7th International Workshop on Nuclear Data Evaluation for Reactor Applications (WONDER 2026)

Fuel decay heat: Nuclear Data Needs from EDF perspective & Nuclear Data uncertainty propagation using CEA's next generation fuel inventory code MENDEL

Øystein BREMNES EDF – DirIN – Design & Technology Branch
Fabrice HOAREAU EDF – R&D

Summary

1. ND & decay heat: what applications at EDF ?
2. Coming next: MENDEL inventory code & JEFF4 ND
3. Industrial decay heat uncertainty evaluations
4. EDF’s DH uncertainty abacus for standard applications
5. ND needs from EDF perspective
6. Conclusions & discussion

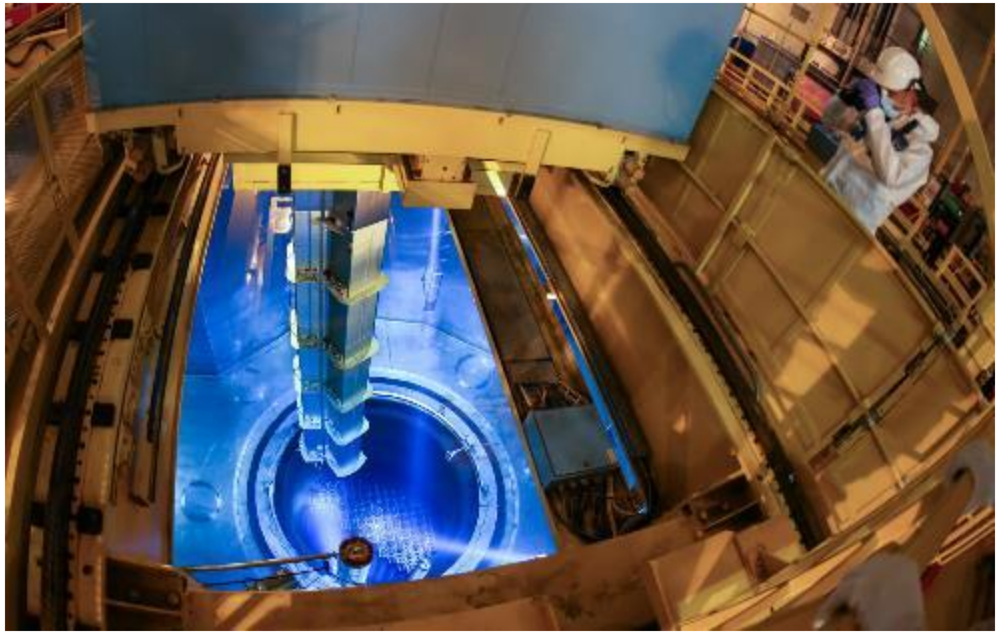
1.

Nuclear Data & decay heat

What applications at EDF?

Nuclear Data & decay heat: what applications at EDF?

DESIGN & TECHNOLOGY BRANCH



4250 MW reactor DH values
Full core :

270 MW	1/2	0 second
130 MW		100 seconds
56 MW		1 hour
29 MW		10 hours
15 MW		3.5 days
7.5 MW		17 days
3.5 MW		75 days

Decay heat

- Thermal power released from the radioactive decay of nuclides
  NB : energy from delayed fissions not discussed in this presentation
- Contributes to 7% of the core power during operation
- Lasts for years after shutdown

Some applications

- Core fault studies (<10 days)
- Spent fuel pool fault studies
- Spent fuel transport (>1 year)

Core size,
Core power before shutdown
Core fuel management

Nuclear Data & decay heat: what applications at EDF?

DESIGN & TECHNOLOGY BRANCH

4250 MW reactor DH values, Unloaded batch :

5.07 MW	4 days
0.46 MW	1.2 years
0.25 MW	2.3 years
0.16 MW	3.5 years
0.12 MW	4.6 years
0.10 MW	5.8 years

Decay heat

- Thermal power released from the radioactive decay of nuclides
  NB : energy from delayed fissions not discussed in this presentation
- Contributes to 7% of the core power during operation
- Lasts for years after shutdown

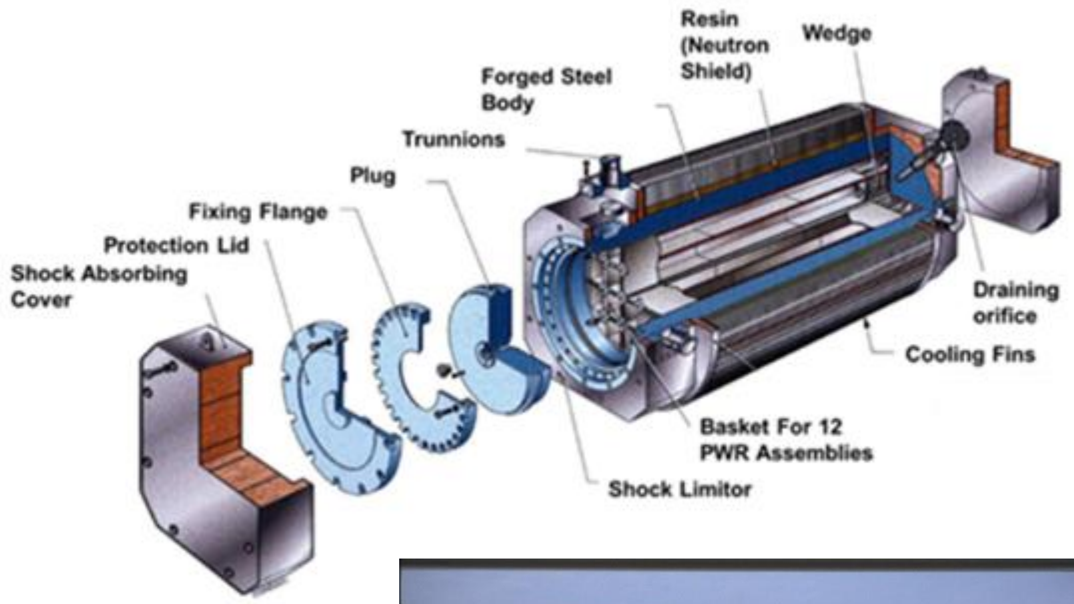
Some applications

- Core fault studies (<10 days)
- Spent fuel pool fault studies
- Spent fuel transport (>1 year)

Unloaded batch size & Burn-up

Nuclear Data & decay heat: what applications at EDF?

DESIGN & TECHNOLOGY BRANCH



Decay heat

- Thermal power released from the radioactive decay of nuclides
  NB : energy from delayed fissions not discussed in this presentation
- Contributes to 7% of the core power during operation
- Lasts for years after shutdown

Some applications

- Core fault studies (<10 days)
- Spent fuel pool fault studies
- Spent fuel transport (>1 year)

UOX / MOX
Burn-up

DESIGN & TECHNOLOGY BRANCH

2.

Coming next:
- MENDEL inventory code
- JEFF4 nuclear data

Coming next: MENDEL inventory code & JEFF4 ND

CONCENTRATIONS

DECAY HEAT

MASSES

ACTIVITIES

WAYS OF PRODUCTION

MENDEL

CEA's next generation code

- Is approaching readiness for EDF's industrial applications
- For nuclear fuel, materials irradiated by neutron flux, waste management.
- Reactor types: Pressurized Water, Sodium Fast and Molten Salt

Ongoing testing phase at EDF

- Iso-functionality with DARWIN
- New features
- JEFF4.0 in industrial configurations

3.

Industrial decay heat uncertainty evaluations

Industrial decay heat uncertainty evaluations

DESIGN & TECHNOLOGY BRANCH

<u>Please note:</u>

All presented data have been obtained with MENDEL during EDF's recent testing.

