APPLICATIONS AND SERVICES AT PUSPATI TRIGA REACTOR IN MALAYSIA
Current status and outlook

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1. INTRODUCTION

Malaysian Nuclear Agency (Nuclear Malaysia) operates the one and only research reactor in Malaysia, Reactor TRIGA PUSPATI (RTP) of Mark II type, commissioned on 28 June 1982. It has a nominal power of 1 MW designed to effectively implement various fields of basic and applied nuclear research or services, education and training. Among the facilities are in-core dry tubes, wet central thimble and the rotary rack for isotope production for medical and radiotracer purpose, as well as neutron activation analysis (NAA). Of the four existing beam ports, two are already used for small angle neutron scattering (SANS) and neutron radiography (NR). Besides these, feasibility studies to undertake various developments such as prompt gamma neutron activation analysis (PGNAA), new neutron radiography at the tangential beamport and the development of the thermal column for boron neutron capture therapy (BNCT) have been carried out. Collaborative projects with the institutions of higher learning to develop these facilities are currently being undertaken.

2. UTILIZATION OF PUSPATI TRIGA MARK II REACTOR

The utilization of reactor for variety of experiments and application were already carried out since commissioning, with the majority for irradiation coming from the neutron activation analysis (NAA) experiments. Others were for the training and research and development (R&D) in SANS and neutron radiography as well as isotopes for tracer studies.

2.1. Radioisotope for medical use

Between 1988 and 2003, Reactor PUSPATI TRIGA (RTP) produced 14 types of radioisotopes especially for medical purposes. However, the production of Technetium-99m from Mo-99 with the specific activity of around 50 mCi per gram required 75 hours of continuous irradiation at the central thimble (neutron flux $1x10^{13}$ cm^2s^{-1}). With yield of about 4 Ci of Mo-99 for 80 g of natural Mo_2O_3 used as the target material, the MEK extraction technique requires delicate control of many parameters to obtain products with reasonable consistent quality [1, 2]. From 1991 to 1994, another radioisotope, Iodine-131 (I-131) was produced with maximum yield of about 2 Ci. However, due to many safety problems faced with the dry distillation production plant, it was later dismantled in 2003 and the hot-cell was decontaminated. Nuclear Malaysia replaced the production of Tc-99m and I-131 from the reactor with portable type chromatographic column generator, which could produce Tc-99m and I-131 on weekly basis and were more suitable for customers regardless of the distance. Due to economic as well as other reasons, Malaysian Nuclear Agency decided to import fission Mo-99 to produce Tc-99m generator from Indonesia or other countries. Apart from that, an irradiated Ir-192 pellet with radioactivity of 50 Ci for each pellet were imported from abroad and final pigtail assembly was done at Nuclear Malaysia laboratory. Iodine-131 is going to be prepared inside a hot-cell with Grade C clean room environment. Such facility which includes processing, packaging and a certified GMP layout is in the progress of development.

The demand for radiopharmaceutical product has increased tremendously in Malaysia when many new nuclear medicine centers were operational. In the 1964 there was only one hospital using radiopharmaceutical but in 2009 the number has increased to 18 hospitals. Table 1 gives the list of hospitals in Malaysia using radiopharmaceutical products.

TABLE 1. LIST OF HOSPITALS IN MALAYSIA USING RADIOPHARMACEUTICAL PRODUCTS

No	Year	Hospitals	Radiopharmaceutical used
1	1964	Kuala Lumpur General Hospital	Tc-99m, I-131, radiopharmaceutical kits
2	1967	University of Malaya Medical Centre	
3	1980	Kuching General Hospital	
4 5 6 7 8 9	1990s	USM Hospital, Kubang Krian, Kelantan Pulau Pinang Hospital National Heart Institute (IJN) UKM Medical Centre Sultanah Aminah Hospital, JB Cancer Society	
10 11 12	2000s	Subang Jaya Medical Center Prince Court Medical Centre Universiti Islam Antarabangsa	
13 14 15	2000s	Nilai Cancer Hospital Penang Island Medical Mahkota Medical Center Melaka	I-131
16 17 18	2009	Putrajaya Hospital UPM Hospital, Serdang Wijaya International Medical Centre	F-18-FDG from cyclotron

2.2. Radioisotope for industrial use

Other radioisotopes for industrial used were produced with limited quantity due to low demands. For example, there was no request for P-32 radioisotope from 1997 to 2006. From time to time, the reactor produced Iridium-glass, Au-198, Na-24, K-42 and some other radioisotopes by request and with limited quantity. The products are to serve non-destructive testing services as well as other users such as industry, agriculture, hydrology, sedimentology, scientific research, etc [1, 2].

