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# Impact of JEFF-3.3, ENDF/B-VIII.0 and JENDL-4.0 uncertainties on PIE isotopic compositions and decay heat



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- Overview of the method
- Global results
- Uncertainties
- Conclusion

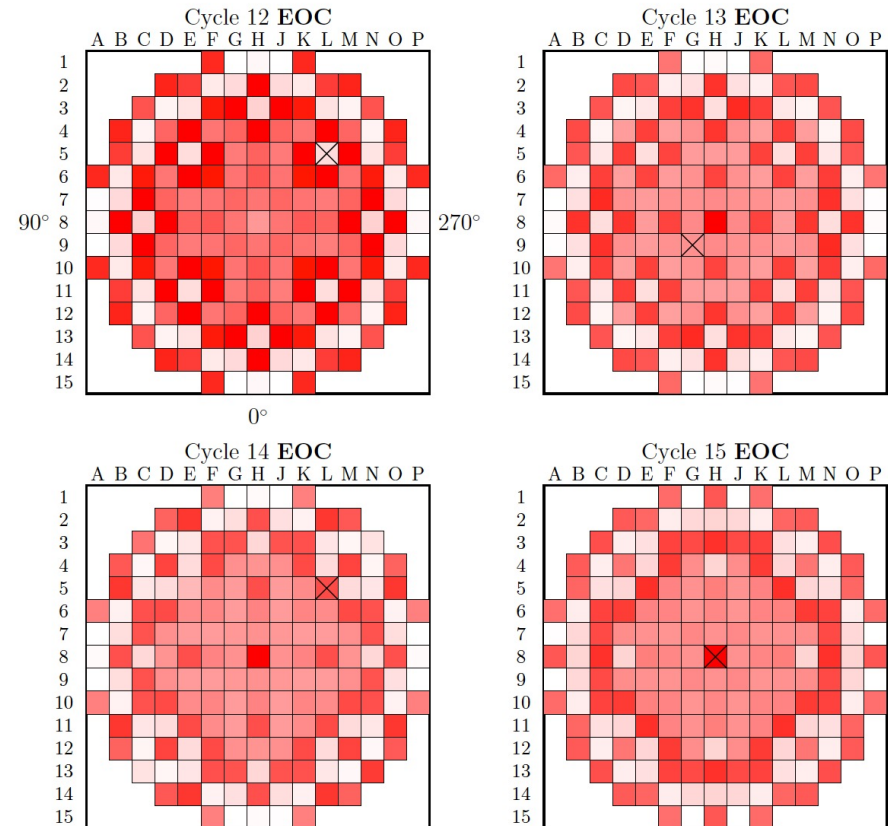
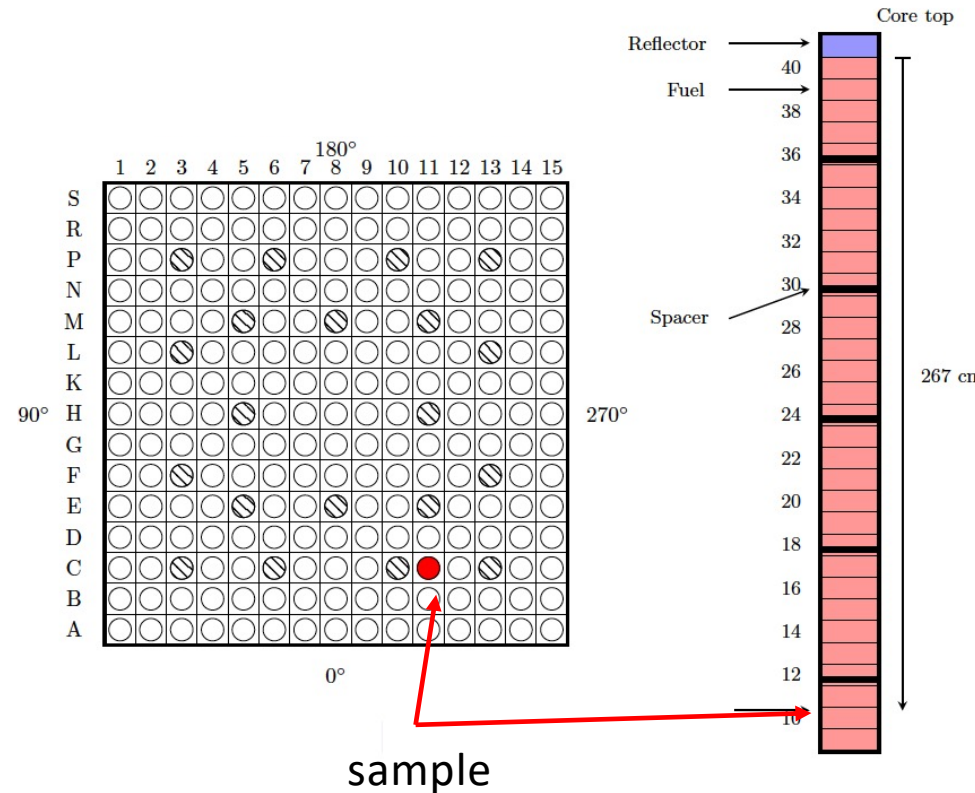
**EU**ropean Joint Programme on **RAD**ioactive Waste Management  
**EURAD**

