OPTIMISATION OF MODERATOR AND NEUTRON GUIDE DESIGN FOR PROMPT GAMMA NEUTRON ACTIVATION ANALYSIS (PGNAA) USING MCNP5 SIMULATION

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ABSTRACT

The performance of prompt gamma neutron activation analysis (PGNAA) setup depends on thermal neutron flux available at the sample. Neutrons available in most reactors consist of thermal, epithermal and fast neutrons with varying ratios. As such for PGNAA to be more efficient, the ratio of the total amount of neutron to the epi-fast neutron must be high and this is being measured by the cadmium ratios. In order to increase the neutron flux, a moderator is used. In this study, combination of carbon, lead and silicon were modelled as a moderator to investigate the optimum thickness of moderator combination through a simulation technique. The moderator was tested with varying thickness of material assemblies and it was found that the combination of 1.48 cm carbon, 0.92 cm lead and 4.40 cm silicon gave the highest cadmium ratio. The Monte Carlo N-Particle transport code version 5 (MCNP5) and the exact dimension of the tangential beamport of Reactor Triga Puspati, Malaysian Nuclear Agency was used for the simulation purposes. The simulations then were run at seven locations along the tangential beamport in order to determine the position to place the moderator that yield the highest cadmium ratio. The location at 41.10 cm from the inner beamport exit produced 8.914 x 10^7 n cm^{-2} s^{-1} thermal neutron and 1.164 x 10^7 n cm^{-2} s^{-1} epi-fast neutron that yield 8.65 for the cadmium ratio. Consequently, this position could be suggested as the specific position to place the moderators for future PGNAA system at Reactor Triga Puspati. A one meter neutron guide has been proposed to be installed at the end of the moderator to transport the neutron with almost no neutron lost. The study shows that the proportion of thermal neutron lost was approximately 1.13 times.

ABSTRAK

Prestasi binaan analisis pengaktifan neutron gama serta-merta (PGNAA) bergantung kepada fluks neutron terma pada sampel. Neutron di dalam kebanyakan reaktor terdiri daripada neutron laju, neutron terma dan neutron epiterma dengan nisbah yang berbeza-beza. Oleh itu, untuk menjadikan PGNAA lebih cekap, nisbah neutron keseluruhan terhadap neutron epi-pantas mestilah tinggi dan ini boleh diukur melalui nisbah kadmium. Moderator digunakan untuk meninggikan fluks neutron. Dalam kajian ini, gabungan karbon, plumbum dan silikon telah dimodelkan sebagai moderator untuk mengkaji ketebalan optimum gabungan moderator melalui teknik simulasi. Gabungan moderator ini telah diuji dengan ketebalan yang berbeza dan didapati bahawa gabungan 1.48 cm karbon, 0.92 cm plumbum dan 4.40 cm silikon memberikan nisbah kadmium yang tertinggi. Perisian Monte Carlo N-Particle versi 5 (MCNP5) dan dimensi sebenar lubang pancaran Reaktor Triga Puspati di Agensi Nuklear Malaysia telah digunakan bagi tujuan simulasi. Seterusnya simulasi dilakukan pada tujuh lokasi di sepanjang lubang pancaran tangen dengan tujuan menentukan kedudukan optimum untuk meletakkan moderator supaya dapat menghasilkan nisbah kadmium tertinggi. Kajian mendapati pada kedudukan 41.10 cm dari pintu keluar lubang pancaran dalam, hasil neutron terma adalah 8.914×10^{7} n cm^{-2} s^{-1} dan neutron cepat adalah 1.164×10^{7} n cm^{-2} s^{-1} menghasilkan 8.65 nisbah kadmium. Maka, kedudukan ini dicadangkan sebagai kedudukan yang sesuai untuk meletakkan moderator bagi sistem PGNAA akan datang di Reaktor Triga Puspati. Panduan neutron sepanjang satu meter telah dicadangkan dipasang pada penghujung moderator untuk memindahkan neutron dengan

hampir tiada kehilangannya. Kajian menunjukkan bahawa nisbah kehilangan neutron terma adalah lebih kurang 1.13 kali.

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A	-	mass number
b	-	Coherent scattering length
CNS	-	cold neutron source
D	-	cell material density
DNRI	-	Dalat Nuclear Research Institute
D_2O	-	Heavy water
geom..	-	Specification of the geometry of the cell
H_2O	-	Light water
j	-	cell number
kW	-	kiloWatt
m	-	material number
MCNP	-	Monte Carlo N-Particle
MW	-	megaWatt
N	-	Number of history
n	-	Index of refraction of boundary material
NAA	-	Neutron Activation Analysis
$ncm^{-2}s^{-1}$	-	neutron per centimeter square per second
Params	-	parameter
PGNAA	-	Prompt Gamma Neutron Activation Analysis
R	-	Relative error
R_{cd}	-	Cadmium ratio
RTP	-	Reactor TRIGA Puspati

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CHAPTER 1

INTRODUCTION

Prompt gamma-ray neutron activation analysis or commonly known as PGNAA, is an important tool for the determination of elemental content of industrial samples (Naqvi, A. A. et al., 2004). The PGNAA method is based upon bombarding sample with neutrons and the detection of prompt gamma ray emitted by the sample material while it is being irradiated with thermal neutrons. The type of elements and their concentration can be determined respectively by its gamma energy and intensity. The rate of activation of elements is relative to the average neutron flux available at the sample volume (Nasrabadi, M. N. et al., 2007). Prompt gamma ray analysis starts after the first reports of gamma radiation from neutron capture by Lea (1934). In the same year, there are also reported about the first published tabulation of gamma ray energies and intensities and the plots of spectra led to a neutron guides. The use of PGNAA has increased because of the availability of high flux thermal and cold beams from neutron guides (Lindstrom, R. M. et al., 2006). The development of PGNAA is important in supporting the use of nuclear analytical technique in detecting trace elements with concentration in the region of parts per billion (ppb).

