# DESIGN OF COLLIMATOR FOR NEUTRON DIFFRACTOMETER SYSTEM AT LOW POWER REACTOR TRIGA PUSPATI

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## ABSTRACT

The objective of this research was to develop a neutron diffractometer system at a low power reactor TRIGA PUSPATI in Malaysia. Neutron diffractometer system consists of a number of vital instrumentations, namely collimator, monochromatic device and detector. However, this study only focus on the design and fabrication of the collimator. The value of neutron and gamma fluxes measured on beam-port 1 of reactor without collimator was $2.12 \times 10^{8}$ $ncm^{-2}s^{-1}$ and $1.97 \times 10^{7}$ $\gamma cm^{-2}s^{-1}$, respectively which are suitable for development of the system. Design of the collimators were done using the Monte Carlo N-Particle simulation software. The collimator is an aluminium tube containing suitable shielding components to filter and shape the neutron beam. Characterization of the shielding materials for the collimator were performed using thermo-luminescence detector devices and the Monte Carlo N-Particle software to investigate the materials with high attenuation coefficient on ionising radiations. The length of collimator was then optimized to obtain high value of thermal neutron flux for neutron diffractometer system. The beam was optimized by using the shortest length of collimator as it produced $6.24 \times 10^{6}$ $ncm^{-2}s^{-1}$ which is 20 % higher compare to the ideal flux required of $1.40 \times 10^{5}$ $ncm^{-2}s^{-1}$. The selected design of the collimator for neutron diffractometer system was installed inside beam-port 1 of reactor TRIGA PUSPATI. The research was useful to obtain measured fluxes from radial beam-port 1, to identify the ideal design of collimator, and to optimize neutron beams for development of neutron diffractometer system at reactor TRIGA PUSPATI in Malaysia.

# ABSTRAK

Objektif penyelidikan ini adalah untuk membangunkan sistem belauan neutron di reaktor TRIGA PUSPATI berkuasa rendah di Malaysia. Sistem belauan neutron terdiri daripada beberapa instrumen penting iaitu kolimator, peranti monokromatik dan alat pengesan. Walaubagaimanapun, kajian ini hanya memberikan tumpuan terhadap reka bentuk dan fabrikasi kolimator sahaja. Nilai fluks neutron dan fluks gama yang diukur pada tiub alur 1 di reaktor tanpa kolimator masing-masing adalah $2.12 \times 10^{8}$ $ncm^{-2}s^{-1}$ dan $1.97 \times 10^{7}$ $\gamma cm^{-2}s^{-1}$ iaitu sesuai untuk pembangunan sistem ini. Reka bentuk kolimator telah dilakukan dengan menggunakan perisian simulasi Monte Carlo N-Partikel. Kolimator adalah tiub aluminium yang mengandungi komponen pelindung yang sesuai untuk menyaring dan membentuk arus neutron. Pencirian bahan perisai untuk kolimator telah dilakukan dengan menggunakan peranti meter dos pendarkilau haba dan perisian Monte Carlo N-Partikel untuk mengkaji bahan yang mempunyai pekali pengurangan yang tinggi terhadap radiasi mengion. Panjang colimator tersebut kemudiannya dioptimumkan untuk mendapatkan nilai neutron terma yang tinggi untuk sistem belauan neutron. Arus neutron itu dapat dioptimumkan dengan menggunakan kolimator terpendek kerana menghasilkan $6.24 \times 10^{6}$ $ncm^{-2}s^{-1}$ iaitu 20 % lebih tinggi berbanding fluks ideal yang diperlukan iaitu $1.40 \times 10^{5}$ $ncm^{-2}s^{-1}$. Reka bentuk kolimator yang terpilih untuk sistem belauan neutron telah dipasang di dalam tiub alur 1 di reaktor TRIGA PUSPATI. Penyelidikan ini adalah berguna untuk mendapatkan fluks yang diukur dari jejari tiub alur 1, mengenal pasti reka bentuk ideal kolimator, dan mengoptimumkan fluks neutron untuk pembangunan sistem belauan neutron dalam reaktor TRIGA PUSPATI di Malaysia.

