APPLICATION OF NONDESTRUCTIVE METHODS FOR QUALIFICATION OF HIGH DENSITY FUELS IN THE IEA-R1 REACTOR

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ABSTRACT

The IEA-R1 reactor of IPEN/CNEN-SP in Brazil is a pool type research reactor cooled and moderated by demineralised water and having Beryllium and Graphite as reflectors. Since 1990, IPEN/CNEN-SP has been fabricating and qualifying its own U_3O_8-Al and U_3Si_2-Al dispersion fuels. The U_3O_8-Al dispersion fuel is qualified to a uranium density of 2.3 gU/cm^3 and the U_3Si_2-Al dispersion fuel up to 3.0 gU/cm^3. The IEA-R1 reactor core is constituted of the fuels above, with low enrichment in U-235 (19.9% of U-235). Nowadays, IPEN/CNEN-SP is interested in qualifying the above dispersion fuels at higher densities. Fuel miniplates of U_3O_8-Al and U_3Si_2-Al fuels, with densities of, 3.0 gU/cm^3 and 4.8 gU/cm^3, respectively, which are the maximal uranium densities qualified worldwide for these dispersion fuels, were fabricated at IPEN/CNEN-SP. The miniplates were put in an irradiation device, with similar external dimensions of IEA-R1 fuel assemblies (FA), which was placed in a peripheral position of the IEA-R1 reactor core. IPEN has no hot cells to provide destructive analysis of the irradiated fuel. As a consequence, non destructive methods are been used to evaluate irradiation performance of the fuel miniplates: i) monitoring the fuel miniplate performance during the IEA-R1 operation for the following parameters: reactor power, time of operation, neutron flux at the position of each fuel assembly, burnup, inlet and outlet water, and radiochemistry analysis of reactor water; ii) periodic underwater visual inspection of fuel miniplates and eventual sipping test for the fuel miniplate suspected of leakage. The miniplates have been periodically visually inspected by an underwater radiation-resistant camera inside the IEA-R1 reactor pool, to verify its integrity and its general plate surface conditions. A new special system was designed for the fuel miniplate swelling evaluation. The fuel swelling evaluation is being performed by means of the fuel miniplate thickness measurement during the shutdown periods between successive irradiation cycles at the IEA-R1 reactor. During the measuring period, the fuel miniplates are transferred from the reactor core to the measurement system positioned at the pool border.

1. Introduction

Since early 1990's, IPEN has been fabricating and qualifying its own LEU (19.9% of ^{235}U) MTR fuels for use in the IEA-R1 research reactor core. MTR fuel elements had been constructed with U_3O_8-Al dispersion fuel plates with densities of 1.9 (from 1990 to 1996) and 2.3 gU/cm^3 (from 1996 to 1999). Since 1999, IPEN has been fabricating U_3Si_2-Al dispersion fuel with uranium density of 3.0 gU/cm^3 [1]. Nowadays, IPEN/CNEN-SP is interested in qualifying the above dispersion fuels at higher densities, with densities of, respectively, 3.0 gU/cm^3 and 4.8 gU/cm^3, which are the maximal uranium densities qualified by the RERTR program and widely used in the world since 1980's decade. In addition, this dispersion fuel (U_3Si_2-Al) has been considered to be used at the core of the new Brazilian Multipurpose Reactor (RMB), now in the conception phase.

Fuel performance evaluation and nuclear fuel qualification require a post-irradiation analysis of the fuel [2]. IPEN/CNEN-SP has no hot cells to provide destructive analysis of the irradiated nuclear fuel. As a consequence, non-destructive methods have been used to evaluate irradiation behavior of the fuel miniplates.

2. Experimental planning for fuel qualification

Given the lack of laboratorial infrastructure of hot cells to perform post-irradiation examination (PIE) of irradiated fuel in the country, IPEN/CNEN-SP decided to adopt an alternative route to achieve the qualification of its own fuels, based on (i) irradiation of fuel miniplates and, (ii) demonstration of good behavior under irradiation of the tested fuels through the application of non-destructive techniques in the IEA-R1 reactor pool. The planned qualification process [3] for the high densities dispersion fuels U_3O_8-Al (with 3.2 gU/cm^3) and U_3Si_2-Al (with 4.8 gU/cm^3) is based on the experience acquired at IPEN during the qualifications programs of the U_3O_8-Al (1.9 and 2.3 gU/cm^3) and U_3Si_2-Al (3.0 gU/cm^3) dispersion fuels. The route consists of miniplate fabrication according tight specifications [4] and irradiation of fuel miniplates in the IEA-R1 reactor core inside an irradiation device. The miniplate irradiation will continue until the average miniplate burnup reaches 80% (at. U-235). The miniplate evaluation consists of two items: i) monitoring the fuel miniplate performance during the IEA-R1 operation for the following parameters: reactor power, time of operation, neutron flux at the position of each fuel assembly, burnup, inlet and outlet water, and radiochemistry analysis of reactor water; ii) periodic underwater visual inspection of fuel miniplates and eventual sipping test for the fuel miniplate suspected of leakage. The miniplates is periodically visually inspected by an underwater radiation-resistant camera inside the IEA-R1 reactor pool, to verify its integrity and its general plate surface conditions. A new special system was designed for the fuel miniplate swelling determination. The fuel swelling determination is being performed by means of the fuel miniplate thickness measurement during the shutdown periods between successive irradiation cycles at the IEA-R1 reactor. During the measuring period, the fuel miniplates are transferred from the reactor core to the measurement system.

