DE LA RECHERCHE À L’INDUSTRIE

Update of CEA DES Criticality-Safety Activities and Perspectives

20 February 2023

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 Probability 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
**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](image1)
![Stochastic tessellations](image2)

![Graph](image3)

Blue = UOX
Red = MOX
Dashed lines = Atomic mix
Dotted line = Reference
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 3 GB with the super history

- **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

\[ R = \frac{\langle \Sigma_f^{Pu239} \phi \rangle_{MOX}}{\langle \Sigma_f^{U235} \phi \rangle_{UOX}} \]
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
TRIPOLI-5

▷ 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** ($k_{\text{eff}}=0.95$) 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 $^{240}\text{Pu}$ 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

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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

- Calculation and comparison of $k_{\text{eff}}$ sensitivity to nuclear data

- Calculation, access and comparison of propagated nuclear data uncertainty

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

Validation of GLLSM: confidence level on the results

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CRISTAL V2.1 : towards a new deterministic calculation scheme

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