It is well known that PGNAA is an attractive option of NAA, which offers an excellent supplement as especially beneficial as a non-destructive nuclear method for the analysis of several elements such as hydrogen, carbon, nitrogen, boron, etc that cannot be determined by other conventional activation analysis (Hanna, A. G. et al., 1981). Furthermore, in most common materials, PGNAA can determine all elements excluding oxygen.

1.1 Background of study

The implementations of PGNAA that use a wide range of neutron source facilities can be divided into two categories, one uses thermal or cold neutrons from nuclear reactors, and the other consumes smaller mobile systems which involve moderated neutrons from isotopic sources, neutron generators or accelerator driven systems. Reactor based systems use an internal target or external direct beam to get benefit of the large neutron flux.

There are several PGNAA facilities worldwide found in the literature (Lindstrom, R. M. et al., 2006). The desirable characteristics of PGNAA facilities comprise the highest possible thermal neutron flux, a low level of background radiation, simple, multipurpose, and reproducible sample-positioning system while allowing great flexibility in the size, shape and type of the samples being irradiated. At the present time, some of these facilities have committed substantial time to PGNAA activities and others have validated the ability to perform nuclear structure investigations. The general trend in most reactor facilities consists of an extracted neutron beam from the reactor core that impinges on a sample target in order to prepare a very clean beam that is free of epithermal neutrons and background gamma rays.

Differences arising from the neutron beam handling process (extraction, shielding, and collimation), as well from the sample-detector layout, make every facility unique. The use of supplementary techniques to reduce the neutron and gamma ray background may enhance these differences. In this thesis, optimization of moderator and neutron guide PGNAA at Nuclear Malaysia TRIGA Mark II Research Reactor has been proposed. In the future, the new data compilation should encourage the further use of PGNAA.

Generally, neutrons commonly are classified according to their energy, as shown in Table 1.1. This classification is somewhat arbitrary and may vary in different contexts.

Table 1.1: Classification of neutron according to their energies.

Energy (keV)	**Type**
Up to 1	Slow or thermal neutron
1 - 100	Epithermal or intermediate neutron
100 – 20000	Fast neutron
More than 20000	High energy or relativistic neutron

The thermal neutron in particular is very useful in the promt gamma neutron activation analysis (PGNAA). As this type of neutron can be obtained from the TRIGA reactor, many institutions that have this reactor have developed this PGNAA. For examples, Dalat Nuclear Research Reactor (DNRR), Cornell University and Budapest, have developed the PGNAA. In these institutions, the tangential beamport of the reactor is chosen as it can produce the highest thermal neutron flux, which is essential for the PGNAA.

1.2 Problem statement

The performance of PGNAA setup depends on thermal neutron flux available at the sample. But the neutron flux in reactor comprises of thermal, epithermal and fast neutron with varying percentage. In order to increase the thermal flux, moderator is used which moderate the fast neutron. However, moderator may reduce total neutron fluxes. Currently, PGNAA is not available at Malaysian Nuclear Agency since the exit of thermal flux is rather low. In view of that, there is a possibility for Malaysian Nuclear Agency (MNA) embarking PGNAA if the thermal flux increases. In this study, we propose to moderate the fast neutron fluxes using carbon, lead and silicon at seven locations to obtain maximum cadmium ratio while maintaining a high thermal neutron flux. Once neutrons have been moderated, it is crucial to transmit the neutrons to the sample location outside the biological shielding. It is hard to conduct experiments at long distances from the reactor core without guide tubes due to the neutron loss. Hence, employing 1 meter guided neutron tube would maintain proportion of neutron up to the end of the guide tube.

1.3 Objective of the study

The objectives of this study are as follows:

i. To optimize the moderator thickness with combinations of carbon, lead and silicon to obtain highest cadmium ratio ie high thermal neutron relative to epithermal neutron by using Monte Carlo N-Particle (MCNP) code.
ii. To optimize the best location to place the moderator along tangential beamport.
iii. To propose the optimal neutron guide material for neutron collimation in PGNAA by using Monte Carlo N-Particle (MCNP).

1.4 Scope of the study

This study will be carried out to choose the best geometry and combinations of materials in order to obtain highest cadmium ratio which is high thermal neutrons compared to epi-fast neutrons. This study will only encompass the use of tangential beamport of Reactor TRIGA Puspati, Malaysian Nuclear Agency for simulation purposes. Simulation work will be done using Monte Carlo N-Particle transport code version 5 (MCNP5) and other suitable software.

1.5 Significance of the study

i. PGNAA is a promising technique for elemental analysis of light elements. For example, waste management, rubber industries, ect.

ii. In a prompt gamma ray neutron activation analysis (PGNAA) setup can even dominate the thermalization effects of the external moderator in some cases.

iii. Design can be used by Nuclear Malaysia Agency for it future development of PGNAA facility.

1.6 Organization of Thesis

This thesis details the work, results and analysis from the study of optimization of moderator and neutron guide for Prompt Gamma Neutron Activation Analysis (PGNAA). The introduction describes the PGNAA broadly. Following the introduction chapter was literature review on MCNP features, neutron moderator, neutron guide, cadmium ratio and characteristic of PGNAA which were reported in Chapter 2. Further in Chapter 3, research methodologies were discussed. Chapter 4 presents the results and discussion of each method. Finally, the conclusion of research and suggestions for other improvements are presented in Chapter 5.

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