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Examples of Use of SINBAD Database for Nuclear Data and Code Validation

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Abstract. The SINBAD database currently contains compilations and evaluations of over 100 shielding benchmark experiments. The SINBAD database is widely used for code and data validation. Materials covered include: Air, N. O, H_2O, Al, Be, Cu, graphite, concrete, Fe, stainless steel, Pb, Li, Ni, Nb, SiC, Na, W, V and mixtures thereof. Over 40 organisations from 14 countries and 2 international organisations have contributed data and work in support of SINBAD. Examples of the use of the database in the scope of different international projects, such as the Working Party on Evaluation Cooperation of the OECD and the European Fusion Programme demonstrate the merit and possible usage of the database for the validation of modern nuclear data evaluations and new computer codes.

1 Introduction

Benchmark experiments can serve several purposes and the availability of suitable experimental data is fundamental to ensure that modelling tools meet the requirements of nuclear industry and licensing needs. Essentially, they are used for:
- validation of nuclear cross-section data,
- validation of nuclear codes and models used,
- qualification and training of users through benchmarking and code comparison exercises.

The Shielding INtegral Benchmark Archive and Database (SINBAD) [1-3] project was started in the early 1990's at the OECD Nuclear Energy Agency Data Bank (NEA DB) and the Radiation Safety Information Computational Center (RSICC) as a collection of quality experiments for validating and benchmarking computer codes and data for radiation transport and shielding applications. Currently, the SINBAD database comprises over 100 benchmark compilations and evaluations of relevance to:
- reactor shielding, pressure vessel dosimetry (48)
- fusion blanket neutronics (31)
- accelerator shielding (23)

In order to facilitate their use, the data are organized in the standardized format structure. The index and the master document (called abstract) use the Hyper Text Markup Language (HTML) format with links to text files, figures, Portable Document Format (pdf) documents and computer code inputs. The format allows easy access and forward/backward navigation among the data and has proved to be suitable, general enough and above all easy (and low-cost) to maintain.

In addition to the characterization of the radiation source, description of the shielding set-up, the instrumentation and the relevant detector measurements, most sets in SINBAD contain also the deterministic or Monte Carlo radiation transport computer model used for the interpretation of the experiment and, where available, results from uncertainty analysis. The set of primary documents used for the benchmark compilation and evaluation are provided in computer readable form.

The database is intended for different types of users, including nuclear data evaluators, computer code developers, experiment designers and university students. SINBAD is available from the NEA Data Bank and RSICC (see https://www.oecdnea.org/science/wprs/shielding/sinbad/). Up to now several hundreds of SINBAD packages were distributed from the NEA DB and RSICC.

Since 2011 the maintenance and further development of the database is coordinated in the scope of the OECD NEA Nuclear Science Committee (NSC) Working Party on Scientific Issues of Reactor Systems (WPRS) Expert Group on Radiation Transport and Shielding (EGRTS). A key objective of the group is to identify, evaluate and preserve experimental data on shielding benchmarks. The Expert Group maintains close links with the International Reactor Physics Experiment Evaluation (IRPhE) and International Criticality Safety Benchmark Evaluation (ICSBEP) projects, as well as in co-ordination with the JEFF and EFF NEA Data Bank projects and with the SATIF community of accelerator shielding specialists. In the last years, much effort was devoted to the quality review of the available benchmark information. Setting up of the official SINBAD Quality Evaluation Group

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such as the groups established for the criticality benchmarks (ICSBEP) and reactor physics experiments (IRPhE) is planned. It would be based on the pilot evaluation group already actively performing the quality evaluations of SINBAD. The exact details on the peer review process for the future quality evaluations is still to be agreed upon.

2 Examples of nuclear data and code validation using SINBAD

The paper covers a few examples of recent analysis of the SINBAD benchmarks, demonstrating how the SINBAD data can be used for modern neutron/gamma nuclear data and computer code validation. The activities were done in the scope of several international projects such as the Fusion for Energy, the Working Party on Evaluation Cooperation of the OECD (WPEC) [4] subgroup SG40 (CIELO), WPEC SG39 and the International Atomic Energy Agency (IAEA). WPEC-SG40 was set up to focus on the evaluated nuclear data of the major nuclides in reactor technology, namely ^{1}H, ^{16}O, ^{56}Fe, ^{235}U, ^{238}U and ^{239}Pu. WPEC-SG39 entitled "Methods and approaches to provide feedback from nuclear and covariance data adjustment for improvement of nuclear data files", also expressed interest in using SINBAD iron benchmarks to study nuclear data adjustment methods. Fusion for Energy (F4E) is the European Union's Joint Undertaking responsible for providing Europe's contribution to ITER and the Development of Fusion Energy.

