NEUTRON MODERATION EFFECTIVENESS BY CO-FIRED CERAMIC BASED MATERIALS, POLYMERIC MATERIALS AND WATER UNDER VARIOUS TEMPERATURES IN THE TRIGA NEUTRON BEAM ENVIRONMENT

Nasri A. Hamid[1], Abdul Aziz Mohamed[1], Azraf Azman[2], Faridah Mohd Idris[2], Syafiq Ramli[1], Asyraf Arif[1] and Mohd Syukri Yahya[1]

[1]Nuclear Engineering and Energy Group, Institute of Sustainable, Mechanical Engineering, College of Engineering, Universiti Tenaga Nasional, 43000 Kajang, Selangor, MALAYSIA.
[2]Fabrication and Material Engineering, Malaysian Nuclear Agency, Komplek PUSPATI, 43000 Kajang, Selangor, MALAYSIA.

ABSTRACT

This study highlights work on investigating the neutron moderation effectiveness of co-fired ceramic based and polymeric based and hydrogenous based materials under various liquid nitrogen temperatures and different reactor TRIGA neutron environments. In this research work, a simple continuous flow (SCF) cryostat has been designed, fabricated and installed for investigating the neutron moderation the moderating materials, in this case, alumina, Teflon and water/ice. The use of a simple continuous flow SCF cryostat usually associates with the cooling system to cool the moderator samples with cryogenic liquid like nitrogen. The SCF cryostat is placed at the small angle neutron scattering (SANS) beam line (port No. 4) and newly built neutron diffraction (ND) beam line (port No. 1) at the TRIGA reactor. In this report we present the SCF cryostat engineering design detail, main parts of SCF, experimental set-up. The results of investigation from cooling down the moderation materials such alumina (LTCC), Teflon (polymeric) and water (hydrogenous) under various liquid nitrogen temperatures and neutron beam conditions are also presented.

ABSTRAK

Kajian ini menyerlahkan kerja-kerja menyiasat keberkesanan neutron moderasi bahan berasaskan berasaskan berasaskan polimer dan berasaskan polimer dan hidrogen di bawah pelbagai suhu nitrogen cecair dan persekitaran neutron TRIGA yang berlainan. Dalam penyelidikan ini, cryostat aliran berterusan mudah (SCF) telah direka, direka dan dipasang untuk menyiasat kesederhanaan neutron bahan penyederhana, dalam kes ini, alumina, Teflon dan air / ais. Penggunaan aliran berterusan mudah SCF cryostat biasanya dikaitkan dengan sistem penyejukan untuk menyejukkan sampel moderator dengan cecair cryogenic seperti nitrogen. Cryostat SCF diletakkan di garis rasuk neutron sudut berselerak (SANS) kecil (port No. 4) dan garis rasuk neutron (ND) yang baru dibina (port No. 1) di reaktor TRIGA. Dalam laporan ini kami membentangkan terperinci reka bentuk kejuruteraan cryostat SCF, bahagian utama SCF, set up percubaan. Hasil penyiasatan dari penyejukan bahan-bahan penyederhanaan seperti alumina (LTCC), Teflon (polimer) dan air (hidrogen) di bawah suhu nitrogen cair dan keadaan sinar neutron turut dibentangkan.

Keywords: neutron moderator, research reactor, cryogenic, cryostat

1 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 have large scattering cross section, small absorption cross section, and large energy per collision [2]. This report will highlight work on investigating the neutron moderation effectiveness by alumina (co-fired ceramic based), Teflon (polymeric based) and water (hydrogenous based) as neutron moderator under **TRIGA** neutron environment with and without beryllium filter for converting neutron beam from the 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.

MATERIALS AND METHOD

Moderator LTCC compounded materials production

The production of alumina materials with controlled porosity is of considerable interest to the international research and development community. Identify formulation and design of the moderator during production was studied in order to produce a sample that comply with the nuclear properties for a good moderator. The moderator produced was an alumina based material through LTCC method and decoupling with polymeric material such as Teflon in laboratory. In this study, alumina co-fired ceramic and polymeric materials such as Teflon have been chosen for investigation as moderator material. The moderator samples of Teflon and co-fired ceramic materials have been prepared to 10mm thickness and 38mm diameter each.

Sample irradiation chamber fabrication and cryostat modification

Cryostat is generally known as any container housing devices or fluids kept at very low temperature. 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 used 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 for investigation of new neutron moderator materials of Alumina in HTCC and polymeric materials such as Teflon at with and without liquid nitrogen temperature. The experimental activities will be held at Reactor hall TRIGA PUSPATI at external core irradiation beam port no. 4. The neutron spectrum will be measure by N-probe neutron spectrometer. N-Probe spectrometer was designed to be used by non-specialists for measurement of low-intensity neutron doses in the mixed field environments.

SCF Engineering Design

The SCF cryostat which was designed by the Drawing Section, Engineering Division, Malaysian Nuclear Agency. The design consists of four main parts and 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 would be stainless steel 304L grade and moderator holder will be 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 1.

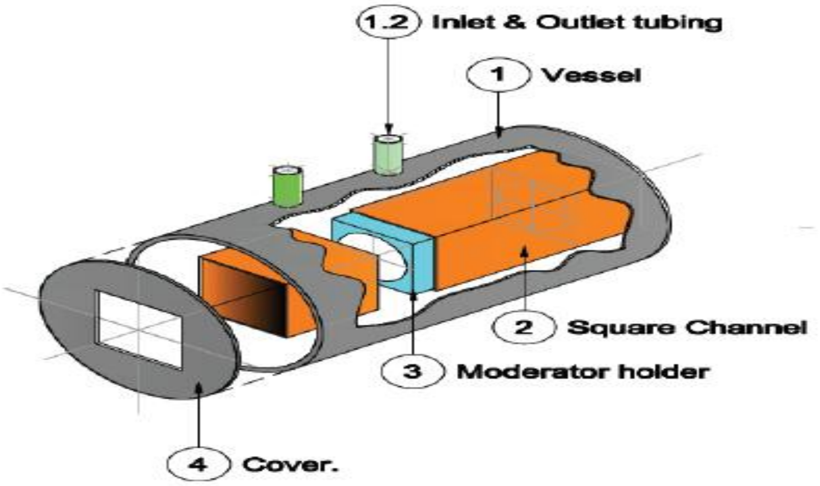


Figure 1: The main parts of SCF cryostat design.

