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Recent developments and enhancements of the APIA methodology

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Asymptotic Progressing Incremental nuclear data Adjustment (APIA)

- Solving just one iterative equation within step ($i = 0$: “prior”):

$$T_{i+1} = T_i + M_0 G_i^T \left(G_i M_0 G_i^T\right)^{-1} (E - C_i)$$

  - Independent of experimental and analytical modeling matrix.
  - Using “prior” covariance matrix M_0.

Once converged ($G = G_i$):

$$M = M_0 - M_0 G^T (G M_0 G^T)^{-1} G M_0$$

  - M in this way: just used as “prior” for new step.

Asymptotic Progressing Incremental nuclear data Adjustment (APIA)

- Previously, two coupled equations → same converged data T:

$$T_{i+1} = T_i + M_i G_i^T \left(G_i M_i G_i^T + \Delta\right)^{-1} (E - C_i)$$

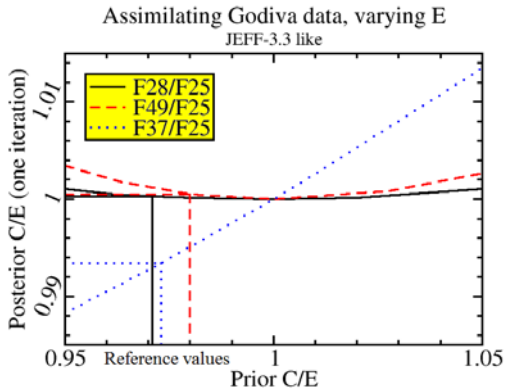
$$M_{i+1} = M_i - M_i G_i^T \left(G_i M_i G_i^T + \Delta\right)^{-1} G_i M_i, \qquad \Delta = V_E + V_M$$

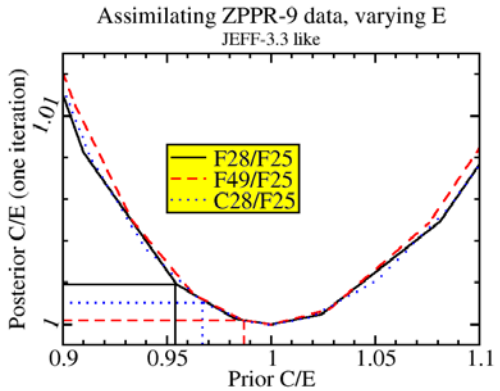
- New scheme: just a few iterations instead of up to several hundred,
  C/E "perfectly" = 1 for assimilated experiments.
  - "Linearity": $C_1/E = 1$, one iteration, namely

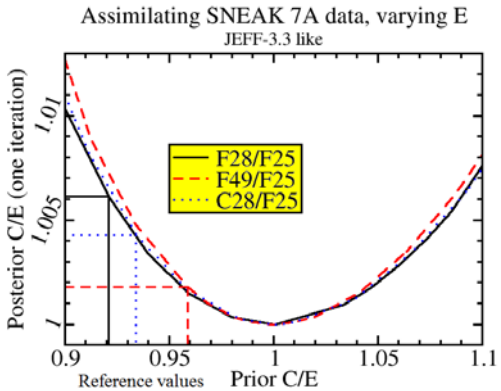
$$C = C_{1,lin} = C_0 + \cancel{G_0 M_0 G_0^T (G_0 M_0 G_0^T + \Delta)^{-1}} (E - C_0) = E$$

  - "Nonlinearity": $C_1/E \neq 1$, more iterations.

“Linearity” and “Nonlinearity”: examples







- Perfect “linearity” ≡ Flat curves (y = 1).
- Except *F37/F25*: slowly varying parabolas; ZPPR-9, SNEAK 7A, Godiva: similar.
  SNEAK 7A: stronger “nonlinearity”, prior C/Es deviate more from 1.
- *F37/F25*: “nonlinear”, partly since Np-237 not adjusted.

APIA: posterior covariance matrix

- Need to reassess after APIA completion, to account for cross-correlations:

$$M = M_0 - M_0 G^T (G M_0 G^T + \Delta)^{-1} G M_0, \qquad \Delta = V_E + V_M$$

M_0: genuine prior covariance matrix.

V_E ; V_M: experimental; analytical modeling covariance matrix e.g. SG33 benchmark, preprocessed.

G: asymptotic sensitivity coefficients matrix from APIA.

This study:

- Basic data: 33 groups, JEFF-3.3-based.
- Covariances, consistently JEFF-3.3: NJOY at NEA, Oscar Cabellos → SG39 participants, code specific formats.
- ERANOS-2.2-N for neutronic parameters:
  could be another code with similar capabilities
  e.g. Serpent or MCNP.

