STUDY ON NEUTRON MODERATION IN ICE AT CRYOGENIC LIQUID NITROGEN TEMPERATURES

Asyraf Arif Abu Bakar[1], Nasri A. Hamid[1*], Abdul Aziz Mohamed[1], Faridah Mohamad Idris[2], Hafizal Yazid[3], Azraf Azman[2], Syafiq Ramli[4]

[1]*Nuclear Engineering and Energy Group, College of Engineering, Universiti Tenaga Nasional, 43000 Kajang, Selangor, Malaysia.*

[2] *Reactor Technology Centre, Malaysian Nuclear Agency, Bangi, 43000 Kajang, Selangor, Malaysia.*

[3] *Materials Technology Group, Malaysian Nuclear Agency, Bangi, 43000 Kajang, Selangor, Malaysia.*

[4]*Nuclear Engineering Department, Tsinghua University, Beijing, China.*

**e-mail: nasri@uniten.edu.my*

ABSTRACT

The present study concentrates on the measurement of neutron fluence in the flux of cold neutrons emanating from an H_2O ice moderator when it is cooled from ambient to several liquid nitrogen cryogenic temperatures. The temperature of neutrons when the moderator is at cryogenic temperature has been determined from this fluence. The integrated cold neutron flux is obtained by using a polycrystalline beryllium low pass filter in the path of a scattered neutron beam – a small angle neutron scattering beam line available at Malaysian TRIGA reactor. The water was cooled inside the cryogenic cooling chamber which based on a simple continuous flow (SCF) cryostat concept. The neutron spectrums were measured using a Portable Spectroscopic Neutron Probe (N-Probe Microspec Version 6). It was observed that the fluence dropped as the water transforming to ice.

ABSTRAK

Kajian ini tertumpu kepada pengukuran fluence neutron dalam aliran neutron sejuk yang berasal daripada penyederhanaan ais H_2O apabila ia disejukkan daripada suhu ambien ke beberapa suhu kriogenik nitrogen cair. Suhu neutrontelah ditentukan dari 'fluence' ini apabila moderator berada pada suhu 'cryogenic'. Fluks neutron sejuk bersepadu diperoleh dengan menggunakan penapis rendah polikristalin berilium yang diletakkan dalam alur neutron yang terserak pada sudut kecil yang terdapat di reaktor TRIGA di Malaysia. Air disejukkan di dalam ruang penyejukan kriogenik yang berdasarkan konsep mudah 'cryostat' aliran berterusan (SCF). Spektrum neutron diukur dengan menggunakan 'Probe Neutron Portable Spectroscopic' (N-Probe Microspec Version 6). Pemerhatian menunjukkan bahawa 'fluence' turun apabila air berubah menjadi ais.

Keywords: ice, neutron spectrometer, TRIGA, cryogenic

INTRODUCTION

Neutron moderation is a process of reducing energy of fast neutron to the thermal region by elastic scattering through a moderating medium [1]. The material used for the neutron moderation is called a moderator. A good moderator should have three nuclear properties which are: large scattering cross section, small absorption cross section and, large energy per collision [2]. This study reports the works on investigating the neutron moderation effectiveness by water (hydrogenous based) – ice and liquid forms - as neutron moderator under TRIGA neutron environment with beryllium filter for converting neutron beam from the reactor core to cold-neutron beam. The main aim of the work is to find practical approach in increasing neutron flux exiting from a beam port for neutron science and engineering application at a low flux research reactor, such as TRIGA Mark II. This basic study is aimed at envisaging the possibility of using ice as a cold neutron moderator.

The cryostat with sample chamber was used to cool down the temperature of water and ice. Cryostat is generally known as any container housing devices or fluids kept at very low temperature. The first performing cryostat was invented by Sir James Dewar and nowadays, cryostats containing cryogenic fluid also called Dewar [3]. One of the applications of cryostat is for neutron conditioning to the required wavelength in the material physics and physics experiments [4]. In this project, the design of the SCF cryostat will be used to investigate the cold neutron moderator from water/ice.

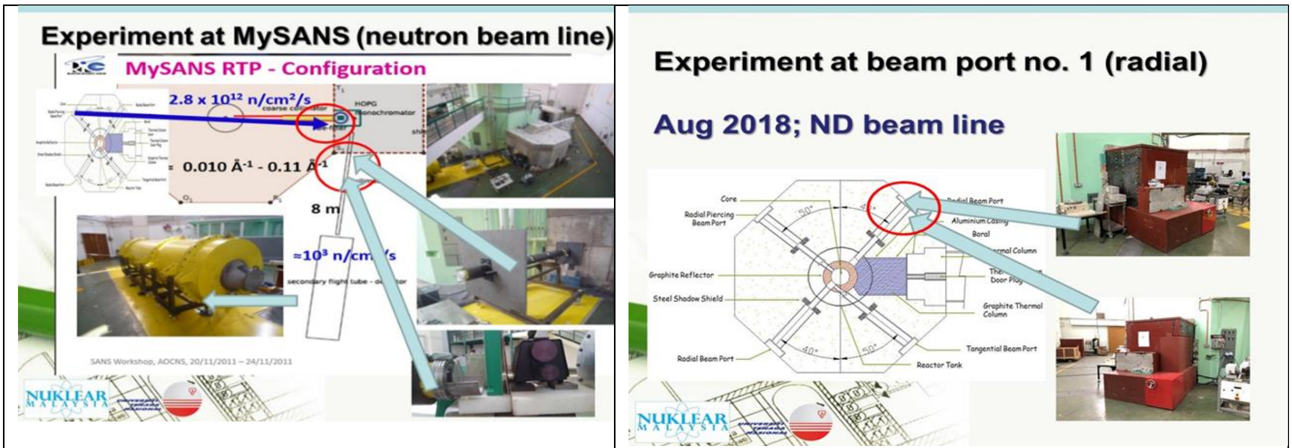
The spectrometry of a neutron beam passing the cooled sample inside the cryostat was measured by using a portable neutron spectrometer, which made the experimental set-up simple and user friendly. This study used a portable spectroscopic neutron probe manufactured by Bubble Technology Industries Inc. company known as a neutron Microspec-6[5].