Thermal shield and insulation shall be ply on the whole body of SCF cryostat to prevent heat loss from the vessel. Material holder was designed and will be 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 2.

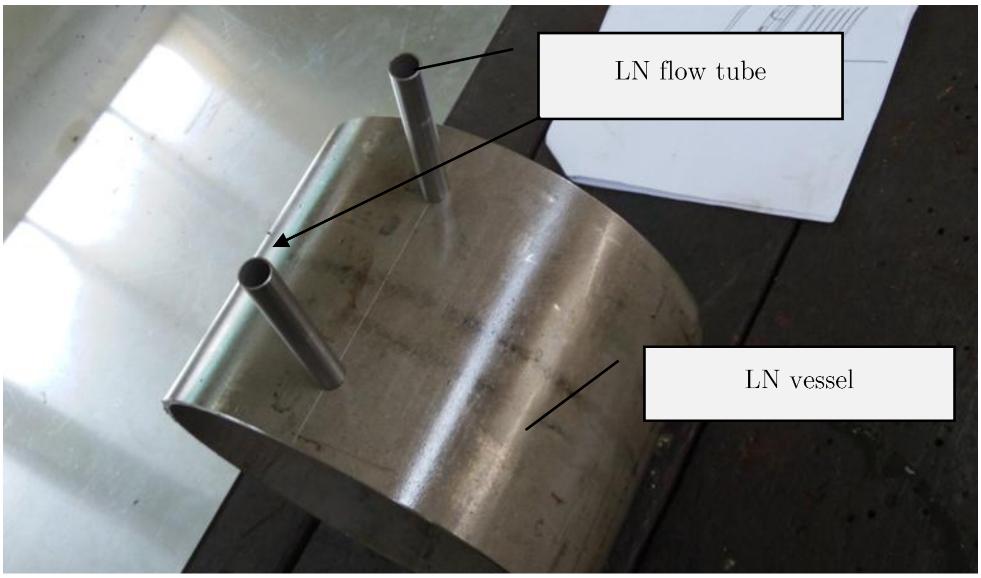


Figure 2: Simple Continuous Flow (SCF) Cryostat Vessel and Tubing

There are two tubes for nitrogen inlet and outlet. The total length of tube is 80 mm. From Figure 3, 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.

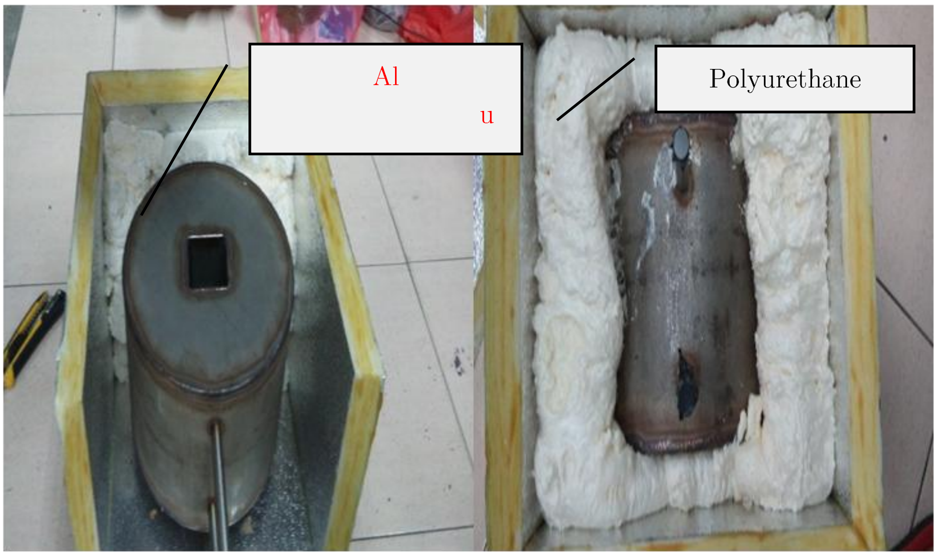


Figure 3: Double Insulation using Polyurethane and Polyurethane Aluminium board

Neutron Measurement

The probe is compatible with the current Microspec 6 analyzer and the neutron measurement data were process dosimetric 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 3He proportional counter based on the 3He(n,p)T reaction is used to cover the energy region from thermal to 800 keV while a NE213-type liquid scintillator is used to cover from 800 keV to 20 MeV. With a command source from analyzer, both collection data are merge and processed automatically to yield a various types of neutron spectrums [5]. 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.

Experimental Set Up

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 4. For detection of neutron spectrum, we used Microspec 6 as analyzer and N-probe neutron as a neutron detector/spectrometer.

