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Minutes of the 33rd Meeting of the International Nuclear Data Committee

Virtual Event

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G. F. Steyn
INDC Executive Secretary
iThemba LABS, P.O. Box 722
Somerset West, 7129
South Africa

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Chairman's Summary

This 33rd meeting of the IAEA International Nuclear Data Committee was held as a virtual event from 29 March to 1 April 2021. Due to the pandemic the original schedule was postponed by a year but it was still not possible to have this event attended in person by the participants. To partially remediate lack of the meeting in 2018 the Nuclear Data Section management prepared and distributed among INDC members a survey seeking answers on quite comprehensive set of issues. The results were collected, evaluated and reported by the NDS Head during the current INDC meeting. While no survey can replace live discussion during the meeting it was my impression that the survey was useful and helped NDS to work out their plan activities until the virtual INDC meeting was held in 2021. The unusual format of this meeting caused departure of the tradition to split the INDC into two Working Groups in the second half of the meeting. Accordingly, there were no Working Groups' reports, which were replaced by a list of recommendations worked out by the entire INDC. Another novelty was forsaking the formal report of the NDS to the INDC which was considered superfluous in view of the presentations by the NDS staff that are archived and made available on the INDC web page. This change allowed NDS staff to save considerable amount of effort and use this time more productively on programmatic activities.

Regarding the INDC membership, it was announced that Ulrich Fisher was replaced by Arnd Junghans for Germany and Basanta Kumar Nayak was replaced by Umasankari Kannan for India. Three current members of the INDC Young-Ouk Lee (South Korea), Deon Steyn (South Africa) and Michal Herman (USA), will reach the end of their mandate by the end of the meeting.

The "actions arising" from the 32nd INDC Meeting (see Appendix 4) were briefly discussed by the NDS Head A. Koning and approved by the INDC members. In the following, A. Koning presented the staffing and budget of the NDS. INDC members were pleased to learn that situation of the Section is stable regarding manpower and funding. It was noted that several guests were working over extended periods at the NDS contributing to the Section's achievements.

The impressive list of various activities was summarized by the Section Head and presented in detail by the responsible NDS staff. These reports on Coordinated Research Projects, Technical and Consultants' Meetings, Networks, Data Development Projects, Special Service Agreements, ICTP Workshops and local courses were generally well-received by the members of the INDC. The highlights of the 2018–2020 period include:

- Successfully completed and published CRPs:
    - Beta-delayed neutron emission;
    - Photonuclear data and photon strength functions.
- Updates of medical isotope production nuclear data for therapeutic isotopes, gamma emitters, and positron emitters.
- Release of important nuclear data libraries:
    - International Reactor Dosimetry and Fusion File (IRDFF-II, nds.iaea.org/IRDFF);
    - Evaluated Photonuclear Data Library (IAEA/PD-2019, nds.iaea.org/photonuclear).

- New database initiatives, e.g., Compilation of Nuclear Data Experiments for Radiation Characterization (CoNDERC).
- Traditionally very active networks: Nuclear Structure and Decay Data (NSDD) providing world's unique source of these type of data and Nuclear Reaction Data Centers (NRDC), responsible for compilation of EXFOR library continued excellent work of fundamental importance to application of nuclear technology and basic science.
- The new International Nuclear Data Network (INDEN) established in 2018 had three meetings per year, on light elements, structural materials, and actinides becoming an important vehicle for international collaboration on evaluation of nuclear reaction data.
- Several Technical Meetings, e.g., on antineutrino data, processing codes, etc. were held contributing to advancing our knowledge and availability of tools.
- Provision of user interfaces is one of the primary functions of the Nuclear Data Center. The INDC appreciated a milestone and NDS undertakings in the matter:
    - The Isotope Browser passed 120 000 downloads for iPhone and Android devices;
    - The Medical Isotopes Browser was launched.

Essential output of the INDC is contained in the recommendations that are briefly summarized below:

- Support international efforts to improve light- nuclide data, including relevant EXFOR compilation and integral experiments.
- Remain involved in WPEC SG-42 on Thermal Scattering Law.
- Release a new IRDFF library.
- Resolve the issue of code distribution to non-OECD countries by the NEA.
- Extend the graphical capabilities for decay data.
- Give more priority to the EXFOR compilation of photonuclear data.
- Make available the displacement damage cross-section data of the CRP.
- Investigate a new initiative on nuclear data for back end of the fuel cycle.
- Enlarge the output options of EXFOR regarding C5M, XC5 and covariance formats.
- Organize training workshop, possibly with ICTP, on nuclear data for multi-scale materials modeling.

On a personal note, as an outgoing chairman of the INDC, I would like to express my strong support for the overall modernization of every aspect of NDS activities, including compilation, evaluation, formats and distribution of nuclear data to diversified customers. A few years ago, NDS became the world's centre of excellence in the evaluation of nuclear reaction data. Recently NDS has followed a wise hiring policy which greatly improved the software development capacity of the Section. The use of artificial intelligence and modern non-relational databases is, in my opinion, the future of every data centre. I also hope that it will not take long before Web portals of NDS (and others!) will catch up with the current standards. Let me remind you that at the early stage of the Internet era nuclear data centres were among the first to apply the new technology. It was not without opposition. Some practitioners then believed that sanding boxes with computer printouts and magnetic tapes by post is the only right way of delivering nuclear data to users. Modernization means not only better and more comprehensive data, improved responsiveness to the user's needs, broader access to nuclear data and building public confidence in the safety of nuclear energy. Modernization is a matter of the field survival which is contingent on attracting new talents – who would like to send out printouts and magnetic tapes today? I understand that NDS is aware of the challenge and has already started investing in artificial intelligence, machine learning, and new forms of databases. I believe that with a proper mix of young and experienced staff NDS is well-posed for a bright future.

Finally, let me thank IAEA and NDS management for allowing me to serve as the INDC member for 12 (actually 13) years, out of which eight as a chairman. I would like to thank also all colleague members of the INDC for the time and effort they dedicated to the meetings and to providing the nuclear data needs of their states. Vivid discussions in the Working Groups were instructive for all of us and consequential for the Section. The NDS staff was always cooperative and professional. As an ex-staff member of NDS I know well how much work it is to prepare for each INDC meeting. Last but not least, my special thanks, and I think not only mine but all of us, go to Deon Steyn who kindly agreed to serve as a rapporteur of multiple INDC meetings.

M. Herman
INDC Chair

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FULL REPORT

1. OPENING

Arjan Koning (Head, IAEA Nuclear Data Section) welcomed the INDC members, observers and advisors, and introduced Ms Melissa Denecke (Director, IAEA Division of Physical and Chemical Sciences). Ms Denecke commented on the negative impact on travel caused by the Covid-19 Pandemic, which necessitated the 33rd INDC meeting to be held virtually for the first time. She asked the attendees to reflect on both the positive and negative impacts of virtual meetings, especially as the IAEA is looking into the option to retain many meetings on virtual platforms also in the post-pandemic world as an efficiency measure, even while most people will agree that this makes certain discussions more difficult. Ms Denecke noted that two matters stand out when perusing the presentations and working papers of this meeting, especially from the photographs, pertaining to "gender balance" and "the next generation". Gender balance is important not only from her personal views on this subject but because it is part of UN Agenda 2030. The Director General placed this high on the agenda of the IAEA and will endeavour to reach gender balance amongst professional staff by 2025. In order for young people to pursue careers where they may contribute to the field of nuclear data, there need to be aspects that young professionals would find attractive. Artificial Intelligence and Machine Learning, which are becoming increasingly important in many fields, might be such attractions. INDC members were requested to consider these challenges, not only pertaining to the NDS but also at their own institutes and the field of Nuclear Data at large. Ms Denecke concluded by thanking all attendees for giving of their time and expertise, especially persons for whom the time of the meeting would be inconvenient night-time hours. She wished the meeting to have fruitful discussions despite the virtual format.

Arjan Koning thanked Ms Denecke and commented that while most of the people present would be familiar by now with virtual meetings, the INDC meeting would probably be one of the toughest to do in this way. There would be no splitting into two Working Groups as in the past as this would be impractical to do virtually. Instead, the Nuclear Data Survey sent to members will be discussed later in the meeting. There may be more of a one-way stream of information from the NDS to the INDC than in previous meetings, however, there will be time for discussions and for members to give feedback, in particular when the Nuclear Data Needs from member countries are presented. Koning expressed his hope that the 34th INDC Meeting in June 2022 will once again welcome everyone back at the IAEA in Vienna and resume its usual format as an in-person event.

The complete list of participants is given in Appendix 2. The "Terms of Reference" of the INDC are stated in Appendix 3. After the announcements, Koning handed the meeting over to the Chairman of the INDC, Mr Mike Herman.

1.1 Chairman's Remarks

The agenda was adopted without objections (see Appendix 1). In order to save time, there was a request to keep "Statements of INDC members" short and only on urgent matters. There were none and the meeting proceeded to the next item on the agenda. The minutes of the 32nd INDC Meeting (INDC/P(18)-15) were approved without changes. Next, the "actions arising" from the 32nd INDC Meeting (see Appendix 4) were briefly discussed. Koning gave a short overview of these ten actions and their current status. As these points were to be discussed in more depth during the Section Review and Section Activities sessions, the relevant comments from this discussion have been incorporated there.

