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IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

# INTERNATIONAL BENCHMARK COMPARISON FOR NUCLEAR DATA AND CODE VALIDATION : OUTLOOK AND STATUS

IRSN-AM13/ORNL-AM10/LLNL-AM5/LANL-AM5

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MEMBRE DE ETSON

# Outline

- Project overview
- $\beta_{eff}$ comparisons (2023 work)
- Conclusion and prospects

# Project overview

- Principle: calculate quantities of interest using multiple Monte-Carlo codes and nuclear data libraries.

- Objectives :
  - Cross-validate Monte Carlo codes :
    - ➢ for the same models, all codes/methodologies shall provide the same results (± 3σ) ;
    
    (source of discrepancies: errors or differences in the reference model (e.g. revision), nuclear data processing, etc.).
  - Have feedback on nuclear data libraries: methodology for assessing library quality and validation.

- Framework :
  - $k_{eff}$ comparisons (2022)
    - ➢ key findings :
      - quite good agreement between codes,
      - interesting feedback on JEFF-3.3, ENDF/B-VII.1 and ENDF/B-VIII.0, especially for reflectors.
  - $\beta_{eff}$ comparisons (2023) ⇦ Topic of the day
  - Shielding comparisons (2024)

# $\beta_{eff}$ comparisons

- Two objectives:
  - Cross-validation of 5 Monte Carlo codes and several $\beta_{eff}$ calculation methods ;
  - Feedback on 2 nuclear data libraries : ENDF/B-VIII.0 [1] and JEFF-3.3 [2].

| / | MORET6 | SCALE6.3 | MCNP6.2 | COG11.3 | MC21.v10 |
|---|---|---|---|---|---|
| Nuclear Data Librarie(s) | ENDF/B-VIII.0<br>JEFF-3.3 | ENDF/B-VIII.0 | ENDF/B-VIII.0 | ENDF/B-VIII.0<br>JEFF-3.3 | ENDF/B-VIII.0 |
| Processing Tool | GAIA1 (based on NJOY2016.35) | AMPX | NJOY | PREPRO (except for TSL and JEFF lib.) | NDEX (based on NJOY2012) |

# $\beta_{eff}$ comparisons

- $\beta_{eff}$ calculation methods
  - MORET6: adjoint flux method with 2 generations (ADNH = 2) to estimate the adjoint flux [3],
  - COG11.3 methods [4] :
    - new method → $\beta_{eff} = F_d/F_t$ ;
    - modified new method → $\beta_{eff} = (nF)_d/(nF)_t$ ;
    - prompt method → $\beta_{eff} = 1 – (k_p/k_{eff})$ ;
  - MC21.v10 methods :
    - MC21.v10 next fission probability method (NFP) [5] ;
    - MC21.v10 correlated sampling method [6] ;
  - MCNP6.2: KOPTS card [7] ;
  - SCALE6.3 : KENO ; Bretscher approximation → $\beta_{eff} = 1 – (k_p/k_{eff})$ [8].

$F_d$ = number of fission induced by delayed neutrons
$F_t$ = total number of fissions

$(nF)_d$ = number of neutrons from fission induced by delayed neutrons
$(nF)_t$ = number of neutrons from all fissions

$k_p$ = prompt effective neutron multiplication factor
$k_{eff}$ = effective multiplication factor