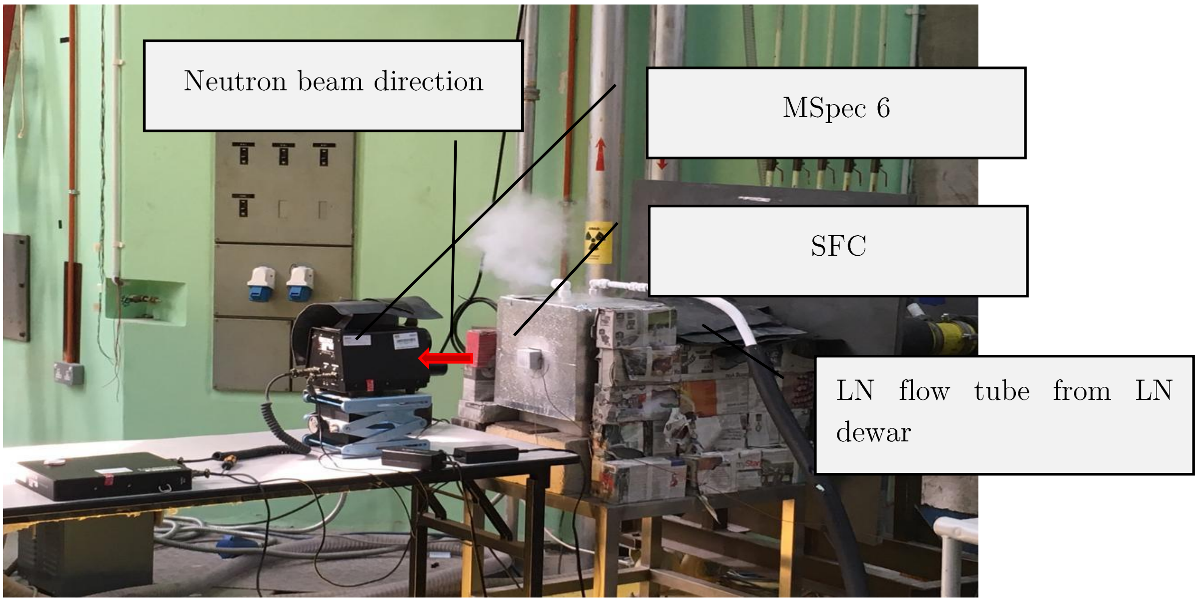


Figure 4: a. Neutron Beam Measurement Set-up at mySANS beam line

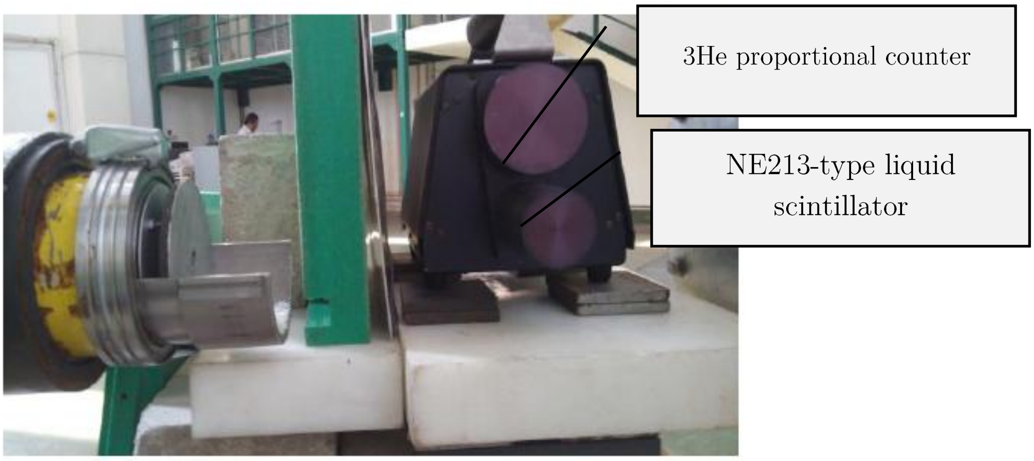


Figure 4: b. Arrangement of experimental set up used to investigate the moderator materials.

The experimental set up for Simple Continuous Flow Cryostat with and without cooled in liquid nitrogen cooling as shown in Figure 5. There are four different thickness of samples have been measured and analyzed. The samples are 5mm, 10mm, 20mm and 30mm.

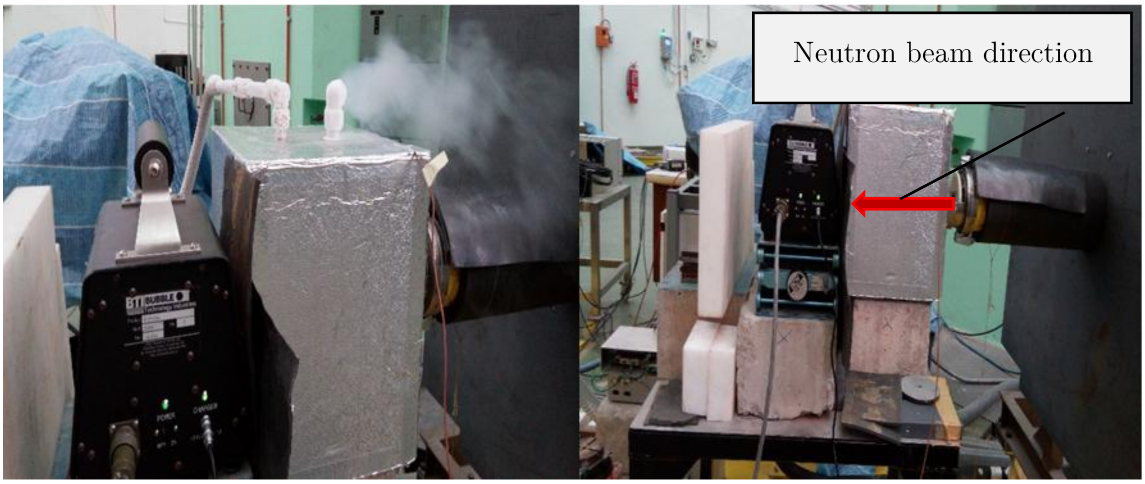


Figure 5: Experimental set up with and without liquid nitrogen temperature.

The samples were cooled from room temperature to about -50°C using liquid nitrogen and measured using Microspec 2.0 (Mspec-2) and Microspec 6.0 (MSpec-6) spectrometer directly using fast neutron detector. The moderator material under investigation was placed at the 8mm aperture in front of the beam port.

RESULTS AND DISCUSSION

Figure 6 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 warm up with measured neutron from the beam port no. 4, the neutron probe shows a response of He_3 counter to 764 KeV neutrons. The neutrons reading show a good agreement with the technical specification data of the manufacturer.

