Performance analysis of digital X-ray radiography system in radiometallurgy installations for pebble bed fuel imaging

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Abstract. Research and studies on pebble bed fuel to support the realization of RDNK based on HTGR have been carried out by BATAN. Indicators of reliability of nuclear fuel are able to fulfill the criteria for irradiation testing and qualify in post irradiation tests. At present, Radiometallurgy Installation as a post irradiation examination location has completed installation of X-ray radiography equipment for non-destructive testing. Performance analysis includes the function of tools and the completeness of test support facilities. Digital X-ray radiography has a maximum voltage capability of 320 kV. X-rays are directed vertically towards the sample and sensor film. X-rays captured by film sensors can be seen directly in real time on a computer. To put the pebble bed fuel is provided a special holder. The X-ray radiography system trials were carried out on a pebble bed fuel model. The purpose of the trial to find out the performance of X-ray radiography systems in capturing the image of the pebble bed fuel model. The fuel model is made of ceramic which simulates graphite and lead material that simulates TRISO. The results obtained indicate that the X-ray digital radiography system is able to capture the image of the pebble bed fuel model with a good image.

1. Introduction

Research and development of Non-Commercial Power Reactors (RDNK) based on HTGR have been carried out in Indonesia, including pebble bed fuel technology. Pebble bed fuel has a diameter of 60 mm and a coated particle diameter of 0.92 mm. 10,000 to 15,000 layered particles are compacted in a graphite matrix to form pebble bed fuels as shown in Figure 1.

Fuel performance indicators are generally indicated by fulfillment the irradiation test criteria and post-irradiation test qualifications. Indonesia has a post irradiation test facility at the Radiometallurgy Installation (RMI) Center for Nuclear Fuel Technology - BATAN. RMI is designed to carry out post-irradiation testing of the G.A Siwabessy Multipurpose Reactor (RSG-GAS) research reactor and Pressurized Water Reactor (PWR) and Pressurized Heavy Water Reactor (PHWR) power reactors [1].

Currently RMI has been equipped with digital X-ray radiography as one of the non-destructive test equipment in hot cell 103. Digital X-ray radiography in RMI hot cells has a maximum voltage of up to 320 kV and has been used to conduct non-destructive testing on the fuel element plates RSG-GAS and PWR pins with quite good results. Through the analysis of material transfer and handling systems that have been carried out in previous studies, RMI hot cells can be used for a pebble bed post irradiation examination [2], [3]. Sawa, et.al in his research used x-ray radiography to control the thickness of the layer in spherical coated particles to mechanical integrity analysis [4]. This was confirmed by De Beer
who mentioned the important role of X-ray radiography in observing the thickness consistency of each layer in the SPF as an indicator of the reliability of pebble bed fuel performance [5]. Development into a micro focus radiograph was also carried out in India to get better image [6]. As a form of RMI hot cell readiness in the development of pebble bed fuels, it is necessary to analyze the performance of X-ray radiography to accommodate the implementation of non-destructive testing with an indicator of its success is to obtain the image distribution of layered particles in a graphite matrix.

![Figure 1. Specification of RDNK Fuel Dimension [7].](image)

### 2. Methodology
Experiments carried out on pebble bed fuel dummy with a matrix made of ceramic material that simulates graphite matrix on the actual pebble bed fuel. For the TRISO particle simulation, the distribution of lead with a diameter of about 1 mm is used, close to the actual diameter of the coated particle which is equal to 0.92 mm. The model is placed on a holder made of acrylic material for image capture. The sample holder is placed on the sample holder installed in addition to supporting the spherical material. X-ray beam tubes, samples and detectors are installed vertically. The complete set-up of experiments is shown in Figure 2. These X-ray radiographic images can be viewed and monitored in real time so that the image quality can be regulated as well as possible before being stored and analyzed further.
3. Result and Discussion

The test is carried out until the exposure is obtained to produce a good image. Adjustment of the test parameters produces a voltage value of 160 kV, a current of 1200 microamperes with a focal spot of 1 mm. From the test results obtained an image with a size in accordance with the pebble bed model that is 60 mm and also the layered kernel model, seen granules with contrasting colors as shown in Figure 3 (a). The image that is not too different is shown in Figure 3 (b) which is a test result using X-ray radiography of PBMR fuel samples with zirconium particle distribution [5] and pebble bed fuel for the HTR-10 reactor in China [8].

![Experimental set-up of digital X-ray radiography.](image)

**Figure 2.** Experimental set-up of digital X-ray radiography.

![X-ray radiography in hot cell 103 RMI on pebble bed dummy with the distribution of lead particles in the carbon matrix (a); on South African PBMR (b); and Chinese HTR-10 fuel (c).](image)

**Figure 3.** X-ray radiography in hot cell 103 RMI on pebble bed dummy with the distribution of lead particles in the carbon matrix (a); on South African PBMR (b); and Chinese HTR-10 fuel (c).

From the image in Figure 3, the distribution of the layered particle model in the matrix is clearly visible. The distribution of coated particles is very important to know both for pre-irradiation quality control and as a form of evaluation of post irradiation fuel performance. Pebble bed fuels have a fuel free zone of around 5 mm which only contains graphite as a matrix. This area was created to accommodate the mechanical effects of damage to coated particles, so that the fuel free zone should not
have coated particles because it will affect the safety and performance of the fuel during irradiation. For HTR-10 fuels, 1% of the 20,540 fuel elements are deemed ineligible due to the homogeneity of the coated particle distribution reaching the fuel free zone [9]. Illustration of the distribution of coated particles in the fuel free zone is shown in Figure 4.

![Illustration of coated particles in fuel free zone](image.png)

**Figure 4.** Fuel free zone and misalignment of particles seen on X-ray radiographic images [8].

The next stage in the use of X-ray radiography is monitoring the thick consistency of each layer of coated particles as shown in Figure 1. Each layer has a fully integrated function to the mechanical strength of a pebble bed fuel. The buffer layer just above the UO2 kernel for example, is composed of carbon with high porosity to accommodate fission gas release. The inner and outer pyrolytic carbon layers function as a protective SiC from mechanical damage due to the release of fission products. Based on this urgency, the use of images produced by X-ray radiography as a detector for anomalies in TRISO plays a vital role. For example, the anomaly that occurs in TRISO particles is shown in Figure 5.

![Images of TRISO particles](image.png)

**Figure 5.** Image of TRISO AGR particle at various conditions used various imaging equipments [10], [11].

4. Conclusion

The test result of pebble bed dummy used digital X-ray radiography showed that digital X-ray radiograph at RMI has been able to produce a good image that is needed as input for further analysis both as a quality control fabrication and evaluation of post-irradiated fuel performance.

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