratio vs. moderator depth

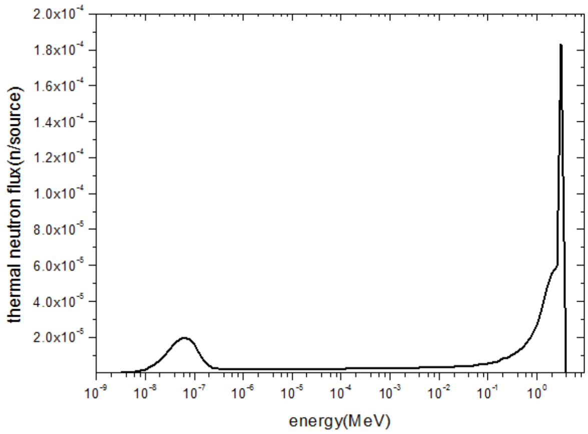
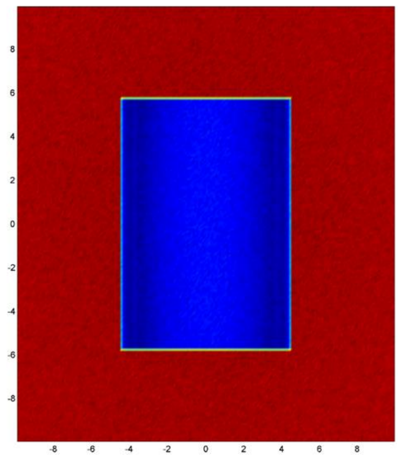


Fig.4 Neutron energy spectrum

As is shown in the Fig.3, at a moderator thickness of about 75 mm, the thermal neutron count reaches its maximum. At the same time, the thermal neutrons account for 25% of the total number of neutrons, and thermal fast neutron ratio is 0.5. So, the proportion of thermal neutrons in the neutron beam is sufficient.

There are two peaks in Fig. 4. Thermal neutron peak at 2.0E-5 and fast neutron peak at 1.8E -4. These two peaks represented the number of moderated neutron have the same order.



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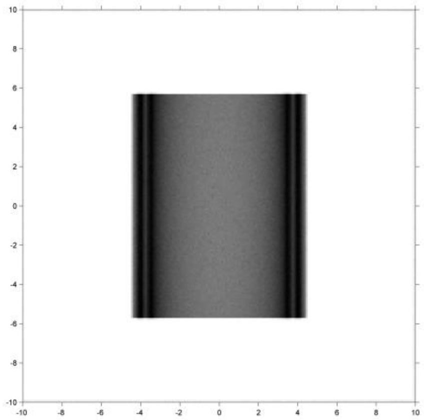

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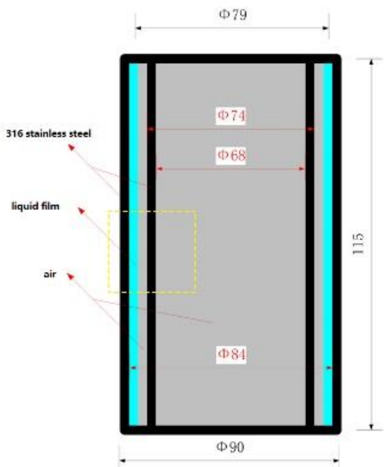

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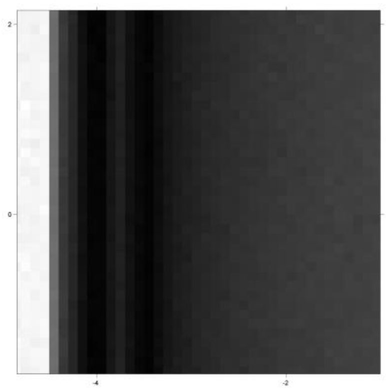


(d)

Fig.5 The sample image of (a) Colored overall neutron image; (b) Black and white overall neutron image; (c) The simulation model; (d) Partial neutron image

3.1.3 Conclusions

Moderator material is polyethylene, and the thickness of moderator is 75 mm, and the structure is hollow cylindrical. As a result, suitable thermal neutron beam is obtained by moderation from D-D neutron generator.