MATERIALS AND METHODS

The 1MW TRIGA Mark II research reactor at the Malaysian Nuclear Institute came into operation in 1982 and since then, had played an important role in developing nuclear technology and radiation safety culture in Malaysia [3]. The internal and external reactor core irradiation facilities were employed for various applications such as neutron activation analysis, neutron radiography, irradiation of samples for studies in radiation hardness and activation of materials. In addition, the reactor was used for staff training and education of university students and future reactor operators [4]. Low flux research reactor such as TRIGA MARK II is not fully utilized for neutron moderation research.

Beam ports

The external core irradiation facilities used for this study are port #4 – small angle scattering (SANS) and port #1 – neutron diffraction (ND) are as shown in Figure 1.



a) SANS facility

b) ND facility

Fgure 1. Beam ports used for moderation study

Sample cryostat

Neutron moderation is a process of reducing energy of fast neutron to the thermal region by elastic scattering through a moderating medium [5]. A simple continuous flow (SCF) cryostat has been designed to investigate the neutron moderation of the high temperature co-ceramic (HTCC) material – alumina, polymeric material – teflon and hydrogenous material – water under various temperatures.

The use of SCF cryostat usually associates with the cooling system to cool the moderator samples with a cryogenic liquid, in this case liquid nitrogen. The SCF cryostat will be place in front of neutron beam port No. 4 in TRIGA reactor with a small testing aperture with 8mm diameter. In this paper we present the SCF cryostat engineering design detail and main parts of SCF cryostat. The SCF cryostat assembly comprises of stainless-steel vessel which is suitable for liquid nitrogen service, tubing, moderator holder and cover. Cross section engineering design of SCF cryostat is shown in Figure 2.

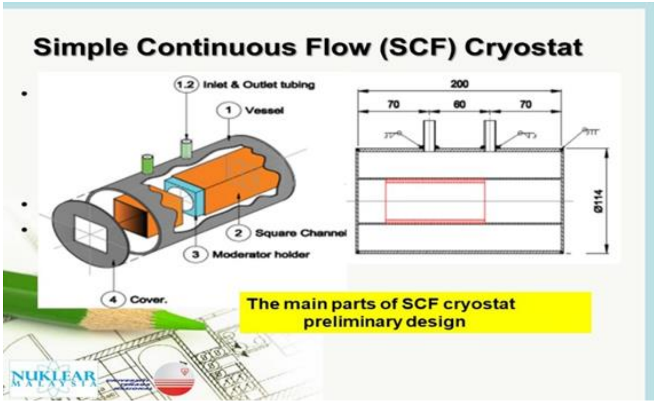


Figure 2. Diagram on engineering design of SCF cryostat with the moderator holder inside the square channel.

This work has fully utilized the completed a working SCF cryostat constructed and measurements of neutron spectrum after neutron passing through the moderating material using a portable neutron spectrometer instrumentation at a room temperature and various cooling condition by the liquid nitrogen flow through the SFC.

The SCF cryostat which was designed by the Drawing Section, Engineering Division, Malaysian Nuclear Agency. The design consists of four main parts and was drawn using AUTOCAD software. SCF cryostat is a fully welded cylindrical vessel with square channel through the middle of cylindrical vessel. The moderator holder will be inserted through the square channel for the investigation of new neutron moderator materials. The material construction of SCF cryostat was made from stainless steel 304L grade and moderator holder was constructed using Aluminum. The overall dimension of the cryostat is 114mm (diameter) x 200mm (length) with a vessel thickness ~5mm. The ASME Section VIII Division 2 shall be used for the design, construction and testing of the cryostat. The main parts of the SCF cryostat are as shown in Figure 3.

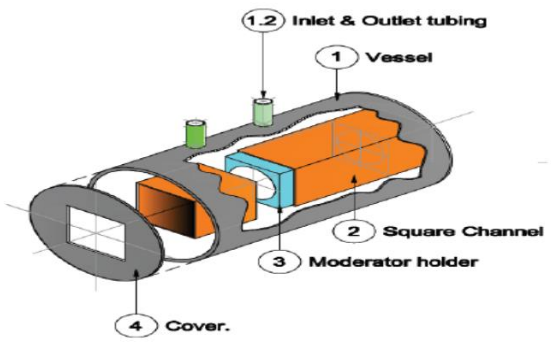


FIGURE 3. The main parts of SCF cryostat design.