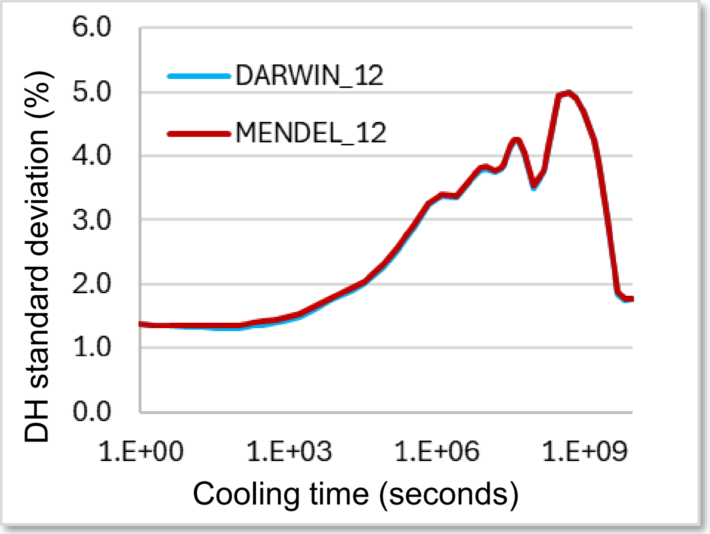
The values have neither been obtained with EDF's final calculation settings, nor have they been through any verification process (work still in progress).

Values do not correspond to the total uncertainty used in safety studies, as only the propagation of ND uncertainties is presented.

Industrial decay heat uncertainty evaluations

DESIGN & TECHNOLOGY BRANCH

DARWIN inventory code



Validation vs experimental data

«High definition» for validation & sensitivity studies

- With DARWIN, EDF's reference inventory code developed by CEA (MENDEL in the future)
- First order perturbation & propagation method
- Long calculation time

«Simplified model» for STRAPONTIN code

- EDF's fast and flexible in-house code for real plant evaluations
- Uses detailed fuel characteristics & irradiation history
- Simplified decay chain
- Simplified uncertainty propagation function (David Le Carpentier)
- Instant calculation time but the standard deviation may be up to 1% higher compared to the reference code

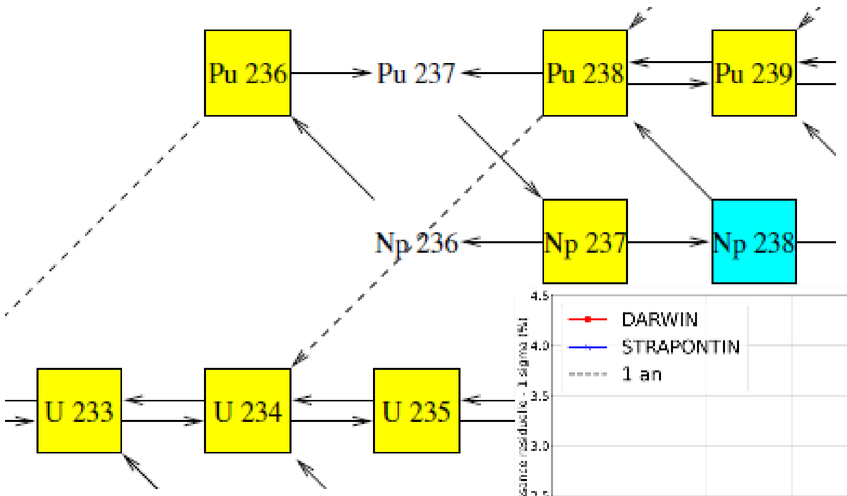
«Uncertainty abacus» for standard safety evaluations with DARWIN (MENDEL in the future)

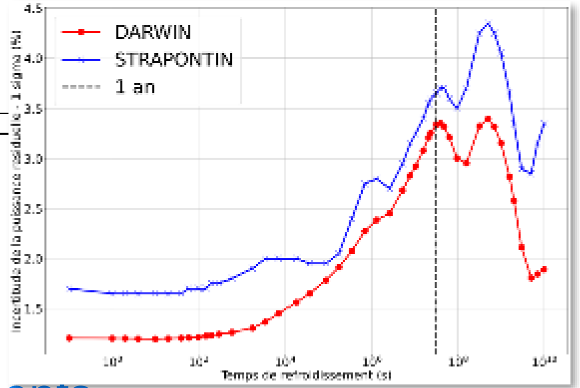
- Abacus = values arranged in a two-entry table obtained by a series of "high definition" calculations
- Only 2 influent parameters taken in account
- Instant calculation time
- Gets us quite close to "high definition" if…

Industrial decay heat uncertainty evaluations

DESIGN & TECHNOLOGY BRANCH

STRAPONTIN inventory code





Reduced decay chain

- 214 fission products
- 26 heavy metal elements

Validation vs reference code DARWIN (MENDEL)

«High definition» for validation & sensitivity studies

- With DARWIN, EDF's reference inventory code developed by CEA (MENDEL in the future)
- First order perturbation & propagation method
- Long calculation time

«Simplified model» for STRAPONTIN code

- EDF's fast and flexible in-house code for real plant evaluations
- Uses detailed fuel characteristics & irradiation history
- Simplified decay chain
- Simplified uncertainty propagation function (David Le Carpentier)
- Instant calculation time but the standard deviation may be up to 1% higher compared to the reference code

«Uncertainty abacus» for standard safety evaluations with DARWIN (MENDEL in the future)

- Abacus = values arranged in a two-entry table obtained by a series of "high definition" calculations
- Only 2 influent parameters taken in account
- Instant calculation time
- Gets us quite close to "high definition" if…

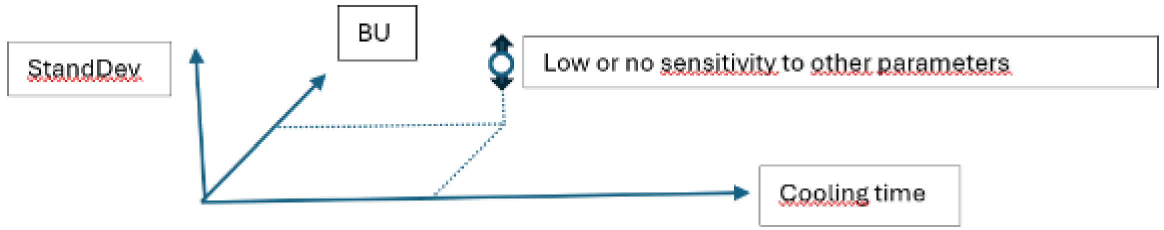
Industrial decay heat uncertainty evaluations

DESIGN & TECHNOLOGY BRANCH

EDF 's uncertainty abacus principle

	5 GWj/t	…	60 GWj/t
0 s			
10 s			
50 s			
…			
1 year			

« high definition » results



«High definition» for validation & sensitivity studies

- With DARWIN, EDF's reference inventory code developed by CEA (MENDEL in the future)
- First order perturbation & propagation method
- Long calculation time

«Simplified model» for STRAPONTIN code

- EDF's fast and flexible in-house code for real plant evaluations
- Uses detailed fuel characteristics & irradiation history
- Simplified decay chain
- Simplified uncertainty propagation function (David Le Carpentier)
- Instant calculation time but the standard deviation may be up to 1% higher compared to the reference code

«Uncertainty abacus» for standard safety evaluations with DARWIN (MENDEL in the future)

- Abacus = values arranged in a two-entry table obtained by a series of "high definition" calculations
- Only 2 influent parameters taken in account
- Instant calculation time
- Gets us quite close to "high definition" if…

4.

