PAUL SCHERRER INSTITUT

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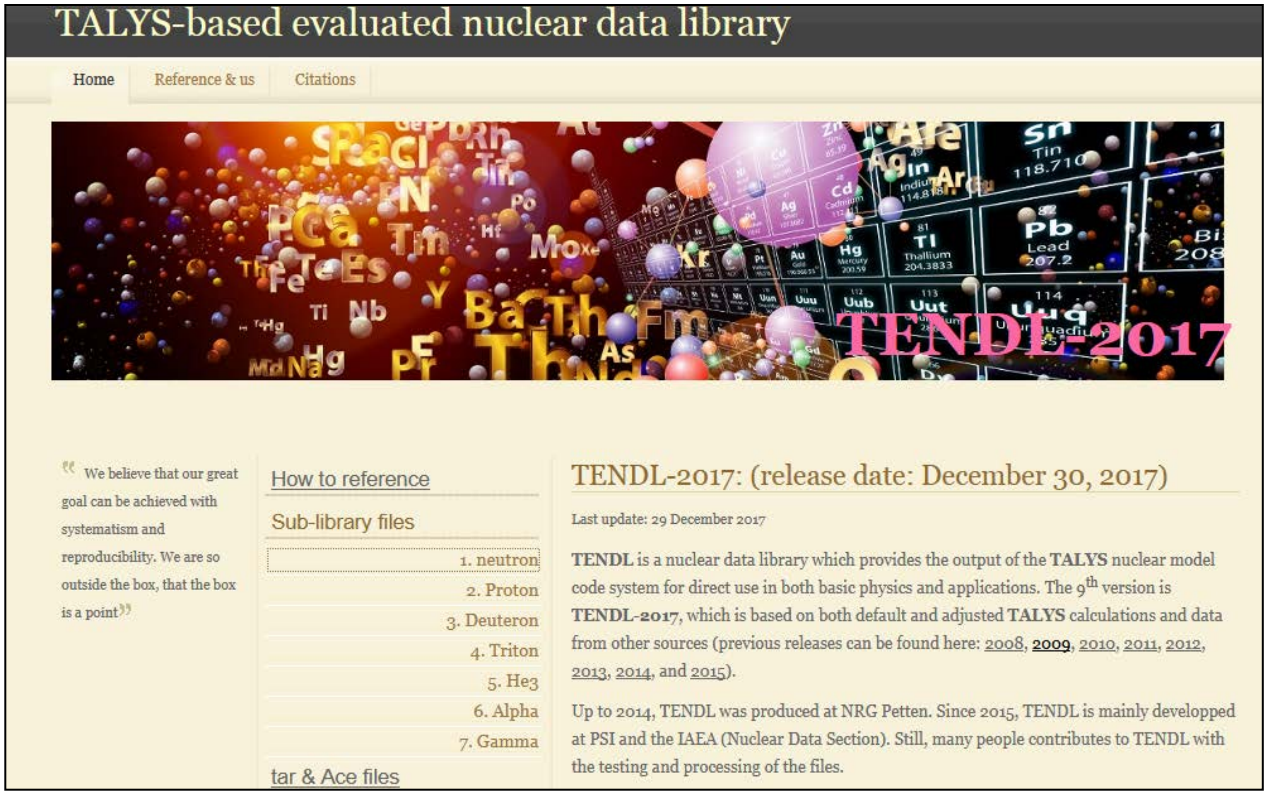
The TENDL nuclear data library: Standing on the shoulders of giants

ImPACT International Symposium on "*New Horizons of Partitioning and Transmutation Technologies with Accelerator System*", 2-3 December 2018, University of Tokyo, Japan

STARS ISO 9001

Summary

- TENDL: a short history and modern approach
- Examples for current research:
  - solving THE equation
  - Include integral observation in a library evaluation ?
  - Uncertainty propagation for Spent Nuclear Fuel



- All slides are available here: https://tendl.web.psi.ch/bib_rochman/presentation.html

What is the TENDL project ?

- TENDL: TALYS evaluated nuclear data library,

- Goal: improve simulations for TENDL and/or other libraries, or solving

$$0 \leq \chi^2 \leq 1$$

$$\chi^2 = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{C_i - E_i}{\Delta E_i}\right)^2$$

- Available at https://tendl.web.psi.ch/home.html

- Comes from T6 (software package)

- T6 leads to TENDL, TMC, BMC, HFR…

- See for instance NDS 113 (2012) 2841, ANE 51 (2013) 60, NDS 139 (2017) 1

What is the TENDL project ?

