Development of detection technique of corrosion and defect by X-ray computed tomography

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Abstract

The non-destructive detection technique of corrosion and defect on the irradiated fuel assembly has been developed in Japan Atomic Energy Agency (JAEA). The X-ray computed tomography (CT) images of the corrosion layers (from 0 mm to 0.7 mm thickness) and the cracks (from 0.1 mm to 0.8 mm width) on a cladding tube were taken. The corrosion layers of more than 0.35 mm thickness and the cracks of more than 0.1 mm width were observed on the X-ray CT images.

Introduction

In the Japan Atomic Energy Agency (JAEA), X-ray computed tomography (CT) technique has been developed as nondestructive examination technique of irradiated fuel assembly [1, 2]. Most of conventional post irradiation examination (PIE) give results on performance of fuel rod after dismantling the fuel assembly [3, 4], but X-ray CT technique has a great merit of being able to examine performance of the fuel rod in the intact fuel assembly.

Recently, this technique was innovated to observe structural change in fuel pellet [5]. As a result, high resolution X-ray CT images could be obtained, and furthermore the image analysis method of X ray CT image was improved to evaluate dimensional change of fuel rod and density change (microstructure change) of fuel pellet. As results, the dimensional change could be measured within an error of with ±0.1 mm and the density change could be evaluated within an error of about ± 2 %.

In this study, the X ray CT technique was applied to the examinations of corrosion and defect on the fuel rod to evaluate the integrity of the fuel assembly.

2. Experiment

2.1. X-ray CT apparatus

The cut-away of the X-ray CT apparatus is shown in Fig.1. A linear accelerator was used as the X-ray source in this apparatus. A short pulse of X-ray of 12 MeV pass through the specimen and then is detected by the silicon semiconductor through 100 channels of collimators, which have narrow slits of 0.1 mm in width and 2mm in length and was installed in front of the detector. The X-ray source and the X-ray detectors were set on the scanner device. The fuel assembly was set between the X-ray source and the X-ray detector. Both X-ray source and the X-ray detector were moved around the fuel assembly by the scanner device as shown in Fig.2. The X-ray data was converted to the X-ray CT image by the image reconstruction processing. The high resolution X-ray CT image could be obtained by this apparatus.

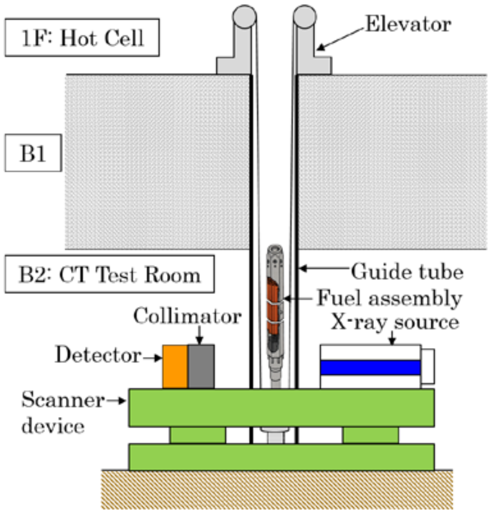


Fig.1 Cut-away of the X-ray CT apparatus

The X-ray CT image is composed of the digital data (CT values). The relationship between the CT values and the densities was obtained by using some reference materials having constant density in this apparatus [5, 6]. It was possible to evaluate the density distribution of an examined specimen by using this relationship.