EDF's DH uncertainty abacus for standard applications

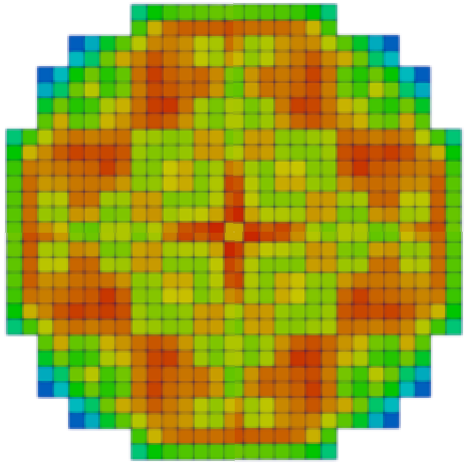
EDF's DH uncertainty abacus for standard applications

Many influent parameters in DH evaluations

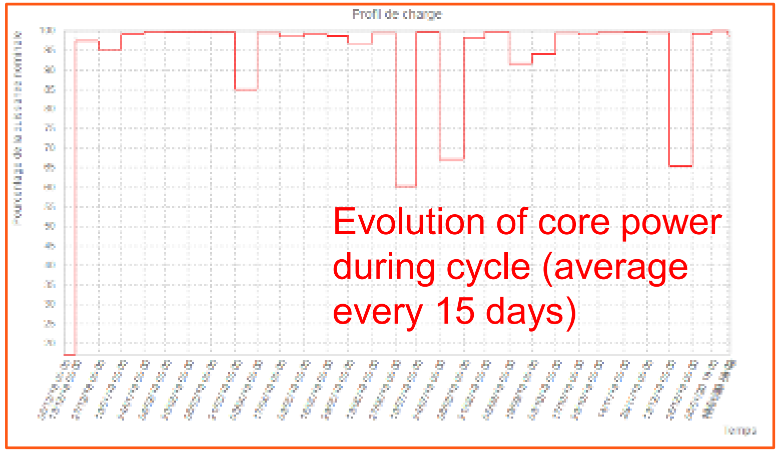
- Fuel initial inventory (% U Pu, Gd, …)
- Fuel irradiation history (burn-up & power curve)

Fuel characteristics

Core loading pattern



Core power history

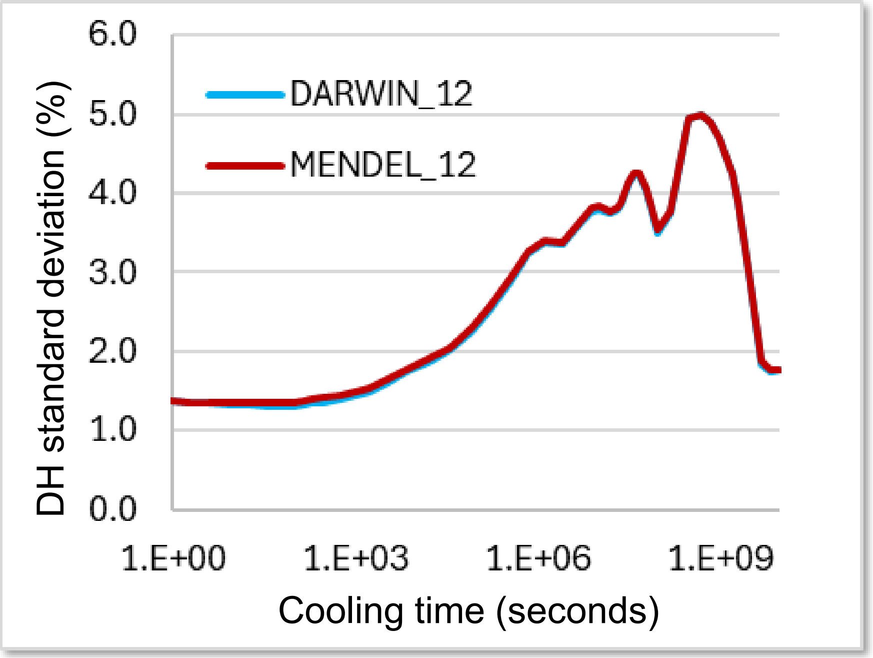


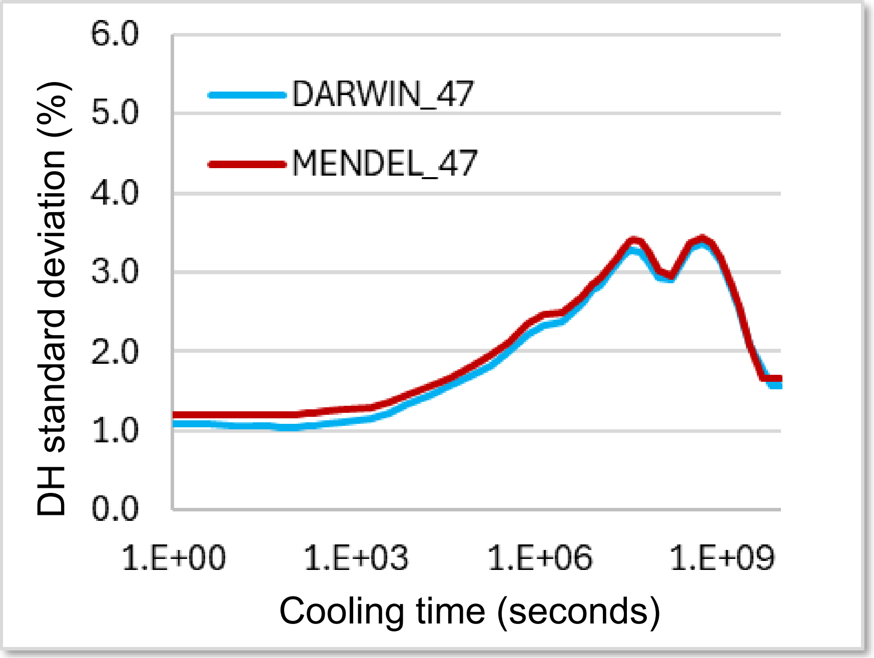
EDF's DH uncertainty abacus for standard applications

SD - UOX 3.7% U235
12 and 47 GWd/t @ 40 MW/t

DH Standard Deviation vs cooling time & BU

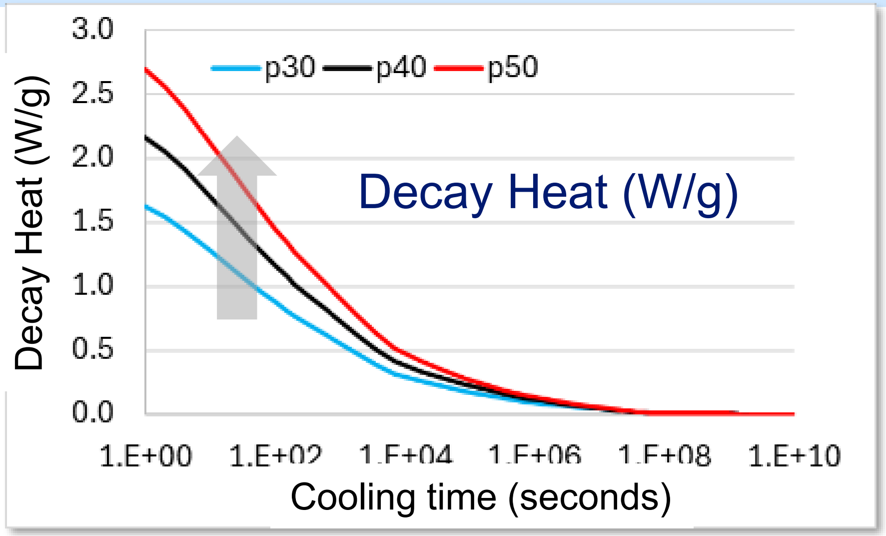
- MENDEL / DARWIN : similar results with similar options
- Strong dependence on BU & cooling time

