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Neutron and Gamma Radiography Inspection on the Delay Neutron Activation Terminus at the REACTOR TRIGA PUSPATI

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Abstract: Neutron and Gamma Radiography techniques were used to inspect the cadmium and regular terminus in the delayed neutron activation instrument of REACTOR TRIGA PUSPATI (RTP) nuclear research reactor in Malaysian Nuclear Agency. The inspection using neutron radiography technique has been conducted at 750 KW of RTP's thermal power. Gamma radiography inspection was conducted using silinium-75 gamma source with the radioactivity of 12 Ci. In neutron radiography testing, the neutron beam from reactor core is extracted through the collimator via radial beamport #3 with the thermal neutron flux at 4.7 meter away from the collimator inlet is around 10^5 $ncm^{-2}s^{-1}$. The exposure for both inspection techniques have been made on the sample and recording the image by utilizing the conventional radiographic film for 20 minutes. The neutron radiograph reveals that there are two plastic vile inside the regular terminus. There is a better contrast seen in the neutron radiographic image as the vile is made from hydrogenous material when compared with the radiography image obtained from gamma radiation. On the other hand, radiograph obtained by gamma inspection showing insight in the terminus contained a layer of cadmium sheet in cadmium terminus.

Keywords: Neutron, Gamma, Radiography, Terminus, PUSPATI

1 Introduction

The reactor TRIGA PUSPATI (RTP) has been established in Malaysia at Nuclear Malaysian Agency since the first criticality was achieved on July 1982. Since then, the RTP has been utilized for neutron irradiation in many applications including for neutron radiography and imaging. Designed reactor power with maximum capacity is 1.0 MW thermal, however, utilization for irradiation is depending on the user requirement, but usually it is operated at nominal power of 750 kW. Maximum neutron fluxes of reactor core irradiation facility is about 8.5×10^{13} $ncm^{-2}s^{-1}$ at central timble, 8.5×10^{12} $ncm^{-2}s^{-1}$ at pneumatic transfer system and 2.0×10^{12} $ncm^{-2}s^{-1}$ at rotary rack [1].

Irradiation facilities at RTP is divided into two type of irradiation channel namely incore and outcore. Incore irradiation mainly for the applications of neutron activation analysis and radioisotope production [1]. These facilities is made by a nuclear grade aluminum piping system standing vertically on the bottom plate of reactor core. This vertical channel is used for transferring sample into the irradiation terminus positioned inside the reactor core. Thermal neutron flux within the terminus is around 2.0×10^{12} $ncm^{-2}s^{-1}$. RTP also has delayed neutron activation analysis instrument. There are two terminus inserted in between the fuel elements of reactor core. The irradiation in this channel is made in the terminus position in the reactor core. Out-core irradiation is obtained using the horizontal channel namely beamport. The radiography facility is located away from the reactor core where utilizing neutrons from the reactor core through the horizontal beamport #3 in radial direction, see Fig. 1.

The beamport is inserted inside the graphite reflector with the inlet facing the reactor core in the radial direction. The thermal neutron flux entering the beamport is around 1.0×10^{11} $ncm^{-2}s^{-1}$. For imaging instrument, neutron reaches the object in the exposure room are extracted by the collimator inserted in the beamport. The layout of RTP showing the horizontal and vertical channel is shown in Fig. 2.

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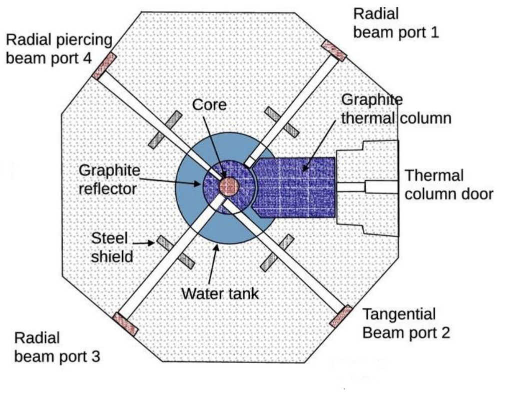

Fig. 1: Cutting view of REACTOR TRIGA PUSPATI nuclear research reactor within the reactor core and horizontal channel showing four beamports and thermal column for outcore irradiation application in Malaysian Nuclear Agency.[6]