2. NUCLEAR DATA SECTION REVIEW (2018–2020)

Comprehensive presentations by NDS staff, describing the nuclear data work undertaken predominantly in the period 2018–2020 but in some cases also the first few months of 2021, were distributed to INDC members in PDF format prior to the meeting. These documents are available on the INDC pages of the NDS website. The main items are summarized below.

2.1 Global overview of the Nuclear Data Section

Koning presented a global overview of the NDS, mainly as an introduction and to explain its structure, role and functions for the benefit of newcomers. Due to the Covid-19 pandemic, the 33rd INDC meeting was postponed from June 2020 to March 2021. As a result, the reporting period will be longer than usual, namely 2018, 2019, 2020, and the first few months of 2021. However, the usual biennium structure of reporting will eventually be restored when the pandemic is over, hence the next biennium will be 2022–2023. The IAEA currently has 172 Member States, about 2500 staff and an annual budget of about € 500 M. The NDS is one of four sections within the Division of Physical and Chemical Sciences, the latter of which is again one of four divisions within the Department of Nuclear Sciences and Applications. The main tools to perform their duties are summarised below:

- Coordinated Research Projects (CRPs): These are multi-year projects with typically three Research Coordination Meetings (RCMs): kick-off, intermediate after 1.5–2 years, final after 3–4 years.
- Technical Meetings (TMs): These typically are large meetings on broad topics, planned years in advance, which require official national delegation.
- Consultants Meetings (CMs): These are short-term (“ad-hoc”) meetings on a certain technical topic, with typically less than 10 participants.
- Networks: Currently the NDS coordinates three nuclear data networks, namely the Network of Nuclear Reaction Data Centres (NRDC), the International Network of Nuclear Structure and Decay Data Evaluators (NSDD), and the International Nuclear Data Evaluation Network (INDEN).
- Data Development Projects (DDPs): These are long-term, ongoing collaborations on nuclear data (mainly libraries) which may or may not require meetings.
- Special Service Agreements (SSAs): These involve individual consultancy contracts and visits.
- Training: ICTP Workshops and local courses.

Some of the highlights of the 2018–2020 period include the following:

- Successfully completed and published CRPs:
  - Beta-delayed neutron emission;
  - Photonuclear data and photon strength functions.
- Very active networks. Since its launch in 2018, INDEN has had three meetings per year, on light elements, structural materials, and actinides.
- Several well-attended TMs, e.g. on antineutrino data, processing codes, etc.
- Updates of medical isotope production nuclear data for therapeutic isotopes, gamma emitters, and positron emitters.
- Release of important nuclear data libraries:

    - International Reactor Dosimetry and Fusion File (IRDFF-II, nds.iaea.org/IRDFF);
    - Evaluated Photonuclear Data Library (IAEA/PD-2019, nds.iaea.org/photonuclear).
- New database initiatives, e.g. Compilation of Nuclear Data Experiments for Radiation Characterization (CoNDERC).
- Provision of popular user interfaces:
    - The Isotope Browser passed 120 000 downloads for iPhone and Android devices;
    - The Medical Isotopes Browser was launched.

In conclusion, Koning mentioned that the NDS has been operating for more than 50 years, providing data services for nuclear, atomic and molecular data. It acts as a Data Centre that also carries out technical work, such as compilations, evaluations and software development. In addition to the coordination of networks, the NDS organizes CRPs and DDPs, produces authoritative documents, and provides training, both internally and regionally.

2.2 Staffing and Budget

Koning gave a presentation on NDS staffing and budget. Currently the NDS has 12 professional staff (P-staff) and 4 support staff (G-staff). Staff movements were significant during the current reporting period. Kalle Heinola started in May 2018 at the Atomic and Molecular Data Unit (AMDU) as an Atomic Physicist. Ludmila Marian joined AMDU in April 2019 as Scientific Data Manager. Her duties, however, also support the other units of the NDS. The other members of AMDU are Christian Hill (Unit Head) and Marco Verpelli (Nuclear Data Analyst & Programmer). Shin Okumura started in September 2018 at the Nuclear Data Services Unit (NDSU) as Associate Nuclear Data Physicist. Charisse Monfero started in March 2020 at NDSU as Team Assistant, while Alex Oechs retired from the NDSU in October 2019. The other members of NDSU are Jean-Christophe Sublet (Unit Head), Naohiko Otsuka (Nuclear Data Physicist), Victor Zerkin (Software Engineer), and Lidija Vrapcenjak (Nuclear Data Services Assistant). Andrej Trkov retired from the Nuclear Data Development Unit (NDDU) in January 2020. Georg Schnabel started at NDDU in January 2020 as Nuclear Physicist (Codes Development). Vivian Dimitriou was rotated out of NDDU in June 2019 but rejoined again in January 2021 as Nuclear Data Physicist. Kira Nathani was temporarily assigned to the IAEA Publications Section in June 2019 but returned to NDDU in May 2020 as Team Assistant. During her absence she was temporarily replaced by Mariam Yaney. The other member of NDDU is Roberto Capote (Unit Head). Lastly, Arjan Koning is the Section Head, Roberto Capote the Deputy Section Head, and Rosalinda Rangel Alvarez is Section Secretary. Koning emphasized that although the NDS has three units with staff allocated to a single unit, several staff members have duties that serve the entire section.

During the 2018–2020 period, the NDS was also assisted by three consultants and eight interns. The consultants were Jan Malek (2019) who worked on GANDR development, Svetlana Selyankina (2018) who helped with EXFOR compilation, and Daniel Lopez Aldama (2020–2021) who worked on ENDF libraries and processing. The interns served as follows: Emanuel Chimanski (2018) worked on nuclear reaction modelling; Takanari Fukuda (2018) worked on fission yield EXFOR completeness; Testuaki Tada (2018) helped with EXFOR compilation; Daichi Imazato worked on openMC; Natalie Gaughan (2018–2019) assisted with the CRP on data for medical isotope production; Ingrid Vavtar (2019) was involved in k-eff benchmarking; Mark Mawdsley (2019) worked on resonance parameters; and Hiroki Kawada (2019–2020) worked on photonuclear data.

It is foreseen that NDS staffing will be stable throughout 2021–2023 at a level of 16.25 FTE. The next two retirements will be at the end of 2023. Koning, as Section Head, has been granted a contract extension until March 2024. The NDS will also attempt to hire more consultants for

1 or 2-year periods.

There were two changes in INDC membership during the present reporting period. Ulrich Fisher was replaced by Arnd Junghans for Germany, and Basanta Kumar Nayak was replaced by Umasankari Kannan for India. Koning welcomed the new members to the INDC. Four INDC members have reached the end of their third term, thus attending their last INDC meeting: Ferenc Tárkányi, Young-Ouk Lee, Deon Steyn, and Michal Herman. Koning asked the Committee to suggest replacements. Appendix 2 presents the complete list of members, advisors and observers attending the current INDC meeting.

In his budget summary, Koning gave the budget breakdowns and totals from 2018 to 2021 as well as an estimate for 2022. Increases of between 3% and 4% between years are mostly to adjust for inflation, but some extra money was received to establish the INDEN network. This allowed the NDS to fund three INDEN meetings per year. Approximately 30.3% of the current budget of ~ € 3.04 M funds the Technical Programme, with the remaining 69.7% funding salaries and various Agency overhead support costs.

Herman asked whether funds not spent on travel and meetings during the Covid-19 period can otherwise be exploited, e.g. by expanding on consultants and/or contracts. Koning replied that such money is not automatically available for other purposes and that the NDS lost unspent funds at the end of the previous year, which is the same throughout the IAEA. NDS is however trying to increase the funding for Special Service Agreements.

2.3 Nuclear Data Section Activities (2018−2020)

2.3.1 Network Coordination (NRDC)

Otsuka presented a report on the activities of the International Network of Nuclear Reaction Data Centres (NRDC) and the coordination role of the NDS. The NRDC currently comprises of 13 data centres from 8 countries and 2 international organisations: BARC (Mumbai, India), CDFE (Moscow, Russia), CJD (Obninsk, Russia), CNPD (Sarov, Russia), CNDC (Beijing, China), JCPRG (Sapporo, Japan), JAEA-NDC (Tokai, Japan), KAERI (Daejeon, Korea), ATOMKI (Debrecen, Hungary), UkrNDC (Kyiv, Ukraine), NNDC (Brookhaven, USA), NEA Data Bank (Paris, France), and IAEA-NDS (Vienna, Austria). The JAEA Nuclear Data Center (JAEA-NDC) started EXFOR compilations in 2019. The role of the NDS within the NRDC remained unchanged, namely to provide coordination via a staff member who serves as the NRDC secretary as well as other staff active in the network. The NDS also compiles data from countries not covered by the other data centres, including Asia (except China, India, Korea and Japan), Eastern Europe (except charged-particle data from Hungary), South America (with significant help from the University of São Paulo), Africa (with significant help from Ithemba LABS), and Oceania.

