Preliminary Inspection of Spent Fast Reactor Fuel Claddings

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Abstract. Electrical potential testing, used as a rapid method for examination of claddings after operation in BN-600 reactor and applied for incoming inspection in INM hot cell laboratory, is described. Electrical resistivity curves, obtained during electrical potential testing, demonstrate the level of the fuel element defectiveness and help to work out a cladding dismantling plan for further post irradiation examination of materials. The aspects of electrical potential testing of ChS-68 and EK-164 claddings are given.

Key Words: Cladding, electrical potential testing, vacancy swelling, corrosion thinning.

1. Introduction

During reactor operation radiation defects, induced by high dose rate irradiation, nucleate and accumulate in the core. These defects cause variations of dimensions, mechanical and physical properties, development of corrosion damages in cladding materials. Therefore on-line control of their state after certain service life is a topical aspect.

Electrical potential testing (EPT), which is a primary nondestructive testing method, is used at INM hot cells as an incoming inspection of spent BN-600 reactor fuel elements. During electrical potential testing electrical resistivity of fuel element areas is determined and a curve of electrical resistivity variation along the fuel element is shown.

Electrical resistivity curves (resistograph images) demonstrate the level of the cladding defectiveness and help to work out a cladding dismantling plan for further post irradiation materials examination of the problem areas.

2. Rapid Method of Evaluation of Cladding Vacancy Swelling and Corrosion Thinning

Electrical potential testing ensures prompt evaluation of cladding structural changes, caused by radiation-induced swelling, by axial profile electrical resistivity distribution. Radiation-induced swelling of claddings (vacancy porosity occurrence) causes cladding external diameter and electrical resistivity to increase [1, 2].

A sharp bell-shaped increase of relative electrical resistivity is clearly seen in *Fig. 1* (0-700 mm coordinates from the core bottom). It correlates with variations of ChS-68 cladding diameter and swelling relative values of the same shape.

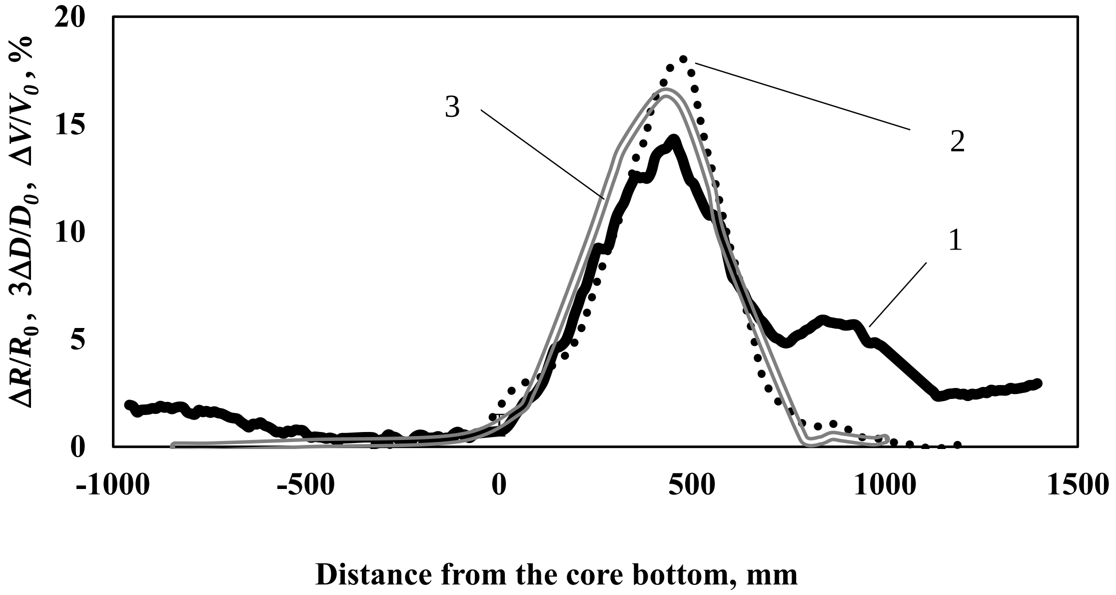

FIG. 1. Relative variation of electrical resistivity $\Delta DR/R_0$ (1), diameter $3\Delta D/D_0$ (2) and swelling $\Delta V/V_0$ (3) changes for BN-600 cladding specimens.

