WP5 - Nuclear data validation, sensitivity analyses and impact studies

Nuclear data validation

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Sensitivity analyses and impact studies

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Objectives WP5

WP5 will produce three sets of results:

(i) **Sensitivity profiles and impact studies for advanced concepts**, relating nuclear data uncertainties to reactor design, operation or safety quantities

(ii) **Nuclear data trends** derived from the analyses of integral experiments and from data assimilation (DA) studies considering multiple integral experiments

(iii) The results of **new integral experiments** and their analysis with the latest JEFF data and the needs for new validation data and facilities

Collaborations will be established with:

- **JEFF** Evaluation and Benchmarking groups
- **IAEA/NDS** expert groups within INDEN Network
- **OECD/NEA WPEC** expert groups working on uncertainty assessments, data adjustments, and data assimilation

A close connection will also be established between WP5 and the other APRENDE work packages, especially WP4.

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Objectives WP5

The APRENDE/WP5 results:

- **New sensitivity profiles** will be made public (NDAST international database)
- **New integral experiments** will be proposed as benchmarks for inclusion in the IRPhE international database (during the project, or after if not possible otherwise)
- **Results of WP5 analyses** and validation studies will serve to motivate revisions in JEFF4 evaluated nuclear data, new entries in the OECD/NEA HPRL priority list and a hierarchy of priorities

Final outcomes:

- **Data adjustment and assimilation** studies are expected to help pinpoint inconsistencies and remove error compensations, which are known to be still very much present in current files
- The WP5 validation activities will **help nuclear data users understand the impact of nuclear data uncertainties on their applications**

End-Users:

- WP5 will liaise with the ND user communities to collect feedback from them. Ref. Sep 2023 OECD/NEA nuclear data stakeholders' meeting
- WP5 will also contribute to the strategic analysis of European nuclear data capacities

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Brief description of Task/SubTasks

Task 5.1. Sensitivity analyses, uncertainty quantification, impact studies (8 Partners)

Task leader: CIEMAT

Other participants: SCK, STUBA, UPM, UMAR, CNRS/Subatech, JSI, UKAEA

This task consists of nuclear data sensitivity analyses (SA), impact studies, and uncertainty quantification (UQ).

- It extends similar studies (a.o. SANDA Task 5.1) to **a wider range of systems and quantities** of interest.
  - Specifically, quantities other than criticality (k_eff) will be investigated. This is important, as the impact of given nuclear data can be quite different for different systems and different dependent variables.
- Priority will be given to **newly evaluated data in WP4 and in JEFF-4**.
- The contributing organisations will use their preferred calculation codes.
- Selected models are derived from nuclear reactor concepts that have already undergone some design feasibility studies, as opposed to unscreened prospective concepts.

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Tasks/Subtasks WP5: Deliverables + Milestones

Task 5.1. Sensitivity analyses, uncertainty quantification, impact studies (8 Partners)
Task leader: CIEMAT
Other participants: SCK, STUBA, UPM, UMAR, CNRS/Subatech, JSI, UKAEA

Subtask 5.1.1. Sensitivity analyses and priorities for nuclear data improvements
CIEMAT, UPM, STUBA, CNRS/Subatech
SCK
UMAR, JSI, and UKAEA
→ **MS5.1:** Calculation of sensitivity profiles for ADS, MSR, LWRs, GFR and SFR, **M24**
→ **MS5.2:** Algorithm for res. param. sens. analysis and new SANDY version, **M24**
→ **D5.1:** Sensitivity analyses and priorities for ND improvements, **M48**

Subtask 5.1.2. Nuclear data uncertainty propagation in reactor and shielding applications
CIEMAT, CNRS, UPM, SCK, STUBA, JSI and UMAR
→ **D5.2:** ND uncertainty propag. in reactor, shielding and adv. fuels, **M48**

Subtask 5.1.3. Nuclear data uncertainty propagation in advanced fuel cycles
CIEMAT
→ **D5.2:** ND uncertainty propag. in reactor, shielding and adv. fuels, **M48**

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Task 5.1. Sensitivity analyses, uncertainty quantification, impact studies (8 Partners)

