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Further Development of the Fusion Evaluated Nuclear Data Library (FENDL)

Summary Report of the Consultants Meeting
30 October – 2 November 2023

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Ljubljana, Slovenia

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Contents

1. INTRODUCTION

A Consultancy Meeting was held from 30 October to 2 November 2023 with the objective of discussing the further development of the Fusion Evaluated Nuclear Data Library (FENDL). As a FENDL reference paper for FENDL-3.2b was just submitted before the meeting, meeting participants reviewed the work done, discussed issues discovered in the meantime and made recommendations on how to address them. Another important topic during this meeting was the collection of recommendations for a major FENDL release.

The meeting was held in hybrid form with 14 participants on-site and 9 participants online from 8 member states and one international organization. Arjan Koning, the head of the IAEA Nuclear Data Section welcomed the participants and summarized recent developments at the IAEA-NDS. Georg Schnabel, the technical officer of the meeting, informed participants about the meeting formalities. Ulrich Fischer agreed to be the chairperson and Andrej Trkov to serve as the rapporteur of the meeting.

2. PRESENTATION SUMMARIES

Participants' presentation summaries are given below. Full versions of their individual presentations are available at: https://conferences.iaea.org/event/373/contributions/

2.1 A brief history of the FENDL Nuclear Data Library for Fusion, U. Fischer

The history of the FENDL project and the associated nuclear data libraries is reviewed. The origin dates back to the mid 1980ies when the US and the Soviet Union agreed on a collaborative international effort to develop fusion energy for peaceful purposes. After some negotiations, an agreement was reached among the European Union, Japan, the Soviet Union and the USA to jointly pursue the design for a large international fusion facility, called ITER – International Thermonuclear Experimental Reactor. Subsequently the FENDL (Fusion Evaluated Nuclear Data Library) project was initiated at the IAEA Nuclear Data Section (NDS). In an Advisory Group Meeting (AGM) on "Nuclear Data for Fusion Reactor Technology" held at Gaussig, German Democratic Republic, 1-5 December 1986, experts from all over the world developed first ideas for the development of an "evaluated nuclear data file dedicated to the design of the ITER fusion reactor". In a Specialists Meeting on "Fusion Evaluated Nuclear Data Library Related to the ITER Activity" held at the IAEA/NDS, 16 -18 November 1987, the FENDL project was finally launched. A pre-selection of candidate evaluations for the first library version, FENDL-1, was made and criteria for the selection of the data evaluations from the then available regional/national data files was elaborated. The final selection was performed in a series of Specialists and Advisory Group Meetings. FENDL-1 was finally released in 1994 including evaluated data files in ENDF6 format and processed files in multi-group and ACE pointwise data format, accompanied by sub-libraries for activation, dosimetry, charged particles and decay data.

The subsequent efforts to update the data evaluations to the then state-of-the-art led to the improved FENDL-2 library which was released in 1997/98 and from then on served as primary nuclear data source for ITER. In 2003, a Consultants' Meeting recommended a further update with suitable up-to-date data evaluations to remove apparent deficiencies and replace obsolete evaluations. A new sub-version, FENDL-2.1, was compiled and subsequently released together with working libraries. FENDL-2.1 since then served as reference data library for ITER neutronics calculations.

FENDL-3, the next major library release, was developed in the frame of a Coordinated Research Project (CRP) from 2008 to 2012. FENDL-3 includes major extensions and updates with regard to the covered neutron energy range (up to 150 MeV to serve also the needs of the IFMIF fusion neutron source), the library contents (number of isotopes, reactions considered, etc.) and the quality (improved evaluations for many isotopes and reactions, including gas production data and secondary energy-angle distributions). FENDL-3 was formally adopted as new reference data library for ITER. Further up-dates to FENDL-3.0 were subsequently produced to solve problems identified later in some evaluations and the processing of the data files. This led to the current version FENDL-3.2, released with sub-version 3.2b in January 2022.

2.2 Potential impact of new evaluated data files on the FENDL library, A. Trkov

This presentation provided a comprehensive review of evaluation and validation efforts within the International Nuclear Data Evaluation Network (INDEN) and the potential impact these evaluations may have on FENDL, once adopted. This summary lists some key developments only. Detailed comparison plots and conclusions can be found in the presentation slides.

The ^{235}U and ^{238}U evaluation in FENDL has been taken from ENDF/B-VII.1 with data from JENDL-HE in the high-energy range (up to 60 MeV). INDEN evaluations show improved performance in criticality benchmarks but only extend up to 30 MeV. For a possible adoption in FENDL, they would therefore need to be extended to 60 MeV.

A lot of effort went into the INDEN ^{56}Fe and ^{57}Fe evaluation. The Rensselaer Polytechnic Institute (RPI) and CV Rez reported excellent validation results for ^{56}Fe. Regarding ^{57}Fe, the nELBE thick transmission experiment by Junghans, Beyer, et al., enabled the resolution of a long-standing problem related to the overestimation of the neutron leakage below 1 MeV. The adoption of the ^{56}Fe INDEN evaluations by FENDL would require the repetition of several benchmarks.

^{28,29,30}Si FENDL evaluations are from ENDF/B-VII.1, with data from JENDL-4/HE for an extension to 60 MeV. Within INDEN, a major re-evaluation of the Resolved Resonance Range (RRR) was performed for these isotopes, including the treatment of the direct capture component. The new evaluations extend up to 150 MeV. The (n,p) reactions were renormalized to IRDFF-II and some additional information on missing particle distributions was added for ENDF/B-VIII.1.

The current ^{55}Mn evaluation in FENDL was performed in 2011 (within the predecessor framework of INDEN). Recently, the capture gamma production cross section was improved by utilizing data from EGAF. Noteworthy, the update does not impact neutronics benchmarks. The evaluation goes up to 60 MeV.

^{50,52,53,54}Cr evaluations in FENDL were adopted from INDEN in 2020. Since then, refinements to the RRR were made for all these isotopes.

Current ^{63,65}Cu evaluations in FENDL are from ENDF/B-VII.1 with extensions to 60 MeV from JENDL-4/HE. A new INDEN evaluation was performed for ^{63}Cu with an RRR update (in particular capture) effected by a collaboration involving IAEA, JSI and ORNL and with an update of the fast range by IAEA and JSI. For ^{65}Cu, the new INDEN evaluation features revised capture data and an update to the fast region performed by IAEA and JSI. It has been checked that (n,p) and (n,α) reactions are consistent with IRDFF-II and the evaluation was also validated in a ^{252}Cf(s.f.) neutron leakage experiment performed by CV Rez. The evaluation extends to 150 MeV and exhibits significantly improved performance in criticality and leakage benchmarks.

