DE LA RECHERCHE À L'INDUSTRIE

Update of CEA DES Criticality-Safety Activities and Perspectives

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TRIPOLI-4® version 12

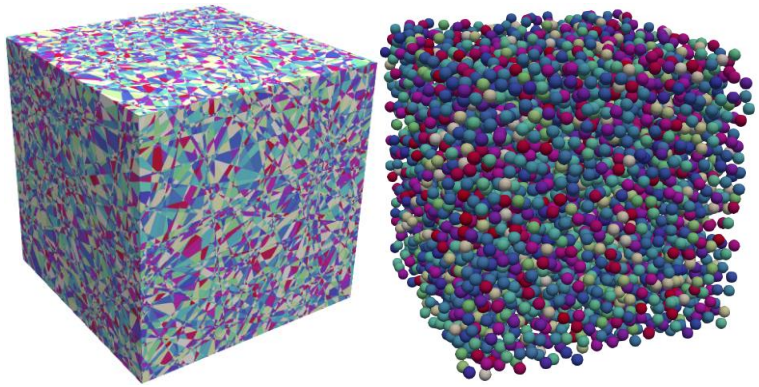
- **Release of the version 12 in November 2022**
  - Part of the next CRISTAL criticality-safety package release
  - https://www.cea.fr/energies/tripoli-4

- **Main features for criticality**
  - History-based keff sensitivities
    - Wielandt or Super-History simulation
  - Generalized Perturbation Theory
    - Sensitivities of reaction rate ratios
  - Stochastic geometry generator (CASTOR)
  - Kinetic simulation
  - Reaction rate and transfer matrix decomposed over real spherical harmonics
  - Use of the MORET Monte Carlo code geometry
  - Temperature stochastic interpolation with Probablity Tables

- **Side tools**
  - MCNP® / TRIPOLI-4® geometry / materials converter
    - https://t4-geom-convert.readthedocs.io/
  - Valjean : tool used for the V&V suite of TRIPOLI-4
    - https://valjean.readthedocs.io/en/latest/

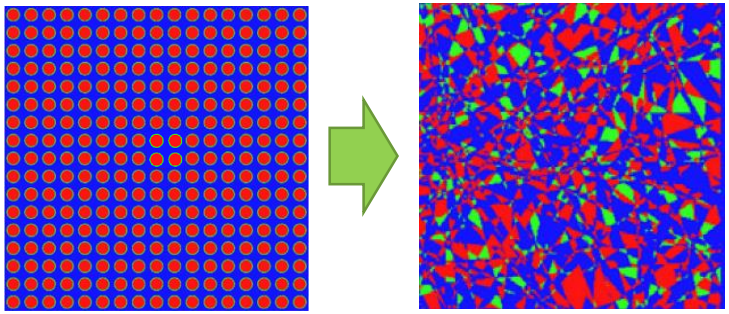
Stochastic geometries generator

- Generates realizations of stochastic geometries
  - TRIPOLI-4 geometries input data
- isotropic and homogeneous Poisson tessellations
- Poisson-Box tessellations
- spherical inclusions