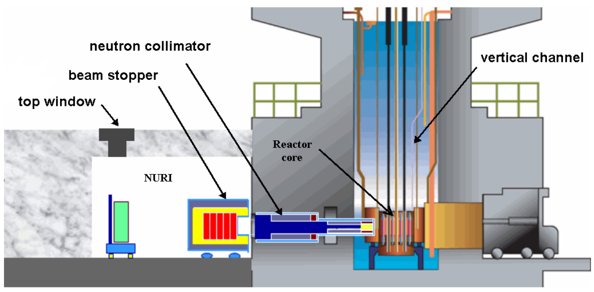

Fig. 2: Illustration of vertical cross section showing the layout of neutron radiography and imaging station at beamport #3 of RTP in horizontal direction and the delay neutron activitation facility in vertical direction relative to the reactor core.

Both irradiation facilities have been refurbished and upgraded. In this article, the inspection on the terminus of delay neutron activation instrument using neutron and gamma radiography technique is discussed. These techniques are considered as complementary to each other, therefore this article exhibits the advantageous of this complementary character of neutron and gamma radiography in non-destructive technique in nuclear application.

2 Materials and Methodology

2.1 Delayed Neutron Activation Terminus

RTP has equipped with the delayed neutron activation analysis facility since 1987 [10] and then refurbished in 2014 [9]. The main parts that have been refurbished including the terminus piping system, radiation detection and data acquisition electronic system. Maintenance on the mechanical components have been conducted regularly. Neutron irradiation is obtained when the sample is transferred into the terminus positioned inside reactor core, where the sample is being irradiated. The movement of sample is done by a pneumatic transfer system. There are two terminus such as the cadmium and regular terminus as illustrated in Fig. 3.

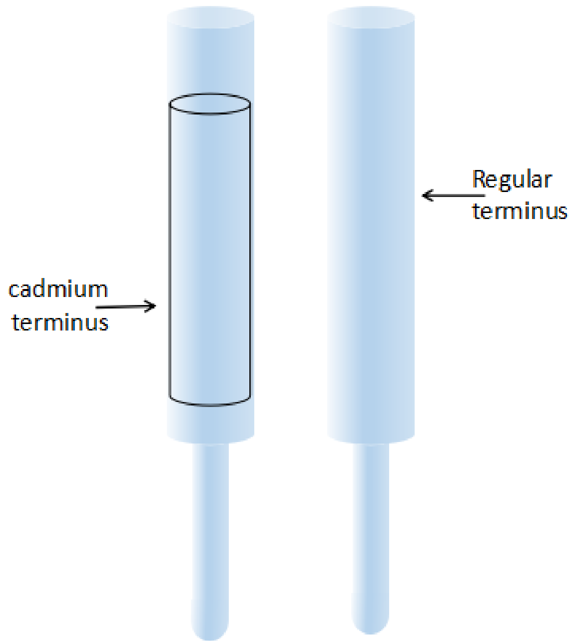

Fig. 3: Tale part of pneumatic transfer system in delay neutron activation analysis instrument consists of regular and cadmium terminus installed in the reactor core at Reactor TRIGA PUSPATI.[6]

This figure shows one of the terminus contains a cadmium sheet covered the inside surface of aluminum pipe and the regular terminus consists of aluminum nuclear grade piping only. These terminus have been used to position the sample inside the reactor core, particularly for the analysis of nuclear materials. These terminus have been detached temporarily from the installation and brought to the neutron radiography instrument exposure room for the inspection. These terminus have been investigated using neutron and gamma radiography inspection technique. Both gamma and neutron radiography testing have been conducted in the exposure room at neutron radiography facility. Both terminus have been radiographed by gamma radiography and the radiograph has been recorded on the film. Sequantially, then neutron radiography technique has been implemented where the film was used to record neutron radiograh.

2.2 Neutron radiography

Neutron radiography and Imaging Instrument (NURI) in RTP nuclear research reactor is divided into four main components including the neutron source which is the reactor core, the collimator for neutron optics, the detection and recording system and the exposure compartment [11]. The development of this facility has been described else where [1,2,3,4,5,6,7,8,9]. The vertical cross section view of RTP building with NURI given in Fig. 2 shows the collimator inside the beamport and the beam catcher in front of beamport outlet.

