GENERAL PURPOSE NUCLEAR IRRADIATION CHAMBER

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ABSTRACT

Nuclear technology has found a great need for use in medicine, industry, and research. Smoke detectors in our homes, medical treatments and new varieties of plants by irradiating its seeds are just a few examples of the benefits of nuclear technology. Portable neutron source such as Californium-252, available at Industrial Technology Division (BTI/PAT), Malaysian Nuclear Agency, has a 2.645 year half-life. However, ^{252}Cf is known to emit gamma radiation from the source. Thus, this chamber aims to provide a proper gamma shielding for samples to distinguish the use of mixed neutron with gamma-rays or pure neutron radiation. The chamber is compatible to be used with other portable neutron sources such as ^{241}Am-Be as well as the reactor TRIGA PUSPATI for higher neutron dose. This chamber was designed through a collaborative effort of Kulliyyah Engineering, IIUM with the Bahagian Teknologi Industri (BTI) team, Agency Nuklear Malaysia.

ABSTRAK

Teknologi nuklear telah menemui keperluan yang besar untuk digunakan dalam bidang perubatan, industri, dan penyelidikan. Pengesan asap di rumah kita, rawatan perubatan dan jenis tanaman baru dengan menyinari benihnya hanyalah beberapa contoh manfaat teknologi nuklear. Sumber neutron mudah alih seperti Californium-252, yang terdapat di Bahagian Teknologi Perindustrian (BTI / PAT), Agensi Nuklear Malaysia, mempunyai separuh hayat tahun 2.645. Walau bagaimanapun, 252Cf diketahui mengeluarkan radiasi gamma dari sumbernya. Oleh itu, ruang ini bertujuan untuk menyediakan pelindung gamma yang sesuai untuk sampel untuk membezakan penggunaan neutron bercampur dengan sinaran gamma atau radiasi neutron tulen. Kamar ini serasi untuk digunakan dengan sumber neutron mudah alih lain seperti 241Am-Be serta reaktor TRIGA PUSPATI untuk dos neutron yang lebih tinggi. Dewan ini direka bentuk melalui usaha sama Kejuruteraan Kulliyyah, UIAM dengan pasukan Teknologi Industri (BTI), Agensi Nuklear Malaysia.

Keywords: *gamma shielding, irradiation chamber, mutation, neutron moderator, pure neutron*

INTRODUCTION

Electronic devices such as diodes and transistors are commonly used in radiation environment such as outer space and nuclear reactor involving high energy particles and photon radiation ranging from keV to GeV (Claeys and Simoen 2002). In each of the above environments electronic equipment is used to sense and monitor radiation as well as to control robots and other machinery remotely. Studies have shown that exposure to radiation can produce measurable changes in the electrical properties of electronic devices such as displacement damage effects and indirect ionisation (Schwank, Shaneyfelt et al. 2008). Due to this reason, there is a need to study the radiation-induced defects in electronic devices. An ab initio experiment done on commercial gallium arsenide (GaAs) diodes under ^{252}Cf neutron source shows an increase in leakage current from the current – voltage (I-V) measurements made. Energetic neutrons are the primary particles involved in cosmic ray single event upsets

(SEUs) (Gordon, Goldhagen *et al.* 2004). The experiment was carried out at the Industrial Technology Division Laboratory, Malaysian Nuclear Agency, Malaysia. Figure 1 shows the reverse bias (RB) I-V characteristics of TSKS5400S GaAs infrared emitting diodes before and after exposure to ^{252}Cf for 21 days. Leakage current increment indicates damage or degradation of the device after irradiation. However, the source of is defect is unknown whether due to neutron, gamma ray or both. Furthermore, we are particularly interested to analyse the effects of pure neutron on the electronic devices. Gamma-rays from an unfiltered ^{252}Cf fission neutron source are known to contribute 33% of the absorbed dose (Endo, Stevens et al. 1999). Hence, a pure neutron irradiation facility named General Purpose Nuclear Irradiation Chamber (GPNIC) was designed to provide shielding against gamma ray while optimizing neutron production and minimizing overheads. This chamber was designed through a collaborative effort of Kulliyyah Engineering, International Islamic University Malaysia (IIUM) with the Industrial Technology Division (BTI/PAT) team, Malaysian Nuclear Agency.