Thermal shield and insulation are plied on the whole body of SCF cryostat to prevent heat loss from the vessel. Material holder was designed and constructed using Aluminium with the ability for insertion of moderator materials with the size of 38 mm diameter and total length of this part is 93.4 mm length. The chamber without thermal shield is shown in Figure 4.

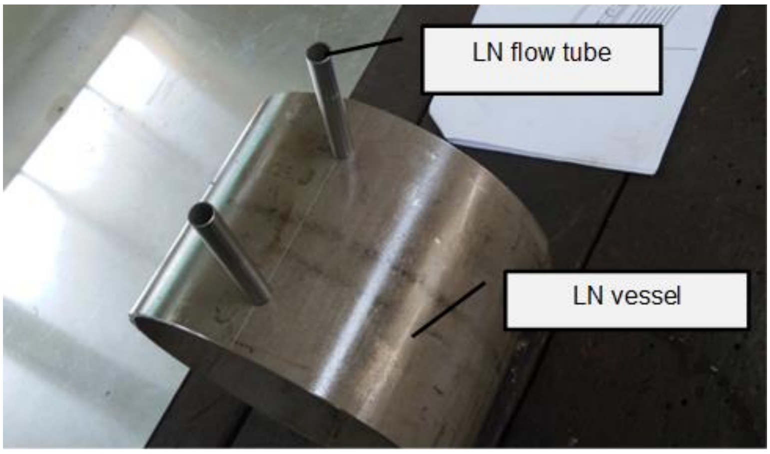


Figure 4. Simple Continuous Flow (SCF) Cryostat Vessel and Tubing

There are two tubes for nitrogen inlet and outlet. The total length of tube is 80 mm. From Figure 5, the Simple Continuous Flow cryostat placed inside the polyurethane aluminium board with the thickness about 20 mm and covered by 8 micron aluminium sheet at both side. The box was injected with the polyurethane foam with the thickness about 30 mm. The total thickness of double insulation is about 50 mm.

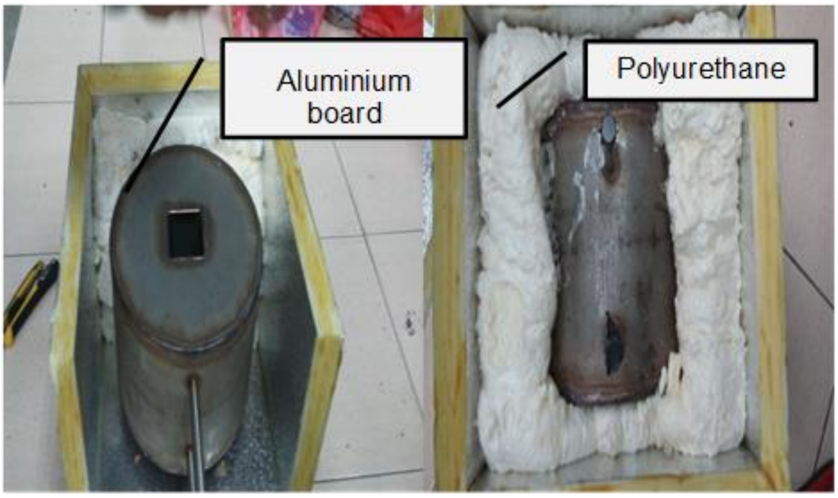


Figure 5. Double insulation using Polyurethane and Polyurethane Aluminium board.

Neutron Measurement

The probe was compatible with the current Microspec 6 analyzer and the neutron measurement data were processed dosimetricly using appropriate fluence-dose conversion functions. The N-Probe consists of two separate detectors to cover the neutron energy range from thermal to 20 MeV. A ^{3}He proportional counter based on the ^{3}He(n,p)T reaction was used to cover the energy region from thermal to 800 keV while a NE213-type liquid scintillator was used to cover from 800 keV to 20 MeV. With a command source from analyzer, both collection data were merged and processed automatically to yield a various types of neutron spectrums [8]. The raw and unfold data from the MSpcec 6 can be export to a file than can be further processes using a suitable software such as excel, Igor and Origin.

RESULTS AND DISCUSSION

The experimental study was carried out in the reactor hall at Malaysian Nuclear Agency under TRIGA neutron environment which are reflected using the beam port No. 4. In this experiment, initial reading of spectrometer without and with moderator samples will be discussed. An arrangement of the experimental set up is shown in Figure 6. For detection of neutron spectrum, we used Microspec 6 as analyzer and N-probe neutron as a neutron detector/spectrometer.

