MONTE CARLO techniques implemented in the MORET code

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The criticality code MORET

- **MORET 4:**
  - **3D Monte Carlo multigroup criticality code**
    - Any energy group structure and Xsct processed to be readable by MORET
    - 172 energy groups from JEF2.2 in the CRISTAL framework
    - Modular combinatorial geometry
  - **Calculates**:
    - Effective multiplication factor (keff)
    - Reaction rates in the different volumes of the geometry
    - Leakage out of the system
  - **Used in the the French criticality-safety package CRISTAL in conjunction with the APOLLO2 deterministic assembly code**
  - **Developed by IRSN**

- **MORET 5:** (in progress)
  - **Continuous energy version**
  - **Xsct processing from any evaluation**

Conventional MC strategy

- **Neutron tracking in heterogeneous systems :**
  - **Tracking through multiple homogeneous material regions** (stopping at each material boundary)

> - Neutron free path sampling for medium i **$(\lambda(\Sigma^T_i))$**
> - Distance to the nearest boundary surface calculation **(D_s)**
> - Distance to next event: **$D = Min(\lambda, D_s)$**

- **Slow procedure for complex geometries:**
  - **High number of volumes**
  - **Volumes with complex shapes**

- **Problems with heterogeneous materials**

Equations to solve :

$Bi(x+\Omega) = 0$

Ω : neutron direction
$Bi(x) = 0$: boundary of vol. i

The Woodcock method is an alternative

⇒ Artificial homogenization of the Xsct

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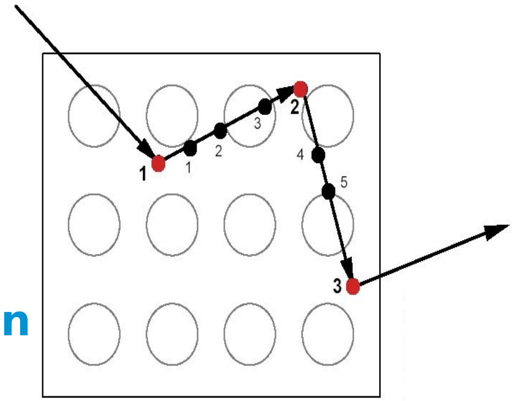
The Woodcock method

- **Making the system share the same total Xsct (Σ^{max})**
  - **Adding a fictitious Xsct (Σ^{δ}_i) to each material $\Sigma^{max} = \Sigma^{T}_i + \Sigma^{\delta}_i = Max(\Sigma^{T}_i)$**
    - Free path sampling according to **($\lambda(\Sigma^{max})$)**
    - Distance to system boundary calculation **(D_s)**
    - Distance to next event: **$D = Min(\lambda, D_s)$**
  - **Hidden geometry**



- **Searching for the material lying at the neutron position**
  - **Fictitious collision probability: $\Sigma^{\delta}_i/\Sigma^{max}$**
  - **Key routine (invoked at each collision)**

Advantages:

- **Faster simulation in some configurations**
  - No need to stop tracking at each boundary surface
  - No distance to inner volumes calculation
  - Procedure giving material lying at a given position
- **Unbiased**

Weaknesses:

- **No track-length estimator**
- **Not efficient when high discrepancies observed in Xsct**

Successful implementation in MORET 5 - multigroup

- **Material searching procedure:**
  - **Very simple and improvable**
  - **Geometry learning procedure to help this search**
    - Two different strategies considered
    - Dynamic Learning + during early stage of calculation

- **Geometrical aspects:**
  - **The user specifies which part of the system is to be treated with the Woodcock tracking method**
  - **Geometrical redefinition of concerned zones**
    - “Woodcock zones” are “holes” in the geometry
    - One Σ^M per zone

- **Estimators**
  - **No track-length flux estimator** (unknown detail of volumes visited by the neutron)
  - **New collision estimator** $\phi = N_{coll} / \Sigma^M$ (Better convergence for optically thin volumes)

