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

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ABSTRACT

IPEN/CNEN-SP manufactures fuels to be used in its research reactor - the IEA-R1. To qualify those fuels, it is necessary to check if they have a good performance under irradiation. As Brazil still doesn't have nuclear research reactors with high neutron fluxes, or suitable hot cells for carrying out post-irradiation examination of nuclear fuels, IPEN/CNEN-SP has conducted a fuel qualification program based on the use of uranium compounds (U_3O_8 and U_3Si_2 dispersed in Al matrix) internationally tested and qualified to be used in research reactors, and has attained experience in the technological development stages for the manufacturing of fuel plates, irradiation and non-destructive post-irradiation testing. Fuel elements containing low volume fractions of fuel in the dispersion were manufactured and irradiated successfully directly in the core of the IEA-R1. However, there are plans at IPEN/CNEN-SP to increase the uranium density of the fuels. Ten fuel miniplates (five containing U_3O_8-Al and five containing U_3Si_2-Al), with densities of 3.2 gU/cm^3 and 4.8 gU/cm^3 respectively, are being irradiated inside an irradiation device placed in a peripheral position of the IEA-R1 core. Non-destructive methods will be used to evaluate irradiation performance of the fuel miniplates after successive cycles of irradiation, by means: i) monitoring the reactor parameters during operation; ii) periodic underwater visual inspection of fuel miniplates, eventual sipping test for fuel miniplates suspected of leakage and underwater measuring of the miniplate thickness for assessment of the fuel miniplate swelling.

1. INTRODUCTION

Since early 1990's, IPEN/CNEN-SP manufactures LEU (19.9% of ^{235}U) fuel assemblies (FA) to be used in the IEA-R1 research reactor. FA had been manufactured with fuel plates containing U_3O_8-Al dispersion meats with densities of 1.9 (from 1990 to 1996) and 2.3 gU/cm^3 (from 1996 to 1999). Since 1999, IPEN manufactures FA containing U_3Si_2-Al dispersion fuel with uranium density of 3.0 gU/cm^3 [1]. However, there are plans to increase the uranium density of these fuels up to 3.2 gU/cm^3 (U_3O_8-Al) and 4.8 gU/cm^3 (U_3Si_2-Al). This dispersion fuel (U_3Si_2-Al) has been considered to be used at 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]. As IPEN/CNEN-SP still doesn't have hot cells to provide destructive analysis of the irradiated nuclear fuel, non-destructive methods have been used to evaluate irradiation behavior of the fuel miniplates.

2. EXPERIMENTAL PLANNING FOR FUEL QUALIFICATION

As Brazil still doesn't have nuclear research reactors with high neutron fluxes, or suitable hot cells for carrying out post-irradiation examination (PIE) of nuclear fuels, IPEN/CNEN-SP decided to adopt an alternative route to achieve the qualification of the technological processes used in the manufacture of its high densities dispersion fuels U_3O_8-Al and U_3Si_2-Al. The route is based on: (i) irradiation of fuel miniplates and, (ii) demonstration of good irradiation behavior of the fuel miniplates by means of non-destructive techniques applied in the IEA-R1 reactor pool.

The qualification plan [3] is based on the experience acquired at IPEN/CNEN-SP during the irradiation tests of FA containing low volume fractions of U_3O_8 (1.9 and 2.3 gU/cm^3) and U_3Si_2 (3.0 gU/cm^3) in the dispersion, according tight specifications [4]. The plan consists in the manufacturing of fuel miniplates using U_3O_8-Al (3.2 gU/cm^3) and U_3Si_2-Al (4.8 gU/cm^3) followed by its irradiation in the IEA-R1 reactor inside an irradiation device. The irradiation should continue until the fuel miniplate average burnup reaches 80% (at. ^{235}U). The fuel 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 temperatures and, radiochemistry analysis of reactor water; ii) periodic underwater visual inspection of the fuel miniplates and eventual sipping test for the fuel miniplate suspected of leakage. The fuel miniplates will be periodically inspected by an underwater camera system inside the IEA-R1 pool, in order to verify its integrity and general surface conditions. A measuring system was designed and manufactured for measurements of fuel miniplates thickness, during the shutdown periods between successive irradiation cycles of the reactor, which will allow the fuel swelling evaluation.

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 burnup period of 5% of ^{235}U.
- 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 ^{235}U).
- No leakage of fission products should occur during irradiation.
- Blisters should not be formed during irradiation.

2.2. Limitations and irradiation time

The fuels are the uranium compounds U_3O_8 and U_3Si_2 dispersed in Al matrix, with densities of 3.2 and 4.8 gU/cm^3 respectively, manufactured at IPEN/CNEN-SP. These are the maximum values qualified by the RERTR program [5, 6] for these dispersion fuels and correspond to the practical limits of the fuel fabrication (45% by volume of U_3O_8-Al and 42.5% by volume of U_3Si_2 fuel in the dispersion).