Experimental and theoretical studies show that in this area swelling is a dominant cause of electrical resistivity variation, and this effect is described with the relation [1, 2, 3]

$$\frac{\Delta R}{R_0} = \frac{5S}{4S+6}, \% \tag{1}$$

where ΔR is electrical resistivity variation, Ohm;

R_0 is initial electrical resistivity of steel, Ohm;

S is radiation-induced swelling, %.

Radiation-induced swelling of cladding materials can be estimated using the results of radiation-induced swelling measurement and equation (1) with relative error of 2 %. Therefore electrical potential testing may be applied as a non-destructive testing for swelling evaluation [1, 2, 3].

EPT resistograph images provide evaluation and comparison of cladding swelling values for different fuel elements depending on damage dose.

Fig. 2 gives the results of electrical potential control for three BN-600 fuel elements with ChS-68 (06Cr-16Ni-15Mo-2Mn-2Ti-V-B induction arc remelting (IAR)) claddings irradiated to damage dose of 83 (1), 71 (2) and 58 (3) dpa, respectively.

Electrical potential testing of these fuel elements is carried out at different time periods (2009-2011) by different operators and at facilities of different modifications. Agreement of control results in the area of small radiation damages (in coordinates from minus 1000 mm to 0 mm) shows good reproducibility and repetition of the technique. Value of relative electrical resistivity in the area of maximum radiation damage (core centre) shows visualization of the technique and its sensitivity to this type of defect.

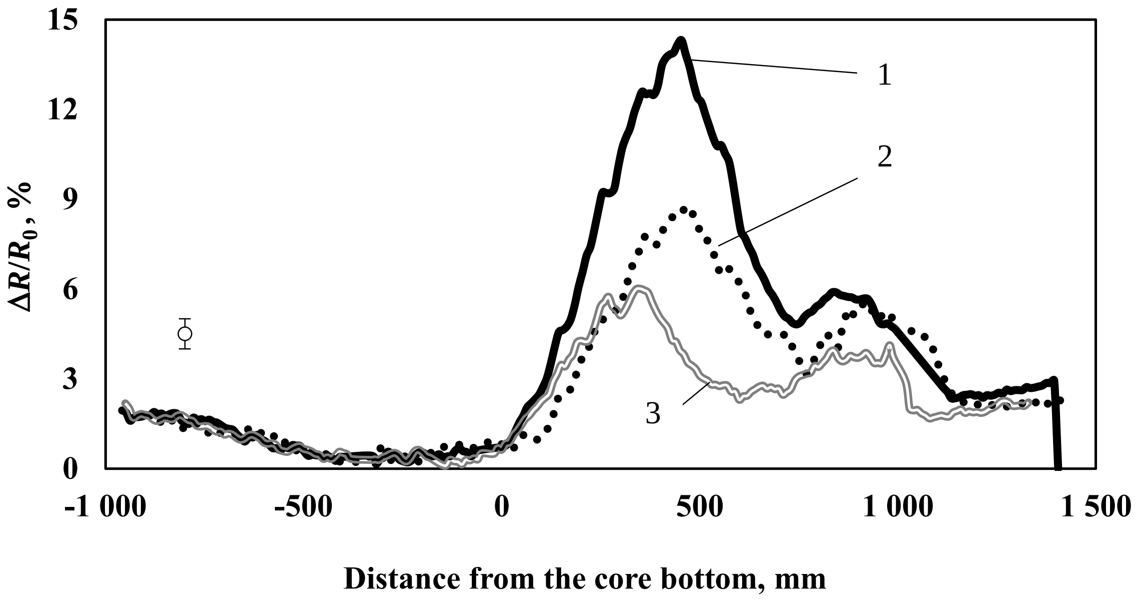

FIG. 2. Electrical resistivity value for ChS-68 cladding material at damage doses of 83 (1), 71 (2) and 58 (3) dpa.

