

# CIEMAT activities on Benchmarking and Nuclear Data Validation using SFCOMPO

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September 20<sup>th</sup> 2022

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# Introduction on SFCOMPO

- OECD/NEA Spent Fuel Isotopic Composition
- Current version: 2.0
- Designed to facilitate the search and visualisation of experimental assay data of spent nuclear fuel
- Data comes from fuel samples irradiated in power reactors, measured in the past 50 years
- Referenced, standardised, cross-checked source of published experimental data

# Introduction on SFCOMPO

- Data from 44 different reactors of 8 different types, for a total of 750 fuel samples:
  - AGR
  - BWR
  - CANDU
  - MAGNOX
  - PWR
  - RBMK
  - VVER-1000
  - VVER-440

# Uses of SFCOMPO by CIEMAT

- PWR
  - Obrigheim reactor for EVOLCODE validation
  - Takahama reactor for EVOLCODE validation
  - Takahama reactor for nuclear data libraries validation
- BWR
  - Cooper reactor for EVOLCODE validation

# EVOLCODE: Theory

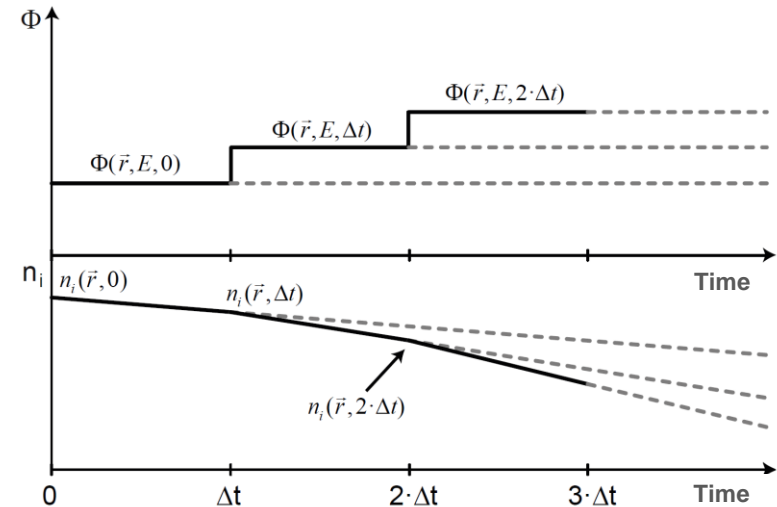
- Developed to cope with the burn-up problem.
- Coupling of the non linear integro-differential equations.
- Versatility: different problems to be solved.
- High precision with moderate computer time (parallel processing).

## Boltzmann equation: Neutron transport

$$\frac{1}{v} \frac{\partial \Phi(\vec{r}, E, t)}{\partial t} + \vec{\Omega} \cdot \vec{\nabla} \Phi(\vec{r}, E, t) = S(\vec{r}, E, t) - \Sigma_T(\vec{r}, E, t) \Phi(\vec{r}, E, t) + \int_0^\infty \Sigma_s(\vec{r}, E', t') f(\vec{r}, E' \rightarrow E, t) \Phi(\vec{r}, E', t) dE' + \int_0^\infty s(E') \Sigma_f(\vec{r}, E', t') \nu(E', t) \Phi(\vec{r}, E', t) dE'$$