**5-year implementation phase 1 – EURAD-1**



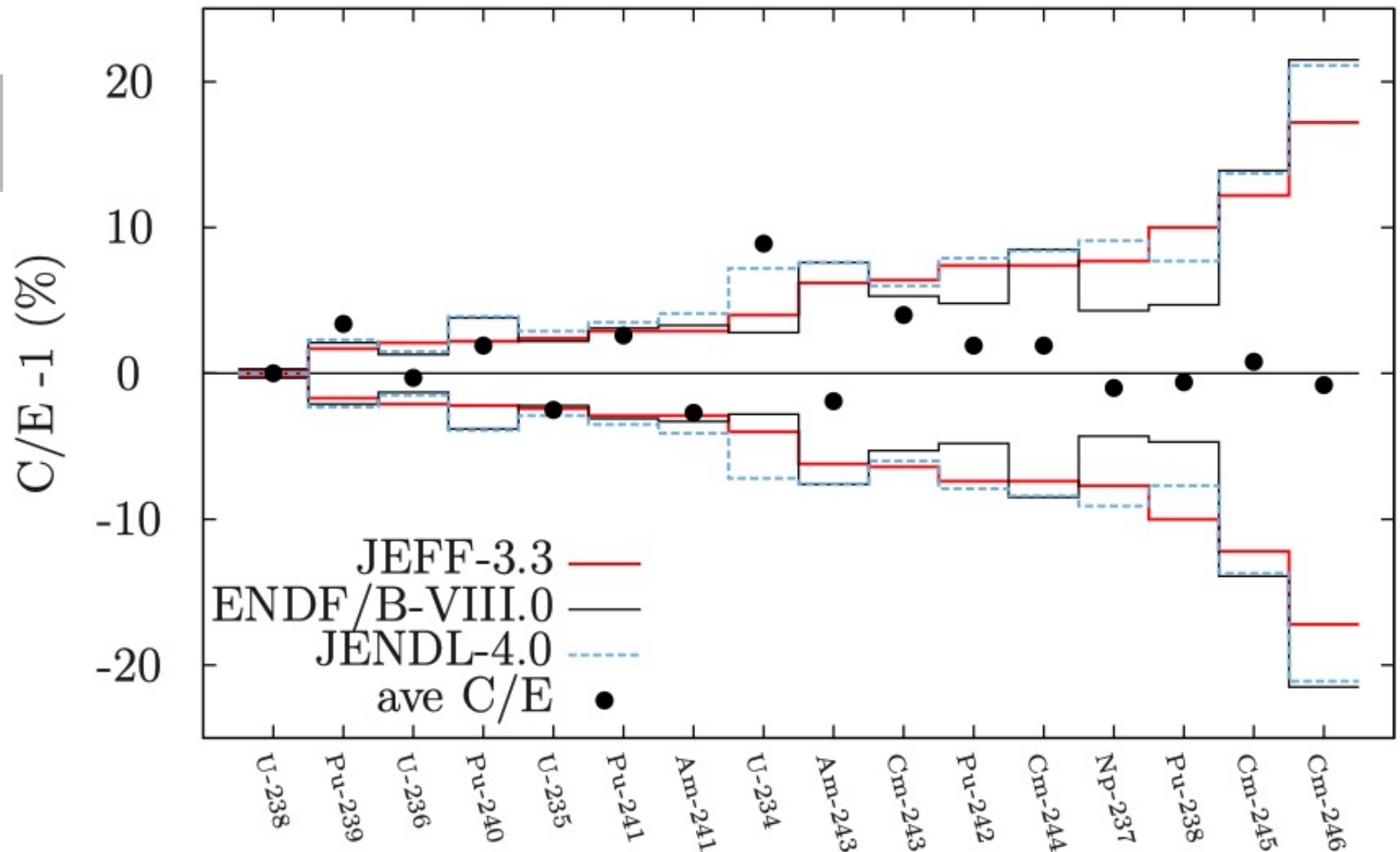
*This project receives funding from the Euratom research and training programme under grant agreement No 847593.*

- PIE data: isotopic concentrations from irradiated samples in a specific reactor
- Measured actinides and fission products (e.g. in mg/gU)
- Used for transport and depletion code validation



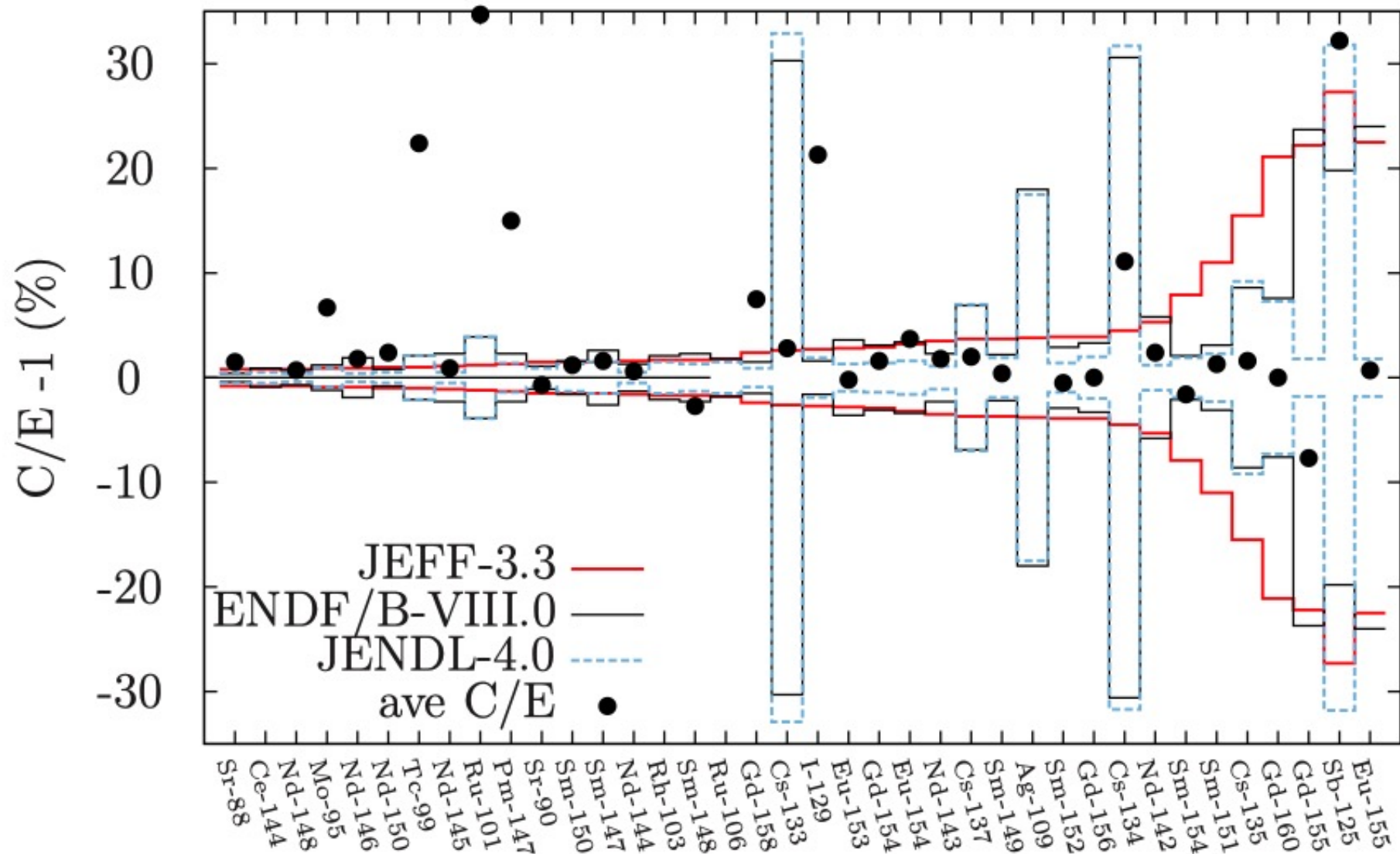
- PSI database: 27 samples irradiated in Swiss reactors
  - $\text{UO}_2$ , MOX, PWR, BWR, 30 to 120 MWd/kgU
- Uncertainty propagation:
  - Repeat 1000 times the same CASMO5 calculation (ENDF/B-VII.1 base library)
  - Each time changing perturbations on nuclear data
  - Performed with JEFF-3.3, JENDL-4.0 and ENDF/B-VIII.0, all covariances
- Results presented are averaged over the 17 samples:
  - 6 PWR MOX
  - 9 PWR  $\text{UO}_2$
  - 2 BWR  $\text{UO}_2$