- TENDL is in fact a by-product of a series of codes,

- This is one fundamental difference with other libraries (no manual work),

- It allows to perform „TMC“ for Total Monte Carlo (uncertainty propagation)

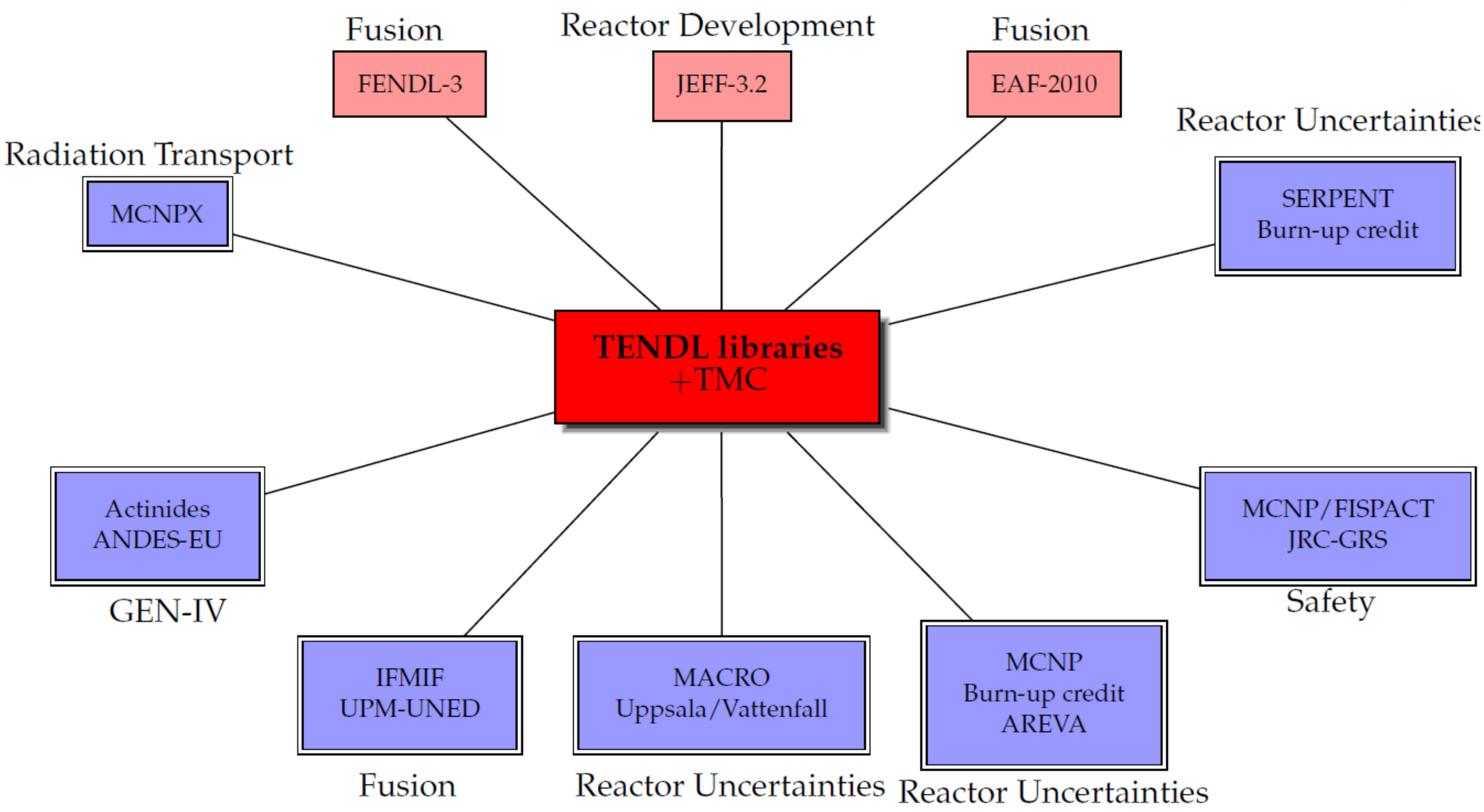
- Methods: reproductibility & completeness, development of a portable system, and making use of the knowledge included in other libraries (JEFF, ENDF/B, JENDL),

- Background: theoretical calculations (TALYS) with experimental inputs, with original resonance evaluations,

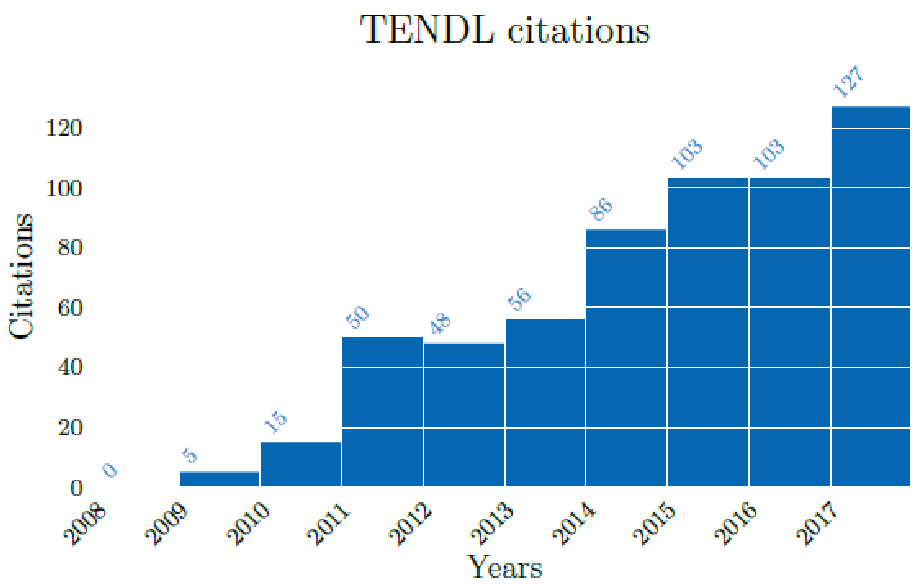
- Impact:
  - TENDL-2008 to 2017 (2800 isotopes),
  - Neutrons, protons, deuterons, tritons, He3, alpha and gamma induced,
  - all isotopes, all cross sections with covariances, 0-200 MeV,
  - more than 300 isotopes in the NEA JEFF-3.3 library,
  - more than 50 isotopes in the US ENDF/B-VIII.0 library,
  - more than 450 publications using TENDL