The 2019 Annual Technical Meeting of the NRDC was held from 9–12 April 2019 in Vienna. It was attended by 16 participants from 12 data centres and 2 international organisations. The discussions were summarized in 27 conclusions and 78 actions (see Summary Report INDC(NDS)-0792). Points of main discussion include the retroactive compilation of fission product yields and EXFOR format extensions for supplementary information, e.g. neutron source spectra and resolution functions. Due to the Covid-19 pandemic the 2020 TM, which would have celebrated the 50th anniversary of the EXFOR collaboration, had to be postponed.

An EXFOR Workshop was held from 22–25 October 2018 in Vienna. It was attended by 25 participants from 12 countries and 2 international organisations. A major topic at this workshop was training on the compilation of fission product yields (FPY). More details are available in Summary Report INDC(NDS)-0773. Due to the pandemic, the planned 2020 workshop was postponed to 2022.

A CM on the Fission Product Yield Experimental Database was held from 27–30 May 2019 in

Tokyo. The meeting created an opportunity for the participants from 5 countries and 2 international organisations to discuss common topics of interest on this major library project, such as a novel technique to measure fission-related observables, data evaluation methods by applying theoretical and/or empirical models, a consistent treatment of FPY data together with uncertainties (covariances), possible extension of the EXFOR data format to accommodate various fission-related observables, and improvement of the user interface in the EXFOR web retrieval system maintained by the IAEA. More information is available in Summary Report INDC(NDS)-0793.

The NDS also supported several workshops in Asian countries on EXFOR compilation training and other nuclear reaction database-related matters. The 9th AASPP Workshop on Asian Nuclear Reaction Database Development was held from 12–15 November 2018 in Gyeongju, Republic of Korea (Proceedings INDC(KOR)-006). The 10th AASPP Workshop was held from 24–27 June 2019 in Almaty, Kazakhstan (Proceedings INDC(KAS)-0002). The 11th AASPP Workshop was scheduled to be held in Mumbai, India in 2020 but had to be postponed due to the Covid-19 pandemic. An Indian EXFOR Workshop, organized by the University of Baroda, NDPCI and DAE-BRNS, was held in Vadodara in 2019. A total of 31 new EXFOR entries were made during this training event.

Otsuka showed several slides on web-based tools for EXFOR coverage control, allocation of articles for compilation, quality assurance of entries, and monitoring. A total of 53 journals are regularly scanned by the NRDC. The interface for registration of articles requiring EXFOR entries is maintained by the NDS. These entries are prioritised as follows:

- Neutron and charged-particle induced reaction data ($A \leq 12$), especially those published in new articles;
- Data for specific projects, e.g. fission product yields, isotope production cross sections, thermal neutron scattering, etc.;
- Data requested from individual users.

The EXFOR Allocation list can be accessed from https://nds.iaea.org/nrdc/alloc/. New entries from all data centres totalled 514 in 2018, 566 in 2019, and 555 in 2020, of which the NDS contributed 79, 44 and 77 in the respective years. There is a backlog of about 1666 articles, of which approximately 200 require further analysis before they can be compiled. Certain types of data compilation were postponed for many years while being discussed by the NRDC, such as photo-induced fission, which can now be compiled satisfactorily. An example was also shown of a new entry for ^{7}Li(d,xn) and ^{7}Li(d,n) absolute energy-differential cross sections, which is important for neutron-source applications. Otsuka showed one example of an unusual user request from Australia, which required a human compiler of the NEA Data Bank to retype 15 262 data-point values from 35 pages of poor-quality type-written tables that could not be successfully interpreted by computer scanning software. This is an excellent demonstration of dedication and international collaboration. The retroactive compilation of 593 entries on fission yields is now about 50% complete, which will hopefully be fully completed over the next three years.

A large collaboration between CERN, IAEA and NEA is the EXFOR compilation of Time-of-Flight (TOF) spectra from the n_TOF experiment, which is now nearing completion. A similar collaboration with the GELINA facility is ongoing.

There is also an effort to standardize EXFOR entries as this will make the library more searchable. One example given was the previously inconsistent notation for metastable states, which is now being corrected.

Otsuka concluded his presentation by referring to the two actions from the 32nd INDC Meeting that concern EXFOR (Actions 1 and 6). No additional effort has been made to compile light-nuclide data but an intensive compilation can be arranged if users make specific requests, e.g. by providing an article list or data specification. Compilation of photonuclear data has been given higher priority by the NRDC and the NDS steps in if there are specific requests outside of the responsibilities of other nuclear data centres.

Herman commended the NDS on their NRDC coordination effort and especially the good progress with compilation of data from n_TOF and GELINA. Umasankari Kannan suggested that a virtual AASPP Workshop during the Covid-19 period could be considered.

2.3.2 Network Coordination (NSDD)

Dimitriou gave a presentation on the coordination of the International Network of Nuclear Structure and Decay Data Evaluators (NSDD). The main task of the NSDD is the continuous updating and development of the Evaluated Nuclear Structure Data File (ENSDF). The network currently has 17 contributing data centres, with the IAEA as the coordinating centre. The ENSDF database management resides at the NNDC in Brookhaven. The data in ENSDF are from measurements only and not from models or theory. It is used by a multitude of nuclear code systems and derivative databases. The coordination role includes various functions and tasks:

- Organization of meetings (NSDD Technical and Consultants Meetings);
- Representing the NSDD at Nuclear Data conferences;
- Training (see also presentation by R. Capote on this topic);
- Technical support: codes, editors, web tools;
- DDP on Improvement of ENSDF Analysis Codes;
- Horizontal evaluations, e.g. the most recent effort on evaluating Nuclear Moments;
- Financial support, mostly for young evaluators at the beginning of their careers;
- Dissemination tools (LiveChart, Isotope Browser, Decay Data Portal, ENSDF Codes).

Dimitriou highlighted the paper titled “International Network of Nuclear Structure and Decay Data Evaluators” published in the proceedings of the ND2019 Conference that was held in China. This is the first paper on the NSDD authored by the whole network.

The 23rd Technical Meeting of the NSDD was held from 8–12 April 2019 in Vienna, attended by representatives of all 17 participating data centres. With regards to data centres, part of the discussion dealt with an expansion effort on evaluations in Japan, and the relocation of NSDD activities in India from the Indian Institute of Technology (IIT) at Roorkee to the Variable Energy Cyclotron Centre (VECC) in Kolkata. Technical discussions focused on open issues with ongoing evaluations, new formats for continuous data, new ENSDF analysis and checking codes. Some of the legacy codes are being rewritten in more modern computer languages and new codes are being developed. The total manpower effort, while having remained relatively stable at 10.49 FTE in 2019, still remain a concern. More than 60% of the effort came from seven data centres in the US, where there is a clear funding pipeline for ENSDF evaluations. It was pointed out that at current manpower levels it is impossible to maintain a 10-year cycle for mass evaluations. Additional funding for network activities in Europe remains elusive. More details are available in Summary Report INDC(NDS)-0783.

The 24th Technical Meeting of the NSDD was scheduled to be held in Canberra, Australia in 2021 but due to the pandemic it has been postponed to 2022. It is hoped that an in-person meeting would be possible in 2022 with a short, one-day virtual meeting in the interim to discuss recent developments and progress.

Discussions with RIKEN for contributions to the XUNDL/ENSDF compilation effort took place during the Japanese Nuclear Data Symposium in November 2018 (see Proceedings INDC(JPN)-0205) at which time that laboratory agreed to assign a dedicated staff position for this purpose. This is commendable as RIKEN is one of the largest manufacturers of nuclear data in the world but previously did not formally support compilation activities.

Financial support was given in the form of contracts to certain individuals. One contract was given in 2018 for an evaluator doing mass-chain evaluations in Romania, which was renewed in 2019. Contracts for horizontal evaluations led to significant reported output, e.g. "Table of Recommended Nuclear Magnetic Dipole Moments – Part I: Long-lived States" (INDC(NDS)-0794); "Table of Recommended Nuclear Magnetic Dipole Moments – Part II: Short-lived States" (INDC(NDS)-0816); and a revision of "Atlas of Nuclear Isomers", which is to be published in the journal Atomic Data and Nuclear Data Tables. Consultancy visits also provided extra resources for work on LiveChart, atomic masses and atomic radiation data.

Dimitriou showed several slides of snapshots of the interactive user interfaces for the Nuclear Moments Database (https://www-nds.iaea.org/nuclearmoments). Evaluations on quadrupole moments are in progress and the database will be updated in due course.

The NDS maintains a repository for ENSDF codes, mainly for the use by evaluators. This is a public dissemination (https://www-nds.iaea.org/public/ensdf_pgm) of legacy codes, editors, web tools, etc. This function also includes ensuring that all codes are running on all platforms and sending notifications of updates when they occur. Highlights are the MyEnsdf web tool and the Ensdf+ browser editor that incorporates codes and evaluation procedures.