2.3. Instrumented neutron activation analysis (INAA)

NAA has become a major analytical tool in Nuclear Malaysia for elemental analysis since 1984 due to its accuracy, precise, sensitive, easy to handle, non-destructive and with multi-element capability. NAA facility is available with the option of ‘Rotary Rack’ (neutron flux: 1×10^{12} cm^2s^{-1}), for producing long-lived radio-nuclides or ‘Pneumatic Transfer System’ for short-lived radionuclides. NAA laboratory is equipped with 7 units of gamma spectrometer system including one automatic sample changer.

Recent use of NAA technique include studies on contamination of marine sediments by anthropogenic activities, identification sources of particulate pollution and their apportionment, provenance study of porcelain from shipwrecks, uptake of toxic and essential elements by human through foods, speciation study of arsenic and chromium in domestic water resources, determination of platinum group metals in catalyst materials, gold in geological and biological materials and mercury in contaminated petroleum sludge and scale.
To date more than 100 undergraduate and postgraduate students have finished their studies by using NAA technique in their research works. Figure 1 shows the number of NAA users in Malaysia from 2006 to 2008 [1, 2].

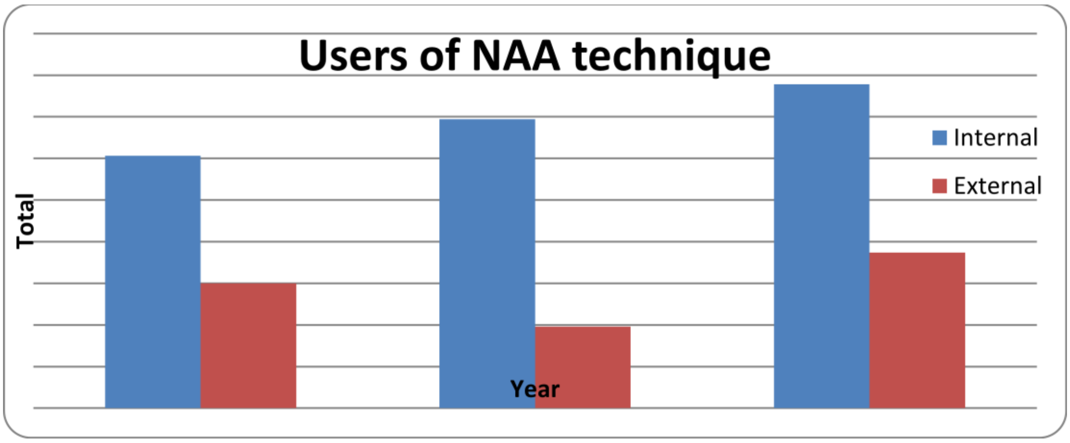

Fig. 1. The number of NAA users in Malaysia from 2006 to 2008.

NAA has been recognized as the official method by the Malaysian Atomic Energy Licensing Board (AELB) for the determination of radioactive elements uranium and thorium in various materials. Minerals such as zircon and ilmenite are common samples received by the Nuclear Malaysian to determine the uranium and thorium concentration before being exported or processed elsewhere.

2.4 Delayed neutron activation analysis (DNAA)

The DNAA system a product of AECL was installed in Nuclear Malaysia in mid-1980's to complement the well known NAA system. Generally DNAA presents a fast, accurate, and reliable method for quantification for simultaneous uranium and thorium detection in geological samples such as oil sludge and mining residues, using delayed neutron. In this analysis, the sample is first irradiated by a neutron in a reactor. The system used delayed neutron detector boron trifluoride (*BF3*) to detect delayed neutron decaying from its precursors. Till mid-90s, the old system was used to analyse more than 20 000 samples. Block diagram of the DNAA system is shown in Figure 2.