The size and shape of the liquid film sample can be distinguished from the neutron imaging result. Through the quantitative analysis, the liquid film thickness is between 2 mm to 3 mm and the shape is hollow cylinder. The film thickness obtained from simulation is similar to the liquid film thickness of the sample.

3.2 Monte Carlo Simulation of Backscattering Neutron Imaging for Defective Bridge

3.2.1 Calculation model

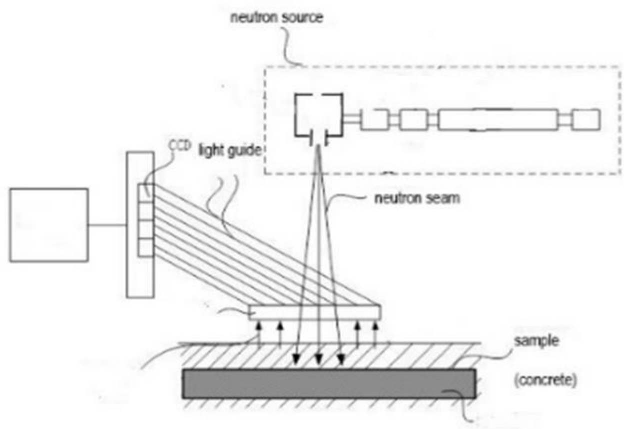


Fig.6 Backscattering image system

As shown in Fig.6, a small fast neutron source is used in this model. The thermal neutron scintillator with high anti-radiation ability and sensitive to fast neutrons is used for receiving the backscattered neutron, the scintillator is connected to the CCD by a light guide fiber. The signal is transferred to the computer and drawing the backscattering image.

