Recent Advances in NDE Techniques During PIE of Irradiated Nuclear Materials

J. L. Singh, Prerna Mishra, B. N. Rath, Nitin Kumawat

Post Irradiation Examination Division, Bhabha Atomic Research Centre, Mumbai

Corresponding author: J. L. Singh <jlsss@barc.gov.in>

1. Introduction

The fuel and structural components used in nuclear reactors are subjected to stringent quality control during fabrication. These components suffer degradation during reactor operation under very hostile atmosphere of fast neutron flux, high temperature and corrosion. To evaluate the condition, many of the reactor components are brought to the hot cells for a detailed post irradiation examination (PIE). NDE techniques are devised to generate more information on the performance evaluation of reactor fuels and structural core components. This paper presents the details of the new informations generated on the irradiated reactor materials using NDE techniques.

2. In-cell visual examination of irradiated 220 MWe PHWR fuel bundle

Fuel bundle 109197P was received at New Hot Cell Facility for failure examination. Fuel bundle was discharged due to failure from N05 channel of Kaiga Generating Station-4. Peak bundle power and discharge burn up of the bundle was reported as 373.4 kW and 601 MWD/TeU respectively.

The yellow colour oxide was confirmed as UO$_2$ by X-ray diffraction analysis. The hydride region in the clad and end plug inner ring were rough due to chipping and falling off the layer.

3. Neutron Radiography of irradiated fuel pins

Neutron radiography was used for detection of massive hydriding locations in zircaloy cladding and end caps, cracking pattern and formation of central voids in fuel pellet, evidence of fuel densification, enrichment mix-up in the fuel columns etc. Radiography using thermal neutrons is most useful because in this energy range the neutrons have got favourable attenuation characteristics in the materials of interest like an irradiated nuclear fuel. Some of the features like pellet cracking pattern and geometrical contours obtained by neutron radiography are shown in Figure 3.
The features obtained from the neutron radiograph were confirmed by metallography after cutting the fuel pin. The hydride blisters in the clad not detected by other NDT techniques are detected by neutron radiography as it is based on attenuation of thermal neutrons with materials of different scattering and absorption cross section.

4. Ultrasonic testing for nodular corrosion in pressure tubes

Ultrasonic testing technique was developed and deployed to detect oxide nodules in the irradiated pressure tubes. The oxide nodules have longer dimension in the axial direction than in the circumferential. Accordingly, to get higher sensitivity of detection, line focused ultrasonic waves were used. Nodules of small depth are not good reflectors of ultrasonic waves. But, a cluster of nodules reflect detectable amount of ultrasonic energy. It is difficult to detect an isolated nodule of depth less than 50 µm. The nodules on the outer surface are best detected by using self-guided internal ultrasonic probe head under water immersion.

5. Summary

The root cause of fuel failure was end plug weld and clad hydriding due to internal moisture mainly. The nodules were detected by ultrasonic testing technique. The primary reason was found to be moisture content in the annulus causing nodular corrosion on the OD surface of pressure tubes.