DE LA RECHERCHE À L'INDUSTRIE

Comparisons & Discussions on Adjustment trends from JEFF (CEA)

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Covariances Matrices methodologies: Cross Section "knowledge", Evaluations and Integral Contraints

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CROSS SECTIONS "KNOWLEDGE" & EVALUATION

Experimentalist

Knowledge of cross section ⟺ finest microscopic experiments and smartest integral experiments;

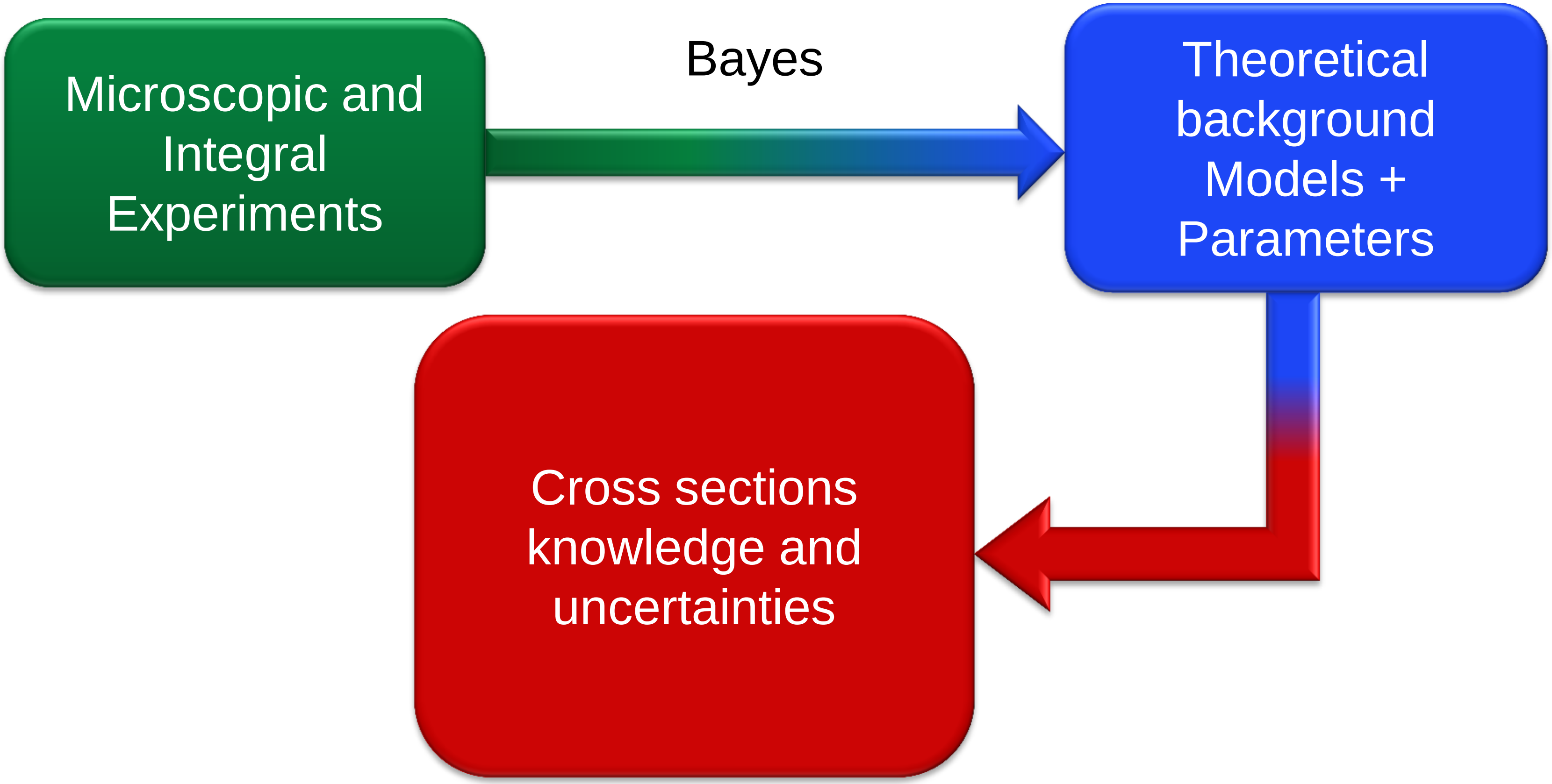
Calibration; Systematical uncertainties…

Theoretician

Knowledge of cross section ⟺ knowledge of models parameters and/or nuclear reaction models (resonance parameters, optical models, fission barrier, average width, ...) ;

Systematics; Model defects

CROSS SECTIONS “KNOWLEDGE” & EVALUATION



Issues:

- **Systematic experimental uncertainties**
- **Phenomenological Nuclear reaction model theories & Parameters**
- **Integral experiment assimilation**