For the DDP on Improvement of Analysis Codes for NSDD Evaluations, a Technical Meeting was held from 3–7 December 2018 in Vienna (see Meeting Report INDC(NDS)-0774). This DDP is active since 2014 and information on progress can be found also in previous INDC reports. Topics discussed included radius parameters for alpha-induced reactions, the treatment of uncertainties using probability distribution functions, new formats for certain codes (e.g. BetaShape), and progress on the development of the Ensdf+ editor by Viktor Zerkin. The complete list of codes is available at https://www-nds.iaea.org/public/ensdf_pgm.

A new dissemination tool is the Decay Data Portal, which collects in one place decay data from sources such as ENSDF, DDEP, CRP data, etc. It can be accessed via LiveChart. This is very useful for evaluators as they can rapidly compare values from previous evaluations. A current activity is to also include data from ENDF/B, JEFF and JENDL to the portal.

In conclusion, several activities have been highlighted for the future (i.e. the next two years). In addition to the Canberra TM of the network, a TM is also being planned on Improvement of Analysis Codes, with some uncertainty as to timing and the format due to the pandemic. A Joint IAEA-ICTP Workshop on NSDD is being planned, which has been very successful in the past to train young scientists and to promote ENSDF evaluations. Enhancements to the Decay Data Portal will be pursued as well as support for horizontal evaluations. The ENSDF codes dissemination will continue and the repository updated when required. Training activities, outreach workshops and webinars in collaboration with data centres in Japan, India and Europe (i.e. events other than the IAEA-ICTP workshops) will help to promote NSDD evaluation activities among members of the international research community. This is important for various reasons, a recent one being that some journals, e.g. Phys. Rev. C and Eur. Phys. J., initiated a scheme whereby submitted articles on nuclear structure and decay data are sent to the NNDC for pre-publication assessment. NSDD analysis codes are used to check new experimental data for correctness, consistency and coherence. This initiative can also be valuable as a first step for future ENSDF evaluations of data from new publications.

During question time, members expressed their satisfaction about the return of Dimitriou to the NDS and her resuming her activities on coordinating the NSDD. Herman commended the NDS and their efforts in this role. Kibédi asked Dimitriou what progress is being made on improvement of documentation, protocols and procedures relevant to evaluations, not only on codes but also on how data should be evaluated. Dimitriou replied that such information is currently scattered in various documents, some of which are not regularly maintained. The need to have a single location for such information has been identified by the NSDD and it is a priority, but action still has to be taken. Such action has been delayed partly because of her absence from the IAEA for over a year. A future, single location for all documents on procedures, policies, guidelines, etc., which will be regularly maintained, is very necessary to support evaluators and to improve the quality of evaluations.

2.3.3 Network Coordination (INDEN)

Capote gave a presentation on the coordination of the International Nuclear Data Evaluation Network (INDEN). This network was established as a follow-up of the CIELO project (OECD/NEA SG-40) after conclusion of the latter in 2017. Its main function is to improve nuclear data evaluation and evaluated data files, not merely to achieve new evaluations but to develop and improve evaluation methodology and processes. Capote explained that the NDS focus is more towards the evaluation side while the NEA focus is more towards the validation side, but that excellent cross collaboration exists between the two agencies. Many other agencies, laboratories and institutes collaborate on INDEN (see https://nds.iaea.org/INDEN/ for the full list of participants and additional information on this network.) As established by a TM on Long-term International Collaboration to Improve Nuclear Data Evaluation and Evaluated Data Files, which was held from 18–21 December 2017 in Vienna (Summary Report INDC(NDS)-0747 still in preparation), the aims and activities of INDEN have been summarized as follows:

- The network will be aimed at streamlining the evaluation activities, taking advantage of expertise in different laboratories in IAEA Member States;
- The activities would follow the pattern of the highly successful CIELO project, organized through the NEA Data Bank with a very strong technical contribution from IAEA research projects.
- The aim will be to define evaluation priorities, identify issues and discrepancies, and minimise duplication of work, except for the testing of different approaches to the evaluation;
- Team work and technical discussions to resolve issues are foreseen;
- Evaluated data files will be produced with a broad consensus that can be adopted fully or in parts by other Data Evaluation projects.

The INDEN Plan provided for one large Technical Meeting every 2.5 to 3 years to set priorities and discuss results. In addition, three Consultants Meetings per year would take care of evaluation issues and challenges. Additional TMs could be arranged as needed to focus on any identified issues. Three working groups would operate and have one CM or TM/year, i.e. nine CMs/TMs in three years. Indeed, each working group met once in 2018, 2019 and 2020, however the last one (on light elements) was postponed to 2021. These working groups are

- INDEN-LE (Evaluation of Light Elements);
- INDEN-SM (Evaluated Data of Structural Materials);
- INDEN-RR (Actinide Evaluation in the Resonance Region).

The first CM by INDEN-LE (Evaluation of Light Elements) was held from 30–31 August 2018 in Vienna (Summary Report INDC(NDS)-0768). Some of the main aims and tasks are as follows:

- Establish a list of evaluations and evaluators for the reactions n+^{9}Be, n+^{14,15}N, n+^{16}O, n+^{23}Na, and α+^{17,18}O;
- Investigate the possibility to push R-matrix theory to higher energies;
- Improve the treatment of break-up channels.

The second CM by INDEN-LE was held from 15–17 May 2019 in Vienna (Summary Report INDC(NDS)-0788). New evaluations were presented for n+^{9}Be, n+^{14,15}N, and α+^{17,18}O. Evaluation challenges were discussed in depth and a full R-matrix treatment considering all channels was endorsed. A common shared experimental database for all evaluated systems was established.

The third CM by INDEN-LE was held from 15–19 March 2021 as a virtual event (Summary Report INDC(NDS)-0827). New experimental data for ^{16}O(n,α)^{13}C and ^{13}C (α,n)^{16}O were extensively discussed. New evaluations were also presented for n+^{9}Be, n+^{14,15}N, and n+^{23}Na. Capote showed some example comparisons of new evaluations versus experimental data and previous evaluations to highlight the improvements achieved. He also explained the importance of the new evaluations for oxygen, which are clearly important for many types of nuclear reactors.

The first CM by INDEN-SM (Evaluated Data of Structural Materials) was held from 19 October to 1 November 2018 in Vienna (Summary Report INDC(NDS)-0770). The second meeting was also held in Vienna, from 2–5 December 2019 (Summary Report INDC(NDS)-0806). The third meeting was held as a virtual event from 14–17 December 2020 (Summary Report INDC(NDS)-0824). The main focus is on evaluations of neutron-induced reactions of medium and heavy mass targets, such as Fe, Cr, Ni, Mn, Cu, Zr, W, Pb, etc. Capote explained that many of these structural materials are near closed shells, having rather low level densities, therefore evaluations have to cope with problems which are essentially different from problems in other mass regions. The main problem for the mid-mass region is that models (such as the optical model and statistical models) reach the end of their applicability. Cross sections show strong fluctuations in the energy region between 1 and 5 MeV, which can no longer be addressed by conventional R-matrix analysis. Indeed, there is a need for consistent methodology that still has to be fully developed, which is part of the reason why INDEN has been created.

Capote explained that problems with the CIELO evaluation for Fe were already known before the end of that project but there was not enough time to address the issues. In a number of experiments, the observed leakage of neutrons from iron shields was found to be higher than expectations based on the evaluation. Further work on Fe was clearly needed, especially considering its importance as a structural material in all reactors. A need for new experiments was also identified and one is being planned to be conducted in Geel. The main change of the most recent evaluation for ^{56}Fe compared to the original CIELO evaluation is a reduction of the inelastic cross sections.

Capote also showed some examples for ^{52}Cr, where improvements in descriptions of elastic and inelastic angular distributions could be obtained with more realistic optical potentials. In fact, a large effort was put into the evaluation of chromium and a paper on this work will be published soon. A need to address experimental discrepancies was also identified for this material. Increased neutron capture yields improve performance in criticality benchmarks. Recent evaluation work also highlighted deficiencies in older evaluations, e.g. the BROND evaluation, the latter of which is not supported by the data.

The first CM by INDEN-RR (Actinide Evaluation in the Resonance Region) was held from 8–11 May 2018 in Vienna (Summary Report INDC(NDS)-0760). The second meeting was also held in Vienna, from 21–24 October 2019 (Summary Report INDC(NDS)-0804). The third meeting was held as a virtual event from 17–19 December 2020 (Summary Report INDC(NDS)-0818). The main activities concern n+^{235}U, n+^{239}Pu, and n+^{233}U. These activities are works in progress.

The main updates to the ^{235}U evaluation include

- Detailed shape fitting of the fission cross section to the measured data in the unresolved resonance range and above;
- Spurious cross-reaction covariance elements between the resonance and fast energy ranges were removed because they gave rise to negative eigenvalues;
- Cross-covariances between nubar and fission cross sections were removed for the same reason.

