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SHADOW CORROSION TESTING IN THE INCA FACILITY IN THE STUDSVIK R2 REACTOR

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Abstract

Shadow corrosion is a phenomenon which occurs when zirconium alloys are in contact with or in proximity to other metallic objects in a boiling water reactor environment (BWR, RBMK, SGHWR etc.). An enhanced corrosion occurs on the zirconium alloy with the appearance of a "shadow" of the metallic object. The magnitude of the shadow corrosion can be significant, and is potentially limiting for the lifetime of certain zirconium alloy components in BWRs and other reactors with a similar water chemistry. In order to evaluate the suitability of the In-Core Autoclave (INCA) in the Studsvik R2 materials testing reactor as an experimental facility for studying shadow corrosion, a demonstration test has been performed. A number of test specimens consisting of Zircaloy-2 tubing in contact with Inconel were exposed in an oxidising water chemistry. Some of the specimens were placed within the reactor core and some above the core. The conclusion of this experiment after post irradiation examination is that it is possible to use the INCA facility in the Studsvik R2 reactor to develop a significant level of shadow corrosion after only 800 hours of irradiation.

1. INTRODUCTION

In reactors with oxidising water chemistry enhanced corrosion has been seen on zirconium alloys in contact with or in proximity to other metallic objects appearing as a "shadow" of the metallic object [1,2]. The shadow effect in the area of a spacer cell on a BWR fuel rod cladding is illustrated in Figure 1 (this measurement has been performed at the Studsvik Hot Cell Laboratory). The magnitude of the shadow corrosion can be significant and is potentially limiting for the lifetime of certain zirconium alloy components in BWRs and other reactors where this phenomenon occurs. In order to evaluate the suitability of the In-Core Autoclave (INCA) in the Studsvik R2 materials testing reactor as an experimental facility for studying shadow corrosion, a demonstration experiment has been performed.

2. EXPERIMENTAL CONDITIONS

2.1 The Studsvik R2 test reactor

The Studsvik R2 test reactor is a 50 MW tank-in-pool reactor, see Figure 2. It has been in operation since 1960. Today it is used for fuel and materials testing, silicon doping, radio-isotope production and basic research. The reactor is in operation 11 cycles a year. Each cycle is about 17 days long with a one week stop between the cycles. The reactor is equipped with a number of facilities in order to perform different types of experiment. For instance it has two in-pile loops in which BWR and PWR conditions are simulated.

2.2 The INCA-facility

The INCA-loop is a test facility for water chemistry and materials research in the Studsvik R2 reactor. INCA is especially designed for experiments under well controlled water chemistry conditions. It consists of two major parts: the external water supply with control and water analysis

