IRSN
INSTITUT DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

NUCLEAR DATA AND BENCHMARKING NEEDS AND DPA RELATED MEASUREMENTS

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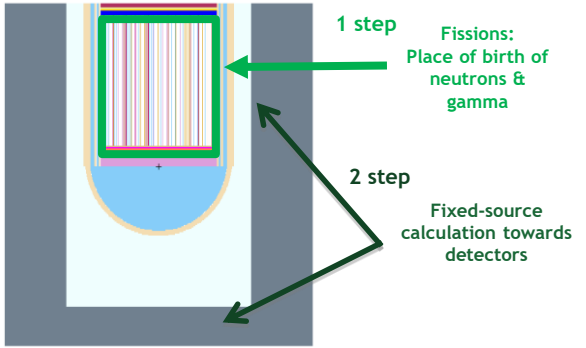
Context

Motivation to have **(validated) tools with precise physical phenomena** description <u>to anticipate the ageing effects</u>

➡ IRSN NEEDS:
nuclear reactor lifetime extension,
new reactors: EPR, ITER, research reactors…

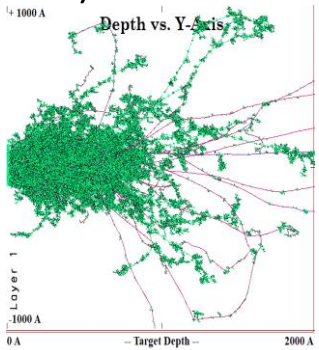


<u>Different axis of R&D:</u>

- Validation of the fission distribution in the core: *R. Vuiart thesis, using SIMULATE diffusion code*
- Variance reduction methods benchmarking for the Monte-Carlo codes (MCNP + TRIPOLI)
- **Need: Nuclear data impact on different stages of these calculations**
- « Good » ageing indicators ?
  - DPA comparison SRIM/DART/NJOY methods: **SRIM & DART similar results**
  - Sensitivity of these methods to composition/**spectrum**/**binding energy E_d**

Different sensitivities to the neutron spectrum between DART and SRIM

Material science issue



Ageing issues – ND needs

Isotopes in structural materials:

- Fe (54,56,58), Ni (58,59), Cr(52,53,54)
- Not structural: O16

Which type of data:

- Accurate capture cross sections above the inelastic threshold and uncertainties
- Angular and energy distributions, that impact the RECOIL energy of the nucleus

Focus on damages estimation

DPA

- Is one of the estimators one can use to quantify the damages
- Can be used (carefully) in relative comparison

More physical

- Effect of irradiation may be comparable if looking at **PKA spectrum**
- Separation between the neutron-nucleus interaction and the atom-cascade
- Nuclear physicists have to assure the precise PKA spectrum calculations

All ND that impact this spectrum: in- & elastic, heavy secondary particle distributions (alpha, He3, ..)

Focus on damages estimation

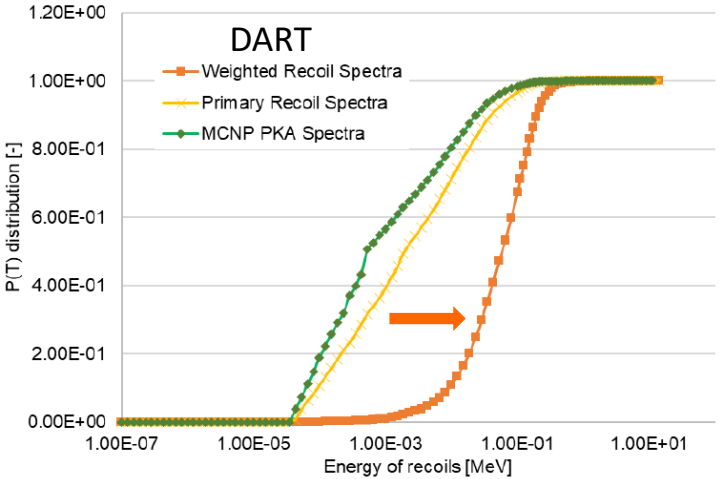
Sensitivity analysis of PKA spectrum could lead to better identify the ND needs

- Literature ?
- Could be done via random sampling of ND…?