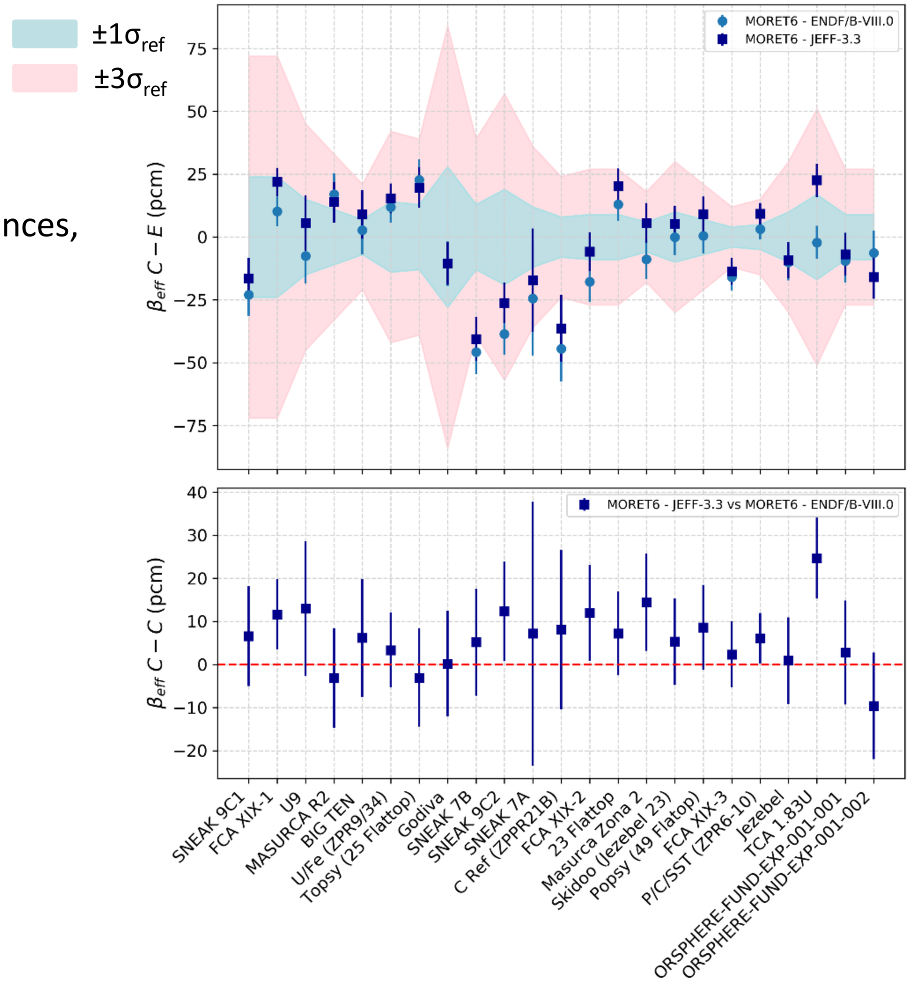
## $\beta_{eff}$ comparisons

- 23 benchmarks selected based on available common benchmarks :
  - all modeled with MORET6, SCALE6.3, COG 11.3 and MC21.v10 ;
  - 10 modeled with MCNP6.2.

| SERIES | MORET6 | SCALE6.3 | COG11.3 | MCNP6.2 | MC21.v10 |
|---|---|---|---|---|---|
| SNEAK 9C1 | ✓ | ✓ | ✓ | | ✓ |
| FCA XIX-1 | ✓ | ✓ | ✓ | | ✓ |
| U9 | ✓ | ✓ | ✓ | ✓ | ✓ |
| MASURCA R2 | ✓ | ✓ | ✓ | | ✓ |
| BIG TEN | ✓ | ✓ | ✓ | ✓ | ✓ |
| U/Fe (ZPR9/34) | ✓ | ✓ | ✓ | ✓ | ✓ |
| Topsy (25 Flattop) | ✓ | ✓ | ✓ | ✓ | ✓ |
| Godiva | ✓ | ✓ | ✓ | ✓ | ✓ |
| SNEAK 7B | ✓ | ✓ | ✓ | | ✓ |
| SNEAK 9C2 | ✓ | ✓ | ✓ | | ✓ |
| SNEAK 7A | ✓ | ✓ | ✓ | | ✓ |
| C Ref (ZPPR21B) | ✓ | ✓ | ✓ | ✓ | ✓ |
| FCA XIX-2 | ✓ | ✓ | ✓ | | ✓ |
| 23 Flattop | ✓ | ✓ | ✓ | ✓ | ✓ |
| Masurca Zona 2 | ✓ | ✓ | ✓ | | ✓ |
| Skidoo (Jezebel 23) | ✓ | ✓ | ✓ | ✓ | ✓ |
| Popsy (49 Flatop) | ✓ | ✓ | ✓ | ✓ | ✓ |
| FCA XIX-3 | ✓ | ✓ | ✓ | | ✓ |
| P/C/SST (ZPR6-10) | ✓ | ✓ | ✓ | | ✓ |
| Jezebel | ✓ | ✓ | ✓ | ✓ | ✓ |
| TCA 1.83U | ✓ | ✓ | ✓ | | ✓ |
| ORSPHERE-FUND-EXP-001-001 | ✓ | ✓ | ✓ | | ✓ |
| ORSPHERE-FUND-EXP-001-002 | ✓ | ✓ | ✓ | | ✓ |

