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INTERNATIONAL NUCLEAR DATA EVALUATION NETWORK (INDEN) ON THE EVALUATED DATA OF STRUCTURAL MATERIALS (5)

Summary Report of the IAEA Consultants Meeting

6 – 9 December 2022

Michal Kostal
Research Centre Řež Ltd
Husinec-Řež, Czech Republic

Georg Schnabel
International Atomic Energy Agency
Vienna, Austria

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IAEA Nuclear Data Section
Vienna International Centre, P.O. Box 100, 1400 Vienna, Austria

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Contents

1. INTRODUCTION

A Consultancy Meeting was held from 6 to 9 December 2022 with the objective of bringing together the collaborators of the INDEN network to discuss the progress made and the issues identified regarding the evaluation of structural materials. The International Nuclear Data Evaluation Network (INDEN), managed by the IAEA, was initiated in 2018 as a platform, with regular meetings of internationally recognized experts to exchange technical information and collaborate on nuclear data evaluation activities with the aim of improving upon the current quality of available nuclear data. The dual focus is convergence of evaluation input data and validation criteria as well as production of evaluated data files for testing, following best evaluation practices. The range of activities is broad and involves besides evaluation work also experimental campaigns, benchmarking to provide evaluation feedback, and methodological developments, in close exchange with national and international evaluation projects.

The focus of discussions at this meeting was the review of the status of evaluations produced within INDEN, including extensive discussions on the observed performance in various types of integral benchmark experiments. Also discussed to a lesser extent were new evaluation methodologies and technical innovations to streamline the organization of the library release process.

Michal Kostal and Georg Schnabel agreed to serve as Rapporteurs of the meeting. Roberto Capote agreed to take on the role of Chairperson to lead through the meeting program consisting of the presentations given by experts from five Member States, OECD/NEA and the IAEA.

2. PRESENTATION SUMMARIES

2.1 Updates to the n+^{63,65}Cu angular distributions, J.D. McDonnell

Progress in the evaluation of neutron reactions on ^{63,65}Cu was presented, focusing especially on the elastic scattering angular distributions.

In the ENDF/B-VIII.0 evaluations, the Legendre coefficients for both isotopes were reconstructed from the resonance parameters up to 300 keV and subsequently smoothed on a coarse energy grid for inclusion in the ENDF-6 format. This procedure produces a discontinuity in the average cosine of the scattering angle between the resolved resonance region and the high energy regions. In this work, it was shown that a simple adjustment to the Legendre coefficients to achieve a smooth transition had a negative impact on integral benchmark performance. The plan was established to base the Legendre coefficients on measured angular distribution data.

2.2 Towards a consistent evaluation of Ni isotopes using a Bayesian network, G. Schnabel

Evaluations in the fast energy range (i.e., above several MeV for structural materials) usually rely on nuclear model codes for a consistent description of all channels. One motivation for employing models is that an evaluation purely based on experimental data proves difficult in this energy region due to the scarcity of data and the need for a consistent treatment of all reaction channels at the same time. This contribution explored an evaluation using Bayesian networks that is mostly based on experimental data and uses a minimum amount of information from nuclear model calculations. The only information used is taken from a previous evaluation from a nuclear data library, i.e., all the evaluated cross section channels, and the second derivative of these excitation functions. The prior was constructed by allowing for a certain variation of the cross section and the second derivative. This prior was then incorporated into a Bayesian network that enforces the consistency of reaction channels. This approach was applied to the evaluation of each nickel isotope individually, resulting in visually pleasing results. Extending the approach further, the individual nickel isotopes were linked within the Bayesian network to enable the inclusion of cross sections measured on natural nickel. It was shown that this extended approach is feasible from the mathematical side and produces reasonable results. In conclusion, the outlined approach opens the possibility to perform evaluations in the fast energy range using only a minimum of information from model calculations.

2.3 NEA processing pipeline, D. Foligno

The preservation of data is a priority at the NEA Data Bank. In this context, “preserving data” means: verifying, processing, sharing, improving, and storing the data. NEA wants to automatize this process as much as possible in order to provide the JEFF community with good quality data. The Data Bank decided to work with GitLab, a web-based distributed version controlled system that allows tracking changes over time and across different users. The Continuous Integration / Continuous Deployment (CI/CD) is a GitLab tool that allows performing unit tests on every commit.

The pipeline is defined by the user in the .gitlab-ci.yml file, placed in the root of the repository. This file contains the description of the stages/jobs, as well as their dependencies. The yaml file is automatically detected by Gitlab, which triggers the pipeline on the runner.

In the NEA GitLab, each isotope has its own repository, containing a nuclear data evaluation, a yaml file, and a read me with the description of the file evolution. Branches and tags are used to identify different versions of the file. Once the pipeline is triggered, the logs of each job appear in the web-based interface like they would do in a local terminal. At the end, the artifacts can either be browsed or downloaded for inspection.

On 14-15th September 2022, NEA organized a hackathon on the NEA Processing Pipeline. Experts from the JEFF nuclear data processing community were invited to give their opinion on the current work and to propose suggestions for future developments. The hackathon was a successful hybrid event, and by the end of the two days, everyone agreed on the content of the pipeline. The current status of the NEA pipeline is shown in Fig. 1.