BEST would be :

sensitivity analysis of weighted PKA spectrum

- DART code provides PKA weighted by DPA
- Even better : PKA weighted by **ARC-DPA** (not available)

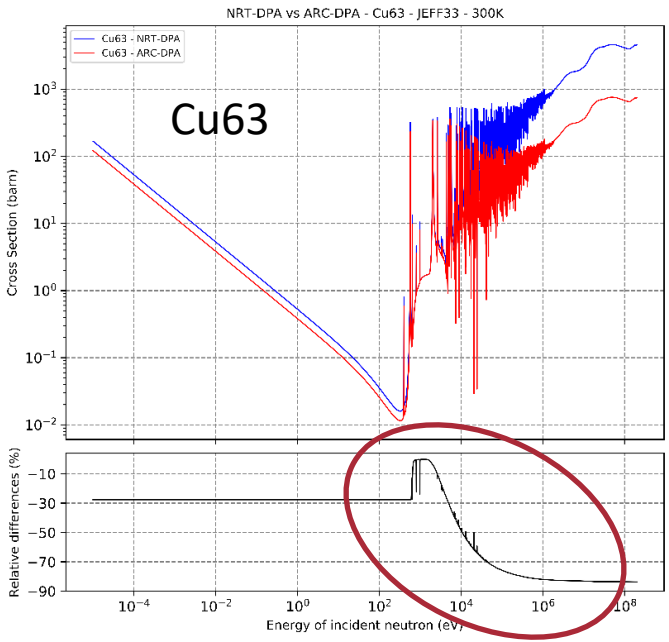


Work performed with IDOM

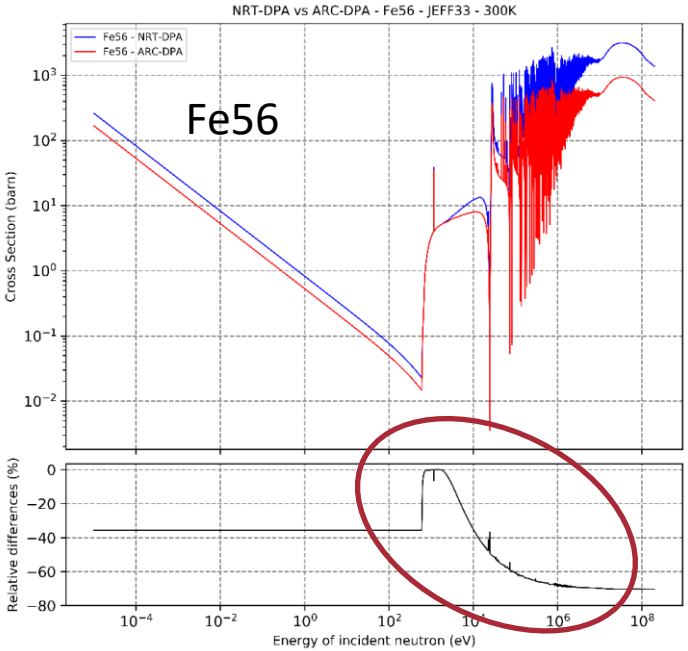
Better represents the number of displacements created during a cascade

DPA vs ARC-DPA

Athermal recombination corrected-DPA



Factor 1/6



Factor 1/3

Impact of the ARC-DPA/DPA varies with energy
Correction factors available only for a few elements

Cst impact for E > 1 MeV

DPA measurements ?

Vacancies measurements

- Material properties analysis : new technique of laser-induced Transient Grating Spectroscopy (TGS)

  Transient grating spectroscopy: An ultrarapid, nondestructive materials evaluation technique
  MRS Bulletin , Volume 44 , Issue 5: Acoustic Processes in Materials , May 2019 , pp. 392 - 402
  DOI: https://doi.org/10.1557/mrs.2019.104, Felix Hofmann, Michael P. Short and Cody A. Dennett

- Transmission electron microscopy (TEM), positron annihilation spectroscopy (PAS) to count the **number of vacancies** before thermal recombination ? **Comparable to simulations ?**