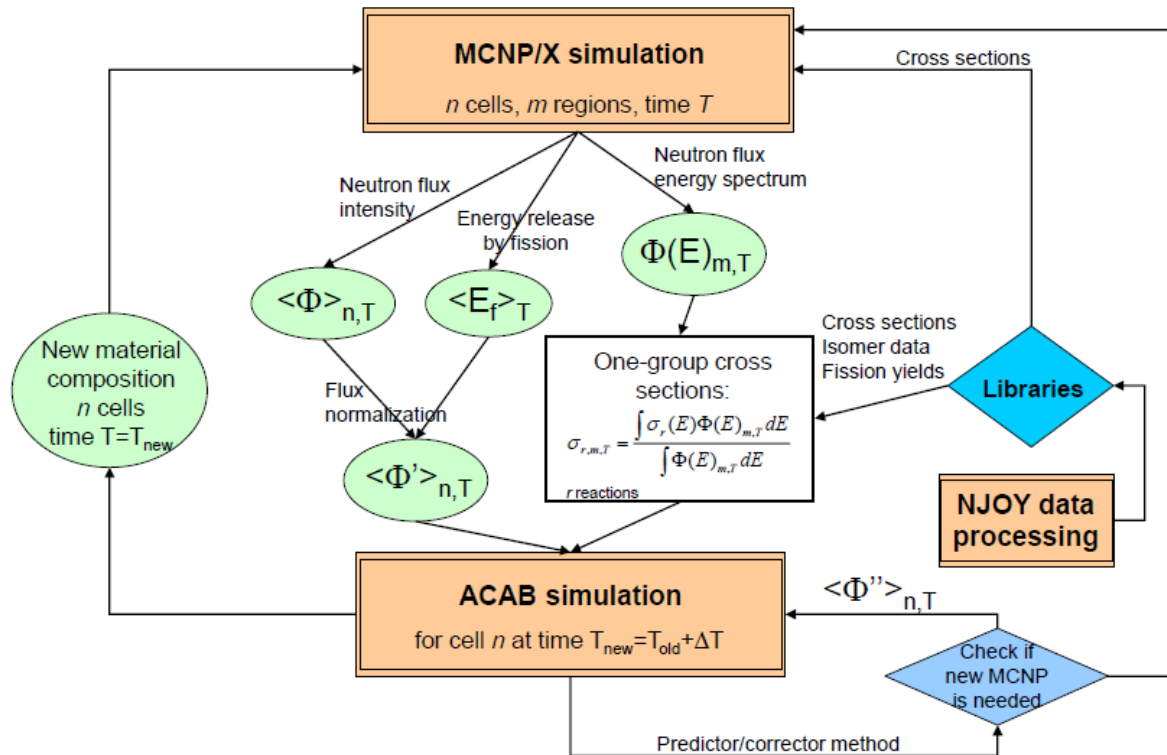
## Bateman equations: Depletion

$$\frac{dn_i(\vec{r}, t)}{dt} = \left[ \sum_{j \neq i} n_j(\vec{r}, t) \left( \lambda_{ji} + \int \sigma_{ji}(\vec{r}, E) \Phi(\vec{r}, E, t) dE \right) \right] - \left[ n_i(\vec{r}, t) \left( \lambda_i + \int \sigma_{abs}(\vec{r}, E) \Phi(\vec{r}, E, t) dE \right) \right], \text{ con } i = 1, M \text{ isótopos.}$$



# EVOLCODE: Implementation

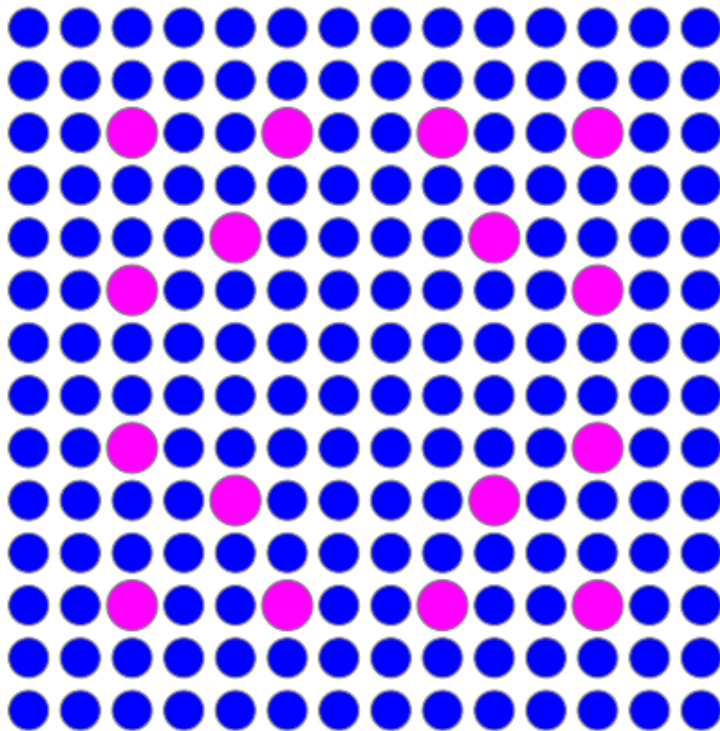
- Written in ANSI FORTRAN 77 standard.
- 8874 code lines (excluding blanks) subdivided in modules.
- Parallel programming in MCNP and ACAB.