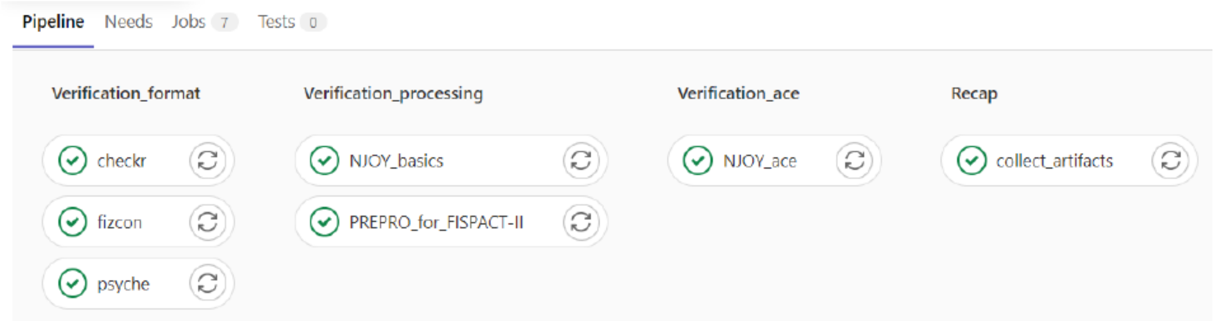

FIG. 1. NEA Pipeline on GitLab

The first stage (Verification_format) consists in using the ENDF-utility codes (CHECKR, FIZCON, and PSYCHE) to review the format of the file and perform physics checks. Warnings and errors must be reviewed by expert users or by the evaluators.

The second stage (Verification_processing) is used to:

- reconstruct resonance cross sections from resonance parameters and cross sections from nonlinear interpolation schemes;
- generate Doppler-broadened cross sections;
- produce effective self-shielded cross sections for resonance reactions in the unresolved energy range;
- generate heat production cross sections and radiation damage energy production;
- add gas production reactions;
- generate plots;
- compare the computed thermal neutron constants with the standards;
- create file 10 activation cross sections;
- generate multi-group cross sections.

The third stage (NJOY_ace) consists in producing the probability tables for unresolved resonance self-shielding, and to prepare the library in the ACE format.

The fourth step (Collect_artifacts) is used to collect and sort the artifacts from previous jobs.

To conclude, the NEA pipeline is an ongoing collaborative effort to standardize the way nuclear data is processed.

2.4 The path to ENDF/B-VIII.1, G. Nobre

The presentation started out with a brief update on the ongoing zirconium evaluation before delving into an extended discussion on the ongoing preparation of the next ENDF/B library release (version VIII.1) planned for 2024. The presentation reviewed the status of ongoing evaluation work, such as for various structural materials, involving various laboratories (LANL, ORNL, RPI, IRSN, etc.). A part of the ongoing work is performed as a collaboration within the International Nuclear Data Evaluation Network (INDEN), maintained and organized by the Nuclear Data Section of the IAEA.

It was mentioned that preliminary “Beta0” version of ENDF/B-VIII.1 had been recently released focusing mostly on INDEN evaluations. In particular, most INDEN evaluations for structural materials were incorporated into the ENDF/B-VIII.1-Beta0 series of releases.

One focus of the presentation was dedicated to explaining the technical workflow for the adoption of new evaluations involving a multi-staged approach within a version control system based on git. Examples of selected evaluations (e.g., Cr) were given to demonstrate technical capabilities of the implemented technical solution, such as the tracking of open issues and the review system.

The presentation concluded by reiterating remarks on the evaluation status of chromium, copper and manganese isotopes.

2.5 INDEN evaluations of Cu, F, Fe, and Mn: The importance of experimental data, R. Capote

Roberto Capote gave a comprehensive overview of the status of ongoing evaluation work on copper, iron, manganese, and fluorine within the International Nuclear Data Evaluation network (INDEN) with a particular focus on comparisons to differential experimental data and integral benchmarks.

A neutron leakage benchmark of a Cu cube with ^{252}Cf(s.f.) neutron source by Schulc. et al. [1] revealed strong under-estimation of measured leakage for ENDF/B-VIII.0 evaluation above 4 MeV, and a very strong overestimation of the JEFF-33 evaluation. Those deficiencies were linked to problems in the evaluated total and elastic cross sections. JEFF-33 total cross section is completely off data, EBDF/B evaluation of the elastic cross section is off data above 4 MeV. Also, alpha emission of ^{63}Cu by ENDF/B.VIII.0 was in complete disagreement with the IRDFF evaluation and off data.

Further analysis revealed that angular distributions of elastic scattering available in ENDF/B.VIII.0 disagreed with the Popov measured data on natural copper up to 300 keV. Additional discrepancies have been identified for ^{63}Cu(n,g). The INDEN evaluation could remove or at least alleviate many of the indicated shortcomings found by comparisons to differential data. Validation with the ICSBEP Zeus Cu benchmark seems to indicate that the INDEN evaluation performs favorably, supporting evaluation choices of the INDEN collaboration. The quasi-differential experiment with a copper sample at RPI [2] seems to agree well with existing evaluations below 4 MeV. The libraries ENDF/B-VII.1, ENDF/B-VIII.0, JEFF-3.3 and JENDL-4.0 all underestimate the experimental measurement. Finally, substituting copper in ENDF/B-VIII.0 by the INDEN evaluation deteriorates results in the Teflon moderated Curie benchmarks. Given that the INDEN evaluation seems to perform better for differential data and that these benchmarks are also sensitive to fluorine-19, also the fluorine data were revisited.

Comparison with experimental data available for the total cross section of ^{19}F reveals discrepancies for ENDF/B-VIII.0 between 0.5 and 1 MeV. Regarding the inelastic channel, two discrepant datasets by Broder and Morgan are available, ENDF/B-VIII.0 and JEFF-3.3 favored Broder data in vicinity of the peak region. A new analysis of the experiments suggested to favor the Morgan experiment due to its agreement with the ^{7}Li(n,ng) recent evaluation. Therefore, it was decided that the INDEN evaluation should follow the lower lying Morgan data. This selection reduces the inelastic cross section of ^{19}F by 40% above 200 keV. Furthermore, issues in the angle-differential elastic scattering cross sections at forward angles were identified and corrected in the INDEN evaluation. The adopted evaluation choices significantly improve the performance in Curie benchmarks, supporting the INDEN evaluation choices for copper and fluorine.