The evaluations for ^{10}B and ^{11}B in FENDL have been performed at Los Alamos National Laboratory (LANL) in 2017 and 1989, respectively. The INDEN collaboration recommends adopting ENDF/B-VIII.0 with patches for consistency with IRDFF-II (coinciding with the evaluation in the Neutron Data Standards project).

The ^{19}F evaluation in FENDL was performed by CNDC and ORNL in 2003. The current INDEN evaluation uses ENDF/B-VIII.0 as the basis to preserve gamma emission and additionally includes angular distributions measured by Elwyn and inelastic data for the first two levels measured by Morgan. The improvement in criticality benchmarks is huge and the new evaluations have also been validated in new RPI experiments. However, the evaluation extends only up to 20 MeV.

In conclusion, several new evaluations have been performed within INDEN. In particular, Fe, Cr, Cu and ^{19}F show significant improvement in shielding and criticality benchmarks. The adoption of these new evaluations in the FENDL project would require the re-evaluation of several benchmarks. In case these evaluations are adopted by the FENDL project, a formal extension to 60 MeV will be mandatory.

2.3 Recent progress in JENDL charged particle files, S. Nakayama

Proton and deuteron sub-libraries are included in FENDL-3.2b, but the charged particle sub-libraries consist of relatively old data (TENDL-2011 and JENDL/HE-2007), except for some nuclides. The need to revise these data for the next FENDL was suggested. In addition, some alpha-particle data are needed in the fusion application field [1]. In JENDL-5, the sub-libraries for three charged particles (proton, deuteron, and alpha-particle) are included. As candidates for adoption into the next FENDL, an overview of these sub-libraries and their advantages over previous libraries was presented. For the proton sub-library, it was suggested that the files taken from JENDL/HE-2007 and TENDL-2011 be replaced with JENDL-5 and the latest versions of TENDL at the time of the next FENDL release. In addition, the ^{7}Li file should be replaced with the revised JENDL-5 file because the first published version of JENDL-5 has deficiencies regarding gamma-ray production data. For deuteron sub-libraries, it was proposed to replace the files obtained from TENDL-2011 with the latest version of TENDL. Although the above applies to most nuclides, it was proposed to replace the files of ^{27}Al, ^{63,65}Cu, and ^{93}Nb with those of JENDL-5. As for alpha-particle data, these would be newly included according to the needs from the fusion application field. If they are included, the candidate is to supplement JENDL-5 with TENDL.

References:

[1] M. Gilbert, (α,n) nuclear data evaluations and data needs", in Report INDC(NDS)-0836 (2022), IAEA, Vienna, https://nds.iaea.org/publications/indc/indc-nds-0836.pdf.

2.4 Fusion related activities at CV Rez, M. Kostal

The Centrum výzkumu Řež (CV Řež) has various particle sources at its disposal for performing fusion-relevant measurements, which are among others a cyclotron, a D-T generator and a ^{252}Cf(s.f) neutron source.

The stilbene neutron spectrometer available at CV Rez has been well-validated using a ^{252}Cf and a Si-filtered neutron spectrum and also at Physikalisch-Technische Bundesanstalt (PTB). Measurements of the neutron leakage beam and neutron background of the IBA cyclotron during the generation of ^{18}F via the ^{18}O(p,n)^{18}F reaction have been performed with the stilbene spectrometer. The comparison to simulations revealed a significant discrepancy for back-scattered neutrons. Measurements of reaction rates (RR) using various foils showed large discrepancies in the upper energy range. For instance, the RR in the ^{nat}Ni(n,x)^{57}Co activation foil at 63.43° is underestimated by about 89%. These measurements indicate that the characterization of leakage spectra is not satisfactory.

The ^{58}Ni(n,x)^{57}Co reaction has been validated in ^{235}U PFNS (in the VR-1 reactor) and in a quasi-monoenergetic neutron field produced via the ^{7}Li(n,p) reaction. Good agreement to measured Spectrum Average Cross Sections (SACS) was observed for the ^{235}U PFNS validation case while a need to better characterize the spectrum measurement via Time-of-Flight (TOF) for the quasi-monoenergetic field case has been identified.

Gamma spectrometry is possible via a High-Purity Germanium (HPGe) detector, for which a response matrix has been recently developed and validation performed with an AmBe+^{24}Na neutron source. Measurements of leakage gammas associated with $MnSO_4$, $FeSO_4$ and NaCl dissolved in water were performed with a HPGe and a stilbene detector using a ^{252}Cf source. Comparisons to calculations show a significant overprediction of the photon flux for all tested nuclear data libraries (ENDF/B-VIII.0 and JEFF-3.3).

Furthermore, results from an integral experiment with a ^{252}Cf(s.f.) have been presented for stainless steel (A-320). The INDEN evaluation performs better than ENDF/B-VIII.0 and will be adopted in ENDF/B-VIII.1.

In conclusion, a large portion of fission-related research is also pertinent to fusion research. For example, the Cf shielding experiment is a valuable for the validation of FENDL as it covers the lower energies, which is relevant for the design of breeding blankets. However, the undertaken experiments also indicated an insufficient understanding of the neutron leakage spectra associated with the production of ^{18}F via $^{18}O(p,n)^{18}F$. Also, the characterization of high energy gammas needs to be improved, and the measurement methodology developed in Rez is suitable for this purpose.

2.5 Current FENDL activities at the University of Wisconsin-Madison, T. Bohm

The impact of the new INDEN evaluation of ^{56}Fe (labelled fe56e80X29r67 on the INDEN website [1]) and of ^{19}F was studied in several computational benchmarks using the MCNP Monte Carlo transport code.

The first considered computational benchmark, ITER1 1-D, exhibits cylindrical symmetry and is based on an early ITER design. It was developed for the FENDL evaluation process and features a simple but realistic model of ITER with three regions: an inboard region, the plasma and an outboard region. Deuterium-tritium fusion is assumed, producing 14.1 MeV neutrons. Flux of neutrons and photons, heating, displacement-per-atom (dpa) and gas production are calculated for all locations. The benchmark geometry and composition are documented and described in [2]. The benchmark was run with versions 2.1, 3.1d, 3.2b, ENDF/B-VIII.0 of FENDL as well as with FENDL-3.2b in combination with the INDEN ^{56}Fe evaluation. The calculated neutron flux and total nuclear heating using FENDL-3.2b and FENDL-3.2b augmented with INDEN ^{56}Fe are quite close to each other and closer to FENDL-2.1 than both FENDL-3.1d and ENDF/B-VIII.0.