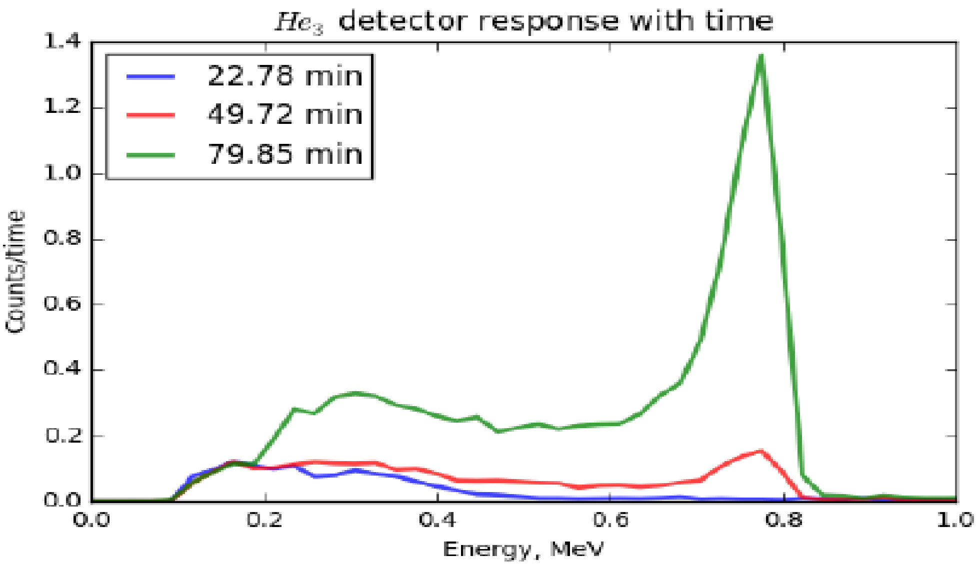


Figure 6: Initial measurement of neutron intensity from N-probe neutron spectrometer with the warm up time (MSpec-2).

Figure 7 shows the various types of neutron spectrum provided by the MSpec-6 spectrometer system. The MSpec-6 has no warm-up time prior to the measurement.

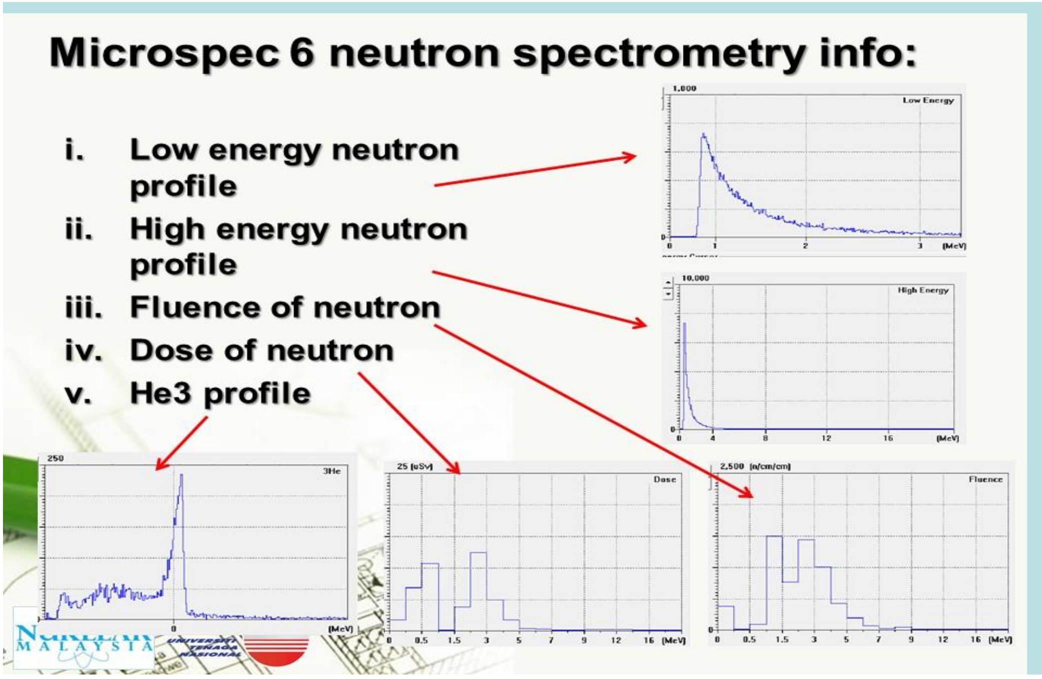
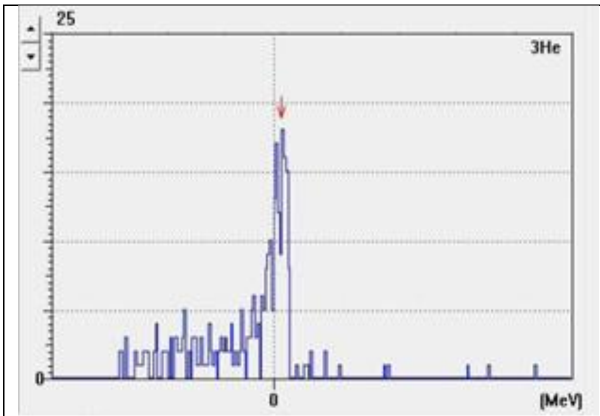


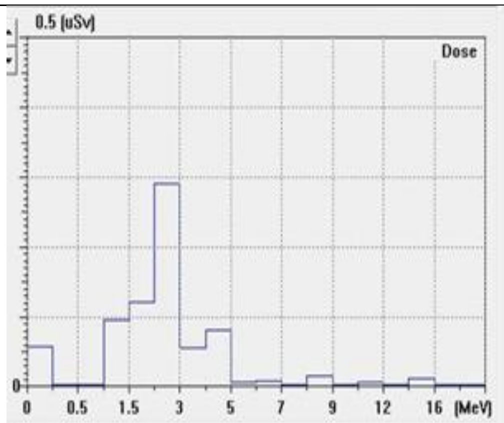
Figure 7: Various neutron spectrum provided by the Microspec-6.