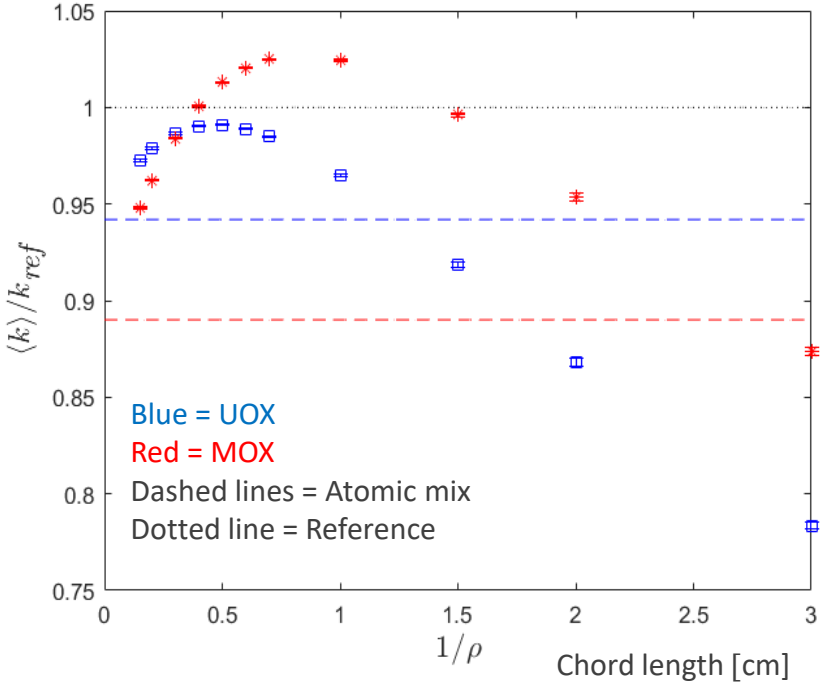
Application to criticality safety

- NEA/WPNCS meeting
- Transport in random media (SG-9)
- Parameter being the « size » of the chunks



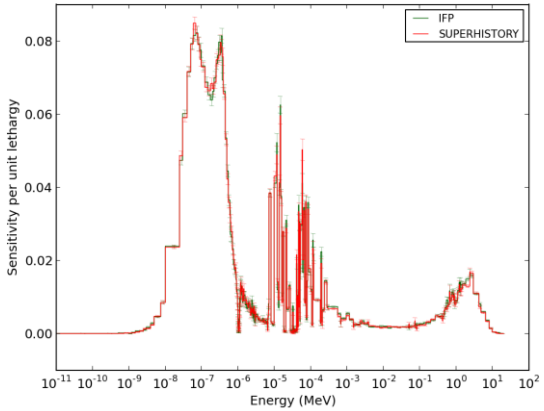
Intact UOX or MOX fuel assembly

Stochastic tessellations



Sensitivities and Perturbations

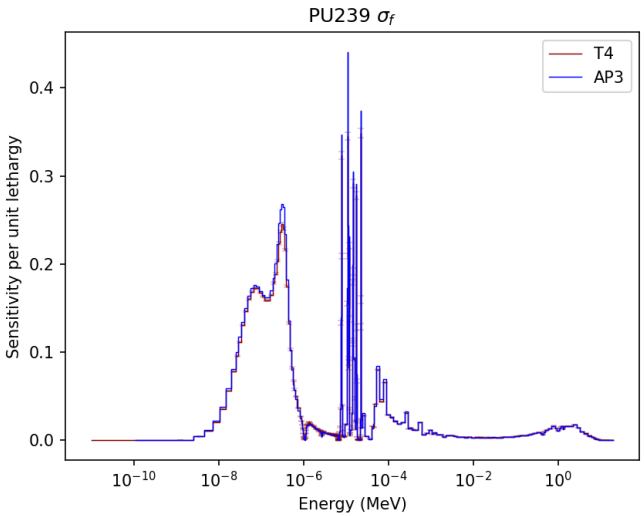
- **Keff sensitivities – Standard perturbation Theory**
  - History-based method
  - Simulate the neutron progeny within each batch
    - Wielandt or Super-history
  - Allow trade-off between memory occupation
    - An example : MIX-SOL-THERM-004
      - 50 GB with the IFP goes down to 3GB with the super history



Comparison of IFP and super-history sensitivity of keff to Pu239 fission cross section

- **Generalized Perturbation Theory**
  - Reaction rate ratios
  - Differential Operator Sampling with source effect
  - Verification
    - SCALE6.2.4 & published results
    - UAM – TMI – pincell case, Godiva
  - Application on a more realistic case
    - EOLE reactor core : EPICURE configuration
    - Comparison with APOLLO3 deterministic code

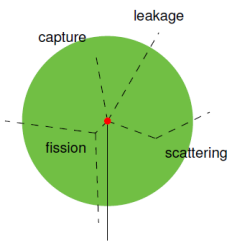
$$R = \frac{< \Sigma_f^{Pu239} \varphi >_{MOX}}{< \Sigma_f^{U235} \varphi >_{UOX}}$$