The second considered computational benchmark, FNSF 1-D [3], also features cylindrical symmetry and is a model of the Fusion Nuclear Science Facility (FNSF) which has been created by the Fusion Energy Systems Studies (FESS) collaboration. It has a breeding zone composed of a helium-cooled steel structure and a lead-lithium breeder. The model consists of 85 radial zones, which include SiC flow channel inserts in the breeding zone, face plates and fillers for the structural ring, the vacuum vessel and the low-temperature shield, inboard, outboard magnet and cryostat. The MCNP material specifications for this model were created with the neutronics materials functions in the PyNE software package [4].
The neutron flux and total nuclear heating were compared for the same nuclear data scenarios as in the first benchmark. Concerning neutron flux, FENDL-3.2b and FENDL-3.2b with the ^{56}Fe INDEN evaluation show good agreement except for a discrepancy observed at the outboard low-temperature shield (OB LTSh), which contains a water-cooled borated steel filler. The agreement in total nuclear heating is good, also at the OB LTSh. Generally, good agreement was observed for the Tritium Breeding Ratio (TBR), dpa and helium production.

The third and last computational benchmark considered is a model of a fluorine-lithium-beryllium (flibe) blanket. The molten salt 2(LiF)-1(BeF_2) is sometimes proposed as a liquid blanket and, for example, considered by Commonwealth Fusion Systems for their reactor design. The benchmark model is based on the FESS-FNSF design but contains a modification of the blanket: The breeding zone has a 2 cm Be multiplier layer and a flibe breeder tank. Two fluorine evaluations (associated with the labels f19j4HE_zc and f19e80_zt9 on the INDEN website), both performed within INDEN, have been benchmarked. Regarding the neutron flux, the f19e80_zt9 evaluation leads to about 10% higher flux behind the inboard flibe breeder zone and about 20% higher flux behind the outboard flibe breeding zone compared to FENDL3.2c with mcplib84. For the f19j4HE_zc evaluation, these numbers are about 20% and 70%, respectively. The possible larger neutron flux (associated with the INDEN f19j4HE_zc evaluation) would require an additional shielding of 3 cm for the inboard (IB) and 17 cm for the outboard (OB). For reference, the Commonwealth Fusion Systems flibe immersion blanket is 25 cm thick at the IB and 110 cm thick at the OB. The impact of the new evaluations on the TBR is small (about a one percent increase). This increase is good for reactor design since flibe designs tend to need more margin to be tritium self-sufficient.

After the computational benchmark studies, the presentation elaborated on the creation of weight windows (WW). The WW generation options ADVANTG (FW-CADIS) and MAGIC were discussed, the former based on discrete ordinates transport and the latter on using MC responses and their spatial distribution from previous runs of a Monte Carlo transport code. To start with a simple test case, the

MAGIC approach was tested on the FNSF 1-D model. It was demonstrated that neutron tracks can easily make it to deep regions in the model and the statistical consistency seems to be preserved (based on the results of ten statistical checks) with a figure of merit much higher for neutron responses in deep locations.

Possible future work is to apply the MAGIC approach in a refined way for 1-D benchmarks, the addition of weight windows for photons, and the addition of other tallies to guide the creation of weight windows. The adoption of ADVANTG using FW-CADIS may also be considered. Furthermore, more 1-D benchmarks may be developed, such as a benchmark model for an updated ITER design, the EU-DEMO helium-cooled pebble bed and water-cooled lead-lithium breeding blanket, the UK Spherical Tokamak for Energy Production (STEP), General Atomics GAMBL (SiC, PbLi waterfall blanket), the CFS flibe immersion blanket, and inertial confinement designs. Sensitivity studies and uncertainty analysis of important neutronics responses for a variety of 1-D models may also be performed. Finally, the study of activation responses with various activation libraries may also be pertinent.

References:

[1] https://nds.iaea.org/INDEN/

[2] M. Sawan, FENDL Neutronics Benchmark: Specifications for the Calculational and Shielding Benchmark, Report INDC(NDS)-316, December 1994, https://nds.iaea.org/publications/indc/indc-nds-0316/

[3] T. Bohm, A. Davis, et al., Initial Neutronics Investigation of a Liquid Metal Plasma-acing Fusion Nuclear Science Facility", Fusion Science and Technology 75 (2019) 429.

[4] https://pyne.io/

2.6 Covariance methodology for the FENDL project, G. Schnabel

With advances in computer hardware and simulation software comes the demand for more rigorous uncertainty quantification (UQ) of nuclear data stored in data libraries. FENDL evolved over more than 30 years and, for a long time, UQ was not a requirement. Only about one third of the nuclides in the transport library contain covariance matrices, and important structural materials, such as chromium, nickel, iron and copper, do not have them. As the situation is changing with an increasing demand for proper UQ, we need to ask the question of how FENDL can be upgraded with UQ data in a principled manner. This presentation briefly introduced Bayesian networks for the purpose of nuclear data evaluation, which also provide a principled framework for the generation of consistent covariance matrices. Furthermore, the features of the covariance matrices for the total cross section of ^{184}W from the library projects TENDL2021, JEFF-3.3, ENDF/B-VIII.0 (equivalent to FENDL-3.2b) were discussed and compared. Finally, the Kullback-Leibler (KL) divergence was suggested as a mathematical tool to augment existing evaluations with covariance matrices based on the discrepancy to experimental data. It was demonstrated how the parameters of a Matern-covariance kernel could be optimized using the KL divergence criterion and the resulting covariance matrix was compared with the aforementioned ones.

2.7 Problems of FNDL-3.2b, S. Kwon

So far, we have performed FENDL-3.2b benchmark tests with the latest nuclear data libraries for several integral experiments in TIARA and FNS, and found that FENDL-3.2b still has some problems in the TIARA Iron Experiment, FNS Iron Experiment, FNS Copper Experiment and FNS Beryllium Experiment.

1) TIARA Iron Experiment

The TIARA iron experiment was analysed for high energy neutrons such as 40 MeV and 65 MeV. The calculation result using FENDL-3.2b represents quite good agreement with the experimental ones except the continuous region (10-60 MeV) of neutron spectra of 65 MeV neutrons, where FENDL-3.2b tends to underestimate and JENDL-5 is better. Another remarkable point of this analysis is a large overestimation tendency using JEFF-3.3. Large elastic scattering cross section and/or small non-elastic scattering cross section could be the reasons for this overestimation.

