Validation of Inspection Software Developed for Rapid Inspection of X-ray Gamma Autoradiograph of FBTR Fuel Pins

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ABSTRACT

Sodium cooled Fast Breeder Test Reactor (FBTR) is being operated at IGCAR, Kalpakkam as a technology demonstrator for future Fast Breeder Power Reactors. The fuel pins are being fabricated at Radiometallurgy division of BARC from the day of its inception. During FBTR fuel pin fabrication, quality control steps are followed to ensure optimum and safe reactor operation. X-Ray Gamma Autoradiography (XGAR) is one of the routinely performed quality control checks to verify the presence and location of all internal components inside a fuel pin along with the measurement of active stack length. The current manual inspection is subjective, cumbersome and strenuous to eyes. Therefore, a software is being developed for rapid inspection of XGAR film. To validate the software, a number of experimental fuel pins have been fabricated with alterations in their internal components. These alterations are cross checked with the recently developed software. Initial results are highly encouraging and the software can be adopted in regular process after few more trials.

Keywords: Fast Breeder Test Reactor (FBTR), Fuel pin, Image processing, Stack length

1. Introduction:

India is testing sodium cooled Fast Breeder Reactor Technology as a solution for its energy needs. In this connection, Fast Breeder Test Reactor (FBTR) is one of the technological milestone which is being successfully operated at IGCAR, Kalpakkam. The fuel pin for FBTR is being fabricated at Radiometallurgy division of BARC since the day of its inception [1, 2]. A fuel pin is the heart of the nuclear fission reactor which provides leak proof enclosure to the fuel pellets. It consists of various components; plenum tube, pellet support disc (PSD), uranium carbide (UC) insulation pellet, uranium plutonium mixed carbide (U, Pu) C fuel pellet, spring support, and spring. Each component has its own specific role. Plenum tube is used to accommodate fission gas products and UC insulation pellet is to provide thermal insulation to the stainless steel (SS) components and weld zone from the high temperature generated due to fission reaction inside fuel pellet. Spring is to accommodate the thermal expansion and to make the fuel column intact. Most of the fabrication work and quality control checks are being done manually, so there may be possibility of human error. Therefore, it is essential to check the quality of fuel pin as per its specification [3].

Out of many quality control steps, X-Ray Gamma Autoradiography (XGAR) is routinely performed to verify the presence and location of all internal components inside a fuel pin along with the measurement of Mixed Carbide (MC) fuel stack length [4]. The whole procedure for performing XGAR inspection usually takes 3-4 hours for evaluation of a single fuel pin. The manual inspection is tedious, less accurate and requires well trained inspectors. FBTR has small core and requires less number of fuel pins in the reactor core. However, in a commercial fast reactor the number of fuel pins per core will be significantly high. So, rapid
inspection of fabricated fuel pins will be certainly useful. In this regard, various R & D works are under progress for increasing the fuel pin production rate.

In this paper, an inspection software is discussed for rapid inspection of FBTR fuel pins followed by its validation against specially designed experimental FBTR fuel pins.

2. FBTR fuel pin details:

The FBTR fuel pin is a 531.5 mm long SS 316 M cylindrical tube with 320 mm stack of MC fuel pellets. Two UC insulation pellet are kept at both ends of the MC stack. At one end of the insulation pellet plenum tube and pellet support disc is placed. On the other end, spring support and spring are loaded. After loading all internal components, helium gas is filled inside the SS 316 M tube and it is welded at both ends with the end plugs. A cross section view of the FBTR fuel pin is provided in Fig-1. Each component is located at their specific location and performs a specific role. Therefore, each component needs to be placed at the right location for optimum performance of fuel as well as safe operation of the reactor. For this purpose, a quality control step is performed during fuel pin production to check the stack length, proper loading of internal components, cross mixing of pellets, missing of any components and physical integrity of the pellet. The NDT technique used for this purpose is known as X-ray gamma autoradiography, which is discussed in subsequent section.