Results from MSpec-6 for water at room temperature measurement is shown in Figure 8.

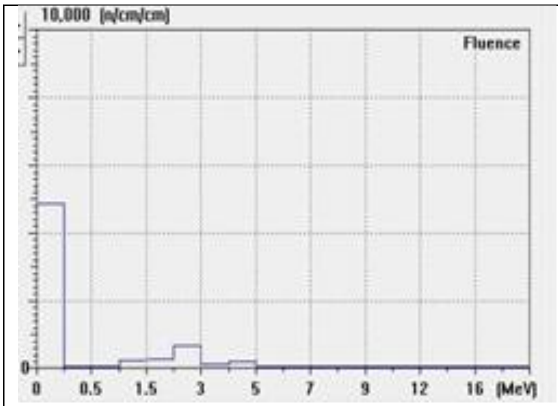
<u>Spectrum (Water)</u>



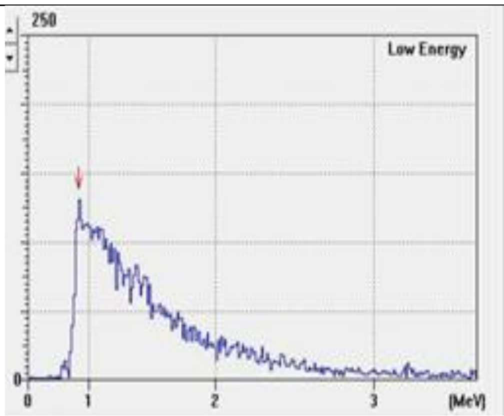
(a) 3He



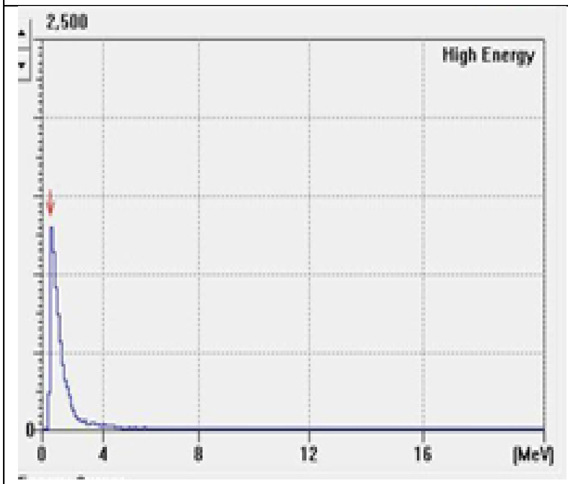
(b) Dose



(c) Fluence



(d) Low energy range



(e)High energy range

Figure 8. Neutron spectrum by MSpec-6 for water at room temperature measurement (*Note: Counting time: 60s*)

The work on neutron spectrums acquisition has extended on beam port #1 (neutron diffraction beam-line). Figure 9 shows the ND facility and the experimental set-up at the beam line.

Figure 9: Neutron Beam Measurement Set-up at beam port #1 ND beam line

RESULTS AND DISCUSSION

The initial results of the measured neutron flux versus energy using MSpec-2 are presented in Figure 10. The two samples investigated new moderator materials are shown in different colors: cyan for Teflon and green for HTCC. At a first glance, we can see that in the 0.01Mev to10MeV region the neutron flux spectrum is similar. In the epithermal 10^{-3} Mev to 0.01MeV region, the figure shows a slightly different neutron flux spectrum for both samples, with HTCC having lower value than Teflon. This indicates that neutrons was scattered when they hit the HTCC sample. Indeed, it is important to keep in mind that these initial results were observed only for each sample of new moderator materials with the thickness of 10mm. The expected output from this experiment is to shift the fast energy spectrum to thermal energy after exposing to the neutron moderator. Figure 11 and 12 represent the outcome of the experiment.

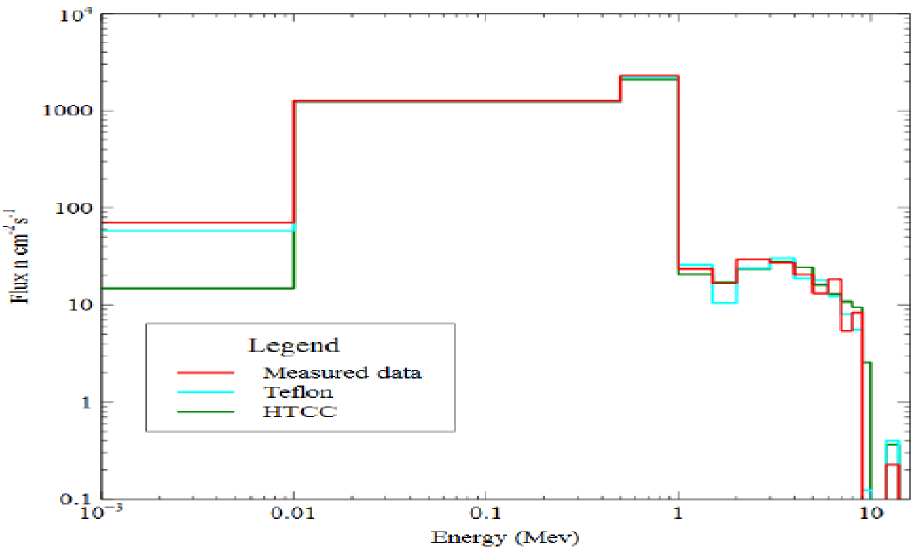


Figure 10: Comparison of the measured neutron flux with and without moderator samples Teflon and HTCC (MSpec-2).