# $\beta_{eff}$ comparisons

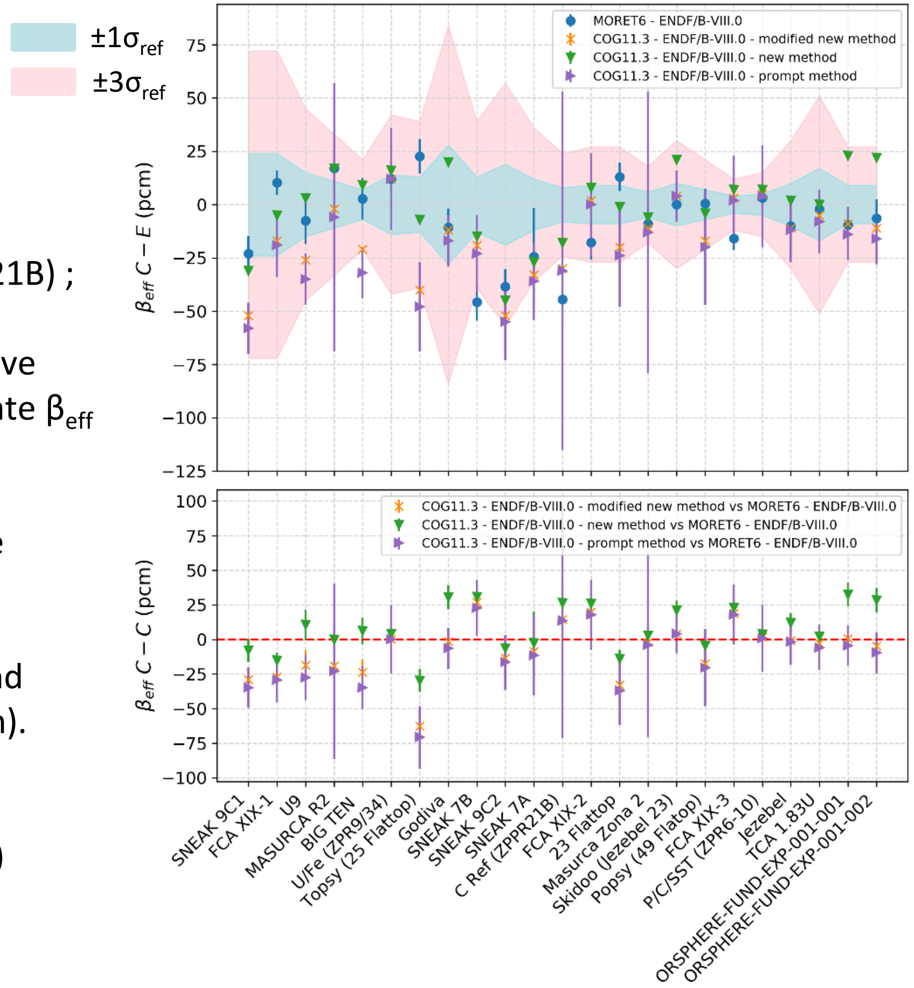
- MORET6
  - $\beta_{eff}$ estimates are consistent with experimental references, except for case C Ref (ZPPR21B) ;
  - Good agreement between ENDF/B-VIII.0 and JEFF-3.3 (discrepancies < 25pcm).



# $\beta_{eff}$ comparisons

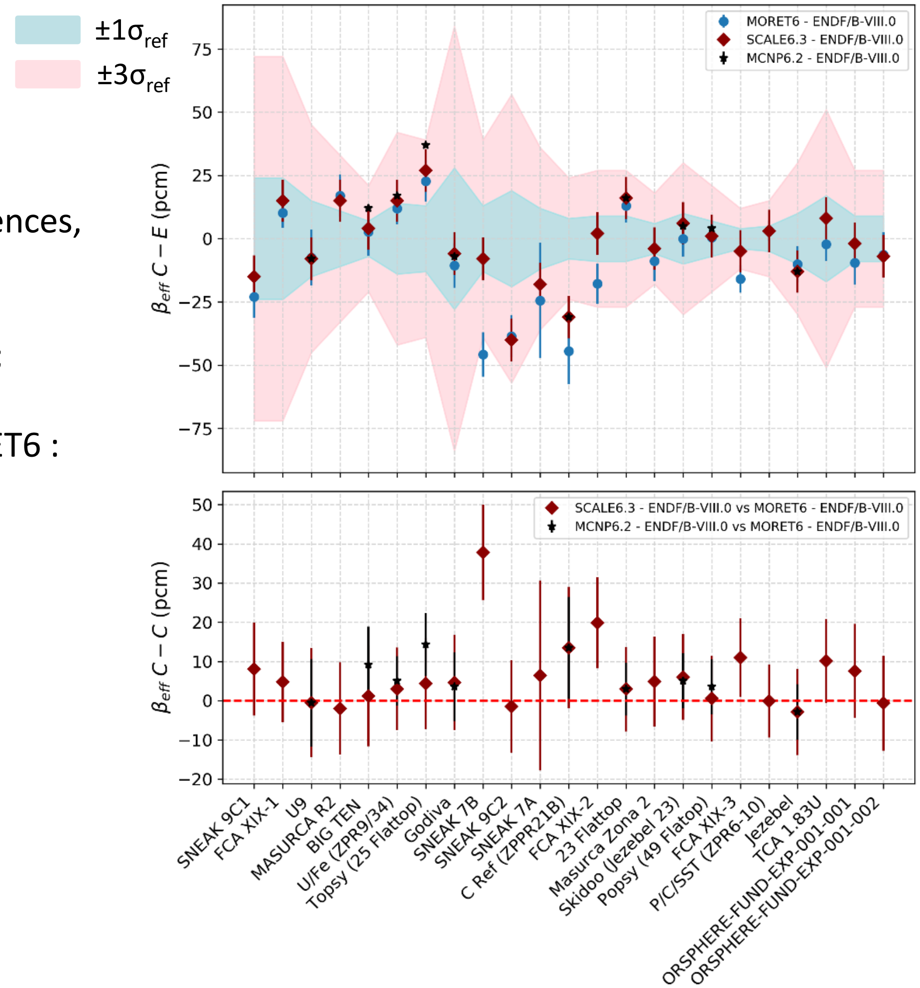
- COG11.3 – ENDF/B-VIII.0
  - For all methods, $\beta_{eff}$ estimates are consistent with experimental references, except for case C Ref (ZPPR21B) ;
  - The "prompt method" and "modified new method" give very similar results → slight tendency to underestimate $\beta_{eff}$ compared to MORET6 ;
  - The "new method" have a slight tendency to estimate higher $\beta_{eff}$ values than other COG methods ;
  - Overall, there is good consistency between all COG and MORET6 methods (max(| $\beta_{COG11.3} - \beta_{MORET6}$ |) = 71 pcm).