# EVOLCODE: Validation with Obrigheim data

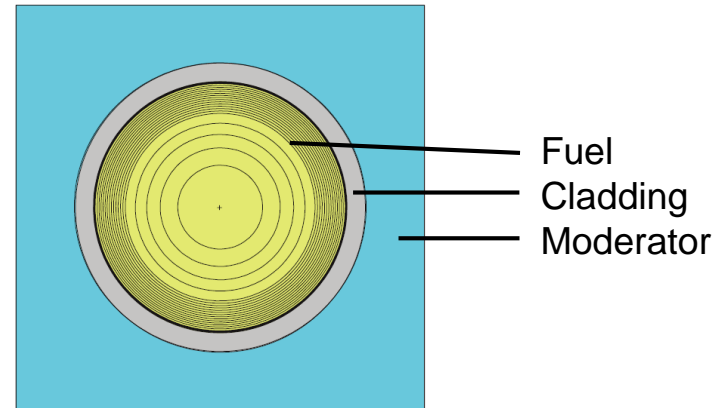
- Experiments made in the 70s over 10 consecutive batches (half assembly)

Obrigheim KWO assembly

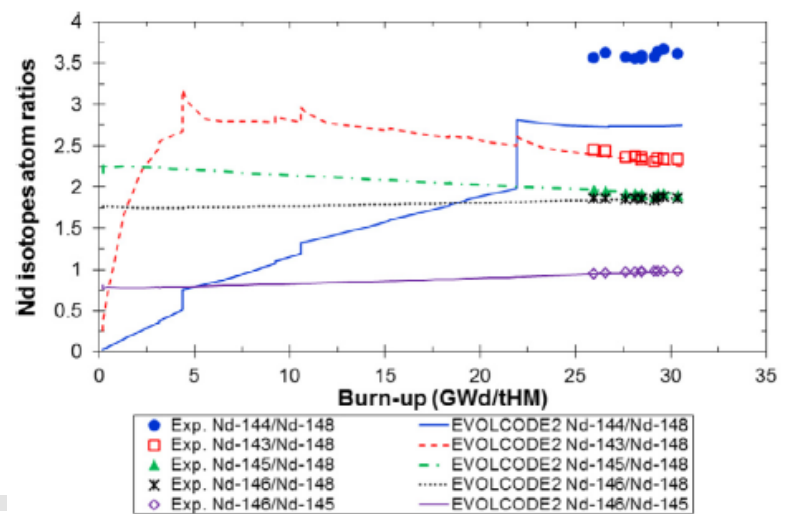
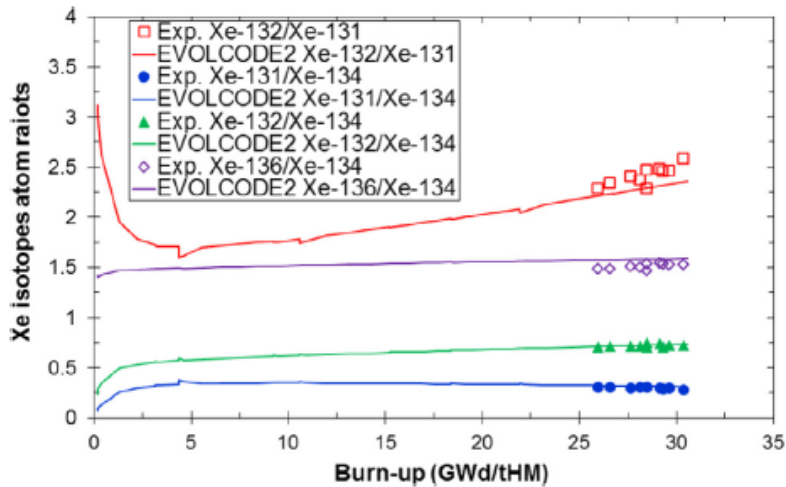
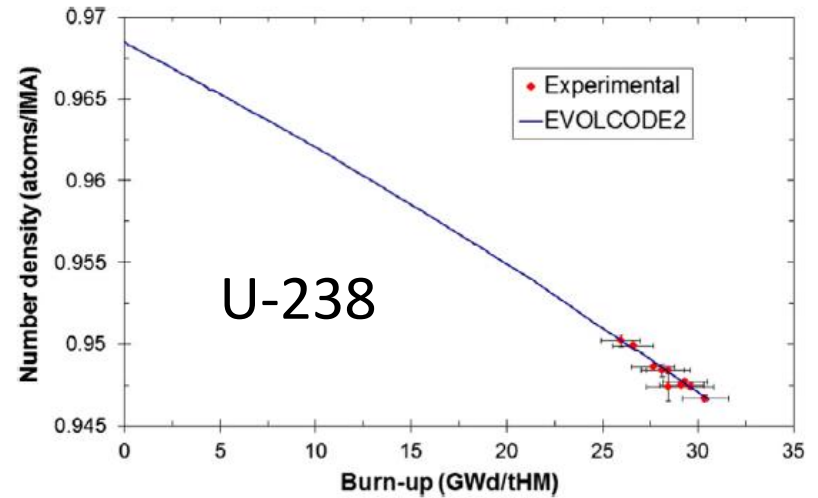
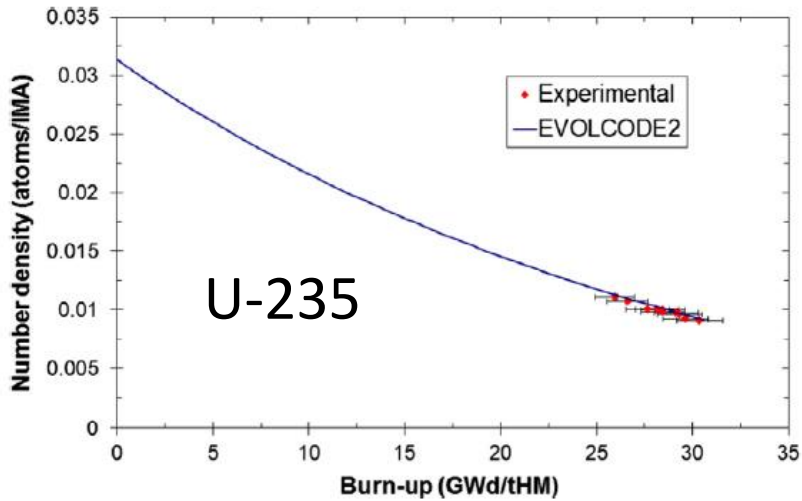


● Guide tube ● Fuel

Actual model in EVOLCODE



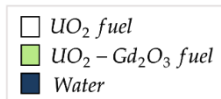
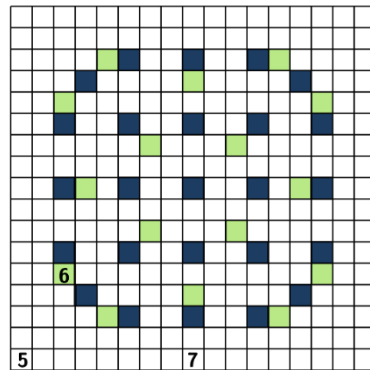
# EVOLCODE: Validation with Obrigheim data



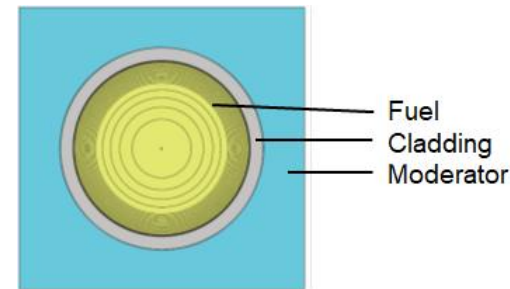
# Validation of nuclear data libraries

- Work done in the EURAD Project (European Joint Programme on Radioactive Waste Management), with the aim of improve the Spent Fuel Characterization and Evolution Until Disposal.
- Burn-up calculations of the Takahama-3 reactor (included in SFCOMPO) have been performed. Sensitivity calculations with the objective of the calculation of uncertainties have been made, leading to some nuclear data library recommendations.