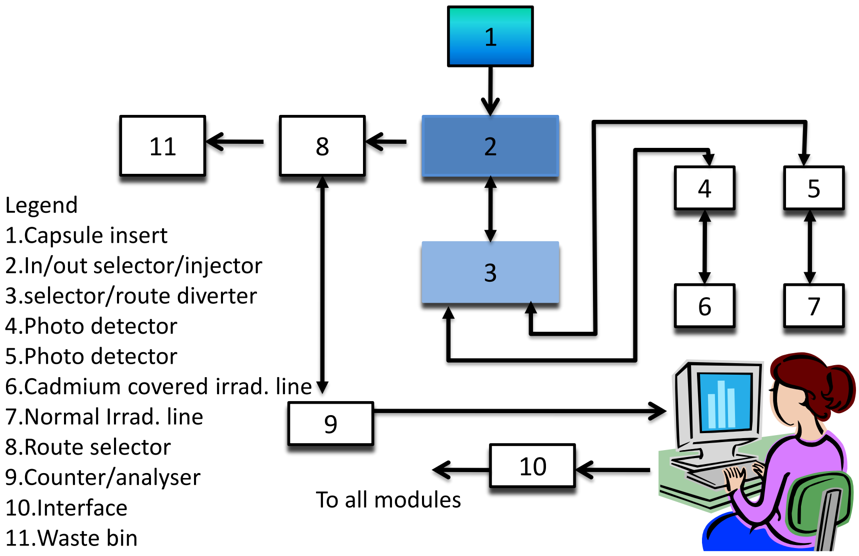

Fig. 2. Block diagram of the Delayed Neutron Analysis (DNAA).

The system is currently under refurbishment due to outdated and faulty electronic, computer systems and detectors. In the refurbishment of the DNAA system, recent technologies in instrumentation system and electronics are introduced, with the design and configuration carried out in-house. The instrumentation modules such as detectors, amplifiers and counters are purchased from established manufacturers and interfaced to a computer. The controlling software is developed to integrate the pneumatic controller for event sequencing or sample movement and to enable counting as well as data retrieval, display and storage [2].

2.5. Neutron beam facilities

The neutron beam facilities at PUSPATI Triga Reactor currently consist of Small Angle Neutron Scattering (SANS) and Neutron Radiography (NR). Current use of SANS and NR are mostly for postgraduate research projects jointly carried out with local universities. These collaborations were carried out through the Reactor Interest Group (RIG), a loosely binding group initiated by Nuclear Malaysia in 2001 to promote the use of RTP for R&D. Through RIG, 6 postgraduates research in neutron beam have been successfully realized. Besides the existing facilities, other neutron beam facilities are planned.

2.5.1. Small angle neutron scattering (SANS)

The SANS system in Nuclear Malaysia can be used to observe in-homogeneity in material ranging between 10 nm and 100 nm using neutrons in the range of 5Å. This is useful for studying alloy, ceramic and polymers and their correlation to alteration of physical, chemical and mechanical properties of their crystallites from bulk materials. The SANS ability to penetrate deeper into the surface of the material provides statistically meaningful measurements to probe the lattice of target material from a few to several hundred nanometres in size.

A block diagram of SANS system is shown in Figure 3. The system uses a monocromatised neutron, scattered by a Highly Oriented Pyrolitic Germanium monochromator (HOPG) setup with cooled beryllium to filter fast neutrons and to increase the conversion of fast neutron to thermal neutrons. This would give higher sensitivity and reliability (no beam hardening artefacts) for radiographic and tomographic reconstruction. The photograph of the SANS facility is shown in Figure 4. It uses a radial beamport number 2 of the reactor and Figure 5 shows the intensity I versus the momentum transfer q of experimental result for carbon glassy sample.

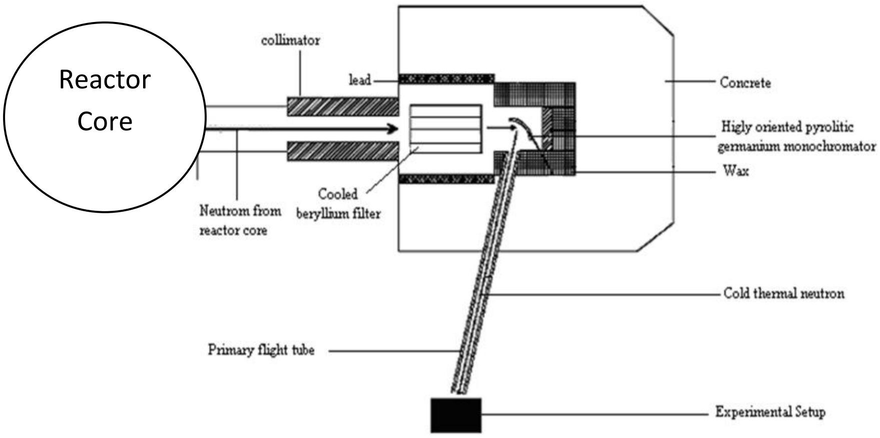

Fig. 3. Schematic design of SANS set-up.