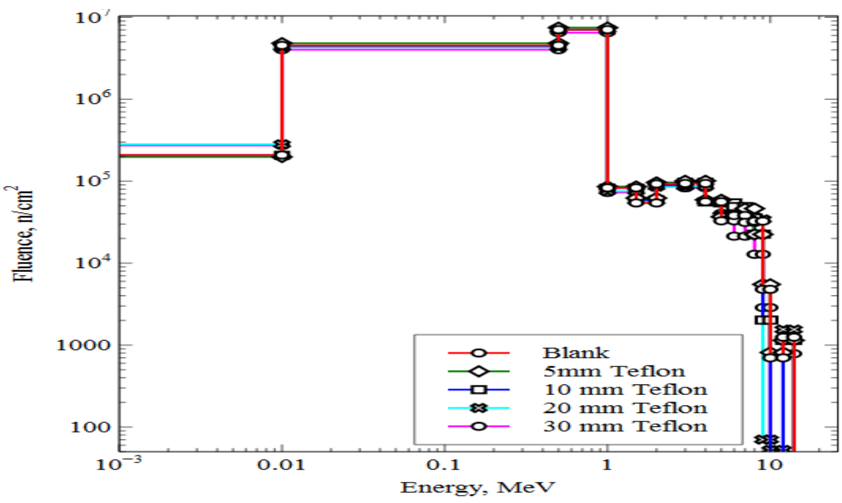


Figure 11: Neutron spectrum for Teflon with different thickness at room temperature (MSpec-2).

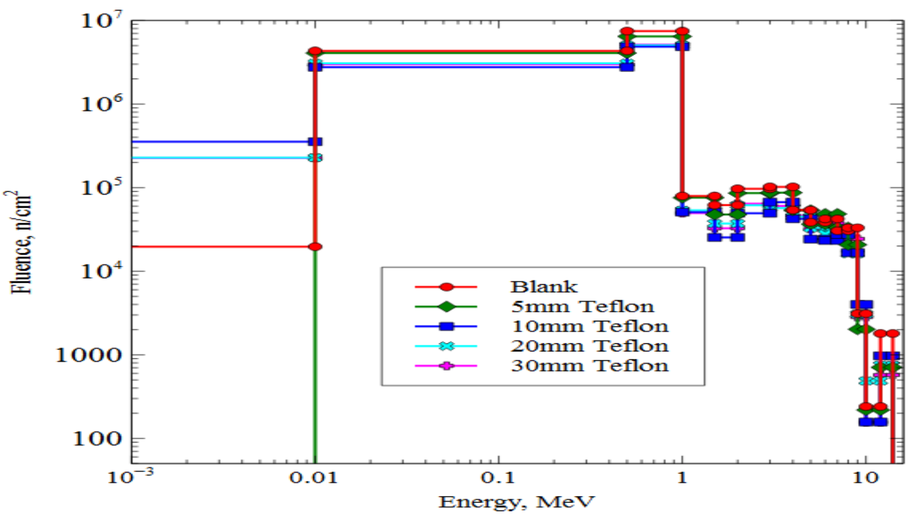
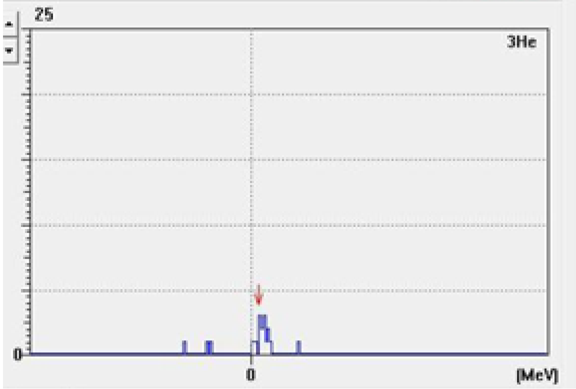


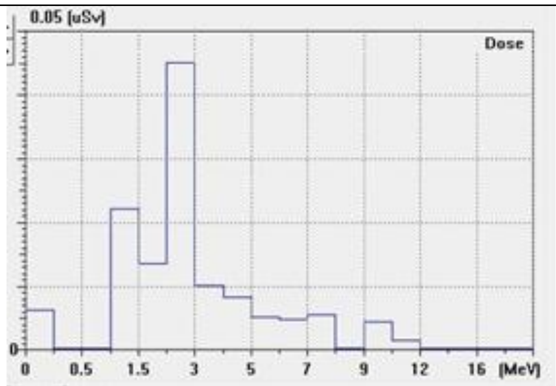
Figure 12: Neutron spectrum for Teflon with different thickness between room temperature and about -55°C (MSpec-2).

Results from MSpec-6 for water at -44ºC measurement is shown in Figure 13.

