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Performance assessment of adjusted nuclear data along with their covariances on the basis of fast reactor experiments

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ABSTRACT

In view of fast reactor analyses, it is shown that efficient nuclear data adjustments can be obtained on a limited assimilation database consisting of just six well documented integral parameters, i.e. the central spectral indices measured in Godiva and ZPPR-9. This study uses a Generalized Linear Least-Squares (GLLS) based data assimilation method by means of Asymptotic Progressing Incremental nuclear data Adjustment (APIA) simulations with two incremental steps, one involving Godiva; the other one ZPPR-9. Consistent JEFF-3.3 and TENDL based prior data including their covariances are used; correspondingly, the assimilation leads to posterior JEFF-3.3 and TENDL data. 34 target experiments are then investigated by means of both prior and posterior data. These experiments consist of spectral indices as well as multiplication factors which pertain to 11 fast spectrum configurations including the six integral parameters which are part of the assimilation.

It is found that (1) after adjustment the mean χ^2 is strongly reduced to values smaller than 2, in each case. (2) The performance of the adjustment is comparable between JEFF-3.3 and TENDL also in terms of the Gaussian Coverage Factor (GCF), which is the common surface spanned below two normal probability density functions associated with data means and variances.

Correspondingly it is found by comparing JEFF-3.3 and TENDL data among each other in a similar way by computing GCFs of cross-sections, that (3) posterior data overall appears less deviating than prior data.

It seems worthwhile investigating whether similar promising results and trends assessed based upon a deterministic code, namely ERANOS, are reproducible with a stochastic method which is deemed to be a reference tool.

1. Introduction

The important task of properly assessing and reducing uncertainties of reactor parameters due to nuclear data uncertainties in a trustful way below given limits can only be achieved by ensuring that covariance data along with the basic nuclear data is obtained in a fully consistent manner. In particular all these data should stem from the same source and would also need to be processed on the basis of a consistent methodology.

This study thus addresses the task of adjusting consistent JEFF-3.3 (Nuclear Energy Agency (NEA), 2018) and TENDL (Koning and Rochman, 2012) based data along with their covariances in the fast energy range; the Asymptotic Progressing Incremental nuclear data Adjustment (APIA) methodology proposed in (Pelloni and Rochman, 2018) is used. At this point it is worthwhile mentioning that JEFF-3.3 is already partly adjusted to integral data.

Section 2 deals with general considerations describing the benchmark case and the experimental database for the assimilation, Sections 2.1 and 2.2 is devoted to APIA features in addition to specific refinements of the methodology; thus enabling to compare adjustments in general terms. Section 3 is dedicated to extensive analyses of the results in particular comparisons of JEFF-3.3 and TENDL data primarily in terms of their performance in analyzing a series of benchmarks. Finally, Section 4 summarizes the main findings, provides conclusions and points on key recommendations for future work.

2. General considerations

The current study supplements activities of the International "Subgroup 33" of the Working Party on Evaluation Cooperation (WPEC) of the OECD Nuclear Energy Agency Nuclear Science Committee (NSC) on "Methods and issues for the combined use of integral experiments and covariance data". The mandate of the subgroup was that of studying methods and issues of the combined use of integral experiments and covariance data with the objective

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of recommending a set of best and consistent practices in order to improve evaluated nuclear data files (Salvatores et al., 2014). The following subgroup on "Methods and approaches to provide feedback from nuclear and covariance data adjustment for improvement of nuclear data files" (WPEC "Subgroup 39"), has also stimulated the current investigations. Dedicated subgroup tasks were namely aimed at finding robust criteria allowing separating effects on adjustments coming from individual assimilations of experimental parameters.

The Asymptotic Progressing Incremental nuclear data Adjustment (APIA) methodology (Pelloni and Rochman, 2018) is thus used to assimilate a small number of relevant experimental data of central spectral indices, Section 2.1. The aim of the study is that of analyzing by means of the resulting adjusted data, i.e. posterior data along with their covariances, several target experiments for fast reactor applications with the majority of these experiments outside the assimilation process, and to compare the results with those obtained based upon unadjusted data, i.e. prior data along with their covariances.

It is recalled (Pelloni and Rochman, 2018) that the main idea lying behind the APIA approach is that the adjustment is made progressively in subsequent steps, by considering at a time small groups of well documented experiments possibly with low experimental uncertainties, which have been performed in the same configuration. In addition, the sensitivity coefficients of the integral parameters to assimilate are recomputed on the basis of iteration dependent adjusted cross-sections. These recalculations thus allow determining asymptotic posterior data along with their covariances which are assessed once convergence is achieved.

The envisaged target experiments include integral parameters considered in the framework of "Subgroup 39". As in (Pelloni and Rochman, 2018) the adjustment is performed for the ten most important nuclides of the benchmarks in view of neutronics analyses. These nuclides are ^{16}O, ^{23}Na, ^{52}Cr, ^{56}Fe, ^{58}Ni, ^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu and ^{241}Pu; thus consistently with (Salvatores et al., 2014), not including ^{237}Np. Adjusted are six data types i.e. elastic and inelastic scattering, lumped (n, 2n) and (n, 3n) named (n, xn), capture and fission cross-sections, as well as $\bar{\nu}$.