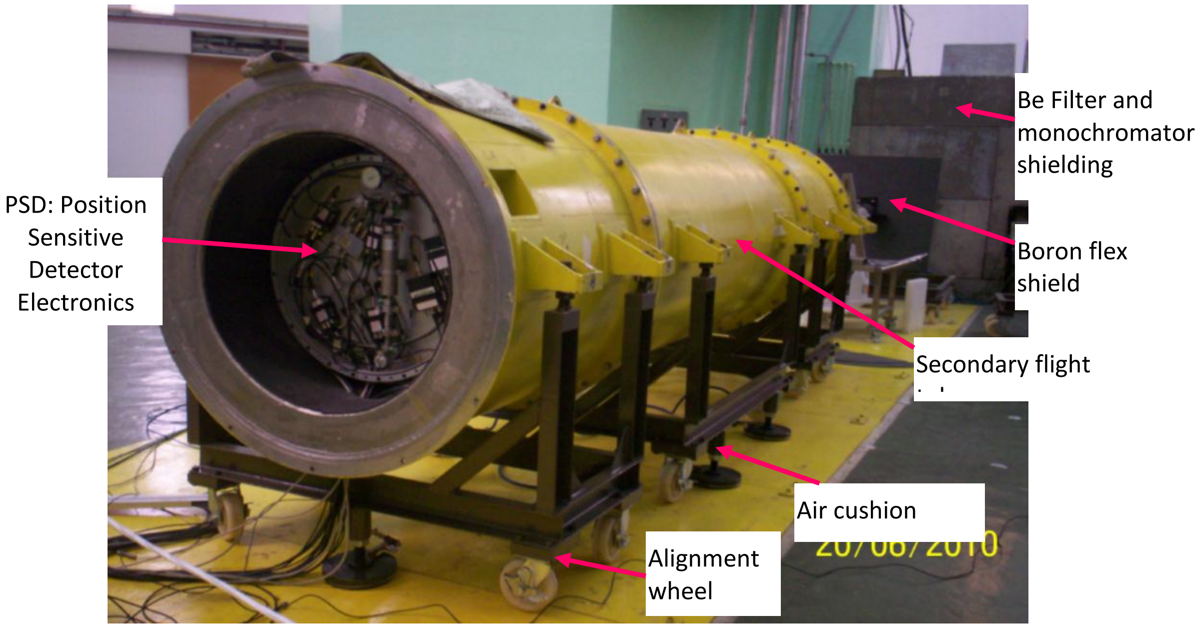

Fig. 4. SANS facility at the Reactor TRIGA PUSPATI in Nuclear Malaysia.

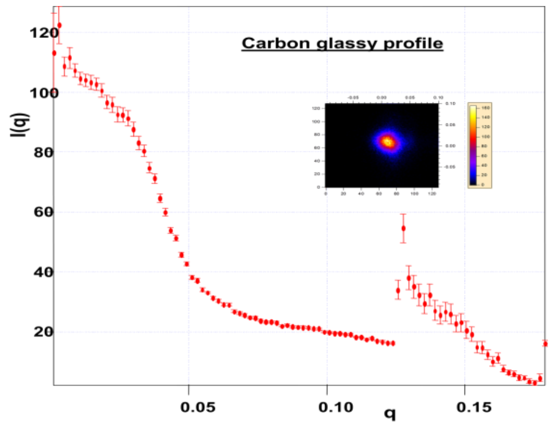

Fig. 5. Carbon glassy sample.