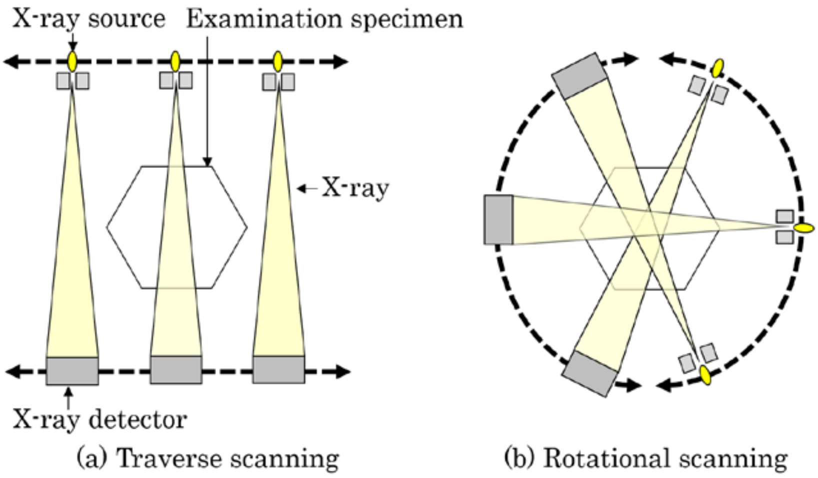
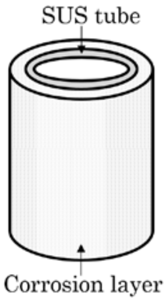


Fig.2 Scanning system

2.2. Specimens

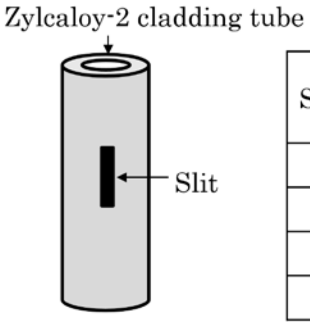
Two type of specimens were prepared to obtain the X-ray CT image of corrosion and crack. Fig.3 and Fig.4 shows the outline of specimens. The corrosion layers were made on outside surface of the SUS tube and had the thickness of 0.02 mm to 0.7 mm as shown in Fig.3. On the other hand, the slits simulating cracks were cut on the zircaloy-2

(Zry-2) cladding tube. The widths of these slits were from 0.1 mm to 0.5 mm and the length was 10 mm. Both types of specimens were examined by X-ray CT technique.



Specimen No.	Average thickness of corrosion layer (mm)
C-1	0.02
C-2	0.05
C-3	0.1
C-4	0.7

Fig.3 SUS tube specimen



Specimen No.	Slit Width (mm)
S-1	0.1
S-2	0.2
S-3	0.3
S-4	0.5

Fig.4 Zylcalloy-2 cladding tube specimen

3. Result and discussion

The X-ray CT images of the SUS tube specimen are shown in Fig.5. The X-ray CT images were obtained on transverse cross section of the SUS tube. In the X-ray CT images of Fig.5, the white regions correspond to the transverse cross section of SUS specimens, while gray color region corresponds to the corrosion layer. The gray region is clearly observed only in the X ray CT image of C- 4 specimen, but is not done in the X ray CT images of other specimens.

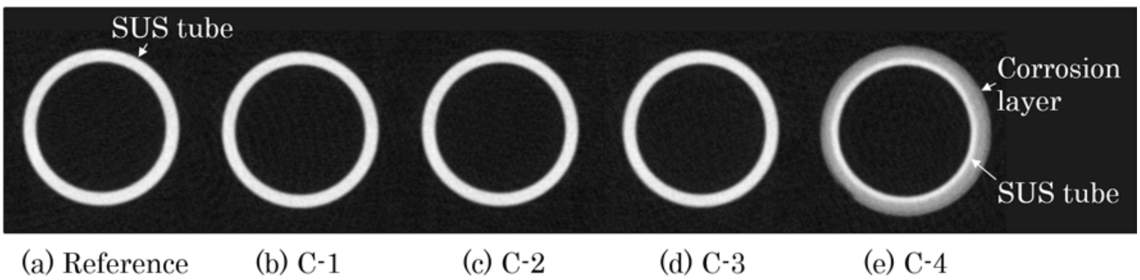


Fig.5 X-ray CT images of the SUS tube

Fig.6 shows the X-ray CT images of Zry-2 cladding tube specimen. In this X-ray CT image, the white color regions correspond to the Zry-2 cladding tube, and the slits appeared in the upper regions of cladding correspond to the cracks. Black and gray region indicated by arrow on the X-ray CT image show the slit. The slits observed in the X ray CT images of three Zry-2 claddings have the sizes from 0.1 mm × 5 mm (width × length) to 0.8 mm × 10 mm (width × length).