Several examples of recent nuclear data validation are presented, including materials such as iron and oxygen, for both neutrons and photons. The data were used also to for computer code validation. In some cases, the analysis was complemented with the sensitivity and uncertainty analyses to provide an insight into the role of the basic data used and help in the interpretation and understanding of the physical phenomena involved.

2.1 Iron cross-section validation

Due to their importance and complexity, the reaction cross sections of the iron isotopes traditionally attracted considerable attention and have been evaluated and measured several times. Altogether 25 SINBAD benchmarks include iron or steel as shielding material. The agreement between measurements and calculations of integral benchmarks using the present evaluations is reasonable, except at certain energy ranges. The comparison is however hindered by the fact that many of the experiments are old and the authors were not able (or willing) to provide additional information to improve the quality of the integral experiments, which would allow detailed explicit modelling of the experimental setup and reduce the uncertainties. Furthermore, much of the data testing refers to energies below 20 MeV.

A recently evaluation is ongoing in the scope of the Working Party on Evaluation Cooperation of the OECD set up a subgroup WPEC-SG40 (alias CIELO). Iron cross-section evaluation and validation is also part of the recent F4E activities. Furthermore, the ASPIS-Iron88 iron benchmark (see Fig. 1) study was also used in the scope of the WPEC WG39 [5, 6] including complete sensitivity and uncertainty analysis combined with data adjustment.

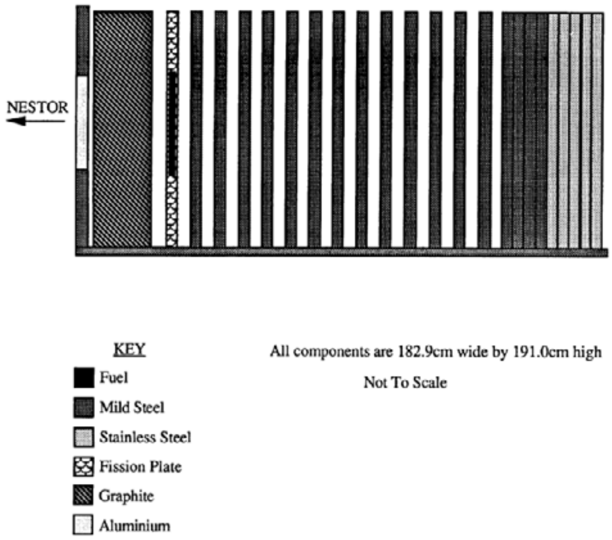

Figure 1. Schematic view of the Aspis Irion88 benchmark experimental shield.

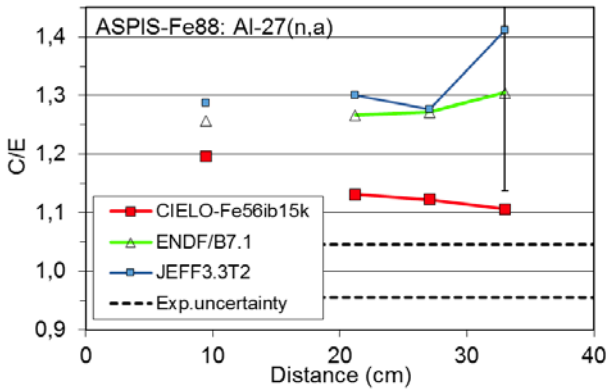

Figure 2. Relative axial ^{27}Aln,α) reaction rate distribution for Aspis Iron88 benchmark. Comparison between experimental data and Monte Carlo simulation using different cross sections for ^{56}Fe. CIELO results refer to the "ib88" evaluation. Dashed lines delimit the ± 1 σ standard deviations of the measurements. ± 1 σ computational uncertainty due to the nuclear data is also shown with the ENDF/B-VII.1 results (at 35 cm).