Regarding iron evaluations, iron leakage experiments revealed an underestimation of neutron leakage between 1 and 4 MeV and an overestimation near 300 keV if using ENDF/B-VIII.0 [3]. Furthermore, also the investigation of the elastic and inelastic cross section revealed discrepancies to experimental data sets. Further evidence for problems in the iron evaluation were provided by new transmission measurements at nELBE showing a significant underestimation of measurements. These experimental hints helped in identifying an issue in ^{57}Fe, which is the lack of fluctuations in the total cross section as compared to the available data measured by Pandey. Including the correction in the evaluation does not deteriorate the performance in various stainless steel reflected benchmarks.

The presentation also highlighted problems in ENDF/B-VIII.0 with gammas produced in inelastic and capture reactions for various isotopes, such as Fe, Mg, Ti and Si. The evaluation for Mn could be improved by using information from the EGAF library and EMPIRE nuclear model calculations

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[1] M. Schulc, et al., Nucl. Eng. Tech. **53** (2021) 3151-3157.
[2] E, Blain, et al, Nucl. Sci. Eng. **196** (2022) 121-132.
[3] M. Herman, et al, Nucl. Data Sheets **148** (2018) 214-253.

2.6 Update on ^{56}Fe: DRC calculations and experiments planned at GELINA, M. Diakaki

G. Gkatis[1,2], M. Diakaki[1], A. Mengoni[3,4],
G. Noguere[2], C. Paradela[5], E. Pirovano[6], A. Plompen[5]

[1] *Department of Physics, National Technical University of Athens, 15780 Athens, Greece*
[2] *CEA/DES/IRESNE/DER/SPRC/LEPh, Cadarache, 13108 Saint Paul Lez Durance, France*
[3] *European Organisation for Nuclear Research (CERN), Switzerland*
[4] *ENEA Bologna / INFN, Sezione di Bologna, Italy*
[5] *European Commission, Joint Research Centre, 2440 Geel, Belgium*
[6] *Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany*

In the present contribution, the progress of the calculations of the neutron Direct Radiative Capture (DRC) process for the ^{56}Fe(n,γ) reaction, performed with a dedicated code, developed by A. Mengoni [1, 2], was presented, as well as the new experiments planned at the GELINA facility for the production of new high quality cross-section data of neutron induced reactions on ^{56}Fe and ^{nat}Fe.

The main motivation behind the DRC calculations were issues that had occurred with the ^{56}Fe(n,γ) reaction at previous evaluations, leading to important implementations in the evaluation of the ^{56}Fe(n,γ) reaction in the latest ENDF/B-VIII.0 library. Specifically, an artificial background was added in the energy region 10 eV - 100 keV and the results above 860 keV based on experimental data from the RPI [3] showed an increase of (n,γ) at ~850 keV, where the (n,inl) channel opens. The previously mentioned issues need physical interpretation, and this was attempted via the Direct Radiative Capture mechanism.

First results and sensitivity studies of the optical model parameters were shown at the meeting of last year. Further attempts to better reproduce the experimental data were shown this year, with use of local OMP and the implementation of the compound capture. The latest INDEN-2022 evaluation proposes (based on a new integral measurement) that the artificial background added for the ENDF/B-VIII.0 evaluation in the energy region 10 eV - 100 keV is too high. Based on this reduced value of background in this region and the value at the thermal point, negative resonances must be added in order to properly reproduce the experimental data in both regions. This will be attempted in the near future. Furthermore, the DRC calculation with TALYS was performed and compared to the present results and showed an overall agreement.

Finally, a short presentation of the upcoming experiments at the GELINA facility was given, which are expected to shed light on various issues of the current experimental data on ^{56}Fe. On the one hand, the ^{56}Fe(n,el) measurement with the ELISA setup [4,5] and a highly enriched target will be performed, and on the other hand, the ^{nat}Fe transmission experiments with natural samples of different thicknesses. Both experimental campaigns will take place in 2023.

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2.7 Validation of Fe data with criticality and shielding benchmarks, H. Wu

For CENDL-3.2(C32), the ^{56}Fe(n,inl) cross sections below 4.5 MeV were adjusted according to the ALARM-Cf-Fe-01-07 benchmark (IPPE/Cf-Fe), because there are large discrepancies among different sets of experimental data deduced from the gamma-ray production cross section. However, there is still a bias larger than 10% below 0.85 MeV for the IPPE iron sphere. And the neutron leakage spectrum of the LLNL pulsed sphere above 250 ns was also underestimated. With the ASPIS/Fe-88 benchmark, trends of overprediction of ^{27}Al(n,α) and ^{32}S(n,p) reaction rates were also found when the CENDL-3.2 data were employed. To further improve the Fe data evaluation, the following four points need to be addressed:

- How to deal with the discrepancy in ^{56}Fe(n,inl) cross sections below 4.5 MeV?
- How to improve the prediction of the neutron leakage spectrum above 250 ns for the LLNL pulse sphere experiment?
- How to improve the prediction of the neutron leakage spectrum below 1 MeV for the IPPE/Cf-Fe sphere?
- How to improve the benchmark results for the ASPIS Fe88 experiment, especially for the ^{32}S(n,p) reaction rates?

To answer the above questions, several trial revisions of Fe isotopes were prepared and tested with the shielding and criticality benchmarks sensitive to iron data. The selected shielding benchmarks are the 0.9mfp-thick LLNL pulsed sphere, the 5cm-thick CIAE iron sphere, the IPPE iron sphere (ALARM-Cf-Fe-01-07) and the ASPIS/Fe-88 experiment. The selected criticality benchmarks are HCI5.2, HCI5.3, HMF013, HMF021, HMF084.7, HMF084.19, HMF085.3, HMI001, ICF001, IMF005, PMF015, PMF025, PMF026, PMF028, PMF032 and PMI002.

