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**NUCLEAR ENERGY AGENCY**
**NUCLEAR SCIENCE COMMITTEE**

## Working Party on International Nuclear Data Evaluation Co-operation

# Meeting of the WPEC Subgroup 46 on the Efficient and Effective Use of Integral Experiments for Nuclear Data Validation

## Summary Record

25-26 November 2019, NEA Headquarters, Boulogne-Billancourt, France

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**OECD/NEA Nuclear Science Committee**

# Working Party on International Nuclear Data Evaluation Co-operation (WPEC)

# Meeting of the WPEC Subgroup 46 on the Efficient and Effective Use of Integral Experiments for Nuclear Data Validation

NEA Headquarters Room BB10

46 quai Alphonse Le Gallo, 92100 Boulogne-Billancourt, France

25-26 November 2019

## SUMMARY RECORD

### 1. Welcome

The Co-Chair, **G. Palmiotti**, welcomed the participants (see ***Appendix 1***) and the WPEC Secretariat, **M. Fleming**, noting that the other Co-Chair, **M. Salvatores**, was momentarily delayed.

### 2. Adoption of the agenda

The agenda (see ***Appendix 2***) was adopted with minor modifications, including a third presentation from **M. Hursin** that was delivered on the 26$^{th}$ via WebEx and a presentation by **M. Salvatores** on MSRs to replace the unconfirmed slot.

### 3. Review of action items

The actions raised at the previous meeting (see ***Appendix 3 of*** **NEA/NSC/WPEC/DOC(2019)4**) were reviewed, with all confirmed model contributions from participants the subject of presentations being made during the meeting. It was noted that these materials must now be made available via a password-protected space on the NEA website and the NEA Secretariat, **M. Fleming**, was actioned to organise this.

### 4. Target Accuracy Requirements

#### 4.1. Target Accuracy Requirements Exercise Proposed Approach and Next Steps

**G. Palmiotti** reminded the participants of the goals of TAR exercise and plan that had been proposed for carrying out the work. This consists of two phases: (1) selection of systems and integral parameters and (2) uncertainty/sensitivity analyses of the model/parameter systems. Example uncertainty tables were shown, with specific isotopes and reaction channels isolated. The 7 group energy structure, a subset of the 33 group used in previous analyses, has been proposed. An option to introduce a ‘cost function’ to prioritise different reaction channels was proposed. **E. Dupont**, the Chair of the EG-HPRL, explained that such a function would be highly dependent upon the incident energy, the range of requested accuracy, and many other factors, which vary over time as new facilities/techniques become available. Weighing the value against the existing capability to perform measurements is precisely the domain of the EG-HPRL and it was proposed to not introduce cost functions, at least in the early phase of the work.

### 4.2. Status on MYRRHA, ESFR, ASTRID and ALFRED

**P. Romojaro** presented the analyses that had been performed by UPM and CIEMAT with the four models that had been selected: MYRRHA, ESFR, ASTRID and ALFRED. The simplified R-Z model for MYRRHA was provided to M. Fleming for distribution to participants in a password-protected area. Sensitivity calculations have been performed for several quantities shown in the presentation using the JEFF-3.3 library. These are being converted into the SG33 format for distribution to other participants. Another model based on the WPRS SFR-UAM benchmark had also been shared with the NEA and initial sensitivity calculations performed. It was noted that void sensitivities were different for heterogeneous models in different locations, largely due to the amount of neutron leakage in the different regions. It was suggested that other SFR concepts could be included, for example minor actinide burning variants.

### 4.3. Preliminary evaluation of ALFRED S/U analysis

**G. Grasso** reviewed work done at ENEA using a simplified R-Z model based on the complex core of a 300 $MW_{th}$ ALFRED core design. Sensitivity-uncertainty analyses were performed with (E)GPT, using ERANOS-2.2N, JEFF-3.1.1 and the BNL-LANL (BOLNA) covariance library. Several integral parameters were selected and results were shown for a variety of actinide, oxygen, iron and lead reaction data. This model and the results will be provided in the password-protected area of the NEA SG46 website. It was proposed that an older variant of a DFLR reactor that had been considered by some reactor designers could be made available to participants and would be of interest to the advanced reactor community.