EVALUATIONS AND UNCERTAINTIES
GENERAL MATHEMATICAL FRAMEWORK

Bayesian inference (probability density):

$$p(\vec{x}\,|\,M,\vec{y},U) = \frac{p(\vec{x}\,|\,M,U)\cdot p(\vec{y}\,|\,M,\vec{x},U)}{\int d\vec{x}\cdot p(\vec{x}\,|\,M,U)\cdot p(\vec{y}\,|\,M,\vec{x},U)}$$

Model

Model parameters

New measurements

a priori information

Formulation:

$$\text{posterior}[p(\vec{x}\,|\,\vec{y},U)] \propto \text{prior}[p(\vec{x}\,|\,U)].\text{likelihood}[p(\vec{y}\,|\,\vec{x},U)]$$

Estimation of the first two moments

of the *a posteriori* distribution

EVALUATIONS AND UNCERTAINTIES
GENERAL MATHEMATICAL FRAMEWORK

Bayesian inference (probability density):

Maximum Entropy Principle

Laplace approximation
(Sammy, Refit, Conrad, SOK…)

Monte-Carlo
(UMC, Forward-Backward…)

Estimation of a cost function
(Generalized Chi-square)

$$\chi^2_{GSL} = (\vec{x}-\vec{x}_m)^T M_x^{-1} (\vec{x}-\vec{x}_m) + (\vec{y}-\vec{t}(\vec{x}))^T M_y^{-1} (\vec{y}-\vec{t}(\vec{x}))$$

- Estimation 1^{st} two moments of $p(\vec{x}|M,\vec{y},U)$ with Monte-Carlo
- Sample of $p(\vec{x}\,|\,M,U) \rightarrow \overrightarrow{x_k}$
- For each $\vec{x}_k$
  calculation of Likelihood $\ell_k[p(\vec{y}|M,\vec{x}_k,U)]$

Bayesian inference (probability density):

- Description of $\vec{x}$ and M:
  - Resonance range:
    - R-Matrix (resonance parameters)
    - Average models (average resonance parameters)
  - Continuum:
    - Optical models (potentials parameters),
    - Fission (barrier penetrabilities models)…
    - Level densities…
  - Multigroup
    - Cross sections
    - Spectra, nu-bar

$$\vec{x} = \{\gamma_{a\lambda}, E_\lambda, a_c, R'\}$$

$$\vec{x} = \{\langle\Gamma_a\rangle, a_c, R^\infty, D_0, S_a\}$$

$$\vec{x} = \{\beta_2, a_c, d_c, V, W, \ldots\}$$

$$\vec{x} = \sigma_g^r, \chi_g, \upsilon \ldots$$

- Description of $\vec{y}$
  - Microscopic experiments (transmission, capture yields, fission …)
  - Integral experiments dedicated to nuclear data (ICSBEP…)

- Description of $\vec{t}(M, \vec{x}, \vec{\theta})$
  - To simulate experiments:
    - $\vec{t}$ → need of a functional → link between models and measurements
    - $\vec{\theta}$ → Experimental parameters → systematic uncertainties
    - Data reduction description → from counts to $\vec{t}$

ASSIMILATION OF INTEGRAL EXPERIMENTS

Data Assimilation framework for evaluation using integral experiments

$$\chi^2_{GSL} = (\vec{x}-\vec{x}_m)^T M_x^{-1}(\vec{x}-\vec{x}_m) + (\vec{E}-\vec{C}(\sigma(\vec{x})))^T M_E^{-1}(\vec{E}-\vec{C}(\sigma(\vec{x})))$$

$\vec{y} \rightarrow \vec{E}$ → Integral Exp.

$\vec{x} \rightarrow$

$\vec{x} = \{\gamma_{a\lambda}, E_\lambda, a_c, R'\}$

$\vec{x} = \{\langle\Gamma_a\rangle, a_c, R^\infty, D_0, S_a\}$

$\vec{x} = \{\beta_2, a_c, d_c, V, W, ...\}$

$\vec{x} = \sigma_g^r, \chi_g, \upsilon ...$

$$\vec{G} = \partial\vec{C}/\partial\vec{x} = \partial\vec{C}/\partial\vec{\sigma} \otimes \partial\vec{\sigma}/\partial\vec{x}$$

Conrad

Sammy, Refit, TALYS...

