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Three Heavy Reflector Experiments in the IPEN/MB-01 Reactor: Stainless Steel, Carbon Steel, and Nickel

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The heavy reflector experiments performed in the IPEN/MB-01 research reactor facility comprise a set of critical configurations employing the standard 28x26-fuel-rod configuration. The heavy reflector, either Stainless Steel, Carbon Steel or Nickel plates, was placed at the west face of this reactor. 32 plates around 3.0 mm thick were used in all the experiments. The aim was to provide high quality experimental data for the interpretation and validation of the SS-304 heavy reflector calculation methods. The experiments of Carbon Steel, which is composed mainly of iron, and Nickel were performed to provide a consistent and an interpretative check to the SS-304 reflector measurements. The experimental data comprise a set of critical control bank positions, temperatures and reactivities as a function of the number of the plates. The competition between the effect of thermal neutron capture in the heavy reflector and the effect of fast neutrons back scattering to the core is highlighted by varying the reflector thickness. For the Carbon Steel case the reactivity gain when all the 32 plates are inserted is the smallest one, thus demonstrating that Carbon Steel or essentially iron does not have the same reflector properties as the Stainless Steel or Nickel plates do. Nickel has the highest reactivity gain, thus demonstrating that this material is better reflector than Iron and Stainless Steel. The theoretical analysis was performed by MCNP-5 with the nuclear data library ENDF/B-VII.0. It was shown that this library has a very good performance up to thirteen plates and overestimates the reactivity for higher number of plates independently of the type of the reflector.

I. INTRODUCTION

Currently, heavy reflectors composed of Stainless Steel (SS) (about 10cm thick) are being considered as an alternative for Light Water Reactor (LWR). The aim is to limit the radial leakage, in particular by back scattering the fast neutrons to the core. The major awaited improvements of such a reflector are: a better reflector savings, i.e., an economy in fissile material, an optimized radial power distribution, and the reduction of fast fluence to the vessel, leading to a plant life extension. The purpose of this work is to present the effect of three types of heavy reflectors on several configurations of the IPEN/MB-01 core.

The heavy reflector experiments considered here are not the only ones of its kind. Similar experiments for the case of Stainless Steel have been performed in other facilities [1]. What makes the IPEN/MB-01 experiments unique is: a)the utilization of plates instead of solid pieces of heavy materials thus allowing the study of the effect of the reflector content as a function of its total thickness, b) the utilization of Nickel plates, and c) the evaluation and approval of the Stainless and Carbon Steel experiments for the IRPhE (International Reactor Physics Experiments) [2].

II. EXPERIMENTAL CONFIGURATION

The IPEN/MB-01 core setup for this experiment and the reflector plate disposition are shown in Fig. 1. The IPEN/MB-01 research reactor facility is a critical zero power facility specially designed to measure a great variety of parameters of reactor physics to be used as benchmarks for the evaluation of calculation methods and related nuclear data libraries. It is located in São Paulo, Brazil, and it reached first criticality in 1988.

The IPEN/MB-01 core consists of a rectangular arrangement of 28 by 26 fuel rods of UO2 enriched at 4.3486% (in weight), and a stainless steel (SS-304) cladding, immersed in a demineralized light water tank. A complete core description of the IPEN/MB-01 core can be found in the ICSBEP (International Criticality Safety Benchmark Evaluation Project) handbook [3]. The control bank (BC) at the upper right corner is named BC1 while the one at lower left corner is named BC2. The other two bank sets placed diagonally (upper left corner and lower right corner) are the safety banks. The chosen

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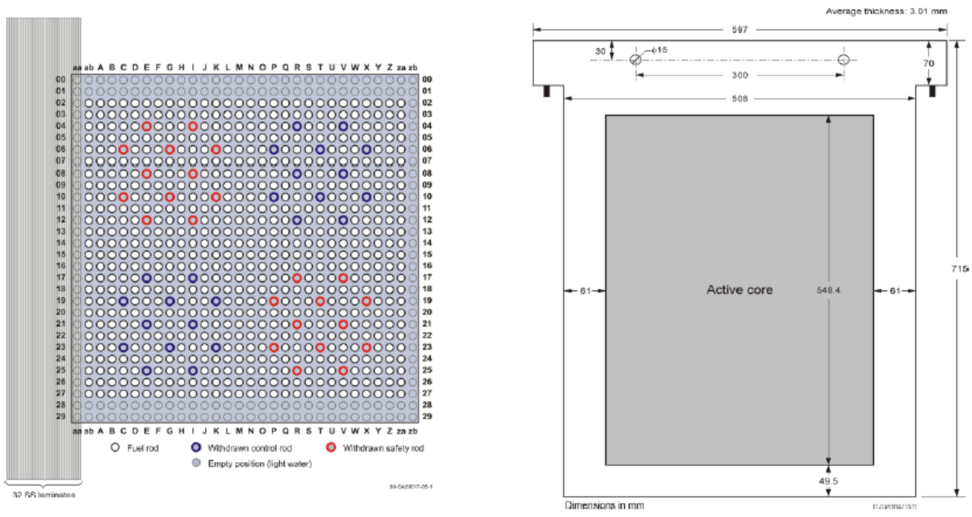

FIG. 1. Experimental core configuration and plate front view relative to the core.

distance between the last fuel rod row and the first plate was 5.5 ± 1.0 mm.