(Trends shown here are unchanged with JEFF-3.3)



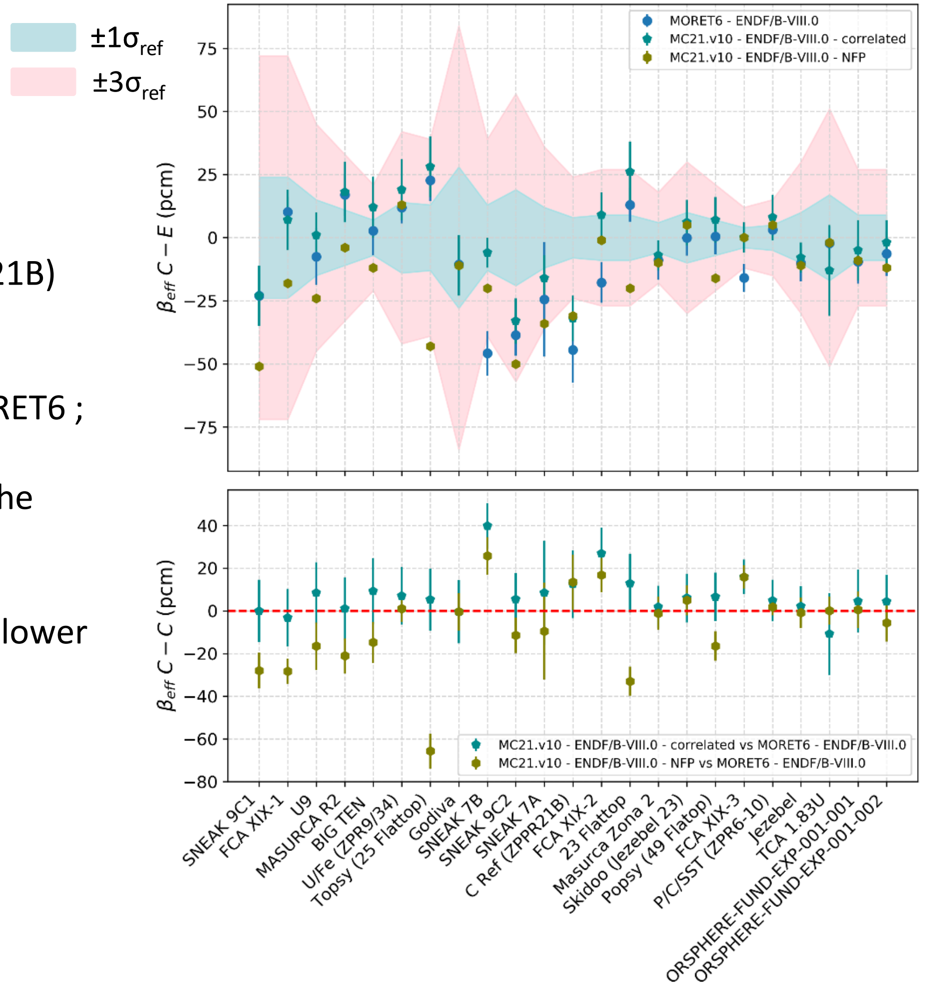
# $\beta_{eff}$ comparisons

- SCALE6.3 and MCNP6.2 – ENDF/B-VIII.0
  - $\beta_{eff}$ estimates are consistent with experimental references, except for case C Ref (ZPPR21B) ;
  - SCALE6.3 and MCNP6.2 give relatively similar results ;
  - Both codes are in overall good agreement with MORET6 :
    - ➢ max(| $\beta_{SCALE6.3} - \beta_{MORET6}$ |) = 38 pcm ,
    - ➢ max(| $\beta_{MCNP6.2} - \beta_{MORET6}$ |) = 14 pcm ;
  - A slight tendency to estimate higher $\beta_{eff}$ values than MORET6 is observed.