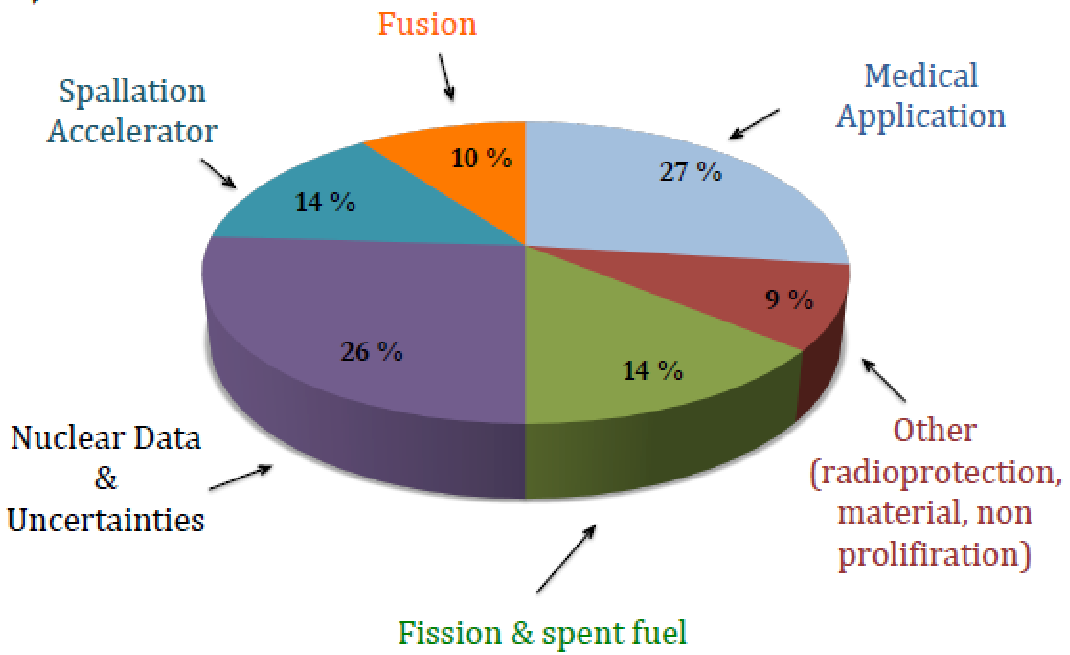
What is the TENDL project ?

- Fully implemented in FISPACT-II, part of GEANT, CASMO...,
- Used in fission, fusion applications, medical isotope productions



What is the TENDL project ?





TENDL: from MF-1 to MF-40, 200 MeV

- MF-1: Description + fission parameters
- MF-2: Resonance parameters (Reich-Moore or Multi-level Breit Wigner)
- MF-3: Cross sections (n,tot), (n,el), (n,non), (n,inl$_i$), ..., (n,γ), (n,p$_i$), (n,α_i)
- MF-4: Elastic angular distribution (Legendre Polynomials)
- MF-5: Fission neutron spectrum
- MF-6: Double differential distributions and spectra for (n,2n), ..., (n,α_i)
- MF- 8-10: Isomeric cross sections
- MF- 12-15: Gamma yields, angular distributions and spectra
- MF- 31-32-33-34-35, 40: nubar, Resonance parameter, cross section, angular distribution and fission neutron spectrum, radionuclide production.

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Nuclear Data Sheets 113 (2012) 2841–2934

Nuclear Data Sheets

www.elsevier.com/locate/nds

Modern Nuclear Data Evaluation with the TALYS Code System

A.J. Koning* and D. Rochman

TENDL: Complete Nuclear Data Library for innovative Nuclear Science and Technology

