NSC-WPEC Subgroup 33

"Methods and issues for the combined use of integral experiments and covariance data“

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The OECD-NEA Evaluation Cooperative Project

- **The OECD-NEA WPEC had launched in 2005 an expert group with the objective of recommending a set of best and consistent practices in order to improve evaluated nuclear data files.**

- **The final goal is that indication should be provided on how to best exploit existing integral experiments, define new ones if needed, provide trends and feedback to nuclear data evaluators and measurers**

- **Large number of participants:**

  - **11 International organizations: ANL, CEA, INL, IPPE, IRSN, JAEA, JSI, KAERI, ORNL, PSI**

- **Many significant and often original results have been obtained**

1) ***The methodologies employed for adjustment of σ have been assessed and compared*:**

NEA, “Assessment of Existing Nuclear Data Adjustment Methodologies”, International Evaluation Co-operation, Intermediate Report of WPEC Subgroup 33, NEA/NSC/WPEC/DOC(2010)429, OECD/NEA, Paris, 2011.

2) To understand the performance of the adjustment methodologies, a benchmark adjustment has been performed:

Participants did use the same integral experiment values (E) and uncertainties, but their own calculated value (C), sensitivity coefficients, and adjustment/assimilation method.

The benchmark steps:

1. **use of its own initial cross sections, own nuclear data and integral experiment covariance,**
2. **use of its own initial cross sections, but a different nuclear data covariance.**
3. **addition of a set of integral experiments in order to test the robustness of the previous adjustments (stress tests).**

Benchmark input

The number of isotopes to be adjusted has been limited to ten:

^{10}B, ^{16}O, ^{23}Na, ^{56}Fe, ^{52}Cr, 58Ni, ^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu, ^{241}Pu.

Selected set of integral experiments

- Jezebel ^{239}Pu configuration: 1 critical mass, 3 spectral indices: F28/F25, F49/F25, F37/F25
- Jezebel ^{240}Pu configuration: 1 critical mass
- Flattop Pu configuration: 1 critical mass, 2 spectral indices: F28/F25, F37/F25

- ZPR6-7 standard configuration: 1 critical mass, 3 spectral indices: F28/F25, F49/F25, C28/F25
- ZPR6-7 High ^{240}Pu content: 1 critical mass
- ZPPR-9: 1 critical mass, 3 spectral indices: F28/F25, F49/F25, C28/F25, 2 Na void configurations: central void and leakage-dominated configurations

- JOYO: 1 critical mass.

3) *Sensitivity studies*

Sensitivity methods are well established, however a number of ambiguities/approximations had to be well understood and eliminated

1) ***For k_{eff}, sensitivity coefficients have been determined based on Standard Perturbation-Theory (SPT) techniques using in most cases transport-theory.***

2) ***For the reaction rate ratios, Generalized Perturbation Theory (GPT) has been consistently used***

3) ***Equivalent Generalized Perturbation Theory (EGPT) or standard GPT has been employed for determining the sensitivity coefficients of the void reactivity effects in ZPPR-9.***

Recommendations

- Sensitivity coefficients calculated with different deterministic methods and codes do agree well among them,
- “Small” sensitivity coefficient values are to be used with care, (e.g. potential numerical problems in the convergence of the importance function).
- Resonance shielding effects should be considered with appropriate algorithms.
- Anisotropy of scattering should be accounted for at high energies
- EGPT provides a powerful tool to calculate sensitivity coefficients for reactivity effects.
- Adjoint-based and direct Monte Carlo techniques provide alternative to deterministic methods for complex geometries.

4) *Covariance Data*

Several recently developed covariance data sets have been used:

Name of covariance data set	Covariance data included	Methodology applied to evaluate covariance data
COMMARA-2.0 (BNL)	Reaction cross-sections + nu-bars for 20 actinides +3 PFNS for Pu-238,239 and 240 + 2 mu-bars for Na-23 and Fe-56.	Generalized least-square method. Resonance R-matrix analysis. Kalman-filter method.
JENDL-4.0 (JAEA)	Reaction cross-sections + mu-bars for 16 light nuclei and structural materials. Reaction cross-sections + nu-bars + PFNS + mu-bars for 79 actinides.	Generalized least-square method. Resonance R-matrix analysis. Kalman-filter method.
COMAC (CEA) + JENDL/ENDF for some isotopes	Reaction cross-sections + nu-bars (taken from JENDL-4) +PFNS (taken from JENDL-4)	Generalized least-square method. Resonance R-matrix and Optical Model analysis Marginalization of Systematic experimental uncertainties
NRG	No covariance files but random ENDF files	Monte Carlo-based method: TMC + selection based on distance minimization
SCALE 6.1 (ORNL)	Reaction cross-sections + nu-bars + PFNS	Generalized least-square method. Delta chi-square filter method.