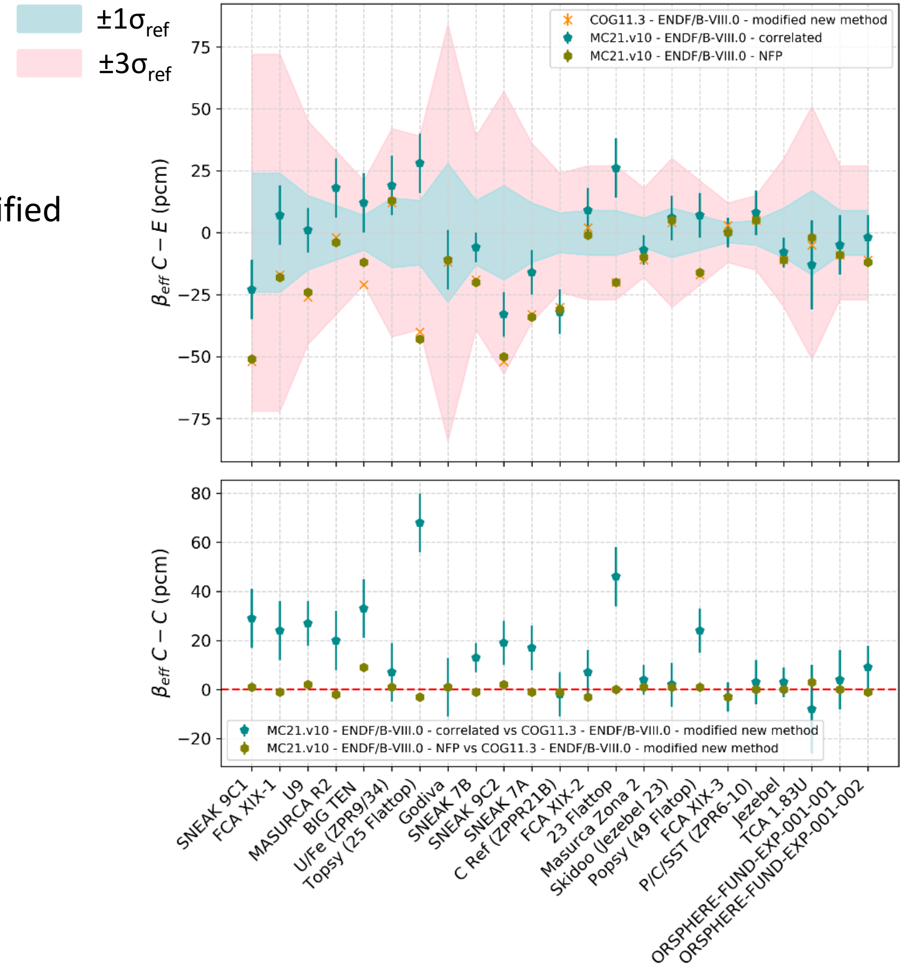
# $\beta_{eff}$ comparisons

- MC21.v10 – ENDF/B-VIII.0
  - For all methods, $\beta_{eff}$ estimates are consistent with experimental references, except for case C Ref (ZPPR21B) (and Topsy (25 Flattop) for the NFP method) ;
  - Good overall agreement between MC21.v10 and MORET6 ;
  - The NFP method gives overall lower $\beta_{eff}$ results than the correlated method ;
  - The MC21.v10 NFP method tends to estimate slightly lower $\beta_{eff}$ values → results a bit more discrepant.
    - ➢(max(| $\beta_{MC21.v10,\ NFP}$ – $\beta_{MORET6}$ |) = 66 pcm for Topsy).



# $\beta_{eff}$ comparisons

- MC21.v10 – ENDF/B-VIII.0
  - NFP method gives results very close to COG11.3 modified new method (and therefore to the COG11.3 prompt method).



# Conclusion

- Key findings on $\beta_{eff}$ :
  - For all codes and $\beta_{eff}$ calculation methods → overall good agreement between calculated values and reference experimental values ;
  - Overall good consistency between code predictions ;
  - ENDF/B-VIII.0 and JEFF-3.3 lead to similar results ;
  - For all codes, methods and nuclear data libraries → tendency to slightly underestimate the $\beta_{eff}$ value for the C Ref (ZPPR21B) benchmark → problem with experimental reference value?

- Report on $\beta_{eff}$ intercomparison is currently being written at IRSN (draft version expected in April 2024).

- Intercomparison exercises are a very efficient way to improve the reliability of calculation database and provide interesting feedbacks on codes, processing tools and nuclear data libraries.

## Prospects

- Planned : shielding calculations in 2024.

- New proposal submitted to the 2024 call : intercomparison exercise on nuclear data processing
  - Feedback on processing tools, options and methods.
  - ➢ Modeling of **simple cases** to avoid compensation effects ;
  - ➢ Use of the same nuclear data evaluation and Monte-Carlo code (and the same input file).

- Acknowledgment
  - ➢IRSN thanks the NCSP for supporting this action on analytical methods and all the partners for this exercise.

# References

[1] A. J. M. Plompen et al., The joint evaluated Fission and fusion nuclear data library, JEFF-3.3 – The European Physical Journal A, (2020), p: 56-181.