Neutron Beam Measurement Set-up at mySANS beam line

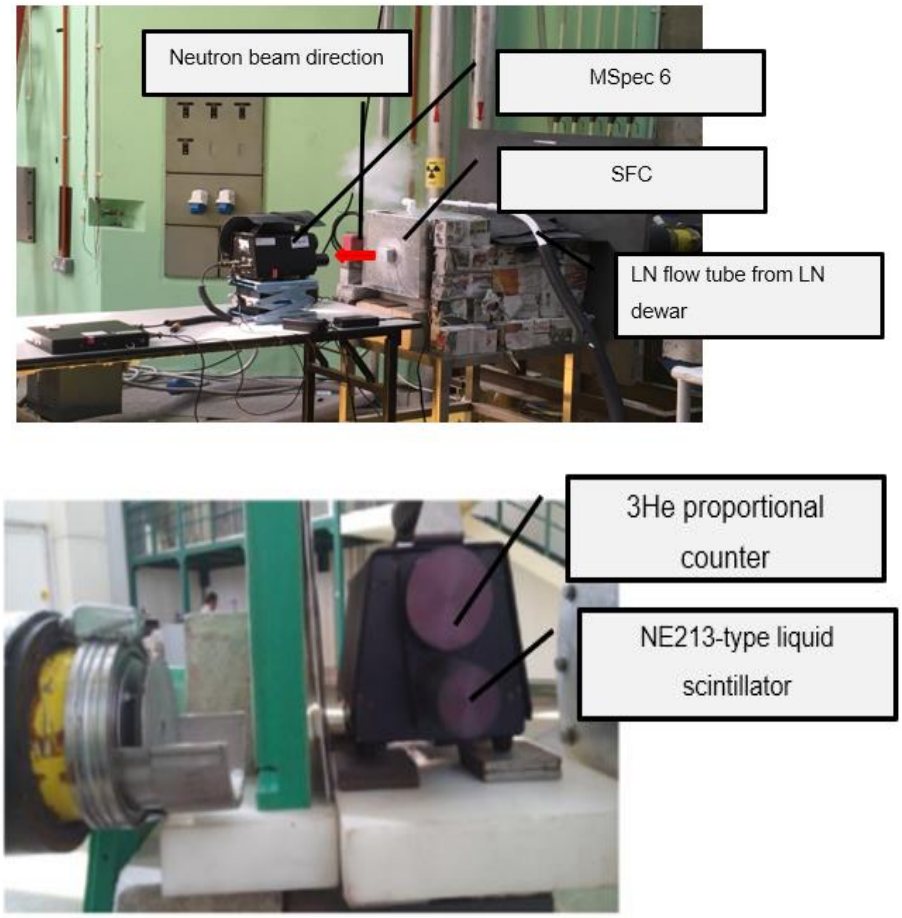


Figure 6. Arrangement of experimental set up used to investigate the moderator materials.

The moderator material under investigation was placed at the 8mm aperture in front of the beam port. Figure 8 shows the initial neutron intensity from N-probe neutron spectrometer after warm up time without neutron moderator samples. After 79.85 minutes warm up with measured neutron from the beam port no. 4, the neutron probe showed a response of ^{3}He counter to 764 KeV neutrons. The neutrons reading shows a good agreement with the technical specification data of the manufacturer.

The experimental set up for Simple Continuous Flow Cryostat with and without cooled in liquid nitrogen cooling as shown in Figure 7.

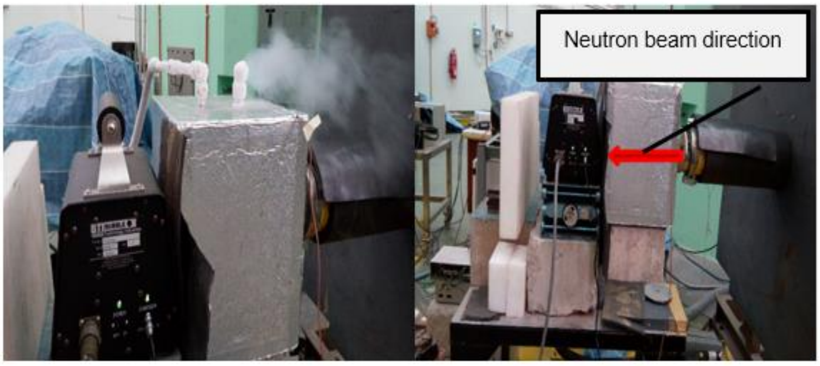


Figure 7. Experimental set up with and without liquid nitrogen temperature.

The moderator material under investigation was placed at the 8mm aperture in front of the beam port. Figure 8 shows the initial neutron intensity from N-probe neutron spectrometer of MSpec 2 (previous instrumentation) for comparison, after warm-up time without neutron moderator samples. After 79.85 minutes of warm up with measured neutron from the beam port no. 4, the neutron probe shows a response of ^{3}He counter to 764 KeV neutrons. The neutrons reading show a good agreement with the technical specification data of the manufacturer.

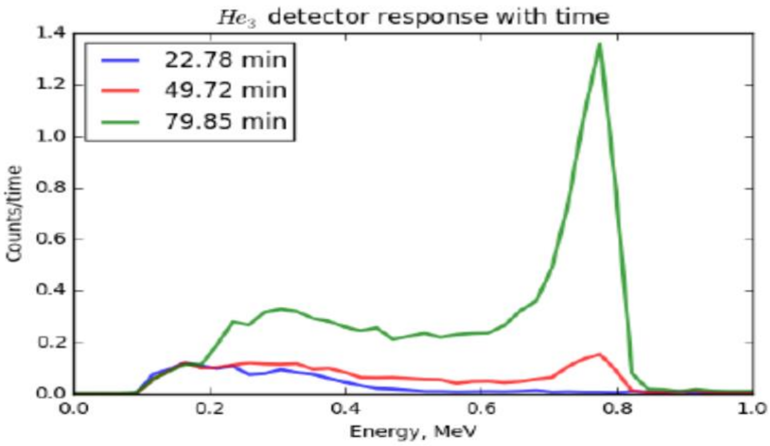


Figure 8: Initial measurement of neutron intensity from N-probe neutron spectrometer with the warm up time (MSpec-2).