### 4.4. Input Information for SG46 Target Accuracy Requirements (TAR) Exercise using Models of 750MWe JSFR Core

**K. Yokoyama** presented analyses performed at JAEA using the 750MWe JSFR simplified R-Z core model. A set of calculations were carried out using the MARBLE/SAGEP system for GPT calculations of time-independent integral parameters and MARBLE/PSAGEP for DPT calculations of time-dependent parameters. Six integral parameters were selected and the varied nuclear data parameters were taken from the initial SG46 TAR activity specification. The results have been converted into the SG33 format and are prepared for distribution to participants through the password-protected area of the SG46 website. The models were already made available in the June 2019 meeting.

### 4.5. Nuclear data for Beff sensitivity-uncertainty analysis

**I. Kodeli** presented analyses of the uncertainties in $\beta_{eff}$ due to a variety of nuclear data, including delayed fission spectra. Examples were shown for SNEAK-7A/B and FLATTOP-23, with correlations calculated between delayed unbars of the major actinides. Analyses for MYRRHA have been performed and published in *Annals of Nuclear Energy* 113 (2018) 425. Sensitivity data are available in 33 groups for both $k_{eff}$ and $\beta_{eff}$. It was confirmed that MYRRHA models for PARTISN and MCNP are available for participants and, after discussion with P. Romojaro, the MCNP model used is identical.

### 4.6. WPEC SG47 and SINBAD

**I. Kodeli** showed the recent progress that had been made in SINBAD, with a newly established review process alongside the ICSBEP/IRPhE Technical Review Groups. Three new sets of experiments were being considered, including a Helium-Cooled Lithium-Lead Fusion blanket and copper experiment performed at Frascati and the HIMAC experiments with multiple targets. New MCNP inputs, weight-windows generated with the ORNL ADVANTG code and CAD geometries are being supplied with the other experimental data. A new WPEC SG47 held its kick-off in 2019. It is working to provide additional validation resources for the nuclear data community and offer these materials for the consideration of the SINBAD technical review body.

### 4.7. Fuel cycle parameters from SG26: Choices and volunteers

**M. Salvatores** reviewed the activities of WPEC SG26 in performing not only analyses related to parameters such as reactivities, but fuel cycle parameters such as decay heat, dose rates, neutron source terms and minor actinide isotope vectors. Examples were shown and the conclusions (originally written by R. Mills) were reviewed. It was generally acknowledged that for advanced systems, including fast reactors and ADS systems, the uncertainties on fuel cycle parameters will be large and these should be addressed alongside other parameters. **R. Mills** agreed to update the material from Appendix P of the WPEC SG26 final report.

### 4.8. Systematic approach to TA establishment: major findings

**E. Ivanov** discussed the principle behind the use of Target Accuracies, how these are connected to Challenge Impacting Phenomena (CIP) and how CIPs are common and different between different systems and operating regimes. LMFRs were given as an example, where, depending on the objective of the reactor (e.g. MA burning, isotope breeding, etc), different CIPs are dominant in the design process. A set of Target Accuracies were proposed for MSRs and LMFRs. **E. Ivanov** raised the availability of ESFR designs and analyses that have been published in peer-review literature and could be used in the SG46 activities.

### 4.9. Specification of the Calculation Benchmarks on Low Void SFR Burner and MOSART

**M. Salvatores** presented, on behalf of **F. Gabrielli**, work done as part of the NEA EGIEMAM-II with two benchmarks for a 1200 $MW_{th}$ low void SFR MA burner and a 2400 $MW_{th}$ Molten Salt Advanced Reactor Transmuter (MOSART) concept with fertile-free fuel. The simplified R-Z model was shown alongside various basic data and isotopic fuel vectors. Calculations were performed with a 33-group structure, using the JEFF-3.1 and COMMARA-2.0 nuclear data. As part of the EGIEMAM-II activities, the sensitivity and uncertainty calculations have already been performed and these data have already been prepared in the formats required for the SG46 activities.