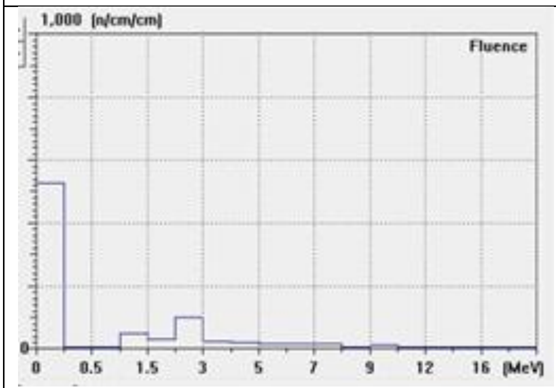
Spectrum



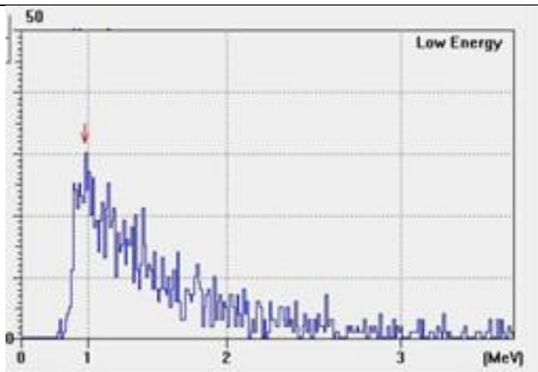
(a) 3He



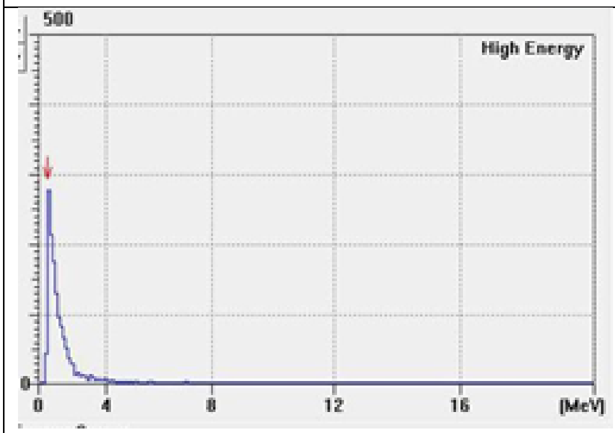
(b) Dose



(c) Fluence



(d) Low energy range



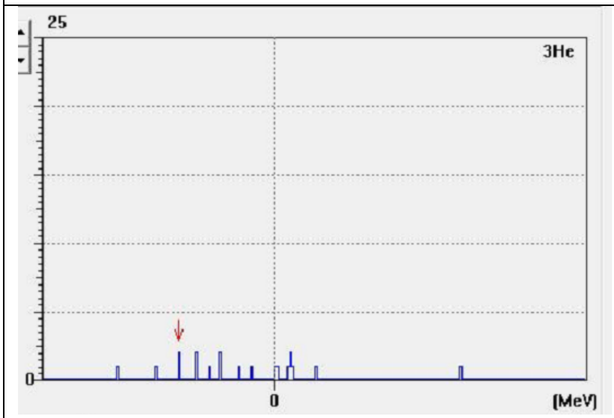
(e) High energy range

Figure 13. Neutron spectrum by MSpec 6 for water at -44 ºC temperature measurement

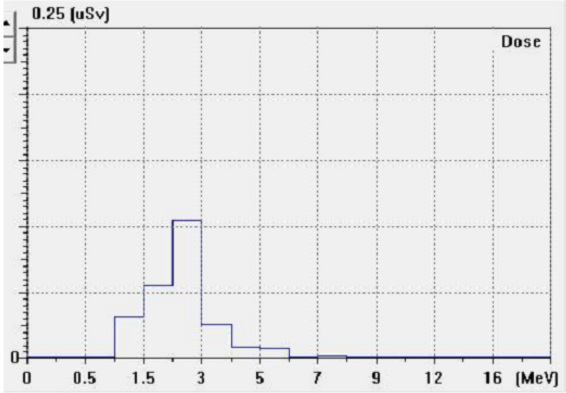
(Note: Counitng time: 60s)

Results from MSpec-6 for alumina at -42°C measurement is shown in Figure 14.

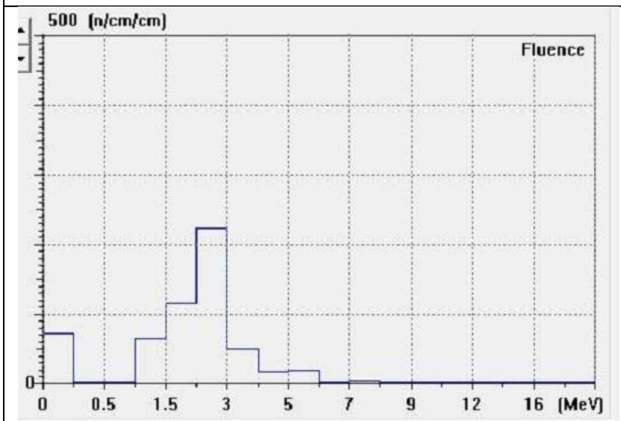
Spectrum



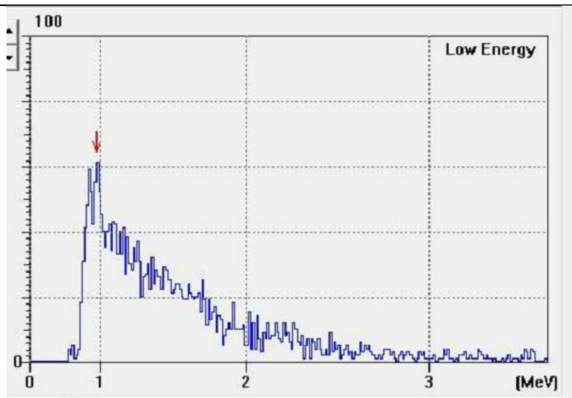
(a) 3He



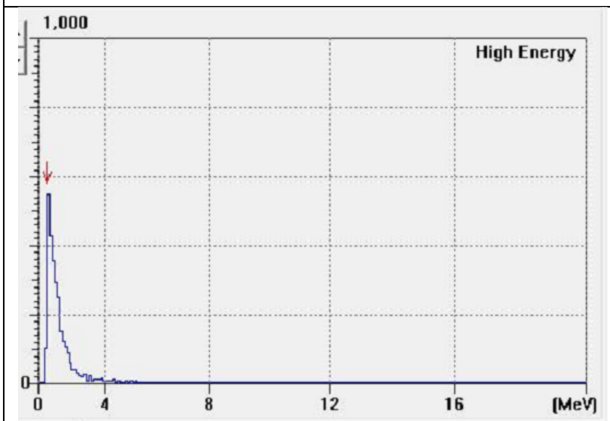
(b) Dose



(c) Fluence



(d) Low energy range



(e) High energy range

Figure 14. Neutron spectrum by MSpec 6 for alumina at -42 °C temperature measurement

(Note: Counitng time: 60s)

The fluence data is used to understand the moderation property of the sample. Figure 15 and 16 show the profile of low energy fluence and high energy fluence for water and alumina.

