MONTE CARLO CALCULATIONS APPLIED TO SLOWPOKE FULL-REACTOR ANALYSIS

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ABSTRACT – Stochastic Monte Carlo calculations are applied to the full-reactor analysis of the SLOWPOKE design. The temperature feedback of reactivity calculated by MCNP for either HEU or LEU core is in good agreement with the experimental data, with a k-eff bias of +3.3 mk for a HEU core and +6 mk for a LEU core. Two methods have been developed for core following: 1) MCNP (for transport calculation) in conjunction with WIMS (for fuel burnup advancement) and 2) SERPENT (that combines both transport and burnup capabilities), and both show very consistent results on core excess reactivity and detailed power distribution vs burnup and shim.

1. Introduction

SLOWPOKE (<u>S</u>afe <u>Low</u> <u>Po</u>wer <u>K</u>ritical <u>E</u>xperiment [1]) reactors are AECL-designed research reactors of pool type, loaded with either HEU (93% U-235) or LEU (20%) fuel elements, cooled and moderated by water, and with neutron reflection provided mainly by beryllium. The SLOWPOKE design has a relatively small excess reactivity (subject to restoration by adding beryllium shims to the top reflector) but large negative temperature feedback of reactivity – a very special feature assuring its safe operation.

Diffusion methods (i.e., EXTERMINATOR [2] or CITATION [3]) applied to reactor physics analysis of SLOWPOKE tend to give rise to large k-eff uncertainty and lack of power and burnup distribution in fuel elements (due to core homogenization). Stochastic Monte Carlo transport methods (i.e., MCNP [4] or SERPENT [5]) are able to eliminate those inaccuracies resulting from the diffusion approximation.

The MCNP full-reactor models of SLOWPOKE, with a HEU or LEU core, have been created to study i) temperature feedback of reactivity, and ii) burnup (or core following) of the SLOWPOKE design. These MCNP models include the main reactor components (inside the reactor container) in detail, each of which may be changed with respect to geometry (e.g., the shim thickness or control rod position), material, or temperature. In particular, fuel elements in a hexagonal lattice are modeled to have the burnup-dependent compositions, which may vary not only from element to element but also axially in each element. Symmetric elements (each 6 or 12 elements in every hexagonal ring) may be grouped for better statistical accuracy.

2. Temperature Feedback

With the multi-temperature ENDF/B-VII cross-section library (and, if necessary, mixing concentrations at the library temperatures), the material temperature in each of the main reactor components (i.e., fuel, coolant/moderator, beryllium reflector and water reflector) can be changed to any desirable values for k-eff calculations. The core excess reactivity calculated by MCNP is biased relative to the measured values, by +3.3 mk for an HEU core and +6 mk for a LEU core. The temperature feedback of reactivity for the MCNP models is consistent with the experimental data. In general, the reactivity feedback is slightly positive at low temperatures and turns negative above the room temperature (Figure 1). MCNP predicts the reactivity peak in a range of 21-27°C for the HEU core and 32-37°C for the LEU core (cf. the experimental peak "points" of 20°C and 33°C, respectively), due to combination of component reactivity feedback of different signs and values. As the temperature of each reactor component is changing, the reflector feedback is mostly positive and small, while the fuel and coolant feedback is always negative, small for fuel and low-temperature coolant but relatively large for coolant above the room temperature (-10 mk and -6 mk over a 50°C change in a HEU and LEU core, respectively), which dominates the SLOWPOKE feedback at higher temperatures.