Assimilation database and target experiments

- Assimilation database: Godiva + ZPPR-9 + Big Ten + Pu239 Jezebel.

- Reference APIA sequence, 8 steps:

Godiva *F28/F25*, *F49/F25*, *F37/F25* } 1-3 ZPPR-9 *F28/F25*, *C28/F25*, *F49/F25* } 4-6 Big Ten *F49/F25* 7 Pu239 Jezebel *F28/F25* 8

- The same 34 target fast reactor experiments as before.

- Individual assimilations: one experiment to assimilate ≡ one incremental step

  ➡ Best separation of effects.

  "Justified" by the new developments: data adjustment independent of V_E, V_M.

Assimilation database and target experiments

1	2	3	4	5	6	7	8	9	10	11
Metal systems						Compound systems				
F28/F25 F49/F25 F37/F25	F28/F25 F49/F25 F37/F25	F28/F25 F49/F25 F37/F25 C28/F25	F28/F25 F49/F25 F37/F25	F28/F25 F37/F25	F28/F25 F37/F25	F28/F25 F49/F25 C28/F25 k_{eff}	F28/F25 F49/F25 C28/F25 k_{eff}	k_{eff}	F28/F25 F49/F25 C28/F25 k_{eff}	F28/F25 F49/F25 C28/F25 k_{eff}

1: Godiva; 2: U235 Flattop; 3: Big Ten: U-based.

4: Pu239 Jezebel; 5: Pu240 Jezebel; 6: Pu Flattop: Pu-based.

7: ZPPR-9; 8: ZPR-6/7 9: JOYO MK-I 64 F/A: with sodium.

10: SNEAK 7A; 11: SNEAK 7B: without sodium.

Results: 8-step APIA

Metal systems	C/E → Integral parameter ↓	Prior	Posterior
Godiva	*F28/F25*	0.971	1.000
	F49/F25	0.980	1.000
	F37/F25	0.973	1.000
	χ^2	4.8	0.0
	GCF	0.43	0.87
U235 Flattop	*F28/F25*	0.970	0.996
	F49/F25	0.985	1.004
	F37/F25	0.984	1.008
	χ^2	4.1	0.2
	GCF	0.48	0.79
Big Ten	*F28/F25*	0.931	0.961
	F49/F25	0.987	1.000
	F37/F25	0.977	1.004
	C28/F25	0.915	0.942
	χ^2	19.3	5.7
	GCF	0.25	0.43
Pu239 Jezebel	*F28/F25*	0.959	1.000
	F49/F25	0.982	1.006
	F37/F25	0.990	1.026
	χ^2	6.2	1.3
	GCF	0.49	0.62
Pu240 Jezebel	*F28/F25*	0.954	0.998
	F37/F25	1.014	1.054
	χ^2	10.9	7.5
	GCF	0.44	0.44
Pu Flattop	*F28/F25*	0.953	0.990
	F37/F25	0.991	1.025
	χ^2	9.4	2.0
	GCF	0.47	0.48

Compound systems	C/E → Integral parameter ↓	Prior	Posterior
ZPPR-9	*F28/F25*	0.954	1.000
	F49/F25	0.987	1.000
	C28/F25	0.967	1.000
	k_{eff}	1.00793	0.99832
	χ^2	13.1	0.5
	GCF	0.49	0.71
ZPR-6/7	*F28/F25*	1.015	1.062
	F49/F25	0.967	0.979
	C28/F25	0.975	1.008
	k_{eff}	1.00862	0.99819
	χ^2	4.5	1.5
	GCF	0.57	0.47
JOYO MK-I 64 F/A	k_{eff}	1.00804	1.00013
	χ^2	1.3	0.0
	GCF	0.57	0.89
SNEAK 7A	*F28/F25*	0.921	0.960
	F49/F25	0.959	0.974
	C28/F25	0.934	0.968
	k_{eff}	1.00740	0.99784
	χ^2	3.8	0.9
	GCF	0.47	0.49
SNEAK 7B	*F28/F25*	0.955	1.000
	F49/F25	0.989	1.006
	C28/F25	0.960	0.993
	k_{eff}	1.00832	1.00067
	χ^2	2.1	0.0
	GCF	0.47	0.78

