USE OF SHIELDING BENCHMARK EXPERIMENT DATABASE (SINBAD) TO IDENTIFY NUCLEAR DATA STATUS AND GUIDE FUTURE EXPERIMENTAL ACTIVITIES

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Validation of nuclear data (ND) libraries and evaluations is crucial to assure their quality before being used in industrial or safety studies and build confidence in the results obtained. Until recently the integral nuclear data validation was still predominantly based on the analysis of criticality benchmarks which interpretation is ambiguous and clearly not suitable for fusion applications. Shielding benchmarks, although computationally more demanding, provide a powerful alternative. Radiation spectra, reaction rates, heating rates or activations are measured in simplified and well characterised, or even close-to-actual, experimental assemblies to be compared with the calculated results.
A series of neutronics benchmark experiments were performed at different experimental facilities over the world to support fusion neutronics needs. To preserve the experimental data and the information on the measurement procedure, we started about 30 years ago at OECD/NEA and RSICC the Shielding Integral Benchmark Archive and Database (SINBAD) [1] project. SINBAD provides an experimental database for the integral validation and improvement of basic nuclear data and computer codes. It also helps to identify the isotopes and energy ranges where further improvements and new experimental information is needed and thus serves as a guide for designing future experimental campaigns. Thirty-one fusion relevant benchmarks involving both neutrons and gamma-rays are included with shielding materials such as Fe/stainless steel, Cu, W, SiC, O, concrete, tritium production rate (PbLi, Li-Be). Experience from the analysis of benchmarks performed at the experimental facilities such as FNG, FNS, OKTAVIAN, ASPIS helps identifying nuclear data needs where future activity should focus.

In the scope of the EUROfusion experimental programme several experimental benchmarks were performed in the recent years or are under preparation at the 14-MeV D-T Frascati Neutron Generator (FNG) at ENEA Frascati and Centrum výzkumu Řež. Benefits of some original approaches used will be demonstrated:

- Systematic integration of sensitivity/uncertainty (S/U) analysis in the benchmark preparation and post-analyses, which allows a better understanding and use of measurements for ND improvement
- Evaluation and preservation of validated experimental information in international databases such as SINBAD, thus avoiding the loss of experimental data and promoting its use.

Examples of shielding benchmark analysis using both Monte Carlo and deterministic transport codes will be presented. Monte Carlo codes, generally more accurate due to fewer modelling and method approximations, provide the reference solution. The main task of the deterministic codes in our computational scheme is to derive the sensitivities of the measured quantities, such as neutron/gamma fluxes, reaction rates, heating, DPA etc. with respect to the nuclear data. These analyses are valuable in the pre- and post-analysis of the benchmark to help design the benchmark and conclude on the quality and specific deficiencies of the basic nuclear data evaluations. Computational uncertainties are evaluated using the sensitivities and nuclear data uncertainties expressed in terms of covariance matrices and compared with the experimental uncertainties to conclude on the specific ND improvement value of measured data. Examples of the on-going and past shielding benchmark analyses include:

- FNG benchmark experiments:
  - two tungsten benchmarks were performed in 2003 and 2023,
  - a new Concrete benchmark is under preparation and planned for 2025,
  - Several Tritium Breeder Modules (TBM) were irradiated to experimentally verify the tritium self-sufficiency and the computational accuracy of modern nuclear codes and data: Helium-cooled Pebble Bed (HCPB) (2005), Helium-Cooled Lithium-Lead (HCLL) (2008) and Water-Cooled Lithium-Lead (WCLL) TBM Mock-up (2020).
- FNS and OKTAVIAN benchmarks (W, Cu, Fe, Ti, Li_2O, etc.)
- CIAE neutron leakage spectra from Fe, Cu, slab with D-T neutrons measuring neutron spectra at different angles from the slabs thus providing information on the anisotropy of scattering,
- challenging applications such as dogleg duct streaming, skyshine, neutron activation
- Gamma-ray measurements: KFK, OKTAVIAN, FNS, FNG, RFNC, SB2/SB3 CSEWG

