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Neutron Spectrum Effects On The Radial Power Distribution In The Fuel Pin: PWR Versus ALFRED-Type Cells

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ABSTRACT

The history of Romania's nuclear landscape spans the decommissioned 2 MW Soviet VVR-S light water research reactor at Măgurele, the American-supplied TRIGA facility at the Institute for Nuclear Research in Pitești, commissioned in 1980 and pairing a 14 MW steady-state core with an ACPR annular pulsed core, the two operating Canadian CANDU pressurized heavy water reactors at the Cernavodă Nuclear Power Plant, and a recent participation in lead-cooled fast reactor development through the European ALFRED demonstrator. Across the European fleet the picture is more uniform: the pressurized water reactor dominates both the reactors in operation and most new construction projects in the European Union, which makes it the natural reference against which a fast-spectrum concept is measured. A nuclear engineer trained in Romania and in the EU as a whole today will work with both, so a like-for-like comparison of how the neutron spectrum governs fuel behavior serves workforce preparation and design alike.

The purpose of this work is to quantify how the neutron spectrum governs the radial distribution of fission power inside a single fuel pin. Two pin cells were evaluated by an identical method and with the same nuclear data library, so that the only intended difference between them is whether the coolant moderates neutrons. The first reproduces standard PWR geometry: 3% enriched UO2, Zircaloy-4 cladding, 1.26 cm lattice pitch, and light water moderation with the thermal scattering law. The second reproduces an ALFRED inner-zone pin from published design parameters: MOX at 22% Pu, an annular pellet with a 1.0 mm central bore, AIM1 cladding, a hexagonal lattice at 1.386 cm pitch, and liquid lead coolant. Both run at

operating temperatures, so Doppler broadening is included. Calculations used the continuous-energy Monte Carlo code OpenMC, with the fuel divided into ten concentric rings of equal volume.

The infinite multiplication factors are 1.31498 plus or minus 0.00063 for the thermal case and 1.46658 plus or minus 0.00048 for the fast case. In the thermal case, spatial self-shielding produces a radial peaking factor of 1.046, the power at the fuel periphery exceeding the pin average by 4.6%. In the fast case the peaking factor is 1.0003, statistically indistinguishable from uniform, and the calculated spectra confirm the mechanism independently. The difference follows from the ratio of neutron mean free path to pin radius: short in a thermal spectrum, so the outer fuel shields the interior; of the order of centimetres in a fast spectrum, leaving the pin effectively transparent to its own neutrons. The study concludes that spectrum alone, with geometry and method held fixed, accounts for the difference between a measurably peaked and an effectively flat profile. A flat profile removes the power-shape contribution to peak fuel temperature, a design margin that fast-spectrum concepts such as ALFRED can draw on in fuel rating or pin diameter. The study is limited to an infinite lattice and to fresh fuel; further work will address burnup and benchmark validation.