From Oct 2017, the MSpec-6 neutron spectrometer was used. Figure 9 shows the various types of neutron spectrum provided by the spectrometer system. The MSpec-6 has no warm-up time prior to the measurement.

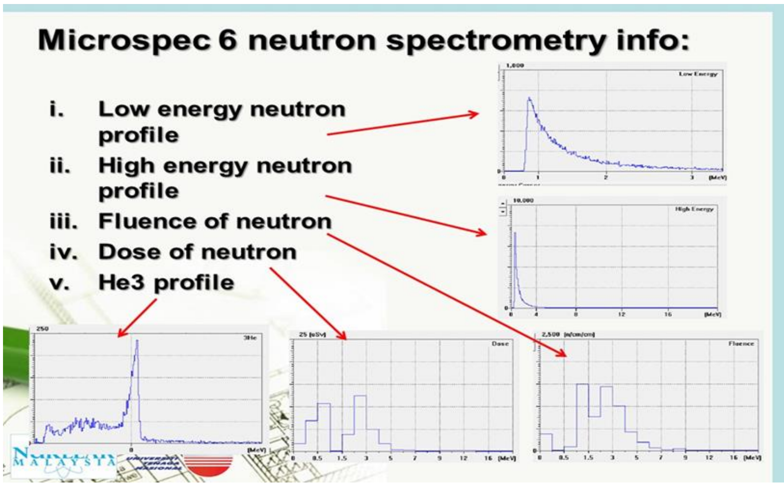
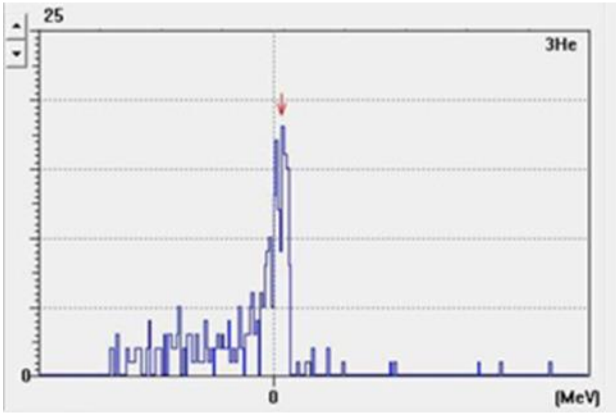


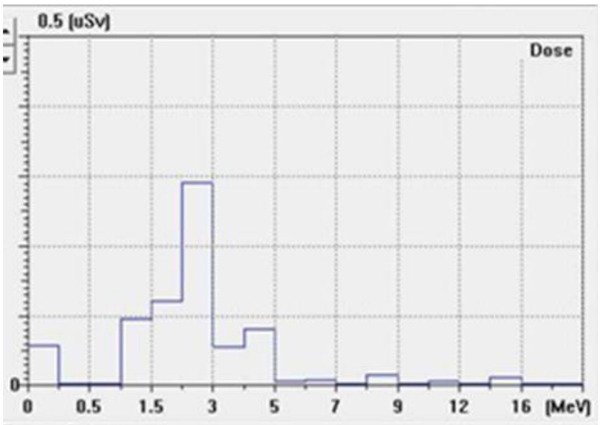
Figure 9. Various neutron spectrum provided by the Microspec-6.

Results from MSpec-6 for water at room temperature measurement is shown in Figure 10.

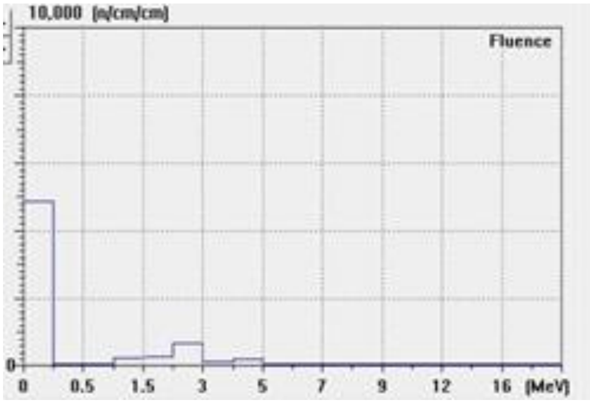
Spectrum (Water)



