DEVELOPMENT OF X-RAY CT APPRATUS FOR IRRADIATED FUEL ASSEMBLY

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ABSTRACT

In order to observe the structural change in the interior of irradiated fuel assembly, the non-destructive post irradiation examination technique using X-ray computer tomography (X-ray CT) was developed. In this X-ray CT system, the 12 MeV X-ray pulses was used in synchronization with the switch-in of the detector to minimize the effects of the gamma ray emissions from the irradiated fuel assembly, and then clear cross section CT image could be successfully obtained.

1 Introduction

X-ray computer tomography (X-ray CT) technique is one of the most powerful non-destructive test tools for characterizing the inner structure as used in medical field. Recently, this technique has been applied to the inspection of mechanical components such as a booster rocket and an automobile engine.

The application of X-ray CT technique was indispensable to observe inner condition of Fast Breeder Reactor (FBR) fuel assembly, because of visual observation was obstructed by the presence of the wrapper tube that completely surrounds the fuel assembly. However, it was thought that the application of X-ray CT technique to the post irradiation examinations (PIE) of irradiated nuclear fuel was impossible due to the effects of gamma ray emitted from the irradiated fuel assembly.

In this study, a pulsed high energy X-ray source synchronizing with the detection was utilized in order to reduce the effects of gamma ray emissions from the irradiated fuel assembly, and then clear cross section CT image could be successfully obtained [1],[2].

This technique makes it possible to observe the inner condition of irradiated fuel assembly by a non-destructive method for the first time in the world, and to allow non-destructive PIE to replace destructive PIE in some cases.

In this paper, we describe following two items ;(1) Development of X-ray CT apparatus for PIE, and (2) Result of applying X-ray CT apparatus to an irradiated fuel assembly.

2. Development of X-ray CT apparatus

2.1 X-ray CT apparatus

Fig.1 shows the outline of X-ray CT apparatus. The irradiated fuel assembly is inserted in the elevator and can be axially moved. The scanner that has an X-ray source and detector is put on the table rotating around the specimen. The specimen is examined by mutually repeating the traverse and rotating scan of X-ray.

The X-ray intensity measured in the detector is converted to the X-ray CT image by the image-processing computer. All system of apparatus is controlled by the main computer and the X-ray CT image can be taken on any cross section.

A large problem is the disturbance to obtain clear CT image by the high level of gamma ray that emitted from the specimen. In order to solve the problem, the pulse of high energy X-ray which is generated by an accelerator was applied to the scanning. Detection of X-ray transmitted through the specimen is synchronized with the pulse of high energy X-ray to minimize the disturbance of gamma ray from the specimen.

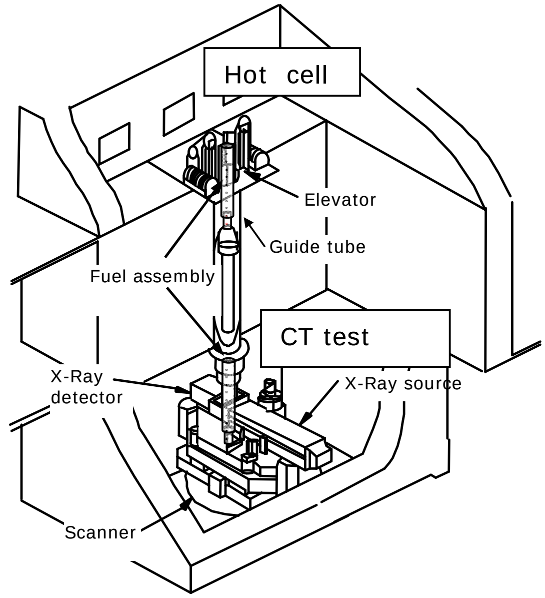

Fig.1 Outline of X-ray CT apparatus

2.2 Performance of X-ray CT image

A preliminary test was performed using the dummy fuel assembly of known dimension, in order to check the accuracy of this method. This preliminary test confirmed that the dimension can be measured within an error of ± 0.3 mm.

From the preliminary test using dummy fuel assembly which have a artificial defect, it was confirmed that a slit defect with a 0.3 mm width x 0.9 mm length and a hole defect with the diameter of 0.5 mm are detected in the X-ray CT image.

In order to confirm the density discernment performance, the test piece joined two materials of copper (8.96g/cm^3) and brass (8.6g/cm^3) was examined for X-ray CT. It is possible to distinguish between copper and brass at the X-ray CT image.

