Ageing assessment of biological shielding integrity for PUSPATI TRIGA Reactor

Nurhayati Ramli\textsuperscript{1,a)}, Julia Abdul Karim\textsuperscript{1}, Hasniyati Md Razi\textsuperscript{1}, Muhammad Khairul Ariff Mustafa\textsuperscript{1}, Noor Azreen Masenwat\textsuperscript{1}, Suhairy Sani\textsuperscript{1}, Mohd Huzair Hussain\textsuperscript{1}

\textsuperscript{1}Malaysian Nuclear Agency, Bangi, 43000 Kajang, Selangor, Malaysia.

\textsuperscript{a}nurhayati@nm.gov.my

Abstract. For more than 35 years of operation and utilization of the neutron source from the PUSPATI TRIGA Reactor (RTP), the reactor has faced ageing challenged and degradation in several structures, systems and components (SSCs). Several modifications have been made since 2010 to ensure safe operation and sustainability, however, due to recent intensively request from the user to use the neutron source, it has shown degradation behaviour in the reactor SSCS including the biological shielding of the RTP. In this paper, it described the assessment of the safety barriers integrity specifically at the biological shielding concrete structure of the RTP. In-service inspection and X-Ray diffraction methodology were used to investigate and analyses the condition. The investigation results show no irregularity except slightly degradation occurrences has been noticed and aware.

1. Introduction

PUSPATI TRIGA Reactor (RTP) is a TRIGA Mark II nuclear research reactor providing training and irradiation services to public and private institutions. It also involved and supported several research projects carried out by other research groups\cite{1}. After serving for almost nearly forty years, the facility has faced with ageing effects and potential failures that reflect the reactor safety. In order to mitigate ageing effects during RTP operational lifetime, the facility has had to deal with several issues due to the time-dependent degradation of its structures, systems and components (SSCs).

In general, safety objectives for a nuclear research reactor are to protect human and environment by maintaining an effective defense-in-depth against radiological hazards. The defense-in-depth is achieved by a multiple barrier system where the integrity of SSCs can be affected by the failure of one or more of these barriers. However, the aging process may lead to the degradation of structural integrity and increase the probability of failures at the biological shielding concrete due to radiation field over a long period of operation time may reduce the ability to confine and contain the radioactive release from the reactor\cite{2}.

In-service Inspection (ISI) has an important role in aging management of the SSCs. ISI is incorporated with risk insights known as Risk-informed In-service Inspection programme. The main objective of ISI is to demonstrate the SSCs that important to safety will not fail during operation\cite{3}. The ISI techniques could aide to assess the surface and volume of the structures by inspect near-surface flaws and volumetric to indicate the depth or size of cracking using radiographic, ultrasonic or eddy current techniques.
The aging mechanism is not limited to physical conditions. The ageing mechanisms such as corrosion, vibrations, temperature and radiation would be expected in the ageing process. The biological shielding concrete can be affected by radiation interactions with material and absorption of the radiation energy. The RTP biological shielding concrete is a reinforced high density concrete with approximately 3.42 g/cm$^3$ density and four beamport which tubular penetrates through the concrete shield[4]. Thus, it is very important to investigate and to understand the physical condition of the biological shielding concrete structure integrity to mitigate consequences (if any) for lifetime extension for the operational sustainability of the RTP.

2. Methodology

The work had conducted using three methodologies. Location mapping for ultrasonic testing has been performed at the surface of the biological shield for the most utilized beamport, i.e. beamport number 4 (BP#4). The location mapped was distributed into two segments as described in Figure 1. Prior to the mapping, the radiation field measurement was also being performed. The NDT technique was used to further assess the mapped surface and concrete specimens were taken to analyze using XRD.

2.1. Location mapping

The RTP biological shielding concrete structure is 6.6 meter in diameter and 6.5 meter height [4]. For this assessment, 8 different locations have been identified where 5 locations were located at the bottom segment and 3 locations at the top segment of the RTP concrete structure. In this study, beam port number 2 (BP#2) and beam port number 4 (BP#4) were chosen to represent the less and most utilized beam port respectively.

![Figure 1. RTP concrete biological shielding structure.](image)

2.2. Radiation field measurement

The Optical Stimulated Luminescence (OSL) is used to measure neutron and gamma dose at the mapped surface location at the NDT inspection region. A total of eight OSLs were exposed in eight different locations during RTP operation at 750kW for a month. Figure 2 shows the black dotted where the OSLs are located.
2.3. Non-destructive testing (NDT) measurement
In-situ measurement using Ultrasonic Pulse Velocity (UPV) to determine the quality of the concrete by measuring pulse velocity. The UPV generated voltage pulses and transformed into wave bursts of mechanical energy by the transmitting transducer (which must be coupled to the specimen surface through a suitable medium). A receiving transducer is coupled to the specimen at a known distance to measure the interval between the transmission and reception of a pulse[5]. There are three practical arrangements for measuring pulse velocity, namely direct, diagonal and surface transmission arrangement. The surface transmission arrangement is used for RTP concrete as the surface concrete is accessible.