European Project H2020 ENTENTE

- **EUROPEAN DATABASE FOR MULTISCALE MODELLING OF RADIATION DAMAGE**

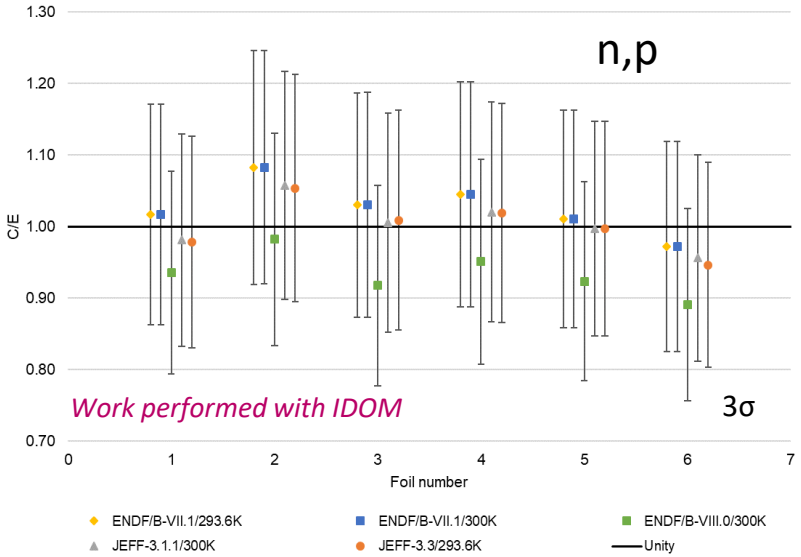
- Goal: *To design and maintain a unique experimental/modelling database for model validation and calibration, to be used in an international framework*

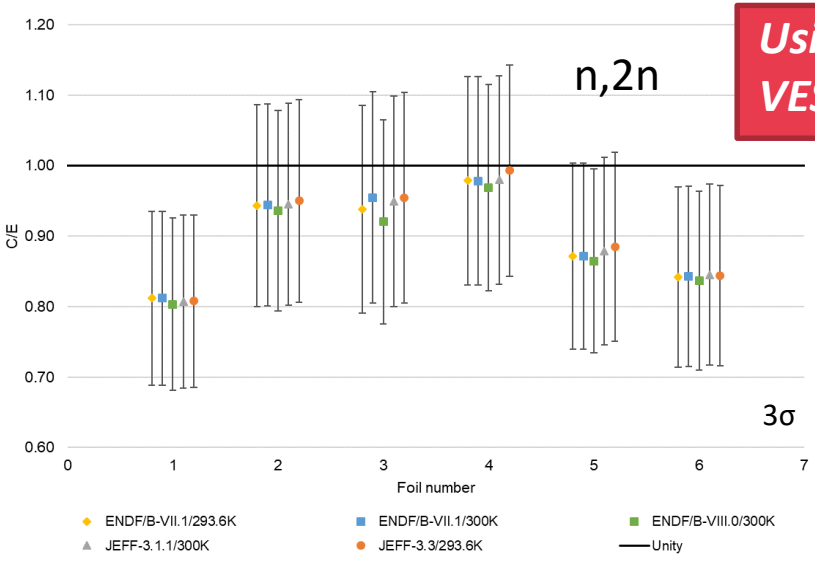
- IRSN task: To evaluate the sensitivity of the models/experiments to the *neutron spectrum* via dpa, fast flux, …

  ⇒ we expect: to have an insight of the importance of the *needed precision of neutronics*

SINBAD benchmarks feedback

- SINBAD benchmark (NEA-1517/96) « **H.B. Robinson-2 Pressure Vessel Dosimetry Benchmark ROBINSON** »
  - Missing information (activations foils) ***-> preliminary results : discrepancies ~20-30%, ongoing analysis***
- SINBAD benchmark (NEA-1553/55) « **FNG-ITER Dose Rate Experiment** »
  - Inconsistencies in compositions; no isotopic content of the Ni58 activation foils; some geometry issues; ..





