COMMISSIONING OF THE NEW LEU CORE OF THE PORTUGUESE RESEARCH REACTOR

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ABSTRACT

The 1 MW Portuguese Research Reactor (RPI) switched from high-enriched uranium (HEU) to low-enriched uranium (LEU) in September 2007. The core conversion was done under IAEA's Technical Cooperation project POR4016, with financial support from the US and Portugal. The safety analyses for the core conversion were made with the assistance of the RERTR program. This paper presents the measurements done during the start-up program and compares them with an as-built MCNP model. The performance of the new LEU core is compared to that of previous HEU cores.

1. Introduction

The Portuguese Research Reactor (RPI) is a 1 MW, pool-type reactor, built by AMF Atomics and commissioned in 1961. The activities currently underway in the RPI cover a broad range from irradiation of electronic circuits to calibration of detectors for dark matter search, as well as by more classical subjects such as neutron activation analysis. Most of these activities use in-pool irradiations.

The RPI was commissioned in 1961 with LEU fuel. However, it was later converted to HEU fuel for economic reasons. In 1999 Portugal declared its interest to participate in the Foreign Research Reactor Spent Nuclear Fuel Acceptance Program (FRRSNF). A commitment was made to stop using HEU after May 12, 2006 and return all HEU fuel until May 12, 2009. The core conversion to LEU was done within IAEA's Technical Cooperation project POR4016 with financial support of the US and Portuguese governments. An extension on the use of HEU until May 31, 2007 was granted by the Department of Energy, in order to minimize the downtime of the reactor. The actual conversion was done in September 2007. Table 1 summarizes the main milestones of the project.

A feasibility study was performed during 2005 with the assistance of the RERTR program at Argonne National Laboratory. Uranium silicide (U_3Si_2-Al) dispersion fuel with a density of 4.8 g/cm^3 was selected because of its widespread use in research reactors and for the relatively large number of manufacturers. The feasibility study also had the goal of minimizing the number of assemblies required for operation during the current FRRSNF acceptance window. The new LEU standard assembly has ^{235}U loading of 376 g vs. 265 g for an HEU standard

* Work supported by the U.S. Department of Energy, National Nuclear Security Administration, under Contract No. DE-AC02-06CH11357.

assembly. With this design the core size remained unchanged, at 12 assemblies, and only 14 assemblies are required for operation until May 2016 [1]. The number of plates (18 for standard and 10 for control assemblies) was kept the same as for the HEU fuel.

Milestone	Planned	Effective
Commitments for funding	Mid 2005	As planned
Feasibility study	End of 2005	As planned
Safety studies	Mid 2006	End of 2006
Project and Supply Agreement	Mid 2006	Early 2007
Fuel manufactured	End of 2006	As planned
Regulatory Approval	End of 2006	August 2007
Conversion	Early 2007	September 2007

Tab. 1: Milestones for the conversion project

The results of neutronic studies, steady-state thermal-hydraulic analyses and accident analyses demonstrated that the RPI could be operated safely with the new LEU fuel [2]. The submission of the safety documentation for approval suffered a 6 month delay from planned. The IAEA initiated the review of the documents shortly after their reception. Revised documents were submitted in June 2007 addressing the issues raised during review. The IAEA provided a letter of support for the conversion in late June and the licensing body of the RPI approved the conversion in August 2007.

The most challenging aspect of this project was the conclusion of the required tripartite agreement between the IAEA and the US and Portuguese Governments, which involved several interactions with the two governments, the IAEA and the European Commission.

2. Conversion

Fig. 1 shows the initial LEU core configuration. LS1 through LS7 are standard assemblies and LC1 through LC5 are control assemblies, NS is a Sb-Be neutron source, FC a fission chamber and the DA are hollow dummy assemblies. The hollow dummy assemblies were introduced in the LEU core in order to improve the thermal hydraulic safety margins [2].