A version of the ^{235}U evaluation was also created where additional work was performed to improve agreement with measurements of the fission and capture cross sections below 20 eV. It is noteworthy that the IAEA evaluation shows improvement over ENDF-8.0 in the low energy range below 11 eV. Convergence of CEA and ORNL/IAEA evaluations in the resolved resonance range is also very encouraging. Capote also showed various examples of technical improvements and updates for ^{239}Pu and ^{233}U, too numerous to summarize in detail here. It was mentioned that adjustments to thermal cross sections and nubar were made to improve agreement with thermal neutron constants (TNC) from IAEA Neutron Data Standards 2017 (see Nuclear Data Sheets 148 (2018) 143–188). Resonance parameters were also refitted after adding new experimental data.

In conclusion, Capote presented a summary of ongoing evaluations of the network as of March 2021:

- Light elements: ^{9}Be, ^{14,15}N, ^{16,17,18}O, ^{23}Na, ^{28,29,30}Si;
- Structural elements: Cr, Fe, Ni, Pb, and Zr isotopes;
- Actinides: ^{233,235,238}U, ^{239}Pu;
- Re-evaluations due to identified issues:
  - ^{54,56,57}Fe, due to issues in (n,el), (n,inl) and $d\sigma/\Omega_{el}$ cross sections from 0.85 – 6 MeV;
  - Cr isotopes: new RR evaluations for ^{50,53}Cr, and new fast evaluations;
  - Si isotopes: updated thermal capture, and inclusion of direct capture;
  - ^{55}Mn: correction of thermal capture gammas;
  - ^{239}Pu: new prompt fission neutron spectrum (PFNS), thermal nubar, and improvements in the resonance region;
  - ^{233}U: new PFNS, thermal nubar, and resonance region;
  - ^{238}U: 14 MeV leakage issue due to inelastic neutron spectra, and PFNS for the energy region 5–8 MeV;
  - ^{16}O: preliminary update for benchmarking.

During the discussion, Herman asked whether there will be an official release of INDEN evaluated files. Capote answered that the short answer is “no”. This is because the main idea is not to freeze files as the work is ongoing, however, contributors will ultimately release files for specific purposes. Files are dated and projects adopting them should make sure this is well documented. But the main emphasis is not to establish extensive evaluations at this time but rather to develop the evaluation methodology, which will eventually lead to the former.

2.3.4 Nuclear Data Development (CRPs and DDPs)

Capote gave a presentation on Coordinated Research Projects (CRPs) and Data Development Projects (DDPs). Five CRPs have been completed with exception of one paper that is still outstanding, while two CRPs are currently active (see Table 1). Nine DDPs are either ongoing or were active in this reporting period.

Some of the decisions, actions, outputs and outcomes concerning the CRPs are summarized below:

- All the recommended cross sections produced by the CRP on "Nuclear data for charged-particle monitor reactions and medical isotope production" are now provided with uncertainties, available from the Medical Portal on the NDS website. The four published papers are as follows:
    - Hermanne et al., Reference Cross Sections for Charged-particle Monitor Reactions, Nucl. Data Sheets 148 (2018) 338–382;
    - Engle et al., Recommended Nuclear Data for the Production of Selected Therapeutic Radionuclides, Nucl. Data Sheets 155 (2019) 56–74;
    - Tárkányi et al., Recommended nuclear data for medical radioisotope production: diagnostic gamma emitters, J. Radioanal. Nucl. Chem. 319 (2019) 487–531;
    - Tárkányi et al., Recommended nuclear data for medical radioisotope production: diagnostic positron emitters, J. Radioanal. Nucl. Chem. 319 (2019) 533–666.

  One outstanding item is the 5th paper: Nichols et al., Selected and Recommended Nuclear Data for Medical Radioisotope Production, which is in preparation and planned to be completed in 2021. Capote highlighted the excellent collaboration between experts on cross sections and production data with experts on decay data, which proved to be very productive.

- The completed CRP on "Testing and improving the International Reactor Dosimetry and Fusion File (IRDFF)" released the IRDFF-II Library in January 2020 (https://nds.iaea.org/IRDFF/). The relevant documentation is published in Trkov et al., IRDFF-II: A New Neutron Metrology Library, Nucl. Data Sheets 163 (2020) 1–108. Capote mentioned that the title of this CRP is a little bit misleading and should rather be seen as one establishing a Neutron Dosimetry Library for Fusion and Fission Applications. The IRDFF-II Library has a strong focus on fusion applications, covering 119 reactions and 4 cover reactions up to 60 MeV. In contrast, fission applications typically only required data up to 20 MeV. The library includes datasets on damage cross sections, cumulative fission product yields (FPY), and a large set of evaluated neutron spectra. Some of the spectra calculated were adopted by the CoNDERC project, which will be discussed in a separate presentation by Sublet (section 2.3.11).

Table 1. Status of Coordinated Research Projects.

No.	Short title	Duration	Participants (contracts)	Project Officer (predecessor)	Status
1	Nuclear data for charged-particle monitor reactions and medical isotope production.	2012–2017 F41029	14 (5) + 1 SSA	Capote	Completed in 2017 except for final publication. Four papers on cross sections and production yields published. A 5th paper on relevant decay data in preparation.
2	Testing and improving the International Reactor Dosimetry and Fusion File (IRDFF).	2013–2018 F41031	13 (5)	Capote (Trkov) (Simakov)	Completed in 2018 except for final documentation and publication, which was completed in 2020.
3	Primary radiation damage cross sections.	2013–2018 F44003	18 (1)	Sublet (Simakov)	Completed. Final publication appeared in 2019.
4	Reference database for beta-delayed neutron emission.	2013–2018 F41030	12 (3)	Dimitriou	Completed except for the last paper, which has been submitted and is expected to be published in 2021.
5	Updating the Photo-nuclear Data Library and generating a reference database for photon strength functions.	2016–2020 F41032	15 (8)	Dimitriou	Completed and published.
6	RIPL for fission cross-section calculations.	2016–2021 F41033	10 (4)	Capote	Ongoing. Some delays due to Covid-19.
7	Updating fission yield data for applications.	2020–2025 F42007	18 (4)	Capote	Ongoing. New CRP had 1st RCM in 2020.

- Capote did not report on the CRP on "Primary radiation damage cross sections" as a separate presentation on this topic by Sublet was to follow later (section 2.3.5).
- The CRP on "Reference database for beta-delayed neutron emission" submitted its final CRP report to Nucl. Data Sheets in April 2021 and is available in arXiv:2102.01165. The database access is at https://www-nds.iaea.org/beta-delayed-neutron/database.html. Evaluations and new systematics of microscopic data for Z > 28 have also been published in the current reporting period (Liang et al., Compilation and Evaluation of Beta-Delayed Neutron Emission Probabilities and Half-Lives for Z > 28 Precursors, Nucl. Data Sheets 168 (2020) 1–116). Macroscopic data are described in a 2019 IAEA report: New Aggregate Data in the IAEA Reference Database for Beta-delayed Neutron Emission (INDC(NDS)-0784).
- The CRP on "Updating the Photonuclear Data Library and generating a reference database for photon strength functions (PSF)" concluded in 2020 with only one task outstanding, namely to develop a better interface for the PSF database. The IAEA Evaluated Photonuclear Data Library (IAEA/PD-2019) was released in August 2020

(https://nds.iaea.org/photonuclear/). It contains 209 evaluations of which 189 are new and 20 adopted from the previous version of the library (IAEA/PD-1999). Several evaluations benefitted from new measurements of photonuclear cross sections by the NewSUBARU gamma-ray beamline at the University of Hyogo, Japan. A paper was presented at the ND2019 conference and the final publication was published in 2020 (Kawano et al., IAEA Photonuclear Data Library 2019, At. Data Nucl. Data Sheets 163 (2020) 109–162). A paper on GDR parameters was also published (Plujko et al., Giant dipole resonance parameters of ground-state photoabsorption: Experimental values with uncertainties, At. Data Nucl. Data Tables 123-124 (2018) 1–85). The PSF reference database is available from https:///www-nds.iaea.org/PSFdatabase/ with a final publication in 2019 (Goriely et al., Reference database for photon strength functions, Eur. Phys. J. A 55 (2019) 172).

- The CRP on "RIPL for fission cross-section calculations" is ongoing, with the 2nd RCM held from 7–11 October 2019 in Vienna (Summary Report INDC(NDS)-0802) and the 3rd RCM planned for December 2021. This is a challenging CRP with focus on parameters for fission cross-section calculations (masses, fission barriers, transitional and class II/III states, discrete levels, level densities, fission reaction models, etc.) Capote mentioned that not only fission cross sections are being addressed but also an update of the entire RIPL database.
- The CRP on "Updating fission yield data for applications" has only recently started. The first RCM was held virtually from 31 August to 4 September 2020 as it was decided that the Covid-19 pandemic should no longer be allowed to cause a further delay. It was attended by more than 50 participants and there were 24 presentations. The CRP is devoted to evaluation efforts of cumulative and independent fission yields for incident energies from the thermal point up to 14 MeV on actinide targets. The produced fission yield evaluations should include full uncertainty quantification and are expected to combine available experimental data and state-of-the-art model information. Activities were organized in four categories, for which working groups were formed and coordinators appointed:
  - Availability of experimental fission product yield data for evaluations;
  - New fission product yield experimental data;
  - Fission product yield evaluation;
  - Fission product yield validation.