Firstly, a beta revision for ^{57}Fe data based on the CENDL-3.2, Fe57b0, was made with the resonance parameters replaced with those from ENDF/B-VIII.0 and total cross sections between 0.19-2 MeV energy region were modified to follow the data measured by Harvey (1987). The test results of the ASPIS/Fe-88 experiment show an improved prediction of the ^{27}Al(n,α) reaction rates and that the calculated reaction rates of ^{197}Au(n,γ) were significantly changed compared to the calculation results based on the NP01u3 library.

Secondly, a beta revision for ^{54}Fe data based on the CENDL-3.2, Fe54b0, was evaluated with the resonance parameters replaced with those from ENDF/B-VIII.0, and the (n,n’) cross sections for the discrete levels were evaluated based on the gamma production cross sections measured by Olacel (2018). For the IPPE/Cf-Fe sphere benchmark, the calculated neutron leakage spectrum was changed slightly below 1 MeV, with the ^{54}Fe data changed from the ENDF/B-VII.1 to the Fe54b0. For the ASPIS/Fe-88 experiment, as thickness of the neutron penetration increases, the calculated results of the ^{197}Au(n,γ) reaction rates were changed significantly, since the resonance parameters of the Fe54b0 were quite different from before. The calculated results of the ^{115}In(n,n')^{115m}In reaction rates were improved at the distal end of the shield penetration thickness, since the evaluation of the (n,inl) cross section was guided by the data measured by Olacel (2018).

Thirdly, five revisions of ^{56}Fe data were created and tested with the selected shielding and criticality benchmarks. The influences of differential changes in ^{56}Fe data on the calculation of integral values were studied, namely the substitution of the double differential sections (DDX) for (n,2n) reaction, replacing the resonance parameters, modification of the MT51 cross section at different energy regions, re-evaluation of the MT52 cross section, and changing the amplitude of the MT71 cross section. The following trues were observed through the tests.

- The substitution of the DDX for (n,2n) reaction has shown that the underestimation of the neutron leakage spectrum later than 250 ns from the LLNL pulsed sphere was related to the DDX for the (n,2n) reaction, and the validation results between the CIAE and LLNL pulsed spheres were discrepant. As shown in FIG.1 and FIG.2, a better prediction of the neutron leakage spectrum from the LLNL experiment calculated based on the Fe56b0 led to a hump between 270-350 ns in the calculated result of the CIAE-Fe-5cm sphere.
- Decreasing the cross sections of MT51 between 6-20 MeV by 10% and re-evaluation of the cross section of MT52 with a lower tail above 8 MeV reduced the deviation of the CIAE-Fe sphere neutron leakage spectrum calculation around 170 ns, as shown in FIG.2.

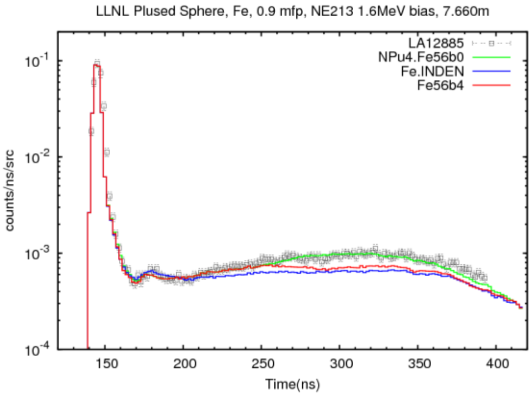

FIG.1. Comparison of the calculated and experimental neutron leakage spectra from the LLNL 0.9-mfp thick iron sphere.

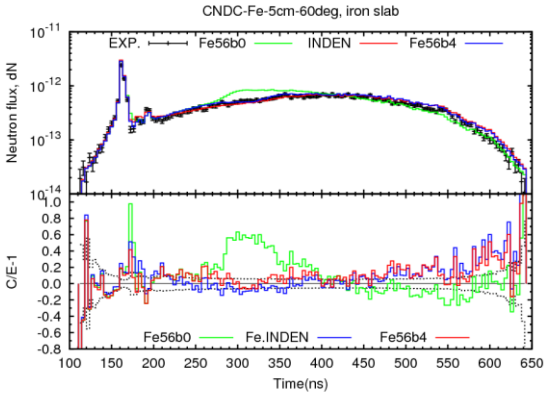

FIG.2. Comparison of the calculated and experimental neutron leakage angular flux from the CIAE 5cm thick iron sphere.

- Revising the MT51 cross sections in the 3.13 - 4.5 MeV energy region using 80%-85% of the experimental data from Negret (2013) improved the C/E values of the reaction rate of ^{32}S(n,p) in the ASPIS/Fe88 experiment significantly, but deteriorated the calculated neutron leakage spectrum of the IPPE/Cf-Fe experiment below 4.5 MeV. So, there are discrepancies between the validation results of the IPPE-Cf-Fe sphere benchmark and the ASPIS/Fe-88 experiment.

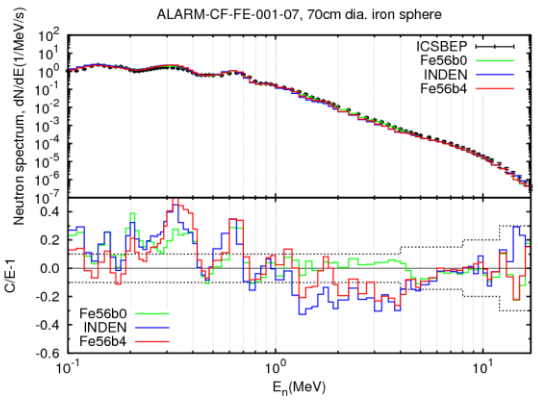

FIG.3. Comparison of the neutron spectra leakage from the 70cm-dia. IPPE iron sphere calculated based on Fe56b0, Fe56b4 and INDEN files with the experimental data.

