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Enhancing nuclear safety

Implementation of the CLUTCH method for sensitivity calculations in the MORET code

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A continuous energy sensitivity coefficients calculation to nuclear data capability is already available in the MORET Monte Carlo code developed at Institut de Radioprotection et de Sûreté Nucléaire (IRSN) using the simulation of “dummy” neutrons in order to estimate the adjoint flux with the Iterated Fission Probability (IFP). In order to increase the Figure Of Merit (FOM), an alternate approach has been recently implemented based on the CLUTCH approach for the estimation of the adjoint source. It consists of estimating the average progeny for a geometrical mesh during inactive cycles and then use this approximation instead of simulating “dummy” neutrons.

Sensitivity coefficients

The sensitivity coefficient (Sα) to the cross section α can be computed using an estimation of the adjoint source (Q⁺) [1].

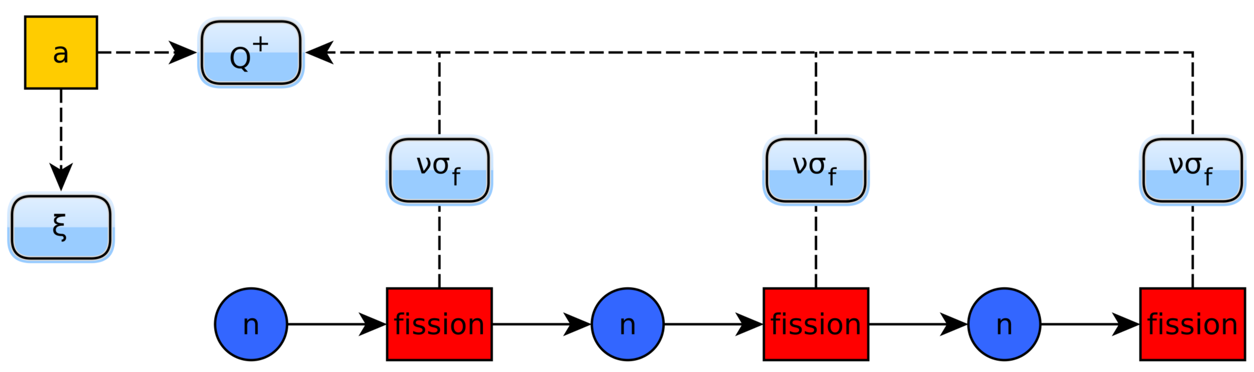
$$S_\alpha = \frac{\alpha}{k_{eff}}\frac{\partial k_{eff}}{\partial \alpha} = \frac{\sum_j p_j \alpha \mu_0 \xi_j Q^+(\mathbf{r}_N)}{\sum_j p_j \xi_j Q^+(\mathbf{r}_N)}$$

Iterated Fission Probability

The adjoint source is related to the adjoint flux.

$$Q^+(r) = \left\langle \frac{1}{4\pi}\chi(x)\phi^+(x)\right\rangle_{E,\Omega}$$

The adjoint flux is estimated by simulating dummy neutrons to access the average progeny [1].



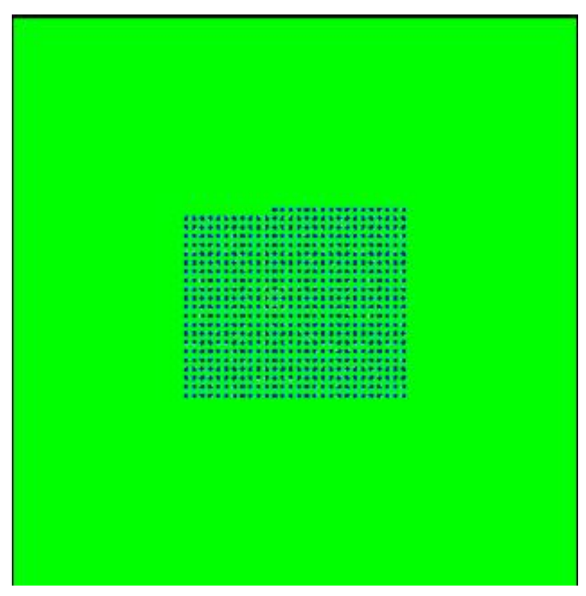
[1] A. Jinaphanh et al., “Continuous Energy Sensitivity coefficients in the MORET code” Nuclear Science and Engineering, 184, 01, 53-68 (2016)