## PIE data: actinides (averaged over 17 samples)





## PIE data: fission products (averaged over 17 samples)



Details for a PIE sample PWR  $\text{UO}_2$ **Table B.2.** Uncertainties  $\Delta C$  from nuclear data libraries for the GU3' sample (CASMO5 v2.03 calculations).

All values are in%.

|                    | ENDF/B-VIII.0 | JEFF-3.3 | JENDL-4.0 |
|--------------------|---------------|----------|-----------|
| $^{234}\text{U}$   | 2.3           | 2.2      | 7.9       |
| $^{235}\text{U}$   | 1.2           | 1.6      | 1.8       |
| $^{236}\text{U}$   | 0.8           | 1.7      | 1.2       |
| $^{238}\text{U}$   | 0.0           | 0.0      | 0.0       |
| $^{237}\text{Np}$  | 3.3           | 3.9      | 4.0       |
| $^{238}\text{Pu}$  | 4.8           | 9.4      | 7.0       |
| $^{239}\text{Pu}$  | 1.8           | 1.7      | 2.2       |
| $^{240}\text{Pu}$  | 4.3           | 2.5      | 4.4       |
| $^{241}\text{Pu}$  | 3.2           | 3.1      | 3.4       |
| $^{242}\text{Pu}$  | 4.8           | 8.5      | 8.6       |
| $^{244}\text{Pu}$  | 8.9           | 8.1      | 9.2       |
| $^{241}\text{Am}$  | 3.4           | 3.1      | 3.9       |
| $^{242m}\text{Am}$ | 3.8           | 3.2      | 4.5       |
| $^{243}\text{Am}$  | 8.5           | 7.7      | 9.0       |
| $^{242}\text{Cm}$  | 3.6           | 2.7      | 4.1       |
| $^{243}\text{Cm}$  | 11            | 16       | 12        |
| $^{244}\text{Cm}$  | 9.7           | 9.3      | 10        |
| $^{245}\text{Cm}$  | 15            | 14       | 15        |
| $^{246}\text{Cm}$  | 24            | 21       | 24        |

|                   | ENDF/B-VIII.0 | JEFF-3.3 | JENDL-4.0 |
|-------------------|---------------|----------|-----------|
| $^{90}\text{Sr}$  | 0.7           | 1.4      | 0.7       |
| $^{95}\text{Mo}$  | 0.9           | 0.7      | 0.9       |
| $^{99}\text{Tc}$  | 1.4           | 0.8      | 1.6       |
| $^{101}\text{Ru}$ | 2.8           | 0.9      | 3.1       |
| $^{106}\text{Ru}$ | 1.5           | 1.7      | 1.5       |
| $^{103}\text{Rh}$ | 1.7           | 1.7      | 1.3       |
| $^{109}\text{Ag}$ | 21            | 4.4      | 20        |
| $^{125}\text{Sb}$ | 18            | 27       | 30        |
| $^{129}\text{I}$  | 3.0           | 6.1      | 3.5       |
| $^{133}\text{Cs}$ | 28            | 2.3      | 30        |
| $^{134}\text{Cs}$ | 29            | 4.6      | 30        |
| $^{135}\text{Cs}$ | 7.1           | 20       | 7.6       |
| $^{137}\text{Cs}$ | 6.7           | 3.6      | 6.9       |
| $^{144}\text{Ce}$ | 0.4           | 0.6      | 0.5       |
| $^{147}\text{Pm}$ | 2.5           | 1.2      | 1.3       |
| $^{142}\text{Nd}$ | 5.1           | 5.0      | 0.8       |
| $^{143}\text{Nd}$ | 2.0           | 3.6      | 0.9       |
| $^{144}\text{Nd}$ | 1.2           | 2.2      | 0.4       |
| $^{145}\text{Nd}$ | 2.0           | 0.9      | 0.4       |
| $^{146}\text{Nd}$ | 1.7           | 0.7      | 0.3       |
| $^{148}\text{Nd}$ | 0.4           | 0.6      | 0.4       |
| $^{150}\text{Nd}$ | 0.4           | 0.9      | 0.5       |
| $^{147}\text{Sm}$ | 2.2           | 1.2      | 1.2       |
| $^{148}\text{Sm}$ | 1.8           | 1.9      | 1.0       |
| $^{149}\text{Sm}$ | 1.7           | 3.5      | 1.6       |
| $^{150}\text{Sm}$ | 1.2           | 1.3      | 1.0       |
| $^{151}\text{Sm}$ | 2.7           | 12       | 2.0       |
| $^{152}\text{Sm}$ | 2.6           | 3.8      | 1.2       |
| $^{154}\text{Sm}$ | 1.6           | 7.3      | 1.7       |
| $^{153}\text{Eu}$ | 3.3           | 2.1      | 1.1       |
| $^{154}\text{Eu}$ | 2.8           | 2.3      | 1.3       |
| $^{155}\text{Eu}$ | 24            | 24       | 1.1       |
| $^{155}\text{Gd}$ | 23            | 23       | 1.1       |