Woodcock tracking : preliminary tests

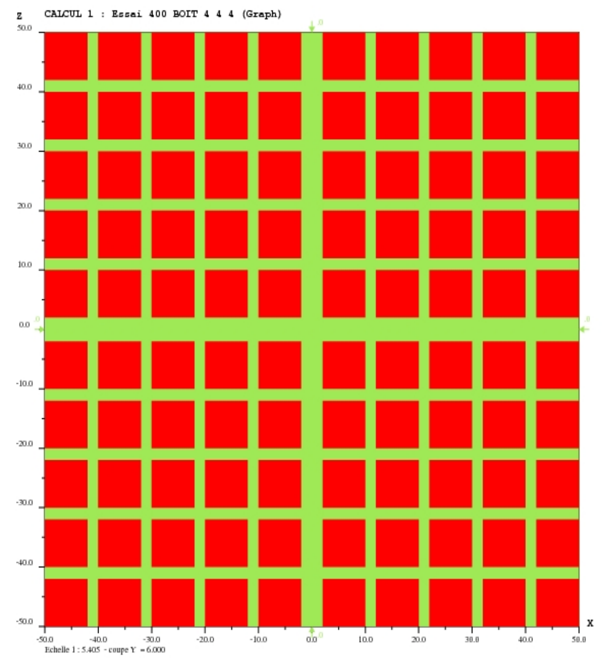
- **Various simple geometrical configurations**
  - Mesh functionalities not used
  - Variation on the number of volumes considered
  - Variation on the size of each volume
  - Different volume shapes
  - Various chemical sets

- **Same keff obtained w/wo Woodcock treatment** (not presented)

- **Simulation time evaluation** (680 neutrons ; 100 cycles)
  - **Simulation time evaluation :**
    - Conventional tracking
    - Woodcock tracking
  - **Presented as simulation time for 100s conventional tracking running**

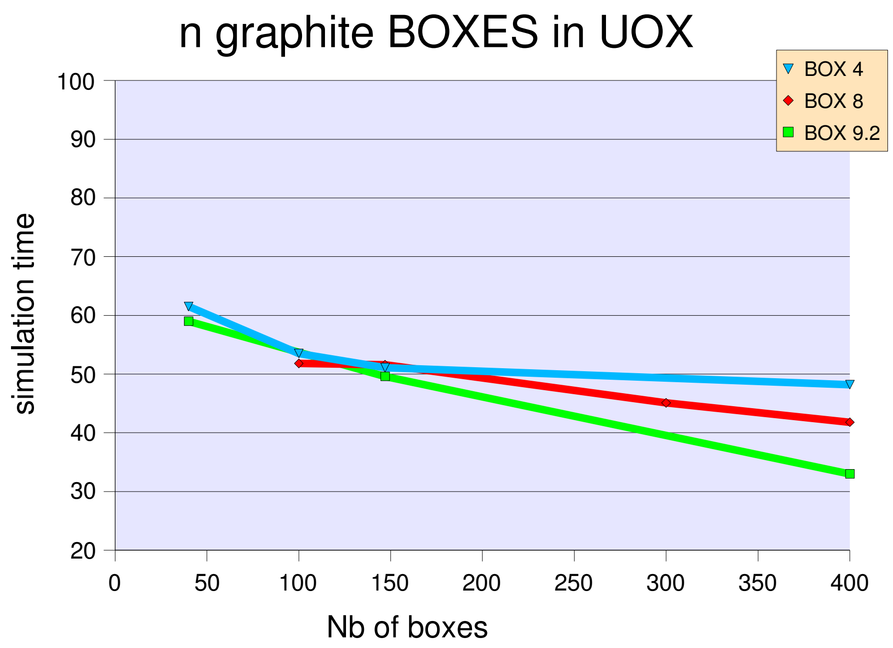
- **Woodcock tracking parametrization effects investigated on complex geometry** (not presented)