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| | | |
|---|---|---|
| BPE | - | Borated Polyethylene |
| BPF | - | Borated Paraffin |
| HDPE | - | High Density Polyethylene |
| IAEA | - | International Atomic Energy Agency |
| LANL | - | Los Alamos Nuclear Laboratory |
| MCNP | - | Monte Carlo N-Particle |
| MINT | - | Malaysia Institute for Nuclear Technology Research |
| MOSTI | - | Ministry of Science, Technology and Environment |
| ND | - | Neutron Diffraction |
| NDS | - | Neutron Diffractometer System |
| NR | - | Neutron Radiography |
| RSICC | - | Radiation Safety Information Computational Centre |
| RTP | - | Reactor TRIGA Mark II PUSPATI |
| SANS | - | Small Angle Neutron Scattering |
| SD | - | Synchrotron Diffraction |
| TLD | - | Thermo-luminescence Detector |
| XRD | - | X-ray Diffraction |

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# CHAPTER 1

# INTRODUCTION

## 1.0 Research Background

Neutron diffraction (ND) is one of the applications of neutron scattering to probe the magnetic and atomic structure of a material. ND is defined as the interference process which occurs when neutrons are scattered by the atoms within solids, liquids or gases. In term of physic, ND is a form of elastic scattering where the neutron exiting has more or less the same energy as the incident neutrons. The technique of ND, x-ray diffraction (XRD) and strong x-ray synchrotron diffraction (SD) are quite similar (Farhi *et al.*, 2015). However, due to the different scattering properties and penetration, ND and XRD provide complementary information. In term of measurement, ND is suited for bulk measurements within thick specimens, SD is appropriate for shallow depths and thin specimens and XRD are suited for surface measurements (Paranjpe, 2005). There are some limitations of XRD method where it needs to recognize between elements of same atomic number while ND can differentiate such atoms type for a similar element with different isotopes (Klooster, 2001).

Nowadays, ND technique has been widely used for applications such as measuring strain within metallic and ceramic components, study the structure and composition of the solid, liquid and amorphous materials, study the structure of atomic length scales and much more (Brückel *et al.*, 2012). There are about 250 operational research reactors in the world (Farhi *et al.*, 2015). However, only about 30 of these reactors are equipped with the ND facility, also known as a neutron diffractometer system (NDS) (Farhi *et al.*, 2015). Mostly, the reactors that are equipped with this system are the reactor with high power operation with a maximum power more than 10 MW. For examples, a four-circle diffractometer has been fully working in multi-purpose research reactor with maximum power of 30 MW at HANARO (Lee *et al.*, 2000), installation of neutron diffractometer system in SAFARI-1 research reactor which operate with 20 MW power (IAEA, 2011), and utilisation of NDS in ANSTO research reactor with power of 20 MW (Kennedy *et al.*, 2000). There are still very less low power research reactors with a maximum power of below 5 MW implemented NDS in their reactor.

Researchers and practitioners are very concern to study more about the utilization of NDS, especially in low power research reactor. Various studies have shown that NDS can be implemented at the beam port facilities of low power research reactor (Tunkelo and Kajamaa, 1965). For example, a diffractometer system was installed at the 100 kW TRIGA Mark II in Finland. A recent study by Farhi *et al*. (2015) has claimed that a TRIGA Mark II research reactor named as Reactor TRIGA PUSPATI (RTP) located in Malaysia operated with a maximum power of 1 MW has a capability to build NDS. Although several studies have been made at low power research reactors, there is still a few in South-East Asian countries. Hence, the present study attempts to design and fabricate the instruments of NDS at Reactor TRIGA PUSPATI (RTP) of Malaysia.

## 1.1 Problem Statement

ND technique has been commonly used to analyse the strain-stress of material, locate the alloy location, phase transition induced and determine the crystalline and magnetic structures in a material (Mergia *et al.*, 2004). In view of medical and education, this technique is used to determine the molecular structure of a medical material and study about the behaviour of neutron interaction respectively. As ND technique has been applied in many countries all over the world, this has led to many research interest to obtain deeper understanding about the technique.

NDS has been implemented in various high power reactors but very rare in low power reactors. This is because of some of the limitations when installing NDS at low power reactors such as low neutron flux intensity at the sample location which led to unfavourable time consumption for collecting data. However, past study has found out that NDS can be installed in a low power reactor with power below 1 MW by optimizing the beams from the core (Tunkelo and Kajamaa, 1965).