2) FNS Iron Experiment

The FNS iron experiment was analysed for almost the whole energy spectra above 1 eV up to 15 MeV. FENDL-3.2b and ENDF/B-VIII.0 tend to underestimate the measured neutron flux above 10 MeV while, below 10 keV up to depth of 60 cm, FENDL-3.2b and ENDF/B-VIII.0 tend to overestimate the measured neutron flux. The reasons for these two discrepancies with ENDF/B-VIII.0 have been already figured out; the (n,2n) cross section and angular distribution of ^{56}Fe for the neutrons above 10 MeV and discrete inelastic scattering cross section of ^{56}Fe for the neutrons below 10 keV. However, it should be investigated to clarify whether the reasons are the same in FENDL-3.2b as well or not.

3) FNS Copper Experiment

There has been an underestimation issue on the lower energy neutrons with copper nuclear data for around 30 years. Even though FENDL-3.2b is the best for neutrons over 0.3 MeV, it still tends to underestimate neutron fluxes below a few keV as confirmed with reaction rates of the ^{186}W(n,g)^{187}W, ^{197}Au(n,g)^{198}Au and ^{235}U(n,f) reactions, which is the same as the previous version and other nuclear data libraries except JENDL-5. Only JENDL-5 improves the C/E of those reaction rates by around 10%. This improvement is linked to a new evaluation of ^{63}Cu based on new experimental data, which exhibits a very different capture cross section below 400 eV compared to other libraries. The copper data of FENDL-3.2b should be re-evaluated on the basis of the latest JENDL.

4) FNS Beryllium Experiment

There has been another issue which has remained unresolved for a long time regarding ^{9}Be nuclear data. All nuclear data libraries cause overestimation of reaction rates sensitive to low energy neutrons such as the ^{6}Li(n,a)T, ^{197}Au(n,g)^{198}Au and ^{235}U(n,f) reactions. Recently, the European Spallation Source (ESS) group has produced thermal scattering law data, known as S(a,b), of beryllium considering crystallite domain size. The cross sections of 0.005 – 0.4 eV are very different corresponding to the crystallite domain size. The overestimation of reaction rates sensitive to low energy neutrons decreases drastically with increasing the crystallite domain size. We figured out that the data of 10 or 15 microns are the best in the beryllium experiment. This could indicate that the crystallite domain size of the beryllium blocks which was used in the experiment is from 10 to 15 microns. It is recognized that adequate thermal scattering law data are important, especially for beryllium. We propose that the next FENDL does have the proper S(a,b) data not only for beryllium but also for other nuclides.

2.8 Neutronics using FENDL data: experimental benchmarking at JET in DTE2 with ITER materials, L. Packer

Lee Packer, P. Batistoni, C. Bearcroft, S. C. Bradnam, E. Eardley, M. Fabbri, N. Fonnesu, M Gilbert, Z Ghani, K. Gorzkiewicz, C. Grove, R. Kierepko, E. Laszynska, I. Lengar, X. Lituadon, S. Loreti, J.W.Mietelski, M. Pillon , M. I. Savva, C.R. Shand, I.E. Stamatelatos, A. N. Turner, T. Vasilopoulou, R. Villari, A. Wójcik-Gargula, A. Zohar and JET Contributors.

During the 2021 D-T (DTE2) experimental campaign at JET, researchers achieved 59 MJ of fusion energy, a world record that was broken again in a more recent experiment in 2023 (DTE3), demonstrating sustained plasma operations at significant power in a tokamak device. The unique nuclear environment at JET, characterized by the production of 14.1 MeV neutrons in the plasma, offers valuable insights for ITER. Some ITER materials are expected to face high neutron fluxes, reaching up to approximately 2×10^{14} n cm^{-2} s^{-1} at the first wall (FW) locations during planned 500 MW fusion operations. In contrast, the highest neutron flux observed at JET's long-term irradiation station (LTIS) during the 59 MJ plasma discharge (shot 99971) was about 2×10^{13} n cm^{-2} s^{-1}. Though one order of magnitude lower in flux, the total neutron fluence at LTIS during the DTE2 campaign was estimated at 4.8×10^{15} n cm^{-2}, significantly lower than the 3.4×10^{21} n cm^{-2} expected at ITER's first wall over 14 years of D-T operations.

The study provided an opportunity to test the latest nuclear modeling predictions and nuclear data libraries, utilising the FENDL-3.2b transport library with TENDL-2017 and IRDFF-II for activation and dosimetry reactions, against measurements of neutron-induced activation in ITER material samples. The ITER samples were exposed in a technologically relevant tokamak environment with the highest 14.1 MeV neutron yield to date. Unique experimental measurements were conducted, with detailed analyses performed post-irradiation during the DTE2 and C40 tritium campaigns. Sensitive radiometric techniques were employed in five EU laboratories to study 27 different ITER material samples, which were analysed using high-resolution gamma spectrometers to quantify neutron-induced activation levels.

Initiated under the EUROfusion JET3 project (2015-2020) and continuing under the Preparation of ITER Operation (PrIO) program's Neutronics, Nuclear waste, and Safety subtask, significant results have been obtained relevant to ITER operations. These include activation measurements, 14 MeV neutron yield monitor calibration, neutronics benchmark experiments, nuclear diagnostics, and data processing for tritium breeding blankets. In this work there were several participating institutes including UKAEA, ENEA, IFJ-PAN, IPPLM, NCSRD, IFJ, CEA with support from F4E in acquisition of the ITER material samples themselves, and from the IAEA through the FENDL nuclear data project and provision of application-suitable nuclear data libraries.

During the DTE2 and C40 tritium campaigns, 68 ITER material samples, 25 dosimetry foils, two VERDI diagnostics, and 12 samples for positron annihilation spectroscopy were irradiated at the JET LTIS. Fig. 1 shows the selected ITER material samples and the LTIS sample holder assembly before irradiation. The assembly was installed in JET in July 2019 and retrieved in September 2022, after which samples were analysed in gamma spectrometry laboratories.

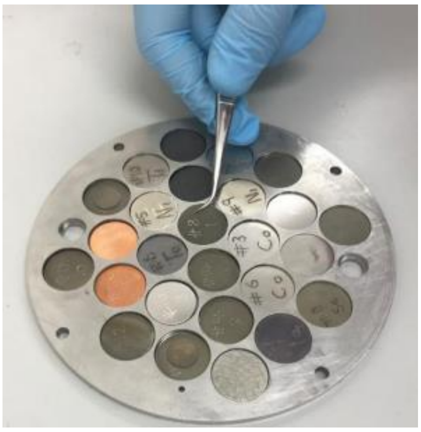

FIG. 1. Photograph of the outer long-term irradiation station sample holder loaded with ITER samples and dosimetry foils. The samples were irradiated in the C38 deuterium campaign at JET (taken from EPJ Web Conf. 253 (2021) 03005).