The nuclear fuel elements in the reactor core of RTP are configured in such that the thermal neutron flux at the neighboring of the collimator inlet at beamport #3 is about with the order of magnitude 10^{11} ncm^{-2}s^{-1}. The collimator inlet is inserted into the graphite reflector of radial beamport #3 where neutrons entering the collimator directly. The collimator is made sandwiches of solid lead and ferro-boron high density concrete. The neutron beam is extracted from the reactor core via the aperture made of cadmium sheet with 1.0 mm thick and 3.0 cm opening. It is located at 27.62 cm from the collimator inlet and several centimeters away from the outer ring of reactor core. The collimator is made by ferro-boron high density concrete and the second aperture is made by cadmium sheet with the opening of 4.3 cm diameter. It is determined the final shape of neutron beam through out the collimation path.

The effect from gamma radiation is suppressed in the collimator by applying the filter made of 15.0 cm length of bismuth rod. Three cylinders of sapphire single crystal with 2.0 cm thick each were installed after the bismuth in order to homogenize direction of fast and thermal neutron. It is installed sequentially with the bismuth in relative to the incoming neutrons beam. The effect from uncollimated neutron beam and streaming gamma radiation is minimized by applying the sandwiches of shielding using the ferro-boronated aggregate for high density concrete and also with a solid lead material. Details design of the collimator and simulation involved in the design is reported in [2,3,10,11].

The neutron and gamma beam catcher made by the arrangement of high density polyethylene and sandwiches with the lead and also ferro-boronated concrete has been installed. It is installed in front of the outlet of collimator opening. Total thickness of the beam catcher is around 48.0 cm. Direct neutron beam will activates the surrounding upon the interaction with the shielding materials. This effect is suppressed by the beam stop which is embedded in the high density concrete wall of exposure room. It is made by ferro-boronated aggregate. The beam stopper is build embedded with the high density concrete wall of exposure room with the total thickness is 40.0 cm, which is in total thickness covers the exposure room shielding. This approach reduces the space in parallel direction with the direct incoming neutron beam, it is quite crucial to optimize thermal neutron flux at the sample position. This is an advantage for neutron radiography instrument in small research reactor without compromises with the safety aspect. The horizontal view of exposure room is shown in Fig. 2.

Recording system for radiography projection images are obtained by conventional film or digital camera. The NURI configuration has been tested using film method as well as digital neutron camera. The cool charge couple device (CCD) coupled with digital camera is used. The conventional film also can be used to record the radiograph image with longer exposure time. The thick of concrete shielding is sufficient to obtain total dose rate outside the exposure room less than 0.5 μ Svhr^{-1}. The roof has 24.0 cm x 24.0 cm square hole, it is for window to enter the exposure room from the roof when using the over head crane if the sample is heavy. The DNAA terminus have been brought into the exposure room via the windows at the roof top. The door for exposure room is made adjacent to the reactor wall. The door itself has an interlocking with the adjacent wall of concrete shielding. It is made from the heavy concrete composited with the lead shots. The door can be moved forward and backward using the steel wheel standing one the steel rails. The opening and closing of the exposure room door is obtained using the steering coupled to the rotating gear system.

2.3 Gamma Radiography

The exposure of the terminus firstly performed using gamma radiation. Neutron radiography has been conducted after the radiogram of gamma exposure is obtained. The time taken to expose the terminus in gamma radiation was 20 minutes and radiogram was recorded using the conventional radiographic films. This gamma radiography experiment has been conducted inside the NURI exposure room. Gamma radiation was obtained from gamma projector silinium source with the activity around 15 Ci. The lead collimator producing cone shape gamma beam was used for directing gamma radiation onto the terminus sample. The terminus is positioned vertically. The advantageous of using silinium-75 is it has gamma energy peaks lower than energy of gamma from iridium-192. The energy peaks of silinium-75 are ranges from 97 to 401 KeV, therefore, the lower energy portion of gamma radiation may give rise onto the contrast of the radiograph of aluminum, cadmium and plastic vile. Higher energy gamma may cause much poor contrast on the radiograph due to less attenuation.

3 Results and Discussion

The radiograph of cadmium terminus and regular terminus obtained from gamma radiography testing is shown in Fig.4. The different between cadmium terminus with regular terminus is clearly seen from the contrast of cadmium layer at the inner surface of the cadmium terminus. There is also the contrast indicates the wall of aluminium. This terminus is empty because there is no shadow through out the thickness is seen. The density of cadmium is around 8.7 gcm^{-3} while aluminum has much less density with only 2.7 gcm^{-3} compared to the cadmium. This reflects by white zone along the cadmium line terminus, while same effect does not seen on the regular terminus.