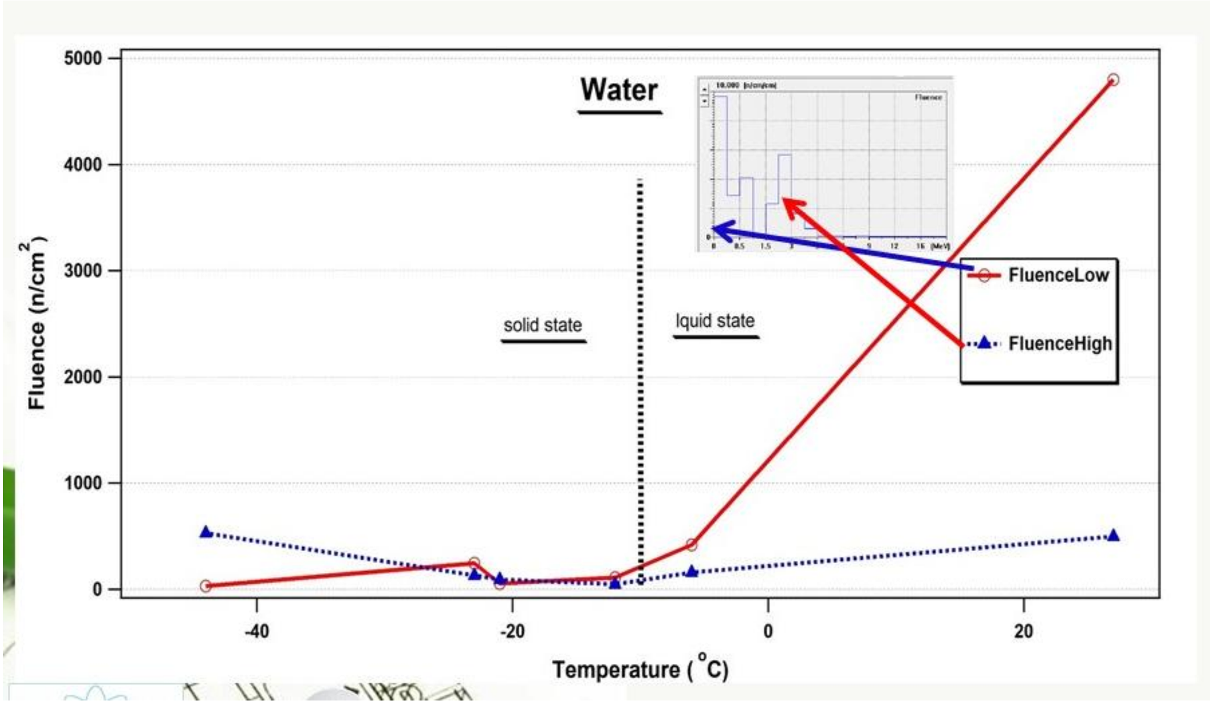


Figure 15. Low energy fluence and high energy fluence profile for water between RT and -45°C (MSpec 6 data) (Note: Counting time: 60s)

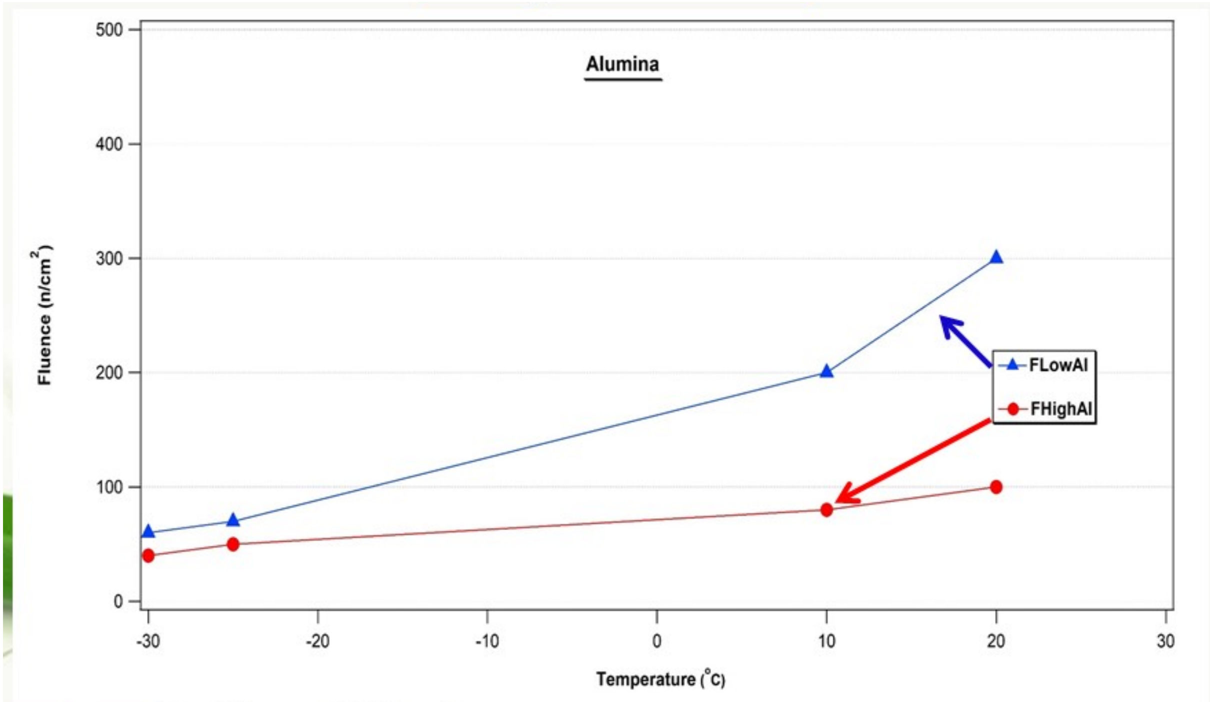


Figure 17. Low energy fluence and high energy fluence profile for alumina between RT and -45°C (MSpec 6 data)

CONCLUSION

The engineering design of SCF cryostat has been carried out using AUTOCAD. Based on the design, 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 Teflon and HTCC. 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 – both water and alumina.

ACKNOWLEDGEMENTS

This work is 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] “Unique portable neutron spectrometer,” BTI Instrument Sheet, 2004.