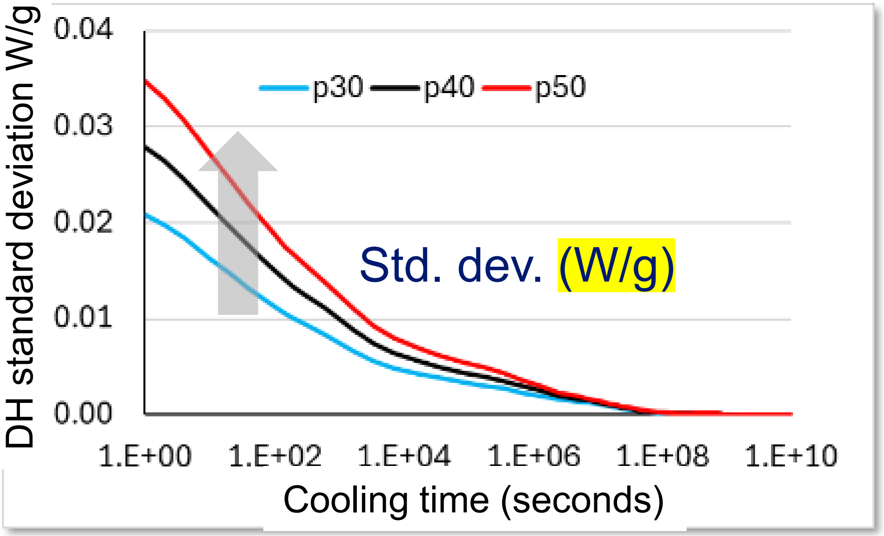




EDF's DH uncertainty abacus for standard applications

DH & SD – MOX 9.54%
30 GWd/t @ 30/40/50 MW/t



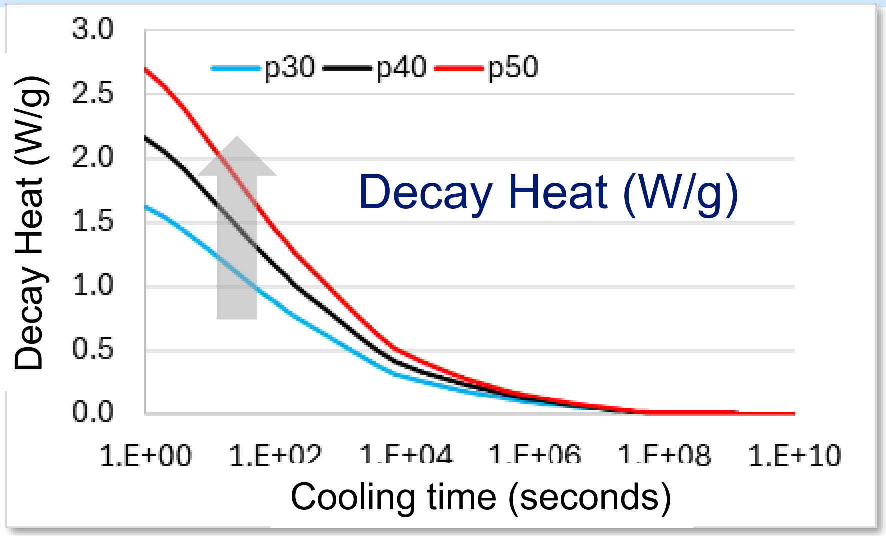


DH Standard Deviation vs irradiation power

- DH increases with power before outage
- Absolute DH Standard Deviation also increases

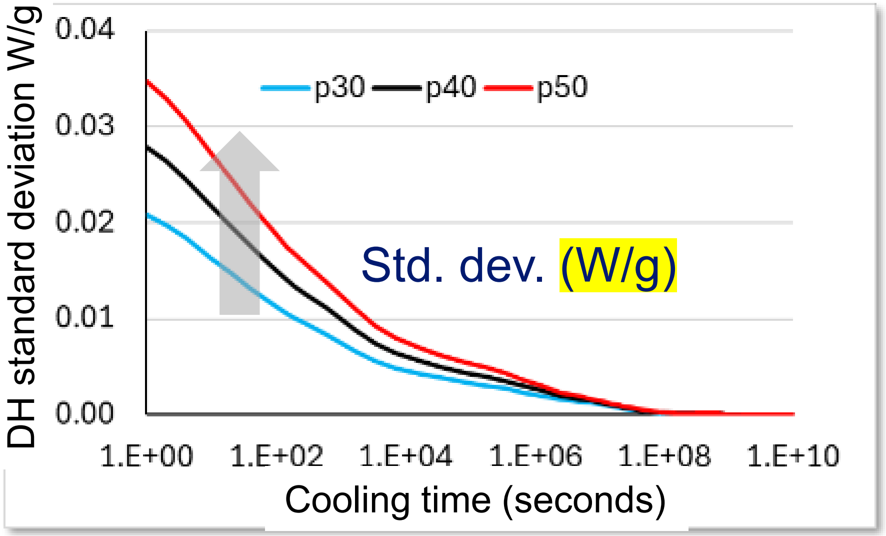
EDF's DH uncertainty abacus for standard applications

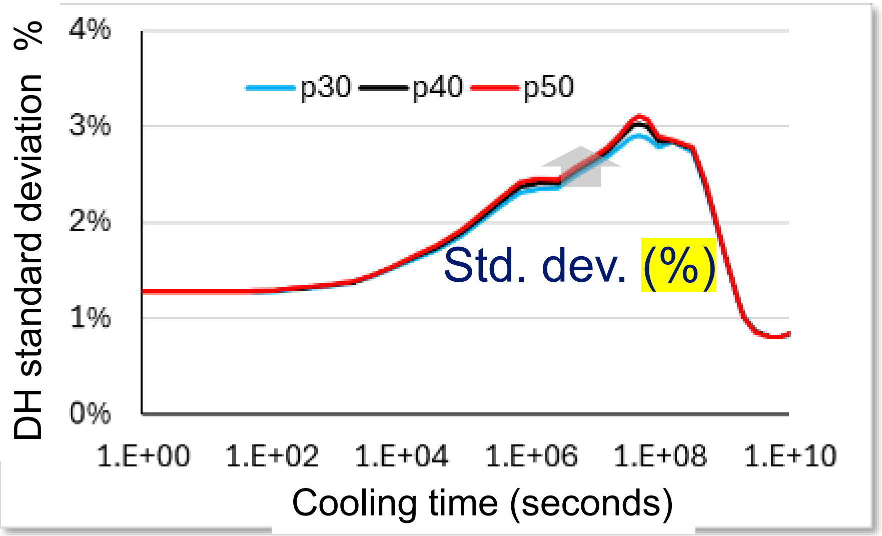
DH & SD – MOX 9.54%
30 GWd/t @ 30/40/50 MW/t