# Details for a PIE sample BWR UO<sub>2</sub>

**Table 5.** Uncertainties  $\Delta C$  from nuclear data libraries for the ENUSA samples for the isotopic concentrations (CASMO5 v2.03 calculations). All values are in %.

|                   | ENUSA-1       |          |           |
|-------------------|---------------|----------|-----------|
|                   | ENDF/B-VIII.0 | JEFF-3.3 | JENDL-4.0 |
| <sup>234</sup> U  | 1.9           | 2.0      | 7.3       |
| <sup>235</sup> U  | 1.6           | 2.1      | 2.5       |
| <sup>236</sup> U  | 0.7           | 1.7      | 1.2       |
| <sup>238</sup> U  | 0.0           | 0.0      | 0.0       |
| <sup>237</sup> Np | 3.3           | 4.0      | 4.0       |
| <sup>238</sup> Pu | 4.8           | 11       | 7.9       |
| <sup>239</sup> Pu | 2.0           | 1.9      | 2.3       |
| <sup>240</sup> Pu | 4.0           | 2.3      | 4.1       |
| <sup>241</sup> Pu | 3.3           | 3.2      | 3.7       |
| <sup>242</sup> Pu | 4.4           | 8.4      | 8.5       |
| <sup>241</sup> Am | 3.5           | 3.3      | 4.1       |
| <sup>243</sup> Am | 8.8           | 7.9      | 9.3       |
| <sup>244</sup> Cm | 9.8           | 9.6      | 10        |
| <sup>246</sup> Cm | 25            | 22       | 25        |

|                   | ENUSA-1       |          |           |
|-------------------|---------------|----------|-----------|
|                   | ENDF/B-VIII.0 | JEFF-3.3 | JENDL-4.0 |
| <sup>94</sup> Mo  | 4.7           | 17       | 13        |
| <sup>109</sup> Ag | 22            | 4.2      | 25        |
| <sup>110</sup> Pd | 15            | 7.3      | 11        |
| <sup>111</sup> Cd | 20            | 8.6      | 17        |
| <sup>125</sup> Sb | 18            | 28       | 16        |
| <sup>133</sup> Cs | 29            | 2.3      | 28        |
| <sup>134</sup> Cs | 29            | 4.1      | 28        |
| <sup>135</sup> Cs | 7.8           | 17       | 7.7       |
| <sup>151</sup> Sm | 2.5           | 13       | 1.9       |
| <sup>154</sup> Sm | 1.7           | 7.4      | 1.7       |
| <sup>157</sup> Gd | 4.6           | 10       | 4.5       |
| <sup>160</sup> Gd | 9.0           | 29       | 9.1       |



# Details for a PIE sample PWR MOX

**Table B.7.** Comparison in % between the impact of the nuclear data libraries for the BM1-P sample with the assembly model, based on the CASMO5 v2.03 calculations. Value are at the time of measurement.