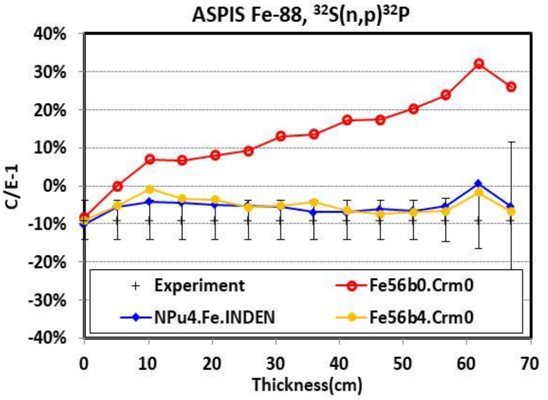

FIG.4. Comparison of the reaction rates of $^{32}S(n,p)$ in the ASPIS/Fe-88 experiment calculated based on Fe56b0, Fe56b4 and INDEN files with the experimental data.

- Adjustment of the MT51 cross sections in the 1.0 - 1.5 MeV energy region based on the IPPE-Cf-Fe experiment improved the calculated reaction rates of the ^{103}Rh(n,n’)^{103m}Rh and ^{115}In(n,n’)^{115m}In reactions in the ASPIS/Fe88 experiment, and showed a better performance of the Fe56b4 revision than the fe56e80X29r61.

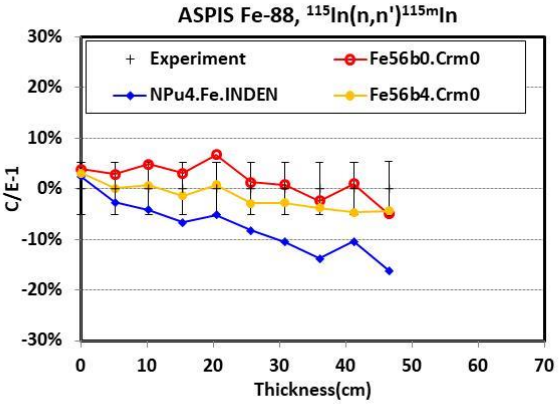

FIG.5. Comparison of the reaction rates of $^{115}In(n,n')^{115m}In$ in the ASPIS/Fe-88 experiment calculated based on Fe56b0, Fe56b4 and INDEN files with the experimental data.

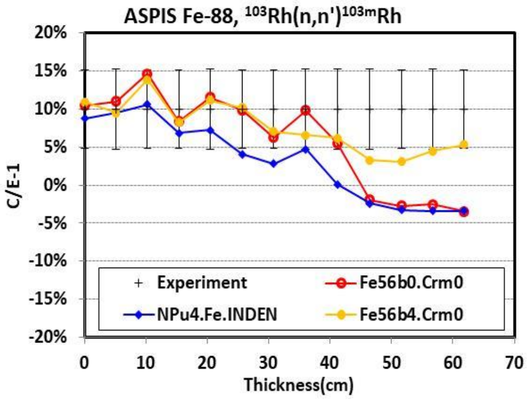

FIG.6. Comparison of the reaction rates of $^{103}Rh(n,n')^{103m}Rh$ in the ASPIS/Fe-88 experiment calculated based on Fe56b0, Fe56b4 and INDEN files with the experimental data.

- The change of resonance parameters not only affects the calculated results of the shielding benchmarks but also the chi square of the criticality benchmarks. Removing the background of the (n,el) reaction increased the calculated neutron leakage spectrum from the IPPE/Cf-Fe sphere around 300 keV. Decreasing the background cross sections of the (n,γ) reaction led to an overall increase of the calculated ^{197}Au(n, γ) reaction rates of the ASPIS/Fe-88 experiment, and at the same time increased the chisquare of the k_{eff} values for the selected criticality benchmarks, as shown in FIG.7 and TABLE 1.

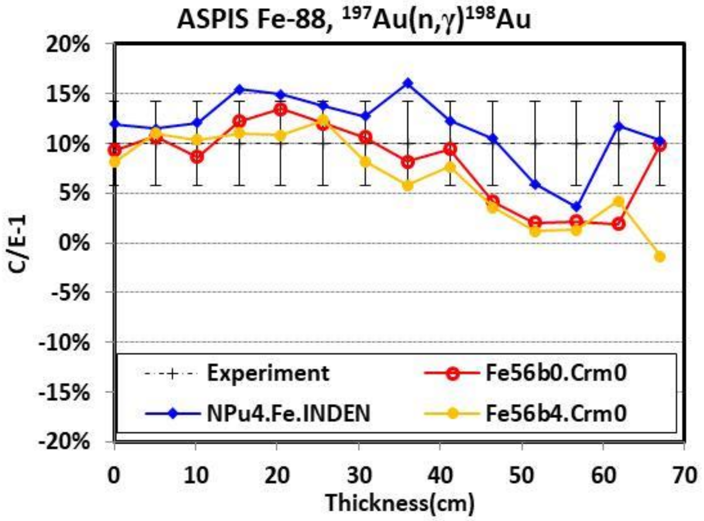

FIG.7. Comparison of the reaction rates of ^{197}Au(n,γ) in the ASPIS/Fe-88 experiment calculated based on Fe56b0, Fe56b4 and INDEN files with the experimental data.