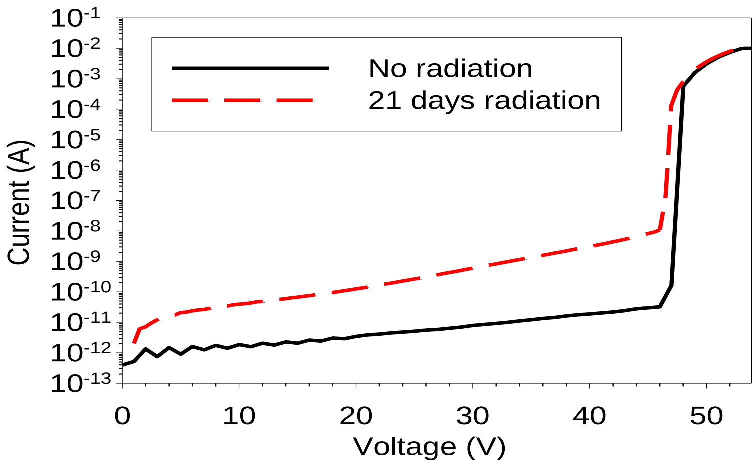

Figure 1. Reverse Bias (RB) I-V characteristics of TSKS5400S GaAs infrared emitting diodes before and after exposure to ^{252}Cf for 21 days.

REVIEW OF RELATED WORKS

Nuclear radiation shielding is an important infrastructure component in nuclear facilities. The design of an irradiation chamber is dependent on the type of radiation, type and volume of samples to serve the main purpose of a research or industrial application. Several works have been done to reduce the gamma ray component of neutron sources such as Cf-252, Am-Be and Am-Li. A recent work was done by comparing Monte Carlo simulation and experimentation study to reduce gamma ray from various types of neutron sources. The Monte Carlo model is a mathematical model constructed to simulate a physical situation. Figure 2 shows their basic neutron irradiation setup with and without lead shielding and its results.

Endo *et al.* reported that lead (Pb) effectively reduces the gamma ray component from the portable neutron source, ^{252}Cf, compared to other materials. The optimum thickness of 40mm shows a gamma ray component reduction of 6.7% of the total dose from 90% of that with no lead filter. The MCNP calculations confirmed the results within 6% accuracy (Endo, Stevens et al. 1999). A study by Kang *et al.* evaluated use of several materials such as polyethylene, k-resin, paraffin and graphite as neutron shield (Kang, Park et al. 2008). Figure 3 (a) shows the measurement test model for neutron shielding material. Results showed continuity in comparison with the Monte Carlo method MCNP-5c code presented in Figure 3 (b).