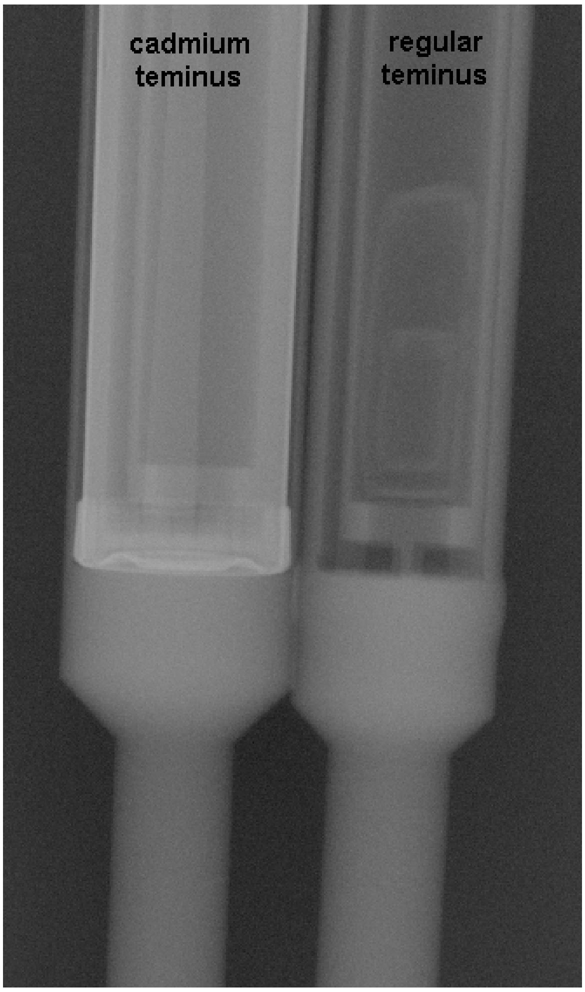

Fig. 4: Radiograph of cadmium terminus and regular terminus of delayed neutron activation analysis instrument at RTP using gamma radiagraphy technique with silinium-75 gamma source projector with the activity 12 Ci.

The adsorption of gamma radiation by the cadmium is large compared with the aluminum. However, there is some foreign object seen from the contrast variation on the regular terminal image. It contained some shadows showing the layers of materials. However, the contrast of the layers is low compared with contrast of aluminum object. This indicates the density of the material form the layer on the radiograph has less density than aluminum.

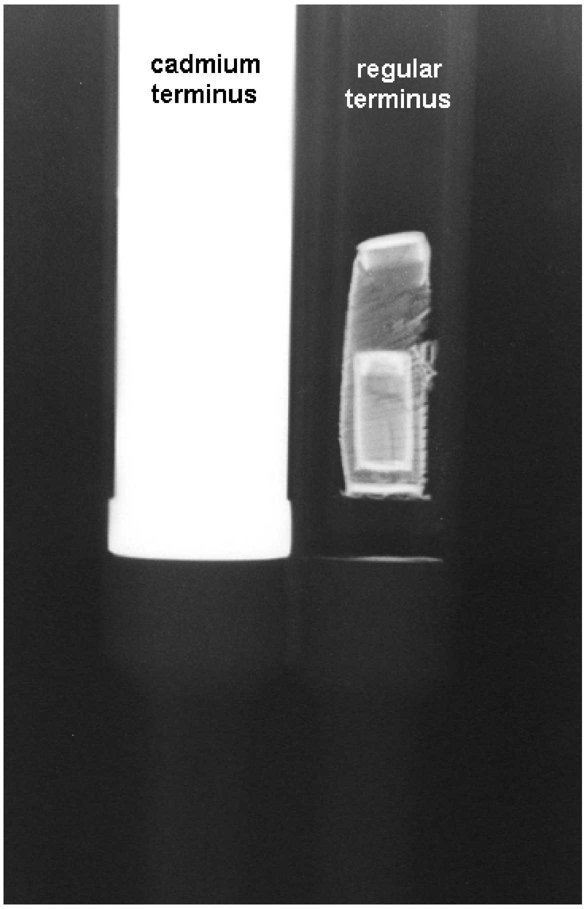

Fig. 5: Neutron Radiograph of cadmium line and regular terminus of delayed neutron activation analysis instrument obtained at RTP thermal power 750 KW

Radiography image of cadmium line and regular terminus obtained from neutron beam radiography is shown in Fig. 5. This figure shows the zone containing cadmium material is totally white. This contrast indicates that thermal neutron has been almost absorbed by the cadmium layers located inside the terminus. This is because the cadmium material has a large neutron cross section to thermal neutron, while the zone for aluminum is almost transparent to similar neutron energy group. Due to this characteristic, the zone for aluminum is having less contrast when comparing with the contrast given from cadmium layer.