To further enhance the reactor usage, a neutron tomography system has been developed using the SANS beamline [3]. Figure 6 shows the system setup where a one-dimensional ^{3}He-detector is positioned in front of the source in the horizontal direction. The data acquisition systems from Mesytec, is used as readout system for the PSD detector. A "GUI CT" image reconstruction software package based on Donner Algorithm developed at Lawrence Berkeley Lab was developed for reconstruction of the projection data obtain. Figure 7 shows the projection data for cylindrical object and Figure 8 shows the results of reconstruction of a spark plug for petrol engine.

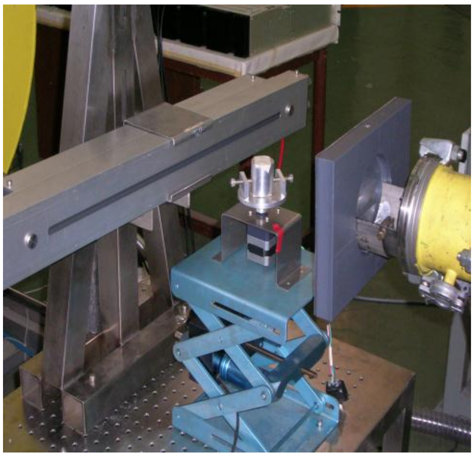

Fig. 6. Tomography system set-up at the SANS facility.

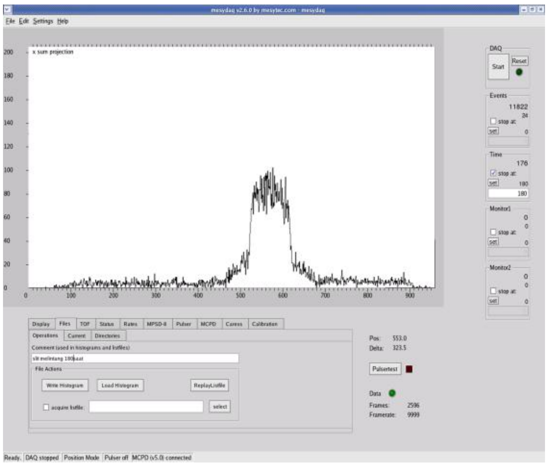

Fig. 7. Projection data for cylindrical object.

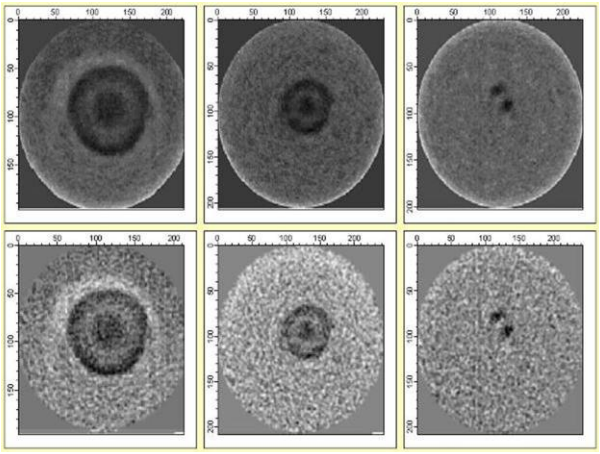

Fig. 8. Results of reconstruction of the spark plug.

At present, the SANS system is undergoing minor modification where the data acquisition and control software is upgraded from DOS to windows. This will enable the image processing of SANS to be carried out concurrent with data taking from the PSD. Other projects currently carried out are modelling and simulation of SANS using McStas/MCNP, radiation damage and doping analysis, and microfocus of neutron, with the latter being part of IAEA CRP on "Improved production and utilization of short pulsed, cold neutrons at low-medium energy spallation neutron sources". To improve the system further, automation for beam adjustment and tuning is planned to be introduced. Works on cold neutron source would also be undertaken.

2.3.2. Neutron radiography and neutron captured tomography

The neutron radiography facility uses conventional techniques such as direct, transfer and track etch. With the advent of digital imaging technique, the film based has been complimented with digital charged cooled device (CCD) based imaging method in 2004 [4]. The neutron tomography facility was installed at radial piecing beam port number 3 since 1985. It consists of three main items namely source, collimator and detection systems. The schematic of the facility is shown in FIG. 9 and FIG.10, while FIG. 11 shows the radiographic image of a turbine blade.