3.2.2 Calculation results

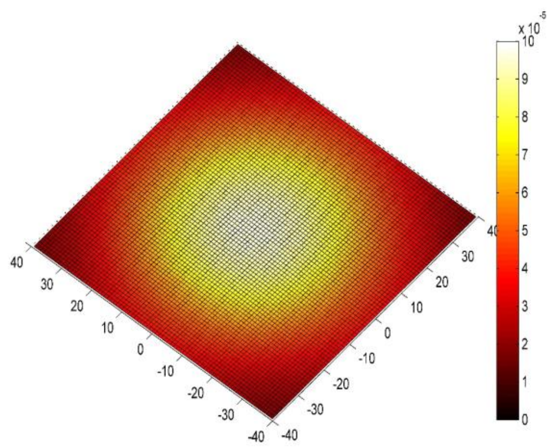


Fig.7 Normal bridge

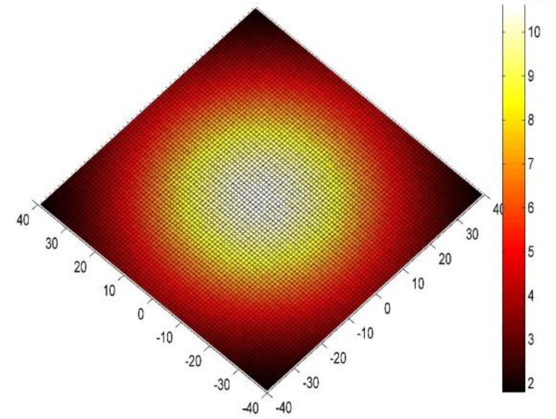


Fig.8 Defective bridge with water

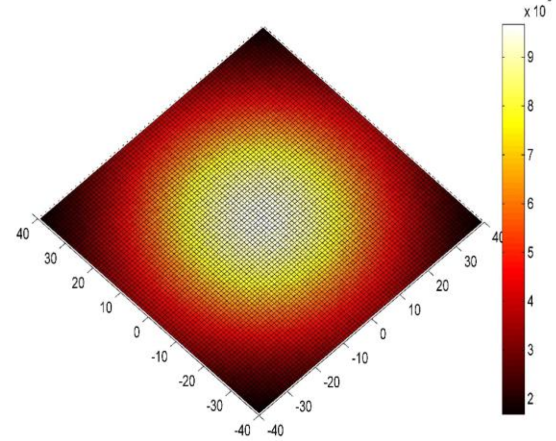
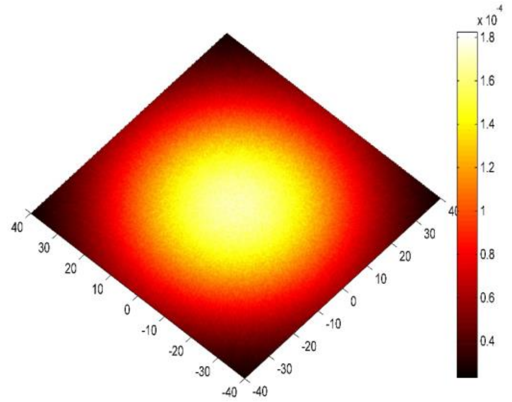


Fig.9 Defective bridge with air



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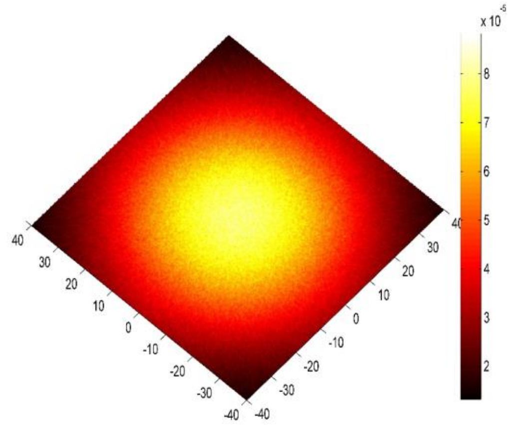

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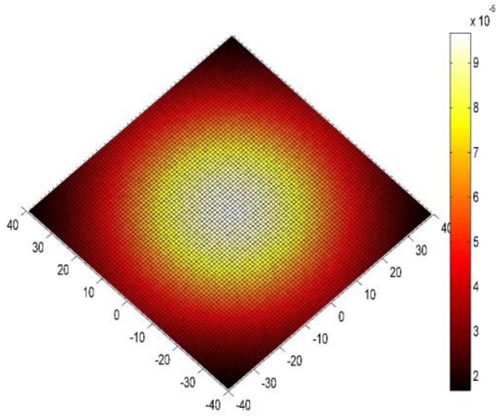

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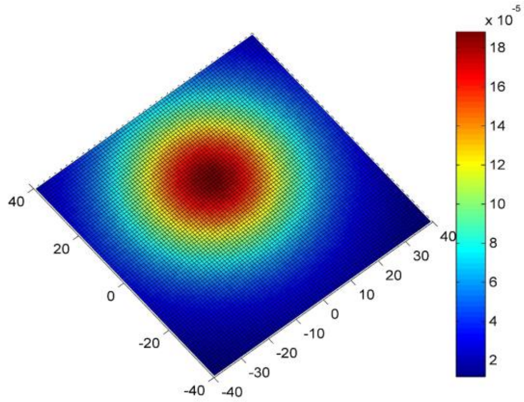
Fig.10 Backscattering neutron flux of defective bridge with water, (a) energy 1Mev; (b) energy 2Mev; (c) energy 4Mev.