TABLE 1. COMPARISON OF THE CHI-SQUARE VALUES CALCULATED BASED ON DIFFERENT VERSIONS OF RESONANCE PARAMETERS

Library	**Fe56b0**	**Fe56b1**	**Fe56b4**
Source of R.P.	e80X27	e80X29r61	B80
Total χ^2	148.1	202.2	153.9

The above tests and comparison lead to the following suggestions and points for further considerations:

- The experimental data of the LLNL/Fe sphere may not be reliable. At least two benchmarks with the same type should be used in validation, so another integral benchmark employing a D-T neutron source is required.
- A discrepancy between the IPPE/Cf-Fe and ASPIS/Fe-88 ^{32}S(n,p) reaction rates was found. The uncertainties of the neutron leakage spectra of the IPPE/Cf-Fe sphere may be underestimated.
- A lower (n,inl) cross section between 0.85 to 2.9 MeV is preferable.
- The resonance parameters of ^{56}Fe still need to be improved.

2.8 New integral experiments in Řež – neutron and gamma leakage, M. Kostal

The presentation gave an overview of the research infrastructure and experimental methods utilized at the Research Centre Rez. It provided details about the LR-0, LVR-15 and VR-1 reactors as well as the available ^{252}Cf source and the Si-filtered spectrum. The presented experimental methods included neutron spectrometry and gamma spectrometry with either stilbene or high-purity germanium detectors. Also discussed were activation measurements (determination of reaction rates of selected nuclei origin) and flux measurements in prompt gamma production experiments. Selected experimental results were presented, especially the recently published ICSPBEP benchmark ALARM-CF-CU-SHIELD-001 with the neutron leakage flux being the benchmarked quantity.

In addition to ongoing and finalized activities, the presentation also outlined future plans and the pertinence of specific types of measurement for validation. Planned benchmark experiments are leakage measurements using a stainless steel cube, iron sphere and nickel sphere. Reaction rates on the surface will also be measured, and in the case of the stainless steel cube also the reaction rates in various depths.

The value of such integral experiments with mono-elemental materials in which also reaction rates are measured is of significant interest because they can deliver complementary information on the performance of nuclear data libraries. For instance, gamma production experiments with various neutron sources, i.e. employing the ^{252}Cf(s.f.) as well as the Am-Be, Deuterium-Tritium reaction, can help in the validation of capture gammas and gammas produced in inelastic scattering reactions. These cross sections are crucial information for validating the gamma production in nuclear data libraries, which are essential for a correct determination of gamma-induced heating.

Another type of experiments that was discussed during the presentation are critical experiments using a core with a well determined reference field.

The presentation concluded with several remarks about the pertinence of various experiments and methods for the verification and validation of nuclear data, which are summarized in the following paragraphs.

Integral experiments using a ^{252}Cf neutron source and well-defined material slabs or spheres of various materials and dimensions are excellent tools for the validation of cross sections because of the simple geometry, the ^{252}Cf spectrum being a neutron data standard (reducing experimental uncertainties) and hence the more accurate deconvolution to determine cross sections. A spherical geometry seems to be especially well-suited for benchmark experiments.

Regarding pure ^{252}Cf neutron sources, the evaluation of the associated neutron spectrum allows for a realistic estimation of uncertainties related to the deconvolution method. Furthermore, filtering a ^{252}Cf spectrum using silicon offers the possibility to verify response matrices used in the evaluation of benchmark measurements. Regarding the source strength, the neutron flux from available ^{252}Cf neutron sources is not high, as the strongest available sources have a neutron emission flux of about $3*10^9$ neutrons per second. This comparatively small flux necessitates the use of thick foils which in turn require well-characterized detectors and, importantly, need to be accompanied by a realistic computational model.

The driver core in the LR-0 reactor possesses a well-characterized reference neutron field and is therefore a valuable facility for validating cross sections of structural materials. Criticality experiments can be realized by placing a material either in the centre of the core or install it as a reflector. Furthermore, gamma and neutron spectra can be determined at various locations. To underline the benefit of such experiments, we can mention the successful implementation of several experiments with a steel baffle, effectively acting as a neutron reflector, that revealed discrepancies between measured and calculated k_{eff} values. This finding implies issues in the neutronic description of steel. Another successful experiment in the LR-0 reactor core using LiF-NaF revealed large discrepancies between calculated and measured neutron spectra, indicating issues with the description of fluorine in the current ENDF/B.VIII library.

Integral experiments dedicated to the benchmarking of gamma production are promising tools for resolving remaining issues in nuclear data libraries related to gammas. In particular, the adoption of water as a solvent thermalizes the neutrons so that gammas produced by thermal neutron capture can be studied. Furthermore, Am-Be sources are pertinent sources as they can be used for validating gammas stemming from inelastic scattering processes involving light elements.

Finally, experiments using independent measurement techniques, such as the proton recoil method combined with activation measurements, offer complementary information to the ones discussed above.

2.9 Evaluation results of ^{56}Fe in JENDL-5, N. Iwamoto

The latest Japanese evaluated nuclear data library JENDL-5 was released in December 2021. The main aim of producing JENDL-5 was to accommodate a variety of needs for the development and decommissioning of nuclear reactors and other facilities (e.g., accelerators), and for radiation applications. JENDL-5 is a generic term used to refer to 11 sublibraries: neutron, proton, deuteron alpha-particle, photon, and so on. The neutron sublibrary contains the nuclear data of 795 nuclides. For this sublibrary four derived data (0K and 300K pointwise data, u20 data and activation data) were prepared on the basis of the original neutron nuclear data. The reference paper has been published in the Journal of Nuclear Science and Technology (see: https://www.tandfonline.com/doi/full/10.1080/00223131.2022.2141903).