In order to avoid inconsistencies (Pelloni and Rochman, 2018) the adjustment is obtained by solely using prior data stemming from the same data source in terms of cross-sections and their covariances, which is JEFF-3.3 (Nuclear Energy Agency (NEA), 2018) and TENDL (Koning and Rochman, 2012). While TENDL data was generated in-house on the basis of available random files produced for the different nuclides (Koning and Rochman, 2008), JEFF-3.3 covariances were evaluated by the JEFF project members, compiled at the NEA Data Bank, and then distributed to the "Subgroup 39"members in different dedicated formats. This covariance data has originally been processed with NJOY (MacFarlane et al., 2012) from ENDF formatted files.

The deterministic code system ERANOS (Edition 2.2-N) (Rimpault et al., 2002) is then used in the framework of the APIA simulations to compute all required neutronic parameters including uncertainties resulting from the propagation of nuclear data uncertainties, by using P_1S_{16} approximations in the required forward and also adjoint transport-theory calculations of the generalized importance functions. As in previous studies e.g. (Pelloni and Rochman, 2018), fission spectra, secondary energy/angular distributions, background cross-section (σ_0) dependences, and data for nuclides other than those aforementioned and thus remaining unadjusted, all are stemming from the original JEFF-3.1 based ERANOS library.

2.1. Experimental database

More precisely, the current assimilation accounts for central core measurements of spectral indices carried out in two configurations, Godiva and ZPPR-9. The APIA simulations performed with data in 33 neutron groups (Rimpault et al., 2002) dealt with in this study correspondingly use two incremental steps. In a previous analysis considering a larger number of steps (Pelloni and Rochman, 2018) it has namely been ascertained that the assimilation of this experimental data is responsible for significant adjustments of U235 (Godiva), respectively of U238 and Pu239 data (ZPPR-9). Also, APIA simulations with different sequences using consistent prior data in terms of the same data source for the data along with their covariances were found able providing similarly adjusted cross-sections and equal posterior sensitivity coefficients. All these characteristics which are indicative of consistent adjustments (Pelloni and Rochman, 2018); along with the consideration of just a few well documented experiments, constitute the basis for the current choice of the assimilation database.

34 target experiments performed in 11 configurations are analyzed with (1) unadjusted data i.e. prior data along with their covariances, and then (2) adjusted data i.e. posterior data along with their covariances, in order to test along with the unadjusted data, the individual adjustments by comparing the performance of the JEFF-3.3 and TENDL based data in a consistent manner, Section 2.2.

These experiments include the 6 parameters which are part of the assimilation supplemented by a larger number of experimental data which are not assimilated, namely 28, Table 1.

The current selection criterion for the target experiments is primarily given by the availability in the ICSBEP (Briggs, 2014) and IRPhEP (Nuclear Energy Agency (NEA), 2017) collections, of configurations in which spectral indices were measured. Due to the approximation of using just $P_0 - P_1$ scattering cross-sections in the current methodology and particularly in the transport-theory calculations carried out with ERANOS, the effective multiplication factor of the envisaged metal systems is not considered, since reliable calculations of this parameter in these cases would require the use of at least $P_0 - P_3$ cross-sections (Pelloni, 2014), Table 1.

It is anticipated that the adjustment of $\bar{\nu}$ is quite small because the database for assimilations is limited to spectral indices having weak sensitivities to $\bar{\nu}$.

k_{eff}, a parameter which is not assimilated (Pelloni, 2017), as usually refers to the effective multiplication factor.

The abbreviations *F28*, *F25*, *F49*, and *F37* are respectively used for ^{238}U, ^{235}U, ^{239}Pu, and ^{237}Np fission reaction rates per atom; *C28* denotes the ^{238}U capture reaction rate per ^{238}U atom.

For general understanding, the individual configurations are briefly characterized (Briggs, 2014), (Nuclear Energy Agency (NEA), 2017) hereafter. It is recalled that

Godiva is a bare sphere consisting of 94 wt% U235 enriched U. The experimental data, a part of which is used in the current assimilation, was obtained in Los Alamos, USA.

U235 Flattop is a spherical, highly enriched U core reflected by natural U. The experiments were conducted in Los Alamos.

Big Ten is a large mixed U metal cylindrical core with 10% average U235 enrichment, surrounded by a thick U238 reflector. The experiments were conducted in Los Alamos.

Pu239 Jezebel is a bare sphere of Pu239 with 4.5 atom% Pu240 and 1.02 wt% Ga. The experiments were conducted in Los Alamos.

Pu240 Jezebel is a bare sphere of Pu239 with 20.1 atom% Pu240 and 1.01 wt% Ga. The experiments were conducted in Los Alamos.

Pu239 Flattop is a spherical Pu239 core reflected by natural U. The experiments were conducted in Los Alamos.

ZPPR-9 is a zero-power mockup of a large pancake like sodium-cooled fast breeder reactor core with conventional Mixed OXide (MOX) fuel. The experimental data, a part of which is also used in the current assimilation, was obtained under a joint research program between the U.S. Department Of Energy (DOE) and the