Task leader: CIEMAT

Other participants: SCK, STUBA, UPM, UMAR, CNRS/Subatech, JSI, UKAEA

Subtask 5.1.1. Sensitivity analyses and priorities for nuclear data improvements

- **CIEMAT, UPM, STUBA and CNRS** will calculate sensitivity profiles of quantities such as reactivity, Doppler coefficient, spectral indices, dose rates, inventories, decay heat, neutrino emissions and eventually others, to nuclear data for a variety of core models, ranking nuclear data by the importance of the uncertainty contribution. Systems of interest include **LWRs with accident tolerant fuels, SFR, GFR, AMR (fast SMR), ADS, MSFR**. The focus will be on steady-state equilibrium operating conditions, accounting for fuel depletion.
- **SCK·CEN** will develop **a new technique for resonance-parameter sensitivity analysis**, integrate it in the SANDY **(MS5.2)** code, and apply it to assess the sensitivity of the Doppler coefficient to changes in the U238 resonances for a **MYRRHA-like SMR-LFR**.
- **UMAR and UKAEA** will perform sensitivity calculations for **out of-core radiation propagation and shielding models** (SINBAD). For some of the above systems, they will investigate transient conditions in which engineering, operating, or safety variables could exhibit a high sensitivity to neutron kinetics data.
- **UPM** SA will address a non-energy application: neutron activation of concrete shields of **proton therapy centres** (PTC) **(MS5.1 and D5.1)**.

	LWR with ATF	SFR	GFR	AMR	ADS	MSFR	MYRRHA-like SMR-LFR	Shielding	PTCs	Others (specify)
Reactivity										
Doppler coefficient										
Spectral indices										
Dose rates										
Inventories										
Decay heat										
Neutrino emissions										
Others (specify)										

by V. Becares
Pre kick-off: Sep 9, 2024

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Task 5.1. Sensitivity analyses, uncertainty quantification, impact studies (8 Partners)

Task leader: CIEMAT

Other participants: SCK, STUBA, UPM, UMAR, CNRS/Subatech, JSI, UKAEA

Subtask 5.1.2. Nuclear data uncertainty propagation in reactor and shielding applications

- **CIEMAT, CNRS, UPM, SCK, STUBA, JSI and UMAR** will perform **calculations to assess the impact of (JEFF-4) nuclear data uncertainties on reactor design-, operation-, and safety-related quantities**. The nuclear systems of Subtask 5.1.1 will be considered, in steady state and transient conditions. The applied models have sufficient fidelity to avoid underestimating or overestimating the final errors.
- **For power transients, the calculations will use coupled neutronics-thermal hydraulics models to propagate nuclear data uncertainties** to power and temperature distributions, reactivity, etc., while accounting for feedback effects and time-dependent phenomena.
- A common reference set of nuclear data covariance data (JEFF-4 complemented as needed and agreed) will be used as input.
- **By comparing the results with the known target accuracy requirements (TAR analyses)** and margins, nuclear data will be ranked by impact motivating priority nuclear data improvement actions (input to HPRL and project). Participants involved in this subtask are the same as in Subtask 5.1.1, leveraging the benefit of this work **(D5.2)**.

Subtask 5.1.3. Nuclear data uncertainty propagation in advanced fuel cycles

- **CIEMAT** will investigate the impact of JEFF nuclear **data uncertainties on fuel cycle variables** of interest including spent fuel inventories, recycled materials, waste streams, etc. A two-tier sustainable fuel cycle scenario involving both light water reactors and advanced plutonium-recycling fast reactors will be considered for this investigation. Responses of interest for this subtask are different from Subtask 5.1.1 and the related Subtask 5.1.2 with which work is done together. Results will be compared with known target accuracy requirements to rank nuclear data uncertainties by contribution and prioritize improvement efforts **(D5.2)**.

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Brief description of Task/SubTasks

Task 5.2: Analysis of experiments, validation, and data assimilation (10 Partners)
Task leader: UPM
Other participants: EPFL, UMAR, IRSN, UU, SCK·CEN, CEA, STUBA, UKAEA, CIEMAT

- **High-quality integral experiments** will be analysed to validate the latest (WP4 and JEFF) evaluated nuclear data. The objective here is limited validation in line with the available experimental data. The eligible measurements are **from experiments or benchmarks that are not part of the (WP4) evaluation process.**
- **High fidelity models** of the experiments are set up to make modelling errors negligible.
- **Comparing calculated and measured responses(C/E),** discrepancies are analysed in terms of possible causes using sensitivity analysis and the available prior covariance information. If enough good-quality integral information is available, **the experiments can be assimilated** in a group-wise data reduction process to obtain trends in the most sensitive nuclear data.
- **Statistically meaningful trends** can be used to justify requests for changes in nuclear data evaluations (new HPRL entries). Evaluators can then improve nuclear data files and get reduced a posteriori uncertainties, as well as new correlations between these uncertainties.