Among the recently revised SINBAD integral benchmarks sensitive to iron cross sections the ASPIS-Iron88, JANUS Phase 1, NESDIP-3 and EURACOS Fe were selected for the validation of the recent iron evaluations. Comparison between the measured and calculated ^{32}S(n,p) reaction rate distributions for the Aspis Iron88 and JANUS-1 iron shielding benchmarks are presented in Figs. 2 – 4. Different ^{56}Fe cross sections (ENDF/B-VII.1 [7], JEFF-3.3T2, and two recent CIELO evaluations "ib04s" and "ib88" [8]) were used in the MCNP-6 simulation of the benchmark. For all other materials, ENDF/B-VII.1 was used. In particular, compared to the ENDF/B-VII.1, the version "ib04s" includes more detailed angular distributions of the firstlevel inelastic scattering, while "ib88" includes a new optical model evaluation of the fast energy.

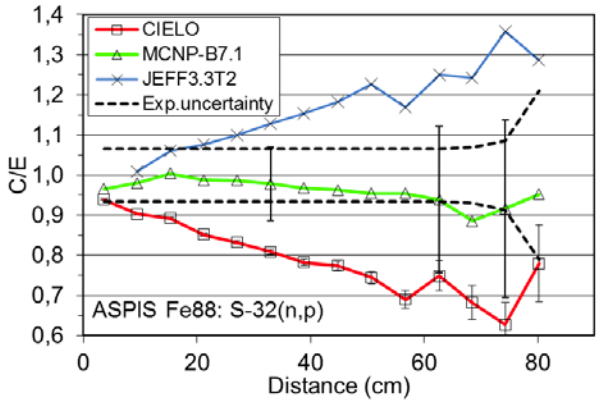

Figure 3. Relative axial ^{32}S(n,p) reaction rate distribution for Aspis Iron88 benchmark. Comparison between experimental data and Monte Carlo simulation using different cross sections for ^{56}Fe. CIELO results refer to the "ib88" evaluation. Dashed lines delimit the ± 1 σ standard deviations of the measurements. ± 1 σ computational uncertainty due to the nuclear data is also shown with the ENDF/B-VII.1 results.

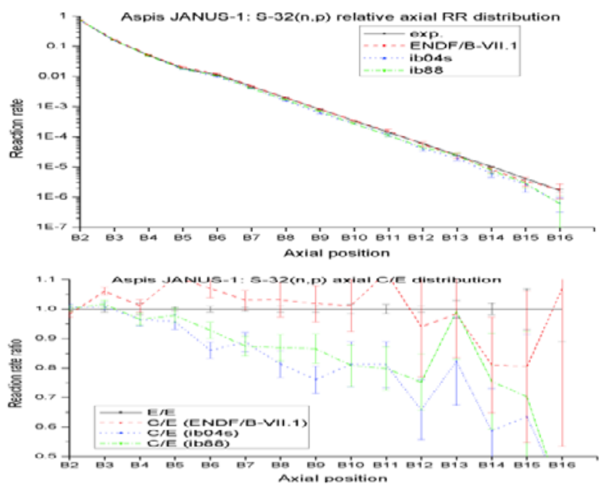

Figure 4. Relative axial ^{32}S(n,p) reaction rate distribution for Aspis JANUS-1. Comparison between experimental data and Monte Carlo simulation using different cross sections for ^{56}Fe.

2.2 Oxygen cross-section validation

The FNS Liquid Oxygen benchmark [9] performed at the 14 MeV D-T neutron facility at FNS/JAERI was considered as suitable for the validation of the new oxygen evaluations prepared in the scope of the CIELO project. In the benchmark the angular neutron leaking spectra from a 20 cm slab of liquid oxygen in the 0.05 - 15 MeV energy range at different angular directions (0, 12.2, 24.9, 41.8 and 66.8 degrees) were measured using the Time of Arrival (TOA) technique.

In 2010 the benchmark was re-analysed and SINBAD compilation updated including complete new revision of time vs. energy domain computational models. The benchmark was found to be of benchmark quality, however more information would be needed on the uncertainty in the neutron effective flight path parameter, on detector efficiency function, details on conversion of experimental TOA to energy spectra.

The analysis was performed using the MCNP-6 Monte Carlo code in the energy and time domain for the oxygen cross sections taken from ENDF/B-VII.1 and new CIELO evaluations by Luiz Leal and Gerry Hale [8]. Results of calculations performed in time domain and converted to energy are presented in Fig. 5. In the past the benchmark was also analysed using DORT with first collision source (GRTUNCL). This approach is suitable for cross-section sensitivity-uncertainty analysis.