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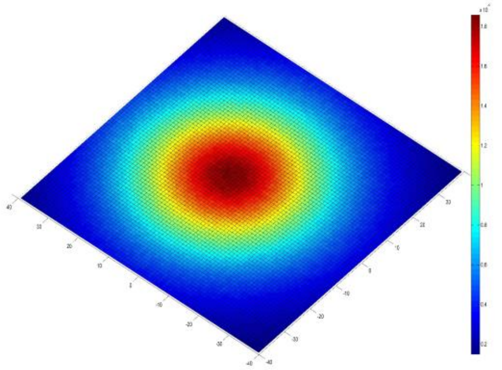

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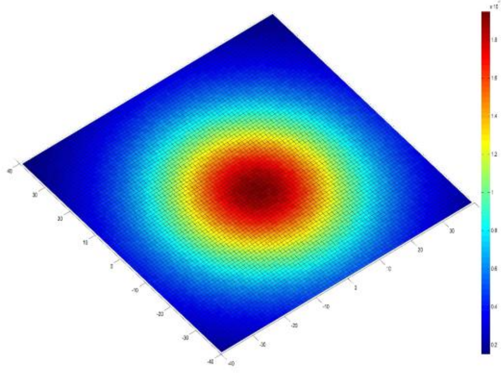

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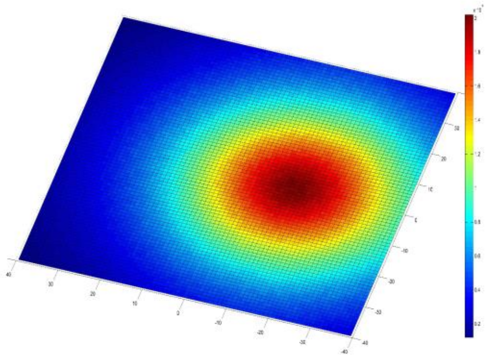

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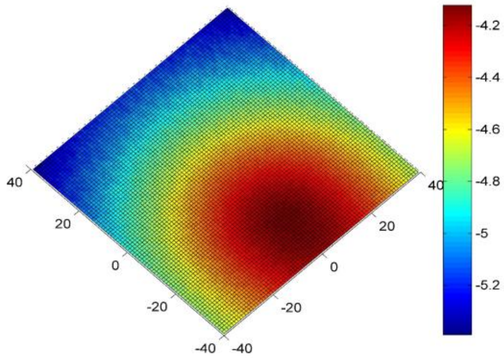

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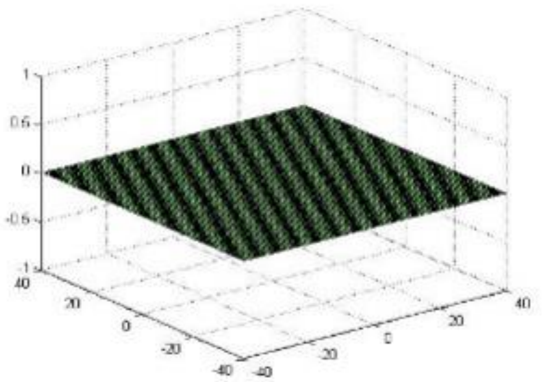

(f)

Fig.11 The backscattering neutron flux of (a) the incident angle = 0◦ ; (b) the incident angle = 15◦ ; (c) the incident angle = 30◦ ; (d) the incident angle = 45◦ ; (e) the incident angle = 60◦ ; (f) the incident angle = 75°

Three bridge conditions were adopted in this simulation. Because the cross section of fast neutron is different from one element to another and several scatterings will be occurred near the concrete, the backscattering neutron flux will change correspondingly. Because the macroscopic cross sections of fast neutron are different among concrete, water and air, the distribution of scattered neutron flux will be different. As Fig.7, Fig.8 Fig.9 shown, the backscattering images differ in neutron flux, the second is lower than the first one, the third is higher than the first one

3.2.3 Conclusions

The distribution images of neutron flux were obtained after simulating three different neutron backscattering conditions. The location and size of the defective bridge can be obtained by extracting and analyzing the edge of the image. It is feasible to find the defective bridge condition by this method.