APOLLO2/CRONOS2, ERANOS/PARIS, APOLLO3, MCNP, Tripoli-4

ND Treatment

ASSIMILATION OF INTEGRAL EXPERIMENTS

Validation and/or Data Assimilation → $\vec{x} = \{\gamma_{a\lambda}, E_\lambda, a_c, R', OMP, \ldots\}$ +BIASES and/or σ_g^r and $\chi_g, \upsilon \ldots$ + TRENDS

"Public" Integral Experiments
- Mini-Inca (ILL)
- ICSBEP / IRPHe
- …

Used as validation for evaluation →C/E ~1

Using benchmark in relative to focus on some reaction : ^{238}U (n,n')

Take care of experimental correlation between ICSBEP series

Additional Integral Experiments
- Irradiation Exp. PROFIL/MANTRA
- Oscillation Exp. MINERVE/DIMPLE
- …

High Precision (Oscillation : 1-3% ; PROFIL : ~2%)

Flexibility in terms of neutronic spectrum

→Deconvolution of energy domain

COVARIANCE MATRICES METHODOLOGIES

Best Knowledge coming from
- ❑Microscopic Measurements
- ❑Nuclear Reaction Models

"Public" Integral Experiments
- ❑Mini-Inca (ILL)
- ❑ICSBEP
- ❑…

Additional Integral Experiments
- ❑Minerve
- ❑PROFIL
- ❑…

Breakthrough
- ❑Covariances [0eV;20MeV]
- ❑Evaluation methodologies
- ❑Understanding of discrepancies
- ❑Covariance methodologies
- ❑Reduction of Uncertainties

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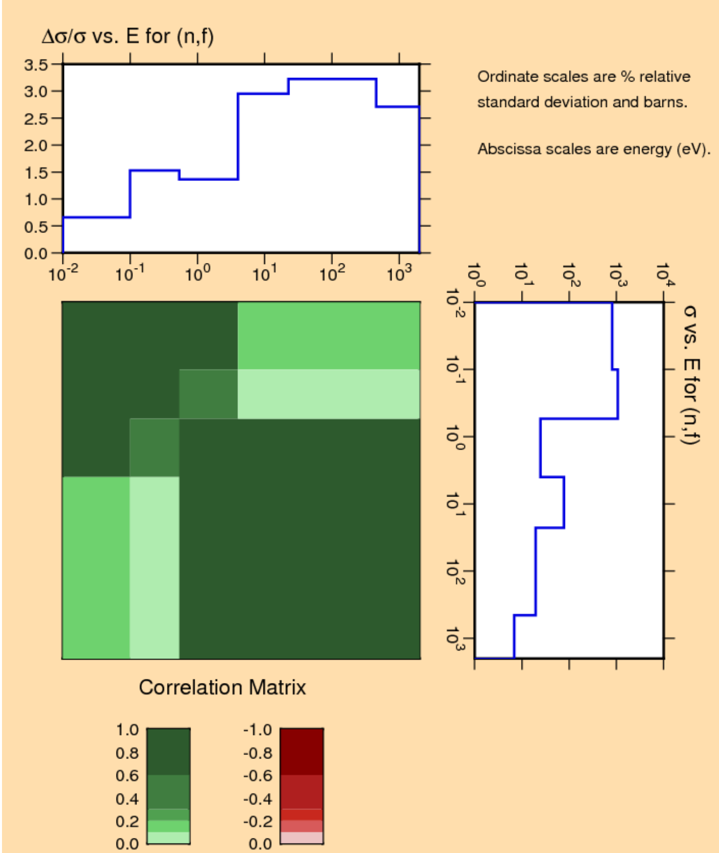
Covariances Matrices evaluation on ^{239}Pu Determination of

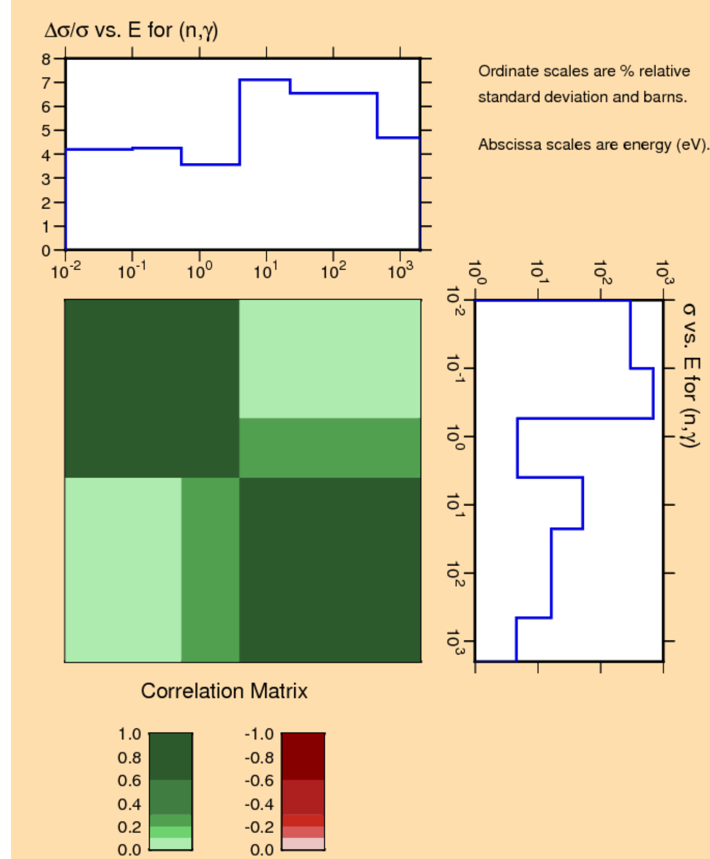
Matrices

^{239}PU COVARIANCE MATRICES (MICROSCOPIC KNOWLEDGE)