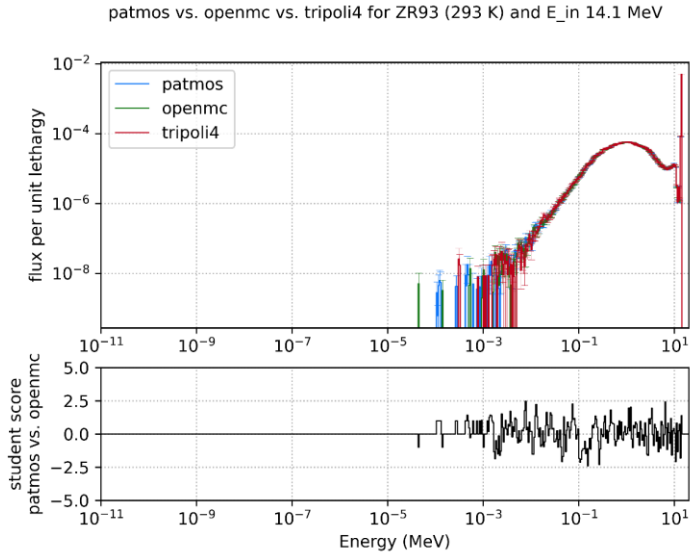


TRIPOLI-5

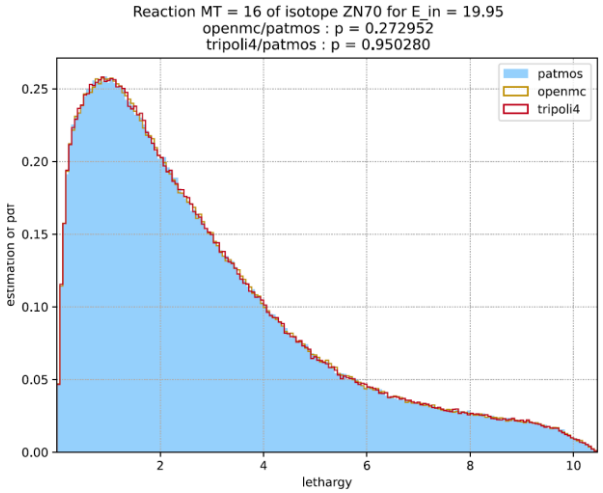
- **New massively parallel Monte Carlo particle transport code**
  - Co-developed by CEA and IRSN
  - For now, relies on the ACE format for nuclear data

- **V&V of the neutron collision physics**
  - Comparison to TRIPOLI-4 and OpenMC
  - Verification test : Single isotope sphere
    - 562 isotopes (JEFF-3.3)
    - 9 energies per isotope from 1e-11 to 20 MeV
    - Energy resolve flux
    - Holm-Bonferroni test





- **Verification of the outgoing distribution sampling**
  - Comparison to TRIPOLI-4 and OpenMC
  - For a given interaction and incident energy E
    - Outgoing energy / cosine distributions
    - Kolmogorov-Smirnov test



Analysis of the discrepancies

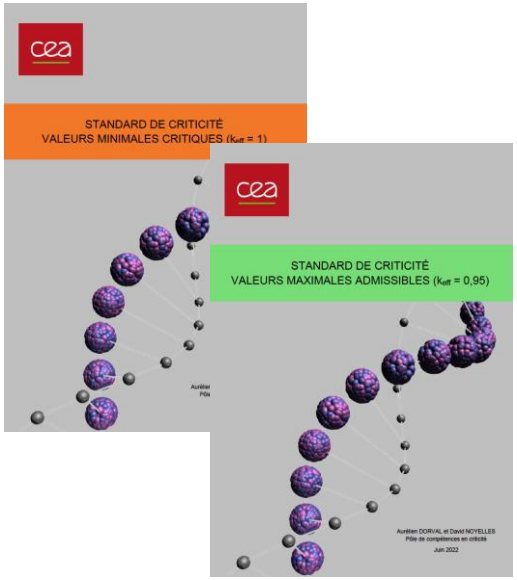
- Reconstruction of some distributions
  - parameters and analytic formula (ENDF format: TRIPOLI-4)
  - pre-computed numerical values (ACE format: TRIPOLI-5 /OpenMC)
- Inconsistencies between reaction Q-value and threshold
  - for level scattering interaction
  - TRIPOLI-4 uses the threshold
  - ACE format uses the Q-value
- Missing delayed data for CM249 at 293K, MT 18
  - TRIPOLI-5 used prompt only instead of total (T4 / OpenMC)
- Bug in OpenMC for ZR93 at 293K, MT 5
  - Correction integrated in OpenMC in November 2022 (hash 765df 91)
- “Gaps” in the distributions energy grids
  - CR50, CR53, CR54, CS135, HF174 and HF176

As a summary

- With the Holm-Bonferroni test with rejection probability $\alpha = 0.001$
- TRIPOLI-5® /TRIPOLI-4® : 91.7% of success rate
  - Data are processed differently
- TRIPOLI-5® /OpenMC : 99.9% of success rate, 6 failures (false negative)
  - Use the exact same ACE files