The incident angle will influence the backscattering neutron image, after the contrast among six angles, the best incident angle is 45., About the energy, the neutrons with lower energy are more properly to be used. Then the most optical location for source is 0, 11, 14, the most optical vertical distance between detector and the concrete is 15 cm.

[Proceedings, etc.]

1. Weiguo Xu, Baolong Ma, Yong Gao, Sheng Wang*, Y. Otake, H. Sunaga. Monte Carlo Simulation of Thermal Neutron Radiography for Liquid Film Samples. 10th XJTU-UT-SJTU Joint International Symposium on Nuclear Science and Technology, Xi'an, Shaanxi, China, Sept. 3-8, 2017.
2. Yanyan Sun, Mingfei Yan, Sheng Wang*, Sihan Xu, Binbin Tian, Baolong Ma, Y. Otake, H. Sunaga. Monte Carlo Simulation of Backscattering Neutron Imaging for Defective Bridge. 10th XJTU-UT-SJTU Joint International Symposium on Nuclear Science and Technology, Xi'an, Shaanxi, China, Sept. 3-8, 2017.
3. Sheng Wang*, Xiaobo Li, Y. Otake, H. Sunaga. Target System Development for Transportable Accelerator-driven Neutron Source. 10th XJTU-UT-SJTU Joint International Symposium on Nuclear Science and Technology, Xi'an, Shaanxi, China, Sept. 3-8, 2017.

[Copy of publications]

10th XJTU-UT-SJTU Joint International Symposium on Nuclear Science and Technology
Xi'an, China, Nov. 22-25, 2017

Monte Carlo Simulation of Thermal Neutron Radiography for Liquid Film Samples

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1. INTRODUCTION

Inspection of liquid film is an important work of engine fuel movement investigation for the aerospace engine . Thermal neutron photography can effectively detect the situation of liquid film and Monte Carlo method, e.g. MCNP, can effectively simulate the neutron transport problem. The results obtained by simulations on different liquid film samples and source intensity situations, were of great significance to the design of the actual neutron imaging system.

2. SIMULATION MODEL

The internal structure image of an object can be obtained through neutron photography.

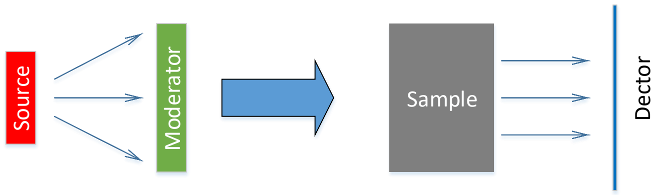


Fig. 1 Simulation model

The simulation model of thermal neutron image system was simplified into four parts: neutron source, moderator, sample and detector as shown in Fig. 1.

The deuterium and deuterium neutron source, with 150 keV, was used in the problem and the fast neutron with 2.5MeV was generated.

The appropriate thermal neutron beam was obtained by the optimized moderator. There were two types of moderator structures, cylindrical and hollow cylinders . The moderator material was polyethylene.

The liquid film in the sample was distributed between two hollow stainless steel shaft interlayers.

Detector was set as an array with 200×200 cells. The resolution of the detector was 1mm. The neutron energy detected by the thermal neutron detector is set to $1.0^{-9} \sim 5.0^{-7}$MeV.

3. RESULTS

The numerical simulation were divided into two parts, neutron moderation and neutron photography . Neutron is detected after moderation, and the neutron energy spectrum is shown in the Fig. 2.