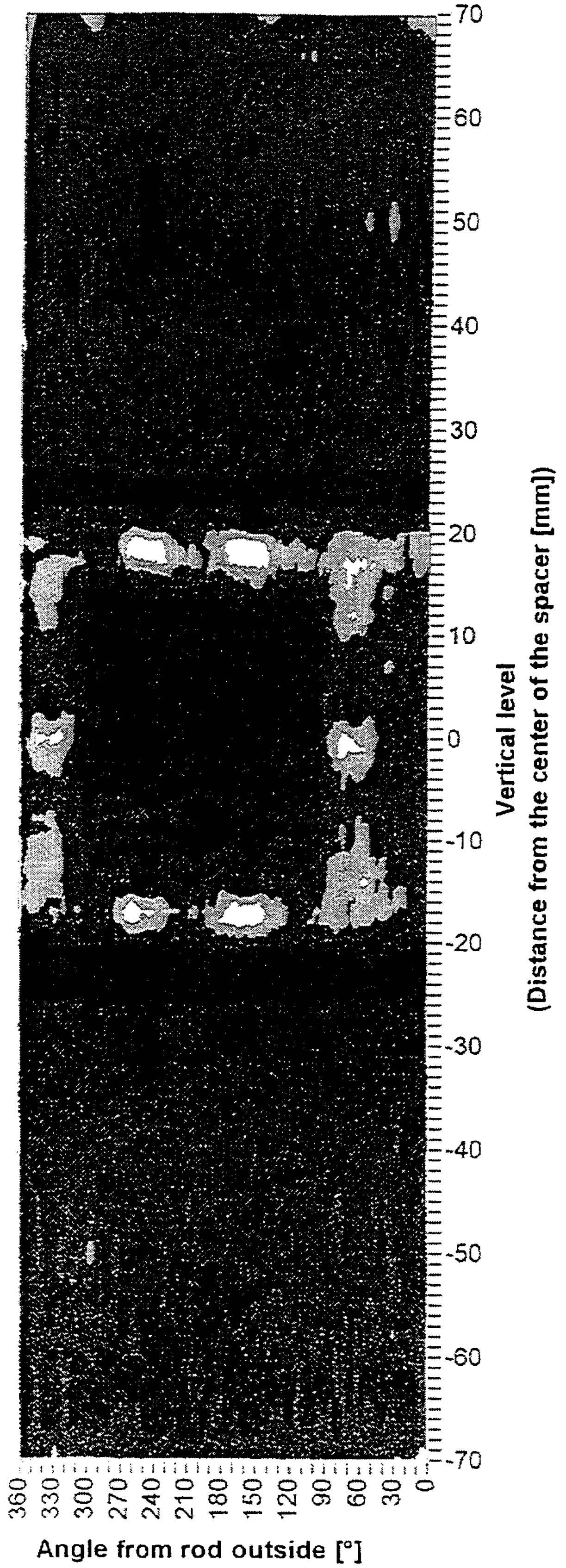

Figure 1. Oxide thickness map (from eddy current measurements) in the area of a spacer cell on a BWR fuel rod cladding. The oxide thickness decreases with the grey scale in the order ○> ◌ >●>●