In structural materials ^{56}Fe is one of the important nuclides. Its abundance (91.8%) covers most of natural iron. Therefore, I focused here on the evaluation results of neutron nuclear data on ^{56}Fe in JENDL-5. The resonance parameters in the resolved resonance region and cross sections in the unresolved resonance region were taken from JENDL-4.0 [1]. The parameters of negative resonance were, however, modified to reproduce measured thermal values because the capture cross section was changed with the addition of a direct capture component as the background cross section. The cross sections, angular distributions, and double differential cross sections were evaluated by the nuclear reaction model code CCONE [2]. The reaction-wise data were provided below 20 MeV. The production data of particles and nuclides were given between 20 and 200 MeV. The covariance was estimated up to 20 MeV by the CCONE-KALMAN system. Total, elastic scattering, nonelastic scattering and (n,2n) reaction cross sections with uncertainties were shown, and the difference in the elastic scattering cross section above 40 MeV between JENDL-5 and JEFF-3.3 is remarkable. Since the capture cross section in the region of 1 keV to several tens of keV was reported to affect a benchmark test (ICSBEP HMI-001), the direct capture component was added with the cross section computed based on the theoretical formulation given in [3], by which partial wave components can be calculated and each cross section can be output. The capture cross section of JENDL-5 lies between those of ENDF/B-VIII.0 and JEFF-3.3 around 10 keV. The (n,p) and (n,α) reaction cross sections were shown together with proton and alpha-particle production cross sections. For the (n,p) reaction cross section which is important as a monitor one, many measured data are available and JENDL-5 shows a good match with them. The elastic scattering mubar was presented. Angular distributions were basically calculated by CCONE, but in the region of 35 keV to 4 MeV measured angular distributions were fitted and the obtained Legendre coefficients were adopted for JENDL-5. The evaluated partial inelastic scattering cross sections were shown. The present cross section of inelastic scattering to the first excited level is smaller than those of Negret et al. [4], especially below 0.94 MeV. This result was supported by benchmark tests.

References:

[1] K. Shibata, O. Iwamoto, T. Nakagawa, et al., J. Nucl. Sci. Technol. **48** (2011) 1.

[2] O. Iwamoto, N. Iwamoto, S. Kunieda, et al., Nucl. Data Sheets **131** (2016) 259.

[3] F. Minato and T. Fukui, EPJ Web of Conference **163** (2017) 00037.

[4] A. Negret, C. Borcea, Ph. Dessagne, et al., Phys. Rev. C**90** (2014) 034602.

2.10 RPI – Nuclear data for structural materials, Y. Danon

Yaron Danon presented on recent measurements and evaluation results for structural materials which included Iron, lead, zirconium, and Cu.

Fe-56 was previously measured at RPI in transmission [1], capture [2], in the resonance region, and fast neutron scattering [3]. The current effort on iron includes measurement and evaluation of ^{54}Fe in the resonance region. Measurements of a 96% enriched sample were made using an array of a C_6D_6 detector at a flightpath distance of 45m, and transmission at a flight path distance of 30m, both measurements added new information particularly in the lower energy range (<100 keV) where a discrepancy between evaluations and previous data where observed.

A project for lead isotopes evaluation is ongoing at RPI and full range evaluations for ^{206}Pb and 208 were completed and delivered to NNDC for consideration in inclusion in ENDF/-8.1. The ^{207}Pb resonance region evaluation was completed, and the fast region is in progress. For ^{208}Pb, a significant improvement was achieved by extension of the RRR to 1.5 MeV and the generation of angular distribution from resonance parameters. An automated methodology was used to find resonance spins so that the new evaluation will best match quasi-integral measurements [4]. The new evaluations resulted in improved critical benchmark performance in the fast energy region.

Measurements of Zr scattering in the keV energy range were discussed, the data covers the energy range from 2 to 1000 keV. Overall, there is good agreement between different evaluations and the experiment, one exception being JEFF-3.3 which is significantly higher for back angles and energy above 200 keV.

Similar scattering measurements for Cu in the keV energy range [5] were also discussed. The evaluations seem to agree with each other and with the experiment with some exceptions near 3 keV.

References:

[1] Y. Danon, A.M. Daskalakis, B. McDermott, et al., Recent Developments in Nuclear Data Measurement capabilities at the Gaerttner LINAC Center at RPI, EPJ Web Conf. **111**, 2016, pp. 02001, DOI:10.1051/epjconf/201611102001.

[2] B. McDermott, E. Blain, N. Thompson, et al., ^{56}Fe capture cross section experiments at the RPI LINAC Center, EPJ Web Conf. **146**, 2017, pp. 11038, DOI:10.1051/epjconf/201714611038.

[3] A.M. Daskalakis, E.J. Blain, B.J. McDermott, et al., Quasi-differential elastic and inelastic neutron scattering from iron in the MeV energy range, Ann. Nucl. Energy **110** (2017) 603 - 612, DOI:10.1016/j.anucene.2017.07.007.

[4] Amanda E. Youmans, J. Brown, A., et al., Fast Neutron Scattering Measurements with Lead, AccApp **15**, Washington, DC, November 10-13, 2015, pp. 355-360.

[5] E. Blain, Y. Danon, D.P. Barry, et. al, Measurements of Neutron Scattering from a Copper Sample Using a Quasi-Differential Method in the Region from 2 keV to 20 MeV, Nucl. Sci. Eng **196** (2022) 121-132, DOI:10.1080/00295639.2021.1961542.

3. SUMMARY AND CONCLUSION

This meeting on structural materials within the International Nuclear Data Evaluation Network (INDEN) managed by the IAEA brought together internationally recognized experts with expertise in nuclear data evaluation, experimental nuclear physics, benchmarking and evaluation methodology.