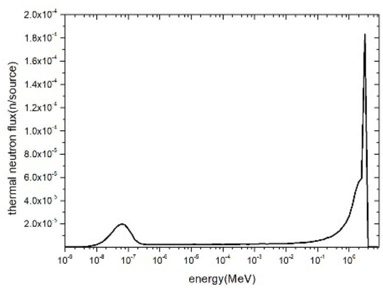
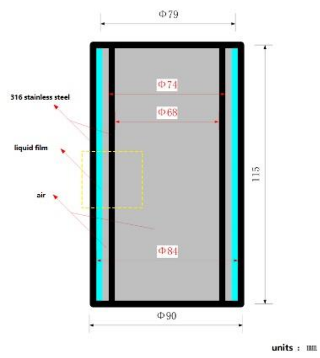


Fig. 2 Neutron energy spectrum

There were two peaks in Fig. 2. Thermal neutron peak at 2.0E-5 and fast neutron peak at 1.8E -4. These two peaks had the same order and the number



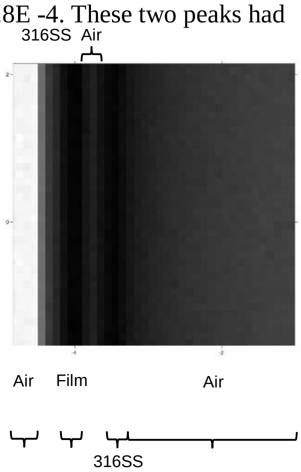


Fig. 3 Sample Fig. 4 Neutron imaging

Materials from left to right in the Fig 4 are air, 316SS, liquid film, air, 316SS, air. Through the quantitative analysis, the liquid film thickness was between 2mm to 3mm and the shape was hollow cylinder.

4. CONCLUSION

Suitable thermal neutron beam is obtained by moderation from D-D neutron generator. The size and shape of the liquid film sample can be distinguished from the neutron imaging result. The film thickness obtained from simulation is similar to the liquid film thickness of the sample.

5. ACKNOWLEDGEMENT

The computational resource for Monte Carlo calculation involved in this study was provided by Advanced Center for Computing and Communication (ACCC), RIKEN.

Monte Carlo Simulation of Backscattering Neutron Imaging for Defective Bridge

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1. INTRODUCTION

This study aims to simulate the backscattering of neutron imaging for defective bridge detection. First, a simulation model, which made up by a rectangular concrete, a neutron source and a detector, was established. The detector plane was divided into 80*80 arrays. The backscattered neutron flux distribution is different from one structure to another. By comparing the backscattering neutron flux distribution under different bridge conditions, whether the bridge is defective or not can be known. Second, this paper studies on the influencing factors of neutron backscattering imaging, e.g. neutron incident angle, incident energy, distance between detector and concrete and the distance between neutron source and concrete. After analyzing the different conditions among the initial settings, the best one was obtained. Third, the image post-processing is an important part of this work. The detective location and size were obtained by analyzing the edge of image using canny operator.

2. SIMULATION MODEL

A novel model, which settled by MCNP5, was used to simulate the system. It contained a rectangular concrete with 15 steer bars, a neutron source and a detector. The rectangular concrete was 60*60*30cm^3. Air and water in concrete were used to simulate the cavity in bridge and corroded section in bridge. The sizes of the sections are same, which were 5cm*5cm*5 cm, the shape of detector was a plane and its size was 80cm*80cm*1cm. It was divided into 80 lines and 80 rows, as shown in Fig.1.

A small fast neutron source was used in this model. The thermal neutron scintillator with high anti-radiation ability and sensitive to fast neutrons is used for receiving the backscattered neutron, the scintillator is connected to the CCD by a light guide fibre. The signal is transferred to the computer and drawing the backscattering image.