In the upper (high temperature) fuel element part, in coordinates from 750 to 1000 mm, corrosion processes in fuel and structural materials are enhanced. Due to fuel element corrosion cladding thinning (conductive section contraction) takes place, causing electrical resistivity to increase. The area of cladding corrosion thinning is not observed at swelling curves and profilometries (Fig. 1), but it is clearly seen in resistograph images (Fig. 1, 2).

Corrosive agents, volatile fission products in particular, with cesium as the most dangerous one, are the main cause of high-temperature corrosion of claddings made of austenitic steels (T_{irr} > 570 °C). The gamma spectrometry data show a typical manner of Cs migration to the core-upper end-shield joint boundary (Fig. 3). It is clear that with Cs redistribution in high-temperature area of the core there is a potential hazard of cladding corrosion from the fuel side to increase [4].

Electrical potential control results enable estimation of cladding corrosion thinning Δh by equation [3] with 5 % error

$$\Delta h = \frac{h(D-h)}{D-2h}\frac{\Delta R}{1+\Delta R}, \text{ mm} \quad (2)$$

where ΔR is electrical resistivity variation, Ohm;

D is initial external diameter of the fuel element, mm;

h is cladding (wall) thickness, mm.

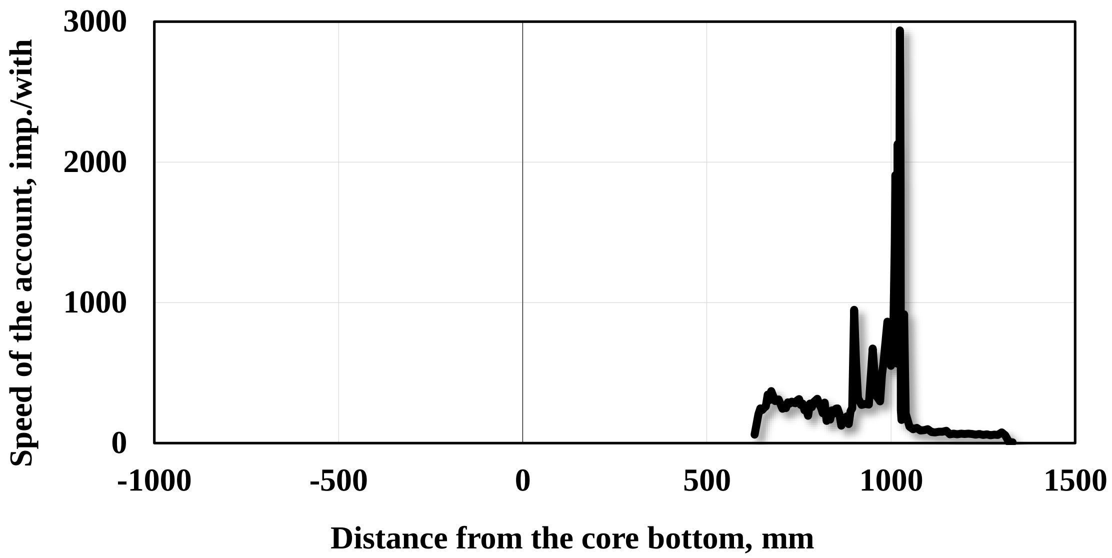

FIG. 3. Fission product (^{137}Cs) distribution along the fuel element according to gamma spectrometry data.

During EPT electrical resistivity of some fuel elements, generally with claddings made of EK-164 (07Cr-16Ni-19Mo-2Mn-2Nb-Ti-B IAR) steel, which is much more resistant to radiation-induced swelling than ChS-68 steel [5], decreases sharply in coordinate range between 600 and 1000 mm from the core bottom (Fig. 4).