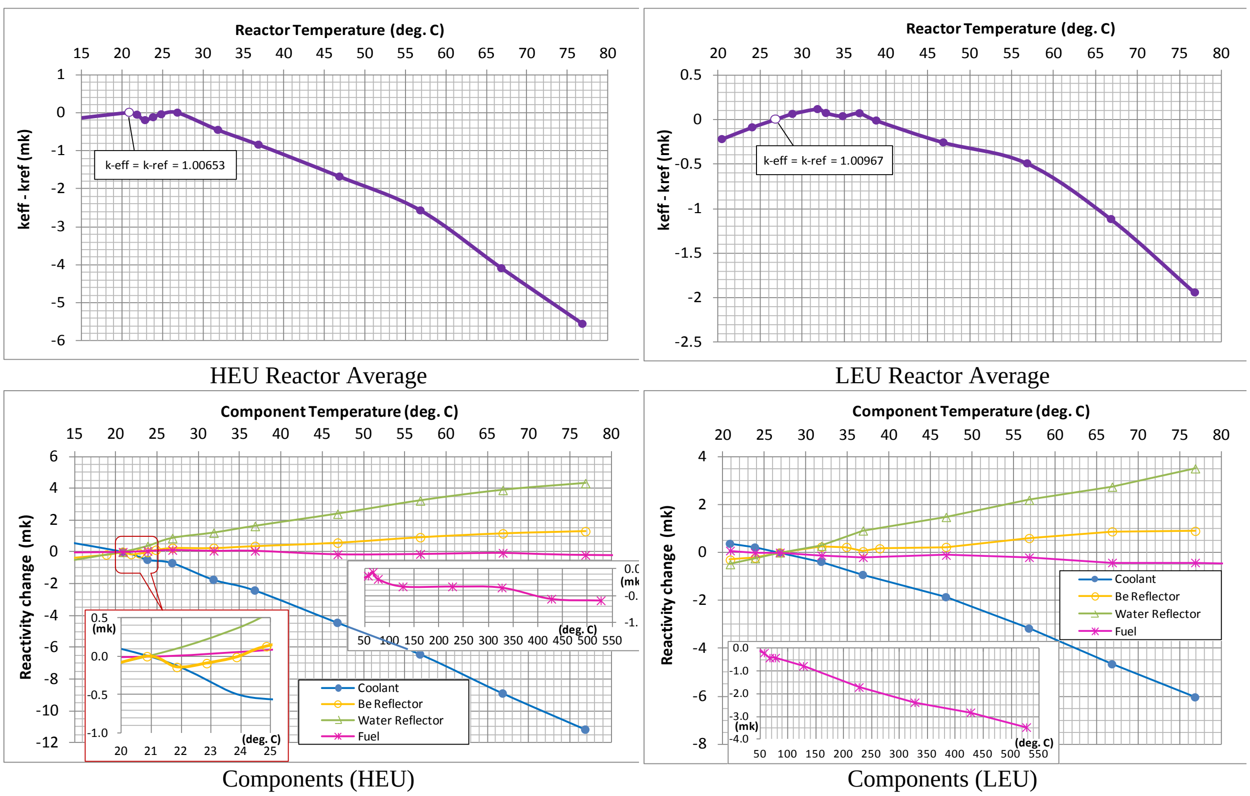


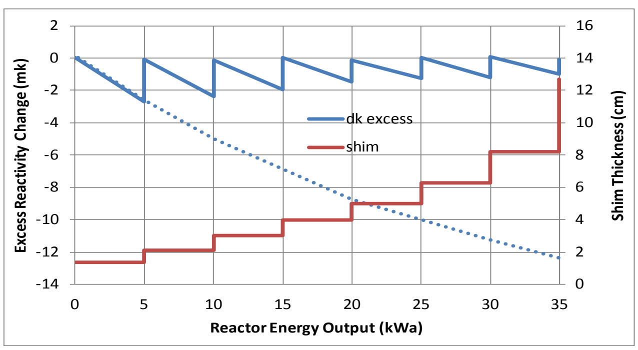
Figure 1 SLOWPOKE temperature feedback of reactivity