[2] D.A. Brown et al., , ENDF/B-VIII.0: The 8th Major Release of the Nuclear Reaction Data Library with CIELO-project Cross Sections, New Standards and Thermal Scattering Data, Nuclear Data Sheets, Volume 148, February 2018, p: 1-142.

[3] J. Miss, A. Jinaphanh, Y. Richet and O. Jacquet, "Calculating the kinetic parameters in the continuous energy Monte-Carlo code MORET", PHYSOR 2010, Pittsburgh, Pennsylvania, USA.

[4] D. Heinrichs, E. Lent and W. Zywiec, COG Beta-Effective Benchmarks, LLNL-TR-843852.

[5] : R.K. Meulekamp and S.C. van der Marck, "Calculating the Effective Delayed Neutron Fraction with Monte Carlo," Nucl. Sci. Eng., 152, pp.142-148 (2006).

[6] : D. P. Griesheimer and N.A. Gibson, "Simplified Method for Estimating the Effective Delayed Neutron Fraction with Monte Carlo Correlated Sampling," Proceedings of the International Conference on Mathematics and Computational Methods Applied to Nuclear Science and Engineering (M&C 2019), pp. 886-895 (2019).

[7] MCNP® USER'S MANUAL, Code Version 6.2, October 27, 2017.

[8] A. Shaw and B.J. William Marshall, Validation of KENO Delayed Neutron Fraction Capabilities. United States: N. p., 2021. Web. doi:10.13182/T125-37018.

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# BACK-UP SLIDES

## $\beta_{eff}$ comparisons

- 23 benchmarks, retrieved from IRPHE Handbook and from open publications

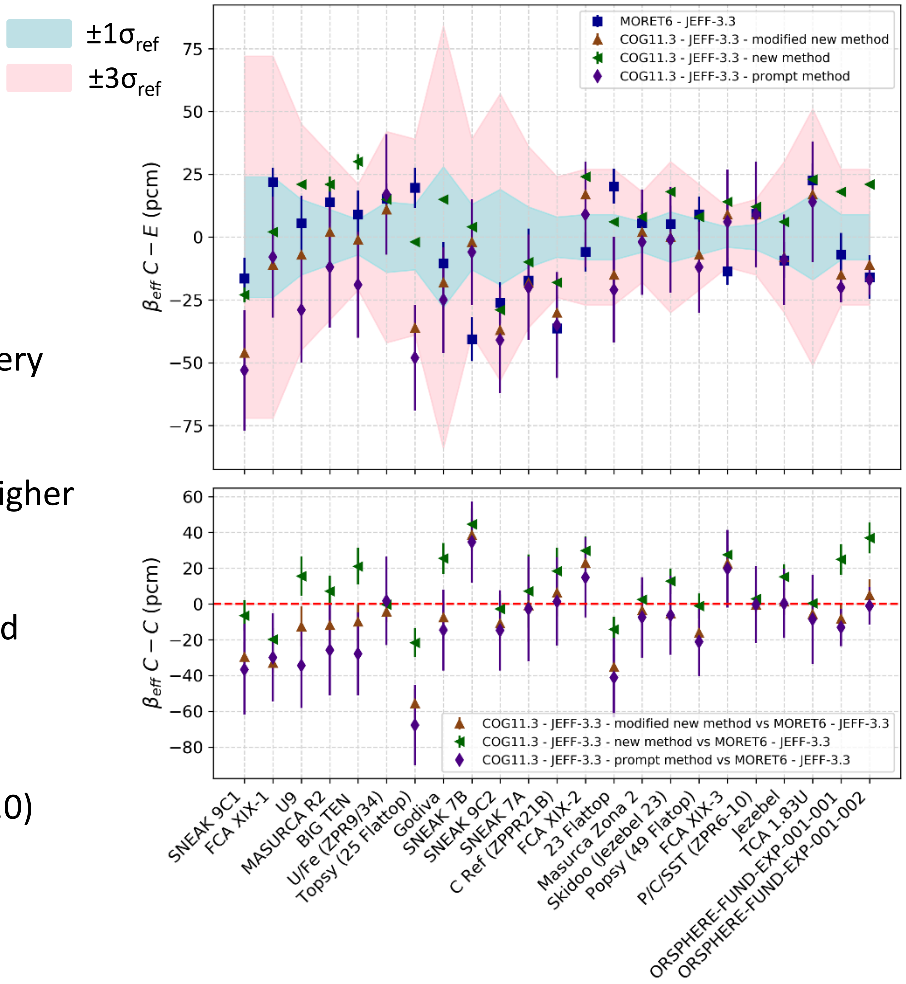
- FCA XIX sources were found to have discrepant densities:
  - Fe for all FCA XIX cases ;
  - $^{10}B$ for FCA XIX-2.