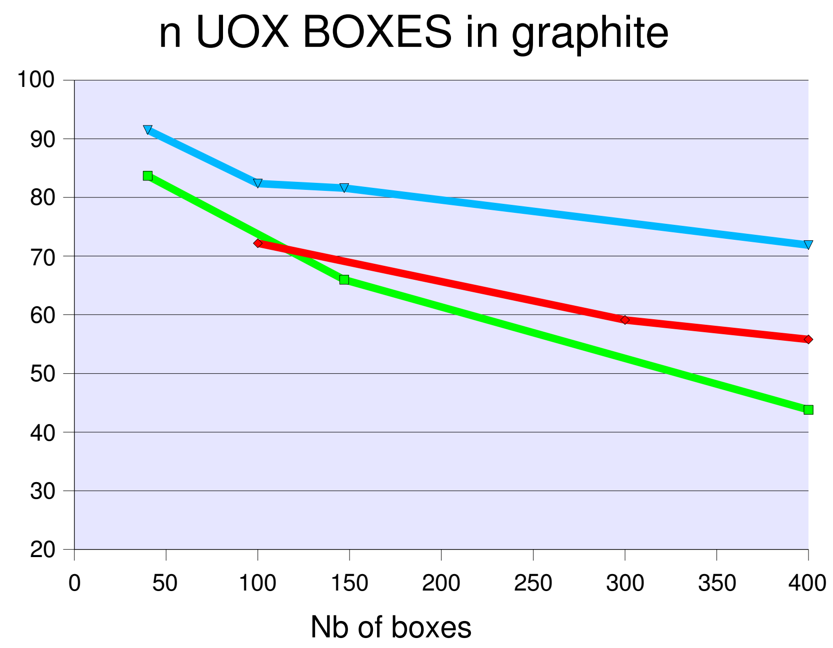
Preliminary results 1/2



Boxes embedded in a 100x100x40 cm³ parallelepiped

- 3 different sizes for boxes
- Variation on the number of boxes
- 2 chemical sets





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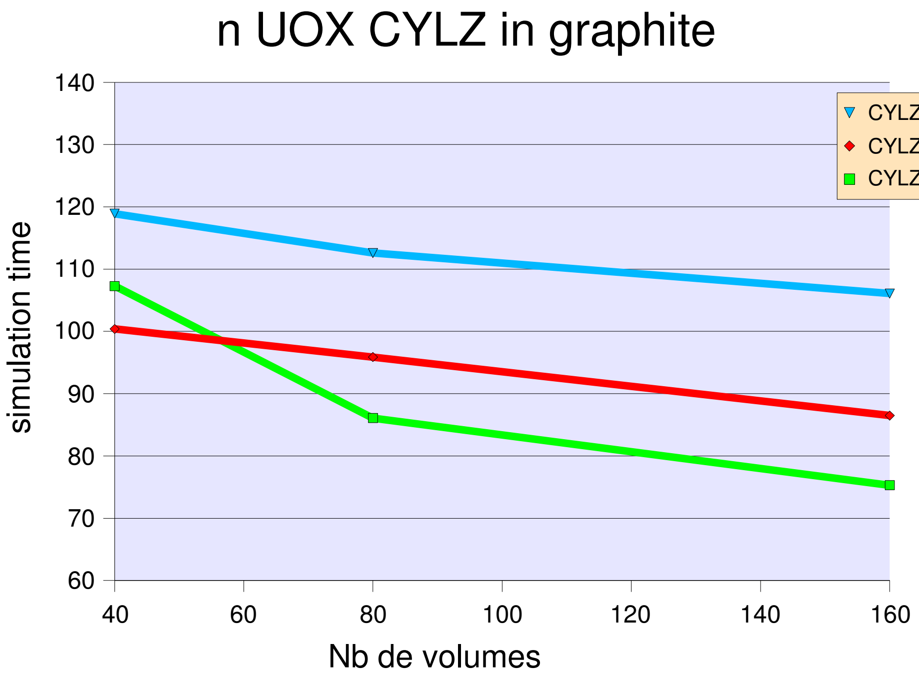
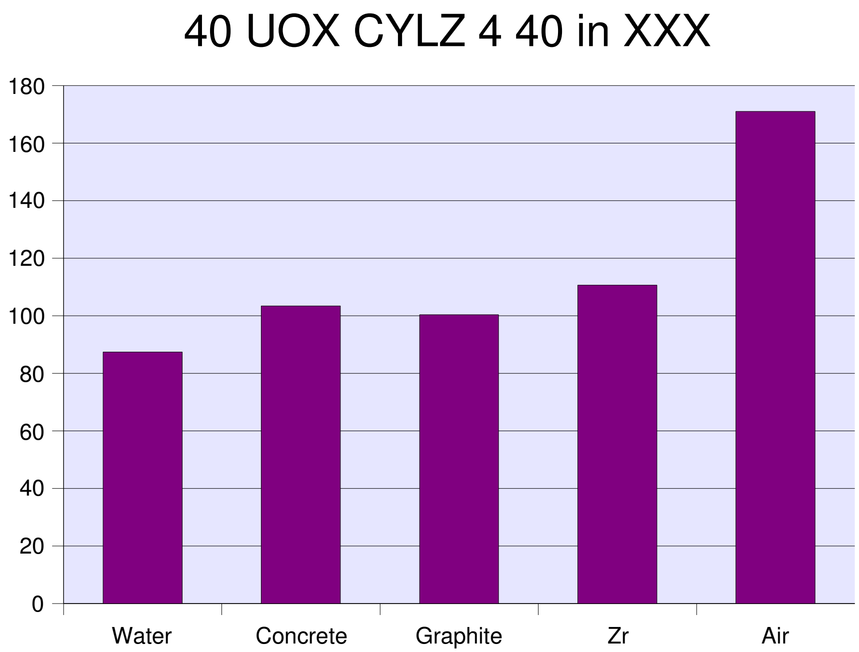
Preliminary results 2/2