DH Standard Deviation vs irradiation power

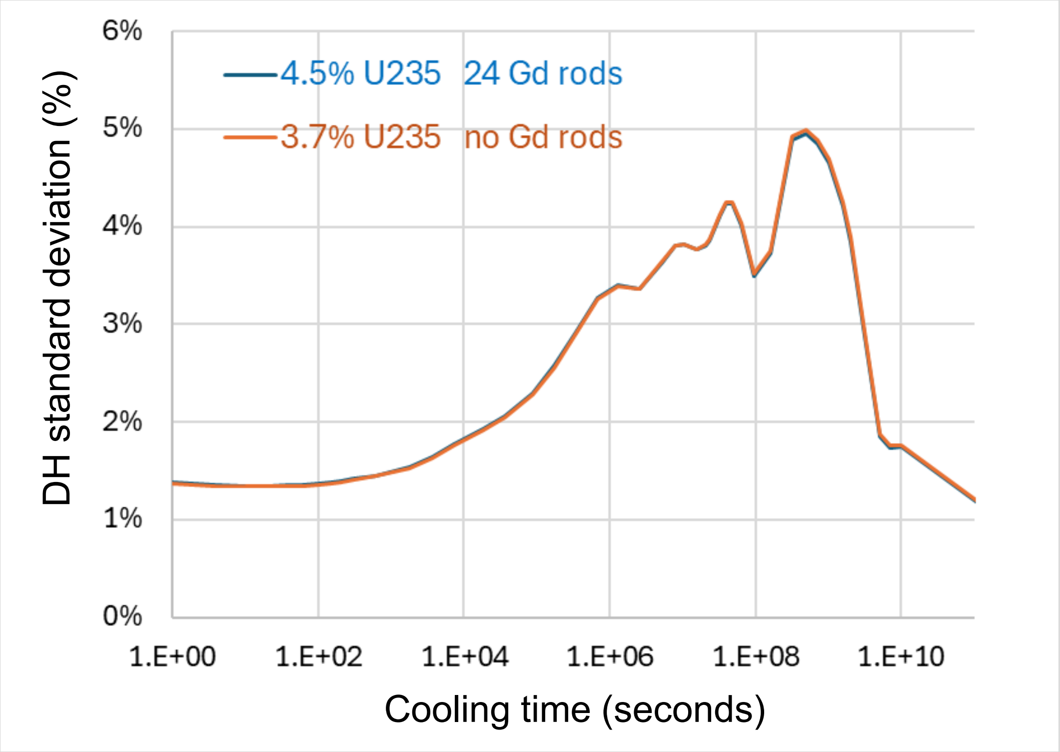
- DH increases with power before outage
- Absolute DH Standard Deviation also increases
- Relative DH Standard Deviation not so much





EDF's DH uncertainty abacus for standard applications

SD comparison between different fuel charact.
UOX 12 GWd/t @ 40 MW/t



DH Standard Deviation vs initial composition

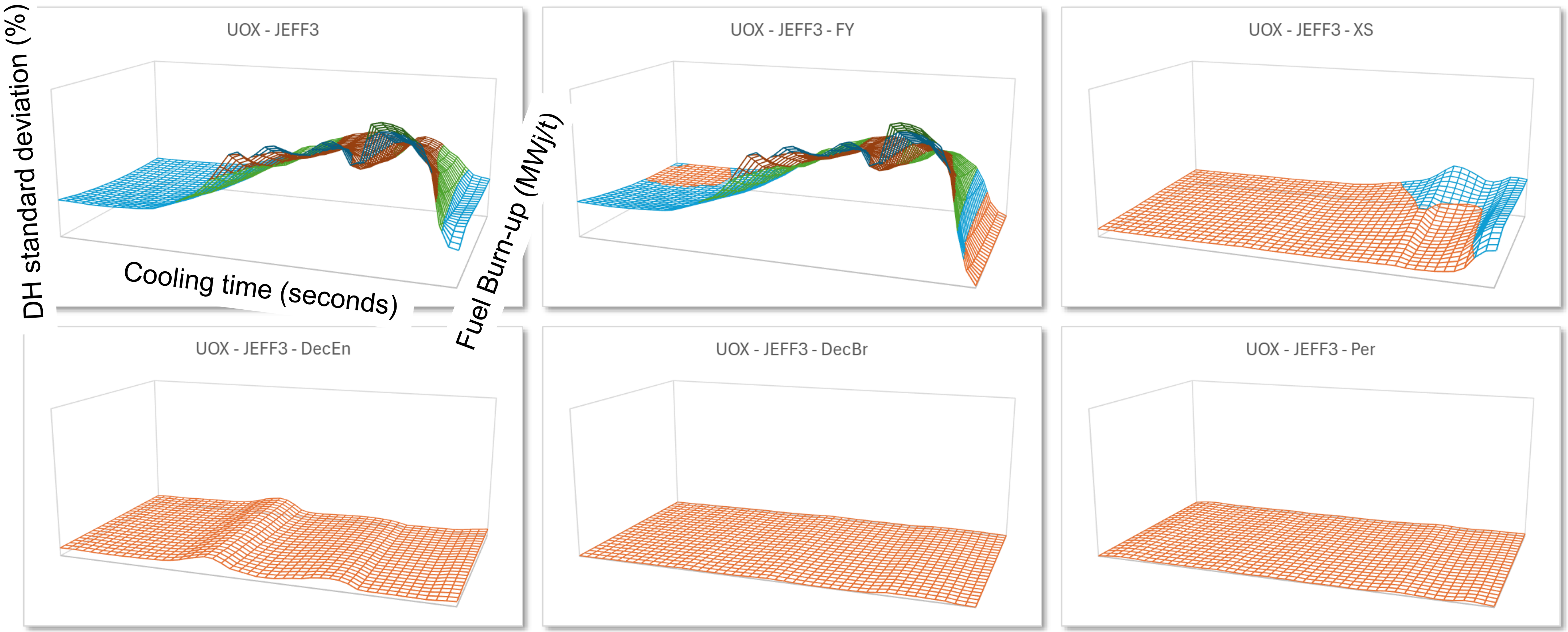
- UOX DH uncertainty does not depend on % U or # Gd rods
- MOX DH uncertainty depends only slightly on %Pu and % Am241

Industrial application

- Fuel type, burn-up & cooling time are the main parameters
- One UOX abacus for EDF UOX fuel range
- One MOX abacus for EDF MOX fuel range
- In case of significantly different initial fuel composition, a specific abacus may be necessary (verification by "high definition" calculations)

EDF's DH uncertainty abacus for standard applications

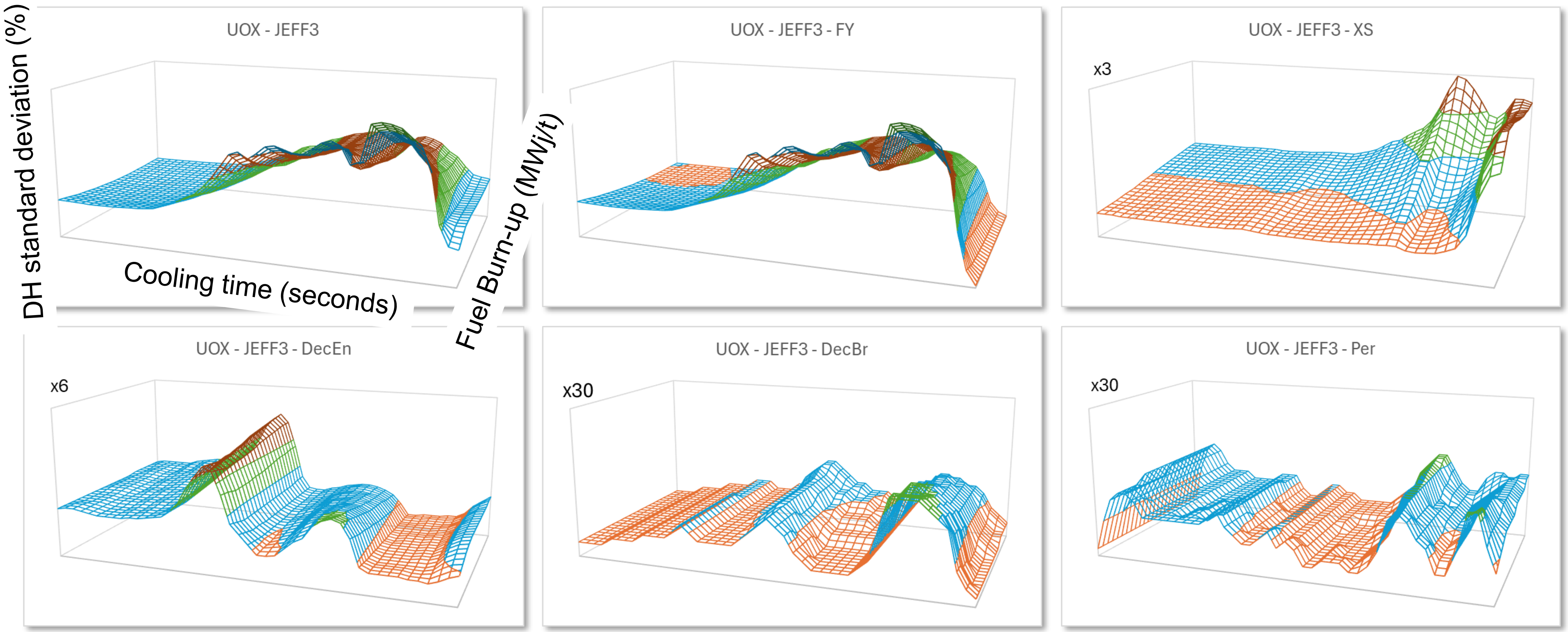
Preliminary SD abacus using MENDEL – JEFF3.1.1 – UOX