  The last working group above will be supported by a subgroup for modelling. More information is available in Summary Report INDC(NDS)-0817, available since April 2021 on the NDS website.

Capote mentioned that many of the DDPs are performed with the help of Special Service Agreements (SSA) as well as NDS staff. A summary of DDP activities during the current reporting period is presented below:

- Inter-comparison of particle induced gamma-ray emission (PIGE) analysis codes to calculate PIGE yields for the analysis of bulk samples: A meeting was held in Vienna, from 1–4 October 2018 to discuss the results of the inter-comparison, decide on further actions, and prepare the results for publication. Results were presented at the 24th International Conference on Ion Beam Analysis (IBA 2019) which was held in October 2019 in Antibes, France. A technical publication followed in 2020 (Pessoa Barradas et al., International Atomic Energy Agency inter-comparison of particle induced gamma-ray emission codes for bulk samples, Nucl. Instrum. Methods B 468 (2020) 37–47). This project has been completed and no further work is foreseen at this time.

- Evaluation of Nuclear Moments: Following the recommendations of the 2017 CM on this topic (see INDC(NDS)-0732), most of the work has been done in collaboration with a contract appointee (N. J. Stone). The results have been compiled in two reports:
    - o Table of Recommended Nuclear Magnetic Dipole Moments – Part I: Long-lived States (INDC(NDS)-0794);
    - o Table of Recommended Nuclear Magnetic Dipole Moments – Part II: Short-lived States (INDC(NDS)-0816).
- Verification of data processing codes for generating ACE-formatted files: A TM on nuclear data processing and inter-comparison of ACE produced libraries was held from 23–26 September 2019 in Vienna. Several codes have been evaluated, including GRUCON (Kurchatov Institute, Russia), Prepro/ACEMAKER (IAEA), FUDGE (LLNL and BNL, USA), NJOY (USA), FRENDY (Japan), GALILEE (France), and NECP-Atlas (China). Deliverables during the current reporting period are listed below:
    - o D.E. Cullen, The Importance of Resonance Self-Shielding, INDC(NDS)-0778, March 2019;
    - o D.E. Cullen et al., The Importance of Resonance Self-Shielding – Part 2, INDC(NDS)-0814, August 2020;
    - o D.L. Aldama and R. Capote, Processing La-139 in the unresolved resonance region for FENDL library, INDC(NDS)-0825, January 2021.

  Capote mentioned that the NJOY and FUDGE codes from the US now have open access and that the FRENDLY code from Japan may also become open access soon.
- Stopping-power database: The electronic stopping-power database created by Prof. Helmut Paul of the University of Linz is being maintained by the NDS since 2015. The database and online retrieval interface can be accessed at www-nds.iaea.org/stopping/.
- Study of scission neutrons: This was a relatively short DDP during 2019 and 2020, producing the following technical reports:
    - o R.C. Haight, Scission Neutrons in Spontaneous and Neutron-Induced Fission: Effect on Prompt Fission Neutron Spectra, INDC(NDS)-0807, February 2020;
    - o A.S. Vorobyev and O.A. Shcherbakov, Scission Neutrons from Thermal Neutron induced Fission of ^{239}Pu and spontaneous Fission of ^{252}Cf, IAEA(NDS)-0808, February 2020;
    - o A.S. Vorobyev and O.A. Shcherbakov, Experimental Investigation of the Properties of Scission Neutrons in Thermal-Neutron Induced Fission of ^{233}U and ^{235}U, February 2020.
- Nuclear Data Libraries for Advanced Systems – Fusion Devices: The maintenance and update of the Fusion Evaluated Nuclear Data Library (FENDL) is continuing. A CM on “FENDL Library for fusion neutronics calculations” was held from 15–18 October 2018 in Vienna, followed by a TM on “FENDL Library for fusion neutronics applications” from 2–5 September 2019, also in Vienna. The NDS is pleased to report that FENDL-3.2 has just been released.
- Electron Photon Interaction Cross Sections (EPICS) Library: EPICS2017 provides the atomic data needed to perform coupled electron-photon transport calculations. The library includes three separate databases that are designed to be used in combination, namely Evaluated Atomic Data Library (EADL), Evaluated Electron Data Library (EEDT) and Evaluated Photon Data Library (EPDL). Several updates were made in 2018 and the webpage was updated in 2020 (see https://www-nds.iaea.org/epics/).

- Nuclear Data for Medical Applications: A TM was held from 10–13 December 2018 at the IAEA Headquarters in Vienna (Summary Report INDC(NDS)-0776). It was attended by 20 participants from 14 countries. Participants assessed future medical applications for the next five to ten years, for many radionuclides based on their existing and potential diagnostic and therapeutic properties. Expansion of the existing database established by several completed CRPs is foreseen. The needs for further cross-section measurements were identified, along with decay data studies for specific radionuclides. Subsequent evaluations in the future are expected. This will be discussed in more detail in a presentation on future NDS activities (see section 3.1).
- Maintain the International Neutron Standards file and evaluation techniques: The reactions included in the IAEA Neutron Data Standards library were published in 2018 (A.D. Carlson et al., Evaluation of the Neutron Data Standards, Nucl. Data Sheets 148 (2018) 143–188) but the webpage (https://nds.iaea.org/standards) has been delayed because of problems with some uncertainties and covariances. Some of the data are still missing but will be included soon (see section 3.1).

2.3.5 CRP on Evaluation of Primary Radiation Damage Cross Sections

Sublet gave an extensive presentation on this CRP, which had collaboration from 19 institutes in 14 countries. The objectives were following:

- To find ways to overcome the drawbacks and limitations of the Norgett-Robinson-Torrens displacement per atom (NRT-dpa) model by relying on recent/modern research and development in primary radiation damage simulations;
- Elaborate upgraded primary radiation defect metrics to better capture the annealing kinetics and evolution of defects in the recoil cascades, but also thereafter;
- Demonstrate better metrics to correlate experimental (ions-based) to model parameters (neutron-based) for microstructural material damage;
- Encourage, entice the nuclear data/processing and materials research communities to more efficiently work together;
- Engage the true multi-scale (atom/isotope-molecule/element-alloy/material) aspects of characterizing material property evolution under particle irradiation;
- Provide, elaborate and engineer more robust methodologies able to cover all experimental and modelling aspects of the study of materials under irradiation by ions and neutrons, taking into account that most experimental information is based on ions, while the next generation devices will endure exposure to high energy neutrons;
- Develop the physics and metrics to bridge the gaps.

The results achieved based on the CRP objectives are summarized below:

- Isotopic and elemental numerical databases for defect production metrics as well as gas production and kerma factors in various materials;
- A much better understanding of the different physics at play, including the high energy non-elastic and time dependent events;
- A pivotal review was published (Sublet et al., Neutron-induced damage simulations: Beyond defect production cross-section, displacement per atom and iron-based metrics, Eur. Phys. J. Plus 134 (2019) 350), now fully integrates an even more concerted World effort in further developing our knowledge of radiation damage and exposure;
- The specific objectives were met with some success as now more research communities are working in unison, whilst the multi-physics, multi-scale aspects of the field are truly

emerging and are considering new materials and plant design.

The CRP generated about 40 publications/articles, the complete list of which is available on https://www-nds.iaea.org/CRPdpa/. Of main importance are also the tools and databases developed. NJOY-2016 pointwise data forms of heating kerma, NRT-dpa damage energy and gas-production metrics were established for 83 elements between hydrogen and uranium. Databases have been developed for the TENDL-2019, JENDL-4.0 and ENDF/B-VIII.0 libraries, as well as graphical comparisons between the libraries. NJOY-2016 groupwise isotopic (287 stable isotopes) and elemental (83 elements) data of recoils and emitted particles primary knock-on atom (PKA) spectra have been established. The processing code SPECTRA-PKA produces energy spectra of primary atomic recoil events for any material composition exposed to an irradiation spectrum. This code is open source and available on GitHub (https://github.com/fispact/SPECTRA-PKA).

Significant progress has been made on a nuclear scale:

- Definitely a step forward in the proper understanding of materials defect metrics induced by radiation:
    - Much better nuclear data (with uncertainty);
    - More complete data forms;
    - Transmutation, decaying effects (also happen after irradiation);
    - Non-elastic events;
    - Incident particle energy dependence.
- A much better coverage of the high energy range.
- Novel on a per-channel metrics (see Gilbert and Sublet, Differential dpa calculations with SPECTRA-PKA, J. Nucl. Materials 504 (2018) 101–108).
- Uncertainty quantification and propagation (UQP) to better serve multi-scale, multi-physics simulations software.

Key performance indicators (KPIs) of the CRP include the following:

- Good interaction with the Accelerator Simulation and Theoretical Modelling of Radiation Effects (SMoRE-II) CRP from NAPC Physics Section;
- Support of MiNES 2019: Materials in Nuclear Energy System (MiNES) is a new conference created to serve the fission reactor materials community that grew out of, and supplants, biennial symposia held at the TMS meeting (Microstructure Processes in Irradiated Materials – MPIM) and the ANS meeting (Nuclear Fuel and Structural Materials – NFSM).
- Support of M&C 2019: The 2019 International Conference on Mathematics and Computational Methods Applied to Nuclear Science and Engineering (M&C 2019) was held from 25–29 August 2019 in Portland, Oregon, USA.