2.1 Criteria for fuel miniplate irradiation tests, inspections and measurements

- Visual inspections and thickness measurements of the irradiated fuel miniplates at the end of each successive burnup period of 5% of U-235.
- The miniplates irradiation should be conducted until they reach high average burnup, about 80%, to demonstrate significant safety margins on the average burnup normally required for discharging the fuel (50% burnup of the initial amount of U-235).
- No leakage of fission products during irradiation
- Blisters should not be formed during irradiation.

2.2 Limitations and applicability

This methodology is applied to the qualification of the dispersion fuel U_3O_8-Al and U_3Si_2-Al, with densities of 3.2 gU/cm^3 and 4.8 gU/cm^3, respectively, fabricated at IPEN/CNEN-SP. For these fuels, LEU uranium densities were qualified by the RERTR program [5, 6] up to 3.2 g U/cm^3 for U_3O_8-Al fuel and 4.8 g U/cm^3 for U_3Si_2-Al. These densities correspond to the practical limits of dispersion fuel fabrication (45% by volume of U_3O_8-Al and 42.5% by volume of U_3Si_2 fuel in the dispersion).

2.3 Irradiation time

Miniplate irradiation should occur under the current operational regime of the IEA-R1 reactor at 3.5 MW, 60 hours per week and 45 weeks per year. However, the reactor can operate up to 5 MW power, with the operational regime of 120 hours per week 45 weeks per year. The time needed to reach a U-235 burnup of 50% and 80% in U_3Si_2-Al miniplates for the two operational regimes of the IEA-R1 has been already performed in the reference [7].

At the actual reactor power of 3.5 MW, the calculated time required to reach the U-235 burnup of 50% and 80% are 1.75 and 2.7 years, respectively. If the reacto power is increased to 5.0 MW, the irradiation times is smaller.

2.4 Frequency implementation of visual inspection, thickness measurements and sipping

The visual inspections and thickness measurements of the fuel miniplates in the reactor pool should be done at the beginning of irradiation and after each period of U-235 burnup of 5%. The irradiation time estimated to reach successive U-235 burnups of 5% in the U_3Si_2-Al miniplates, with 4.8 gU/cm^3, in the irradiation position 36 of IEA-R1 core matrix plate, for 3.5 and 5 MW, are 8 and 4 weeks, respectively. Sipping tests should be conducted for fuel elements suspect of leakage.

3 Methods for fuel miniplate irradiation

For the miniplates irradiation it was designed and built a new Miniplate Irradiation Device (MID), which has the external dimensions of a standard IEA-R1 fuel element. Inside the MID can be housed up to ten U_3O_8-Al and / or U_3Si_2-Al fuel miniplates. Neutronic and thermal-hydraulics calculations as well safety assessment of MID has been already developed [8]. Methodologies were established for miniplates thickness measuring and for swelling calculation, as well as for visual inspection. The fuel miniplates are being irradiated at a peripheral position (position 36) of the IEA-R1 reactor core, inside the MID, showed in the figures 1 and 2.

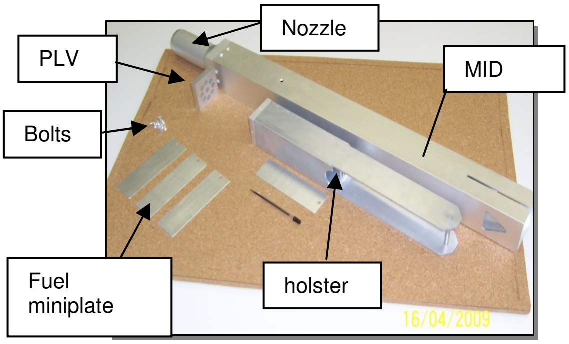

Fig 1. MID components.

Fig 2. Miniplate fuel assembled inside the holster.

4 Nondestructive methods for irradiated fuel miniplates evaluations at the IEA-R1 reactor pool

4.1 Visual inspection

The Irradiated fuel miniplates are being visually inspected by an underwater and radiation-resistant video camera system inside the IEA-R1 reactor pool to verify its integrity and its general surface conditions. The video images obtained from the camera system can be recorded by a DVD recorder. The underwater radiation resistant video camera of the visual inspection system is positioned 2 m from the fuel miniplate thickness measuring system (FMTMS) in an appropriated position to allow visualization of individual miniplate unloading operations. After the visual inspection, each miniplate is conducted to the FMTMS and positioned for thickness measurements. Figures 3 and 4 present the control module of the visual inspection system and the camera Cyberia, mod. LEO, available at IPEN/CNEN-SP.