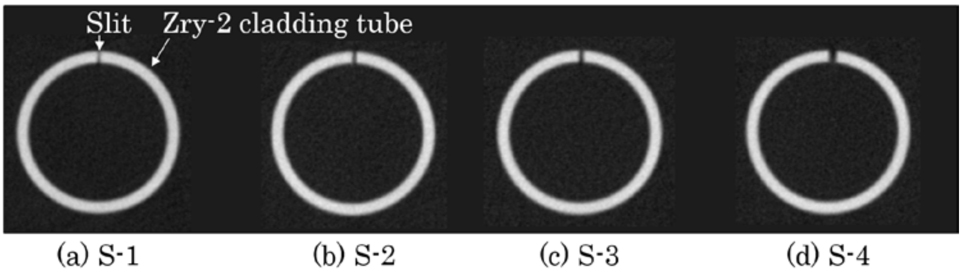


Fig.6 X-ray CT image of the Zry-2 cladding tube

The corrosion layer was evaluated by using the radial distribution of CT values measured in the region across SUS cladding as shown in Fig.7. Its length (thickness) is 3 mm. This image analysis method has been method developed in JAEA.

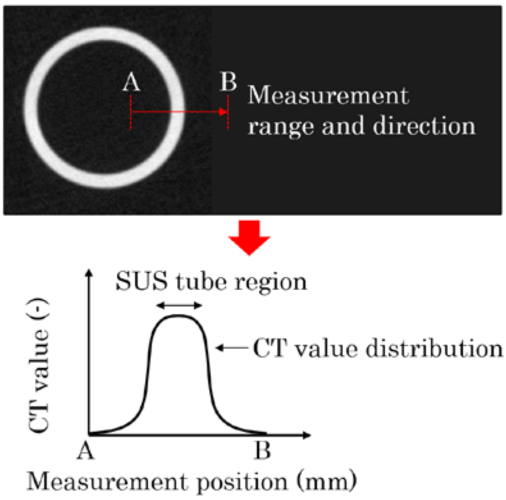


Fig.7 Measurement of CT value distribution

The CT value distributions obtained on the CT images of four specimens are shown in Fig.8. The CT value distributions of the SUS tubes having the corrosion layers are compared to the distribution of the reference specimen. Fig.8 (a) and (b) show that the data of the specimen C-1 and C-2 agree with the data of the reference specimen. In Fig.8 (c), it is shown that the data measured in the region from 1.8 mm to 2.0 mm (corresponding to the outside position of the SUS tube) are slightly lower than the data of reference specimen. In addition, the distribution of X ray CT values is clearly different from the one of reference specimen as shown in Fig 8 (d). It is concluded that the corrosion is identified if its thickness is more than 0.1 mm.