### 4.10. TARS from NEA activities Past and Present

**I. Hill** presented a review of TARs from the 1980s, including numerous accuracy requirements for different isotopic concentrations at the end of irradiation, neutron production cross sections, and detailed energy-dependent cross section requirements. Taking one example, cross-sections on $^{151}$Eu, it was shown that different major libraries differ by more than the target accuracies set in the 1980s, strongly implying that these accuracy requirements have not been met. Multiple participants in WPRS activities have been contacted to participate in the SG46 activities and positive responses have been obtained from TerraPower and FHR, with potentially more in advance of the May 2020 meeting.

### 4.11. Status of TAR tables

**M. Salvatores** reviewed the status of the previous TAR tables, highlighting values that had been selected from recent analyses and from previous subgroups, including SG26. Updates to these values were welcomed and participants are requested to provide any suggestions. As part of the ongoing discussion on SFR void coefficients, it was agreed that the spectral and the leakage components of the void coefficients should be separately analysed. A practical approach was suggested by Romojaro: to consider the void coefficient at the core centre (to suppress the leakage effect) and the peripheral void coefficient, to maximise the leakage effect.

### 4.12. UPM contribution to Action 6: “Revision of TAR tables”

**O. Cabellos** highlighted recent examples of benchmark calculations with the most recent nuclear data evaluations, demonstrating significant issues with libraries including ENDF/B-VIII.0. Parameters and criteria from the ANSI/ANS-19.6.1-2011 were presented and compared against other TARs at the meeting. Challenge accuracies set by code developers K. Smith and B. Forget were much more ambitious - as low as 25 ppm of boron at HZP and HFP. Several uncertainty propagation examples were shown for LWR cases and the recent ENDF/B-VIII.0 library changes to $^{235}$U capture were highlighted, demonstrating the need for strict quality control.

### 4.13. Nuclear Data Uncertainty Quantification for Operated Cycles in a Swiss PWR

**M. Hursin** presented work done by PSI to develop and use a methodology for uncertainty quantification and propagation in nuclear power plants based on nuclear data uncertainties. This uses a combination of CASMO-SIMULATE simulations with perturbed nuclear data libraries based on the underlying covariances. All of this is contained with the Shark-X platform for stochastic sampling of output quantities. Examples were shown for boron curves, assembly power distributions and various safety parameters of interest to the Swiss regulatory bodies.

## 5. Integral Feedback Methods

### 5.1. Development and Application of Data Assimilation Methods in Reactor Physics

**M. Hursin** presented, on behalf of **D. Siefman**, a review of different data assimilation methods, including GLLS, MOCABA, BMC and BFMC. These methods are compared in the work presented, with particular focus on the BMC and BFMC methods that apply different arbitrary weight methods. The convergence of the different posteriors were shown, using a LWR-Phase II Proteus experiment to adjust nuclear data parameters within the GEF code, which generates fission yields and other fission observables. Marginal likelihood optimisation is also used and compared against the results without MLO. The general results are generally positive, with BFMC+MLO adjustments bringing the simulation results into agreement with the experiment. However, in cases with prior data that are tightly constrained and in significant disagreement with the experimental results, improved agreement is not found.

### 5.2. Application of Marginal Likelihood Optimization to Haicheng’s Stress Test

**M. Hursin** presented an application of marginal likelihood optimisation (MLO) to a SG33 benchmark exercise where missing constraints on the $^{235}$U fission cross section and seemingly contradictory benchmarks result in decreased performance after integral data assimilation is performed. To avoid this, MLO is applied to effectively (and consistently, in a mathematical sense) adjust the uncertainties on benchmarks to avoid the adjustment contradictions and improve the library performance.

### 5.3. Update on Bias Factor Methods for Nuclear Data Validation

**G. Palmiotti** reviewed the use of bias factor methods with a variety of different approaches, including a product of exponential bias factor method (PEBFM), best representativity method (BRM), extended bias factor method (EBFM) and the generalised bias factor (GBF). These were applied to a set of four uncorrelated experiments, including ZPPR-15 A, CIRANO 2B, FFTF start-up and ZPR3-56B. The different methods have shortcomings, with EBF providing the only method to reproduce the results from adjustments on the same experiments.