3. Result of applying X-ray CT apparatus to the irradiated fuel assembly

3.1 Specimen

Fig.2 shows the fuel assembly and fuel pin used in th study, which was irradiated in experimental fast reactor Jo 127 fuel pins was loaded in the assembly. In as-fabricat condition, the fuel pellets averaged in diameter, in dens respectively around 5.42 mm, 93 % theoretical density. T fuel pin diameter was 5.5 mm. The maximum burn-up a fast neutron fluence calculated were respectively 66.1 GW and 8.92 × 10^{22} n/cm^2 (E≥0.1 MeV) at the pellet peak.

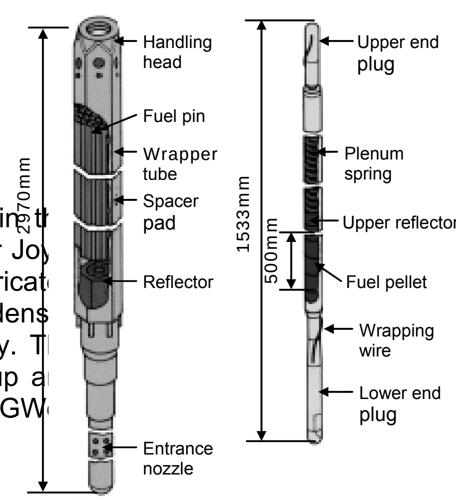

Fig.2 Outline of Joyo fuel assembly and fuel pin

3.2 Observation of the two-dimensional X-ray CT image

A representative cross section image obtained from the irradiated fuel assembly in the position of axial core center is shown in Fig.3. It can be seen that the wrapping wires, claddings and fuel pellets with central voids are distinguished respectively, and this observation made it possible to grasp the displacement of fuel pin and wrapping wire position around fuel pin.

In the case of FBR fuel, the central void is formed because of the influence of steep temperature gradient in radial direction of fuel pellet. The central void diameter could be measured by analyzing of X-ray CT image [3]. Until now, the central void diameter has been measured by the metallurgical observation on the cross-section of the fuel after sectioning it.

This technique made it possible to measure the central void diameters on the cross-section of all fuel pins included in the fuel assembly at same time without sectioning.

Using this technique, the central void diameter was determined within an error of ±0.1 mm. Fig.4 shows the estimated result of central void diameters at the position of axial core center. The central void size becomes larger for larger red color strength in the fuel pin, and it becomes smaller for increasing green color strength. The diameters increase toward the center of the reactor core. It is expected from this result that the temperatures of fuel pins and coolant in the fuel assembly increase as their positions approach the reactor center region.

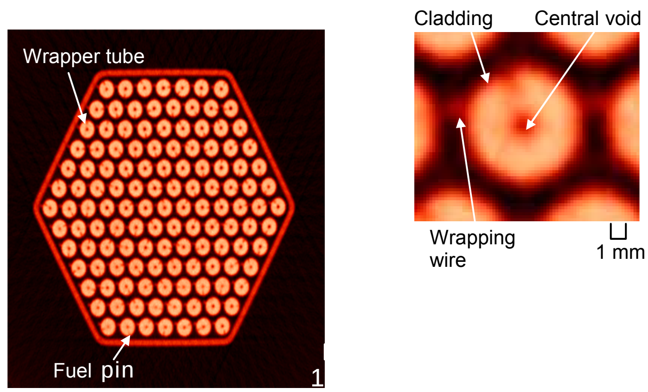

Fig.3 Cross sectional X-ray CT image of the axial center of the core fuel column

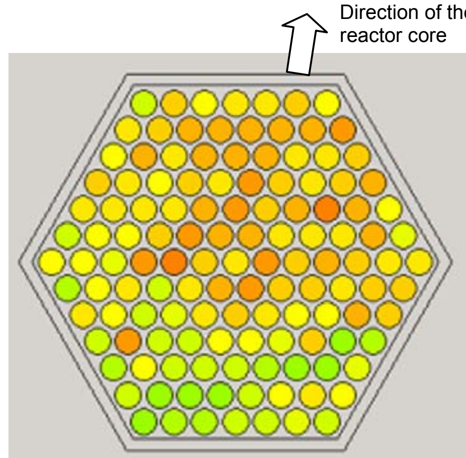

Fig.4 The estimated result of central voids size at the axial center of core fuel column

3.3 Observation of the three-dimensional X-ray CT image

The three-dimensional X-ray CT images were synthesized from two-dimensional X-ray CT images taken on the cross section in the region of core fuel column of the irradiated fuel assembly. Fig. 5(a) shows a three-dimensional X-ray CT image of irradiated fuel assembly in the core fuel region. The configuration of all fuel pins and the outer surface of wrapper tube can be seen clearly. The outline of irradiated fuel assembly can be grasped from this image. Fig. 5(b) shows a side view observed on the cross section exposed if the wrapper tube is removed. This kind of image can be taken on any cross section in the interior of the fuel assembly, and then it is possible to observe the deformation of cladding and detect abnormalities in any region of the fuel assembly. Fig. 5(c) shows the X-ray CT image obtained on an oblique surface of the fuel assembly. This image is helpful to quickly and simply judge the integrity of the assembly.