There are some studies reported to install the NDS at low power reactor such as TRIGA reactor in Pavia, Italy (Di Tigliole *et al.*, 2014), Vienna, Austria (Böck *et al.*, 2013), Ljubljana, Slovenia (Snoj and Smodis, 2011), and Bangi, Malaysia (Sufi *et al.*, 1997). A recent study has been made in order to determine whether Malaysia has the ability and suitable condition to implement this system. Furthermore, the development of NDS is needed to enhance the utilization of reactor beam ports in Malaysian research reactor located at Bangi. This is because, since the RTP was commissioned in 1982, the utilization of neutron beam ports was only for neutron radiography (NR) and small angle neutron scattering (SANS) which were implemented at radial beam port 3 and radial beam port 4 respectively (Mohamed *et al*, 2003).

In view of this, to improve the utilization of reactor, radial beam port 1 was selected to develop a NDS. Additionally, there are few studies has been conducted to implement NDS at 1 MW research reactor in Malaysia. Considering this, the present study is focused on the characterization and design of neutron collimator in order to develop a NDS at TRIGA Mark II research reactor with an optimized beam. Indirectly, the utility of beam facilities in RTP can be maximised.

## 1.2 Objectives

The main goal~~s~~ of this study is to design a collimator for neutron diffractometer for low power nuclear research reactor. The specific objectives are:

i) To design an ideal convergent collimator for the NDS at radial beam port 1.
ii) To optimize the neutron beams in terms of flux intensity.
iii) To measure background of neutrons and gamma fluxes produced from beam port 1.

## 1.3 Scopes of Study

In order to achieve the objectives of this study, the following scopes of study have been identified:

a) Simulation of material characterization and collimator geometries were performed using Monte Carlo N-Particle (MCNP) software.
b) Suitable neutron and gamma shielding materials for the collimators obtained from MCNPX simulation results.

c) Optimization of the neutron beam was obtained by selection of collimator with appropriate length depends on the size of beam port.

d) Collimation of neutron beams from 20 cm diameter to 5 cm diameter with thermal neutron intensity at least $1.4x10^5 ncm^{-2}s^{-1}$.

e) Measurement of neutrons and gamma doses using Thermo-luminescence Detectors (TLD) at beam port 1.

f) Calculation of neutrons and gamma fluxes yielded from beam port 1 using conversion equation.

g) Fabrication of the selected design of collimator for neutron diffractometer system at radial beam port 1 in the RTP.

## 1.4 Significance of Research

This research has its significance by contributing to basic knowledge, improved technologies and usage of effective neutron applications. Most of the prior studies have considered about the application of ND in high power reactor with a power more than 10 MW. Whereas, the present study examines the suitability of the NDS installation at low power research reactor with a maximum power of exactly 1 MW.

Furthermore, the findings of this study will give more data for fabrication and operation of the NDS facility at low power research reactor in South-East Asian countries. Indirectly, the utilization of RTP in Malaysia can be enhanced. This way, local communities of neutron scattering users can arise around these facilities in order to train young scientists and disseminate the possibility to use these methodologies which are more advanced technology. It is expected that this study would help researchers and practitioners, especially around South-East Asian countries to have a better understanding and eventually guide them in order to implement NDS in low power research reactor.

## 1.5 Structure of Thesis

The work summarized in this thesis explains the characterization of neutron and gamma shielding materials and selection of suitable collimator for NDS facility at radial beam port 1 of RTP. Basically, the flow of this thesis was organized as follows:

Chapter 1 highlights a general introduction on the ND techniques and the importance of ND applications in various fields including industrial, medical and educational. In addition, problem statements, objectives and scopes of the studies are listed out in this chapter.

Chapter 2 contains the theoretical background of ND techniques. The examples of the ND facilities from the other studies from around the world is presented. The procedure of ND applications and characterization of ideal neutron beams for ND techniques are discussed in the literature reviews included in this chapter.

In chapter 3, the materials and methodologies of this research were discussed. All of the materials used in characterization of shielding materials and measurement of radiation doses were explained in detail. Furthermore, methodology used in simulation, characterization, measurement and fabrication of neutron collimators ware also presented.

Chapter 4 discussed the results and discussions of characterization of suitable shielding materials for collimators. The simulation and calculation of neutron and gamma fluxes yielded from radial beam port 1 were defined. The discussion was extended further with the results of ideal collimator geometries selected based on the neutron and gamma intensity which suitable for ND application. Finally, the conclusion of this thesis and recommendation for the future works are presented in Chapter 5.

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