Fuel assembly NT3G23 from Takahama-3



Actual model in EVOLCODE



Fuel  
Cladding  
Moderator

# Sensitivity analysis: JEFF-3.3 vs ENDF/B-VIII.0

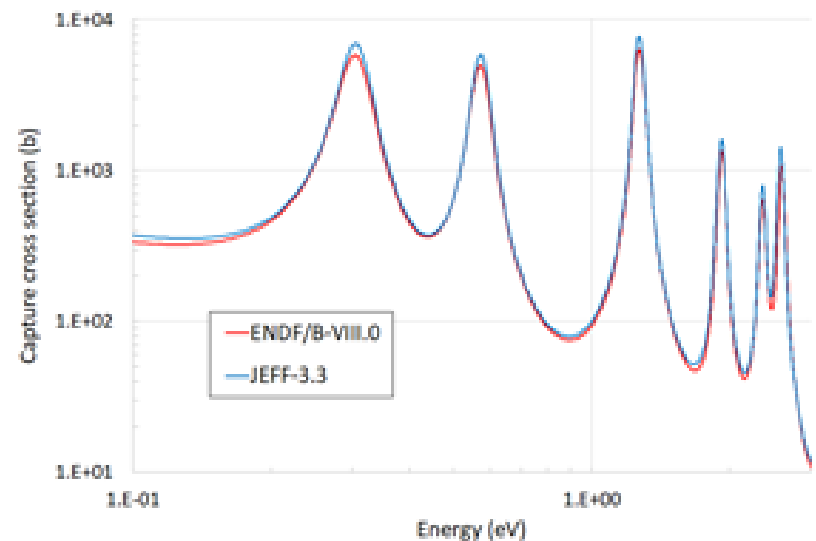
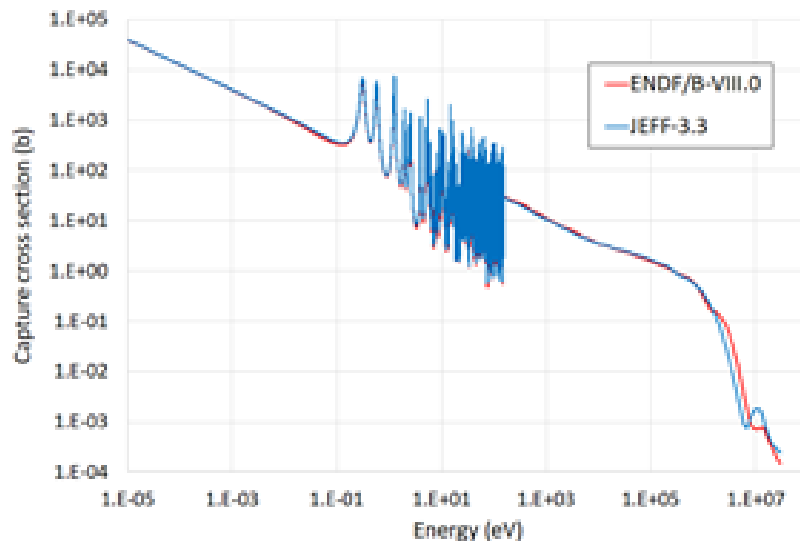
| Isotope        | Relative difference |
|----------------|---------------------|
| U-233          | 0.7%                |
| U-234          | 0.2%                |
| U-235          | -0.2%               |
| U-236          | -1.6%               |
| U-238          | 0.0%                |
| Np-237         | 1.8%                |
| Pu-238         | 1.7%                |
| Pu-239         | 0.1%                |
| Pu-240         | 0.3%                |
| Pu-241         | 0.4%                |
| Pu-242         | -0.1%               |
| Am-241         | -5.7%               |
| <b>Am-242m</b> | <b>22.2%</b>        |
| Am-243         | 2.1%                |
| Cm-242         | 3.7%                |
| Cm-243         | 3.9%                |
| Cm-244         | -4.9%               |
| Cm-245         | -4.2%               |
| Cm-246         | -3.5%               |