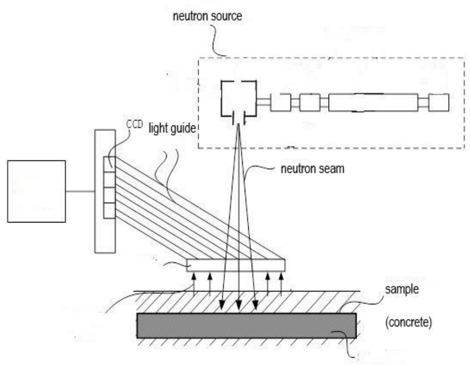

Fig.1 backscattering image system

3.RESULTS

Three bridge conditions were adopted in the simulations. Because the cross section of fast neutron is different from one element to another and several scatterings will be occurred near the concrete, the backscattering neutron flux will change, correspondingly. Fig.2, Fig.3, Fig.4 shown, because the macroscopic cross sections of fast neutron are different among concrete, water and air, the distribution of scattered neutron flux will be different. The backscattering images differs in color, the second is lighter-colored than the first one, the third is darker than the first one.

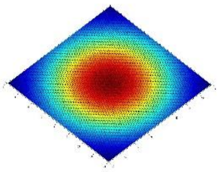

Fig.2 normal bridge

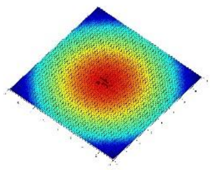

Fig.3 defective bridge with water

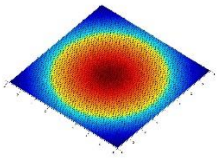

Fig.4 defective bridge with air

4. CONCLUSION

By simulating three different neutron backscattering conditions, the image can be obtained by the neutron flux. Then extracting and quantitative the edge of the image. Finally, the location and size of the defective bridge can be obtained, which should be offered to the bridge workers. Therefore, fast neutron backscattering image detection for defective bridge conditions is feasible.

5. ACKNOWLEDGEMENT

The computational resource for Monte Carlo calculation involved in this study was provided by Advanced Center for Computing and Communication (ACCC), RIKEN.

REFERENCES

1. Cor P.Datema, Victor R.Bom, anf Carel W.E.van Eijk, Landmine Detection With the Neutron Backscattering Method[J],IEEE Transactions on nuclear science, 2001, VOL. 48, NO.4, 1087-1091.

2. Marko Maučec, Robert J. de Meijer Nuclear Geophysics Division Kernfysisch Versneller Instituut, Rijksuniversiteit Groningen Zernikelaan 25, 9747 AA Groningen, The Netherlands, A Monte-Carlo study of landmines detection by neutron backscattering method

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Target System Development for Transportable Accelerator-driven Neutron Source

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1. INTRODUCTION

As a probe, neutron has many advantages , such as non-destructive, excellent penetrability to high density material, sensitivity to light nucleus material and so on. By neutron imaging, it is possible to have the details of an internal structure for an object. In the real situation, the objects to be detected usually can 't be moved such as bridge, building, rocket, airplane, et. al . So t ransportable neutron source is highly demanded and will expand the application field of non-destructive testing greatly. With the requirement on compact size and light weight to achieve transportation, proton linac (linear accelerator) with low energy (such as ≤4 MeV) is a suitable choice [1]. For the transportable accelerator-driven neutron source, a key part is to have a reliable and long -life target with high neutron yield.

Be (Beryllium) and Li (Lithium) are the two target material candidates. But both of them have the problem of hydrogen embrittlement. Compared with Be, Li has a higher (p, n) reaction cross-section in the case of low proton energy than Be target as shown in Fig.1.However, Li has a very poor thermodynamic property which is displayed in Table 1.

Therefore, in the paper Li target system for transportable neutron source has been designed carefully to overcome the problems of hydrogen embrittlement and poor thermodynamic property.

Table1 Thermodynamic Property Comparison: Be and Li

Mat	Thermal conductivity (W/cm/K)	Specific Heat Capacity(J/gK)	Melting Point(℃)
Be	250	1.82	1278
Li	84.7	3.6	180.54

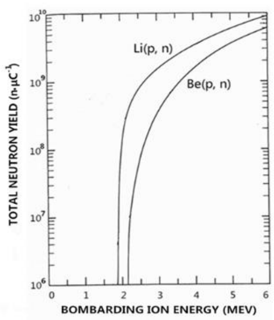

Fig.1 Reaction (p, n) neutron yield of Li and Be [2]

2. LITHIUM TARGET SYSTEM DESIGN

To keep the lithium target solid during operation, a cooling system shown in Fig.2 has been designed by finite element method , and the maximum temperature under the different conditions has been calculated in Fig.3.