To improve the neutron radiography services, a feasibility study for new neutron radiography at the tangential beamport has been carried out in 2007. The tangential beamport would provide an increase of thermal to fast neutron ratio, as well as decrease direct gamma from the reactor core. FIG 13 shows the result of optimised collimator design for neutron radiography at the tangential beamport. The study was also complemented with neutron flux spectrum measurement giving thermal neutron flux of 2×10^{6} $cm^{-2}s^{-1}$ and cadmium ratio of 2.1 near the outer part of the tangential beamport.

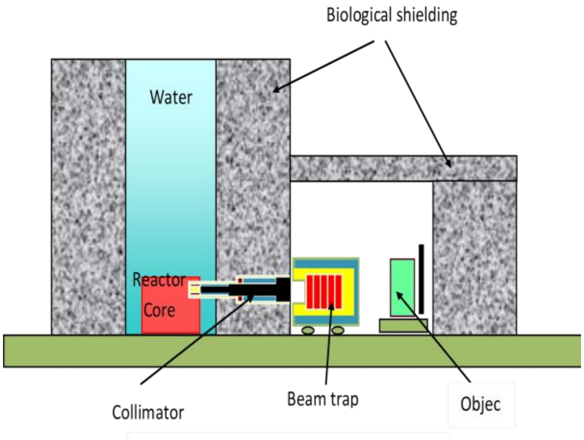

Fig. 9. The side view of NUR-2 facility.

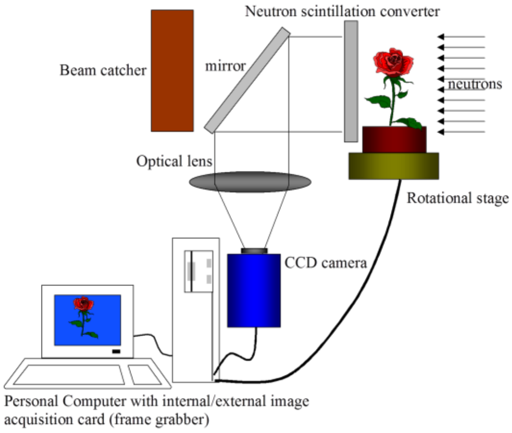

Fig. 10. Schematic set-up of the digital neutron radiography.

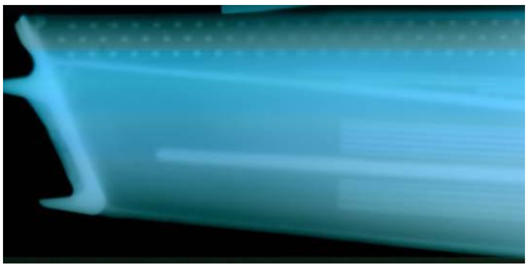

Fig. 11. Neutron radiographic image of a used turbine blade.

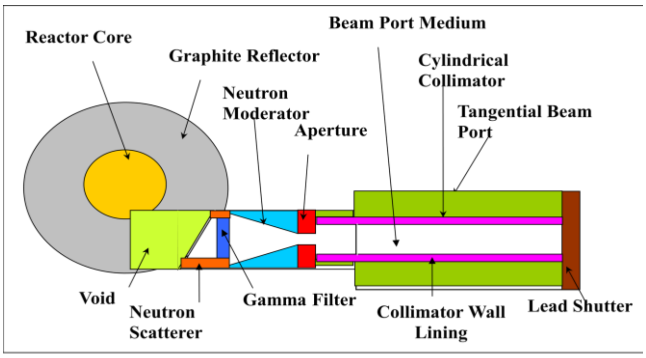

Fig. 12. Final design of The optimized neutron collimator for tangential beamport of RTP.

2.4. New reactor application system proposed

Through project collaboration with the local institutions, Nuclear Malaysia has carried out other feasibility study to enhance the usage of reactor beamports and thermal column. From

2003 to 2009, feasibility studies of the prompt gamma neutron activation analysis (PGNAA) for radial beamport number 1 and boron neutron capture therapy (BNCT) using thermal column has been carried out. The following sections describe some of the works that has been carried out.

2.4.1. Prompt gamma neutron activation analysis (PGNAA)

A feasibility study of setting up of the Prompt Gamma Neutron Activation Analysis (PGNAA) at the radial beamport number 1 of the reactor has been carried out in 2006, through project collaboration with University of Technology Malaysia [5]. PGNAA could provide a technique to detect light elements, e.g., H, N,P, Al, O, C etc in trace elements studies, for wide range of sample materials. These include big sample material that is combustible or volatile in nature and not suitable for in-core irradiation facility. The works on PGNAA development that has been carried out which include, radial beam port collimator design using MCNP5, FPGA-based prompt gamma spectroscopy.