EDF's DH uncertainty abacus for standard applications

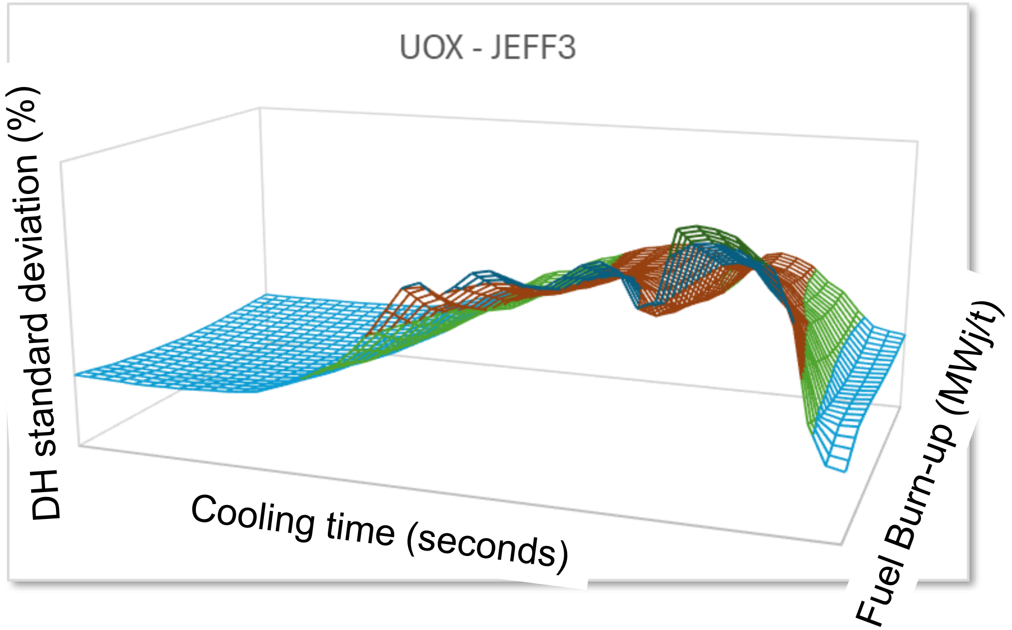
DESIGN & TECHNOLOGY BRANCH

Preliminary SD abacus using MENDEL – JEFF3.1.1 – UOX



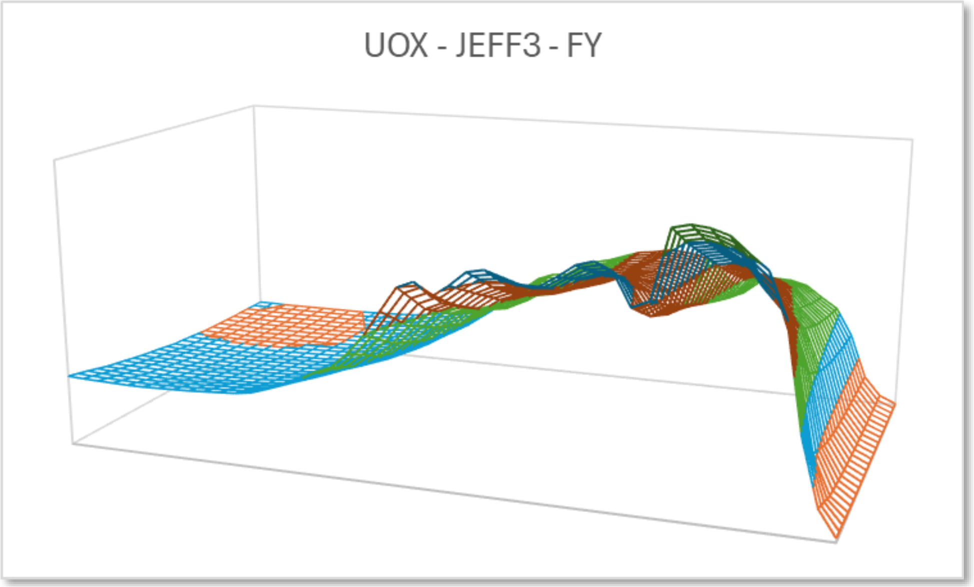
EDF's DH uncertainty abacus for standard applications

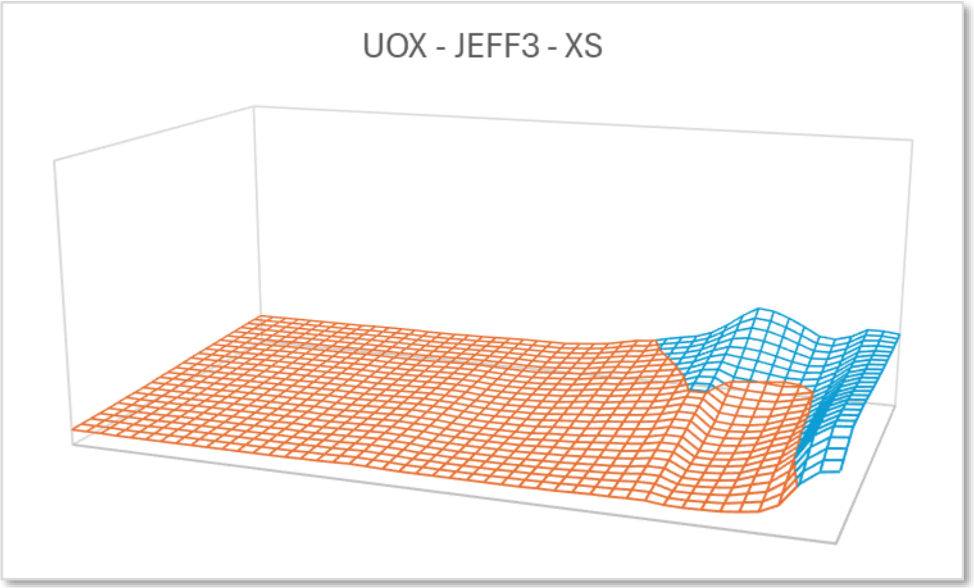
Preliminary SD abacus using MENDEL – JEFF3.1.1 – UOX