The study included comparisons of calculated-to-experimental (C/E) ratios to validate neutronics models, codes, and nuclear data. A detailed model using the MCNP radiation transport and FISPACT-II inventory codes was used to predict the nuclide inventory for each irradiated ITER sample. Previous work in L.W. Packer et al., Nucl. Fus. **61** (2021) indicated that the C/E values for certain nuclides, like ^{57}Co, ^{58}Co, ^{51}Cr, ^{59}Fe, and ^{54}Mn, were close to 1, with greater variance for others like ^{60}Co. Discrepancies in C/E values, such as for ^{65}Zn and ^{182}Ta, suggested impurities requiring further investigation. Recent work on CuCrZr samples revealed unpredicted nuclides, indicating the presence of impurities. Future analyses, including mass spectrometry analysis, are planned to explore these findings further, along with supplementary data following DTE3 irradiation activities expected to be reported in 2024.

In summary, key insights have been gained from neutron activation studies and characterisation of ITER materials in a tokamak operating with significant nuclear fusion conditions. Using FENDL-3.2d for radiation transport simulations and TENDL-2017 activation libraries, alongside IRDFF-II for dosimetry foils, advanced post-irradiation techniques have identified radionuclides with good C/E value agreement, in general (within 25%). However, some anomalies, to be detailed in a forthcoming publication such as Nuclear Fusion and reported at the IAEA's Fusion Energy Conference held in London in October 2023, have highlighted the need for improvements, such as conducting independent elemental analysis to better understand material compositions. The manufacturing and cutting processes impact surface impurities, influencing additional nuclide production in fusion environments. It is recommended to use ultra-sensitive analysis techniques for long-lived nuclides that are relevant to assessing fusion waste inventories. This research provides a valuable experimental dataset which helps to validate neutronics methodologies and their underpinning nuclear data. It shows that MCNP6.2 with FENDL-3.2d and FISPACT-II with TENDL-2017 can accurately predict nuclide activation in materials exposed to fusion environments, provided that detailed neutronics models and well-known material specifications are used.

2.9 Issues related to the next FENDL, C. Konno

We examined FENDL-3.2b and its ACE file in detail and found the following issues.

- Too small damage production energy cross section above 20 MeV or a few MeV;
- Inadequate ACE files of proton sub-library.

The first issue occurs only in nuclei from JENDL-4.0/HE and JEFF-3.1.1. The current JENDL and JEFF have improved the issue. We recommend replacing nuclei from JENDL-4.0/HE and JEFF-3.1.1 with those from JENDL-5 and JEFF-3.3, respectively, in the next FENDL. The second issue was newly found. FENDL-3.2b proton ACE files from JENDL/HE-2007 have angular distributions of LAW=61 but MCNP6.2 cannot treat charged particle ACE files of LAW=61 correctly. The NJOY patch for JENDL-5, which is available from https://rpg.jaea.go.jp/main/en/ACE-J50/, has a function to produce not ACE files of LAW=61 but those of LAW=67. FENDL-3.2b proton files from JENDL/HE-2007 should be replaced with JENDL-5 and/or should be reprocessed by using NJOY2016.65 with the patch for JENDL-5, where LAW=67 is adopted. We hope that the above issues are solved in the next FENDL.

2.10 The importance of W cross sections in compact fusion devices, T. Eade

Spherical tokamaks generally have aspect ratios <2. Compared to a conventional tokamak this leads to a relatively compact inboard region. This inboard region needs to house several key components including the first wall vacuum vessel, thermal shield, neutron shield and inboard magnets. High Temperature Superconducting (HTS) tapes are proposed for use as the magnet technology in spherical tokamaks. Experiments have shown that the HTS tape performance drops after a certain fast neutron fluence.

To ensure the continued operation of a spherical tokamak it is therefore vital to ensure sufficient neutron shielding is included within the inboard build. Due to the compact nature of a spherical tokamak's inboard region, it is necessary to use the most effective fast neutron shielding materials. It has been shown that tungsten (W) compounds and mixtures provide excellent fast neutron shielding. However, differences of up to 50% have been noted in simple W sphere leakage tests when using difference nuclear data libraries. Differences have also been found in the heating values provided in the ACE libraries of FENDL 3.2b and ENDF/B-VIII.0. In order to predict inboard magnet lifetime accurate W cross sections are required and need to be prioritised.

2.11 Nuclear data used for IFMIF-DONES and current issues, Y. Qiu

As IFMIF-DONES progresses towards its final design and construction phases, the precise nuclear data becomes increasingly important. Notably, the D-Li neutron yield presents large discrepancies between the FZK-2005 and JENDL/DEU-2020 datasets, primarily attributed to differences in forward angles, low energy peaks, and gamma production. Furthermore, the evaluation of D-Li-induced (and safety-critical) Be-7 and H-3 production reveals substantial discrepancies, underscoring the urgent need for experimental data to resolve these discrepancies. As for D-Cu transport data, the preference is JENDL-5 deuteron data, as well as a specialized TENDL version with Kalbach neutron angular distribution for MCUNED calculations. Deuteron activation data encountered multiple challenges, which might be potentially resolved through the use of TENDL-2023, featuring M. Avrigeanu's updated nuclear model. As for the neutron transport cross-section data from FENDL-3.2, further benchmarking is required, particularly for neutron energies exceeding 20 MeV.

2.12 UKAEA experience in V&V of FNDL-3.2 and proposals for future activities, I. Kodeli

UKAEA's interest in the FENDL-3.2 nuclear data library progress is associated with its involvement in fusion reactor projects such as JET, ITER, STEP, MAST-U, DEMO. Several activities closely linked to the FENDL project were presented:

- Experience in the SINBAD shielding benchmark database: UKAEA used several SINBAD benchmarks to test the performance of FENDL-3.2 and found that potential for further SINBAD based V&V work exists. We are convinced that the cooperation between IAEA/FENDL and NEA/SINBAD would be beneficial for both projects. IAEA already has experience in the collection and evaluation of shielding benchmark databases from the member states. Currently the IAEA is developing the CoNDERC database, and in the past collected benchmarks for FENDL-2.0 validation. Combining those efforts would contribute to the development of framework(s) for storing standards, verified and validated sets of benchmark experiments, (as) easily (as possible) available to the international community. NEA and IAEA are encouraged to discuss the coordination of efforts which are believed to be of interest to the international community and the IAEA, in particular, could promote the activities among the countries which are not members of NEA. UKAEA is interested and willing to contribute to these efforts. A few candidate benchmarks were identified, such as CIAE experiments with D-T neutrons, recent FNG and older KFK benchmarks.
- The SUSD3D/XSUN-2023 sensitivity/uncertainty code package released to NEA Data Bank in 2023 includes FENDL-3.2 neutron and gamma cross sections and covariances data. Further work on covariances is encouraged and XSUN-2023 could serve for the testing of new data and contribute to the further development of covariances for S/U studies. Some specific needs were pointed out, such as interest in covariance data relative to gammas, secondary angular and energy distributions etc.