Miniplate irradiation is on going at the IEA-R1 reactor (which currently operates at 4.5 MW power, 62 hours per week and 45 weeks per year). However, the reactor can operate up to 5.0 MW power, with the operational regime of 120 hours per week 45 weeks per year [7]. The whole irradiation time needed to reach ^{235}U burnup of 50% and 80% in U_3Si_2-Al miniplates for these two operational regimes of the IEA-R1 has been estimated. At the reactor power of 4.5 MW, the calculated time periods required to reach the ^{235}U burnup of 50% and 80% are too long, about 12.7 and 20.3 years respectively. Under reactor power operation at 5.0 MW and considering the operational regime of 120 hours per week, 45 weeks per year, the irradiation times are shorter, about 5.8 and 9.3 years respectively.

2.3. Frequency of the visual inspection, thickness measurements and sipping tests

The visual inspections and thickness measurements of the fuel miniplates in the reactor pool should be done after reaching each successive ^{235}U burnup of 5% (initial amount of ^{235}U), which represents a irradiation period about 7 months.

3. METHODS FOR FUEL MINIPLATE IRRADIATION

For the miniplates irradiation it was designed and built a miniplate irradiation device (MID), which has the external dimensions similar those of a standard IEA-R1 fuel element. The MID components are tube, nozzle, holster and bolts, all these in aluminum. 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 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 Figs. 1 and 2.

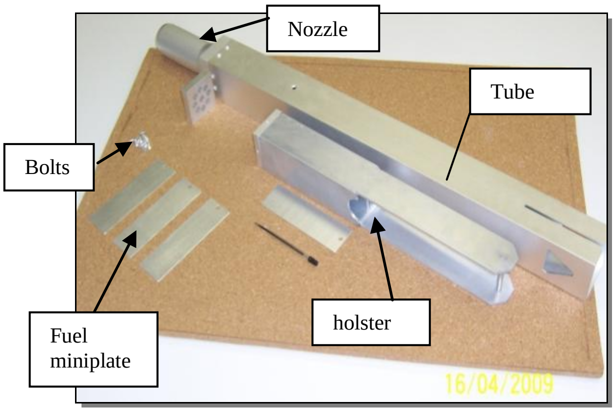


Figure 1. Miniplate irradiation device (MID)

Figure 2. Fuel miniplates assembled inside the holster.

4. NON-DESTRUCTIVE METHODS FOR IRRADIATED FUEL MINIPLATE EVALUATIONS AT THE IEA-R1 REACTOR POOL

4.1. Visual inspection

Irradiated fuel miniplates are visually inspected by an underwater and radiation-resistant video camera system inside the reactor pool, in order to verify its integrity and general surface conditions. The video images obtained from the camera system can be recorded by a

DVD recorder. The underwater camera is positioned 2 m away 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. Figs. 3 and 4 present the control module of the visual inspection system and the camera Cyberia mod. LEO, available at IPEN/CNEN-SP.

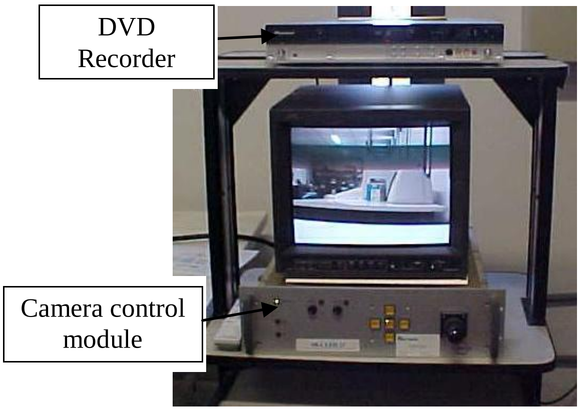


Figure 3. Camera control module.