Using MCNP + VESTA codes

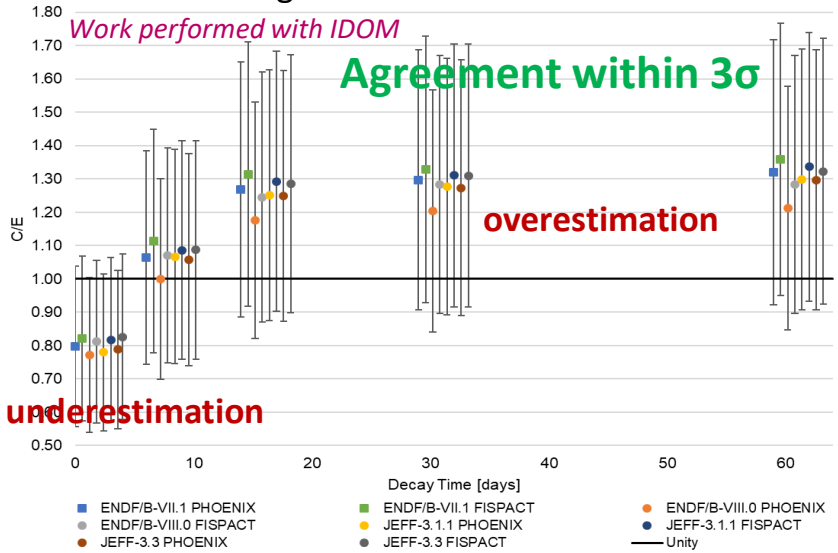
In-house developed depletion code

SINBAD benchmarks feedback

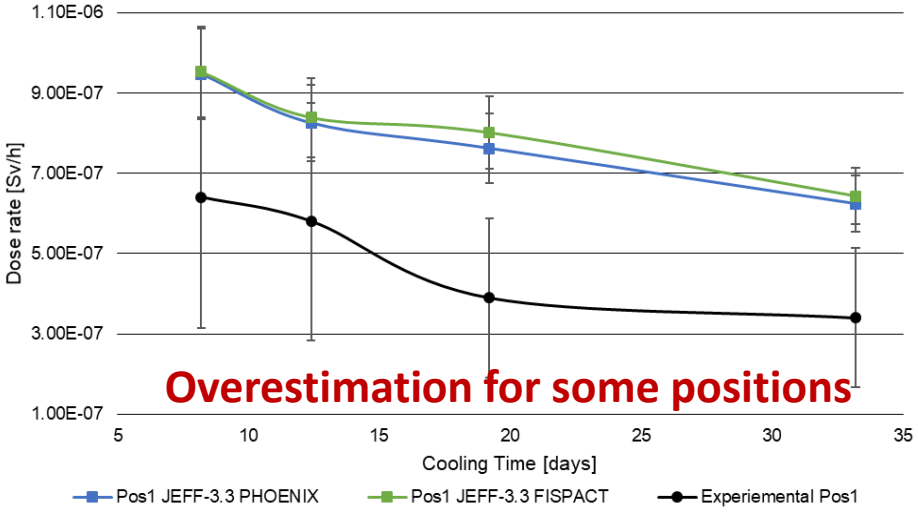
Using MCNP + VESTA codes

- SINBAD benchmark (NEA-1553/55) « FNG-ITER Dose Rate Experiment »
  - Shut down measurements

Geiger-Müller measurements



TLD measurements



Concluding remark: SINBAD should include more information to help on practical applications

Summary - Conclusion

ND needs concern:

- Transport -> neutron flux and spectrum
- Recoil energy of the nucleus -> PKA, we will focus our analysis on PKA (DPA, weighted PKA, ARC-DPA, ..)

Other material damages indicators:

- ARC-DPA data is not available for all elements & same corrections for all isotopes ?
- Future: Measurements of the vacancies ? (before thermal recombination ?)
- Future: Feedback from the European project ENTENTE on the sensitivity to the precision of the indicator
  - ➢ Multi-scale software and experimental data

Feedback on the SINBAD benchmarks:

- FNG-ITER dose rate experiments: missing information, inconsistencies, some discrepancies in the results…
- H.B. Robinson-2 Pressure Vessel Dosimetry Benchmark : missing information, some discrepancies in the results

How to share this feedback with the SINBAD community ?

NRT-DPA

$$N_d(T_d) = \begin{bmatrix} 0 & , & T_d < E_d \\ 1 & , & E_d < T_d < \frac{2E_d}{0.8} \\ \frac{0.8T_d}{2E_d} & , & \frac{0.8T_d}{2E_d} < T_d < \infty \end{bmatrix}$$

ARC-DPA

$$N_d(T_d) = \begin{bmatrix} 0 & , & T_d < E_d \\ 1 & , & E_d < T_d < \frac{2E_d}{0.8} \\ \frac{0.8T_d}{2E_d}\xi_{arcdpa}(T_d) & , & \frac{0.8T_d}{2E_d} < T_d < \infty \end{bmatrix}$$

$$\xi_{arcdpa}(T_d) = \frac{1 - c_{arcdpa}}{(2E_d/0.8)^{b_{arcdpa}}} T_d^{b_{arcdpa}} + c_{arcdpa}$$