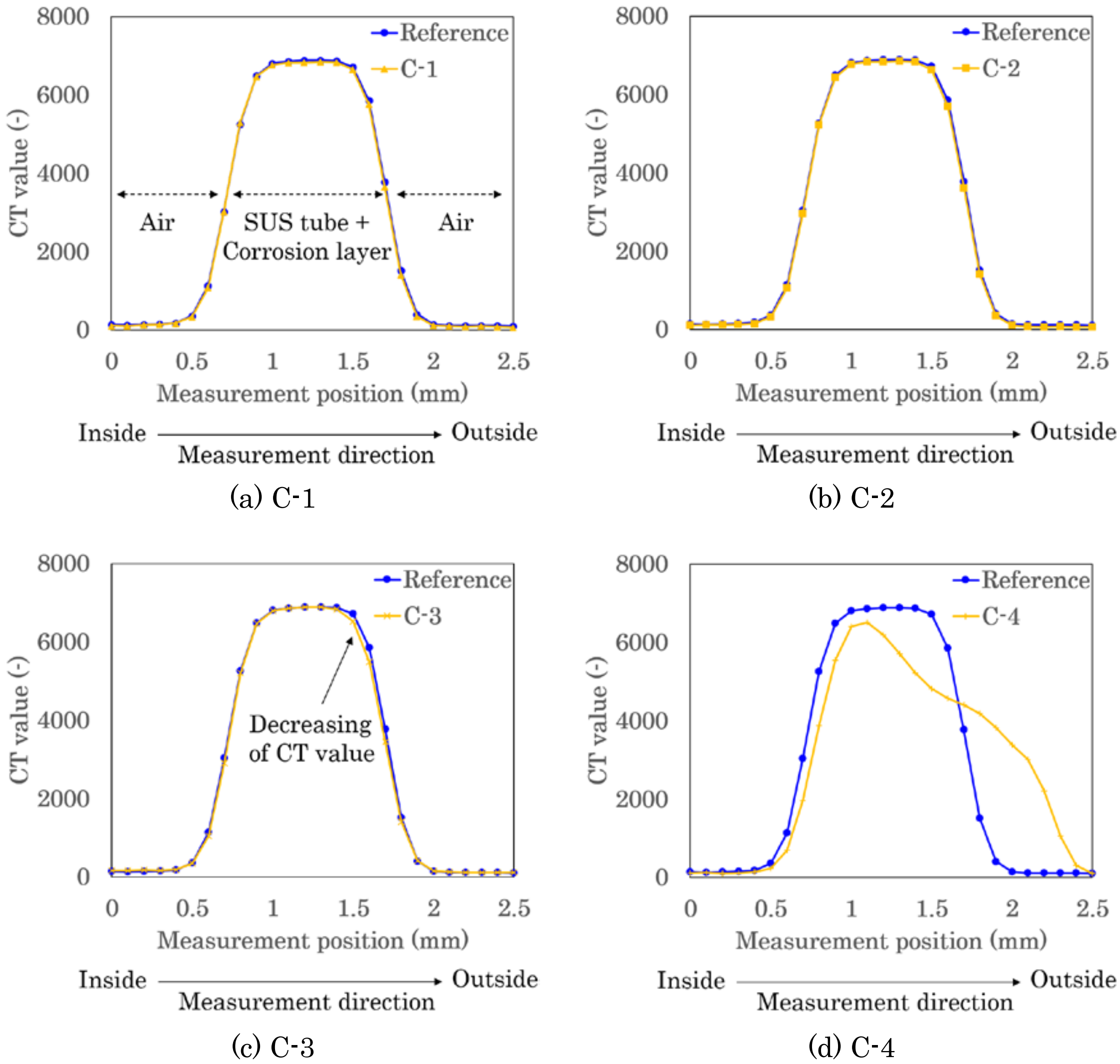


Fig.8 CT value distributions of the SUS tube

On the other hand, the slits corresponding to the cracks are clearly seen in the X ray CT images of all specimens. From these results, it is conclude that the crack can be found by the X ray CT technique if its width is more than 0.1 mm

4. Conclusion

The detection technique of the corrosion and crack cloud be successfully developed in this study.

The corrosion layer of more than 0.7 mm thickness cloud be observed on the X-ray CT image. In addition, the corrosion layer of more than 0.35 mm cloud be evaluated from the X-ray CT image by using the CT value distribution.

The slit simulating the crack on the Zry-2 cladding tube cloud be observed to 0.1 mm width (lowest) on the X-ray CT image.

It is expected in a near future that the integrity of an irradiated fuel assembly (fast breeder reactor and light water reactor) can be evaluated.

5. Reference

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