Sublet discussed two KPIs that could not be achieved:

- A planned ICTP-IAEA Workshop at Trieste on “Radiation Damage in Nuclear Systems: from Bohr to Young”, which was to be held from 11–22 May 2020. This event had 175 applicants of whom 54 were selected, but was postponed due to Covid-19. It was postponed to Spring 2022.
- Consensus across the physical societies: nuclear, atomic-molecular, material sciences, and engineering.

Sublet concluded with statements on impact, relevance, recommendations, and a final list of conclusions. The CRP had a significant impact on our understanding of radiation damage beyond the traditional iron-based fission applications. It allowed a clean-up of the R&D and establish new, better practices able to serve novel applications, e.g. advanced fission, accelerators, space applications, fusion, etc. The recommendations include organizing a number of future events:

- Workshop on multi-scale physics developments, organized with the Physics Section, to be held as a virtual event from 12–16 July 2021;
- ICTP Workshop at Trieste in 2022;
- CM on nuclear radiation heat and particle energy production, probably in autumn 2021.

The conclusions are as follows:

- Multi-scale modelling of materials across the length and times scales requires overcoming the borders between the disciplines for a seamless integration of the models on different length scales into one coherent multi-scale modelling framework (after D.G. Pettifor, 1991);
- A third scale exists: matter state, temperature scale;
- Modelling is difficult not so much for components or atoms but for in-between interactions;
- Assuming that the general purpose nuclear data files are fit to the tasks (of sufficient completeness to capture all relevant processes, particularly at high energy), progress in data provision at the nuclear scale is a step forward in the proper understanding of material defect metrics induced by radiation but small step with regard to the seamless integration of the models across the length (nm → μm → mm → m) and time (ps → μs → ms → s) scales into one coherent modelling framework.
- Fundamentally, the CRP leads to the conclusion that a simple integral measure such as dpa (NRT, arc, or any other) is not sufficient, even though it may be a good first-order estimate, to fully capture the damage metrics from complex irradiation.
- More substantial methodologies and algorithms from the nuclear-reaction space to the molecular-material ones must be included in complete plant and material modelling.

During question time, there was a short discussion on the difficulties and uncertainties associated with energies of recoils for processes more complex than simple 2-body reactions.

2.3.6 Training and Workshops (ICTP, Trieste)

Capote gave a presentation on ICTP-IAEA Workshops over the period 2018–2020:

- Joint ICTP-IAEA Workshop on Nuclear Structure and Decay Data: Experiment, Theory and Evaluation, was held from 15–26 October 2018 in Trieste. It was attended by 17 trainees. In addition to the seminars, hands-on course work included the compilation of several XUNDL datasets during the first week, subsequently uploaded to the XUNDL library. Evaluation of mass chain A = 218 was started in the second week, which eventually led to a publication (Singh et al., Nucl. Data Sheets 160 (2019) 405–471.)
- Joint ICTP-IAEA Workshop on Radiation Damage in Nuclear Systems: from Bohr to Young, scheduled for 11–22 May 2020, but had to be postponed due to the Covid-19 pandemic. This workshop will probably be held in 2022.
- Joint ICTP-IAEA Workshop on Monte Carlo radiation transport and associated data needs for medical applications, also planned to be held in 2020 but postponed due to the

pandemic. This workshop may also be held in 2022.

During question time, Koning observed that these ICTP-IAEA workshops are the least appropriate for virtual events as hands-on training and in-person learning are essential, and just not possible in a virtual environment. Capote added that the NDS had the possibility to hold the postponed workshops as virtual events but decided against that. Herman asked if the NDS is considering another workshop on reactions, as the last "Joint ICTP-IAEA Workshop on the Evaluation of Nuclear Reaction Data for Applications" was held as far back as 2017. Capote replied that this has become a priority, however, there is significant competition for access to the ICTP for workshops, as also other units within the IAEA hold workshops there. In previous years the NDS would organize 2 to 3 workshops per year, but recently this has reduced to only two, including the needs of the Atomic and Molecular Data Unit (AMDU) who also hosts workshops.

2.3.7 Project Nuclear Data Services Dissemination – Deployment

Sublet gave a short presentation on nuclear data services and dissemination activities for the period 2018–2020. New libraries and library updates include the following:

- CENDL-3.2 is a new version of the Chinese general purpose Evaluated Nuclear Data Library, released in 2020 (available from https://www-nds.iaea.org/public/download-endf/CENDL-3.2/);
- JENDL/PD-2016.1 is a revised version of the Japanese Evaluated Nuclear Data Library (JENDL) Photonuclear Data File 2016, released in February 2020 (available from https://www-nds.iaea.org/public/download-endf/JENDL-PD-2016.1)/;
- IAEA-PD-2019 is a new version of the IAEA Photonuclear Data Library;
- JENDL/ImPACT-2018 is the JENDL Transmutation Cross Section File released in 2018, developed for innovative studies on nuclear transmutation of long-lived fission products (LLFPs);
- JENDL/AD-2017 is the Activation Cross Section File for Nuclear Decommissioning;
- TENDL-2019, released in December 2019, is the latest version of the TALYS-based Evaluated Nuclear Data Library;
- TENDL-2019 Pointwise2020, released in May 2020, is a temperature-dependent cross section library for incident neutrons on 630 evaluated target nuclides between hydrogen and fermium (Technical Report IAEA-NDS-0233).
- EPICS2017, the Electron Photon Interaction Cross Sections library, had several updates during 2018, with the latest update in 2020.

There were also several updates to codes. PREPRO 2019 is the latest version of this pre-processing code for ENDF formatted data, for subsequent further processing for use in applications (INDC(NDS)-229). GRUCON 2020 is the latest version of the GRUCON processing code for generating ACE files. There is also progress in providing data output from certain libraries in newer formats such as JSON, plotting groupwise data online and plot comparisons. Sublet also briefly discussed the new online portal for CoNDERC, a new project which will be discussed in more detail in a subsequent presentation (section 2.3.11).

Data are also being disseminated via mirror sites. The mirror site at Atomstandard, Russia, is functioning. The mirror site at BARC, India, is in process of reopening while the site at the CNDC in China is currently frozen.

The NDS web statistics show a steep increase in accesses and downloads throughout the 2000s, reaching a peak in 2018 and essentially plateauing in subsequent years. During the present reporting period, more than 80% of web traffic was for accesses to ENDF, EXFOR, and

NuDat/LiveChart.

In conclusion, Sublet put forth several questions related to the present trends. In terms of customer outreach, has an actual plateau been reached and what are the reasons? Do the present data services correspond to demand, especially in terms of quality, diversity, continuity, sustainability, etc.? Is there a better way for the NDS to serve Member States? Advice from the INDC would be welcome on these questions.

During question time, Herman commented that a similar plateau has been observed at the NNDC in the US. It may be that data centres are just seeing a saturation in demand. Alejandro Sonzogni commented that the NNDC has seen an increase in web traffic of about 25% since the Covid-19 pandemic started, but prior to that it was typically on the level of 2–3 % increase per year in recent years. There was a lengthy discussion on how one should be careful in interpreting web statistics, e.g. number of downloads and size of downloads give different perspectives. Sublet observed that there may be a need to refine the statistics. Users may also change their behaviour as web speeds increases, e.g. fewer large downloads nowadays where previously more frequent but smaller downloads would have been preferred.

2.3.8 User Services for Nuclear Reaction Data

Zerkin gave a presentation on user services for nuclear reaction data. A major development is the implementation of the JSON format in EXFOR, ENDF and ZVView. An explanation was given of the computational formats in EXFOR and their progression with implementation over time, i.e. C4→XC4→C5→C5M. The latter three are essentially C4 with various data extensions. The C5M format, for example, is C5 + a covariance section, requested by WPEC SG-50. JSON (JavaScript Object Notation) is an open standard file format and data interchange format that uses human-readable text to store and transmit data objects consisting of attribute–value pairs and arrays. It found application in a diverse range of fields, one example being web applications that communicate with a server. It is a popular format amongst young programmers and is easy to use in programming. JSON is simpler than XML and supported by modern programming languages and IT systems. Versioning has been implemented and there is an online link to earlier/different versions. Since 2019 preliminary files (PRELIM files) are stored in the EXFOR database with temporary ID (Y series), therefore PRELIM data are immediately available for search, presentation in output formats, conversion to other formats, plotting, comparison with other experimental and evaluated data, etc. This is a very useful feature that can also be used to simplify communication and interaction between compilers and authors. An online evaluator's flags system has also been implemented. This allows an evaluator to indicate which datasets were selected/unselected from an evaluation process with a description of the reasons. This information is submitted to the NDS and shared with other evaluators. Optionally, the system can also include and operate with "statistical verification scores" indicating differences between a dataset and other experimental/evaluated data.

