Working Party on International Nuclear Data Evaluation Co-operation (WPEC) Subgroup 33
Methods and issues for the combined use of integral experiments and covariance data
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ADJUSTMENT METHODOLOGY IN USE AT JAEA

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1. Cross-section Adjustment Theory

$$\begin{cases} \mathbf{T}' = \mathbf{T}_0 + \mathbf{M}\mathbf{G}^t \left[\mathbf{G}\mathbf{M}\mathbf{G}^t + \mathbf{V}_e + \mathbf{V}_m\right]^{-1} \left(\mathbf{R}_e - \mathbf{R}_c(\mathbf{T}_0)\right) \\ \mathbf{M}' = \mathbf{M} - \mathbf{M}\mathbf{G}^t \left[\mathbf{G}\mathbf{M}\mathbf{G}^t + \mathbf{V}_e + \mathbf{V}_m\right]^{-1} \mathbf{G}\mathbf{M} \end{cases}$$

- Definition of matrices and vectors -

- Experiment values: $\mathbf{R}_e$
- Calculation values: $\mathbf{R}_c(\mathbf{T}_0)$
- Experimental error values: $\mathbf{V}_e$
- Analytical modeling error values: $\mathbf{V}_m$
- Cross-section data: $\mathbf{T}_0$ (Before adjustment), **T'** (After adjustment)
- Sensitivity coefficients to cross-section: **G**
- Covariance data: **M** (Before adjustment), **M'** (After adjustment)

Cross-sections and their covariance are adjusted so as to maximize the probability that the cross-sections could give more reliable C/E values based on the Bayesian theory.

2. Evaluation of Experimental Errors

- Experimental error values and their correlations in the adjustment are based on the evaluation by experimenters.

- Representative one is documented IRPhEP, where an extensively peer-reviewed set of reactor physics-related integral data is provided.

- Correlation coefficients based on the systematic errors

$$\rho_{AB} = \frac{\varepsilon_C \cdot \varepsilon_D}{\sqrt{\varepsilon_A^2 + \varepsilon_C^2} \cdot \sqrt{\varepsilon_B^2 + \varepsilon_D^2}} \quad \begin{cases} \varepsilon_A, \varepsilon_B : \text{Random errors} \\ \varepsilon_C, \varepsilon_D : \text{Systematic errors} \end{cases}$$

2. Experimental Errors (Cont'd)

- Example of correlation coefficients estimation

[Criticality]

Systematic (Composition): 0.032%

Total: 0.037%

$$\rho = \frac{0.032^2}{0.037^2} = 0.748 \approx 0.7$$

[Na void reactivity]

Systematic (Reference*): 1.2%

Total: 2.0%

$$\rho = \frac{1.2^2}{2.0^2} = 0.36 \approx 0.4$$

* Na void reactivity was measured by modified neutron source multiplication method and reference reactivity (subcriticality) was by inverse kinetics method.

2. Experimental Errors (Cont'd)

- Correlation coefficients of experimental errors used in JAEA's study

Core characteristics	Correlation coefficient	Application condition
Criticality	0.7	Between cores of identical experimental series
Control rod worth	0.7	Between patterns in identical core
Reaction rate distribution (F25s, F49s, C28s) (F28s)	0.5 0.5	Between positions in identical core
Spectral index (F25/F49s, C28/F49s) (F28/F49s) (F25/F49-C28/F49) (F25/F49-F28/F49, C28/F49-F28/F49)	0.8 0.6 0.5 0.3	Between types and positions in identical experimental series
Na void reactivity	0.4	Between patterns in identical core

3. Evaluation of Analytical Modeling Errors

- Continuous energy Monte Carlo method: Statistical error

- Deterministic method: Relatively evaluated by a kind of sensitivity consideration about the influence of analytical modeling methods
(Estimation of analytical modeling error so as to set the chi-square value to the degree of freedom or the number on integral data)

Estimation

$$\chi^2 = \left[\mathbf{R}_e - \mathbf{R}_c(\mathbf{T}_0)\right]^t \left[\mathbf{G}\mathbf{M}\mathbf{G}^t + \mathbf{V}_e + \mathbf{V}_m\right]^{-1} \left[\mathbf{R}_e - \mathbf{R}_c(\mathbf{T}_0)\right]$$

3. Analytical Modeling Errors (Cont'd)

- Estimation by correction factors

$$V_{m,i} = \sum_j \left\{\alpha\left(f_{i,j} - 1\right)\right\}^2 \qquad f_{i,j} : \text{Correction factor}$$

- Example of analytical mode error estimation

Correction	Factor	|Factor-1|	Variance	Error
Spatial mesh	1.10	0.10	0.9E-03	0.03
Transport theory	1.20	0.20	3.6E-03	0.06
Ultra-fine group	0.90	0.10	0.9E-03	0.03
Total	1.19	-	5.4E-03	0.07

> Base calculation conditions: Multi-group, finite difference diffusion theory
> α=0.3

- Correlation coefficients

Sometimes by engineering judgment (Strong: 0.8-0.7, Intermediate: 0.6-0.4, Weak: 0.3-0.2)

3. Analytical Modeling Errors (Cont'd)

- Correlation coefficients used in JAEA's study

Core characteristics	Correlation coefficient	Application condition
Criticality	0.8	Between cores of identical experimental series
Control rod worth (Between similar patterns in identical core) (Between different patterns in identical core) (Other than above-mentioned)	 0.7 0.6 0.5	Between patterns in identical experimental series
Reaction rate distribution (Between IC) (Including OC)	 0.5 0.3	Between types and positions in identical experimental series
Spectral index (Excluding F28/F49) (Including one F28/F49) (Between F28/F49)	 0.5 0.4 0.3	Between types and positions in identical experimental series
Na void reactivity	0.5	Between patterns in identical experimental series

4. Elimination of Abnormal Data

- To avoid the influence from abnormal data, the data is eliminated if the deviation of the C/E value from unity is twice larger than the estimated total error value
  (The confidence level of the integral data set is almost two sigma, 95.4 %.)

$$\chi_i = \frac{\left| R_{e,i} - R_{c,i}\left(\mathbf{T_0}\right) \right|}{\sqrt{\mathbf{G}_i \mathbf{M} \mathbf{G}_i^t + V_{e,i} + V_{m,i}}}$$