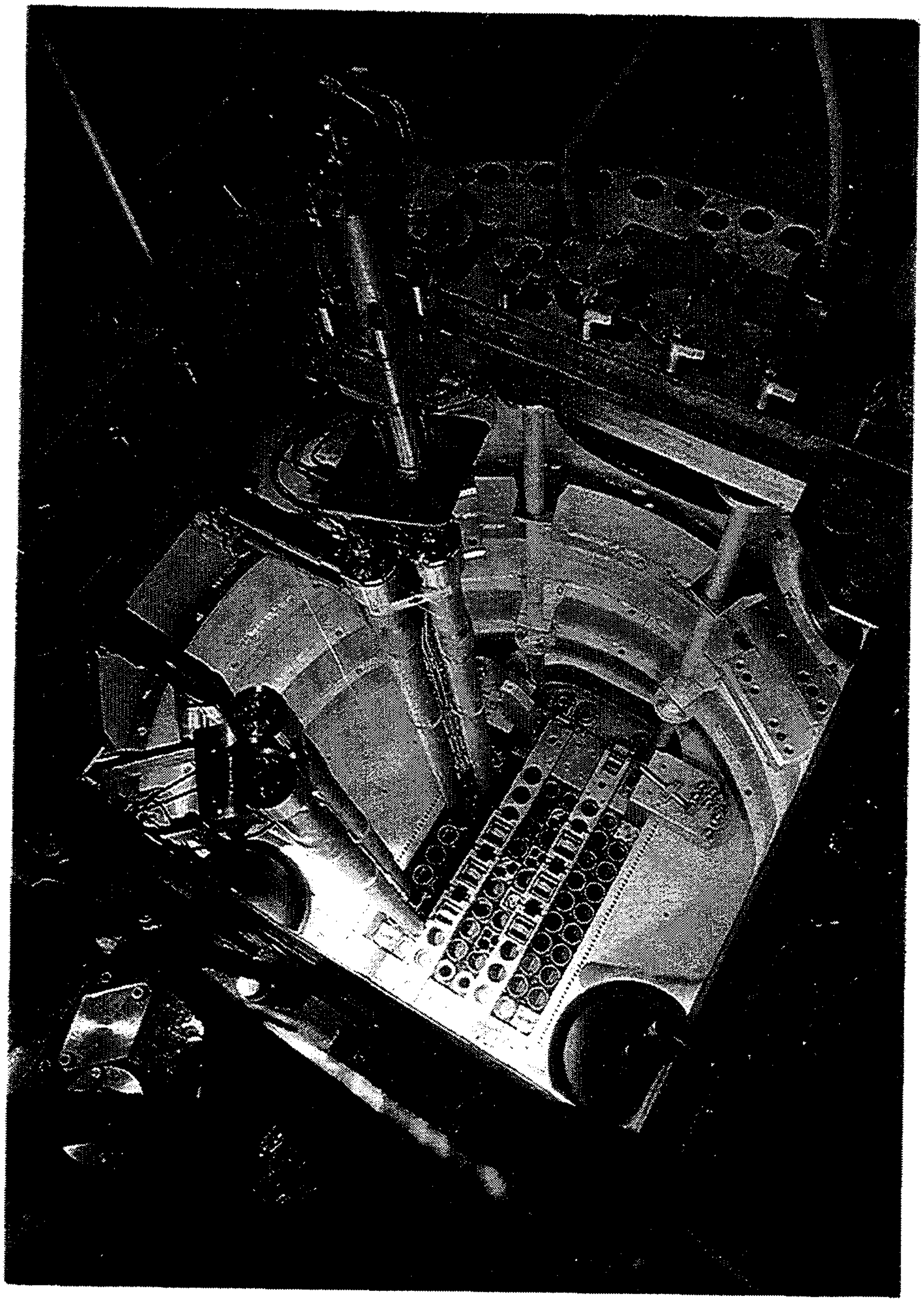

Figure 2. General view into the R2 reactor tank.

systems and the in-core rig. Degassed, high-purity water feeds the INCA-loop with a variable flow-rate. Injections of additives and impurities can be performed either before the water enters the rig or just above the in-core section of the rig. Both the inlet and outlet water can be analysed (content of oxygen, hydrogen, hydrogen peroxide, ions, conductivity etc.).

The INCA rig is illustrated in Figure 3 in its once-through operation mode where the water is drained after it has passed the in-core section. It is installed within one of the LWR loops in the R2 reactor. The water of the main loop serves as a heating or cooling medium for the INCA-rig. The two main parts of the INCA rig are the rig tube and the insert. The test specimens are installed on the test specimen rod. The rod can easily be changed between two cycles of operation. The INCA-loop can be operated from ambient conditions up to 15 MPa and 325°C.