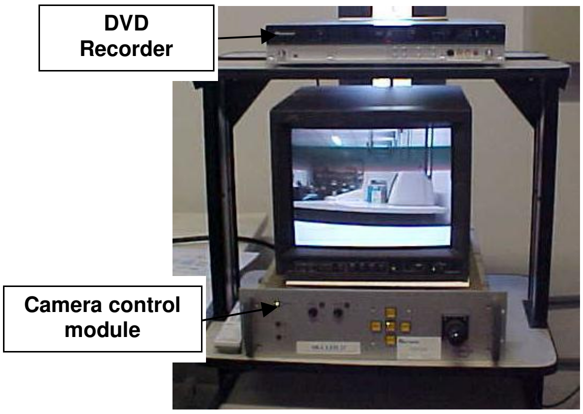

Fig 3. Camera control module.

Fig 4. Camera Cyberia, model LEO

4.2. Sipping tests of irradiated fuel miniplates

Sipping test is a non-destructive technique employed to evaluate the structural integrity of the cladding of irradiated nuclear fuels, which is based on the detection of radioactive fission products leakage to the reactor coolant, usually by means of gamma-ray spectroscopy. Basically, the test consists in the storage of the fuel miniplate suspect of leakage inside a recipient, called here as sipping tube, which contains demineralised water. After an initial homogenization it is collected the first water sample, characterized as background (BG) sample. After a given time in rest, the second water sample is collected from the sipping tube and characterized as the “sipping sample for that in test fuel miniplate”. Additional data collection are: water temperature from inside the sipping tube, the sample collection time and the reactor power during the sipping test; as well the demineralised water characteristics used in the washing (pH, conductivity, chlorides). Radiochemistry analyses are made on the collected samples. The presence of chemistry elements fission products at the samples indicates the existence of some defective part in the fuel miniplate cladding. A detailed description of the sipping tests performed at IPEN is presented at reference [9].

4.3 Method for irradiated miniplate thickness measurement

A system for fuel swelling evaluation, by means of the fuel miniplate thickness measurement performed at the reactor shutdown periods after irradiation cycles, was designed and constructed within the framework of IAEA Project BRA/4/047 and is available at IEA-R1. This device, showed at figure 5, is used inside the reactor pool, beside the spent fuel storage area. It should be operated from the reactor pool border, and allows the measurement of the fuel miniplate thickness along its surface. The swelling can be periodically evaluated in increments of 5% burnup of the initial amount of U-235 until it is achieved an average burnup of 80% of U-235 atoms. It required the fabrication of a device for additional support that will keep both the MID as the case containing the fuel miniplates at a depth of about 2m, next to the bench of the fuel miniplate Thickness system (FMTMS). The thickness measurement is performed by electronic probes (LVTD). The results are obtained by measurement instrumentation connected to the probes.

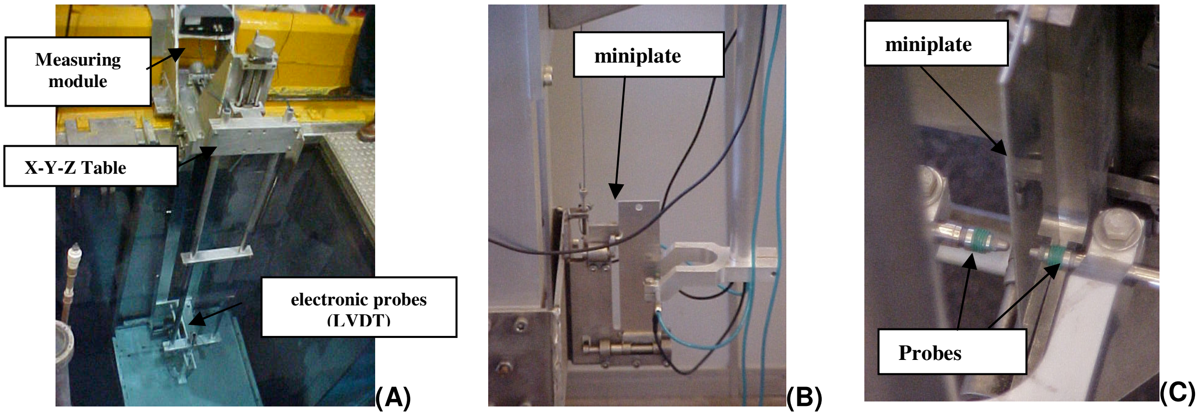

Fig 5. SMENC bench inside the IEA-R1 pool: (A) Structure of metal assembled on the edge of the pool and; (B) e (C) Miniplate at the measuring position

5 Conclusions

The presented nondestructive methods, with emphasis to the visual inspections, sipping tests and thickness measurement for swelling evaluation are important tools to the characterization of the general conditions, verification of the cladding integrity and swelling evaluation of the irradiated fuel miniplates. These nondestructive techniques are providing input to the ongoing U_3Si_2-Al (4,8 gU/cm^3) and U_3O_8-Al (3,2 gU/cm^3) dispersion fuel qualification plan.

6 References

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