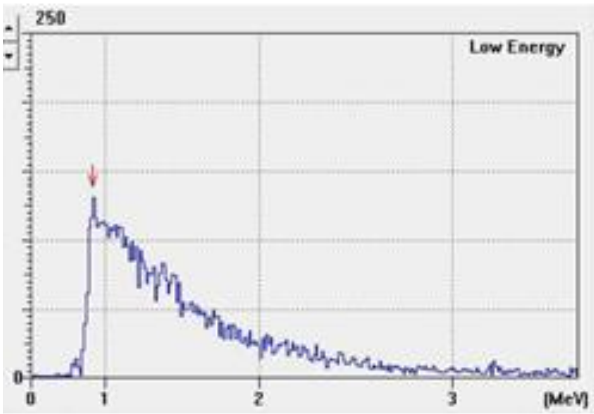
(a) 3He



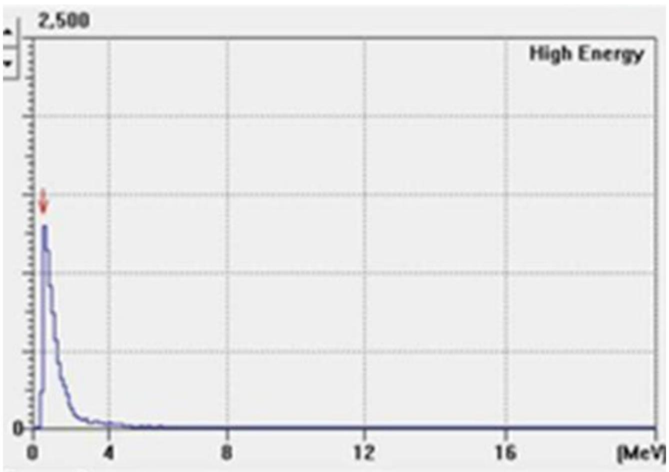
(b) Dose



(c) Fluence



(d) Low energy range

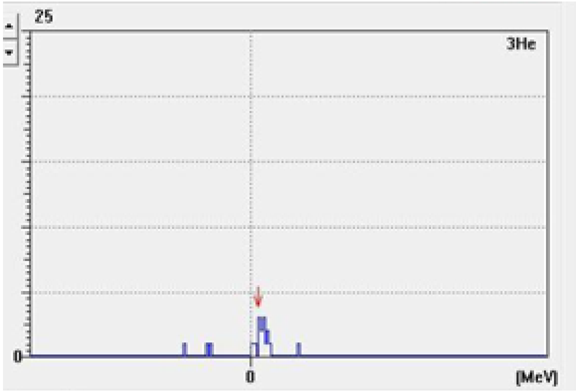


(e) High energy range

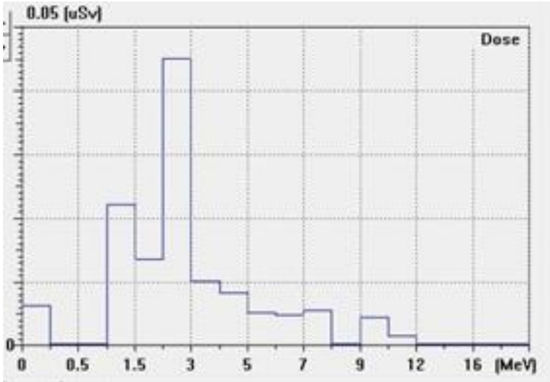
Figure 10. Neutron spectrum by MSpec-6 for water at room temperature measurement (Note: Counting time: 60s)

Results from MSpec-6 for water at -44^{o}C measurement is shown in Figure 11.

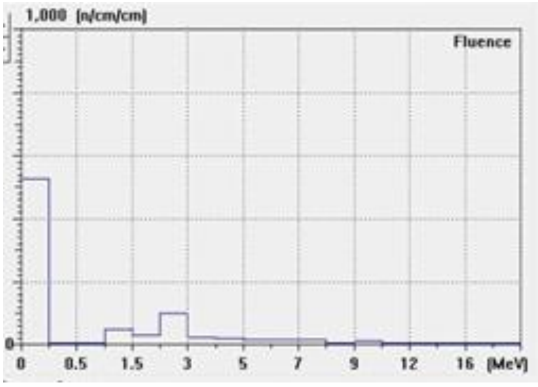
Spectrum



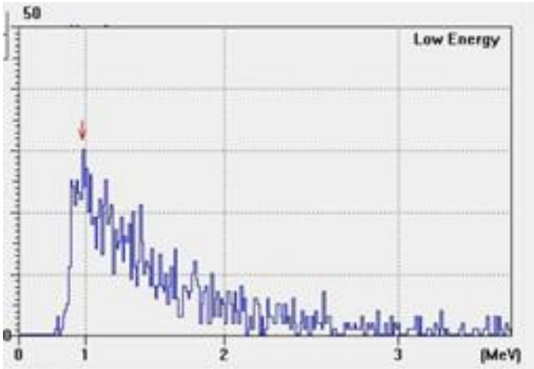
(a) 3He



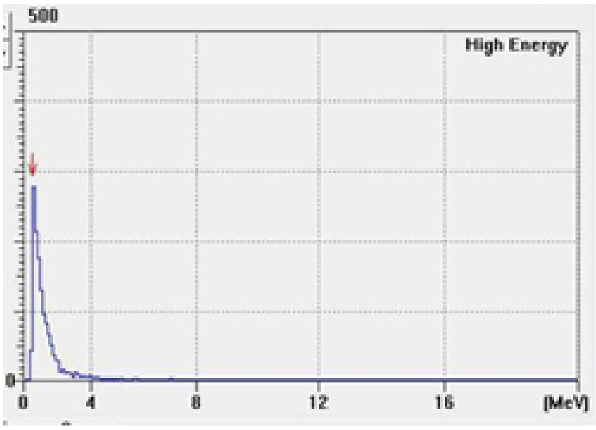
(b) Dose



(c) Fluence



(d) Low energy range



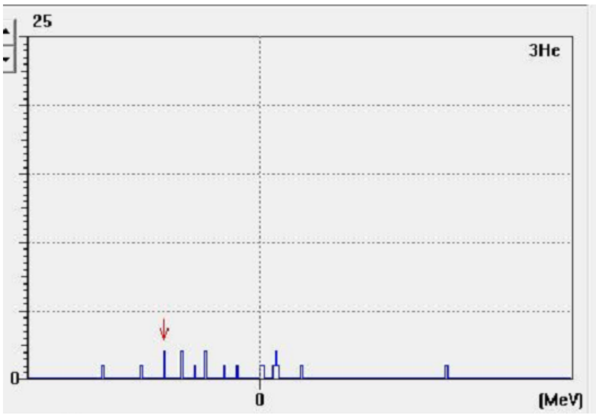
(e) High energy range

Figure 11. Neutron spectrum by MSpec 6 for water at -44 °C temperature measurement