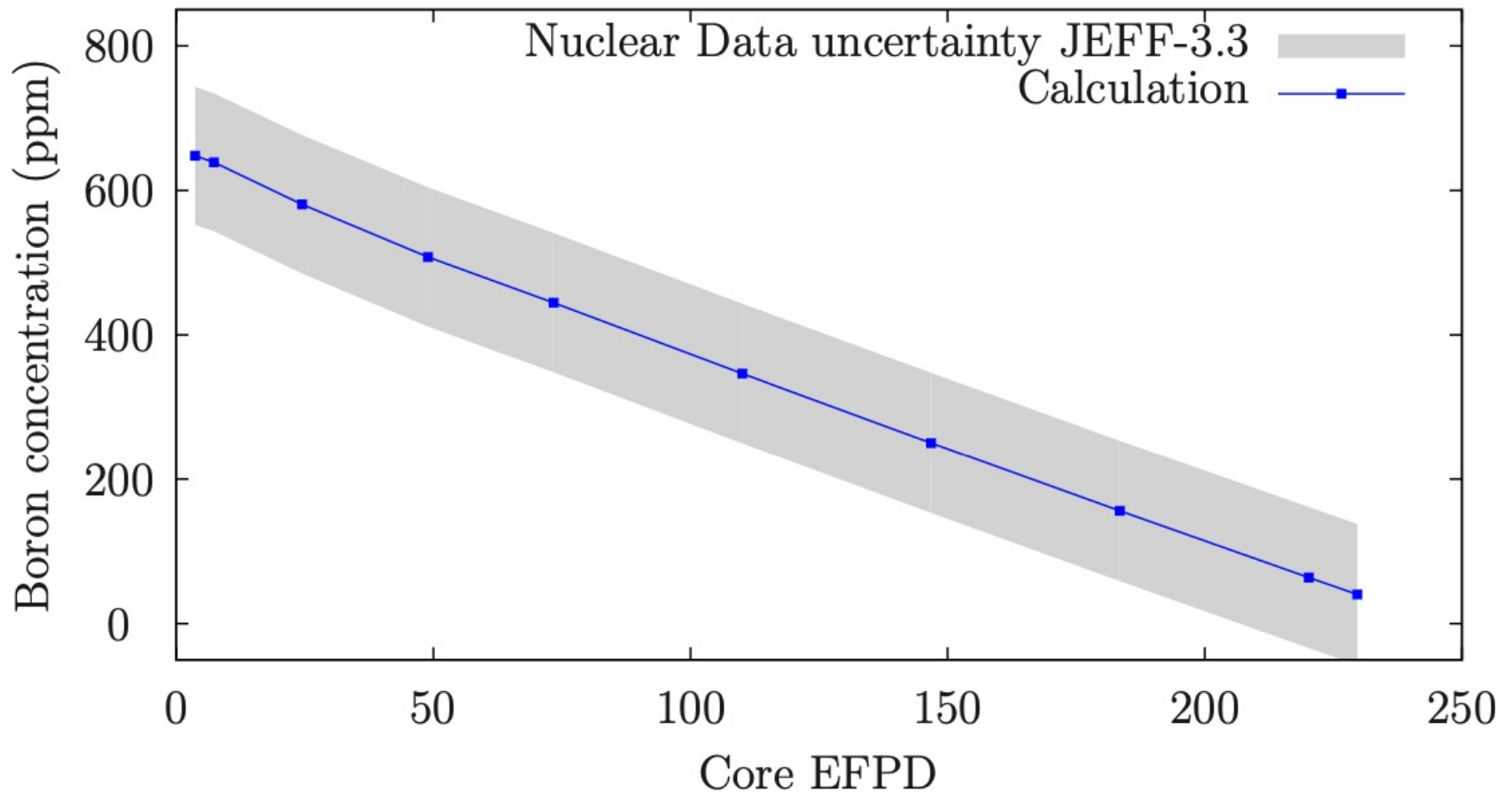
|                   | ENDF/B-VIII.0 | JEFF-3.3 | JENDL-4.0 |                    | ENDF/B-VIII.0 | JEFF-3.3 | JENDL-4.0 |
|-------------------|---------------|----------|-----------|--------------------|---------------|----------|-----------|
| <sup>234</sup> U  | 2.0           | 4.0      | 4.5       | <sup>235</sup> U   | 0.8           | 1.1      | 1.0       |
| <sup>236</sup> U  | 0.9           | 1.7      | 1.1       | <sup>238</sup> U   | 0.0           | 0.0      | 0.0       |
| <sup>237</sup> Np | 5.9           | 18       | 18        | <sup>238</sup> Pu  | 3.2           | 8.0      | 5.3       |
| <sup>239</sup> Pu | 1.8           | 1.7      | 2.0       | <sup>240</sup> Pu  | 2.2           | 1.5      | 2.8       |
| <sup>241</sup> Pu | 1.7           | 2.6      | 3.2       | <sup>242</sup> Pu  | 3.8           | 6.2      | 6.1       |
| <sup>241</sup> Am | 1.9           | 2.4      | 3.6       | <sup>242m</sup> Am | 1.9           | 2.1      | 3.5       |
| <sup>243</sup> Am | 6.2           | 3.8      | 4.9       | <sup>244</sup> Cm  | 6.8           | 4.2      | 5.4       |
| <sup>245</sup> Cm | 12            | 9.6      | 11        | <sup>246</sup> Cm  | 23            | 15       | 21        |
| <sup>90</sup> Sr  | 1.1           | 1.5      | 1.1       | <sup>95</sup> Mo   | 1.1           | 0.9      | 1.1       |
| <sup>99</sup> Tc  | 2.6           | 1.1      | 2.4       | <sup>101</sup> Ru  | 5.0           | 1.3      | 4.7       |
| <sup>106</sup> Ru | 1.4           | 1.8      | 1.4       | <sup>103</sup> Rh  | 1.8           | 1.5      | 1.6       |
| <sup>109</sup> Ag | 24            | 4.3      | 22        | <sup>125</sup> Sb  | 22            | 35       | 35        |
| <sup>133</sup> Cs | 33            | 2.9      | 37        | <sup>134</sup> Cs  | 33            | 5.0      | 35        |
| <sup>135</sup> Cs | 12            | 13       | 13        | <sup>137</sup> Cs  | 6.8           | 4.4      | 6.8       |
| <sup>144</sup> Ce | 0.5           | 0.9      | 0.5       | <sup>142</sup> Nd  | 7.1           | 7.0      | 0.9       |
| <sup>143</sup> Nd | 1.4           | 1.6      | 0.6       | <sup>144</sup> Nd  | 1.0           | 1.3      | 0.4       |
| <sup>145</sup> Nd | 1.5           | 1.1      | 0.6       | <sup>146</sup> Nd  | 1.4           | 0.8      | 0.5       |
| <sup>148</sup> Nd | 0.5           | 0.8      | 0.5       | <sup>150</sup> Nd  | 0.6           | 1.1      | 0.6       |
| <sup>147</sup> Sm | 2.6           | 1.5      | 1.7       | <sup>148</sup> Sm  | 2.4           | 1.6      | 1.8       |
| <sup>149</sup> Sm | 2.2           | 4.1      | 1.8       | <sup>150</sup> Sm  | 1.5           | 1.7      | 1.5       |
| <sup>151</sup> Sm | 3.2           | 12       | 2.5       | <sup>152</sup> Sm  | 2.8           | 4.2      | 1.6       |
| <sup>154</sup> Sm | 2.0           | 11       | 1.8       | <sup>153</sup> Eu  | 3.3           | 3.5      | 1.3       |
| <sup>154</sup> Eu | 4.2           | 3.9      | 1.6       | <sup>155</sup> Eu  | 27            | 33       | 1.5       |
| <sup>154</sup> Gd | 4.4           | 4.2      | 1.6       | <sup>155</sup> Gd  | 27            | 33       | 1.5       |
| <sup>156</sup> Gd | 4.8           | 6.5      | 2.7       | <sup>158</sup> Gd  | 1.2           | 3.3      | 0.9       |
| <sup>160</sup> Gd | 9.2           | 27       | 8.6       |                    |               |          |           |