2.4.2. BNC for medical and industrial research

Feasibility study to develop the thermal column of RTP for BNCT research has been carried out [6]. The aim is to simulate and measure neutron fluxes in the thermal column. Neutron fluxes measured with various foils such as Au, Ni, Fe, Al etc. were input into SAND-II code to obtain the entire spectrum and compared against the simulated values using MCNP5. FIG 13 shows side view of the 4ft by 4ft thermal column at RTP, while FIG.14 shows comparison of neutron fluxes between SAND-II and MCNP at the centre of thermal column. If materialized the facility would be used for research in tumor treatment, and boron capture radiography for industrial applications.

Fig. 13. A 4ft by 4ft thermal column, side view, stacked with blocks of graphite stringers.

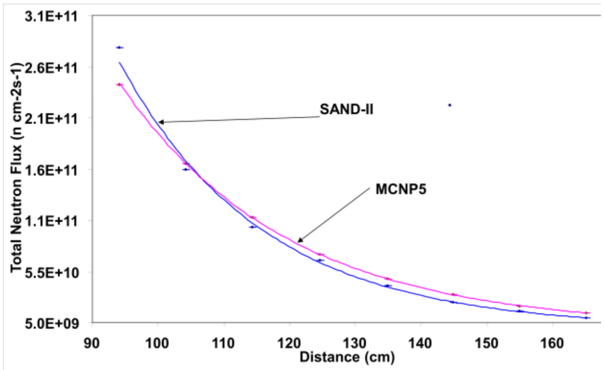

Fig. 14. Comparison of neutron fluxes between SAND-II and MCNP at the centre of thermal column.

2.4.3. Neutron transmutation doping (NTD)

In semiconductor production, doping is the process of intentionally introducing impurities into an extremely pure (also referred to as intrinsic) semiconductor to change its electrical properties. NTD is the process of creating non-radioactive impurity isotopes from the host atoms of a material by thermal neutron irradiation and subsequent radioactive decay. This technique is applicable particularly to dope semiconductors in cases of better control on the spatial uniformity of doping, and where a very small amount of dopants must be added. Due to a number of semiconductor industry in Malaysia, it may be worth for Nuclear Malaysia to study on the feasibility of using RTP for such purposes.

3. PROPOSED COOPERATION AMONG REACTOR USERS IN MEMBER STATES

In general, the low neutron flux at PUSPATI TRIGA Reactor posed certain limitation to advanced research in Malaysia. To enhance the knowledge of fundamental research and engineering design related to reactor utilization and neutron beam applications, Nuclear Malaysia has formed project collaboration with local institutions of higher learning and, currently is expanding it with other research institute in Malaysia. The existing Project collaborations through Reactor Interest Group (RIG) initiated by Nuclear Malaysia have proved to be successful in the past 8 years, will continue to be enhanced in the coming years.

In general the expansion of technology related to neutron sciences in developing member states is not progressing fast as expected. They are due to numerous limitations such as limited budget, low neutron flux to meet advanced research and applications as well as limited number of scientist with adequate level of expertise to undertake advance research. The strict procurement of nuclear instruments and material for neutron beam applications imposed by suppliers further inhibit fast track research on neutron beam applications.

To enhance the application of research reactor and neutron sciences, it is proposed that IAEA and member states continue to collaborate in a project. Each member states will propose a project and at the IAEA level they are consolidated and prioritize. There will be exchange of experts and knowledge as well as scientific visits between member states. IAEA may not fund for equipment but member states should be assisted in scientific visits and expert assignments. Member states that participate in the project should share the knowledge and results obtained from the project with other members. Multilateral cooperation with member countries facilitated by IAEA is proposed, especially for projects related to advanced neutron beam applications.

4. CONCLUSIONS

The research projects carried out at the Reactor TRIGA PUSPATI (RTP) has proved to be effective albeit on a smaller scale, due to certain limitations of RTP. Further support from IAEA and other member countries is needed especially for projects related to advanced research in neutron beam applications

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