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DOUBLE BEAM NEUTRON RADIOGRAPHY FACILITY

of the

RESEARCH ESTABLISHMENT RISØ

by

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6 pages + tables + 1 illustrations

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Abstract

The DR1 reactor at Risø is used as a neutron source for neutron radiography. In the doublebeam neutron radiography facility a neutron flux of an intensity of 1.4 and 1.8 x 10^6 n. $cm^{-2} \cdot s^{-1}$ reaches the object to be radiographed.

The transport and exposure container used for neutron radiography of irradiated nuclear fuel rods is described, and the exposure technique and procedure are reviewed. The mode by which single neutron radiographs are assembled and assessed is described.

This report will be published in the "Neutron Radiography Newsletter" (a publication of the American Society for Nondestructive Testing).

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DOUBLE BEAM NEUTRON RADIOGRAPHY FACILITY
of the
RESEARCH ESTABLISHMENT RISØ

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1. INTRODUCTION

To be able to perform neutron radiography of irradiated fuel rods the DR1 reactor was adapted for that purpose. Many of the fuel rods to be examined by neutron radiography are fabricated at Risø and are irradiated in the 10 MW DR3 reactor. After irradiation the rods are first transported from the DR3 to the Risø Hot Cells, where the fuel elements are disassembled and are undergoing different nondestructive and destructive post irradiation examinations. One of these NDT methods is neutron radiography. In the Hot Cells the rods are placed in special transport containers in which they are transported to the neutron radiography facility at the DR1. Also fuel elements arriving to Risø for post irradiation examination are first disassembled in the Hot Cells. There the individual rods are loaded to the transport container and sent to the DR1. Short fuel pins of a 170 mm length till full-size power reactor rods up to 3 m long have been neutronradiographed at Risø.

Routine neutron radiography has started late in 1975 and since then about 1500 neutron radiographs were taken.

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2. THE DR1 REACTOR AS NEUTRON SOURCE

As neutron source for neutron radiography the DR1 reactor is available at Risø. The technical data of the reactor are the following:

Thermal output - 2 kW

Designer - Atomics International, USA

Date critical - Aug. 15, 1967

Coolant and moderator temperature - light water, 25°C

Reflector - graphite

Fuel - Uranyl sulphate

Enrichment - 19,9%

U_{235} content - 1 kg

Max. neutron flux: thermal - 6×10^{10}, fast - 12×10^{10} $n/cm^2.s$

This reactor, which is used for training and basic research purposes has been adapted to perform neutron radiography.

3. THE DOUBLE BEAM NEUTRON RADIOGRAPHY FACILITY

The Risø double beam neutron radiography facility is schematically shown on fig. 1. Two graphite blocks (3) have been removed from the reflector (1), thus permitting the neutrons from the reactor core (2) to emerge through the reactor shielding as two beams (4) of a 10 x10 cm cross section.

The neutron flux reaching the object to be radiographed has an intensity of 1.8×10^6 $n/cm^2.s$ at the left port and 1.4×10^6 $n/cm^2.s$ at the right port.

The irradiated nuclear fuel rods are transported from the Hot Cells to the DR1 reactor in a dual-purpose transport/exposure container (5). To the back of this container a steel rod (6) is attached by the use of which the rod (8) can be pushed out of the container and positioned before the two neutron ports This part of the rod which has left the shielding container (5) enters a shielded enclosure (7) made of concrete. The imaging foil is introduced behind the fuel rod to be radiographed by means of the machanism (9) consisting of two curved guides, which accomodate the foil.

The neutron beam, originating at the reactor core (2), is collimated in the graphite collimator, having an inlet of 2 cm (vertically) x 8 cm(horizontally), and an outlet of 10 x 10 cm. The distance between the inlet and the exposure surface is 220 cm, which gives an L/d ratio of 110 (in the vertical direction).

The cadmium ratio (measured with gold) is 4.2 at the left port (1.8×10^6 n/cm^2/s) and 3.8 at the right port (1.4×10^6 n/cm^2.s).

4. TRANSPORT AND EXPOSURE CONTAINER

For the purpose of transport of fuel elements between the Hot Cells and the DR1 reactor two multipurpose transport/exposure containers are used. One is designed to accomodate fuel rods up to 2.5 m in length and the other up to 4.5 m.