The experiments consider SS-304, Carbon Steel and Nickel reflectors with a varying thickness at the west face of the IPEN/MB-01 core. The experiments were performed with each type of heavy reflector individually. Carbon Steel and Nickel experiments were performed to provide a consistent and an interpretative check for the SS-304 reflector experiment. 32 plates (around 3 mm thick) of each type of reflector were introduced in the west face of this reactor and the quantities such as critical control bank configuration, temperatures and reactivities were measured as a function of the number of plates. The theoretical analysis is performed employing MCNP-5 [4] computer code with the ENDF/B-VII.0 nuclear data library [5]. The Stainless Steel and Carbon Steel experiments have already been evaluated and approved for inclusion in the IRPhE handbook. The Nickel experiment is still in the process of evaluation for inclusion in this handbook and some points such as uncertainty analysis are under development and they are not completed yet.

III. THEORY-EXPERIMENT COMPARISONS

Fig. 2 shows the theory-experiment comparisons for the reactivity for all kinds of heavy reflector plates performed in this work. Both the measured and calculated reactivities inserted by the plates refer to the condition without plates. Fig. 2 shows that the competition between the effect of thermal neutron capture in the heavy reflector and the effect of fast neutrons back scattering to the core is highlighted by varying the reflector thickness. Both the measured data and the calculated data show this characteristic. When the number of plates are small (around 4), the neutron absorption in the plates is more important than the neutron reflection and the reactivity decreases. This condition holds up to a point where the neutron reflection becomes more important than the neutron absorption in the plates and so the reactivity increases. The neutronic importance of a thermal neutron scattered back to the core by a water reflector is larger (in term of ability for fuel fission) than a fast neutron. However, a lot of fast and epithermal neutrons are also scattered back through Stainless Steel, and this compensates their small neutron importance.

The theoretical values are from MCNP5 which can model the IPEN/MB-01 core with plenty of details. As shown in Fig. 2, the calculated reactivities show a good agreement up to thirteen plates independently of the type of heavy reflector considered here. For Carbon Steel, good agreement is reached even for fifteen plates. When the neutron reflection dominates the neutron transport phenomena in the reflector region (number of plates higher than 15), the disagreement becomes more pronounced. For this region and for all the heavy reflector cases analyzed in this work the calculated values are consistently overpredicted. There are no experimental data for Chromium; one of the constituents of the Stainless Steel, which would make the comparisons here more consistent, but it is believed that the tendency of the nuclear data of this nuclide would be the same as that of Iron and Nickel. Therefore, the reason for the overprediction of the calculated values of Stainless Steel may be credited to the overprediction of the neutron reflection properties of Iron, Nickel and Chromium.

IV. CONCLUSIONS

The heavy reflector experiments in the IPEN/MB-01 research reactor facility have been successfully per-

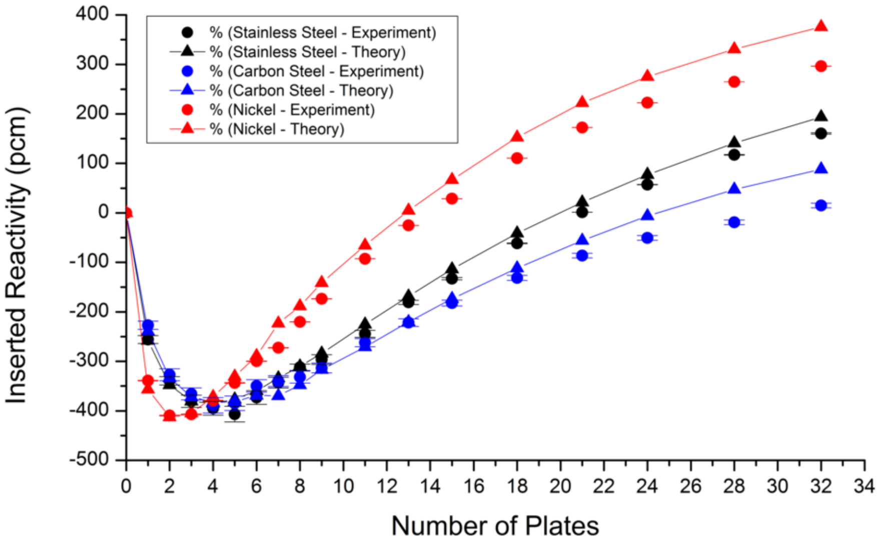

FIG. 2. Theory-Experiment comparison for the heavy reflector experiment.

formed. The uncertainties are well understood and suitable for a benchmark problem. All the experiment results show clearly the competition between neutron absorption and neutron reflection in the heavy reflector. The analyses reveal that the MCNP5 calculated values together with ENDF/B-VII.0 library agree well with the experiment up to thirteen plates and after that the calculated results are overestimated. These trends were found independently of the type of the heavy reflector employed in the experiments.

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