| Isotope        | Relative difference |
|----------------|---------------------|
| <b>C-14</b>    | <b>97.3%</b>        |
| Sr-88          | 1.2%                |
| Sr-90          | -0.7%               |
| Mo-95          | 0.2%                |
| Tc-99          | 0.0%                |
| Ru-101         | 0.2%                |
| Ru-106         | -0.2%               |
| Rh-103         | 0.3%                |
| Ag-109         | 9.6%                |
| <b>Ag-110m</b> | <b>99.6%</b>        |
| <b>Sb-125</b>  | <b>-28.2%</b>       |
| <b>I-129</b>   | <b>20.1%</b>        |
| Cs-133         | -1.0%               |
| Cs-134         | -0.6%               |
| Cs-137         | -0.4%               |
| Ce-144         | 0.0%                |
| <b>Nd-142</b>  | <b>-8109.3%</b>     |
| Nd-143         | -0.5%               |
| Nd-144         | 0.2%                |
| Nd-145         | 0.7%                |

| Isotope       | Relative difference |
|---------------|---------------------|
| Nd-146        | 1.8%                |
| Nd-148        | 2.3%                |
| Nd-150        | 0.6%                |
| Pm-147        | 2.4%                |
| Sm-147        | 1.9%                |
| Sm-148        | -0.5%               |
| Sm-149        | -0.7%               |
| Sm-150        | -1.5%               |
| Sm-151        | 1.6%                |
| Sm-152        | 2.3%                |
| Sm-153        | 6.6%                |
| <b>Eu-151</b> | <b>100.0%</b>       |
| Eu-153        | 7.9%                |
| Eu-154        | 7.4%                |
| Eu-155        | 4.0%                |
| Gd-154        | 5.6%                |
| Gd-155        | 2.5%                |
| <b>Gd-156</b> | <b>-12.7%</b>       |
| <b>Gd-157</b> | <b>47.7%</b>        |
| <b>Gd-158</b> | <b>38.8%</b>        |