Overall, the presentations and discussions demonstrated the significant progress made in the evaluations that have been produced by participants of the INDEN network in a collaborative effort, demonstrating the value of this international network for improving the quality of nuclear data. The identified open issues and on-going evaluation work make the INDEN network an essential platform for future collaboration and knowledge sharing.

Appendix 1

IAEA Consultancy Meeting of the International Nuclear Data Evaluation Network (INDEN)
on the Evaluated Data of the Structural Materials

6 – 9 December 2022
IAEA, Vienna

ADOPTED AGENDA

Tuesday, 6 December (starting 13:30, open 13:15 Vienna time, breaks as needed)

13:30 - 17:00	**Opening of the meeting,** A. Koning / NDS Section Head **Election of Chair and Rapporteur(s), adoption of Agenda**	
	Welcome and introduction, Georg Schnabel	
	Participants' Presentations (~30' each)	
14:00	J. McDonnell	Evaluation and validation of the n+^{63,65}Cu cross sections
	G. Schnabel	Towards a consistent evaluation of Ni isotopes with a Bayesian network
	D. Foligno	OECD/NEA pipeline developments
	G. Nobre	The path to ENDF/B-VIII.1

Wednesday, 7 December (starting 13:30, open 13:15 Vienna time, breaks as needed)

13:30 - 17:00	**Participants' presentations** cont'd (~30' each)	
	R. Capote	On Fe and Cu evaluations
	M. Diakaki	DRC development and Fe56 measurements at JRC Geel
	H. Wu	Validation of Fe data with shielding and criticality benchmarks

Thursday, 8 December (starting 13:30, open 13:15 Vienna time, breaks as needed)

13:30 - 17:00	**Participants' presentations** cont'd (~30' each)	
	M. Kostal	New integral experiments in Rez – neutron and gamma leakage
	N. Iwamoto	Evaluation results of ^{56}Fe in JENDL-5
	Y. Danon	RPI – Nuclear Data for structural materials

Friday, 9 December (starting 13:30, open 13:15 Vienna time, breaks as needed)

13:30 – 17:00	**Participants' presentations** cont'd (~30' each)	
	G. Schnabel	Towards a consistent evaluation of Ni isotopes with a Bayesian network (cont')
	R. Capote	On Fe and Cu evaluations (cont')
	Technical Discussions & drafting of the meeting summary report	
	Closing of the meeting	

Appendix 2

PARTICIPANTS

Country		Name	Surname	Affiliation	Email
CHINA	🎧	Haicheng	WU	China Institute of Atomic Energy	haicheng@ciae.ac.cn
CZECH REPUBLIC		Michal	KOŠŤÁL	Research Centre Rez	michal.kostal@cvrez.cz
FRANCE	🎧	David	BERNARD	CEA Cadarache	david.bernard@cea.fr
	🎧	Luiz	LEAL	Institut de radioprotection et de sûreté nucléaire	luiz.leal@irsn.fr
GREECE	🎧	Maria	DIAKAKI	National Technical University of Athens	diakakim@central.ntua.gr
JAPAN	🎧	Nobuyuki	IWAMOTO	Japan Atomic Energy Agency	iwamoto.nobuyuki@jaea.go.jp
SLOVENIA	🎧	Andrej	TRKOV	Jozef Stefan Institute	andrej.trkov@ijs.si
SWITZERLAND	🎧	Dimitri	ROCHMAN	Paul Scherrer Institute	dimitri-alexandre.rochman@psi.ch
USA	🎧	Gustavo	NOBRE	Brookhaven National Laboratory	gnobre@bnl.gov
	🎧	Jordan	McDONNELL	Oak Ridge National Laboratory	mcdonnelljd@ornl.gov
	🎧	Marco	PIGNI	Oak Ridge National Laboratory	pignimt@ornl.gov
	🎧	Yaron	DANON	Rensselaer Polytechnic Institute	danony@rpi.edu
INT. ORGANIZATION	🎧	Stefan	KOPECKY	European Commission, Joint Research Centre	stefan.kopecky@ec.europa.eu
	🎧	Daniela	FOLIGNO	OECD Nuclear Energy Agency	daniela.foligno@oecd-nea.org
		Georg	SCHNABEL	International Atomic Energy Agency	g.schnabel@iaea.org
		Roberto	CAPOTE	International Atomic Energy Agency	r.capotenoy@iaea.org
		Arjan	KONING	International Atomic Energy Agency	a.koning@iaea.org

Appendix 3

PRESENTATION LINKS

#	Author	Title	Link
1	J.D. McDonnell	Updates to the n+^{63,65}Cu Angular Distributions	PDF
2	G. Schnabel	Towards a consistent evaluation of Ni isotopes using a Bayesian network	PDF
3	G. Nobre	The path to ENDF/B-VIII.1	PDF
4	D. Foligno	NEA Processing Pipeline	PDF
5	R. Capote	INDEN evaluations of Cu, F, Fe, and Mn: The importance of experimental data - Part I	PDF
6	M. Diakaki	Update on ^{56}Fe: DRC calculations and experiments planned at GELINA	PDF
7	H. Wu	Validation of Fe data with criticality and shielding benchmarks	PDF
8	M. Kostal	New integral experiments in Rez - neutron and gamma leakage	PDF
9	N. Iwamoto	Evaluation results of ^{56}Fe in JENDL-5	PDF
10	Y. Danon	RPI - Nuclear Data for structural materials	PDF
11	R. Capote	INDEN evaluations of Cu, F, Fe, and Mn: The importance of experimental data - Part II	PDF

Nuclear Data Section
International Atomic Energy Agency
Vienna International Centre, P.O. Box 100
A-1400 Vienna, Austria

E-mail: nds.contact-point@iaea.org
Fax: (43-1) 26007
Telephone: (43-1) 2600 21725
Web: http://nds.iaea.org