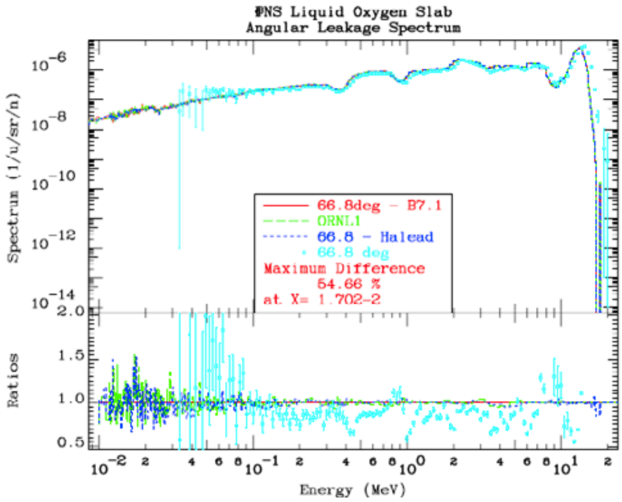

Figure 5. Neutron spectra calculated using the ENDF/B-VII.1 and new evaluations by Luiz Leal (file ORNL1) and Gerry Hale (file "O16_halead") [6] compared to the measured at the FNS-O benchmark at the 66^0 angle.

The main conclusions are the following:
- Relatively good agreement was found between the measured and calculated spectra for Leal, Hale and ENDF/B-VII.1 evaluations, with no significant trends with increasing angle.
- Little difference observed between spectra calculated using MCNP6 with ENDF/B-VII.1, Luiz and Hale files suggests that the benchmark may not be sufficiently selective in this particular case.

2.3 Photon data validation

In the scope of the F4E project the photon libraries available in the MCNP-6 code package were studied, in particular the following sets [10]:
• 04p: ENDF/B-VI.8 Photoatomic Data (MCNP standard library),
• 84p: Update of MCPLIB04 Photon Compton Broadening Data,
• 12p: new library (extended to lower energies).

SINBAD includes two sets of Photon Leakage Spectra benchmarks measured at RFNC-VNIITF (Zababakhin Russian Federal Nuclear Center – All-Russian Scientific Researching Institute of Technical Physics), Snezhinsk [11]:
• NEA-1517/74: Photon Leakage Spectra from Al, Ti, Fe, Cu, Zr, Pb, ^{238}U Spheres with a Central 14-MeV Neutron Source

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• NEA-1517/80: RFNC Photon Spectra from H_2O, SiO_2 and NaCl with a Central 14-MeV Neutron Source.

Both benchmarks used 14-MeV neutron source placed in the center of spherical samples of inside diameter 100 mm and outside diameter 200 mm (see Fig. 6). Absolute measurements were conducted using the activation method and the reaction $^{27}Al(n,\alpha)^{24}Na$. The photon spectrum measurements were conducted using a scintillation detector having a stilbene crystal with dimensions of 60 × 60 mm. Measured energy range is 0.3 - 8.0 MeV. Energy resolution for ^{60}Co lines (1.17 and 1.33 MeV) was about 10%. At energies higher than 3 MeV it was 6-7% and at energies less than 0.5 MeV it was 15-20%.

The results are shown on Fig. 7 indicating good consistency between the measured and calculated spectra. Almost no differences were observed between the 04p, 84p and 12p data for the studied cases (iron and water).

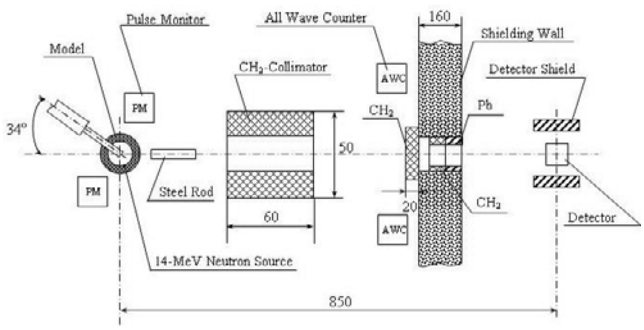

Figure 6. Experimental arrangement of the RFNC photon spectra experiment.