Resolved Resonance Range (SG34 and JEFF-3.2)

- Final uncertainties dominated by normalization accuracy introduced in the Marginalization procedure (0.5-3% for the fission cross section and 4-9% for the capture cross section)



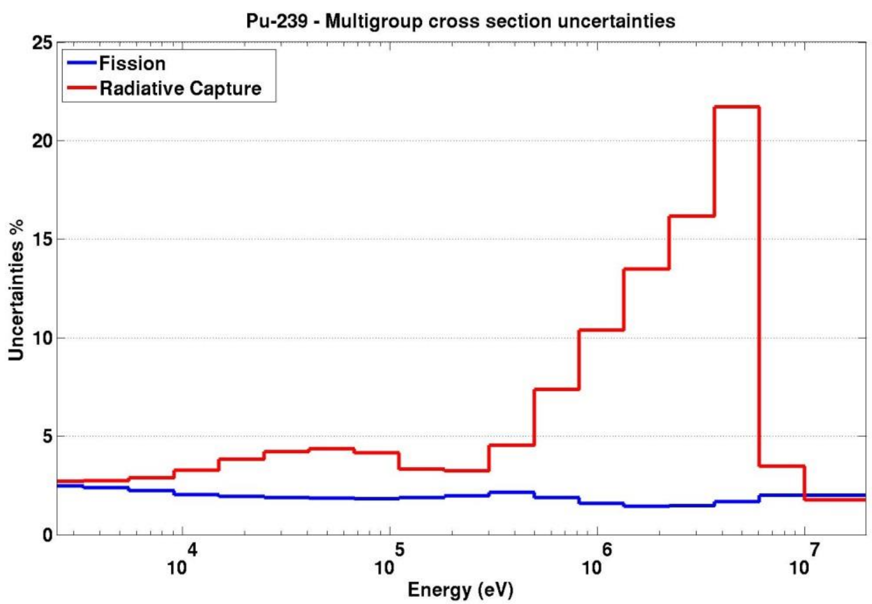


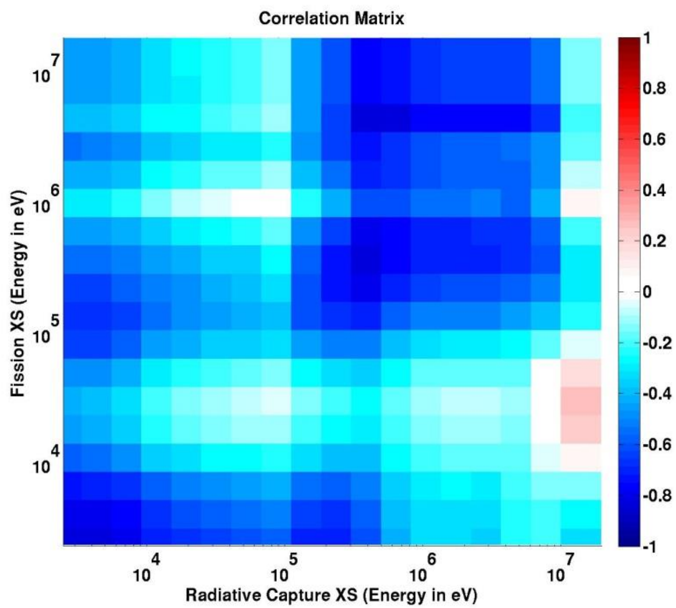
@ G. Noguère (CEA) / L. Leal (ORNL)

^{239}PU COVARIANCE MATRICES (MICROSCOPIC KNOWLEDGE)

Covariances in the continuum (COMAC-V0.1)

- Construction of an a-priori based on JEFF-3.2 cross sections
- Systematic uncertainties on fission and capture XS, based on “International Evaluation of Neutron Cross Section Standards” by Carlson *et al.* (CRP Report)





- Same conclusions : a few % of uncertainties with high correlations

^{239}PU COVARIANCE MATRICES (MICROSCOPIC KNOWLEDGE)

- Covariances on Nuclear model parameters **and** related Cross sections
- High influence of systematic uncertainties

  → High and long range correlations
  → Uncertainties around 0.5-10 % (^{239}Pu Capture high even in thermal range)