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Tasks/Subtasks WP5: Deliverables + Milestones

Task 5.2: Analysis of experiments, validation, and data assimilation (10 Partners)
Task leader: UPM
Other participants: EPFL, UMAR, IRSN, UU, SCK·CEN, CEA, STUBA, UKAEA, CIEMAT

Subtask 5.2.1. Analyses of integral measurements, reactor data
UPM, IRSN, CIEMAT, UKAEA, STUBA
→ **MS5.3:** Results of nuclear data impact studies, **M24**
→ **D5.3:** Analyses of int. msmts, reactor data and corr. between int. data, **M48**

Subtask 5.2.2. Correlations between integral data
IRSN, UMARIBOR, UPM
→**D5.3:** Analyses of int. msmts, reactor data and corr. between int. data, **M48**

Subtask 5.2.3. Assimilation using group-averaged data, derivation of JEFF4 trends
CEA, EPFL, SCK·CEN, UMARIBOR ,UPM, SCK
→**D5.4 :** Assimilation techniques for the derivation of ND trends, **M48**

Subtask 5.2.4. Direct inclusion of EXFOR data in a global assimilation process at the level of nuclear model parameters
CEA, UU, EPFL
→**D5.4 :** Assimilation techniques for the derivation of ND trends, **M48**

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Task 5.2: Analysis of experiments, validation, and data assimilation (10 Partners)

Task leader: UPM

Other participants: EPFL, UMAR, IRSN, UU, SCK·CEN, CEA, STUBA, UKAEA, CIEMAT

Subtask 5.2.1 Analyses of integral measurements, reactor data

The main goal of this subtask is to include integral measurements and reactor data in the benchmarking of JEFF evaluations to detect potential deteriorations for this type of applications prior to a final release of the evaluated files.

- Integral measurements such as ex-core calculations in **SINBAD benchmark H.B. Robinson-2** for comparison of computed neutron spectrum, fast neutron fluence and iron dpa **(UPM)**
- Depletion and burnup calculations to assess the potential reactivity changes with burnup using SFCOMPO benchmark **PWR/ARIANE GU3** **(IRSN)**
- It will be complemented with a set of **ICSBEP, IRPhE and SINBAD** integral experiments to assess the impact of new JEFF evaluations:
    i. with integral benchmark experiments which are **sensitive to the URR** range and perform calculations of k_eff, but other parameters such as kinetic parameters **(CIEMAT)**,
    ii. suitable SINBAD benchmarks for critical isotopes and reactions Fe, O, W, Cu, H2O, both for neutrons and gamma leakages and spectral indices like **ASPIS/JANUS, CIAE Fe, OKTAVIAN, FNS, FNG and LLNL** **(UKAEA)**
    iii. fast reactor systems **GFR2400 and ESFR-SIMPLE**, which were not investigated in the SANDA project **(STUBA).**

(MS 5.3 and D5.3)

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Task 5.2: Analysis of experiments, validation, and data assimilation (10 Partners)

Task leader: UPM

Other participants: EPFL, UMAR, IRSN, UU, SCK·CEN, CEA, STUBA, UKAEA, CIEMAT

Subtask 5.2.2. Correlations between integral data

- The main goal of this subtask is to **develop a new robust methodology based on Monte Carlo calculations** of technological parameters on k_eff to determine experimental correlations **(IRSN)**.
- Applying and assessing this methodology to an **ICSBEP/IRPhEP** selection of critical benchmarks with high similarities for current LWRs, advanced systems and SMRs (e.g. **LEU-COMP-THERMs, MIX-COMP-THERM**, etc). This will allow to quantify the relative independence of the selected experimental measurements (that use the same fuel material, common instrumentation, etc.) to be included in GLLS approach. Consequently, the assimilation process which is based on an effective selection of experimental benchmarks will benefit of this work.
- **Efficient nuclear data assimilation techniques** to provide evaluators with meaningful feedback for JEFF-4 will be explored. Target nuclides will be **^{235}U, ^{238}U, ^{239}Pu and ^{240}Pu (IRSN, UMARIBOR)**.
- **Consistency between the data assimilation results using different choices of integral benchmarks** (ICSBEP, IRPhEP and SEFOR experiments) and experimental data (k_eff, spectral indices and reactivity coefficients such as coolant voiding, Doppler broadening, or reflector-worth values) will be studied **(UPM) (D5.3)**.