Benefits of using several different integral measurements for the verification and validation (V&V) of evaluated nuclear data libraries will be demonstrated on the examples of Fe and W nuclear data, for which we dispose of measurements independently performed at different laboratories, by their proper research teams and experimental equipment. Four tungsten benchmarks are included in the SINBAD database and a new experiment was performed at FNG in 2023 which contribute to the wider validation of nuclear data for fusion applications. Iron and steel were tested even in a total of 25 benchmarks included in SINBAD and many more are available in the literature to test iron nuclear data for fission, fusion and accelerator shielding applications. Examples of the use of the validation procedure which includes radiation transport and nuclear data S/U analysis will be presented, focusing mainly on fusion use. Performance of several data libraries, both recent and older are intercompared. XSUN-2023 package which is used for the deterministic transport and S/U analysis includes transport cross sections and covariance matrices from nuclear data libraries such as JEFF-3.3, FENDL-3.2, ENDF/B-VII, -VIII.0 and some JENDL-4.0 data. ENDF/B-VIII.1, JENDL-5.0, CENDL-3.2 and JEFF-4T were recently processed and the results will be shown. Although it is often difficult to unambiguously disentangle and identify the cross-section deficiencies from the integral measurements and the C/E comparisons, the benchmarks still provide essential tool for nuclear data V&V, in combination with the differential measurements and nuclear model predictions.

The need to continue the efforts to preserve, properly evaluate, verify, revise if needed, and preserve the experimental results and the complete benchmark information is strongly highlighted. A wider international effort is needed to carefully validate and update of existing benchmark experiment database such as SINBAD and consciously work on new benchmark evaluations. Making freely available these data to the international community would have positive impact on nuclear safety and radiation hazard and accident prevention, and therefore beneficial to all parties.

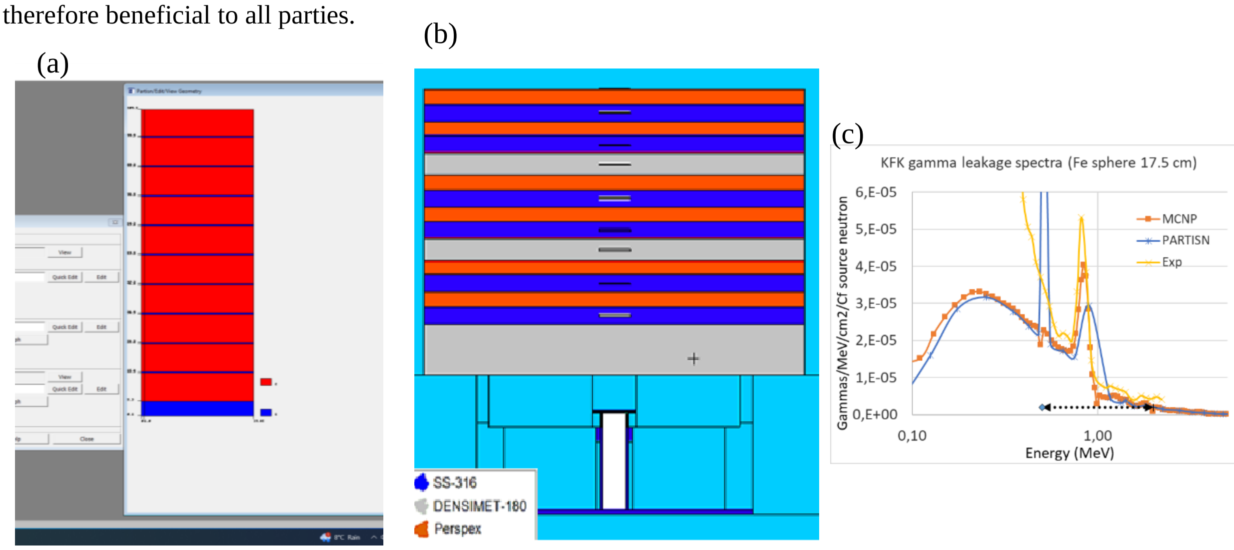

Fig. 1. Examples of benchmark experiments and analyses: (a) XSUN-2023 geometry model of the ongoing FNG Concrete experiment (b) experimental assembly of the FNG Tungsten benchmark (2023, (c) comparison of the measured gamma leakage spectra from the KFK iron spheres with the calculations using the MCNP and PARTISN codes.

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