FIRST STEPS TOWARDS VALIDATION OF POWER DISTRIBUTION CALCULATIONS FOR INVOLUTE PLATE REACTORS

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ABSTRACT

Involute-plate type reactors represent a special class of research and test reactors that are able to produce a high neutron flux in a very compact core. In such reactors, the power generated in the fuel tends to be non-uniform and local power densities can be very high. The three reactors in the world making use of involute plates are actively working on the conversion of their core to LEU fuel. To estimate if the proposed LEU designs will have sufficient safety margins, it is critical to evaluate correctly the distribution of power. The critical experiment FOEHN made use of involute plates and the distribution of power within these plates was measured. Therefore, this experiment is particularly interesting for the conversion of the involute plate reactors. Using the Monte Carlo codes MCNP and SERPENT, a model of the FOEHN experiment was created and the distribution of power was calculated. A preliminary comparison between calculated and measured data is presented and discussed.

INTRODUCTION

- Involute-plate reactors are reactors that have annular-shaped element containing fuel plates curved as involute (a spiral generated around a circle). Figure 1 provides a depiction of these fuel elements.
- The are only three reactors of this type in the world: the HFIR (Oak Ridge National Laboratory, Tennessee, USA) [1]; the RHF (Institut Laue-Langevin, Grenoble, France) [2]; the FRM II (Technische Universität München, Garching, Germany) [3].
- These compact reactors provide some of the most intense and continuous neutron fluxes (i.e. ~1x10^{15} n/cm^2/s) for science, industry, and medical applications.

Figure 1: From left to right, top view of the HFIR, RHF and FRM II fuel element

- All three reactors are currently using Highly Enriched Uranium (HEU, ^{235}U/U ≥ 20 wt. %) fuel and are actively engaged in the conversion to Low Enriched Uranium fuel (LEU, ^{235}U/U < 20 wt. %).
- Monte-Carlo neutronic tools such as MCNP [4] or SERPENT [5] are used to calculate the time and space dependent power distribution, which is then used as input to steady-state and transient thermal-hydraulics analysis.
- For these reactors, the power is unevenly distributed within a plate and tends to exhibit local extrema and sharp gradients. This is why it is of paramount importance to calculate it as accurately as possible.
- The work presented here represents a first step in an effort to validate the methodologies used with Monte-Carlo neutronic tools to evaluate the distribution of power for involute-plate reactors.
- MCNP and SERPENT models of the involute-plate critical experiment FOEHN have been created and distribution of the calculated fission distribution are compared to the experimental one.

THE CRITICAL EXPERIMENT FOEHN

- The critical experiment FOEHN was designed to validate the design analysis performed for the RHF reactor [6]. As such, it was designed to be a highly-representative mockup of the RHF reactor and had a single annular fuel element made of 276 involute plates (see Figure 2). It was carried between 1968 and 1969 in the zero-power reactor EOLE facility located in Cadarache, France.
- Special involute fuel plates were made that contained several detectors (0.5 x 0.3 cm). After irradiation, the gamma activity of the fission products, which is proportional to the power generated by fission, was measured and normalized to extract the power distribution.

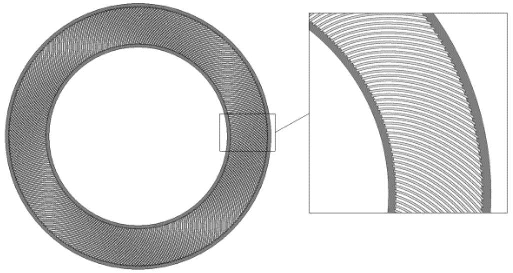

Figure 2: FOEHN's fuel element

FOEHN – MCNP/SERPENT MODELING

- Based on the information provided in [6-7], MCNP 6.2 and SERPENT 2.1.31 models of the FOEHN experiment have been created (see Figure 3).
- Multiple critical states obtained experimentally were simulated with MCNP and SERPENT. Calculated reactivity varies between ~0.2 and ~0.6% from the measured one. Models agree relatively well with the measurements.