### 5.4. Summary of Derivations and Equivalence between Various Bias Factor Methods and Adjustment Methods

**K. Yokoyama** reviewed the differences between Extended Bias Factor Methods with the Product of Exponentiated values (EBPE) with Classical Bayesian Conventional Adjustment (CBCA), which can generate approximately equivalent adjustments through linear estimation and Bayesian inference, respectively. The extended version of the CBCA, known as CBEA, applies the optimisation to some application-specific functions instead of cross sections. It was also demonstrated that the Bayesian approaches could be derived from linear estimation methods with appropriate assumptions.

### 5.5. On the combined use of differential and integral experiments in Bayesian optimization of nuclear data

**E. Alhassan** presented work that utilises both differential data and integral data simultaneously in a Bayesian algorithm to optimise nuclear data. This approach takes advantage of the input parameter modification capabilities of the TASMAN code, but allows weight functions to use both differential and integral data. Results were shown for work with $^{208}Pb$ after different adjustment methods were performed, including: (1) only differential data, (2) differential followed by integral and (3) simultaneous integral with differential. The integral results for a set of related benchmarks and the differential data were shown, demonstrating the potential for the simultaneous adjustment to improve overall agreement.

## 6. Summary of commitments and next steps

In ***Appendix 3***, the list of available (or very likely available) systems for the TAR exercise have been summarised. For each system, the leading members and/or main contributors have been tentatively suggested. Parameters to be considered should be specified by the leading member(s) by the end of February 2020. A general list has been provided, however for each system the main contributors should be free to adapt the list to their available resources. Frist results for the S/U analyses are expected by the next meeting in May 2020 (see actions in ***Appendix 4***).

## 7. Next meeting and any other business

The next meeting will occur during the week of 11-15 May 2020 at the NEA Headquarters in Boulogne-Billancourt. The exact dates will be confirmed with all of the WPEC subgroup chairs and communicated in December 2020.

# APPENDIX 1

List of participants to the 25-26 November 2019 Meeting of Subgroup 46 on the Efficient and Effective Use of Integral Experiments for Nuclear Data Validation

| | First Name | Last Name | Country | Notes |
|---|---|---|---|---|
| 1 | Erwin | ALHASSAN | SWITZERLAND | |
| 2 | Marilena | AVRIGEANU | ROMANIA | |
| 3 | Vlad | AVRIGEANU | ROMANIA | |
| 4 | Oscar | CABELLOS | SPAIN | |
| 5 | Coralie | CARMOUZE | FRANCE | |
| 6 | Christophe | DESTOUCHES | FRANCE | |
| 7 | Emmeric | DUPONT | FRANCE | |
| 8 | Michael | FLEMING | NEA | *Secretariat* |
| 9 | Mario | GOMEZ-FERNANDEZ | UNITED STATES | |
| 10 | Giacomo | GRASSO | ITALY | |
| 11 | Ian | HILL | NEA | |
| 12 | Mathieu | HURSIN | SWITZERLAND | |
| 13 | Alexander | KONOBEEV | GERMANY | |
| 14 | Robert | MILLS | UNITED KINGDOM | |
| 15 | Denise | NEUDECKER | UNITED STATES | *Remote* |
| 16 | Giuseppe | PALMIOTTI | UNITED STATES | *Chair* |
| 17 | Pablo | ROMOJARO | SPAIN | *Remote* |
| 18 | Massimo | SALVATORES | UNITED STATES | *Chair* |
| 19 | Allan | SIMPSON | UNITED KINGDOM | |
| 20 | Henrik | SJOSTRAND | SWEDEN | |
| 21 | Vladimir | SOBES | UNITED STATES | |
| 22 | Alejandro | SONZOGNI | UNITED STATES | *Remote* |
| 23 | Haicheng | WU | CHINA | |
| 24 | Xiaofei | WU | CHINA | |
| 25 | Kenji | YOKOYAMA | JAPAN | |