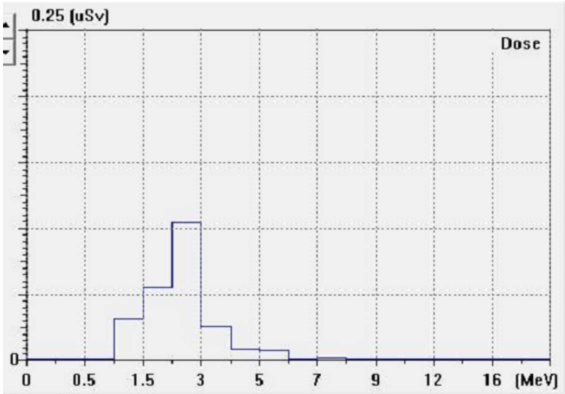
(Note: Counitng time: 60s)

Results from MSpec-6 for alumina at -42ºC measurement is shown in Figure 12.

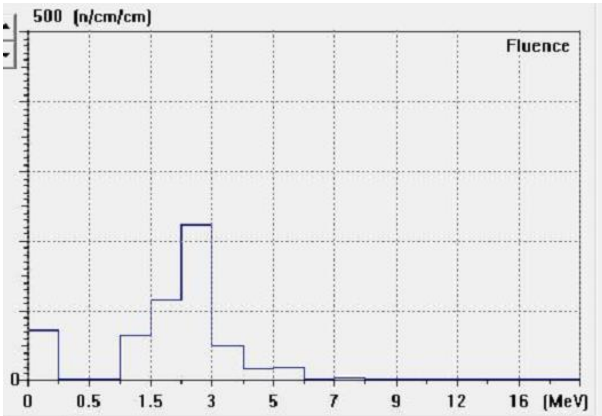
Spectrum



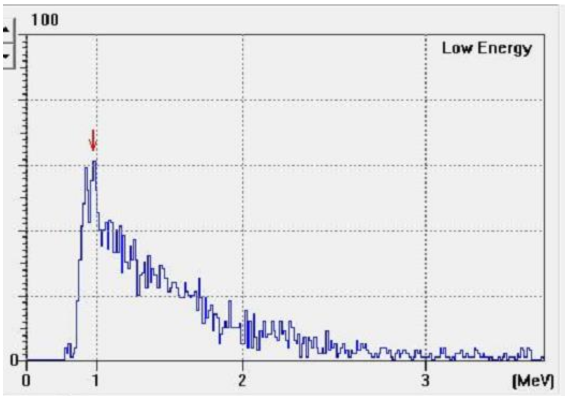
(a) 3He



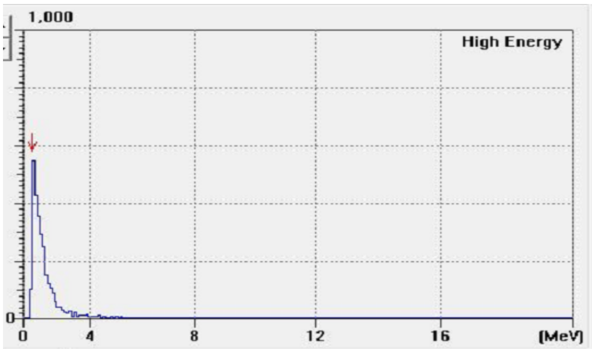
(b) Dose



(c) Fluence



(d) Low energy range



(e) High energy range

Figure 12. Neutron spectrum by MSpec 6 for alumina at -42 ºC temperature measurement

(Note: Counitng time: 60s)

The fluence data is used to understand the moderation property of the sample. Figure 13 and 14 shows the profile of low energy fluence and high energy fluence for water and alumina.