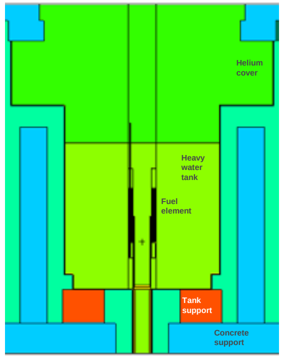

Figure 3: FOEHN MCNP model (vertical cross-section)

FOEHN – MCNP/SERPENT FISSION DISTRIBUTION

- Based on the encouraging reactivity calculation results, the distribution of fission within a plate has been calculated. Obtained results are shown in Figure 4 to 5. An uncertainty of 1% is suggested for the measured data [6]. The calculation uncertainty is less than 0.1% at one standard deviation.
- Figure 4 (left) shows the dispersion between MCNP-calculated and measured data at every corresponding location. It can be seen that the calculated values are within -4 / +8 % of the measured ones. SERPENT results lead to the same observation. Note that in this context, negative deviation means calculation under-prediction.
- Figure 4 (right) shows the dispersion between MCNP-calculated and SERPENT-calculated data at every corresponding location. The agreement between the two computer codes is excellent (+/- 0.3%).

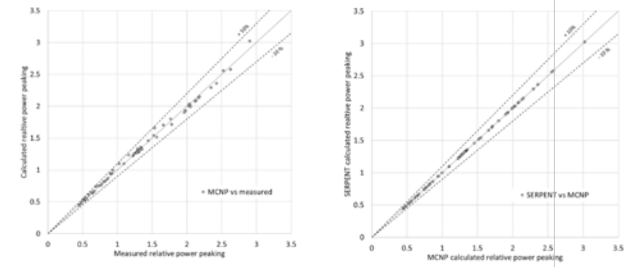

Figure 4: Dispersion of the data: MCNP versus measured (left); MCNP versus SERPENT (right)

- Figure 5 (left) presents the measured and calculated relative power in the hottest stripe. It can be seen that the agreement between the experiment and calculation is relatively good as the shape of the calculated power is relatively close to the experimental one.
- Figure 5 (right) shows the deviation between MCNP, SERPENT and the measured data. It can be seen that for most of the hot stripe, the calculations tends to underestimate the power (0 to ~4%) with the exception of the very top and bottom were both MCNP and SERPENT tends to overestimate the power (4 to 8%). The reasons for this local behavior are being investigated.

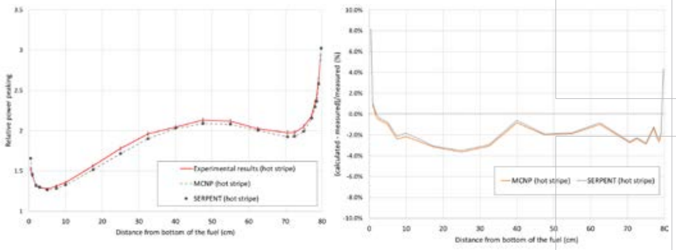

Figure 5: Measured and calculated relative power density in the hot stripe (left); measured versus calculated deviation (right)

CONCLUSIONS

- Based on this preliminary work it can be concluded that both MCNP and SERPENT are able to reproduce relatively well the distribution of fission in an involute-plate geometry.
- With both computer codes, 100% of the data points are within -4% (underestimation) to +8% (overestimation) of the measured ones.
- Deviation between MCNP and SERPENT are extremely small (+/- 0.3%).
- The magnitude of the discrepancy between calculated and measured data in the hot stripe seems to be correlated to the position within the fuel.
- Based on these results, and considering the high degree of similarity between the involute-plate reactors and the FOEHN experiment, applying a uniform uncertainty of +4 % on the calculated fission distribution seems to be a reasonably conservative approach.
- This work focused on the fission distribution. Future work will focus on the gamma distribution to ultimately be able to validate the power distribution calculation methodologies used in Neutronic Monte-Carlo computer codes and define an overall power distribution calculation uncertainty.

ACKNOWLEDGMENTS

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