# APPENDIX 2

## Working Party on International Nuclear Data Evaluation Co-operation (WPEC)

## Meeting of Subgroup 46 on the Efficient and Effective Use of Integral Experiments for Nuclear Data Validation

NEA Headquarters Room BB10

46 quai Alphonse Le Gallo, 92100 Boulogne-Billancourt, France

25-26 November 2019

## AGENDA

| SG 46 - 25 November 2019 | | | |
|---|---|---|---|
| 10:00 | 10:30 | Welcome, meeting plan and objectives | G. Palmiotti,<br>M. Fleming |
| 10:30 | 11:00 | Review of actions | M. Fleming |
| 11:00 | 11:30 | Resources and plan for storage and distribution | M. Fleming |
| 11:30 | 12:00 | Benefits of using MLO for data assimilation and LWR full core uncertainty quantification at PSI | M. Hursin |
| 12:00 | 13:30 | **Lunch Break** | |
| 13:30 | 14:00 | Proposed approach and next steps | G. Palmiotti |
| 14:00 | 14:45 | Status on MYRRHA, ESFR, ASTRID and ALFRED | P. Romojaro |
| 14:45 | 15:15 | Preliminary evaluation of ALFRED S/U analysis | G. Grasso,<br>D. Castelluccio |
| 15:15 | 15:45 | Input Information for SG46 TAR Exercise using the R-Z Models of the 750 MWe JSFR core | K. Yokoyama |
| 15:45 | 16:00 | **Coffee Break** | |
| 16:00 | 16:20 | Beff and Keff, interaction with SG47 | I. Kodeli |
| 16:20 | 16:50 | Fuel cycle parameters from SG26: Choices and volunteers | M. Salvatores |
| 16:50 | 17:10 | Systematic approach to TA establishment: major findings | E. Ivanov |
| 17:10 | 17:30 | MSR systems and sensitivity coefficients | M. Salvatores |
| 17:30 | 18:00 | TARs from NEA activities Past and Present | I. Hill |

| SG 46 - 26 November 2019 | | | |
|---|---|---|---|
| 09:00 | 09:10 | Status of TAR tables | M. Salvatores |
| 09:10 | 10:30 | Revision of TAR tables | E. Ivanov, K. Yokoyama, O. Cabellos, M. Hursin |
| 10:30 | 10:40 | **Coffee Break** | |
| 10:40 | 11:10 | Update on Bias Factor Methods for the Validation of Nuclear Data | G. Palmiotti |
| 11:10 | 11:40 | Summary of Derivations and Equivalence between Various Bias Factor Methods and Adjustment Methods | K. Yokoyama |
| 11:40 | 12:00 | Combining differential and integral experiments in Bayesian optimisation of nuclear data | E. Alhassan |
| 12:00 | 12:30 | Summary of commitments | M. Salvatores, M. Fleming |
| 12:30 | 13:00 | Deliverables, next meeting, any other business | G. Palmiotti, M. Fleming, M. Salvatores |
| 13:00 | 14:00 | **Lunch Break** | |

# APPENDIX 3

System availability summary after SG46 November 25-26 2019 meeting

- JSFR 750 MWe fast neutron core (JAEA, K.Yokoyama)
- ESFR (European Na-cooled fast reactor) (CIEMAT, UPM, ENEA: P. Romojaro, G.Grasso?)
- ASTRID-like: Na-cooled fast reactor, low Na-void coefficient (CIEMAT, UPM, P. Romojaro, O. Cabellos)
- ALFRED: European Pb cooled fast reactor. (ENEA, G. Grasso)
- MYRRHA: Pb-Bi cooled fast reactor experimental reactor. ADS demonstrator. (CIEMAT, UPM, P. Romojaro)
- EFIT (High Minor Actinide content, G.Grasso. ENEA). To be verified if S/U analysis can be provided
- JAEA MA-loaded ADS: model available; to be verified if S/U analysis can be provided (K.Yokoyama?)
- MOSART MOlten Salt (Na,Li,Be/F) Actinide Recycler & Transmuter (MOSART) system fuelled with Pu plus minor actinide trifluorides (AnF3) from PWR spent fuel without U-Th . (NEA?)
- MSFR (CNRS, Grenoble): to be verified (model available) I. Ivanov? NEA?
- PWR as defined and studied at UPM by O. Cabellos team

Model available but no S/U analysis foreseen:

- SG26 GEN-IV systems; High BU PWR; VHTR; MA burner ADS (ADMAB)
- SG33 systems (ABR FR metal and oxide fuel, Na-cooled. JOYO).