The estimation of the concrete quality condition is based on Table 1:

| Pulse velocity (m/s) | Strength     |
|----------------------|--------------|
| Above 4500           | Excellent    |
| 3600 – 4500          | Generally good|
| 3000 – 3600          | Questionable |
| 2100 – 3000          | Generally poor|
| below 2100           | Very poor    |

Figure 2. OSL locations.

Figure 3. Surface transmission arrangement.
2.4. **Quantitative Analysis using X-ray**

X-ray scattering techniques reveal information about the crystallographic structure, chemical composition, and physical properties of materials and thin films. These techniques are based on observing the scattered intensity of an X-ray beam hitting sample as a function of incident and scattered angle, polarization, and wavelength or energy.

In this study, two commonly X-ray techniques were used. X-ray Fluorescence (XRF) is used to determine elemental presents in the sample. There are two types of XRF systems, i.e. Energy Dispersive XRF (EDXRF) and Wave Length Dispersive XRF (WDXRF). In this assessment, the EDXRF is performed to determine the elements presents in the biological shielding concrete specimen.

While an X-ray diffraction (XRD) is used to obtain qualitative and quantitative analysis of crystalline compounds. In this assessment, XRD analysis was performed using Bruker AXS D8, USA and conducted in a range of Bragg angles (2θ) of 20°-90° using Copper K-α radiation. Concrete samples were analyzed with X-ray diffraction (XRD) in powder forms. The analysis result was then plotted in a graph with intensity vs diffraction angle of 2θ.

3. **Results and discussion**

3.1. **Neutron and gamma dose**

The results of neutron and gamma dose measurement is shown in Figure 4. It can be deduced the neutron and gamma radiation of concrete exposed to irradiation related to the depth of the RTP tank. The neutron dose is slightly higher than the gamma dose due to the high penetration power and strong radiation field came from the reactor core inside concrete shielding during operation. The radiation field was observed for one month. It is found the dose was larger around 1 meter depth from the bottom of RTP tank at where the core is located.

![Figure 4](image-url)

**Figure 4.** Relation of neutron and gamma dose with reactor tank height in meter.
3.2. Non-destructive testing (NDT) measurement

Figure 5 shows the UPV results for surface where the BP#2 and BP#4 were located. Measurement for each surfaces were taken at 8 different locations and the average velocity was calculated. It is found the velocity of BP#4 surface has higher velocity than surface BP#2. The velocity at surface BP#4 (location 6) was 3891 m/s. This indicates the greater strength of the concrete according to the quality of concrete condition as described in Table 1.

![UPV with respect to the reactor tank height](image)

3.3. X-ray analysis

The EDXRF and XRD analysis were performed for eight samples of the biological concrete as described in Table 2. From the analyses, the elements in the concrete contained mainly from Silicon (Si), Aluminium (Al), Potassium (K) and Calcium (Ca). In this studies, the aggregates of the concrete were not included.

| Sample       | Element (%) | Si  | Al  | K    | Ca   |
|--------------|-------------|-----|-----|------|------|
| Top Segment  | 1           | 80.65 | 6.36 | 3.29 | 7.63 |
|              | 2           | 79.13 | 4.05 | 4.65 | 9.01 |
|              | 3           | 71.10 | 6.31 | 2.76 | 14.32|
|              | 4           | 75.90 | 0.8  | 2.86 | 15.27|
| Bottom       | 5           | 76.17 | 4.78 | 2.77 | 8.01 |
| Segment      | 6           | 82.78 | 0.83 | 2.21 | 11.37|
|              | 7           | 69.20 | 5.21 | 1.93 | 14.26|
|              | 8           | 68.53 | 5.8  | 2.60 | 11.11|

The concrete samples were analyzed with X-ray diffraction (XRD) in powder forms. XRD was carried out using Bruker AXS D8, USA and conducted through a range of Bragg angles (2θ) of 20°- 90° using Copper K-α radiation. The analysis result was plotted for intensity in a function of diffraction angle at 2θ. Figure 6 and Figure 7 shows XRD patterns of the RTP biological shielding concrete compounds. The XRD patterns of the concrete compounds showed the presence of Calcium Oxide (CaO), Silicon Dioxide (SiO₂), Aluminium Oxide (Al₂O₃) and Potassium Oxide (K₂O) at all location. The XRD results are in agreement of XRF results.
4. Conclusions
The ageing assessment of RTP has focused to the SSCs for lifetime extension of the sustainability in RTP operation. The biological shielding concrete has been identified as 4th barrier in defense in depth philosophy as described in the safety function of RTP. Preliminary assessment of the surface structure gives some ideas and information on the degradation of the concrete especially in the high radiation field (neutron, gamma) region. More detailed studies will be performed to obtain overall information of the degradation assessment of the reactor. Risk-informed In-service Inspection methodology are adopted for the ageing assessment of RTP and this method will be continued pursued in the next studies.

5. References
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