CLUTCH

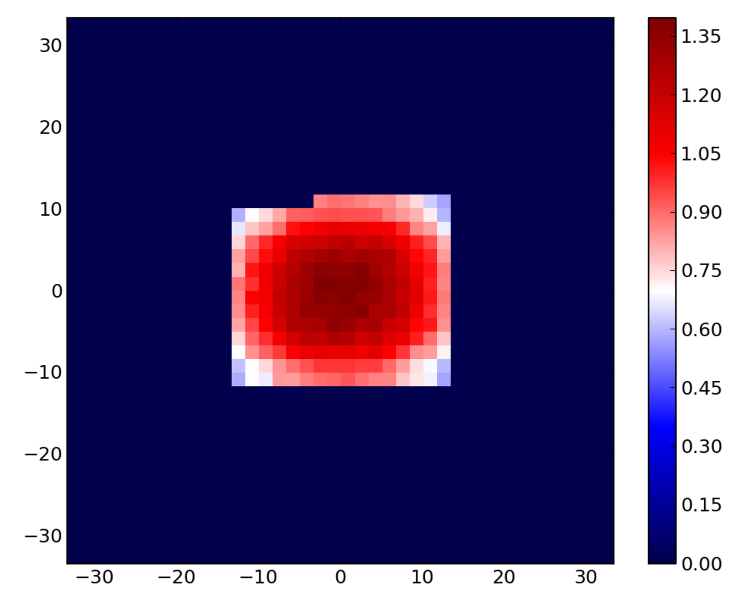
The adjoint source is estimated on a spatial mesh and considered as constant over each single mesh interval and represents the average progeny (importance) for a neutron in this mesh [2].

During inactive cycles, the procedure used to estimate the average progeny is :
1-Store the particle weight (ω_j) at mesh k,
2-Add the index k to the list of ancestors birth location,
3-Transmit the list to the progeny,
4-Sum production rates for the last generation of each neutron progeny
5-Normalize the progeny by the weights of neutrons born in each mesh

UACSA Phase III - Radial view



UACSA Phase III - Importance Map

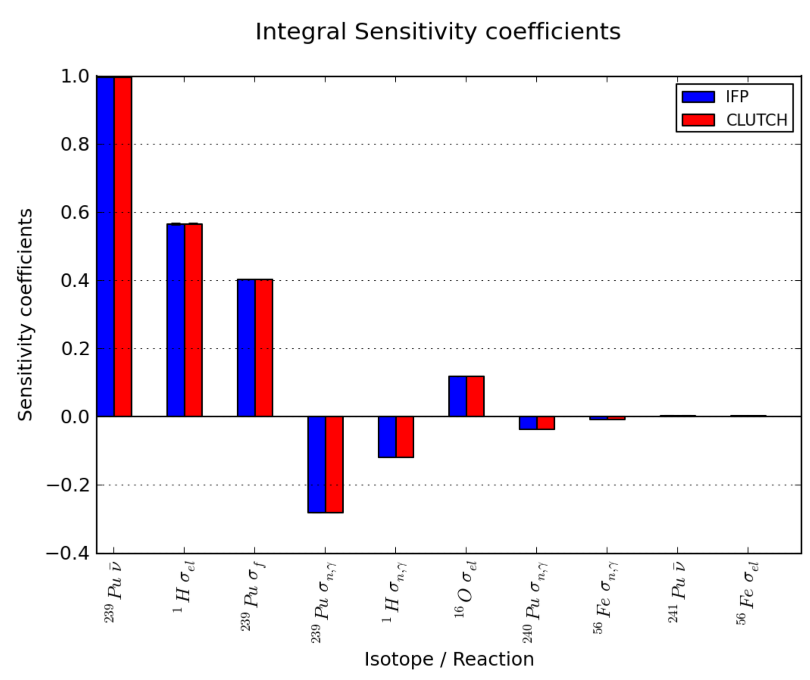


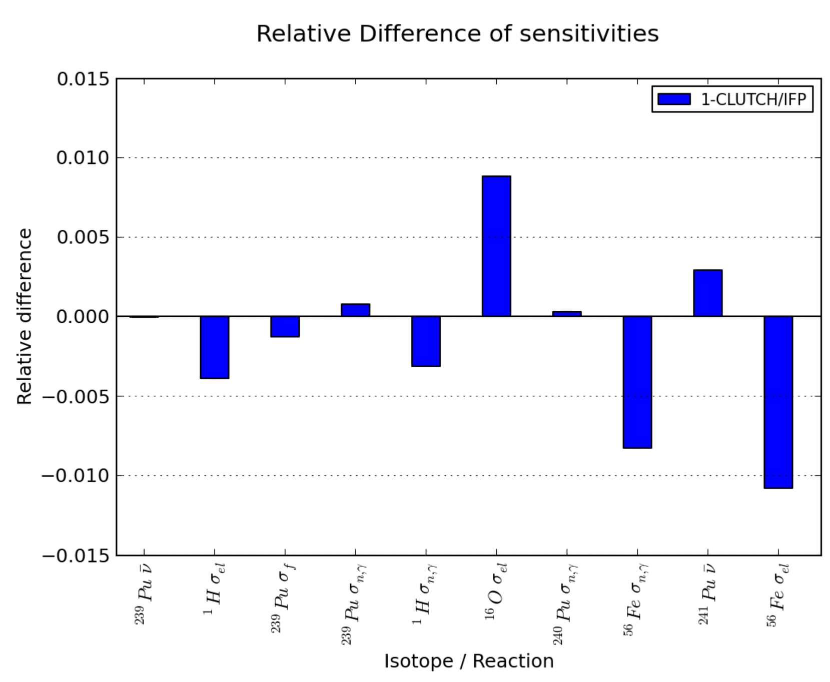
[2] C. Perfetti et al., “SCALE Continuous Energy Eigenvalue Sensitivity Coefficient Calculation” Nuclear Science and Engineering, 182, 01, 332-353 (2016)