In the Hot Cells fuel rods to be neutron radiographed are placed in an aluminium canning tube (wall thickness of 1 mm) which protects the container from contamination and at the same time serves for manipulation of the rods during neutron radiography. This Al canning tube, open on one side,is closed by a plug after the rod has been placed inside of it. A steel rod is fastened to the other end of the canning tube. This steel rod can be extended to such a length as to be able to push the rod in the canning tube to the desired position into the neutron beam during radiography. At the end of the steel rod a square or a hexagonal plate (see 6 in fig. 1) can be affixed. With this plate rotation of the rod is possible by 90^o (square plate) or 60^o (hexagonal plate) increments. This rotation is used, when a new projection of the rod during neutron radiography is desired.

At the bottom end of the transport/exposure container a horizontal plate is connected (seen on fig. 1 under the plate 6). In this plate holes have been drilled at 10 cm distances and in those holes a stop is inserted against which the rotation plate (6) is pressed. Going from one position during neutron radiography to the next one, one removes the stop, puts it in the next consecutive hole and shovs the rod in the canning tube by 10 cm.

At the end of a series of neutron radiographs the steering steel rod is pulled back (to the left on fig. 1) and the rod returns to the shielded position in the exposure container. If another projection for neutron radiography is necessary the rod can be then rotated. If, however, the neutron radiography is terminated the upper end of the exposure container (to the right on fig. 1) is closed by an appropriate shielding plug.

5. EXPOSURE TECHNIQUE

Neutron radiography of irradiated fuel rods is performed at Risø using the transfer technique. A 0.1 mm Dysprosium imaging foil is used (40 x 120 mm). This foil is introduced through the guiding mechanism (9 on fig. 1) to be in close contact with the rod under examination. After the exposure (about 30 min for Agfa-Gevaert Structurix D4 film or 90min for Kodak single coated SR film) the Dy foil is removed from the exposure mechanism (9) and transported to the darkroom. Here X-ray film is placed at both sides of the foil and the foil with the film is inserted into a plastic vacuum casette (which assures good contact between the foil and film). The films are exposed by the Dy foil overnight and are developed next day in standard X-ray processing solutions.

The film which was exposed in contact with that side of the foil which was facing the fuel rod is used for assessment purposes and the other film (showing a less sharp picture) is used for filing purposes only.

For routine neutron radiography the double coated D4 X-ray film is used as with this film reasonable exposures can be used during a larger number of neutron radiographs. The single coated SR film is used in special instances, where neutron radiographs of higher quality are required and the longer exposure time is acceptable.

6. EXPOSURE PROCEDURE

The fuel rod under examination is exposed through both neutron ports (4 on figl 1). The first exposure starts when the top of the rod is positioned approximately in the middle of the right part. Simultaneously with the exposure through the right port an exposure through the left port occurs. Due to the differences in the neutron flux intensities the exposure through the left port is a little shorter than through the right port (25 and 30min respectively for the D4 film).

After the termination of the first exposure (through both ports) the rod is moved by 100 mm into the next exposure position. After four consecutive exposures (with a 100 mm shift between them) the rod is moved by 500 mm and a series of four exposures with a 100 mm shift occurs.

The distance between the neutron port axis being 385 mm there is an overlap of the consecutive exposures.

The developed films are next assembled in such a way as to give a single neutron radiograph of the whole rod. This occurs by cutting the overlapping parts of the film. At the bottom of each neutron port two cobalt wires are located. The distance between these two wires in the left port is 80 mm and in the right port 85 mm, whereas the distance between the wires in both ports (left as well as right) is 100 mm. The wires are reproduced on the neutron radiographs as white lines. By measuring the distance of the wires on one radiograph one can see wheather the picture was taken through the left or the right port. Cutting of the overlapping parts of the neighbouring radiographs occurs after measuring the 100 mm distance between the corresponding wires.

7. ASSESSMENT OF NEUTRON RADIOGRAPHS

The developed neutron radiographs are assembled to give a picture of the whole fuel rod under examination. They are next assessed to find defects and measure dimensions. The search for defects is concentrated on five areas of the rod: fuel, cladding, plenum, plugs and instrumentation, which may be included in the fuel rod.

In the fuel, pellets are examined for cracks, chips, dishing and central void. Fuel-to-clad and pellet-to-pellet gap are revealed and assessed. The presence of hydrides in the cladding or plugs can be also revealed.

All irregularities in the plenum (spring, spring sleeve or disc displacement) are well visible on the radiographs.

The fuel column length as well as top of fuel column to plug distance is measured.

