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Analysis on cracking of baffle former bolts from a PWR plant

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1. Introduction

Research on using materials from dismantled nuclear power plants as data for continued operation is being actively conducted at home and abroad [1-4]. The first nuclear power plant in Korea (Kori Unit 1), which started operating in 1978, was permanently shut down in 2017 for the first time after 40 years of operation, and full-scale dismantling will begin after 2027. In the final outage inspection before the permanent shutdown in 2015, defects were found in eight bolts in the former (Level A) at the bottom of the reactor internal structure. The Korean regulatory authority has requested that the cause of this defect signal be identified. Due to this need, a national research project supervised by the Korea Atomic Energy Research Institute is being carried out. Two defective bolts and two sound bolts in the adjacent area were pulled out and non-destructive and destructive tests were performed. Clear cracks were observed at the shank of the defective bolt by X-ray 3 D computed tomography. An analysis is being carried out to determine the cause of the defects found in the four precisely symmetrical areas. It is estimated that the defect occurred only in bolts in a specific direction in a similar location due to asymmetric stress applied to baffles in different directions caused by thermal expansion. A more detailed analysis is needed. Since the flow of cooling water around the baffle-barrel changed from down flow to up flow in 1986, so we are examining whether there is any effect of this converted up flow design change.

This paper explains NDE signal evaluation, calculation of radiation dose, observation of the defect shape and the cause of the defect performed so far.

2. Experimental

The defect signal was obtained from the field ultrasound NDE inspection during the final outage. Cumulative irradiation dose for high-speed (E >1.0 MeV) neutron calculated from the head of the bolt to the lower screw for one of the defective bolts. 3D computed tomography X-ray photos were taken to determine the shape of the defect. Applied stress analysis was performed in order to find the main cause of the defect.

3. Research and discussion

3.1 Defect observation

The nuclear power plant has a structure in which 728 baffle former bolts and 176 baffle plate edge bolts made of type 304 stainless steel are connected to each other to support the nuclear fuel assembly as shown in Fig.1. The bolt material connecting these two plates is cold worked type 316 stainless steel. During the in-service inspection in May 2015, a defect named UDL (Unknown Defect Location) was found on eight bolts in symmetrical locations in four places of the lowest former. Fig. 2 is the defect signal obtained from the field inspection. A clear backwall signal was found in sound bolts, whereas no such signal was found in defective bolts. Based on this, the form of the defect was unknown, but it was determined that there was some discontinuous defect.

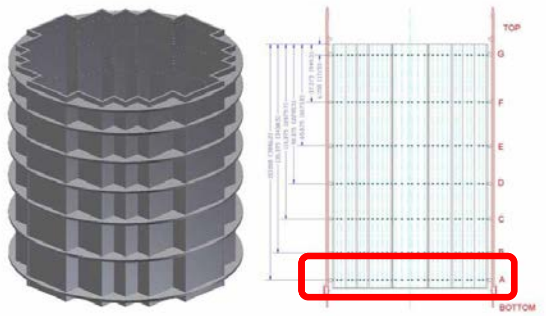

Fig. 1. Location of defect signal bolts (lowest former)

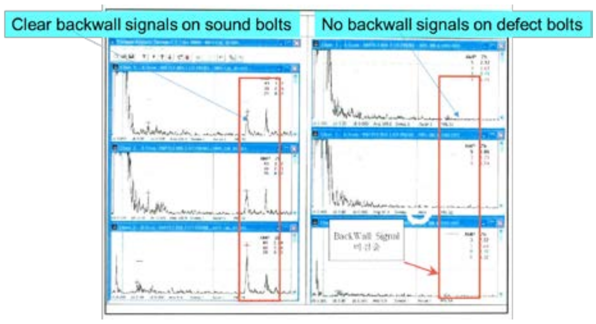

Fig. 2. Comparison of NDE signals on sound and defect bolts

3.2 Calculation of radiation dose

Fig. 3 shows the high-speed (E >1.0 MeV) neutron cumulative dose calculated from the head of the bolt to the lower screw for one of the defective bolts of the plant. Because it is the lowest former location, the amount of irradiation was calculated to be less than that of the belt line location, but it shows a value of about 26 dpa(displacement per atom) which is larger than the critical value (about 2.5 dpa) that causes IASCC.

3.3 Non-destructive observation by 3D X-ray

Before viewing the fracture surface with a scanning electron microscope, 3D computed tomography X-ray photos were taken to determine the shape of the defect. As shown in Fig. 4, clear defects are shown in the shank area just below the head.

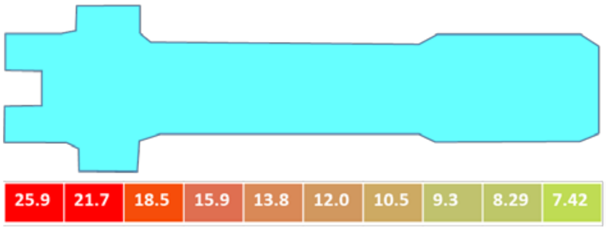

Fig. 3. Fluence (DPA) calculation on a defect bolt

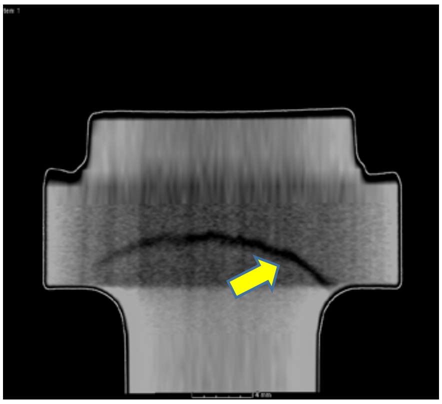

Fig. 4 X- ray 3 D CT image on a defect bolt

3.4 Applied stress analysis

The fact that crack defects were found at exactly symmetrical 4 locations was determined that the main cause of the defect was stress caused by the structural factor in which the bolt was fastened, rather than the factor of the material or operating environment. Fig. 5 shows a schematic of asymmetrical applied load on the bolts. It is assumed that tensile stress was applied to the defective bolt due to radiation induced void swelling or asymmetric stress from other factors. This would explain the defect found only on the A14 and 15 bolts, but not on the A12 and A13 bolts, which are perfectly symmetrical in terms of nuclear fuel arrangement and distance. A more precise stress analysis may be performed and the results will be published later on.

4. Summary

- A defect named UDL (Unknown Defect Location) was found on 8 bolts in symmetrical locations in 4 places of the lowest former in a Korean plant.
- It shows a maximum dose value of about 26 dpa on the bolt head surface which is larger than the critical value that causes IASCC.
- Clear defects were shown in the shank area just below the head.
- The main cause of the defect was stress caused by the structural factor in which the bolt was fastened, rather than the factor of the material or operating environment.

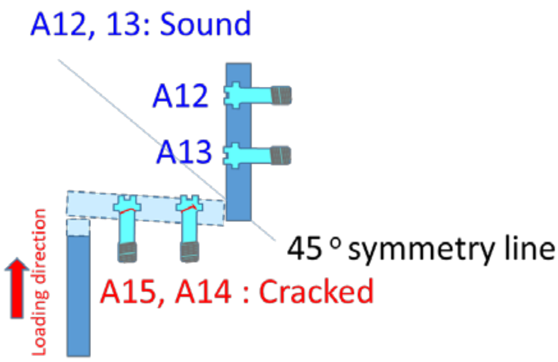

Fig. 5. Different stress conditions due to asymmetrical applied load on the defective bolts

ACKNOWLEDGEMENTS

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