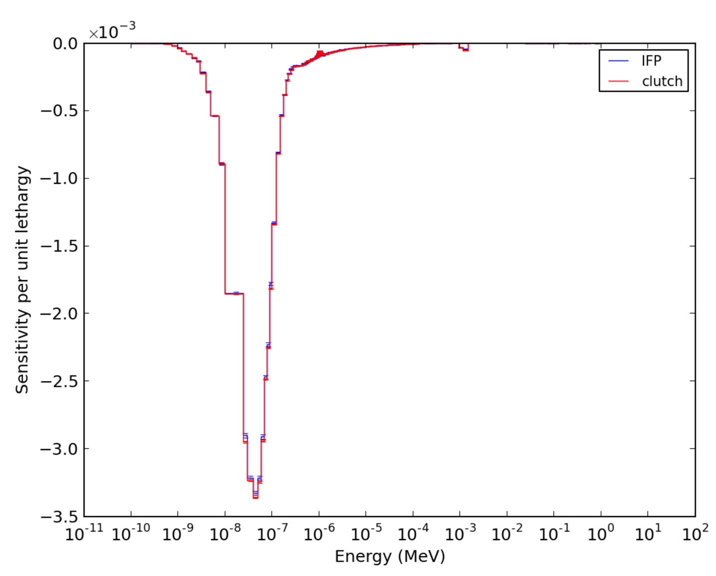
Verification

The verification has been performed using several benchmarks. Results show a very good agreement between the IFP and the CLUTCH method about 2% for integrated sensitivity coefficients.

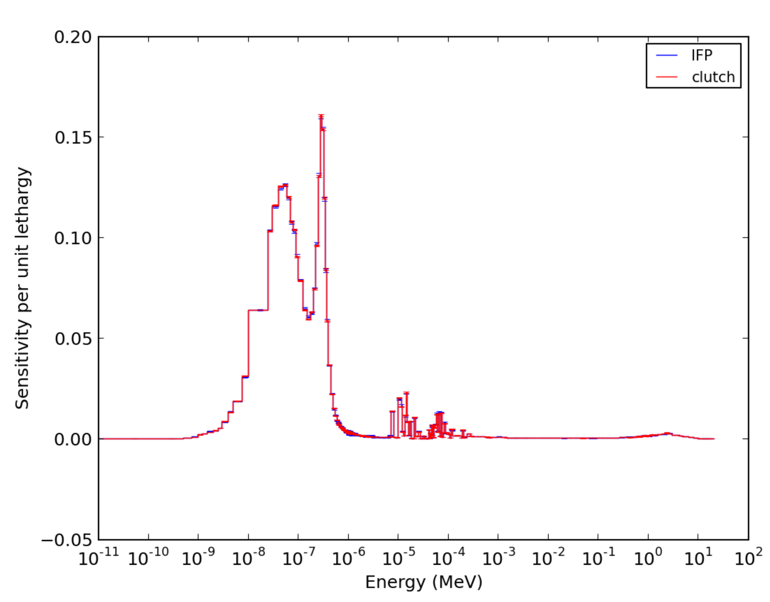
Results for the PST-001 simplified configuration of the ICSBEP handbook.







^{56}Fe sensitivity to capture



^{239}Pu sensitivity to fission

Performance

In order to compare performance of CLUTCH to the IFP, Figures of Merit (FOM) of several energy integrated coefficients were used. The ratio is defined as the CLUTCH’s FOM divide by IFP’s FOM.

Case	Isotope reaction	IFP T(min)	IFP σ(%)	CLUTCH T(min)	CLUTCH σ(%)	ratios of FOM
Jezebel	$^{239}Pu\ \sigma_f$	88	0.02	86	0.01	4.1
UACSA	$^{239}Pu\ \sigma_f$	766	0.11	625	0.06	4.1
	$^{1}H\ \sigma_{el}$		0.82		0.40	5.2
	$^{16}O\ \sigma_{el}$		1.24		0.66	4.3
PST-001	$^{1}H\ \sigma_{el}$	537	0.57	483	0.27	5.0
	$^{239}Pu\ \sigma_f$		0.09		0.04	5.6
	$^{56}Fe\ \sigma_{n,\gamma}$		0.26		0.10	7.5

Performance of the IFP and CLUTCH methods for sensitivity calculations

The figure of merit is increased by a factor comprised between 4 and 7.5 according to the observed sensitivity coefficient.

Results may depend on the spatial mesh resolution and the number of neutrons simulated to estimate the average progeny in each mesh interval. A study is planned on the mesh spatial resolution and tally convergence for Q⁺ in order to provide recommendations for the users.

An alternate approach based on the CLUTCH method for weighting sensitivity coefficients has been successfully implemented in the MORET code. The preliminary verification has been performed on three different benchmarks and show a very good agreement between the Iterated Fission Probability and CLUTCH methods. Performance have been compared demonstrating, for the studied cases, a better computational efficiency of the CLUTCH approach.