# Reactor and SNF Quantities

- System: PWR
- Propagation through 7 cycles
- Results are shown only for the 7<sup>th</sup> cycle, including MOX
- Uncertainty propagation:
  - Repeat 100 times the same CMSYS (CASMO5/SIMULATE/SNF) calculation
  - Each time changing perturbations on nuclear data
  - Performed with JEFF-3.3, JENDL-4.0 and ENDF/B-VIII.0, all covariances
- Quantities of interest:
  - Boron curve
  - SNF Decay heat

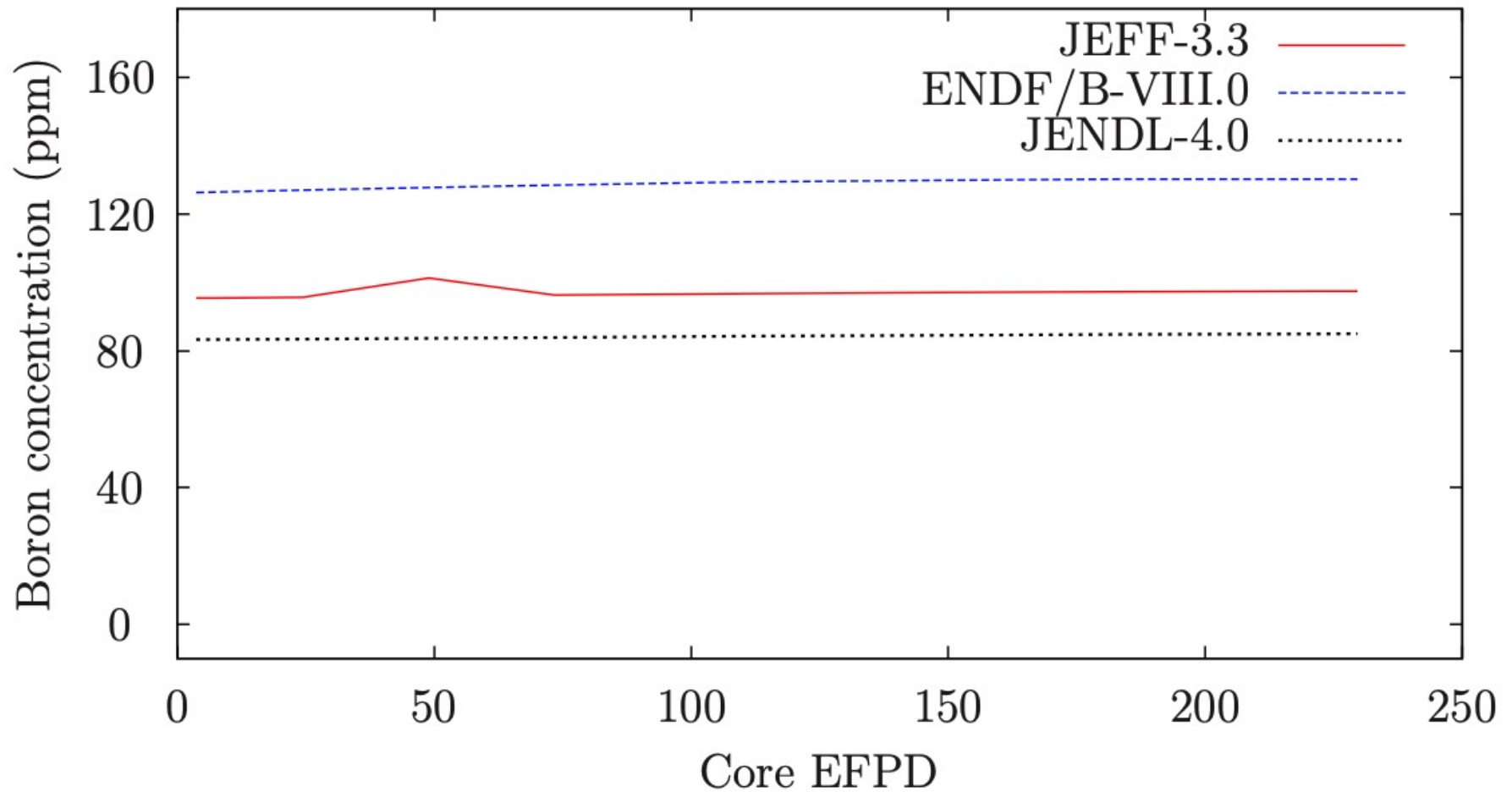
# Reactor Quantities: Boron curve

7<sup>th</sup> cycle



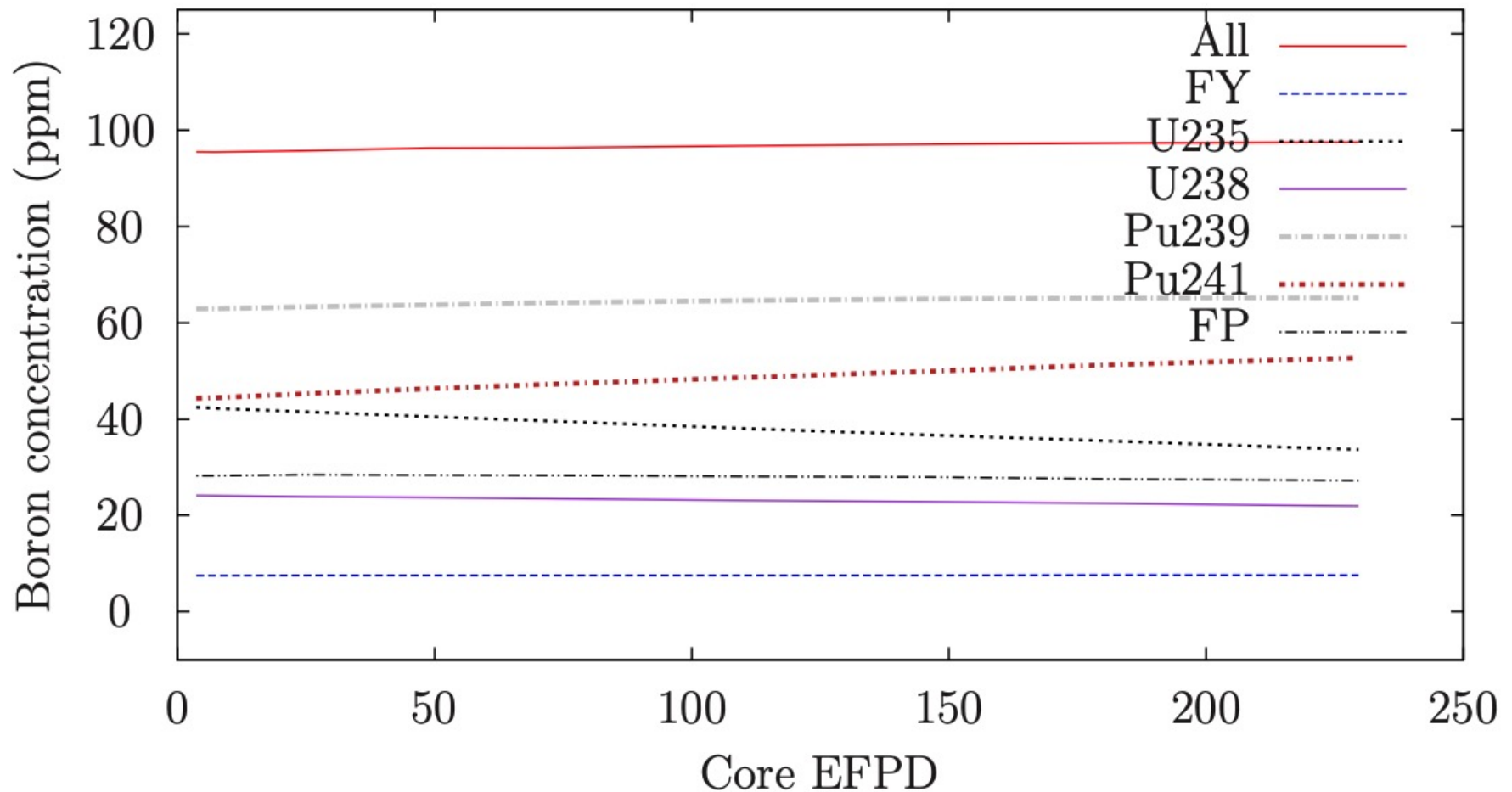
# Reactor Quantities: Boron curve

7<sup>th</sup> cycle Nuclear Data uncertainty



# Reactor Quantities: Boron curve

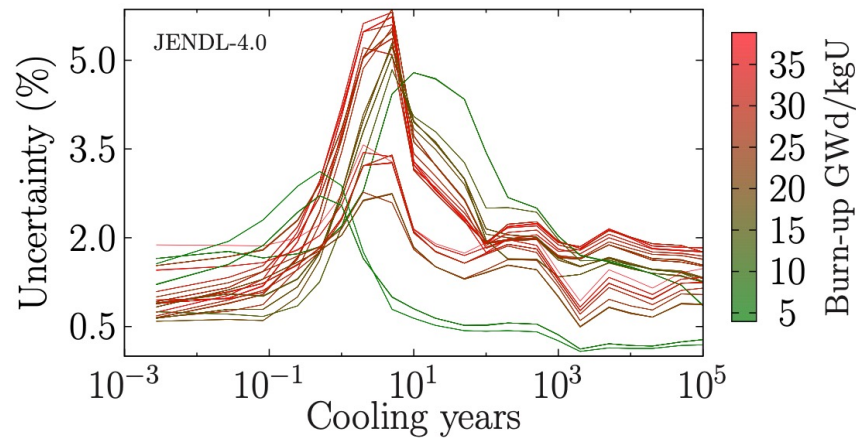
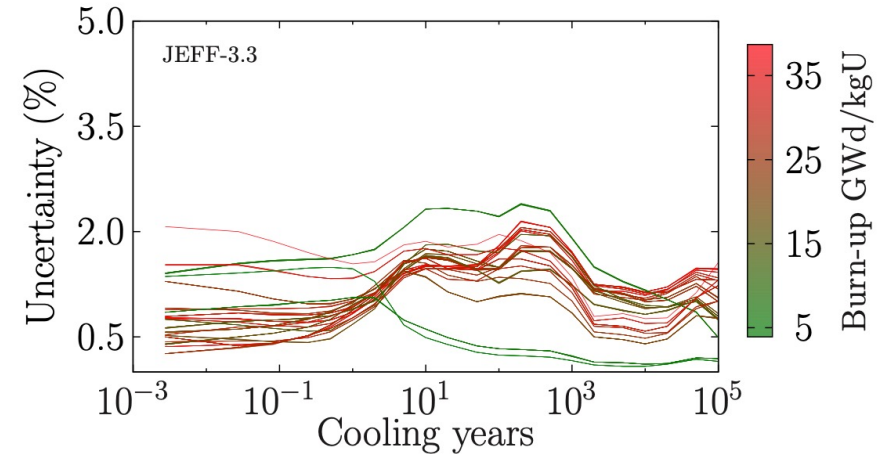
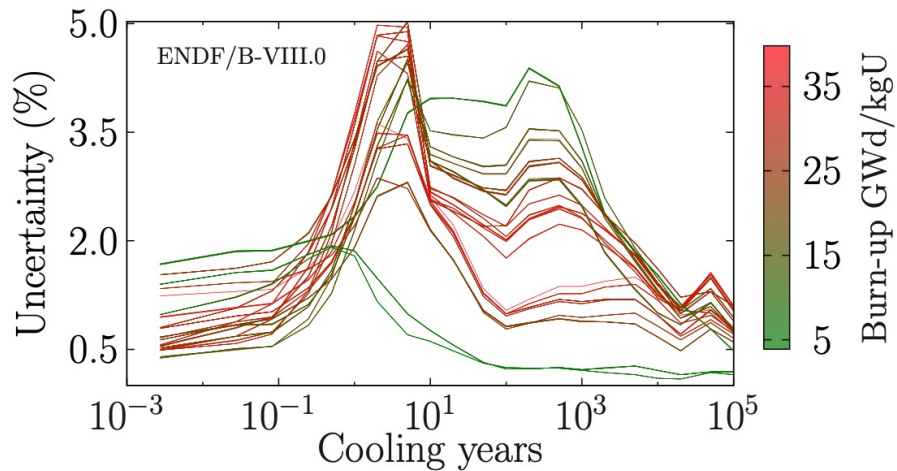
7<sup>th</sup> cycle Nuclear Data uncertainty JEFF-3.3