FY

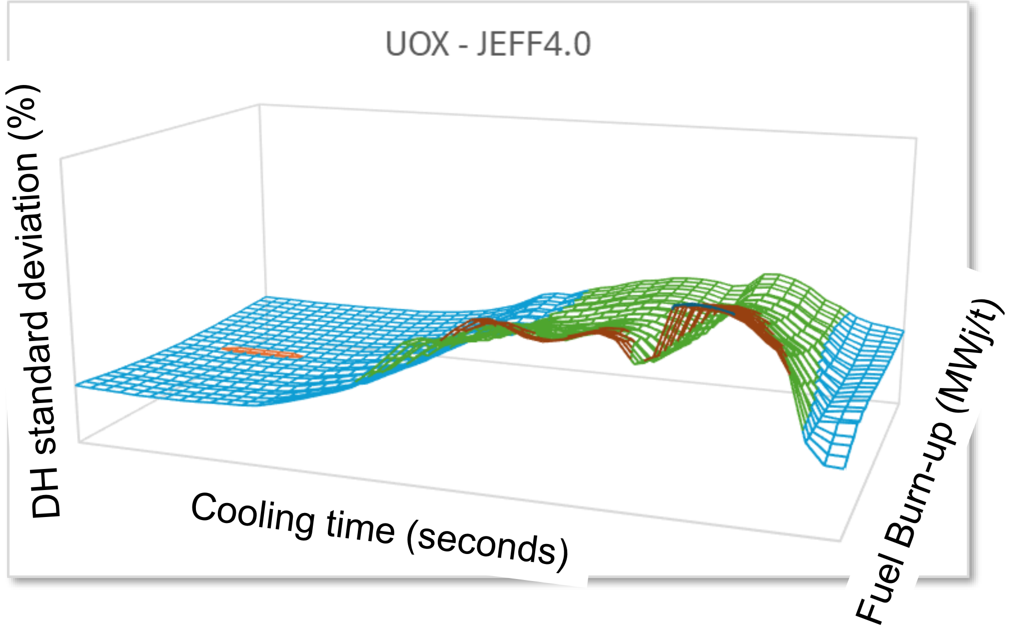
XS





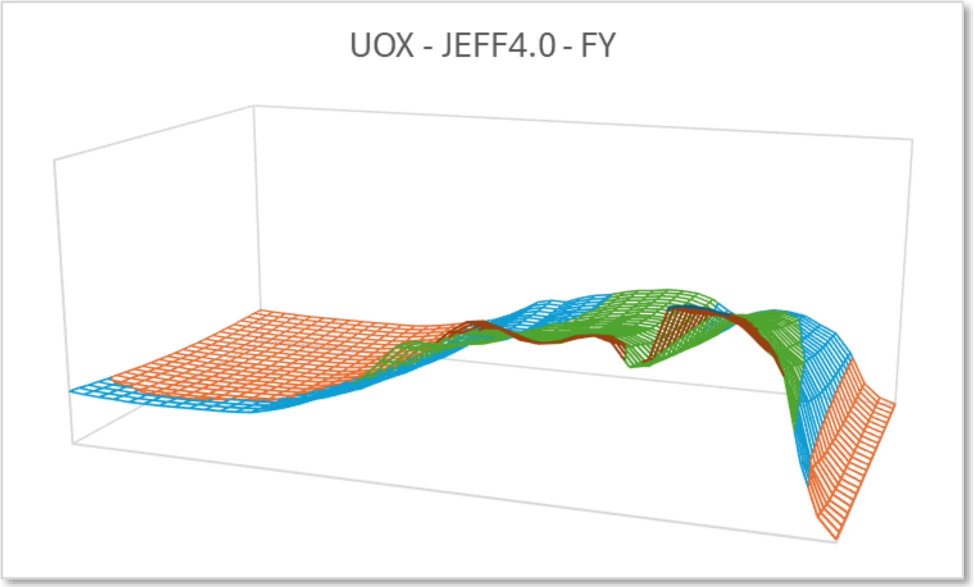
EDF's DH uncertainty abacus for standard applications

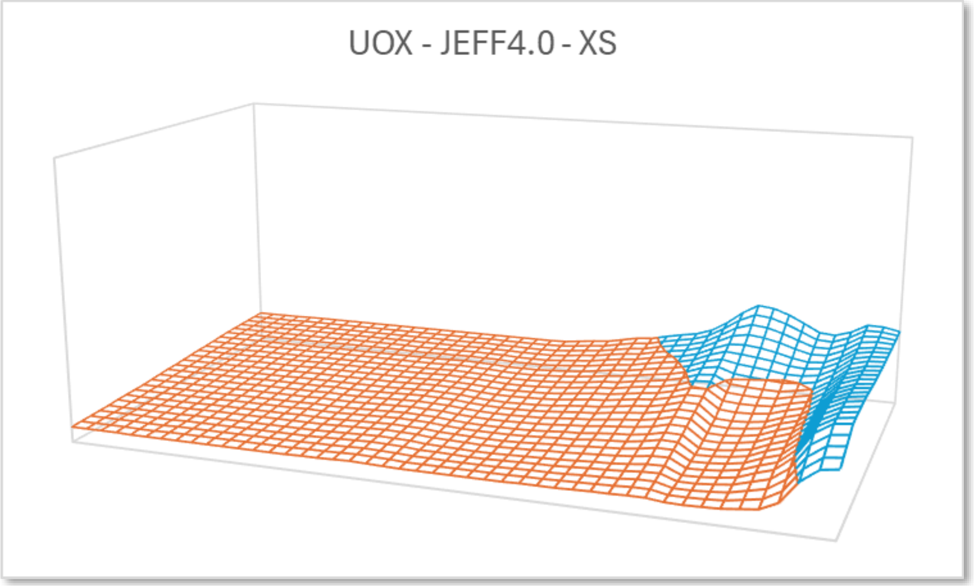
Preliminary SD abacus using MENDEL – JEFF4.0 – UOX



FY

XS





5.

Nuclear Data needs from EDF perspective

Nuclear Data needs from EDF perspective

DESIGN & TECHNOLOGY BRANCH

Continuation of ND improvement for core calculations & fuel inventory calculations → JEFF4.0.1

Objectives : reduce bias & uncertainties in DH evaluations + ensure penalized estimation for safety studies

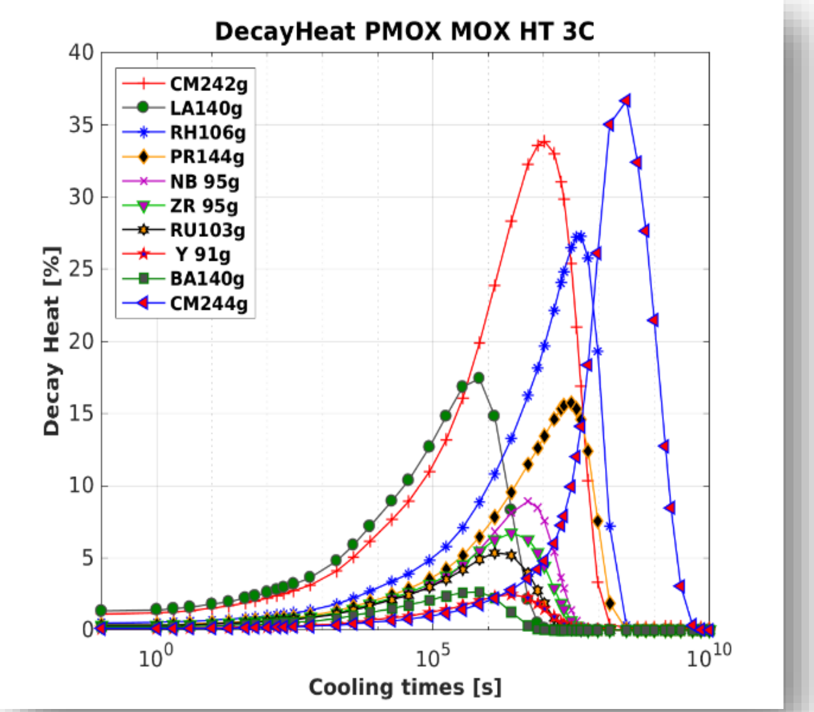
Examples :