- RRR/URR/OM treated separately

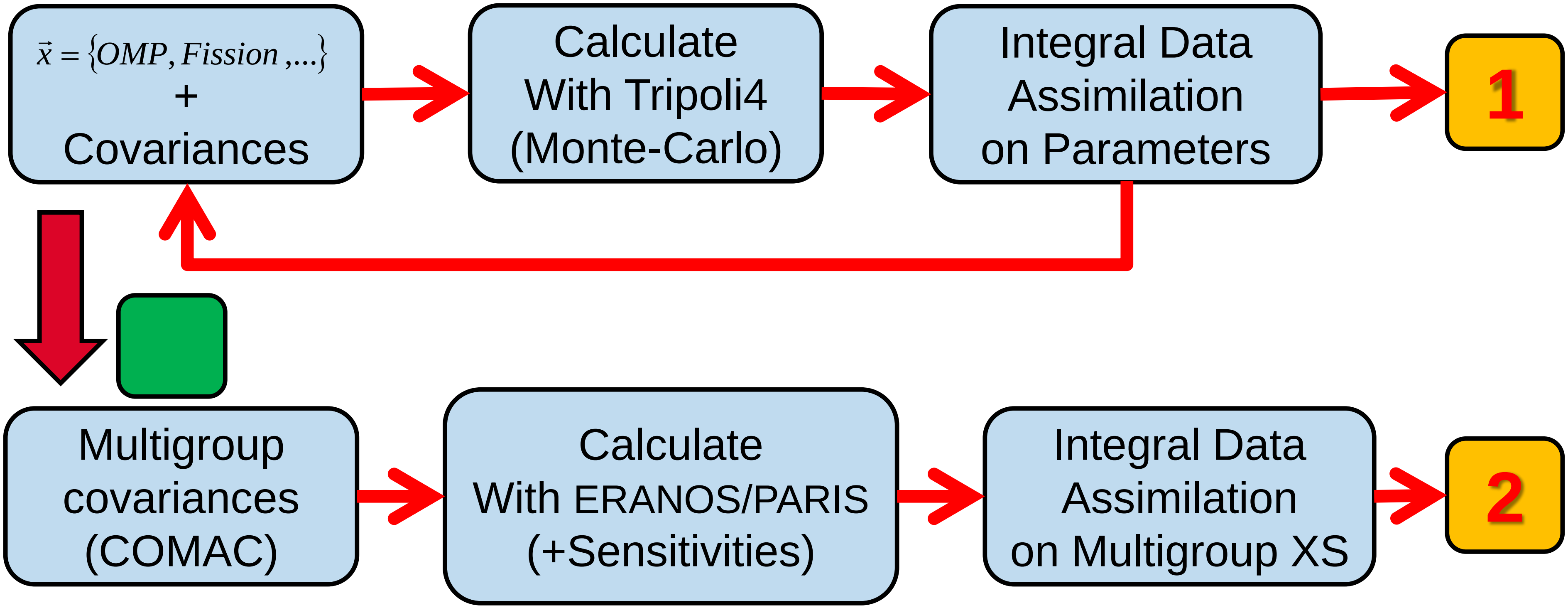
  → Importance of cross-correlations between reactions / energy ranges

Still important uncertainties
→Needs for integral constraints

- Short term → Add integral information + Additional energy ranges constraints
- Long term → New microscopic/integral experiments even for well-known isotopes (Normalization/background issues, URR, angular distributions, …)
- Long term → More microscopic ingredients (less "free" parameters)

^{239}PU COVARIANCE MATRICES (PUBLIC INTEGRAL EXPERIMENTS)

- JEZEBEL → define a consistent benchmark

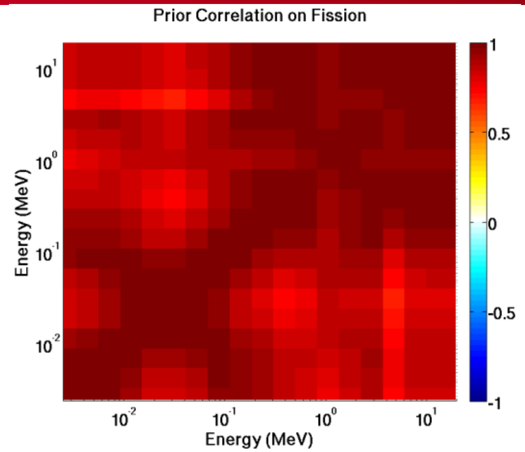


A. Only Cross sections and related model parameters
B. Investigate results
C. Add other nuclear data (PFNS, nu, etc…)
D. Propagate to a Fast Reactor

^{239}PU COVARIANCE MATRICES (PUBLIC INTEGRAL EXPERIMENTS)

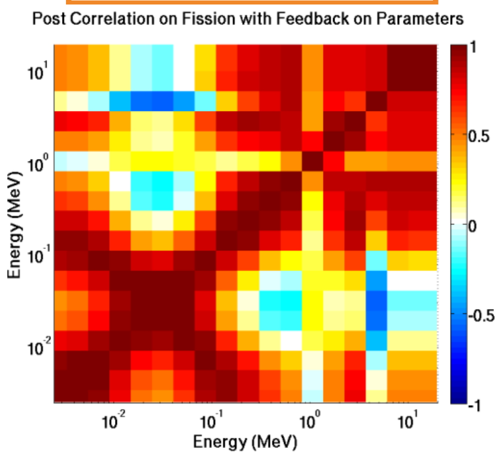
"Public" Integral Experiments

- ICSBEP (JEZEBEL)