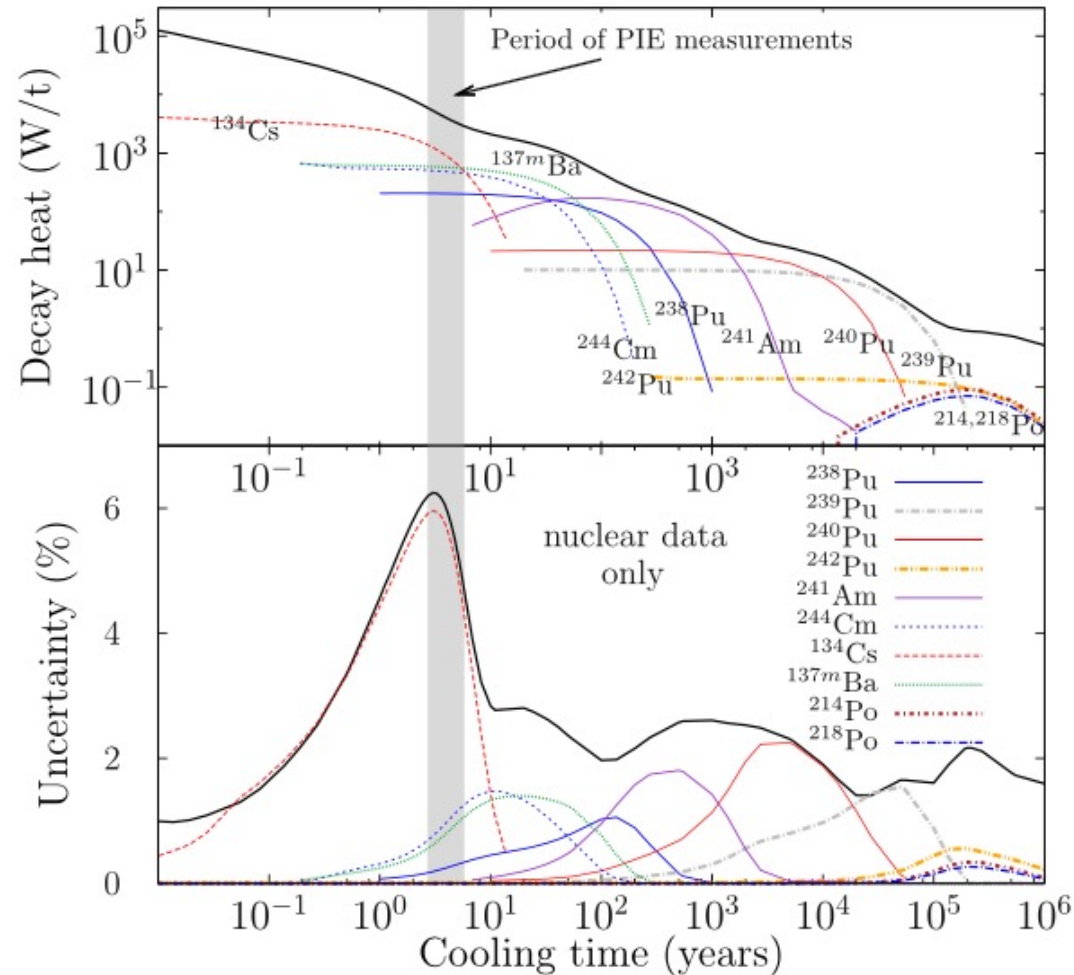
# SNF Quantities: Decay heat

- 121 SNF at end of the 7<sup>th</sup> cycle



# SNF Quantities: Decay heat

- Effect of Cs134 different in JEFF-3.3



**Fig. 10.** Calculated decay heat for the assembly containing the GU1 sample (top) and uncertainties due to nuclear data (bottom, with the ENDF/B-VIII.0 library). The ten most important contributors for the uncertainties are also presented.

# Conclusions

- Uncertainties propagated for PIE data, boron curves and SNF decay heat
- Some differences between JEFF-3.3 and JENDL-4.0, ENDF/B-VIII.0 for decay heat and PIE data, to be explored.
- Main differences between libraries for uncertainties (XS and FY):  
 $^{238}\text{Pu}$ ,  $^{237}\text{Np}$ ,  $^{94}\text{Mo}$ ,  $^{110}\text{Pd}$ ,  $^{111}\text{Cd}$ ,  $^{109}\text{Ag}$ ,  $^{125}\text{Sb}$ ,  $^{133,134,135}\text{Cs}$ ,  $^{151,154}\text{Sm}$ ,  $^{157,160}\text{Gd}$
- Missing covariances in JEFF-3.3:
  - $^{236}\text{U}$ ,  $^{242\text{m}}\text{Am}$ ,  $^{242}\text{Pu}$ ,
  - $^{153,154}\text{Eu}$ ,  $^{155,156,158,160}\text{Gd}$ ,  $^{135}\text{Cs}$ ,  $^{109}\text{Ag}$ ,  $^{129}\text{I}$ ,  $^{148}\text{Sm}$ ,  $^{144}\text{Nd}$ ,  $^{147}\text{Pm}$ ,  $^{144}\text{Ce}$ ,  $^{99}\text{Tc}$ ,  $^{148}\text{Nd}$
- No fast range covariances:  $^{241}\text{Am}$