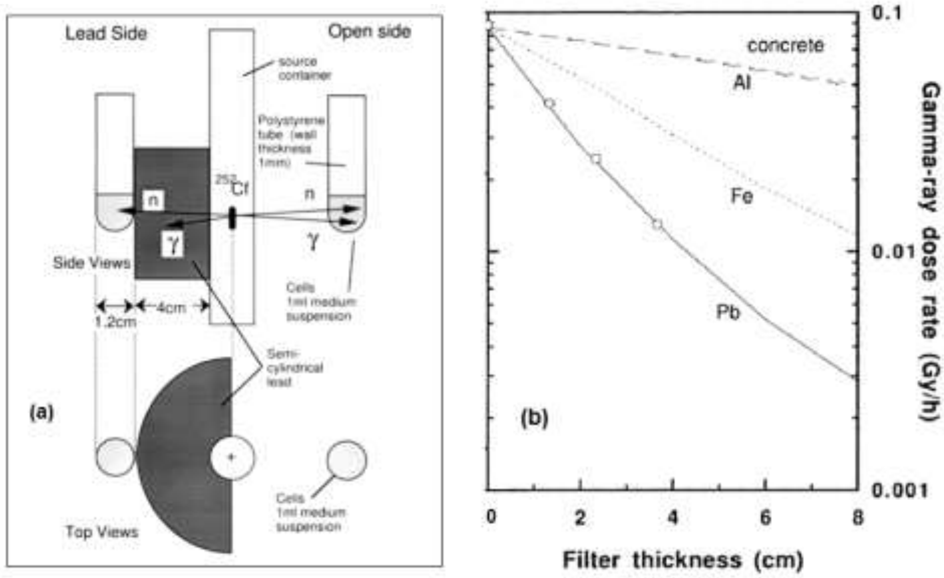

Figure 2. (a) Neutron irradiation configuration (b) Gamma-ray dose rate as a function of thickness of various filter materials (concrete, Al, Fe and Pb) (Endo, Stevens et al. 1999).

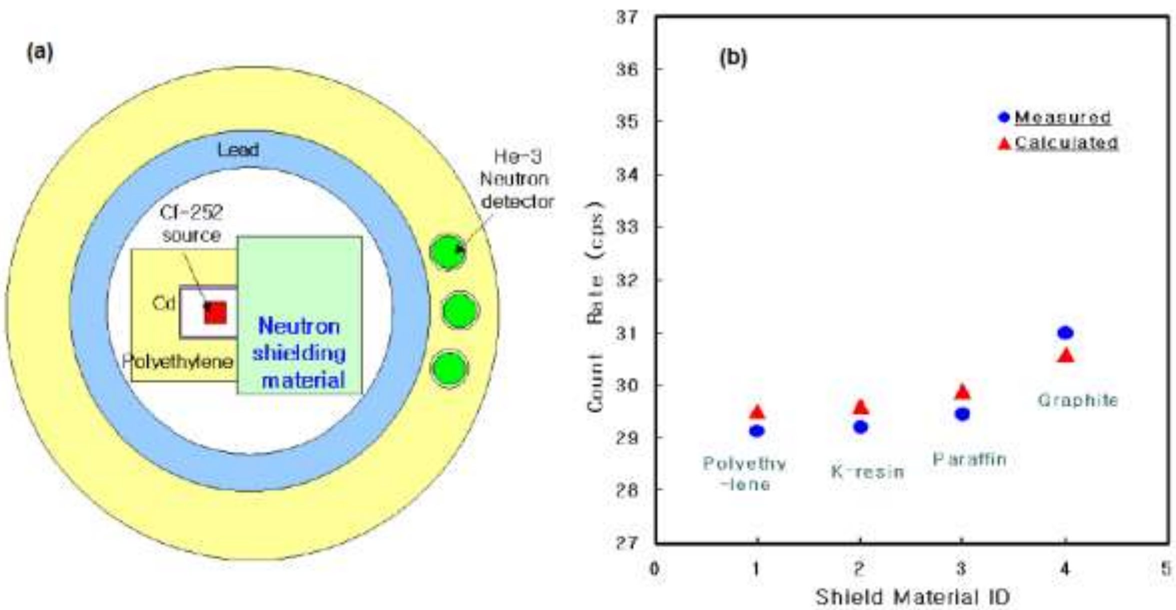

Figure 3. (a) Basic neutron irradiation setup and (b) comparison of experimental and calculated results for various neutron shielding materials (Kang, Park et al. 2008).

Neutron energy spectrum for this study is modelled by Watt fission spectrum provided with the MNCP code where E is the neutron energy (MeV).

$$N(E) = 0.30033 \exp\left(-\frac{E}{1.025}\right) \sinh(2.926)^{1/2} \quad (1)$$

The count rates and the shielding effects for k-resin and the polyethylene materials are slightly better compared to other materials. Kang *et al.* concluded that polyethylene exhibits the best shielding effects compared to other materials due to its higher ratio of hydrogen compared with carbon.