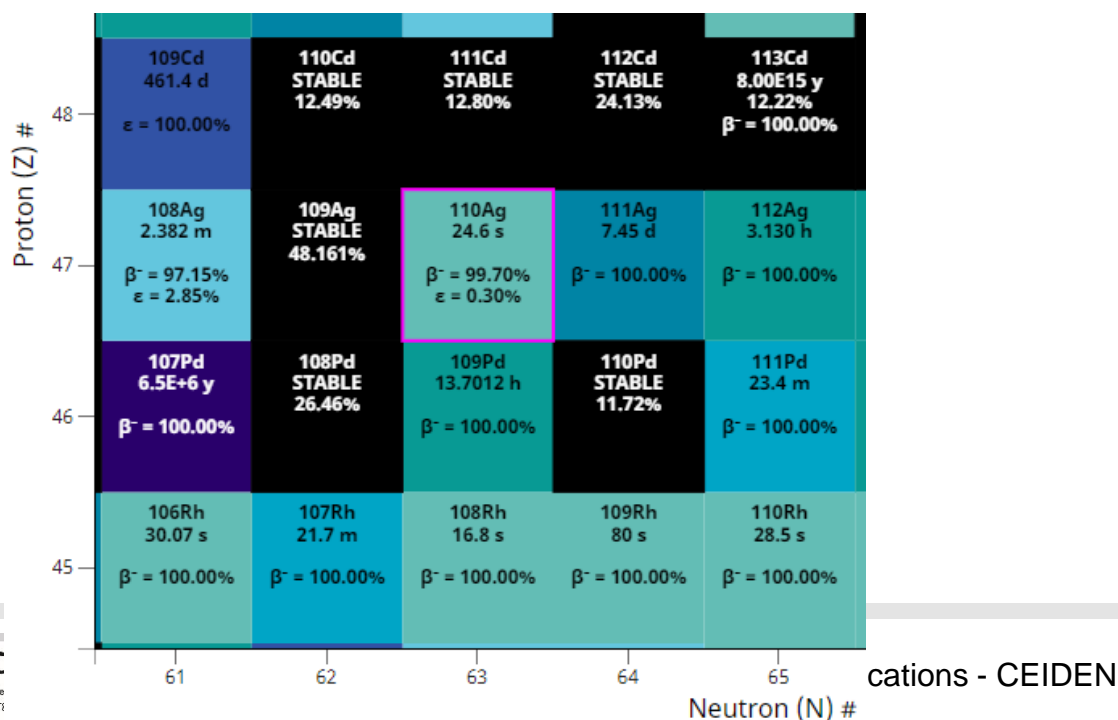
# Sensitivity analysis: Am-242M

- JEFF result is a 22.4% larger than ENDF result.
- The cause is the different values of  $^{241}\text{Am}$  ( $n,\gamma$ ) cross section between libraries.
- One-group cross sections obtained with EVOLCODE are systematically around 37% larger along burn-up with JEFF.



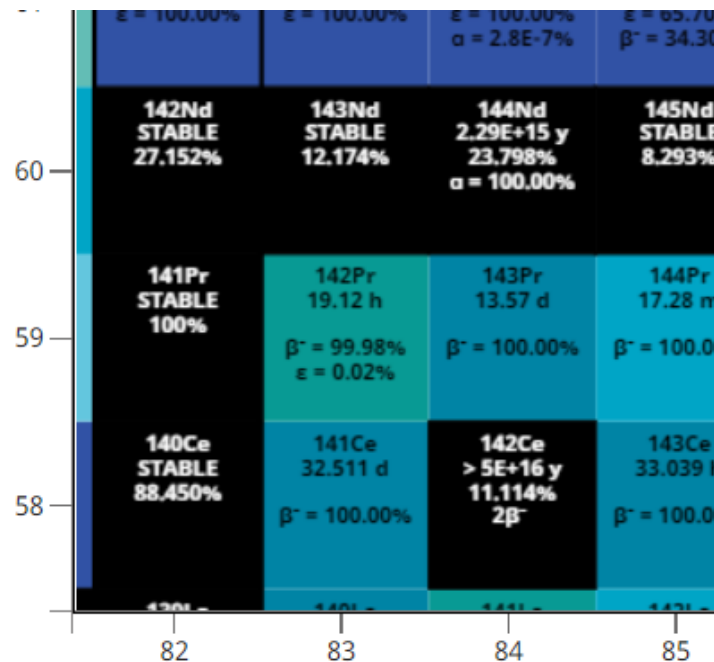
# Sensitivity analysis: Ag-110M

- JEFF result is two orders of magnitude larger than ENDF result.
- Created as independent fission product in both libraries. No possible decay parent since  $^{110}\text{Pd}$  is stable and none of these libraries include the  $^{109}\text{Ag}$  ( $n,\gamma$ ) branching ratio towards the metastable state in MF=9. The main source is  $^{239}\text{Pu}$  fissions (95% in ENDF/B-VIII.0 and ~67% in JEFF-3.3).
- However, for ENDF/B-VIII.0, only the fusion table includes a non zero value.