2.13 Updating the NJOY2016.71 code for processing FENDL, D.L. Aldama

A set of patches for NJOY2016 to process FENDL has been introduced. For incident neutrons, the main updates enhance heating and damage calculations in HEATR. Additionally, minor corrections were applied to probability tables, Bondarenko cross-section calculations in the unresolved resonance range, and energy-angle distributions for several materials.

For charged particles, the laboratory angle-energy representation (MF6/LAW7) is now converted to LAW67 in ACE-formatted files for all materials, whereas previously, it was converted to ACE/LAW61, except for certain light elements sourced from Japanese evaluated nuclear data libraries. The updates also affect energy-angle distributions, the scattering cross-section at low energies, and the treatment of redundant cross-sections for charged particles.

The updated NDS/NJOY2016 package can be found on https://github.com/IAEA-NDS/NJOY2016.

2.14 Status of JADE and recent development, A. Bittesnich, M. Fabbri, D. Laghi

The current status and ongoing development of JADE, a tool suite for V&V nuclear data libraries, are presented. The goal is to pave the way for full standardization and automation of V&V processes for neutron-gamma Monte Carlo transport in fusion applications. This effort aims to save substantial user time and avoid error-prone editing operations. JADE is a Python 3-based software designed to automatically run and post-process a comprehensive suite of computational and experimental benchmarks. It also incorporates pre-existing quality check strategies.

Recently, several additional computational and experimental benchmarks, such as TIARA, FNG Bulk blanket, TUD Fe Slab, FNG W, ASPIS Iron 88, FNS W –BLKT –TOF, have been implemented. These benchmarks have been used to test a series of nuclear libraries, and the results obtained are reported and discussed.

Finally, ongoing developments are discussed and presented, including (a) the development of a JADE version compatible with Linux OS, (b) the re-organization of experimental output classes, (c) the inclusion of additional benchmarks, (d) the correction of minor bugs, and (e) the possibility to employ OpenMC instead of MCNP6.

In conclusion, the JADE code has been moved from a standalone GitHub to a more professional GitHub organization to recognize and welcome substantial contributions, such as the one from UKAEA, which is working on points (a) and (e). Fusion For Energy, along with all involved parties, is actively working towards consolidating this open-source tool for the fusion nuclear data community with the goal of establishing it as the officially adopted tool for FENDL V&V.

2.15 UKAEA development of the JADE tool for V&V of nuclear data and particle transport codes, A. Valentine

This talk presented UKAEA contributions to the JADE tool which is being used as a verification and validation tool for the nuclear data libraries including FENDL. UKAEA have been focusing on three main developments to the code:

- Support for Linux operating system.
- Addition of OpenMC and Serpent as transport code options when running JADE.
- Support for running JADE in parallel as a job on HPC systems.

Initial work included allowing installation via *pip* and removing *conda* dependency. Windows only dependencies have also been removed and the input and output folder structure has been modified to include an additional layer for the different transport codes that can be run. The 'Config' Excel document that is used to specify which benchmarks to run and their configurations was also modified to reflect the extended functionality of JADE. A demonstration of running in parallel has been performed on UKAEA compute clusters.

For the initial work, the sphere leakage benchmark in JADE has been the focus of the developments. For post processing, additional parsers have been written for OpenMC and Serpent to allow equivalent Excel and PDF documents capturing the results across the three codes. A v3.0.0 release of the code is planned for Q1 2024 which includes full Linux compatibility of JADE and a demonstration of running additional transport codes for the sphere leakage benchmark. UKAEA will also add CIAE Fe, FNG SiC, FNG HCPB and PCA replica to JADE.

2.16 Current data management practices in FENDL, G. Schnabel

FENDL is a library that evolved for more than 30 years, with progress documented in various reports and now a recently published reference paper [1]. While documenting progress in reports is important and pertinent, they cannot be regarded as sufficient for nowadays requirements of traceability of software and data. Therefore, the FENDL data management process was significantly modernized. This presentation elaborated on the new data management procedures and tools of FENDL at the nuclide level and at the library level. At the nuclide level, the Python package endf-parserpy [2], recently developed at the IAEA Nuclear Data Section was adopted to validate new ENDF-6 files in the FENDL library, query essential information from them for checking, and also to update meta information in these files to properly reflect changes of the nuclear data. At the library level, it was explained that Git and GitHub were adopted for tracking the evolution of both fundamental nuclear data in ENDF-6 files and derived application files (e.g. ACE). As many files of FENDL are quite large, git-annex [3] was adopted as a tool to separate the tracking of changes in git from the storage of the data themselves elsewhere. Because the application files are generated based on the ENDF-6 files by using NJOY2016 [4], the container solution Apptainer [5] was adopted to enable users to perfectly reproduce the application files themselves. The presentation also featured a proof-of-concept website interface to browse through FENDL, which is inspired by the visual interface of GitHub but displays more nuclear physics-specific meta information.

References:

[1] https://github.com/IAEA-NDS/NJOY2016
[2] https://github.com/iaea-nds/endf-parserpy
[3] https://git-annex.branchable.com/
[4] https://github.com/njoy/NJOY2016
[5] https://apptainer.org/

2.17 Making fusion experimental data FAIR, N. Cummings

This presentation outlined the FAIR Principles for research data management, and ongoing work to apply them to nuclear fusion experimental data at the UK Atomic Energy Authority (UKAEA) in Oxfordshire, England, as part of a larger collaborative project with the UK's Science and Technology Facilities Council (STFC). The work focusses on data from the Mega-Ampere Spherical Tokamak (MAST), although both the principles and some of the implementation details are applicable more generally and were presented to demonstrate the advantages of applying the FAIR principles when managing scientific data. The presentation concluded with a discussion about some recommendations that could be appropriate for consideration by the nuclear data community.