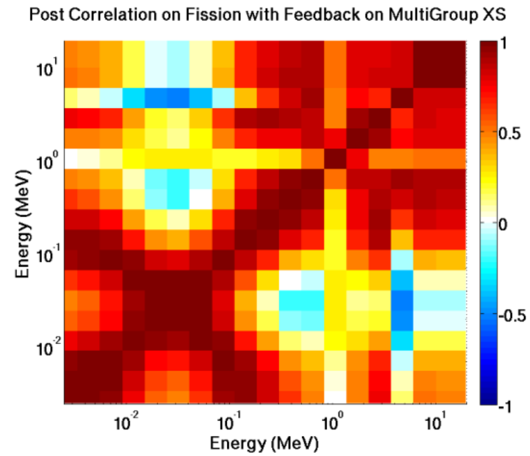
Nuclear model parameters Data Assimilation

$$\vec{x} = \{OMP, Fission, ...\}$$



Multigroup cross section Data Assimilation

$$\sigma_g^r$$

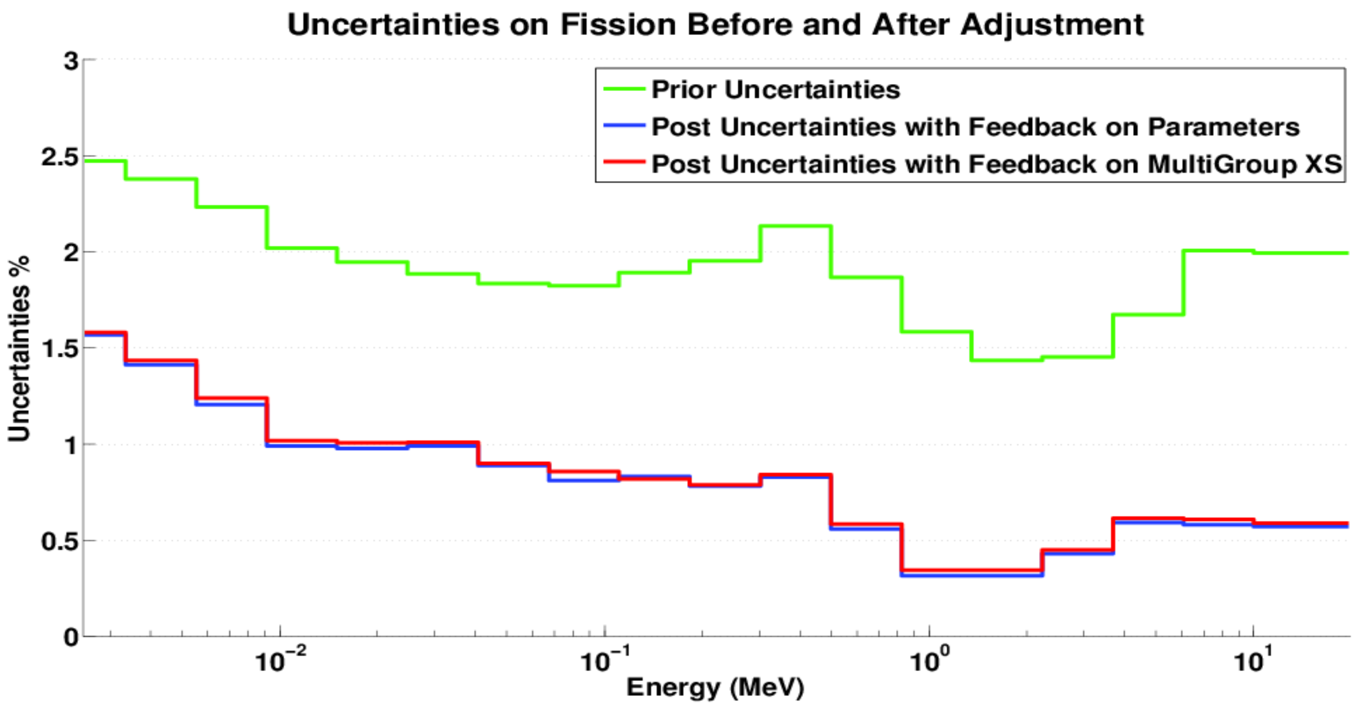


Correlation Matrices are almost equivalent:

$| C(param \rightarrow \sigma_g) – C(\sigma_g) |_{max} \sim 0.1$

^{239}PU COVARIANCE MATRICES (PUBLIC INTEGRAL EXPERIMENTS)

"Public" Integral Experiments
❑ICSBEP (JEZEBEL)