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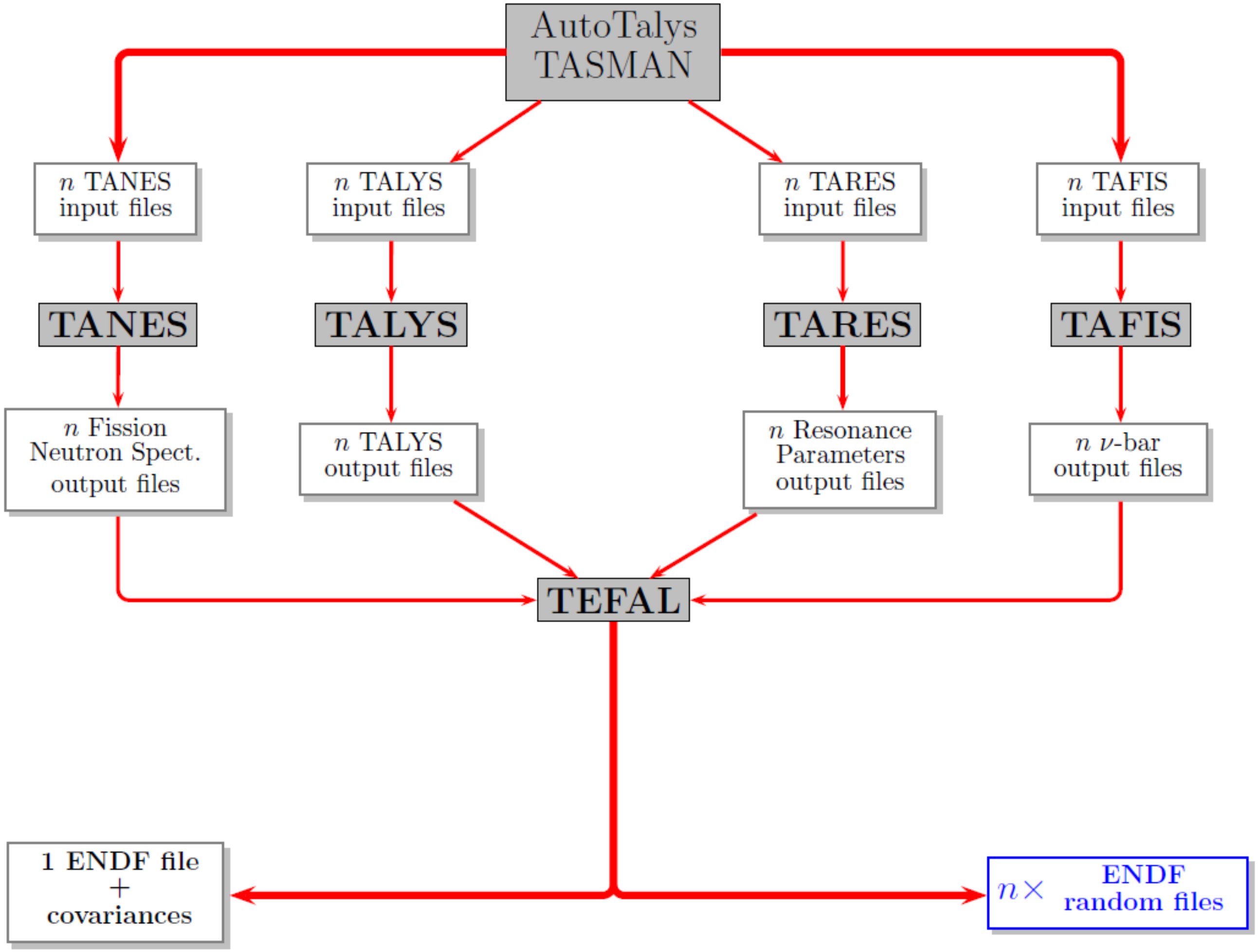
(Dated: November 7, 2018; Received xx July 2018; revised received xx September 2018; accepted xx October 2018)

T6: source of TENDL

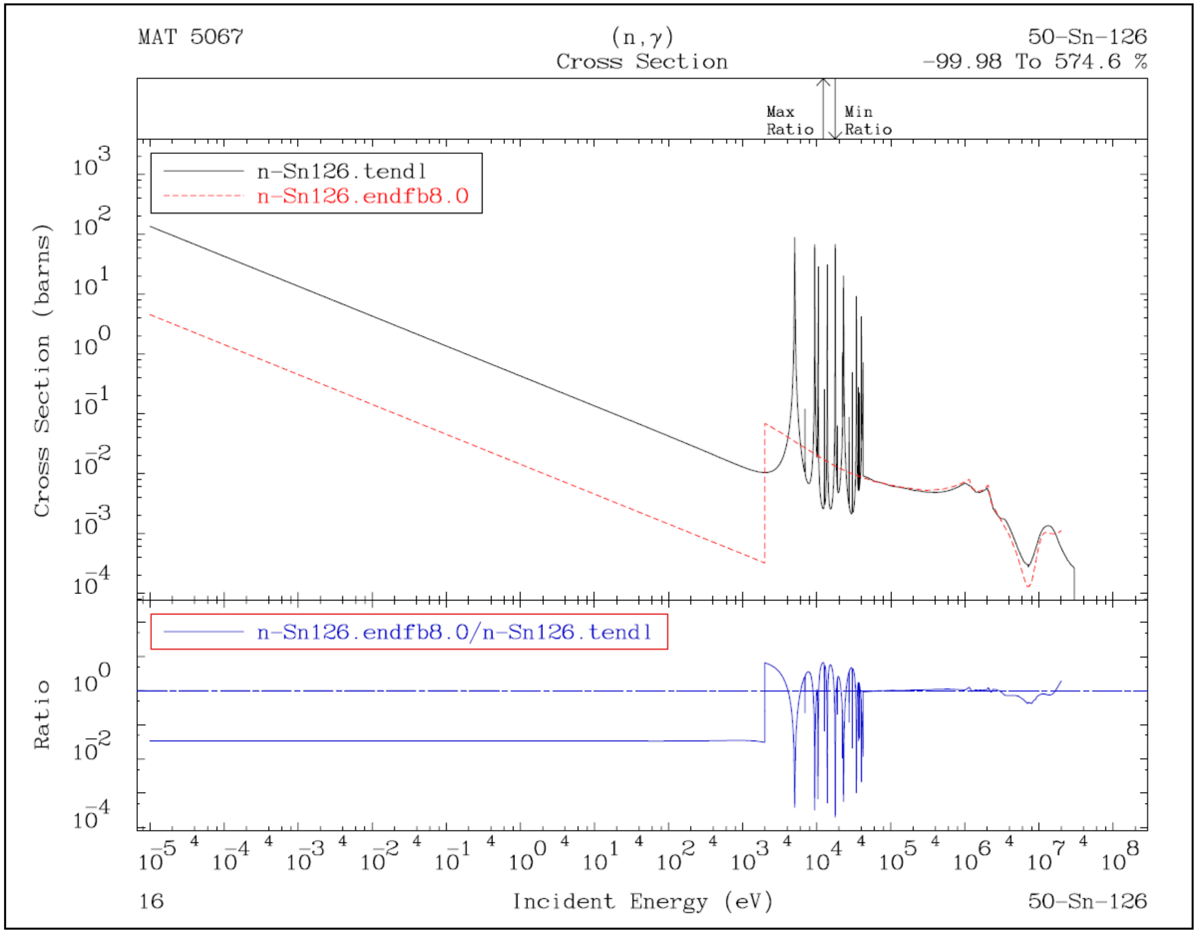
- T6: at the origin of TENDL. Combination of 6 codes plus utilities,
- Available on demand, easy to install,
- Make your own TENDL !