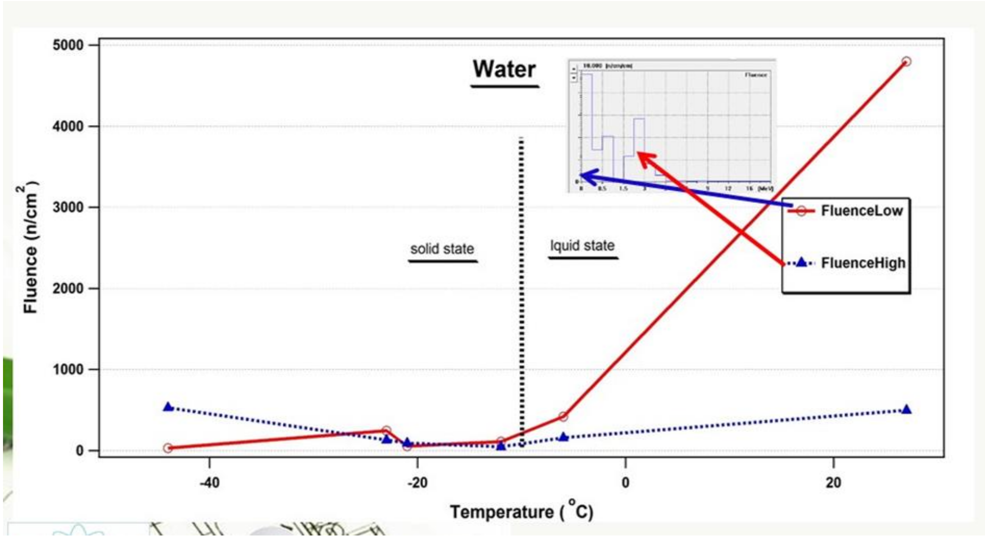


Figure 13. Low energy fluence and high energy fluence profile for water between RT and -45°C (MSpec 6 data) (Note: Counting time: 60s)

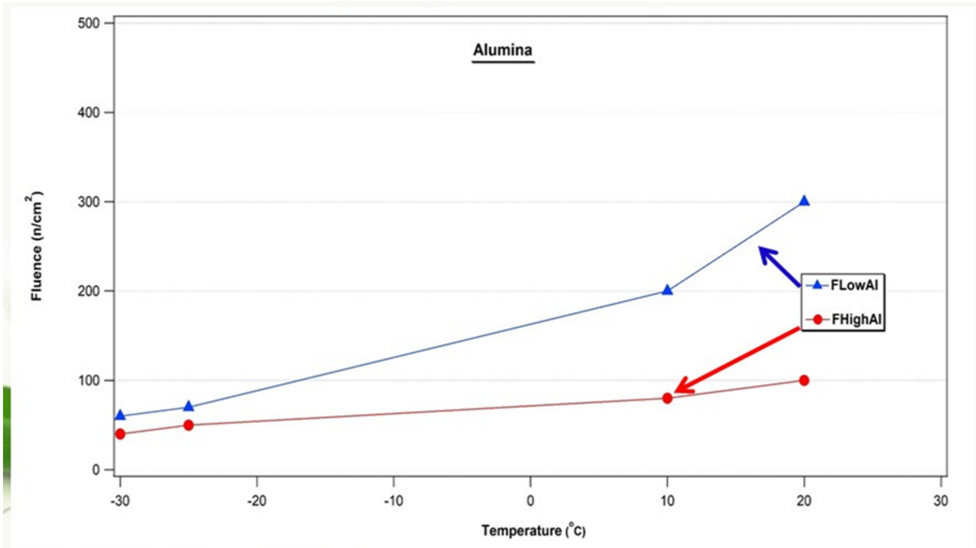


Figure 14. Low energy fluence and high energy fluence profile for alumina between RT and -45°C (MSpec 6 data) (Note: Counting time: 60s).

The work on neutron spectrums acquisition has extended on beam port #1 (neutron diffraction beam-line). Figure 15 shows the ND facility and the experimental set-up at the beam line.

Figure 15. Neutron Beam Measurement Set-up at beam port #1 ND beam line – preliminary

CONCLUSION

The SCF cryostats has successfully fabricated with the support of Prototype and Plant Development Centre of Malaysian Nuclear Agency. Although the SCF cryostat itself is very simple construction, it is designed with inexpensive yet efficient system for testing new moderator materials. We have shown in this paper that the comparison of the measured neutron flux with and without moderator samples water and ice. Comparison results obtained from Mspec-2 and MSpec-6 neutron spectrometers instrumentation are also presented. MSpec-6 is considered the most convenient instrument used in this work. Using fluence data there is no significant difference for cryogenic temperatures region for ice condition but for water there is significant difference between the low fluence and high fluence results.

ACKNOWLEDGEMENTS

This work was supported by IAEA CRP on “Advanced Moderators for Intense Cold Neutron Beams in Material Research”. Thanks to all members who participated and supported for this research proposal and future research activities. For Nuclear Malaysia and Uniten their supports are extremely appreciated.

REFERENCES

[1] M. H. Parajon, E. Abad, and F. J. Bermejo, “A Review of the Cold Neutron Moderator Materials: Neutronic Performance and Radiation Effects,” Phys. Procedia, Vol. 60, no. August 2012, pp. 74–82, 2014.

[2] Y. Kasesaz, H. Khalafi, and F. Rahmani, “Annals of Nuclear Energy Design of an epithermal neutron beam for BNCT in thermal column of Tehran research reactor,” Ann. Nucl. Energy, vol. 68, pp. 234–238, 2014.

[3] V. Parma, “Cryostat Design.”, CERN Yellow Report CERN-2014-005, pp.353-399.

[4] M. Mocko, L. L. Daemen, M. Hartl, T. Huegle, and G. Muhrer, ICANS-XIX, 19th Meeting of the International Collaboration on Advanced Neutron Sources March 8–12, Grindelwald, Switzerland, pp1-9, 2010

[5] Portable Spectroscopic Neutron Probe. Ing, H., et al., Ontario: Bubble Technology Industries Inc., June 16, 2007, Radiation Protection Dosimetry, pp. 1-6.