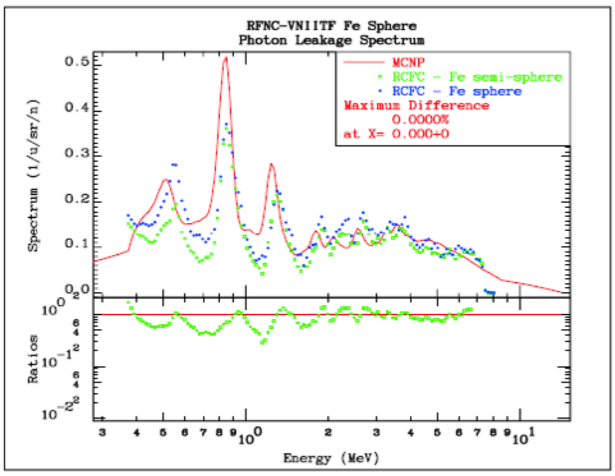

Figure 7. Measured and calculated gamma spectra for the RFNC-VNIITF Iron sphere measurements.

2.4 IRDF-2002 and IRDFF dosimetry data validation

The IAEA Research Coordination Project on "Testing and Improving the International Reactor Dosimetry and Fusion File (IRDFF)" [12] is aimed at updating the library of dosimetry cross sections. Several benchmark experiments performed at the ENEA Frascati Neutron Generator (FNG), and in ASPIS, AEA Technology, Winfrith included in SINBAD were analysed to compare the performance of the new IRDFF and previous IRDF-2002 libraries, to check for improvements between measured and calculated reaction rates and removal of some inconsistent trends in the results for different monitors. An example of results is shown in Fig. 8 below.

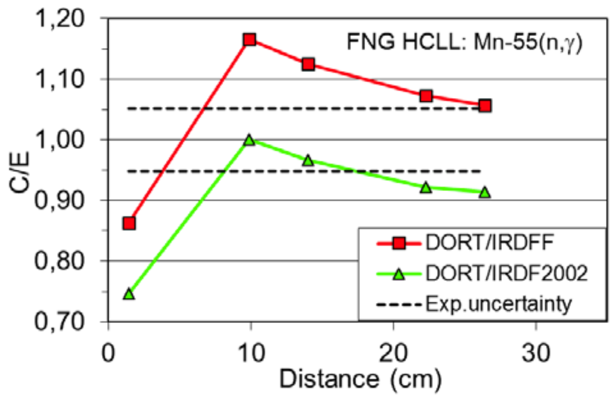

Figure 8. Calculated/Experimental (C/E) $^{55}Mn(n,\gamma)$ detector responses for the FNG Bulk-shield benchmark based on calculations with IRDFF and IRDF-2002 libraries. Dashed lines delimit the ± 1 σ standard deviations of the measurements.

2.5 Computer code testing

The MCNP model of FNG benchmarks presently included in SINBAD makes use of the ENEA-JSI source subroutine. This approach requires a recompilation of MCNP, therefore access to MCNP Fortran source code. As an alternative the replacement of the MCNP subroutine with the MCUNED [13] model was studied, allowing an explicit modelling of DT reactions (see Fig. 9).

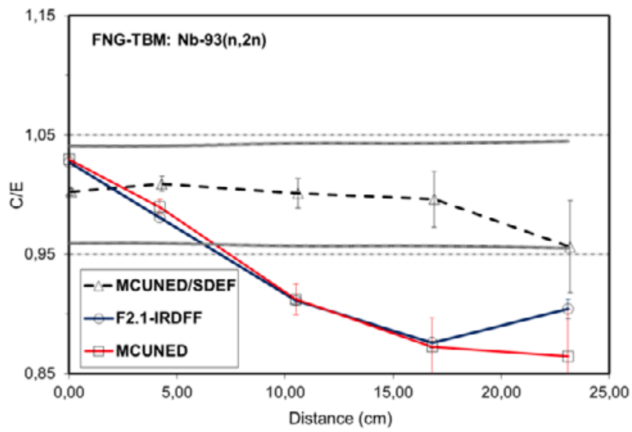

Figure 9. Validation of the MCUNED using the FNG HCPB benchmark experiment.

3 Conclusions

The SINBAD database currently contains compilations and evaluations of experiments for 48 reactor shielding problems, 31 for fusion neutronics shielding and 23 for accelerator shielding cases. 17 experiment re-evaluations to be updated. Revision and classification of benchmark experiments according to the completeness and reliability of information is ongoing in order to provide the users more detailed information on experimental setup, measurements and corresponding uncertainties and in this way facilitate the use of these data.

Results of the analysis of several SINBAD benchmark experiments demonstrate that these data can be useful for modern nuclear data and code validation, provided additional effort is invested in obtaining additional information on the measurements and in developing more detailed computational models for transport calculations. Sensitivity and uncertainty analysis provide a valuable insight into the importance of different nuclear data and reactions involved in the measurements.

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