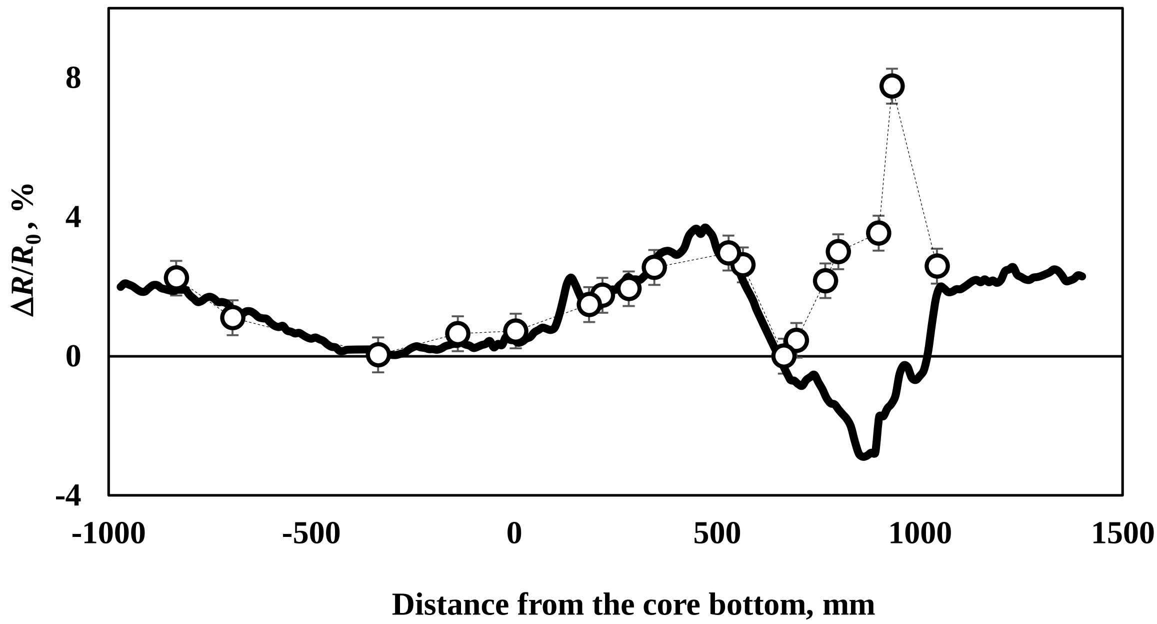

FIG. 4. Resistograph image of the fuel element with EK-164 cladding (▬) and relative electrical resistivity of specimens of the dismantled fuel element (o).

This is due to the fact that with swelling of fuel kernel a fuel-cladding gap in the the core top reduces, and an area of tough contact of electrically conductive fission products with slightly swelling cladding generates.

Metallographic examination proves presence of an adherent sublayer of fission products and metal slime removed by etching [4].

This sublayer appears during electrical potential testing as a sharp electrical resistivity decrease to 2-4% beyond reference values (gaseous cavity and lower end-shield joint) and conceals true electrical resistivity values for the cladding material in this area. The effect of the sublayer complicates corrosion thinning evaluation for the cladding in this fuel element section.

To specify electrical conductivity characteristics for the cladding material electrical resistivity is additionally determined for specimens of the dismantled fuel element. Fuel is mechanically removed from cladding specimens, and sediments inside are etched away in boiling nitric acid.

Variation of electrical resistivity of one cladding specimens is marked with circles and error bars in *Fig. 4*. After fuel and inner sediment removal electrical resistivity of specimens from the core top (coordinates 700-1000 mm) significantly increases, as compared with underestimated values in EPT resistograph images. It is confirmed by cladding bypassing with electrically conductive sediments inside cladding-fuel gap. Moreover, electrical resistivity of specimens enables prediction of corrosion thinning in this cladding area, confirmed by metallographic examinations [4].

3. Conclusion

Electrical potential testing proved itself as a rapid-method for the cladding state evaluation after operation in BN-600 reactor.
Electrical potential testing of spent fuel elements is one of the main non-destructive tests for evaluation of the effect of radiation-induced swelling, local defects and corrosion of fast reactor cladding material.

4. References

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