An attempt was made to introduce a classification of defects revealed by neutron radiography, in which 20 types defects in the above mentioned five areas are assessed according to their location and intensity.

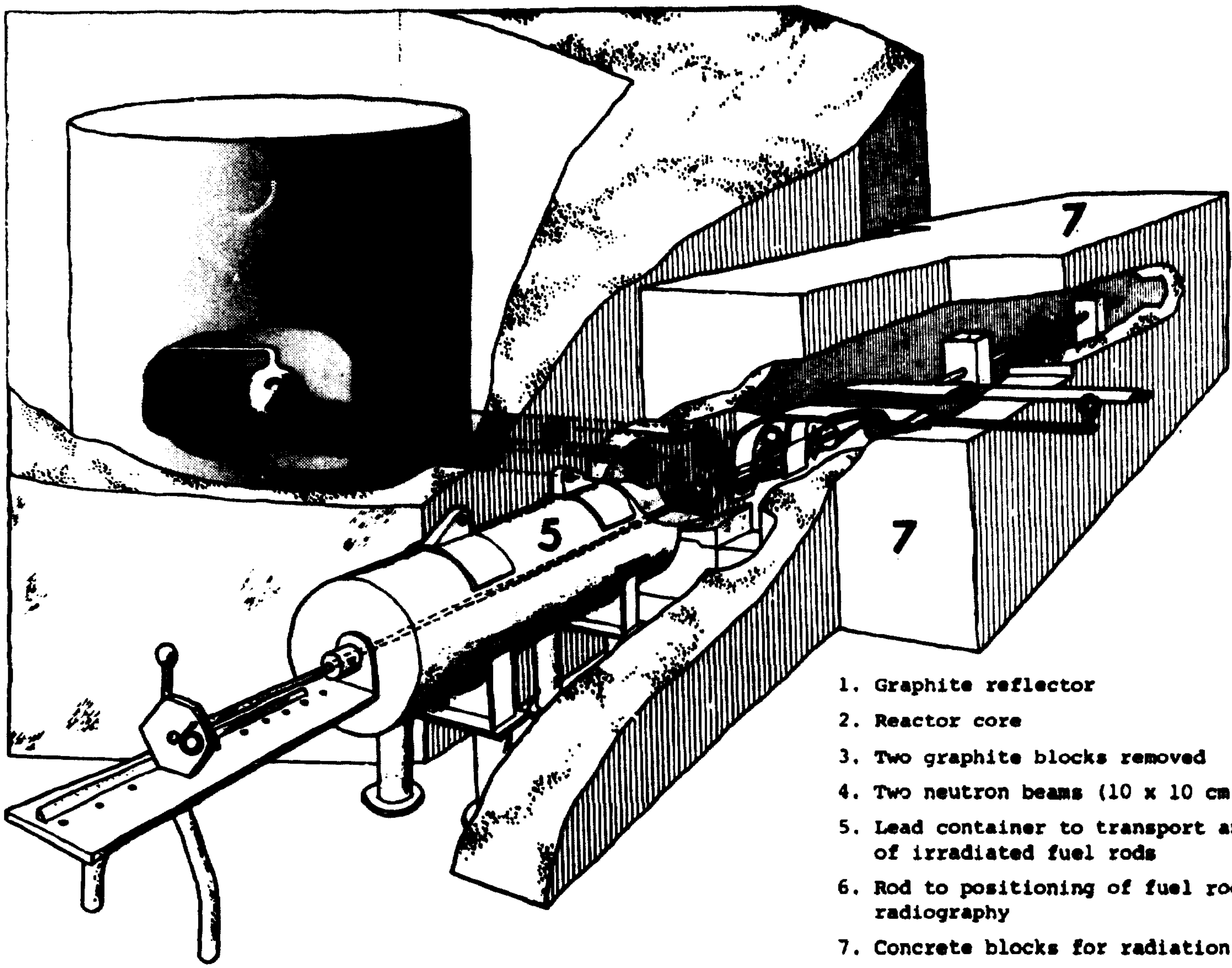

Fig. 1. Double beam neutron radiography facility at Risø.

1. Graphite reflector
2. Reactor core
3. Two graphite blocks removed
4. Two neutron beams (10 x 10 cm)
5. Lead container to transport and handling of irradiated fuel rods
6. Rod to positioning of fuel rod during radiography
7. Concrete blocks for radiation shielding
8. Tube supporting the fuel rod
9. Mechanism for introduction of imaging foils behind fuel rod to be radiographed.