| SERIES | IRPHE reference | $\beta_{ref}$ (pcm) | $\sigma_{ref}$ |
|---|---|---|---|
| SNEAK 9C1 | Not in IRPHE | 758 | 24 |
| FCA XIX-1 | Not in IRPHE | 742 | 24 |
| U9 | Not in IRPHE, IMF010-1 | 731 | 15 |
| MASURCA R2 | Not in IRPHE | 721 | 11 |
| BIG TEN | Not in IRPHE, IMF-007 | 720 | 7 |
| U/Fe (ZPR9/34) | Not in IRPHE, HMF-035 (HMI-001) | 671 | 14 |
| Topsy (25 Flattop) | Not in IRPHE, HMF-028 | 665 | 13 |
| Godiva | Not in IRPHE, HMF-001 | 659 | 28 |
| SNEAK 7B | SNEAK-LMFR-EXP-001 | 429 | 13 |
| SNEAK 9C2 | Not in IRPHE | 426 | 19 |
| SNEAK 7A | SNEAK-LMFR-EXP-001 | 395 | 12 |
| C Ref (ZPPR21B) | Not in IRPHE, MIX-MET-FAST-011-1 | 384 | 8 |
| FCA XIX-2 | Not in IRPHE | 364 | 9 |
| 23 Flattop | Not in IRPHE, UMF-006 | 360 | 9 |
| Masurca Zona 2 | Not in IRPHE | 349 | 6 |
| Skidoo (Jezebel 23) | Not in IRPHE, UMF-001 | 290 | 10 |
| Popsy (49 Flatop) | Not in IRPHE , PMF-006 | 276 | 7 |
| FCA XIX-3 | Not in IRPHE | 251 | 4 |
| P/C/SST (ZPR6-10) | Not in IRPHE, PMI-002 | 223 | 5 |
| Jezebel | Not in IRPHE, PMF-001 | 195 | 10 |
| TCA 1.83U | TCA-LWR-EXP-001, LCT-006-008 | 771 | 17 |
| ORSPHERE-FUND-EXP-001-001 | ORSPHERE-FUND-EXP-001 | 657 | 9 |
| ORSPHERE-FUND-EXP-001-002 | ORSPHERE-FUND-EXP-002 | 657 | 9 |

# $\beta_{eff}$ comparisons

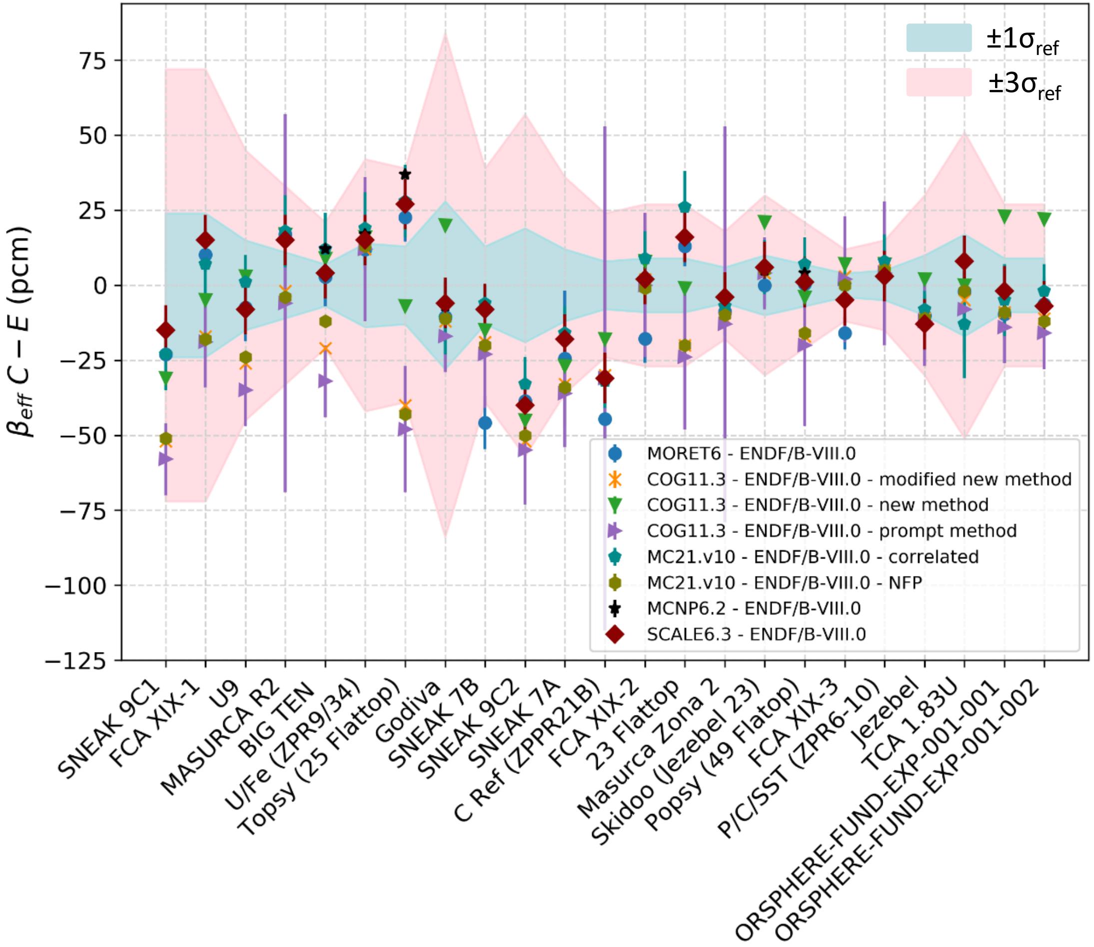
- COG 11.3 – JEFF-3.3
  - For all methods, $\beta_{eff}$ estimates are consistent with the experiment ;
  - The prompt method and modified new method give very similar results ;
  - The new method have a slight tendency to estimate higher $\beta_{eff}$ values than other COG methods ;
  - Overall, there is good consistency between all COG and MORET6 methods (maximum difference = -68 pcm).