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Task 5.2: Analysis of experiments, validation, and data assimilation (10 Partners)

Task leader: UPM

Other participants: EPFL, UMAR, IRSN, UU, SCK·CEN, CEA, STUBA, UKAEA, CIEMAT

Subtask 5.2.3. Assimilation using group-averaged data, derivation of JEFF4 trends

- The goal of the proposed work is **to investigate nuclear data assimilation techniques** to be used more efficiently to provide feedback to the evaluators, by the development of advanced Bayesian techniques as well as the proper selection of experimental data, **both energy dependent (EXFOR) and integral experimental data (beta_eff, k_eff, spectral indexes, reactivity coefficients and PIE measurements)**. The feedback to the evaluators will not be provided at the multi-group level (constant quantity for an energy range) as it was usually the case in the past, but at the nuclear parameter level, e.g., for any parameter available in the ENDF-6 format such a resonance parameters. The targeted nuclides will be **238U, 235U, 239Pu and 240Pu** and the most relevant FP data and their impact on thermal and fast reactors applications (from current LWR to SMR and Gen-IV FBR) **(CEA, EPFL, SCK, UMARIBOR)**.
- In addition, one outcome of these techniques will be the prioritization of new experiments which will be added to the HPRL with the corresponding **Target Accuracy Requirement (TAR) calculations** **(UPM, SCK)** **(D5.4)**.

Subtask 5.2.4. Direct inclusion of EXFOR data in a global assimilation process at the level of nuclear model parameters

- The goal is to combine both energy dependent (EXFOR) and integral experimental data (beta eff, keff, PIE measurements) when performing data assimilation exercises to provide feedback to the evaluators. **Moreover, the feedback to the evaluators** will not be at the multi-group level, as is common, but **at the nuclear parameter level (any parameter available in the ENDF-6 format)**. The target nuclides are **235U, 239Pu and 240Pu** **(CEA UU, EPFL)** **(D5.4)**.

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Brief description of Task/SubTasks

Task 5.3: New integral experiments and validation data (4 Partners)

Task leader: CEA

Other participants: CVREZ, SCK·CEN, IRSN

- The goal is **to support integral experiments useful for the validation of nuclear data**.
- Thanks to these experiments, it will be possible **to assess the performance of new JEFF evaluations** for different applications and, if required, proceed with a precise integral data assimilation on nuclear data.
- The experiments address **iron** (reflector – shielding), **aluminium** (structural material) and **fission products** (sample oscillations for burnup calculations).
- This task will provide **additional recommendations for the European experimental infrastructure** (facilities, nuclear materials, equipment, instrumentation…) **and expertise** needed for nuclear data validation of a recent NEA Task Force on ZPRs.

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Tasks/Subtasks WP5: Deliverables + Milestones

Task 5.3: New integral experiments and validation data (4 Partners)
Task leader: CEA
Other participants: CVREZ, SCK·CEN, IRSN

Subtask 5.3.1. Experiments in LR-0 and other reactors
CVREZ, CEA
→**D5.5:** Experiments in LR-0, **M36**

Subtask 5.3.2. Source-detector experiments
CVREZ
→**D5.6:** Benchmark-quality leakage measurements in an aluminium block, **M24**

Subtask 5.3.3. Future experiments for nuclear data validation
CEA,SCK·CEN, IRSN
→**D5.7:** Report on the European needs of new integral expts for ND validation, **M24**

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Task 5.3: New integral experiments and validation data (4 Partners)

Task leader: CEA

Other participants: CVREZ, SCK·CEN, IRSN

Subtask 5.3.1. Experiments in LR-0 and other reactors

- The main goal of LIRICS experiment is aiming at the development of a **new integral reactor experiment with a large iron reflector surrounding a well-defined core with a reference benchmark neutron field in its centre at the LR-0 reactor (CVREZ)**. The experiment will bring new benchmark quality data on criticality and pinpower distribution which can be benchmarked with JEFF-4 nuclear data.
- **A pile sample oscillator (POSEIDON)** will be installed at LR-0 for doing an integral benchmark using reactivity worth measurements for burnable poisons. This experiment is designed for the improvement of the reactivity versus burn-up prediction, which is a key-parameter for power reactors. The list of isotopes to be measured is: ^{95,98}Mo, ^{99}Tc, ^{107}Ag, ^{109}Ag, ^{101}Ru, ^{102}Ru, ^{104}Ru, ^{131}Xe, ^{147S}m, ^{149}Sm, $^{149, 152}$Sm, ^{143,146,148}Nd, ^{142}Ce, ^{151,153}Eu, ^{155,156,157,158}Gd, ^{133}Cs and Hf isotopes **(CEA)** **(D5.5)**