Furthermore, the foreign object in the regular terminus is clearly seen from the contrast in the neutron radiography image. The contrast of the image for this object indicates that the material has relatively large neutron absorption cross section to the aluminum and comparable with the cadmium. Further investigation was performed to confirm what is the foreign object and it made by what material that gives contrast in the neutron radiography image.

The mechanical suction by pneumatic was performed to get the foreign object. It was found that the foreign object is consists of the small and big vile made of polyethylene material. The small vile is contained inside the bigger vile. The bigger one has some damage near the top and the small vile has minimal changes. Since the vile is made of hydrogenous materials so the neutron cross section of thermal neutron is relatively much higher than aluminum, therefore, the radiography image of vile have high contrast and seen clearly in the neutron radiograph.

This inspection provide insight into the maintenance activities on the delayed neutron activation analysis terminus in particular. These terminus have restated at the previous location inside the reactor core of RTP for any work related with the delayed neutron activation analysis experiment.

4 Conclusion

This article shows the application of combined inspection method for investigation of the terminus for delayed neutron activation analysis instrument, in particular at RTP in Nuclear Malaysia. Neutron and gamma radiography could provide details information about the object inside the cadmium line terminus and regular terminus of the DNAA instrument. This is the example that could exhibits the complementary character of the neutron and gamma radiography technique implemented in the inspection of the instrument component and also to other components important in industries.

Acknowledgment

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

References

[1] R. B. Jaafar, *The Development of Neutron Radiography and its Potential Application in Malaysian Industries, Neutron Radiography*, Proceeding of the Third World Conference, Osaka, Japan, 171-178, (1989).

[2] M. R. M. Zin et al. Simulation of Collimator for Neutron Imaging Facility of TRIGA MARK II PUSPATI Reactor, *Physics Procedia*, **69**, 138-142, (2015).

[3] R. Jamro et al., Monte Carlo Simulation for Designing Collimator of the Neutron Radiography Facility in Malaysia, *Physics Procedia*, **88** 361-368, (2017).

[4] A. G. Ramli, A. Muhamad, R. Jaafar and S. N. Khamseah, *Status of Neutron Radiography in Malaysia*, In: Barton J.P., Farny G., Person JL., Röttger H. (eds) Neutron Radiography. Springer, Dordrecht, (1987).

[5] T. F. de Moraes, F. Azevedo, P. H. J. Amorim, J. V. L. da Silva, In Vesalius – An open-source imaging application, *World Journal of Urology*, **30**,687-691, (2011).

[6] F. Emmanuel et al., Neutron scattering instrumentation at low power reactors for science, engineering and education, *Journal of Neutron Research*, **18**, 61-77, (2015).

[7] A. P. Kaestner, Samples to Determine the Resolution of Neutron Radiography and Tomography, *Physics Procedia*, **88**, 258-265, (2017).

[8] A. P. Kaestner et al., Verifying Neutron Tomography Performance using Test Objects, *Physics Procedia*, **43** 128-137, (2013).

[9] Z. B. Jaafar, M. A. Khalid, H. Sanusi, M. M. B. Mustafa, A. Ghazali, Pembangunan Semula dan Penentuan Keboleharapan sistem kawalan automasi analisis serentak uranium dan torium (PUAS), *Journal of Nuclear and Related Technologies*, **11**, 59-71, (2014).

[10] A. Ramli and H. Mohamad, Analysis Uranium Dan Thorium Melalui Teknik Analisis Neutron Tertunda, *Journal Sains Nuklear Malaysia*, **5**(1), 15-28, (1987)

[11] M. R. M. Zin et al., The Development of Neutron Imaging Instrument atPUSPATI TRIGA MARK II Nuclear Research Reactor, *J. Rad. Nucl. Appl. 5*, No. 2, 81-86, (2020).