3. Burnup Analysis

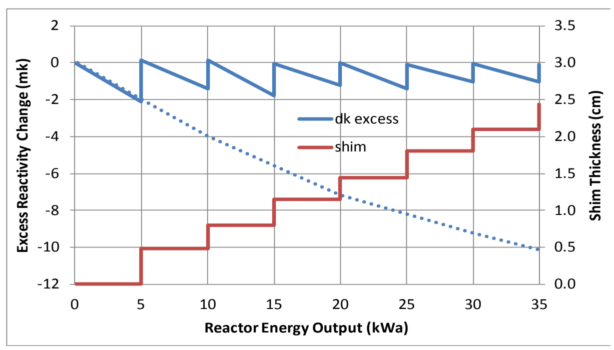
For core following, the MCNP full reactor calculation is performed to provide a 3D power distribution, while a burnup code, such as WIMS-AECL [6] in this study, is required for fuel burnup advancement. The burnable materials in the MCNP model are updated using the WIMS pre-computed isotopic composition vs burnup. Since SLOWPOKE fuel depletes only slightly in practice, the whole-element (radial) power distribution does not change significantly with any burnup and shimming, but the axial power distribution does change with the shim thickness (provided the control rod position is fixed).

For a hypothetical operation of SLOWPOKE that restores the excess reactivity by shimming after every 5 kWa, the reactivity loss rate due to burnup decreases with the core burnup, from ~0.4 - 0.5 mk/kWa at the beginning of the core life to ~0.2 mk/kWa at 35 kWa. The shim effectiveness (i.e., mk gain per cm beryllium added) also decreases with the core burnup (or more correctly, with the total shim thickness), greater in the HEU core, from 3.4 mk/cm at the beginning to 0.1 mk/cm at 35 kWa (where the shim is full), but less in the LEU core, from ~5 mk/cm at the beginning to ~3 mk/cm at 35 kWa (where the shim is ~20% full, so the LEU core could still operate much longer) (Figure 2).

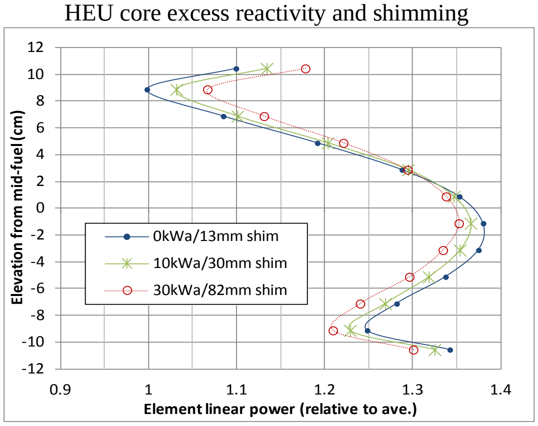
To verify the MCNP/WIMS core following method, SERPENT that combines both Monte Carlo transport calculation and burnup capability is used independently. For any core of a given burnup and shim thickness, the SERPENT and MCMP power (and burnup) results agree very well, within their statistical errors (<0.5%), providing confidence in using either of the two methods.



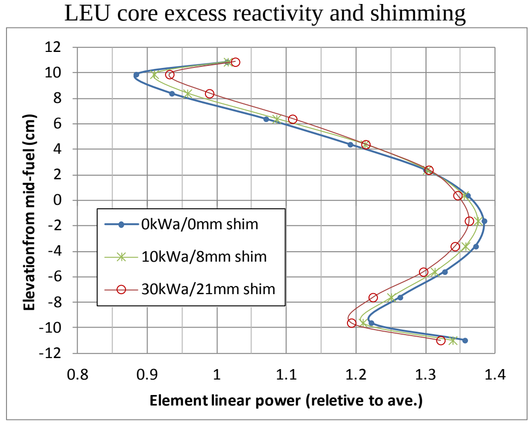
HEU core excess reactivity and shimming



LEU core excess reactivity and shimming



HEU element power



LEU element power

Figure 2 SLOWPOKE reactivity and element power vs burnup

4. Conclusions

Monte Carlo methods are computing intensive and time-consuming, and so are generally not well suited for real time core following in large reactors like NRU or CANDU that require fuel shuffling and replacement in time frames of the order of days. However, as this paper has demonstrated, Monte Carlo methods *are* practical for tracking burnup and reactivity shimming in small low-power reactors like SLOWPOKE where reactivity adjustments occur on the order of months. The method is also useful for analyzing reactivity coefficients and characterizing experiments.

5. References

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