PROPOSED DESIGN AND ITS SIGNIFICANCE

The main objective of the design is to irradiate electronic devices with pure neutron source where currently only mixed neutron and γ ray is available in Malaysia. After several revisions and help from the BTI team, the design of the chamber was fully modelled using, SolidWorks, a 3D computer-aided design (CAD) software. Table 1 shows the technical specifications of the GPNIC.

Table 1. Technical specifications of the irradiation chamber, GPNIC.

Specifications	**Details**
Gamma shield	41 kg
Neutron Moderator	29 kg
Max sample capacity	3644 cm^3
Sources of Radiation	• Portable neutron dose (252Cf or 241Am-Be) • High neutron dose (Nuclear Research Reactor)
Range of speed	90 – 1400 rpm

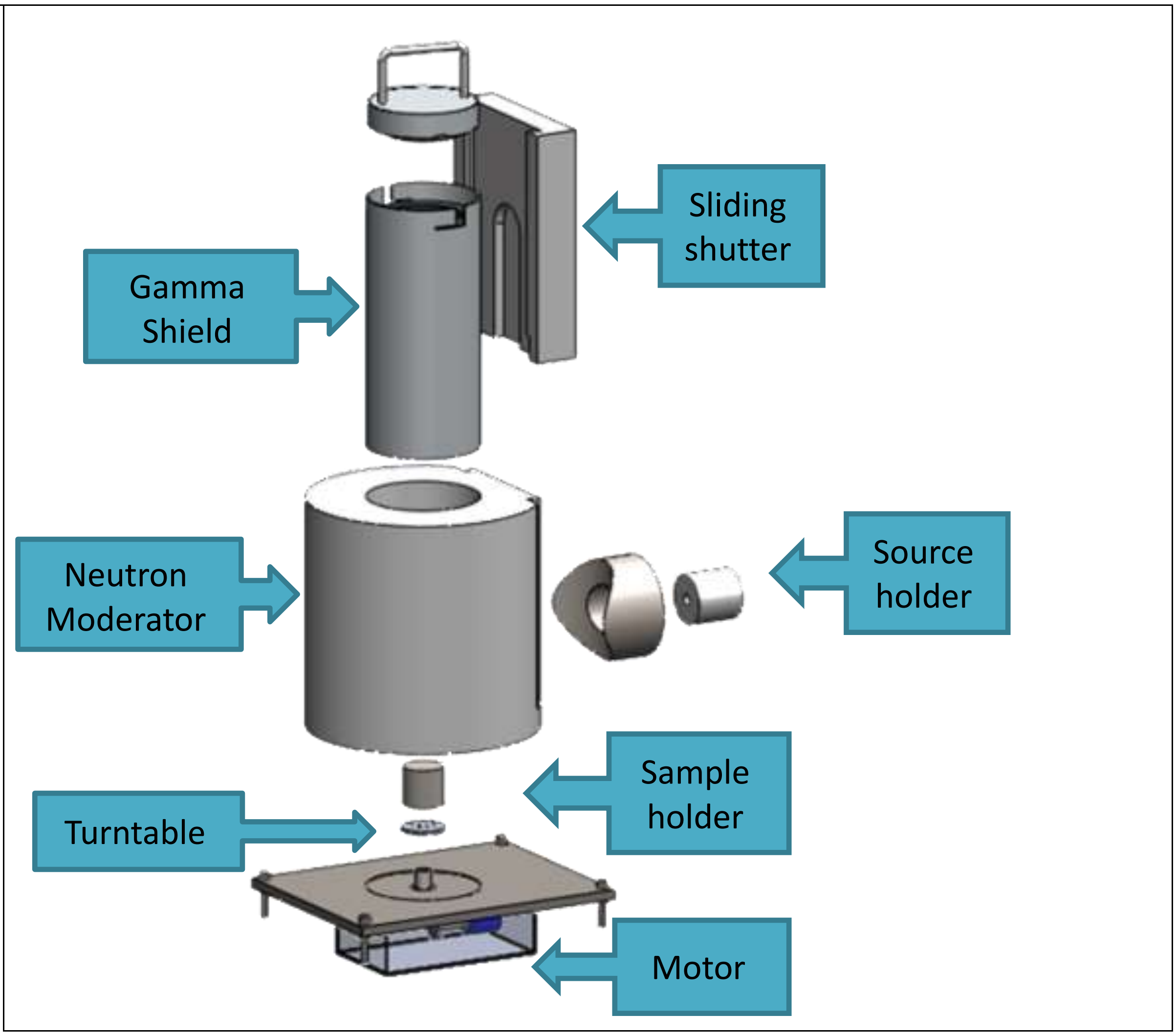

Figure 4. 3D design of the GPNIC for pure neutron irradiation.

The main components of the design include the gamma ray shield, neutron moderator and the turntable. The cylindrical gamma shield was built using lead (Pb) with a minimum thickness of 4cm to approximately reduce gamma ray to 6.7% of the total dose produced by the ^{252}Cf neutron source. Lead (Pb) has smaller atoms but high in density which is a proper material