TENDL related projects

The TENDL way is strongly linked to other methods:

- (fast) TMC: Total Monte Carlo for uncertainty propagation,
- BMC: Bayesian Monte Carlo for model parameter updates and sampling,
- HFR: Resonance parameters for all isotopes consistent with the fast neutron range.



Example 1: Solving THE equation

- The goal of all libraries is to solve this equation:

$$0 \leq \chi^2 \leq 1$$

- C_i: calculated quantities (differential and integral)
- E_i: measured quantities
- $n \to \infty$

$$\chi^2 = \frac{1}{n} \sum_{i=1}^{n} \left(\frac{C_i - E_i}{\Delta E_i} \right)^2$$

- Solutions: random search, or GLLS, MOCABA…
- Another solution: iterative search with model parameter weighting + model defects
  1. Select the experimental data
  2. Select a library (i=0) and calculate χ^2
  3. Replace the most sensitive element by *n* random evaluations
  4. Calculate n χ^2
  5. Library i = library (i-1) + best random (smallest χ^2)
  6. Repeat for all elements

- NSE 169 (2011) 68

Example 2: Using integral data

- Open discussion in the nuclear data community:

Shall we explicitly use integral data (PIE, reaction rates…) at the evaluation level (when creating a library) ?

- Motivation 1: integral data are already used during adjustment
- Motivation 2: This should be done at the evaluation level
- Motivation 3: It leads to uncertainty reduction and cross-isotope correlations
- Motivation 4: reduce the bias
- Motivation 5: nothing new: already done with GLLS by SG… at the OECD

- One method: Bayesian Monte Carlo (with or without model defect)

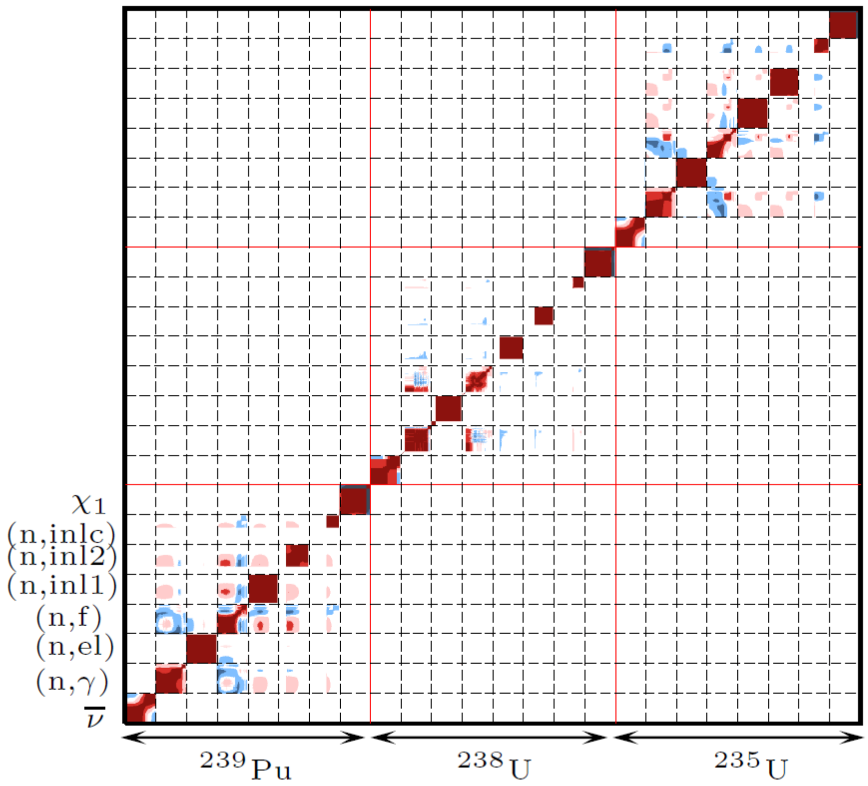
For a random file i and a set of p benchmarks:

$$\chi_i = \sum_j^p \left(\frac{\mathrm{k}_{\mathrm{eff,i}}^{(\mathrm{j})} - \mathrm{k}_{\mathrm{exp}}^{(\mathrm{j})}}{\Delta \mathrm{k}^{(\mathrm{j})}} \right)^2 \quad (1)$$