Graphite cylinders embedded in a 100x100x40 cm3 UOX parallelepiped

- Variation on the number of volumes
- 3 different radius for cylinders
- **Vol_{UOX}/VOL_{graph} = cst** (for a given radius)
- One configuration has been tested with different chemical sets





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Options for source re-sampling at each cycle 1/3

- **Conventional strategy:**
  - **Number of neutrons renormalized at each cycle**
  - **Source neutrons sampled in the fissile volumes on the basis of collision sites from the last cycle**

- **Limitations:**
  - **Neutrons can possibly desert some important fissile volume**
  - **Problems with loosely coupled systems**

- **4 other simulation options are proposed in MORET:**
  - Stratified Sampling
  - Superhistory powering
  - Fission matrix method
  - Importance function method

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Options for source re-sampling at each cycle 2/3

- **Stratified sampling:**
  - **Aim:**
    - Prevent neutrons from deserting some important fissile volumes
  - **Method:**
    - At least 1 neutron per fissile volume **(possibly with a weight <1)**

- **Superhistory powering:**
  - **Aim:**
    - Prevent the systematic renormalization of the neutrons
    - Prevent the positive correlation that exists between iterations (cf. Brissenden & Garlick)
  - **Method:**
    - Each neutron is followed through L generations before starting a new cycle

Options for source re-sampling at each cycle 3/3

- **Fission matrix method**
  - **Aim:**
    - Speed-up source convergence
  - **Method:**
    - Every F cycle, the eigenvector of Kij matrix is used to establish new fission distribution **(using the F previous generations)**
    - During other cycles the stratified method is employed

- **Importance function method**
  - **Aim:**
    - Speed-up source convergence
  - **Method:**
    - Use of the adjoint Kij matrix to estimate the importance of each volume
    - Weight each potential fission site by the ratio

$$R = \frac{\text{Importance of the volume where the fission site sits}}{\text{Importance of the volume where the neutron comes from}}$$

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Conclusions

- **MORET 4 includes various simulation options**
  - **4 different strategies for source re-sampling at each new cycle**
  - **Can help for loosely coupled systems**
  - **Full validation needed**

- **MORET 5 includes Woodcock tracking method**
  - **Successfull implementation in the multigroup version**
  - **Encouraging first results**
    - Up to a factor 3 gain on simulation time
    - Even with a simple volume searching algorithm
    - No difference between keff calculated with and without the Woodcock tracking method
  - **Full performance study needed**

Perspectives

- **Full performance study**
  - **Woodcock tracking:**
    - Quantified gain on simulation time for various simple configurations
    - Compared performances for various settings on a complex geometry
    - Define application domain and emit recommendation for users
  - **Geometry learning:**
    - Compared benefits of both methods
    - Sensibility to parametrization
  - **Source sampling options:**
    - Full validation of both methods
    - Compared benefits of each option
- **Upcoming developments**
    - Get a better volume searching procedure
    - Estimators
    - Second strategy for geometry learning
    - Compatibility with the continuous energy version of MORET