Optimization Study on the Fuel Cycle Length for Small PWR Concepts

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This work investigates the fuel cycle length for a once-through fuel loading strategy for a class of pressurized water reactor (PWR)-based small modular reactors (SMRs). A conventional 17×17 PWR fuel assembly model is used to estimate the maximum achievable fuel cycle length through lattice-level calculations. The optimization studies focus on varying fuel compositions and radial enrichment zoning strategies. Depletion simulations implemented within the Monte Carlo code OpenMC are performed to quantify the evaluation of the infinity multiplication factor (k_{inf}) burnup for both conventional UO_2 fuel assemblies and assemblies incorporating burnable absorbers with heterogeneous enrichment zoning. The long-term objective of this research is to establish representative fuel assembly and reactor core models consistent with the design characteristics of the state-of-the-art industry small PWR concept such as the Last Energy SMR-20 reactor, for which the full details are not yet publicly available.

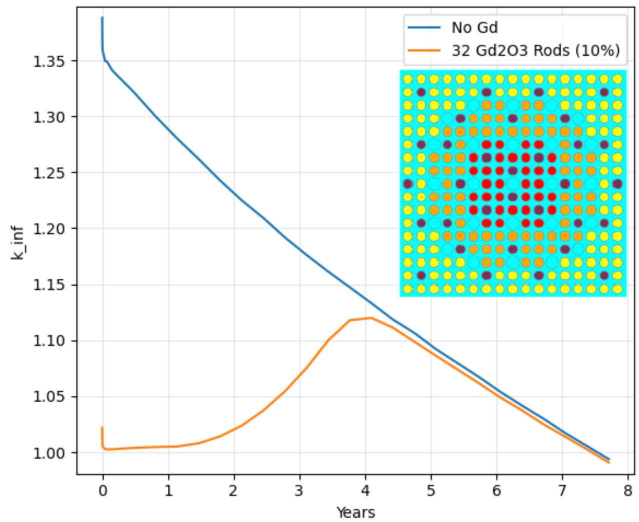

Figure 1. The k_{inf} changes with burnup for two assembly models with 17×17 rod configurations.

To better reflect SMR operating conditions, a reduced fuel specific power was assumed relative to that of large commercial PWRs. Based on estimates of fuel mass, thermal power, and fuel cycle length, a representative specific power of approximately 13.89 W/gU was applied in the depletion calculations. Enrichment distributions, burnable absorber concentrations, and fuel zoning configurations were systematically varied while maintaining consistent geometric and operating conditions. The resulting burnup dependent k-eff trends were analyzed to evaluate initial excess reactivity suppression, mid-cycle reactivity stability, and end-of-cycle performance.

The preliminary calculation results indicate that optimized enrichment zoning and absorber placement can significantly reduce early-cycle reactivity peaks while maintaining acceptable end-of-cycle reactivity margins. The low power-density assembly design can operate continuously for approximately 7-7.5 years without refueling. These findings provide valuable insight into fuel management strategies for small PWR designs and support the development of optimized SMR fuel assembly models based on depletion-based neutronic analysis.