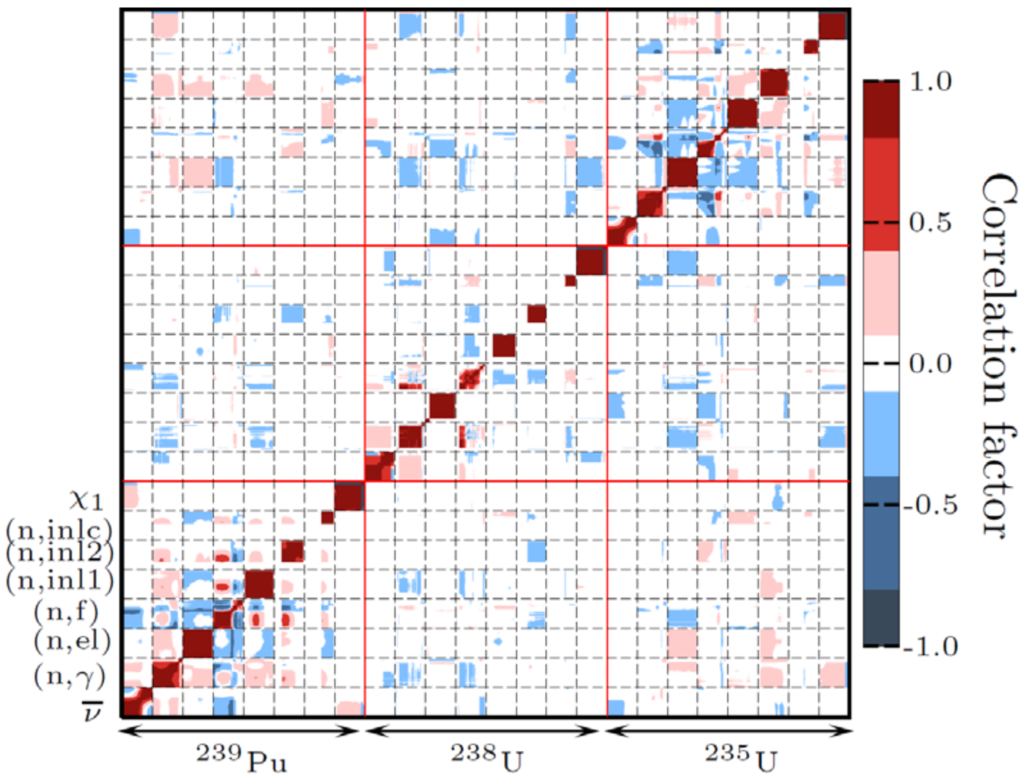
$$w_i = \exp(-\frac{\chi_i}{2}) \quad (2)$$

Example 2: Using integral data

- Fast range: 14 reactions together (k_{eff} and reaction rates) (EPJ/N **4** (2018) 7)