Subtask 5.3.2. Source-detector experiments

- The main goal is to provide **new integral values for the improvement of nuclear data for aluminium**. An aluminium assembly will be made with a cubical shape of 50×50×50 cm^3. A ^{252}Cf neutron source will be placed in the centre. The measured leakage spectrum will be used to validate evaluations of Al **(CVREZ)** **(D5.6)**

Subtask 5.3.3. Future experiments for nuclear data validation

- The purpose of this action will be **to review the integral experiments needs arising from the loss of ZPR-type experimental capabilities**. An already-perceptible consequence of the presently degraded situation is a critical shortage of new integral data for the JEFF-4 validation activities, for various applications (e.g. SMRs). This action is therefore of relevance to the JEFF-4 objective of “broadening the range of benchmarks reflecting applications, quantities, and specific nuclides of interest **(CEA, SCK·CEN, IRSN)** **(D5.7)**

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Deliverables WP5

#	Title	Lead	Type	Diss Level	Due
D5.1	Sensitivity analyses and priorities for ND improvements	CIEMAT	R	PU	48
D5.2	ND uncertainty propagation in reactor, shielding and advanced fuels	CIEMAT	R	PU	48
D5.3	Analyses of integral measurements, reactor data and correlations between integral data	UPM	R	PU	48
D5.4	Assimilation techniques for the derivation of ND trends	UPM	R	PU	48
D5.5	Experiments in LR-0	CVREZ	DATA	PU	36
D5.6	Benchmark-quality leakage measurements in an aluminium block	CVREZ	DATA	PU	24
D5.7	Report on the European needs of new integral experiments for ND validation	CEA	R	PU	24

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Milestones WP5

#	Title	Lead	Verification	Due
MS5.1	Calculation of sensitivity profiles for ADS, MSR, LWRs, GFR and SFR	-	Presentation of results	24
MS5.2	Algorithm for resonance parameter sensitivity analysis and new SANDY version	-	Report to the WP lead	24
MS5.3	Results of nuclear data impact studies	-	Presentation of results	24

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Effort in WP5

#	Institution	PMs	Deliverables D5.1/D5.2/D5.3/D5.4 in 48 Month D5.5 in 36Month and D5.6/D5.7 in 24Month	Milestones (All in 24 Month)	Contact person (with permanent position)
1	CIEMAT	12.3	D5.1 D5.2 D5.3	MS5.1 MS5.3	Vicente Bécares
2	CEA	15.1	D5.4 D5.5 D5.7		Robert Jacqmin
3	CVREZ	9.0	D5.5 D5.6		Michal Košťál
4	IRSN	5.3	D5.3 D5.7	MS5.3	Raphaelle Ichou
5	JSI	3.5	D5.1 D5.2	MS5.1	Ivo Kodeli
6	SCK·CEN	2.9	D5.1 D5.2 D5.4 D5.7	MS5.2	Luca Fiorito
7	STUBA	3.6	D5.1 D5.2 D5.3	MS5.1 MS5.3	Jakub Luley
8	UMAR	3.4	D5.1 D5.2 D5.3 D5.4	MS5.1	Ivo Kodeli
9	UPM	9.8	D5.1 D5.2 D5.3 D5.4	MS5.1 MS5.3	Oscar Cabellos
10	UU	2.4	D5.4		Erik Andersson Sundén
11	EPFL(AP)	2.5	D5.4		Mathieu Hursin
12	UKAEA(AP)	1.0	D5.1 D5.3	MS5.3	Ivo Kodeli
13	CNRS (total)	14.5			
14	Subatech (AE)	1.5	D5.1 D5.2	MS5.1	Lydie Giot
15	IMITEL(AE)	13.0			
	Total	**85.3**			

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Contact List in WP5

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Questions & Comments
about WP5?

Suggestions

- Provide a pptx/docx/latex template for APRENDE reports&presentations.
- Provide a common Acknowledgment for presentations in JEFF, WPEC, etc…

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