for gamma shielding. Fast neutrons are more difficult to shield against because absorption cross sections are much lower at higher energies. Thus it is first necessary to moderate high speed neutrons through elastic or inelastic scattering interactions. The process of slowing down the high speed neutron is called neutron moderation or thermalization. Hence, the outermost filter is composed of polyethylene (PE) to moderate fast neutrons to low energy thermal (slow) neutrons and reduce the risk of neutrons for personnel. Since lead or borated-polyethylene is substantially more expensive than pure polyethylene, the additional cost is an important consideration to minimize overheads. Radiation uniformity is achieved by rotating samples on a turntable within the radiation field by including an electrical motor with varying speeds. The effects of neutron radiation may not be sufficient at lower doses of up to 10^7 n/cm^2.s, thus the gamma shield was designed to fit the beamport for use at the reactor TRIGA PUSPATI (RTP) for higher neutron doses as shown in figure 5.

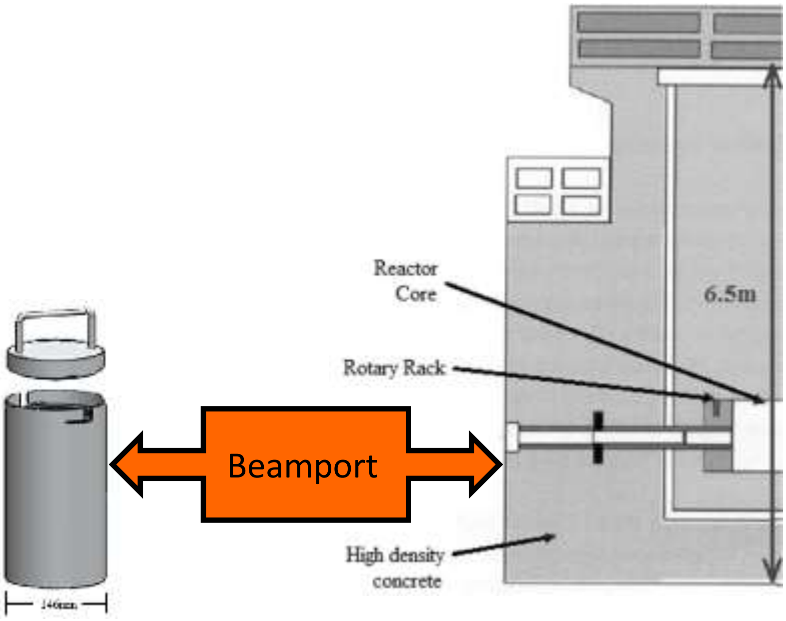

Figure 5. Design of the gamma shield to be compatible with the beamport of RTP.