For each system, parameters to be considered in the S/U analysis should be specified. A general reference list (that can be adapted, enlarged, reduced for each reactor type) is given below:

- $k_{eff}$
- Reactivity coefficients (void, possibly fuel expansion, Doppler, Boron etc.)
- Power peak (see SG26 for definition)
- Reactivity loss per cycle
- Selected actinides (to be selected among Pu, U, Th isotopes, Np, Am, Cm isotopes) time evolution (e.g. between beginning and end of irradiation (see examples in SG26 report))
- Shielding parameters: high energy neutron attenuation, thermalized neutron attenuation (e.g. via detector-type responses)

# APPENDIX 4

## Action list from the November 2019 meeting of the WPEC Subgroup 46 on the Efficient and Effective Use of Integral Experiments for Nuclear Data Validation

### Action on shielding data accuracy requirements

1. **[By end of February 2020]** For the systems chosen for the TAR exercise, define required, design-oriented accuracies on high energy or low energy neutron attenuation via, e.g., responses as S(n,p) and Au (n,γ) **[I. Kodeli to coordinate]** requests as formulated/proposed by:

   1.a. **P. Romojaro** for MYRRHA, ESFR and ASTRID-like

   1.b. **G. Grasso** for ALFRED

   1.c. **K. Yokoyama** for JSFR

   1.d. **E. Ivanov** for MSRs

2. **[By next meeting]** Make selection of systems to provide S/U analysis and commitments to perform the corresponding S/U analysis **[All]**

### Action on coolant void coefficients with leakage and non-leakage components

3. **[By next meeting]** Select, for specific systems, appropriate regions where leakage is the dominant. Separate out the central and leakage regions and perform sensitivity/uncertainty analyses for the different regions **[P. Romojaro, G. Grasso, K. Yokoyama, All]**

### Action on decay heat uncertainty requirements

4. **[First draft by next meeting]** **R. Mills** to update Appendix P of the WPEC Subgroup 26 final report to include new material, new experiments and specific isotope requirements

5. **[First draft by next meeting]** **M. Hursin** to include in the update the activity as required by the Swiss safety authority to quantify decay heat for LOCA assessment

### Action on Pressurised Water Reactor tables

6. **[By end of February 2020]** **O. Cabellos** to update the SG26 PWR system with models provided by UPM, provide proposed parameters and associated target uncertainties based on work described

7. **[By end of February 2020]** **M. Hursin and E. Ivanov** to provide O. Cabellos with input/comments on this work

8. **[By end of February 2020]** **O. Cabellos, M. Hursin, E. Ivanov and M. Salvatores** to specify the goals of the TAR for design, if different for any acceptance criteria used by safety bodies

**Actions on the Accelerator Driven System tables**

9. **[By end of February 2020]** Verify the availability of ADS systems with high minor actinide loading, including:

9.a. **K. Yokoyama** to review those considered by JAEA

9.b. **G. Grasso** to review those considered by ENEA (EFIT)

10. **[By next meeting]** **E. Ivanov** to review any required updates by ADS systems and the data proposed for TAR tables

**Actions on the Molten Salt Reactor tables**

11. **[By next meeting]** **E. Ivanov** to modify, as required, the present table for the MOSART case

12. **[By next meeting]** **E. Ivanov** to include the European MSFR with mixed thorium-uranium fuel in the systems database, providing references to the Grenoble research and/or input data from the CNRS model

13. **[By next meeting]** **M. Fleming** to report on the possibility for NEA resources on S/U analysis for MSR systems

14. If the MSFR system is included in the list, contact the Grenoble group to invite them to participate in the SG46 activities **[E. Ivanov, M. Salvatores, M. Fleming]**

**Action on system availability consolidation and for S/U analysis performance**

15. **[By February 2020]** **All leaders/main contributors** confirm their commitment and provide the list of parameters to be considered for each system, including shielding parameters

16. **[By next meeting]** **All leaders/main contributors** to provide S/U analysis results at the May 2020 meeting