^{239}Pu (n_{th},f) yields

^{242}Cm → MOX DH between 10 days and 1 year (NEA HPRL request)

Recent ND topic not linked to decay heat :

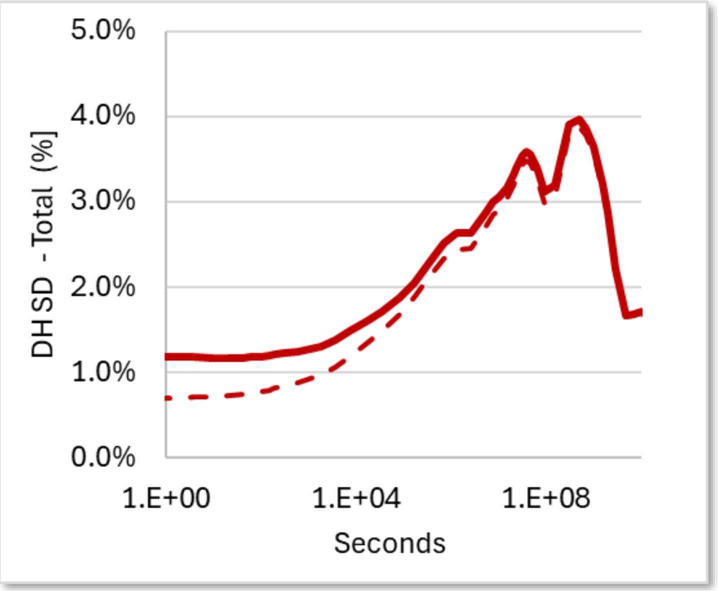
$^{10}B(n,t)$ → LWR tritium production predictions (NEA HPRL request)



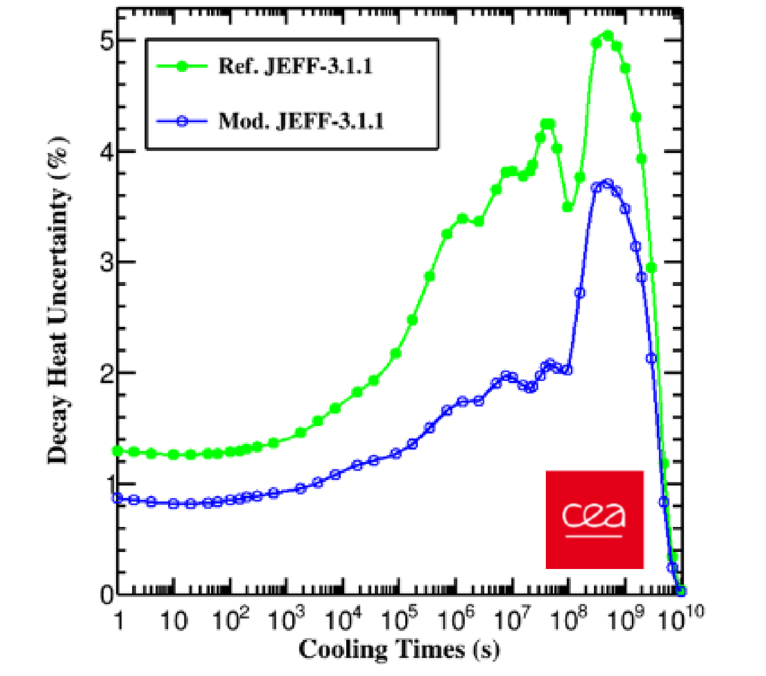
Nuclear Data needs from EDF perspective

Less penalized calculation options → better assessment of margins and experimental data priorities

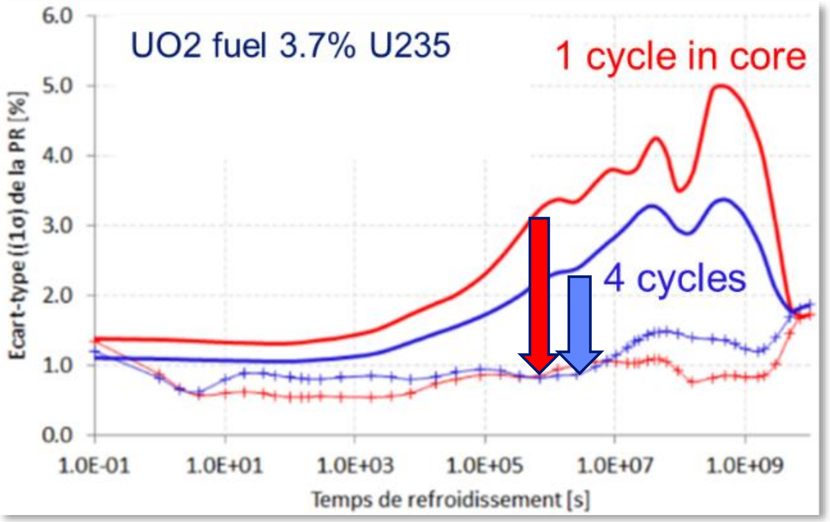
Independent fission yield renormalization



Use of cumulative fission yield data



Use of FY correlations



DESIGN & TECHNOLOGY BRANCH

6.

Conclusions & discussion

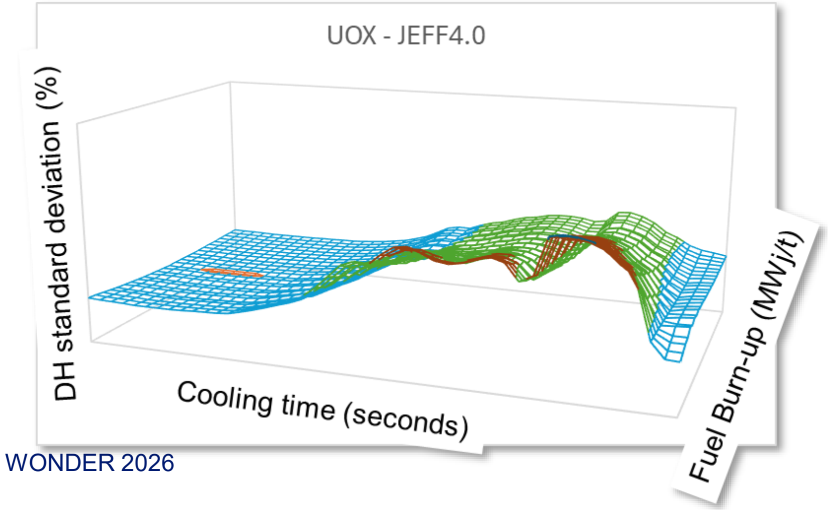
Conclusions

MENDEL

- CEA's next generation code MENDEL is **approaching readiness for EDF**'s industrial applications

JEFF4.0 in industrial decay heat calculations

- **Some preliminary results** are recently available
- Global DH uncertainty decrease linked to FY
- Stable DH uncertainty linked to XS
- Total DH : work in progress



Decay heat uncertainty abacus construction

- **Sensitivity studies**
- **Preliminary MENDEL abacus available**
  JEFF3.1.1 & JEFF4.0 UOX & MOX

ND needs

- **JEFF 4.0.1**
- **Experimental data** for decay heat evaluations (full assembly, rod, pellet, target…)

For more details on fuel decay heat

« An introduction to Spent Nuclear Fuel decay heat for Light Water Reactors: a review from the NEA WPNCS »

https://www.epj-n.org/articles/epjn/abs/2024/01/epjn240001/epjn240001.html

Thank you

DESIGN & TECHNOLOGY BRANCH