Prior

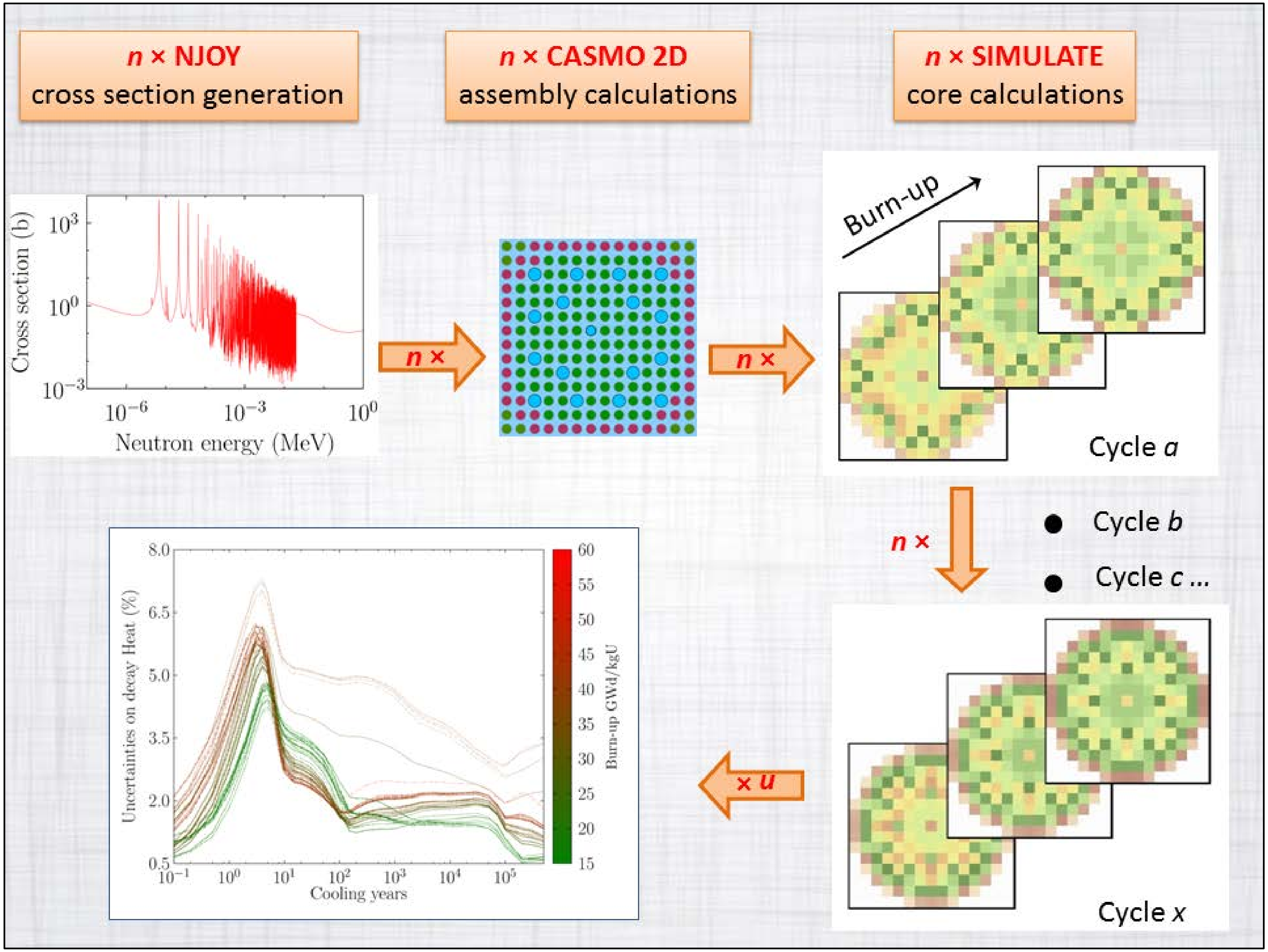


Posterior

More correlations → uncertainty reduction

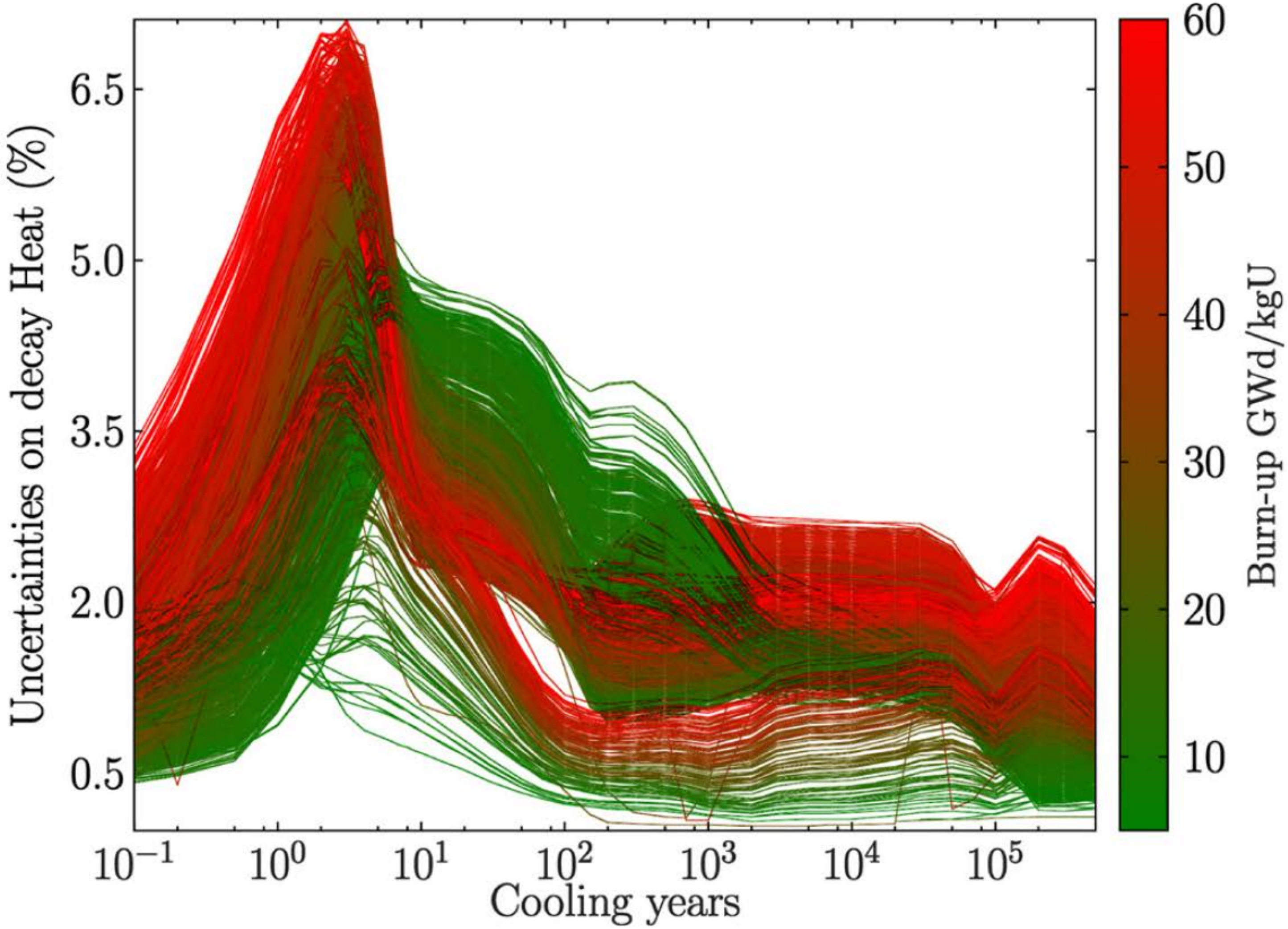
Example 3: Uncertainty propagation

- Nuclear data uncertainties for Spent Nuclear Fuel (EPJ/N **4** (2018) 6)