MAST ran from 1999 to 2013 producing data from over 30,000 shots in its lifetime. The data were typically 1D time-series measurements from a variety of diagnostic systems. There were also several cameras that produced video data. A typical shot, particularly towards the end of the lifetime of the machine, when it had most of its diagnostic systems operational, produced around 11,000 signals, or roughly 7 GB of uncompressed data. There are currently 2 ways to access MAST data. One is via the website, at https://opendata.ukaea.uk/mast-data/, and the other is programmatically, via a software library called UDA (Unified Data Access). Both methods have limitations. The website only includes data that has been included in publications and does not provide a useful way to search and explore the archive. In most cases, if a user can find data of interest, the website does not permit their immediate download, but the user must instead submit their contact information and explain why they are requesting the data. In the case of UDA, access is restricted by IP whitelisting, so only pre-approved users can connect to the server and download data. Neither system provides access to much of the metadata that is captured by MAST's data acquisition system, neither are they designed to support the performance requirements of data-intensive workflows such as AI and machine-learning.

The FAIR Principles were introduced as a widely adopted and endorsed set of guidelines for best-practice research data management. They outline a range of recommendations for making data more findable, accessible, interoperable and reusable. An important detail which is potentially relevant to the nuclear data community, is that FAIR does not mean 'open'. Access to data can, and in many cases should, be controlled by an appropriate authentication mechanism, and for those that are authorised to access them, the data should be easy to find, access, and work with.

The motivation for applying the FAIR principles to the MAST archive were discussed. The main justification for this effort comes from the policies of the research council, UK Research and Innovation (UKRI), that funded the MAST experiment. They state that, "UKRI aims to achieve open research data that is 'findable', 'accessible', 'interoperable' and 'reusable'…" and that "Publicly funded research data should generally be made as widely and freely available as possible in a timely and responsible manner." In addition to this, the benefit to the research community is significant, as removing barriers to data can accelerate the process of data discovery, analysis and publication, foster collaboration, and enable greater trust by enabling more reproducibility of research output. As previously mentioned, the fact that it is important to consider the implications for making data fully open was also discussed. In the case of MAST, there is a policy of a 3-year research embargo on the data, but as the newest MAST data is from 2013, this is no longer a concern. Similar policies may exist for the nuclear data community, and these should be taken into consideration. Other considerations for making data open may include concerns that data could be misinterpreted, a problem that is mitigated by providing rich, descriptive metadata, or that data could be misused, which is also mitigated against by specifying an appropriate licence, and publishing relevant disclaimers as required.

The system developed for applying the FAIR principles to MAST was presented. It comprises 2 main components. The first is a metadata service, exposing both REST and GraphQL APIs to enable performant and flexible querying of the dataset. The other is a publicly accessible repository of the data that has a common and widely implemented interface (s3), stored using the Zarr format, free and open format for storing self-describing, multidimensional data, optimised for object storage. By adhering to the FAIR principles in terms of adopting formats that have free and open specifications, the dataset can be interoperable with powerful, well-developed and maintained, free and open-source data-analysis tools, such as those that comprise the Pandata stack (10.25080/gerudo-f2bc6f59-00b).

The presentation concluded with a discussion of some recommendations and considerations for the FENDL group. These were:

- Licencing – The database should be distributed with an appropriate licence such that usage limitations and responsibilities are clearly established.
- Separate metadata – One of the FAIR principles states that metadata should be separate from the data, such that the metadata records are still available if the data no longer are.
- Self-describing format – In addition to separate metadata, having some descriptions and other metadata with the data themselves can be very helpful. Formats such as HDF5, NetCDF, Zarr and Parquet allow the producer to keep this information in the same file, to avoid the two becoming disassociated.
- Versioning (data and software) – The FENDL library includes both data and software tools for working with them. The versioning scheme could be more clearly defined and communicate more clearly when data have changed versus when software is updated and how.
- Data model – Several nuclear databases exist, and there could be some benefit to users to work towards a standard representation such that tools could work across data sources.
- Pandata stack – many open-source analysis tools exist and are robustly maintained by a team of cross-field developers. Providing data and tools that are interoperable with such ecosystems can remove some overhead for in-house development efforts and unlock powerful analysis capabilities 'for free'.

2.18 An overview of nuclear data processing with OpenMC, J. Shimwell

This presentation provided an overview of the nuclear data processing scripts available at https://github.com/openmc-dev/data for converting the ACE Files of various nuclear data libraries (including FENDL) to the HDF5 format. It was suggested that the provision of HD5 files directly on the FENDL project website may be useful to some users, in particular those relying on OpenMC for their simulations. The presentation also featured a recently released Python parser for ACE and ENDF files available at https://github.com/paulromano/endf-python. Finally, a prototype was presented that shows how some operations, such as the conversion and validation of file formats, e.g. ACE files, can be performed in modern browser by leveraging WebAssembly, which is a portable binary instruction format designed to run code on the web.

3. RECOMMENDATIONS

This consultants' meeting was held right after the submission of the FENDL-3.2b reference paper. In the meantime, some minor processing issues were discovered in the NJOY2016 processing of FENDL-3.2b. To address the discovered issues, meeting participants agreed that:

- FENDL-3.2b will *not* be retroactively changed, so consistency with the reference paper is maintained.
- Minor updates of evaluations, of the processing code NJOY2016 and of the application files will be released as a follow-up version FENDL-3.2c.

The naming scheme of FENDL was not regarded as ideal by meeting participants and it was recommended to adopt a new version naming scheme (e.g. inspired by semantic versioning) after the release of FENDL-3.2c.

It was discussed to develop a new major library starting from scratch with a "TENDL-skeleton", as discussed in preceding FENDL AGMs but this possible approach is not recommended for the time being and will be revisited in the future.

The value of the JADE Verification & Validation tool was appreciated by meeting participants, and they expressed their support to adopt JADE as the main tool for V&V in the FENDL project. It was agreed to put a link to the JADE project on the IAEA-NDS FENDL website.

In the next sections, recommendations concerning a major FENDL release (i.e. after FENDL-3.2c) are listed, grouped by categories “Evaluations”, “Verification & Validation”, “Application files” and “Community building”.

3.1 Evaluations

Meeting participants stressed the fact that the adoption of new evaluations should also consider the criteria that were adopted for the FENDL-3.0 release.
The recommendations regarding evaluation data covered a variety of aspects. The first group of recommendations concerned updates of the nuclear data:

- New evaluations of JENDL-5 and TENDL-2023 should be considered for the update of the proton sublibrary.
- New evaluations of ENDF/B-VIII.1, JEFF-4, JENDL-5 and TENDL-2023 (subject to the acceptance criteria) should be considered for the update of the neutron sublibrary. New evaluations developed within the IAEA INDEN collaboration should also be considered for the update.
- New evaluations of TENDL-2023 and JENDL-5 should be considered for the update of the deuteron sublibrary.
- Thermal Scattering Law (TSL) data should be included in the FENDL library or, alternatively, a recommendation issued which TSL library to use.
- The adoption of arcDPA data should be considered for improved damage calculations. (arcDPA data is available on the IAEA-NDS website for some structural materials and in JEFF-3.2 for elements). Alternatively, JEFF-3.2 may be recommended for arcDPA data.