Data Assimilations using multigroup cross sections or nuclear reaction model parameters seem to be very consistent

^{239}PU COVARIANCE MATRICES (PUBLIC INTEGRAL EXPERIMENTS)

Effect on a Fast Reactor (large size core)

Uncertainties on Keff :

With COMAC-V0.1 :

Isotope	FISSION	CAPTURE	ELASTIC	INELASTIC	NXN	NU	DISTRIBUTION	TOTAL
Pu239	782.45	234.45	-14.24	67.63	-12.39	109.76	199.06	850.35
TOTAL	955.27	598.58	30.30	449.18	-43.25	157.94	253.96	1249.44

With COMAC-V0.1 + JEZEBEL :

Isotope	FISSION	CAPTURE	ELASTIC	INELASTIC	NXN	NU	DISTRIBUTION	TOTAL
Pu239	304.31	176.87	-18.03	50.03	-7.93	56.36	144.41	387.34
TOTAL	626.83	578.46	28.21	446.87	-42.19	126.78	213.83	994.00

Major changes due to new ^{239}Pu covariance

→ ^{238}U next

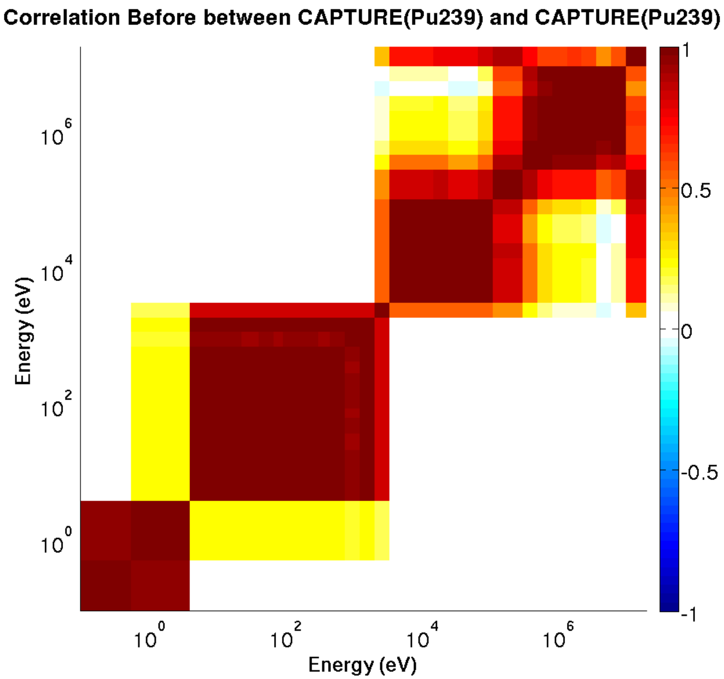
→ Add dedicated integral experiments (PROFIL)

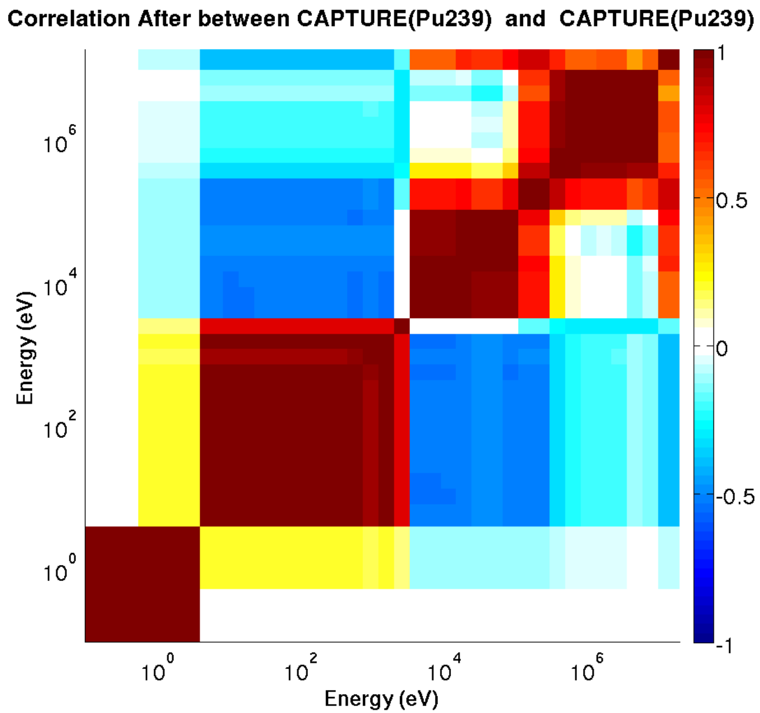
→ All usual suspects (Fe…)

^{239}PU COVARIANCE MATRICES (ADDITIONAL INTEGRAL EXPERIMENTS)

Additional Integral Experiments

- PROFIL experiments (CEA Marcoule)