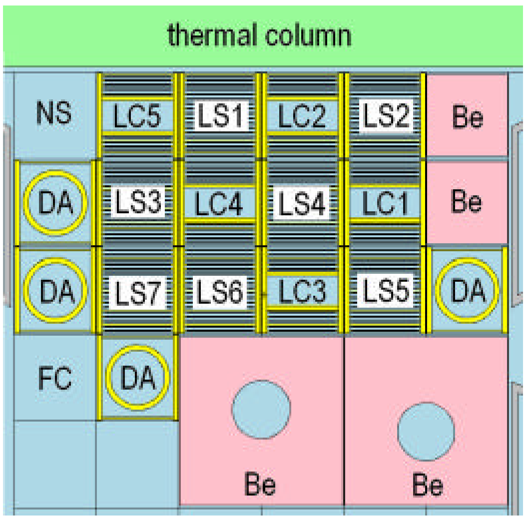

Fig. 1. Initial LEU core configuration, adapted from MCNP model of core.

The shim-safety rods B1 to B4 are mounted in assemblies LC1 to LC4; the regulating rod, BR, in LC5. The regulating rod was calibrated using the positive period method. The shim-safety rods were calibrated in pairs B1/B2 and B3/B4 by comparison with a known displacement of the regulating rod. At the end of these calibrations, the safety parameters of Table 2 were determined, where B1 through B4 represent the shim-safety rod worth. The quoted uncertainties of 3% derive directly from the uncertainty in the calibration of the regulating rod and its propagation to the other parameters through the calibration process.

Parameter (%?k/k)		Description	Required in OLC	Measured
1	Core Excess Reactivity	E	< 4.80	4.11 ± 0.12
2	Total Shutdown Subcriticality	E – (B1+B2+B3+B4+BR)	< -3.00	-9.09 ± 0.27
3	Min. Shutdown Subcriticality	E – (B1+B2+B3)	< -1.00	-4.73 ± 0.14
4	Regulating Rod Worth	BR	< 0.60	0.33 ± 0.01

Tab. 2: Compliance with Safety Parameters

All safety parameters obtained from the rod calibrations satisfy the requirements of the OLC.

3. Neutron fluxes

Thermal, epithermal and fast neutron fluxes were measured in 13 grid positions, including the 4 hollow dummy assemblies in positions 62, 63, 13 and 54, as shown in Fig. 2.

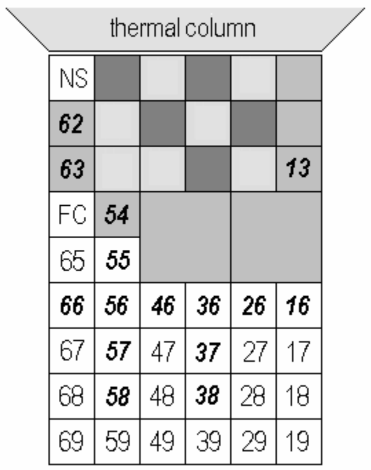

Fig. 2. Plot of core grid showing highlighted in bold and italic the positions where neutron fluxes were measured.

The RPI does not have a regular fuel cycle, with a standard core configuration. Configurations with up to 15 HEU assemblies were previously used; configurations up to 13 LEU assemblies are now foreseen. For the purposes of flux comparisons, the best match with the current LEU core is the first HEU core [3], implemented in February 1990; it is not a perfect match, since the HEU core had one Be reflector in position 13 and the fission chamber in position 54.

Table 3 compares the measured thermal fluxes at core mid-height. Measurements were done at 1 MW and 100 kW. The average ratio between the thermal fluxes measured in the HEU and LEU cores is 0.9 $\pm$ 0.3, covering two orders of magnitude of the values. We are conservatively assuming an uncertainty of 10% and 20% for the measured LEU and HEU flux values, respectively. From the available data there is no clear loss or gain of thermal neutron flux with the conversion to LEU. Furthermore, the LEU core has 2 additional irradiation positions, inside the hollow dummy assemblies in positions 13 and 54, which have thermal neutron fluxes of 1.9×10^{13} and 1.8×10^{13} $n/cm^2/s$, respectively.

Grid position	**LEU thermal flux ($n/cm^2/s$) ± 10%**	**HEU thermal flux ($n/cm^2/s$) ± 20%**	**Ratio HEU/LEU (± 22%)**
55	7.7E12	5.4E12	0.7
56	1.7E12	1.2E12	0.7
46	2.8E12	2.6E12	0.9
36	3.9E12	3.2E12	0.8
26	2.8E12	3.0E12	1.1
57	2.8E11	2.4E11	0.9
37	5.0E11	4.5E11	0.9
38	5.0E10	5.6E10	1.1

Tab. 3: Comparison between thermal neutron fluxes for HEU and LEU comparable cores.