POTENTIAL APPLICATIONS IN MALAYSIA

Research on radiation defects in electronic devices dates back to the mid of the 20th century. In radiation environments electronic devices are used to sense and monitor radiation as well as to control robots and other machinery remotely. Electronic devices may continue to evolve in the near future and there will always be a need to do basic evaluations of new device types as radiation effects may differ. Besides electronic devices, radiation is employed in a number of industrial activities, which includes; retardation of food spoilage, sterilization of medical supplies, sewage processing and modification of polymers. Figure 6 (a) and (b) show the final product of the actual design.

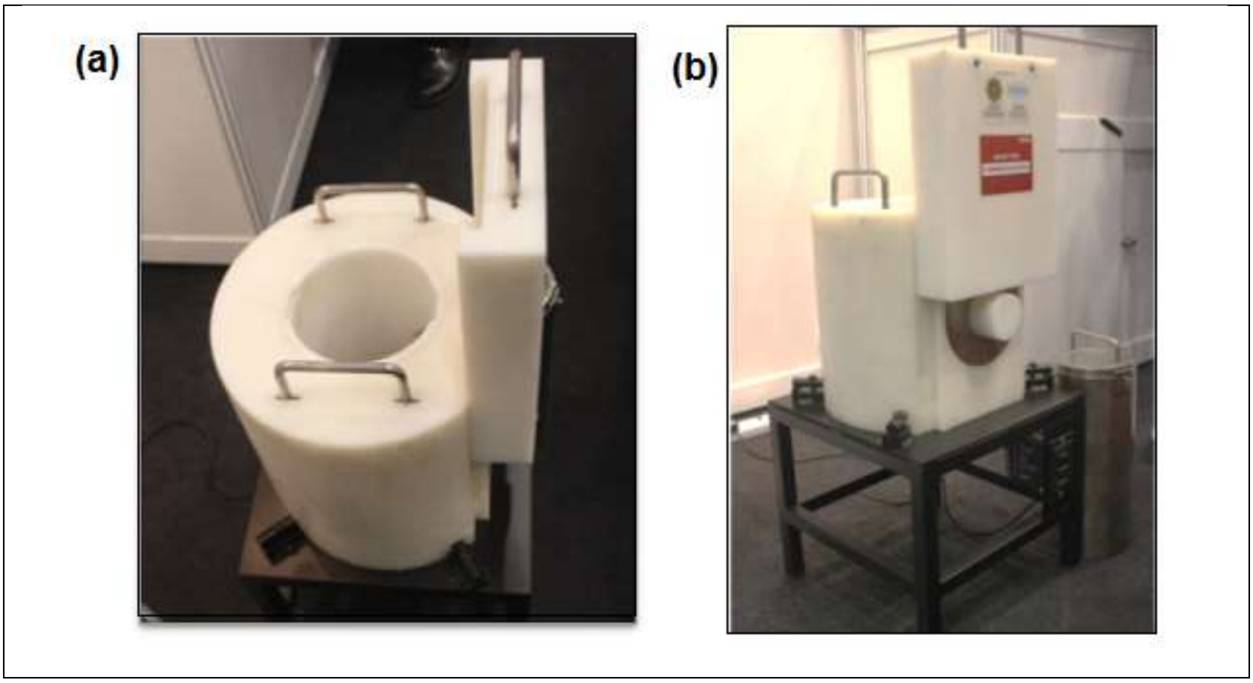

Figure 6. Finished product of the general purpose nuclear irradiation chamber, GPNIC.

CONCLUSION

Nuclear radiation shielding is an important infrastructure component in nuclear facilities. Hence, we believe that this chamber could contribute to the industry as well as the research community in production as well as research findings. Furthermore, this facility is the first in Malaysia to produce pure neutron source. Neutron and gamma radiation is important in research development where it is known to induce mutation in plant breeding for improved plant cultivars and also used identify composition of human tissue (Miri-Hakimabad, Panjeh et al. 2007) for medical use.

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