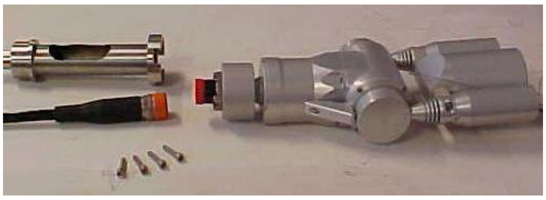


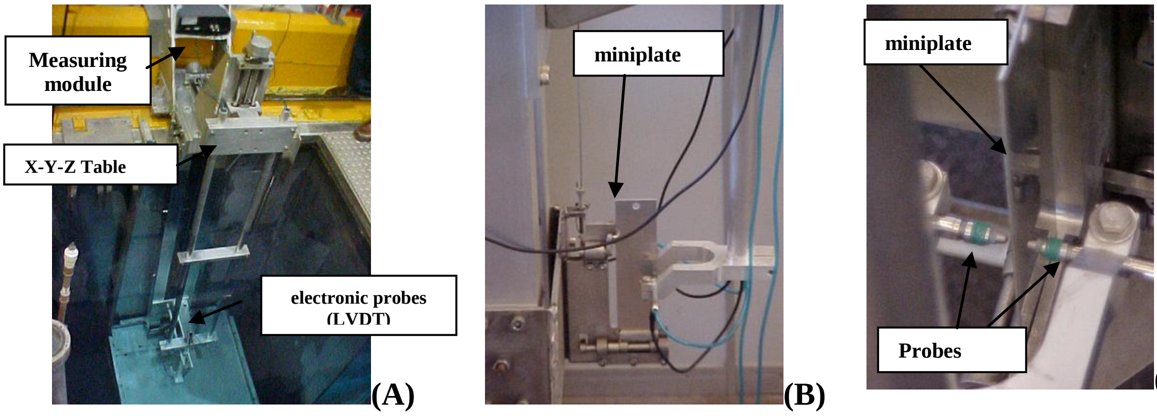
Figure 4. Camera Ciberia, model LEO

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 deionized water. After an initial homogenization, the first water sample is collected and 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 fuel miniplate in test”. 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 deionized water characteristics used in the washing (pH, conductivity, chlorides). Radiochemistry analyses are made on the collected samples. The presence of 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 in reference [9].

4.2. Method for thickness measurement of irradiated miniplate

A system for fuel swelling evaluation, by means of the fuel miniplate thickness measurement performed during 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 Fig. 5, is used inside the reactor pool, beside the spent fuel storage area. The swelling can be periodically evaluated in increments of 5% burnup of the initial amount of ^{235}U until it is achieved an average burnup of 80% of ^{235}U atoms. It was required the manufacturing of a device for additional support that will keep both the MID and the case containing the fuel miniplates at a depth of about 2 m, next to the bench of the Fuel Miniplate Thickness Measuring System (FMTMS). The thickness measurement is performed by electronic probes (LVTD). The results are obtained by measurement instrumentation connected to the probes.



(A) (B) (C)

Figure 5. FMTMS bench inside the IEA-R1 pool: (A) Structure of metal assembled on the edge of the pool; (B) e (C) Fuel miniplate at the measuring position.

5. CONCLUSIONS

As a consequence of the low neutron fluxes in the IEA-R1, the duration of the fuel miniplates irradiation tests are larger than those typically observed in the tests reactors abroad, with higher neutron fluxes (> 10^{14} n/cm^2.s). 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. These nondestructive techniques should provide original results to the fuels qualification plan at IPEN/CNEN-SP.

REFERENCES

1. J. A. Perrotta; J. E. R. Silva, "Estratégia de utilização de combustíveis MTR de alto teor de urânio para operação do reator IEA-R1 a 5 MW", *Proceedings of VI CGEN Meeting*, Rio de Janeiro, Brazil, Oct 27 to Nov 01, 1996, Vol. 1. (1996).
2. "Good Practices for Qualification of High Density Low Enriched Uranium Research Reactor Fuels." Nuclear Energy Series Nr. NF-T-5.2, International Atomic Energy Agency (IAEA), Vienna. http://www-pub.iaea.org/MTCD/publications/PDF/Pub1400_web.pdf (2009).
3. A. T. Silva; L.A.A. Terremoto; J.E.R. Silva; C.T. Almeida; M.A. Damy; P.E. Umbehaun, M. Yamaguchi, "Qualification program of research reactor fuels manufactured at IPEN-CNEN/SP". Elsevier. *Progress in Nuclear Energy* **50**, pp.795-799 (2008).

4. "Research reactor core conversion guidebook - Volume 4: Fuels- (Appendices I-K)". TECDOC 643, International Atomic Energy Agency (IAEA), Vienna. IAEA-TECDOC-643 (April 1992) Volume 4: Fuels, Appendix I-1.1 (1992).
5. A. Travelli, "The RERTR Program Status and Progress", *Proceedings of the XVIII International RERTR Meeting*, September 17-21, 1995, Paris, France (1995).
6. "*Currently-Qualified Fuels : RERTR- Reduced Enrichment Research and Test Reactors"*. Argonne National Laboratory (ANL), Argonne, http://www.rertr.anl.gov/QualFuel.html (2010).
7. D. B. Domingos; A. T. Silva; P. E. Umbehaun; J. E. R. Silva; T. N. Conti; M. Yamaguchi, "Neutronic, Thermal-Hydraulic and Accident Analysis Calculation for an Irradiation Device to be Used in the Qualification Process of Dispersion Fuels in the IEA-R1 Research Reactor", *Proceeding of International Nuclear Atlantic Conference - INAC 2009*, Rio de Janeiro. v. 1 p. 01-09 (2009).
8. D. B. Domingos, *Cálculos Neutrônicos, Termo-hidráulicos e de Segurança de um Dispositivo para Irradiação de Miniplacas (DIM) de Elementos Combustíveis Tipo Dispersão*, MSc Dissertation (In portuguese) - São Paulo /Brazil (2010).
9. C. A. Zeituni; L. A. A. Terremoto; J. E. R. Silva, "Sipping tests on a failed irradiated MTR fuel element". *Proceeding of PHYSOR 2004 - The Physics of Fuel Cycles and Advanced Nuclear Systems: Global Developments.* Chigago, Illinois, April 25-29, on CD-ROM, Americam Nuclear Society, Lagrange Park, IL (2004).