Gamma dose rates were also measured in all free grid positions, at mid-height of the core, using a Radiotechnique Compelec CRGA11 ionization chamber. The measurements were done at a power of 100 kW and extrapolated to 1 MW using the ^{16}N linear channel. The ratio of HEU to LEU values is 1.1 ± 0.2 covering one order of magnitude of the values.

4. Updated MCNP model

The MCNP core model used in the feasibility and safety studies [1,2] was updated using the extensive data provided by the fuel manufacturer CERCA. Measured values for the uranium isotopes, impurities in fuel meat and cladding were introduced, as well as measured values for the plate and clad thickness.

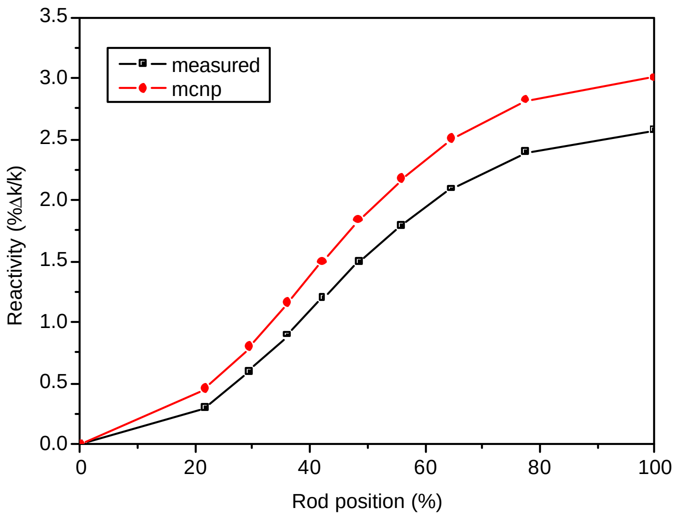

Fig. 3. Integral rod worth curve of shim-safety rod 1: measured vs. MCNP calculated values. The lines were drawn to guide the eye.

Since there is considerable shadowing between the shim-safety rods in this compact core, the integral worth of the rods was calculated by simulating the actual rod positions that were used in the measurement. The same procedure was applied before for the HEU cores with excellent results [1]. Only preliminary results are shown here. A comparison of calculated and measured values in determining the worth of shim-safety rod B1 is plotted in Fig. 3. The integral worth was measured to be 2.6 ± 0.1 %?k/k and calculated to be 3.0% ?k/k.

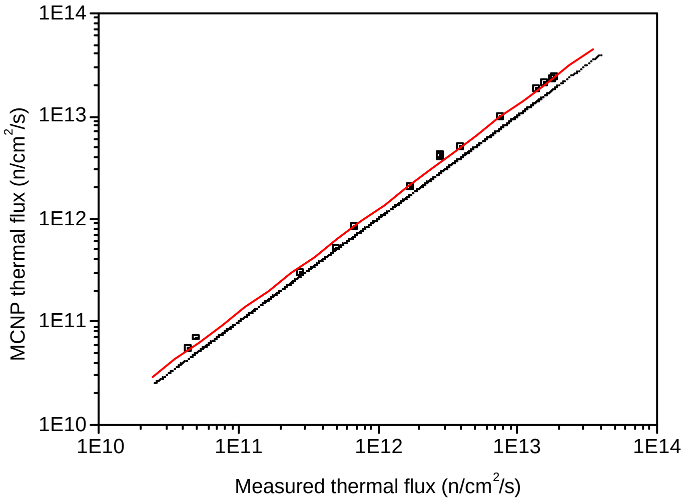

Fig. 4. Thermal neutron fluxes: measured vs. MCNP values. The top line is a least-squares linear fit; the bottom line shows a 1:1 ratio.

Figure 4 shows preliminary results of the calculated thermal neutron fluxes vs. measured values. Calculated values are along a straight line with a small offset to the 1:1 relationship over nearly 3 orders of magnitude.

Conclusions

The RPI switched from HEU to LEU in September 2007 within IAEA project POR4016, with financial support from the US and Portugal. For in-pool irradiations, the new LEU core has the same performance as a comparable HEU core. The core change also allowed the introduction of two high-flux positions which did not exist before, increasing the pool irradiation capabilities. Work in progress includes the measurement of neutron fluxes and gamma dose rates in the beam tubes and improvements in the as-built MCNP model of the core.

References

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