(Trends shown here are unchanged with ENDF/B-VIII.0)



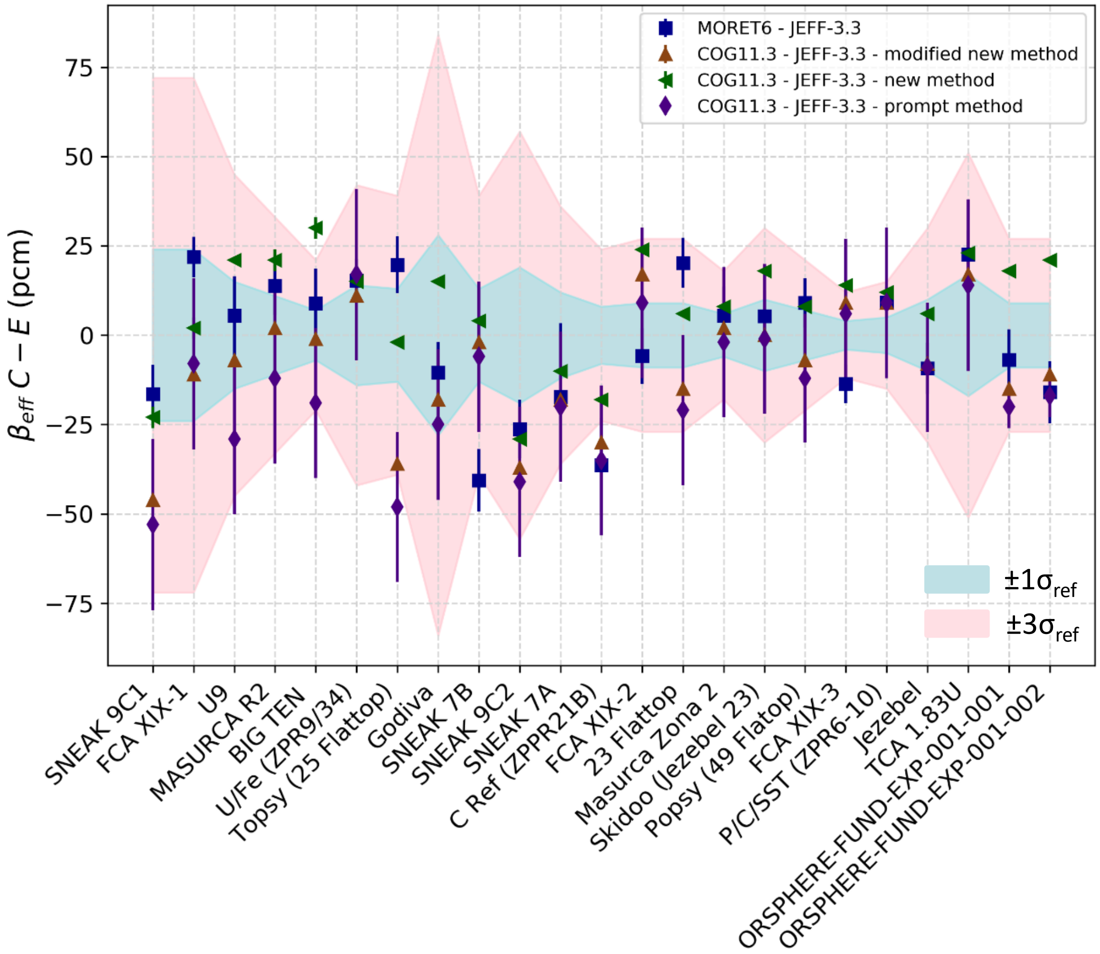
# $\beta_{eff}$ comparisons

- Results with ENDF/B-VIII.0



# $\beta_{eff}$ comparisons

- Results with JEFF-3.3



# $\beta_{eff}$ comparisons

- COG 11.3 – ENDF/B-VIII.0 vs JEFF-3.3