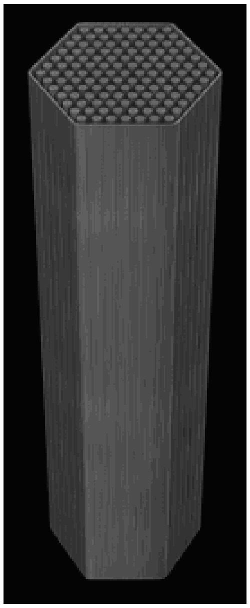

Fig.5(a) Three-dimensional X-ray CT image of core region in the fuel assembly after irradiation.

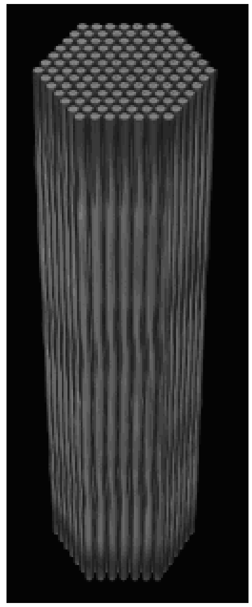

Fig.5(b) Three-dimensional X-ray CT image without duct tube

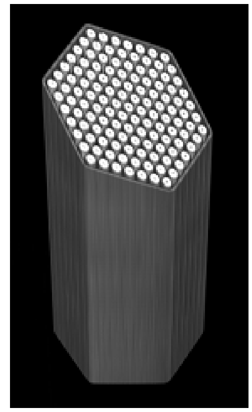

Fig.5(b) Three-dimensional X-ray CT image obtained on an oblique surface

Fig. 6(a) shows detailed X-ray CT images which were synthesized from two-dimensional X-ray CT images taken on 40 cross sections at an interval of 1.0 mm in the region of ± 20 mm from the axial center of the core fuel column. This technique enables us to observe the detailed inner condition of the irradiated fuel assembly. Fig.6 (b) is the one on the cross section when the fuel assembly is axially cut into equal halves around the axial center of the core fuel column, and the central void can be seen. The axial distribution of central void sizes can be grasped from this image.

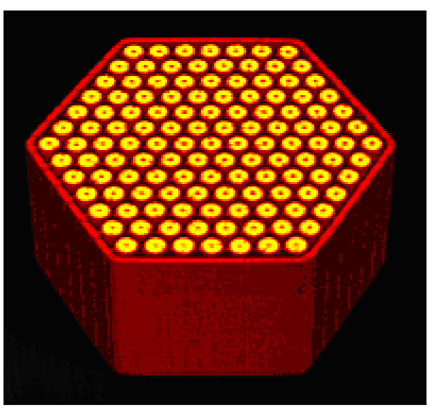

Fig.6(a) Detailed three-dimensional X-ray CT images around the axial center of the core fuel column

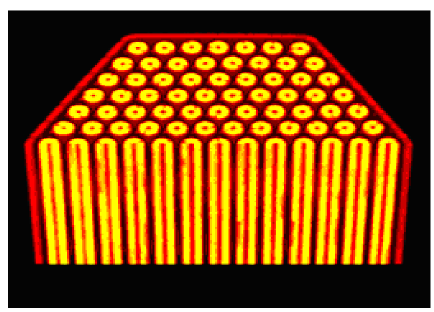

Fig.6(b) Detailed three-dimensional X-ray CT images cut longitudinally at the fuel pellet center

4. Conclusion

In this study, the non-destructive examination technique using X-ray computer tomography was developed for the purpose of post irradiation examination. This X-ray CT technique is characteristic of using a pulsed high energy X-ray source in order to reduce the effects of gamma ray emissions from an irradiated fuel assembly, and then made it possible to obtain the clearly cross section image.

This non-destructive PIE technique using the X-ray CT can eject destructive methods in many measurements. This enhances efficiency and reduces radioactive wastes. This technique can be applied further to overall fuel assembly behavior, such as bundle-duct interaction, central void distribution and so on.

References

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[3] K. Katsuyama, et al. “High energy X-ray CT study on the central void formations and the fuel pin deformations of FBR fuel assemblies”, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, Volume 255, Issue 2, February 2007, Pages 365-372