	Prior		Posterior
Arithmetic mean	χ^2	7.6	1.7
	GCF	0.46	0.62

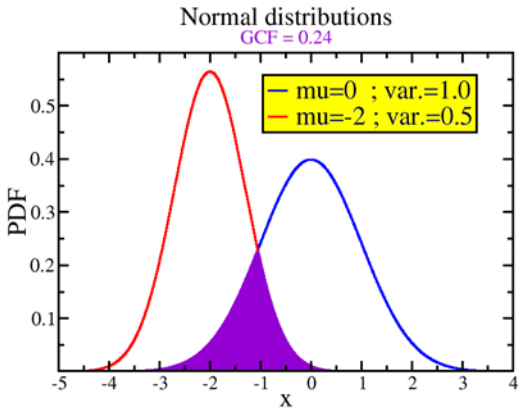
- Assimilated: C/Es ≡ 1.
- Posterior: C/Es closer to 1.
- χ^2s lower, significant k_{eff}.
- GCFs grow.
- Similar to previous study.

Separation of effects

Assimilating

- *F28/F25* in Godiva: χ^2 from 7.6 to 5.7, improving metal systems.
- *F49/F25* in Godiva: χ^2 from 5.7 to 4.3, improving most systems.
- *F49/F25* in ZPPR-9: χ^2 down to 1.8, improving compound systems, k_{eff}.
- Other steps: less efficient.
- Data adjustment within 1σ, reasonable; largely sequence independent; no major conflicts between steps.

GCFs



A : SG33 data.
B: experimental σs doubled.
C: experimental σs 5 times.
D: no experimental cross-correlations.
E: doubled analytical modeling σs .
F: no analytical modeling cross-correlations.

GCF	A	B	C	D	E	F
Godiva	0.87	0.78	0.55	0.86	0.88	0.87
U235 Flattop	0.79	0.77	0.55	0.79	0.77	0.79
Big Ten	0.43	0.63	0.71	0.44	0.40	0.43
Pu239 Jezebel	0.64	0.67	0.49	0.64	0.60	0.64
Pu240 Jezebel	0.44	0.55	0.55	0.44	0.38	0.44
Pu Flattop	0.48	0.60	0.49	0.48	0.52	0.48
ZPPR-9	0.71	0.60	0.52	0.69	0.76	0.71
ZPR-6/7	0.47	0.55	0.53	0.46	0.51	0.47
JOYO MK-I 64 F/A	0.89	0.83	0.52	0.89	0.85	0.89
SNEAK 7A	0.49	0.56	0.41	0.48	0.53	0.49
SNEAK 7B	0.78	0.71	0.48	0.76	0.82	0.78
Arithmetic mean	0.62	0.65	0.53	0.62	0.63	0.62

- Effects by comparing with A: weak.
  Case C, diminishing: too large experimental uncertainties in this case.
  Case B: nominal experimental uncertainties too low for spectral indices ?

Unsuited sequences: inconsistent adjustment

E.g. 7-step APIA:

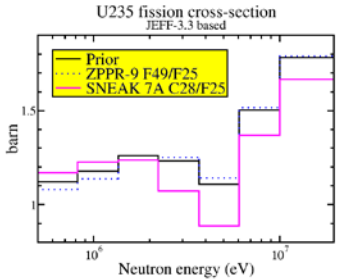
Godiva *F28/F25*, *F49/F25*, *F37/F25* } 1-3

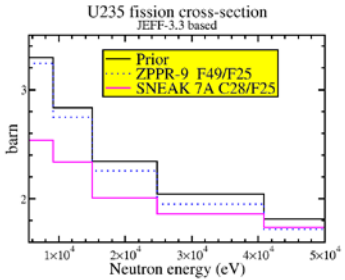
ZPPR-9 *F28/F25*, *C28/F25*, *F49/F25* } 4-6

To reject: SNEAK 7A *C28/F25*

7

- Posterior C/Es of the assimilated experiments, Steps 1-6: slightly $\neq 1$ (≡ 1 after Step 6).
- Target experiments: χ^2 increases from 1.8 to 2.8, degradation of k_{eff}s.
- Conflicting effects between steps + strong adjustments of several σs.





Conclusions + recommendation

- Decoupled approach providing best separation of effects justified: APIA adjustment independent of V_E and V_M.

- Powerful selection criterion: Envisaging new experiment, any type including k_{eff}: additional assimilation does not perturb C/Es = 1 for experiments assimilated in previous steps.

- Not possible to have $\chi^2 < 2$ based on the 34 experiments.
  One-step approach (iterative GLLS): possible, $\chi^2 = 0$, 34 experiments simultaneously, however unwished hidden compensation effects.

- Individual adjustment depends on specific code: C/E= 1, no adjustment → stochastic as a reference tool.