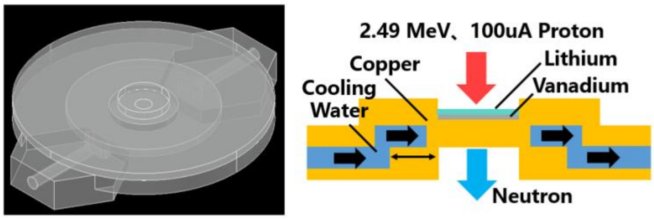

Fig. 2 Schematic diagram of the target system

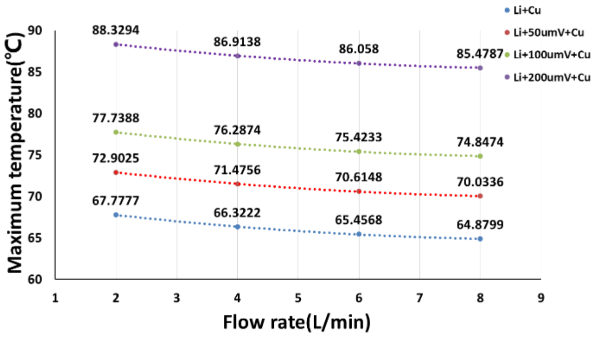

Fig. 3 Cooling effect of the target system

To prevent the occurrence of hydrogen embrittlement, a thin vanadium layer between Li and Cu to hold H ion is added, which could help to keep the target system safe operation. The maximal co ncentration is shown in Table 2. They all don 't exceed the limitation.

Table2 Maximal H concentration of different V thickness

Thickness(um)	50	100	200
Maximal H concentration(mol/m^3)	264.585	132.418	66.292

The maximal temperature of the target under 250W heating and it is up to about 90 ℃ which is still below the lithium melting point. So in theory the target system could operate safely.

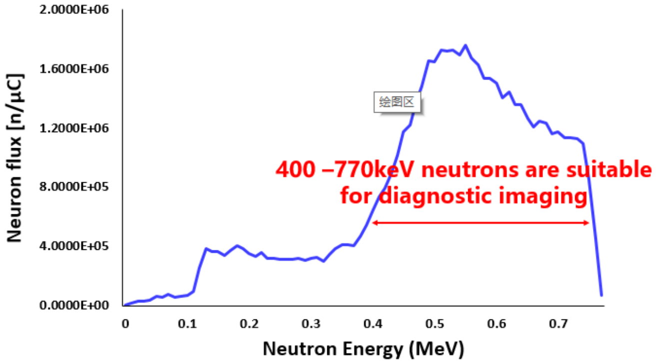

Fig. 4 Forward neutron flux of 40°flare angle

The neutron emission at forward direction is do minant and most of them consist of fast component (0.4-0.77 MeV). The forward neutron flux of 40°flare angle is calculated up to 1.7×10^{6}n/μC(Shown in Fig. 4).It is estimated to be sufficient to distinguish void with water or air gap in 30cm thick concrete slab with our fast neutron imaging technique.

3. CONCLUSION

The achievement of lithium target is significant for the development of transportable accelerator-driven neutron source. Now the t heoretical design work has been finished. Relevant experiment validation is planned and prepared.

4. ACKNOWLEDGEMENT

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REFERENCES

1. Kiyanagi Y (2006) Experimental studies on neutronic performance of various cold-neutron moderators for the pulsed neutron sources. Nucl Instrum Meth A 562: 561-564
2. M. R. Hawkesworth, Atomic Energy Review 15 2(1977), p. 169