3. X ray Gamma Autoradiography(XGAR):

In this technique, the fuel pins are X-ray radiographed to register the SS outline of the fuel pin along with the internal SS components. An almost parallel beam of 120 KV X-ray is allowed to fall on a moving platform upon which a set of 10 fuel pins are kept in close contact with flexible light tight PVC cassette preloaded with Agfa D4 film. A stepper motor is attached with the platform to control its axial movement and allows exposure to the full length of fuel pins. After the X-ray exposure, the fuel pins are left to record the extent of gamma ray exposure on the film. The exposed film is developed chemically and radiograph is obtained. Then, the radiograph is evaluated for the following check points as per FBTR specification:

(i) Presence of all internal components and their correct loading sequence.
(ii) Measurement of MC fuel stack length.
(iii) Total number of fuel pellets present within MC fuel stack
(iv) There should not be any anomaly in loading sequence.
(v) Check on physical integrity of the fuel pellets.

In case, any deviation is observed from the specification, the fuel pin is rejected.

4. Inspection Software:
The method of manual inspection is tedious, inconsistent, less accurate and strenuous to eyes. Human eyes has limited resolution. An automated inspection system would help in minimizing the associated problems with manual inspection and would ensure a repetitive and consistent result. Therefore, an inspection software is being developed for rapid inspection of XGAR film in collaboration with RRCAT. The inspection software has a user friendly Graphical User Interface (GUI) which processes the XGAR film image to detect the number of fuel pins in the image and extracts the image of individual fuel pins separately. Then, each fuel pin is analyzed for the presence of internal components, detects the anomaly in loading sequence, computes the MC fuel stack length and counts the number of fuel pellets within MC fuel stack.

The idea behind the algorithm of inspection software is that each component of the FBTR fuel pin had its own distinct mean value, shape and grayscale variation. Thereby, measuring the intensity profile and mean value of grayscale across the fuel pin image can be utilized to extract the information desired from the inspection software.

The first step of the inspection software is the digitization of the XGAR film. Digitization of XGAR film is done using an optical scanner. The digitized image of XGAR film of 10 FBTR fuel pins is shown in Fig-2.

![Digitized image of XGAR film of 10 FBTR fuel pins.](image)

After getting the digitized image of the XGAR film, the inspection software processes the image to indicate the number of fuel pins, separates out each pin from the cluster of pins and then analyses it for presence of all the components and active stack length measurement and then generates a decision of accept/reject following user defined criteria. The software also indicates the bit depth of the loaded image along with its dpi. The GUI of the inspection software is shown in Fig-3. It shows the identification no of the fuel pin, displays the presence/absence of all internal components through the green/red buttons, displays the stack length in mm and plots the intensity profile across the active stack. The valleys in this intensity profile is used to compute gap between pellets. The result of acceptance/rejection of each fuel pin is indicated by green/red color of the “Final Decision” button.
5. Validation of Software:

Validation of the inspection software was carried out by investigating its performance for evaluating the XGAR features discussed earlier.

(i) Absence of any fuel component:

An experimental FBTR fuel pin has been fabricated with a defect of not having the pellet support disc (PSD). XGAR of the defective fuel pin was performed following standard procedure and the radiograph was obtained. The radiograph was digitised and it was fed in the inspection software for defect analysis. The inspection results is shown in Fig-4, the
software shows the absence of PSD by showing the red coloured “PSD” button and rejected the fuel pin by showing red colour in the “Final Decision” button.

(ii) **Number of fuel pins in a radiograph:**

To evaluate the software performance for the number of fuel pins, three sets of X-ray gamma-auto radiographs were generated having 2, 5 and 7 number of fuel pins. The digitised image of each radiograph is then fed into the inspection software. The software was successfully able to count the correct number of fuel pins present on the XGAR in each set.

(iii) **Intermixing of insulation and fuel pellets:**

An experimental fuel pin was fabricated in which few UC pellets are intentionally placed in between MC fuel stack. The radiograph was generated using standard XGAR technique. The radiograph was digitised and fed into the inspection software. The intensity profile across the MC stack showed bumps corresponding to UC pellets. The “Final Decision” button appeared in red colour showing the fuel pin rejection. Hence, the anomalies of intermixing of pellets were determined successfully by the software.

6. **Conclusion:**

An Inspection software was developed for evaluating the arrangement of internal components inside a FBTR fuel pin. The software is being evaluated for its performance for various characteristics of FBTR fuel pin evaluation. The software is able to successfully predict the no. of fuel pins, absence of any internal components, intermixing of insulation and fuel pellets. Initial results are highly encouraging suggesting that the developed software may be adopted in regular quality control process after few more trials.

**Reference:**