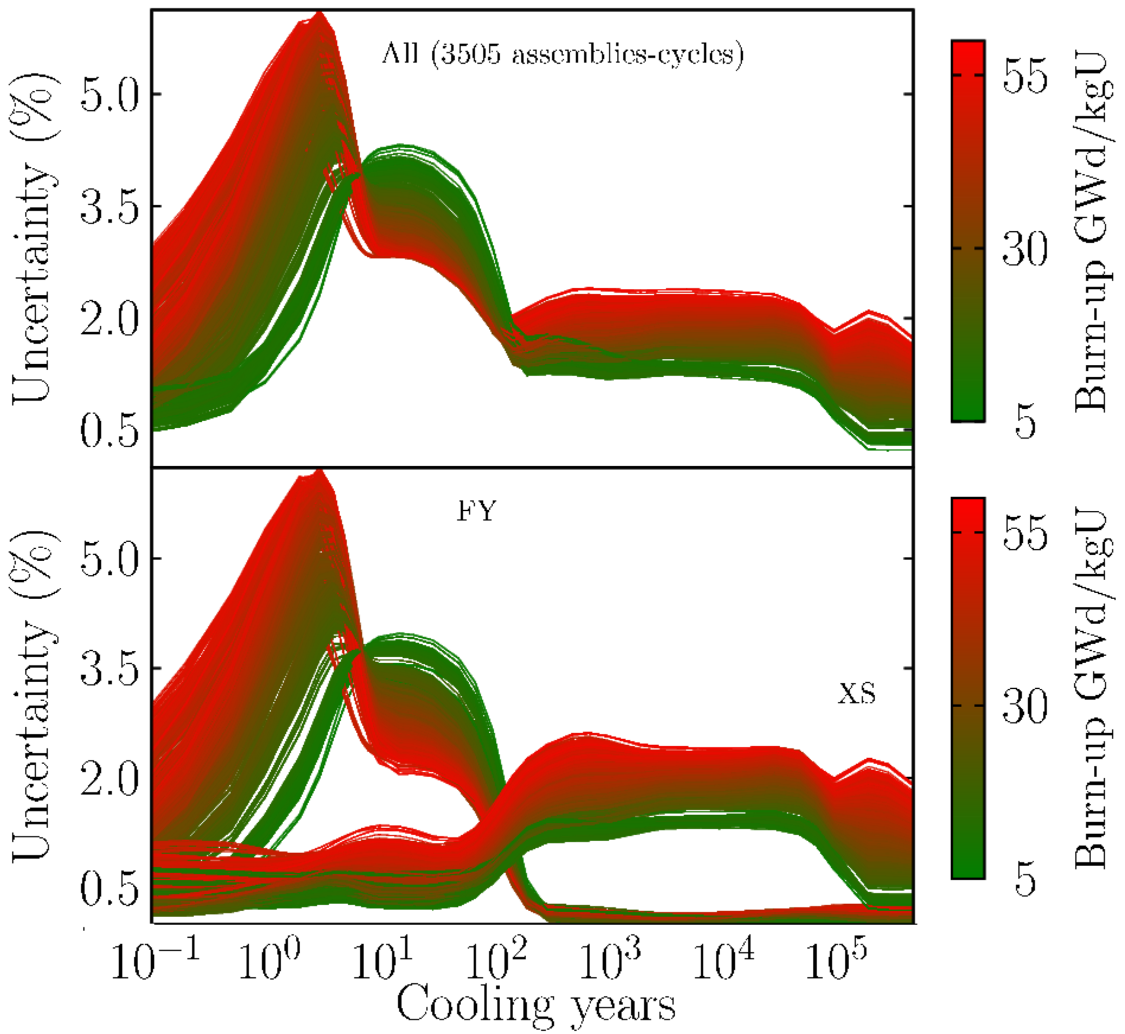
Example 3: Uncertainty propagation

- Nuclear data uncertainties for Spent Nuclear Fuel (one curve = one assembly)
- <u>PWR and BWR</u> assemblies



Example 3: Uncertainty propagation

- Nuclear data uncertainties for Spent Nuclear Fuel (one curve = one assembly)
- BWR assemblies only



Conclusion

- Nuclear waste is a major concern in Europe

- The current knowledge of nuclear data have an significant impact for waste estimation and disposal,

- New methods for nuclear data evaluation are still being developed, given the existing computer power,

- Connecting all the dots is an essential part of building a reliable simulation system


photo courtesy of Gerry Hofstetter

Wir schaffen Wissen – heute für morgen