The benchmark integral experiment covariance matrix

No.	Core		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Jezebel - Pu239	keff	0.2																			
2		F28/F25	0	1.1																		
3		F49/F25	0	0.23	0.9																	
4		F37/F25	0	0.23	0.32	1.4																
5	Jezebel - Pu240	keff	0	0	0	0	0.2															
6	Flattop	keff	0	0	0	0	0	0.3														
7		F28/F25	0	0	0	0	0	0	1.1													
8		F37/F25	0	0	0	0	0	0	0.23	1.4												
9	ZPR6-7	keff	0	0	0	0	0	0	0	0	0.23											
10		F28/F25	0	0	0	0	0	0	0	0	0	3.0										
11		F49/F25	0	0	0	0	0	0	0	0	0	0.23	2.1									
12		C28/F25	0	0	0	0	0	0	0	0	0	0.23	0.32	2.4								
13	ZPR6-7 Pu240	keff	0	0	0	0	0	0	0	0	0.13	0	0	0	0.22							
14	ZPPR-9	keff	0	0	0	0	0	0	0	0	0.31	0	0	0	0.30	0.117						
15		F28/F25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.7					
16		F49/F25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.23	2.0				
17		C28/F25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.23	0.32	1.9			
18		Central Na void	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.9		
19		Large Na void	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.41	1.9	
20	Joyo	keff	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.18

Correlations among reaction rate measurements

Correlations among reactivity measurements

5) *Summary of results* (1/2)

- **Subgroup 33 has succeeded in providing a deeper understanding of nuclear data adjustment methods and of their application.**

- **The findings of the Subgroup have pointed out that the statistical adjustments methodologies in use worldwide are well understood and essentially equivalent.**

- **The results of the adjustments indicate, for some important data, common trends for modification even if starting from different basic nuclear data and different covariance matrices. A-priori uncertainties are often significantly reduced.**

- **Robustness of the adjustments: the observed trends can "survive" rather severe "stress tests".**

- **Careful use of sensitivity tools and choice of experiments is needed**

Summary of results (2/2)

- **Crucial role of the covariance data used, both those associated to the nuclear data and those associated to the integral experiments.**

- **The a-posteriori correlations are mainly responsible for the uncertainty reduction of parameters of reference design systems. Their physics meaning and appropriate utilization will need further studies.**

- **Methodologies can provide a powerful tool for nuclear data (and associated uncertainties) improvement.**

- **Key role of NEA to provide framework and synergies with new initiatives (in future: CIELO)**

The final report has been assembled and is being finalized. Moreover, a presentation has been made at a plenary session of ND2013 and an extended paper will be published in Nucl. Data Sheets

6) *Perspectives*

An enlarged role for cross section adjustment requires tackling and solving a new series of issues:

- **definition of unambiguous criteria to alert for inconsistency between differential and integral data**
- **development of new methods for nuclear basic parameter adjustment**
- **provide methods and define conditions to generalize the results of an adjustment in order to evaluate the "extrapolability" of the results of an adjustment to a different range of applications (e.g. different reactor systems)**
- **suggest guidelines to enlarge the experimental data base in order to meet needs that were identified by the cross section adjustment.**

Proposal for a follow-up Subgroup (see G. Palmiotti presentation)

Acknowledgments

The Subgroup has produced results thanks to outstanding participation of all members. They have provided numerous original results and theoretical analysis, helping to progress in the understanding of the performances and potential of the nuclear data adjustment data.

However, no success would have been possible without the contribution of Emmeric Dupont not only as secretary of the group but also as an essential actor of the discussions and of the analysis of the results.