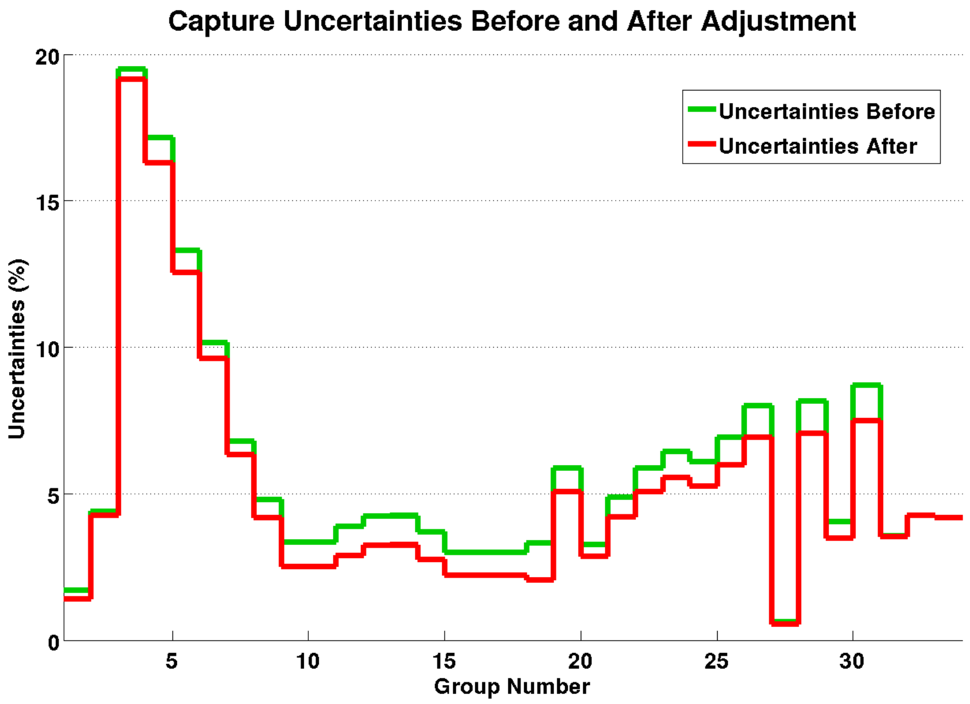




^{239}PU COVARIANCE MATRICES (ADDITIONAL INTEGRAL EXPERIMENTS)

Additional Integral Experiments

- **PROFIL experiments (CEA Marcoule)**



→Slight reduction of the uncertainties but large anti-correlations appear between the keV and the MeV energy regions

→Additional experiments are required for the thermal region

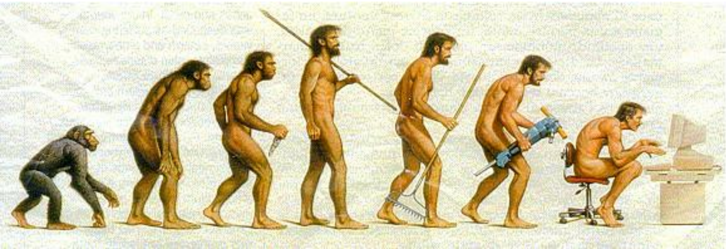
IMPOSING CONSTRAINTS ON MODELS INTEGRAL EXPERIMENTS

- Reduction of uncertainties with dedicated integral experiments is major (Factor 5-10)
- Work presented here on multigroup cross sections and nuclear reaction model parameters
- Choice of integral experiments is crucial to disentangle nuclear data sensitivities
  - Use integral experiments sensitive to different reactions or parameters
  - Relative integral experiments (reflector effect instead of reactivity…)
- Difficulty arises if :
  - Parameters are not well chosen or forgotten (PFNS, angular distributions …etc…)
  - Spurious Integral experiment (as for microscopic ones) with hidden error
  - Correlation between experiments are neglected (ICSBEP series …)
- Traditional questions arises → "old" experiments, effect is diluted on several ND,.. etc
- JEZEBEL is quite unique…
- Investigate cases with bad C/E or if two different evaluations are giving same C/E

→ **Sometimes true but**
CIELO and SG39 could give answers

CONCLUSIONS

- Several kind of Nuclear Data
- Several kind of Nuclear Reaction Models
- Several kind of Experiments
- Several kind of Covariance Matrices



- Progress on Methodologies needed:
  - Data assimilation techniques
  - Adding physical constraints (On several models)

- Progress on Experiments needed:
  - Reduction of systematic uncertainties for microscopic measurements
  - Integral experiments to target limited energy domain / reactions / isotopes

- Progress on Nuclear models needed:
  - Microscopic models
  - Avoid compensations

- **Needs to define Covariance estimation benchmarks:**
  - Fixed experiments
  - Fixed a priori (on parameters and/or cross section & uncertainties)
  - Incremental complexity
  - Compare covariance evaluation methodologies