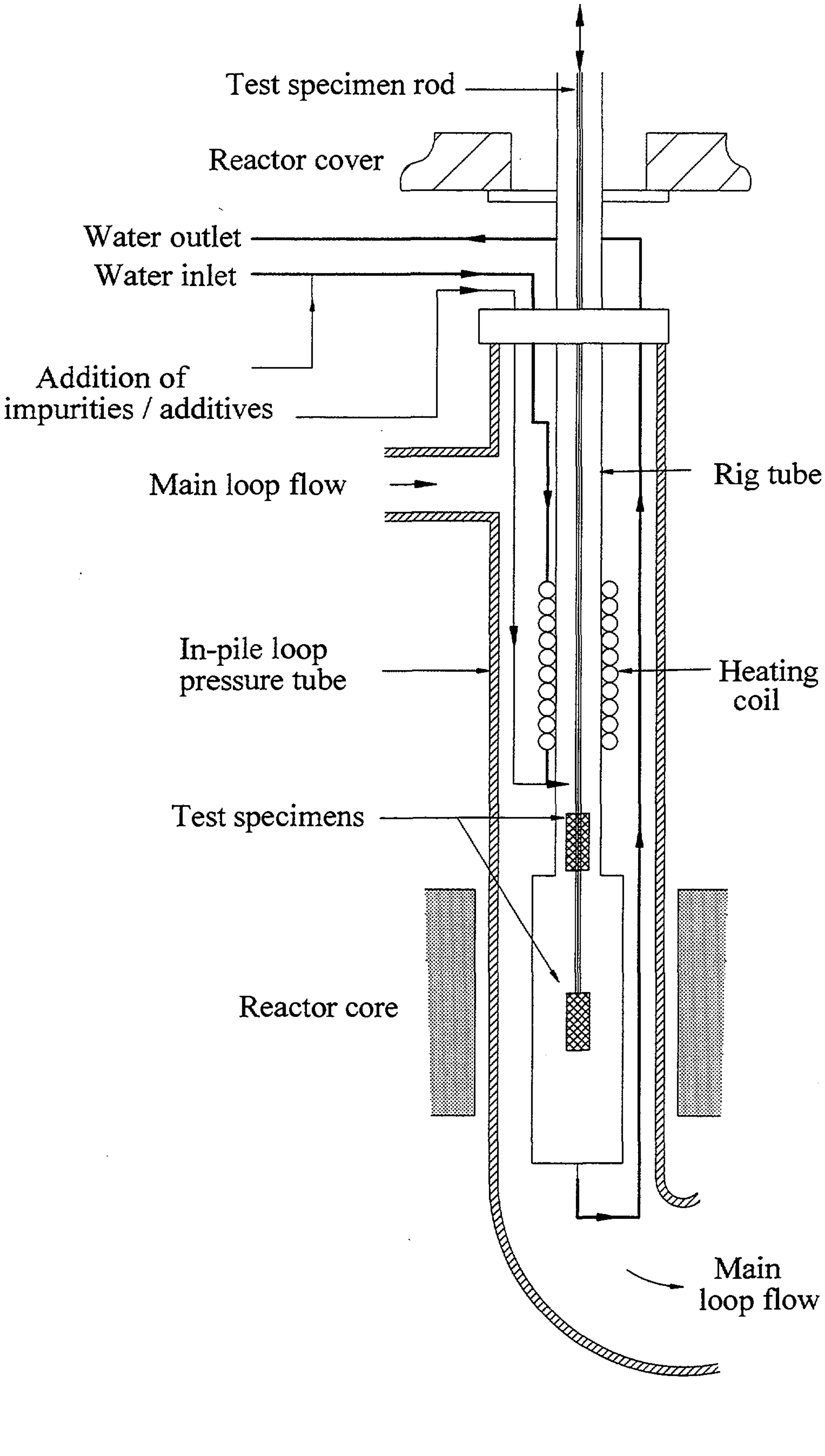

Figure 3. The in-core part of the INCA loop.

The INCA facility was used for this experiment. Earlier it has also been used for in-core electrochemical potential measurements [3,4]

2.3 The demonstration test

In this shadow corrosion demonstration test the water inlet temperature was 275°C at 8.5 MPa, (no boiling). The oxidising water chemistry typical of BWRs and other reactors where shadow corrosion has been observed, was created by adding 200 ppb of oxygen to the inlet water. The irradiation lasted for about 800 hours (two cycles of about 17 days each with a shutdown period in between the two cycles).

A number of test specimens were supplied by ABB Atom, and assembled on a stringer (the test specimen rod) in such a way that some of the specimens were within the reactor core, while some of them were above the core. The water flowed downwards through the rig which means that it passed the out-of-core specimens first and then the in-core specimens. This means that the changes of the water chemistry caused by the irradiation only affected the in-core specimens. Each test specimen consisted of a 35 mm long piece of Zircaloy-2 tubing in contact with Inconel.

The water chemistry was analysed during the test (average values by weight):

O_2 measured at inlet	200 ppb
O_2 measured at outlet	270 ppb
H_2 measured at inlet	0 ppb
H_2 measured at outlet	25 ppb

The neutron flux plus the gamma and neutron intensities were calculated after the test.

The fast neutron flux was 0,7-0,9 10^{14} n/cm^2,s (>1MeV)
The thermal flux was 1,4-2,0 10^{14} n/cm^2,s (<0,625 eV)
The dose rate from gamma radiation was 3,4-4,6 W/gH_2O
The dose rate from neutron radiation was 3,7-4,9 W/gH_2O

3. OXIDE MEASUREMENTS

Following the irradiation, two of the specimens, consisting of exactly the same types of materials in the same geometry, were examined by optical microscopy at 825X magnification in order to measure the oxide thickness. One of the specimens had been in the out-of-core location during the test, while the other specimens had been in-core. The specimens were embedded in epoxy prior to sectioning and polishing, so that the Inconel and Zircaloy were kept in contact. No oxide could be detected anywhere on the test specimen located outside the core illustrated in Figure 4, so the oxide thickness was concluded to be less than 0,5 µm (the microscope resolution). The test specimen exposed inside the core, see Figure 5, was generally covered with a 1-2 µm thick oxide layer, with local areas of accelerated corrosion at, and in proximity to, the points of contact between the Inconel and Zircaloy. The oxide thickness was about 10 µm in these areas, which were a few millimetres in extent.

4. CONCLUSION

The conclusion of this experiment is that it is possible to use the INCA facility in the Studsvik R2 Reactor to develop a significant level of shadow corrosion after only 800 hours of irradiation. Standard Post Irradiation Examination techniques can be used to evaluate the shadow corrosion. Since local accelerated corrosion was not observed on the specimens tested outside the core, shadow corrosion was shown to be an in-core reactor phenomenon.

5 . FUTURE PLANS

The specimen in-core and out-of-core was exposed to the same conditions except the irradiation. Future experiments are planned to be performed in the INCA-loop. The objectives of future tests are to find the parameters that will influence shadow corrosion and to determine the mechanism of shadow corrosion. Parameters that will be /can be tested are type of material, irradiation time, dose and fluence, water chemistry, geometrical aspects etc.

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