New criticality handbooks (2022)

- **New criticality handbooks**, 44 years after the aging "Maubert"
- **Permissible** (k_{eff}=0.95) and **critical** values → 2 handbooks
- **Latest criticality code package and calculation options of CRISTAL V2**
- Several **fissile media** studied:
  - Uranium homogeneous media with enrichment from 1.5% to 93.5%
  - Uranium heterogeneous media with enrichment from 1% to 10%
  - Plutonium media with ^{240}Pu content from 0 to 25%
  - Mixed media with Pu content from 2.5% to 40%
  - Actinides
  - Some results for polyethylene and graphite moderators, and also for 25 non standard reflectors
  - Homogeneous poisoning (B, Cd, Gd)
- **Both are published, free for downloading**
- **Translation in English ongoing**



https://rebrand.ly/ebsk7xw

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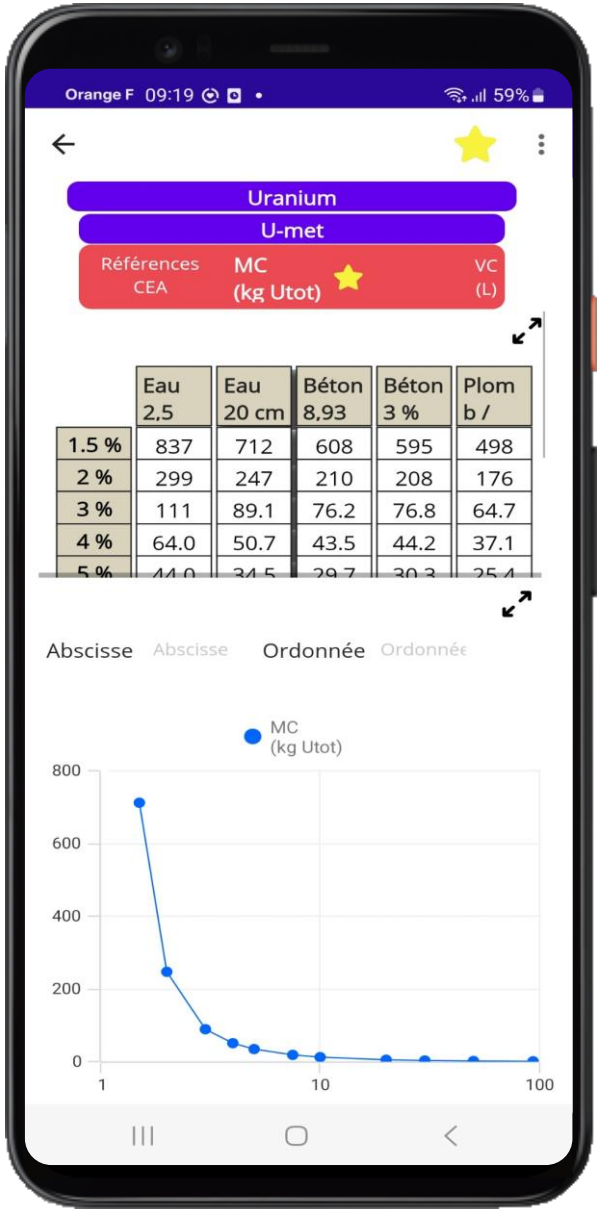
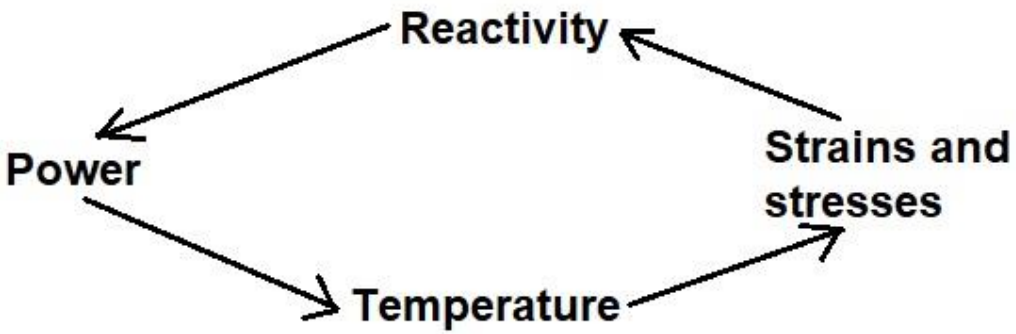
- **iOS** and **Android** app in development to embed these handbooks on a portable device



