Establishment of best practices in reducing uncertainties in multigroup cross-sections with Bayesian methods

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The multiplication factor (k_{eff}) and its uncertainty are critical design parameters in nuclear reactors. The k_{eff} uncertainty must be considered for operation, safety, and economic reasons. Consequently, reducing uncertainty in the k_{eff} has been of interest to the nuclear industry for as long as nuclear reactors were designed. Two methods are currently in use to accomplish that: Generalized Linear Least Squares (GLLS) and A General Monte Carlo-Bayes Procedure for Improved Predictions of Integral Functions of Nuclear Data (MOCABA). Both methods can reduce the k_{eff} uncertainty by reducing uncertainty in cross-sections by assimilating measured critical systems' or nuclear reactors' operational data. However, GLLS is limited to linear models and multivariate normal prior and posterior, while MOCABA can use any (non-linear) model but is also limited to multivariate normal prior and posterior.

This work implements a universal and rigorous algorithm called Sequential Monte Carlo – Approximate Bayesian Computation (SMC-ABC) for the same application. The algorithm can calibrate parameters with any prior and any posterior distribution. The calculations were conducted on select cross-sections from the 56-multigroup library based on the ENDF/B-VII.1 nuclear data library. It is found that despite the greater reliability of SMC-ABC, all three algorithms give essentially the same results for the same problems. Therefore, it is not worth using the computationally expensive SMC-ABC for neutron cross-section calibration.

A thorough study of the uncertainty sources in experimental k_{eff} is also presented. It is investigated how the omission of the uncalibrated uncertain cross-sections during the Bayesian assimilation impacts the results. The conclusion is that omitting uncalibrated parameters in Bayesian calibration, often done by researchers, is an incorrect approach.

In the context of nuclear engineering inverse problems, a new validation technique is presented and applied for inverse problem-solving. The technique relies on so-called "synthetic experiments". Synthetic experiments are computationally generated data used in place of experiments. The method verifies whether there is a risk of overfitting the calibrated parameters (cross-sections in the case of this work) during the data assimilation. Finally, the dissertation combines all the findings of the work to establish a best-practices guide for calibrating neutron cross-sections through the assimilation of experimental integral parameters' values.