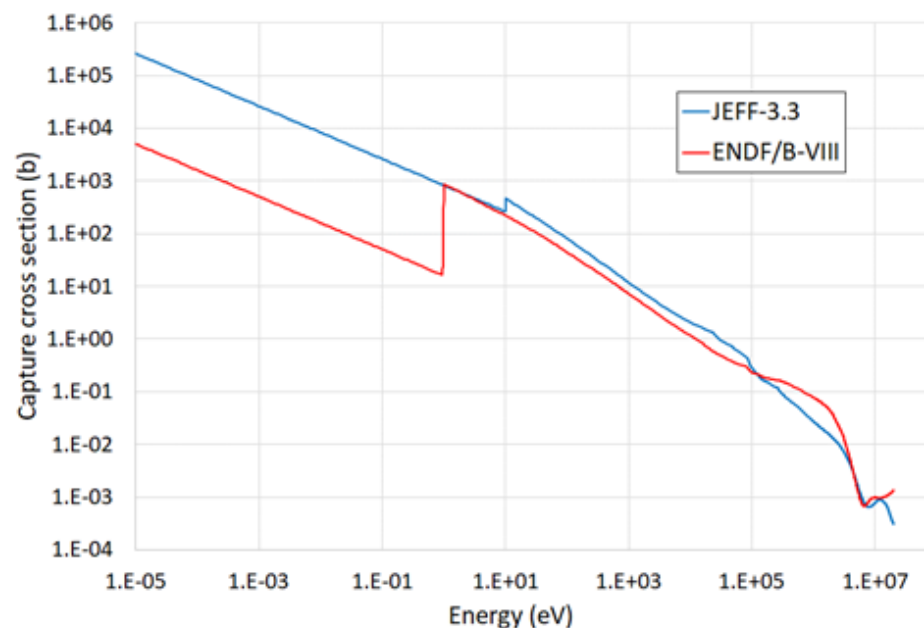
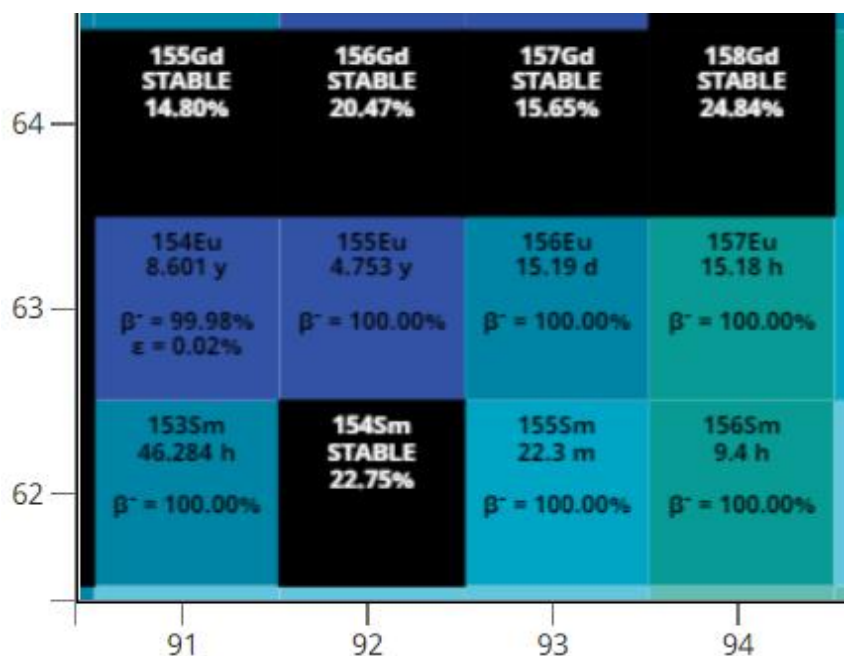
# Sensitivity analysis: Nd-142

- Discrepancy of two orders of magnitude: 4.4 mg in ENDF/B-VIII and 0.053 mg in JEFF-3.3.
- JEFF reference result shows a C/E of 0.92.
- Discrepancy due to the  $^{142}\text{Ce}$  double  $\beta^-$  decay. Almost stable, but included in ENDF/B-VIII.0 with a half-life of zero, causing instant decay of  $^{142}\text{Ce}$  and leading to its incorrect accumulation. Similar issue for  $^{151}\text{Eu}$ .



# Sensitivity analysis: Gd-156 and Gd-157

- Discrepancies of -12.7% for  $^{156}\text{Gd}$  and 47.7% for  $^{157}\text{Gd}$ .
- $^{157}\text{Gd}$  can be created from different sources. One of them comes from captures and decay starting in  $^{156}\text{Eu}$  ( $\beta^-$  emitter with a half-life of 15.2 d).
- One-group cross section in EVOLCODE of 342 b in JEFF-3.3 and 52 b in ENDF/B-VIII.0.



## Conclusions

- The SFCOMPO database has been of large importance for the validation of the CIEMAT developed EVOLCODE burnup system.
- This database has also been use for the validation of nuclear data libraries: ENDF/B-VIII.0 and JEFF-3.3, finding some cases to report to the developers.
- Also, BWR experimental data is being used to validate EVOLCODE with this kind of technology.

Thank you for your attention

Authors would like to acknowledge the EURAD contribution to this work and also the CIEMAT-ENRESA collaboration.