Criticality accidents studies

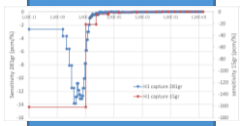
Modelling of criticality accidents occurring in metallic fissile systems, and beginning beyond prompt-criticality

- **In the chosen configurations, the fissile material has a simple shape**
  - sphere, cylinder
  - directly combining equations associated with different fields of physics :
    - neutronics, thermodynamics, thermomechanics

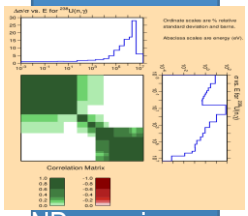


- **Purpose : Getting, as simply as possible, the order of magnitude of parameters depicting the way some solid fissile systems evolve, during power bursts.**
  - Application : Godiva-I, CALIBAN

Sensitivity and uncertainty analysis



Sensitivity profils



ND covariances

Impact of exp. correl. on ND bias

- Calculation and comparison of **k_{eff} sensitivity to nuclear data**

  → Consistency and completeness of deterministic and Monte Carlo calculation routes + study of similarity coefficient

- Calculation, access and comparison **of propagated nuclear data uncertainty**

  → Nuclear data covariances (COMAC[1]) confidence on specific isotopes of interest for criticality studies + study of similarity coefficients and recommendation for its use

- Calculation of bias due to nuclear data, and the associated posterior uncertainty using **assimilation/transposition method (GLLSM)**

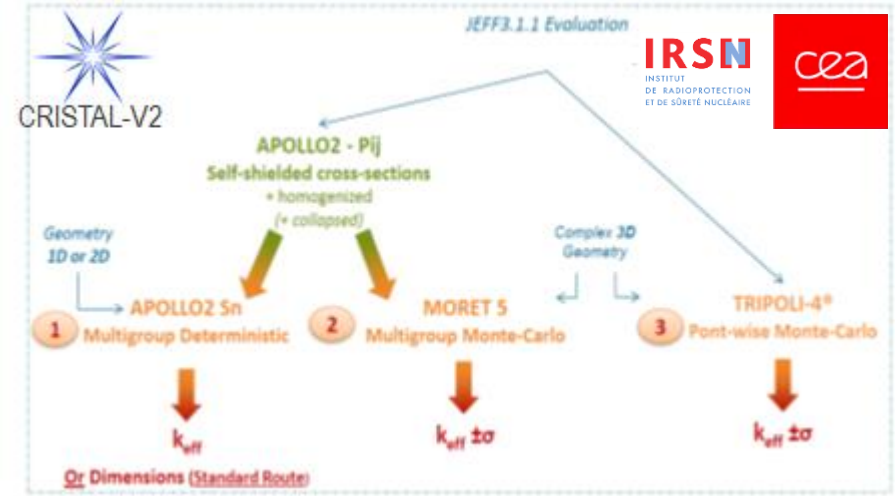
  → experimental correlations estimation and impact on GLLS method (comparison with published data and participation to OCDE/NEA WPNCS- SG11)

  Validation of GLLSM : confidence level on the results

[1] P. Archier et al., "COMAC Nuclear data covariance matrices library for reactor applications," Proceeding of the International Conference PHYSOR 2014, Kyoto, Japan, Sept 28 –Oct 3, 2014

Optimization between C-E improvement and calculation time

- Nuclear data library : based on JEFF3.1.1 with different probability tables processing
- Refinement of energy meshes
- New Self shielding treatment
- Harmonization of spatial meshes



Needs of experimental results for experimental validation of :

- Intermediate enriched uranium (between 10 % and 20 %)
- Low moderated U, Pu, U+Pu

Two-week Criticality Safety Engineers course

- **A senior criticality safety engineer and officer @ CEA/Cadarache, attended the NCSP Two-week Criticality Safety Engineers Course @ NATM/NFO and SNL (August 8-19, 2022)**
- **The feedback is excellent:**
  - the first week allows a direct view on the US Criticality Safety regulation and approach, with a lot of valuable exchanges with US colleagues working on installations,
  - the second week is also a very interesting experience: calculations are combined with fuel manipulation and the experimental setup of the core.
- **We are very thankful for this opportunity and would like to propose another candidate for the 2-week CSE course (August 7-18, 2023).**

Thank you for your attention