Regarding the coverage in terms of number of nuclides, meeting participants did not see the necessity to increase the number of nuclides for the time being. However, it was agreed upon that all evaluations should extend to 60 MeV (at least, preferably 150/200 MeV as in major libraries).

Several recommendations were issued regarding covariance data for improved uncertainty quantification. The following covariance data was considered to be essential by meeting participants:

- Consistent covariance data for alle evaluations in the neutron sublibrary;
- Covariance matrices for gamma emission in the neutron sublibrary;
- Covariance matrices for photo-interaction data.

It was further recommended to investigate how covariance data can be produced and provided for neutron-induced gas production.
As a minor point of improvement, it was recommended to correct the library designation of files in the proton sublibrary.

3.2 Verification & Validation

The distinction of the meaning of verification and validation was subject to discussion. Meeting participants agreed upon the following distinction: During verification, it is assessed whether the data files conform to format specifications, are internally consistent, and compare reasonably to differential experimental data. Validation efforts, on the other hand, assess the compatibility of nuclear data files with well-defined integral experiments.

The following recommendations concerning V&V for the next major FENDL release were issued.
The decision of adopting a new evaluation (e.g. in the neutron library) should be based on the performance in agreed upon integral benchmarks. Ideally, most (if not all) experimental integral benchmarks covered in the FENDL reference paper should be included. The decision of final adoption should be done by evaluation experts.

It was also recommended to add more benchmarks to expand the coverage of V&V:

- High-energy neutron benchmarks
- Benchmarks relevant for inertial confinement fusion (ICF)
- Charged-particle benchmarks
- Benchmarks including a ^{252}Cf source
- Benchmarks to assess gamma production

The benefit of publicly available benchmarks to automate and reproduce V&V of FENDL was recognized by meeting participants. It was recommended that as many benchmarks as possible that have been used for the V&V of FENDL-3.2b (and described in the associated FENDL reference paper) should be sent to the IAEA for inclusion in JADE.

It was recommended to discuss with Oliver Buss a potential collaboration regarding the creation of benchmarks and the release of some benchmarks relevant for the FENDL project. The clarification of ownership of benchmarks is an important aspect in this regard.

It was recommended to create a benchmark repository at the IAEA with openly available benchmarks, a prerequisite for reproducible V&V in the FENDL project.

3.3 Processing and application files

Processed files (e.g. in ACE format) are very important for applied fusion research. Meeting participants suggested to consider the following extensions for a major FENDL release:

- The inclusion of processed files for higher temperatures;
- The provision of processed data in HDF5 format, and, for reproducibility, the creation of an apptainer/singularity definition file for performing the translation task.

3.4 Community building

For a better interaction with stakeholders, meeting participants suggested to:

- Involve more people from the private fusion community (the list of the Fusion Industry Association may be a good starting point);
- Determine whether private companies would be willing to contribute fusion benchmarks.

4. SUMMARY AND CONCLUSION

This consultants' meeting brought together internationally recognized experts to discuss the further development of the Fusion Evaluated Nuclear Data Library (FENDL). This meeting was held just after the submission of a FENDL reference paper for FENDL-3.2b, with contributions of all meeting participants, among other collaborators. The meeting helped in identifying and discussing issues of FENDL-3.2b and it was decided to release a follow-up version FENDL-3.2c to fix these issues. A large part of the discussion also focused on collecting recommendations for the development of a major FENDL release in the future.

Appendix 1

IAEA Consultancy Meeting on Further Development of the Fusion Evaluated Nuclear Data Library (FENDL)

30 Oct-2 Nov 2023, IAEA Vienna, Meeting room MOE05 (hybrid)

PRELIMINARY AGENDA

Monday 30 October (10:00 – 17:00, open 09:45 (all times Vienna time))

10:00	**Opening and Welcome address – A. Koning / Section Head-NDS** **Election of Chair and Rapporteur(s), Adoption of Agenda**	
Participants' Presentations: Introduction and Evaluations (~20'+10')		***Coffee breaks as needed***
	Georg Schnabel	Introduction
	Ulrich Fischer	History of FENDL
	Andrej Trkov	Status of INDEN evaluations
	Shinsuke Nakayama	Recent progress in JENDL charged particle files
12:30-14:00	***Lunch break***	
Participants' Presentations cont': FENDL-related activities (~20'+10')		
	Michal Kostal	Fusion related activities at CV Rez
	Tim Bohm	Current FENDL activities at UW-Madison
	Georg Schnabel	Covariance methodology for the FENDL project

Tuesday 31 October (10:00 – 17:00)

Participants' Presentations cont': Benchmarking, Open Issues (~20'+10')		***Coffee breaks as needed***
10:00	Saerom Kwon	Problems of FENDL-3.2b
	Lee Packer	Neutronics using FENDL data: Experimental benchmarking at JET in DTE2 with ITER materials
	Chikara Konno	Issues to the next FENDL
12:30-14:00	***Lunch break***	
Participants' Presentations cont': Benchmarking, Open Issues, Planning (~20'+10')		
	Tim Eade	The importance of W cross sections in compact fusion devices
	Yuefeng Qiu	Nuclear data used for IFMIF-DONES and current issues
	Ivo Kodeli	UKAEA experience in V&V of FENDL-3.2 and proposals for future activities

Dinner at a restaurant (separate information)

Wednesday 1 November (10:00 – 17:00)

Participants' Presentations cont': Codes development (~20'+10')		***Coffee breaks as needed***
10:00	Daniel Lopez Aldama	Updating the NJOY2016.71 code for processing FENDL
	Marco Fabbri, Davide Laghi	F4E: Contributions and needs / Status of JADE and recent developments
	Alex Valentine	UKAEA development of the JADE tool for V&V of nuclear data and particle transport codes
12:30-14:00	***Lunch break***	
Participants' Presentations cont': Data governance & IT infrastructure (~20'+10')		
	Dieter Leichtle	Neutron data and experimental benchmarks in the EU fusion programme (*tbd*)
	Georg Schnabel	Current data management practices in FENDL
	Nathan Cummings	Data management, fair principles, etc. (*tbd*)
	Jonathan Shimwell	An overview of nuclear data processing with OpenMC

Thursday 2 November (10:00 – 15:00)

10:00	**General discussion // Drafting of the meeting summary report // Recommendations and actions**
15:00	**Closing of the meeting**
	Break(s) as needed

Appendix 2

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