ENDF online has links to JSON for cross sections and decay data (MF3, MF33, and MF8:MT457 file types). Online comparison of decay data is a valuable tool for evaluators and users. Similarly, comparison of cross sections is very useful, e.g. between ENDF/B-VIII, JEFF-3.3, and also EXFOR data. Zerkin showed several plots of such comparisons. One example showed the online use of code GROUPIE, which is useful to reduce the number of points in fluctuating data. Resonance or strongly fluctuating data are very difficult to compare to low-resolution measured or evaluated data. Averaging such fluctuating data with GROUPIE make comparison with low-resolution data much easier, where average behaviour rather than high-resolution is required for a proper interpretation.

Several new options have also been added to ZVView plotting on the Web. The creation of JSON output from within Web-ZVView can now be performed. The implementation is ZVView→JSON→AJAX→HTML5, where AJAX (Asynchronous JavaScript and XML) allows webpages to be updated asynchronously by exchanging data with a web server behind the scenes. This means that it is possible to update parts of a webpage without reloading the whole page. A new option is the “control file”. Online smoothing of data can be done by using the “smooth” command in the control file. Editing the control file can change attributes of the plot.

The second part of the presentation focused on integrated databases. Some important changes were made to the database CINDA (Computer Index of Nuclear Reaction Data). Briefly, CINDA has been extended by photonuclear and charged-particle reaction data since 2005. CINDA has been extended regularly by new information from EXFOR and NSR since 2010. Since 2017, import from EXFOR and NSR is done fully automatically. Since November 2019 the import from NSR to CINDA is no longer available. In 2020 the maintenance of CINDA was migrated from Windows to Linux. The main purpose of recent extensions to CINDA is to make it more useful for searching candidates for EXFOR compilation.

Zerkin gave a historical overview of the EXFOR-NSR PDF database. EXFOR source papers are stored in the IAEA-NDS PDF archive since 2005. Web retrieval systems were added later to give access to authorised users (also from NSR and CINDA). IAEA-INDC reports have been added since 2016. Some laboratories donated lab reports and conference proceedings, e.g. Institute for Nuclear Research (Ukraine) in 2019. Some ENSDF evaluators also donated their PDF collections. In April 2021 the PDF collection contained some 219855 publications, of which only 2550 are public (i.e. just over 1%). Hopefully the collection will become progressively more open in the future.

The third part of the presentation focused on local databases and new retrieval tools. There was a modernization of CD-ROM packages. A pilot project called X4Lite is ongoing. There is significant interest to make data available not only via interactive Graphical User Interfaces (GUI) but also via Application Programming Interfaces (API). This will provide for communication between different applications, direct communication between applications and databases, facilitate automatic access to nuclear data, give more freedom and power to applications, etc.

The following concluding remarks were presented:

- Recent development of “nuclear reaction data service” is mostly oriented to the needs of advanced users, including new data formats based on JSON.
- Development of X4Lite versus storage computational data in the database, Web-download and Web-API: this development still has open questions as X4Lite has some advantages and disadvantages, and there are alternative approaches. INDC support and/or alternative views will be appreciated.
- API for local database access versus API for remote database via the Web: investigate possible IT problems: the development of remote access via APIs still has open questions. Also on this point INDC support and input is welcome.
- Continue development of the EXFOR-NSR PDF database and try to obtain public access to more laboratory reports.

During question time, Gonzales enquired about the X4Lite Pilot Project, whether it can access a full library (of e.g. EXFOR or ENDF) or only a local “snapshot” thereof, and its general availability. Zerkin replied that both possibilities of access exist and that API access to a live database is indeed possible. The X4Lite capability is not yet generally available as there are still outstanding IP issues, therefore the NDS has not yet announced it. Capote added that the development is ready for a general roll-out and it will eventually happen, but there are still authorization issues that needs to be cleared up. Gonzales wanted a clearer idea of when such remote access via APIs will be possible. Capote replied that it will probably be in a few months.

2.3.9 NDS Computing Infrastructure

Marian gave a presentation on NDS computing infrastructure. Currently the NDS has 19 machines, both virtual and physical. The in-house data centre has 14 physical machines and there are 5 virtual machines in the Microsoft Azure Cloud. Outside user's access is via load balancers to the virtual machines. Separate but essentially identical infrastructure serves Nuclear Data (nds.iaea.org) and Atomic & Molecular Data (amdis.iaea.org) websites, each service consisting of three physical and two virtual machines. Some of the standalone physical machines are for testing and power users. All codes are implemented and tested on a staging server, before being pushed to the cloud servers. Both data services have two virtual servers to provide redundancy and to avoid any single point of failure. The fifth virtual machine is for hosting the EMPIRE SVN repository. The remainder of the in-house machines are used for calculations and contain in total about 160 CPUs.

Over the last 1 – 2 years, a large effort was made to optimize the cloud services in order to reduce cost. This is for the cost of virtual machines, bandwidth, storage and backup. The effort was very successful, leading to a 52% reduction it total cloud costs ($26 351 in 2018, $26 547 in 2019, and $12 860 in 2021). Some additional optimization of the settings was done in September 2020 and it is expected that the cost will go down further.

The free service UptimeRobot is used to monitor the uptime/availability of the servers. It has a dashboard set-up and updates its notifications about every 5 minutes.

Each application, before deployment, goes through a full security scan. For this purpose Netsparker is used, which is provided by corporate IT but the scans are performed by the NDS. Full security information is displayed on the Netsparker dashboard. System scanning is done with Nessus and performed by IT. For security in static code analysis, each developer can use their own choice. A previous local solution, the web application security scanner Acunetix, has been decommissioned.

The NDS has looked for ways to streamline software and data development processes. One way was to introduce version control for some projects, which is a great way to increase transparency, traceability, reproducibility, and to offer a collaborative environment. Projects are free to choose which version control tools they prefer, e.g. the EMPIRE project uses SVN. GitHub has been introduced for some projects where non-IAEA collaborators are involved (e.g. Stopping Powers, FENDL-ENDF, ConDERC, TRIPOLI dataset, Oktavian dataset, etc.) while GitLab is available only internally (current NDS website, TALYS webpage, etc.). It is worthwhile noting that GitHub is the largest platform in the world for hosting source code and code developing. The NDS currently maintains 29 repositories in GitHub, both public and private. GitLab is used more for operations, prototypes and proof-of-concepts.

Another tool that has been set up is Jupyter Notebooks, which allows access to computational infrastructure from a browser. It is a useful way to run various languages, e.g. Python, R, Julia, Fortran, etc. Its uses include fast prototyping, easy sharing of code, dependency encapsulation, etc., all with easy access from a browser. A user has a docker container running on one of the computational machines, from which it can access that machine's terminal.

Marian gave some examples of activities aiming to modernize legacy systems, such as the Atomic & Molecular Data Unit (AMDU) website. AMDU is modernizing their legacy systems and building new ones using a new software stack, Django/Python + MySQL. The project uses GitHub version control and collaborative development. New applications coexist with the legacy ones on the same computing infrastructure. Anaconda is used for requirements management and dependency encapsulation. Basically, Anaconda is a free and open-source distribution of the programming languages Python and R, distributed with the Python interpreter and various packages related to machine learning and data science.

In a similar fashion, new projects may benefit from the above approach. ConDERC, for example, uses a Python software stack, GitHub version control, Anaconda for the reasons mentioned above, and coexists with the existing software applications on the same computing infrastructure.

Marian concluded her presentation with some thoughts on long-term strategy. Computing infrastructure remains a rapidly developing technology. There is a well-known concept in the "open data community" called FAIR data (i.e. adhering to the principles of Findable, Accessible, Interoperable, Reusable). In order to reuse data it must be findable. Metadata and data should be easy to find for both humans and computers. Machine-readable metadata are essential for automatic discovery of datasets and services, so this is an essential component of the FAIR process. Interoperable refers to a need for data to be integrated with other data. In addition, the data need to interoperate with applications or workflows for analysis, storage, and processing. It is also necessary to ensure that all systems are secure and that data are well preserved for long-term archival.

2.3.10 Software Support for Structure & Decay Data

Verpelli gave a presentation on software support for structure and decay data. Ongoing support is given to CRPs, TMs and DDPs, mostly activities related to database maintenance and further development and implementation of web applications. Some examples were shown of β^--delayed neutron emission, RIPL discrete levels, and NSDD Analysis & Utility software. RIPL was updated after the new ENSDF release and matching of unknown level energies was done with data from the 2016 Atomic Mass Evaluation (AME 2016).

An active area of development is LiveChart, especially the implementation of requests from users. Recently β^+ and β^- spectra were included. Contributions from β^+ emission and electron capture (EC) are now given separately, which is required for medical radioisotope scouting. X-ray intensities are provided according to their association with individual gamma-rays. Interactive plotting of spectra has been implemented. The legacy Fortran code RADLST (for calculating atomic radiation) was no longer maintained and has now been completely rewritten. It is used to calculate intensities of X-rays, conversion electrons, and Auger electrons for K and L shells. Verpelli reported that parts of the GUI of LiveChart need a redesign and there is also a need to keep up with evolving web technologies. Adaptive designs enable successful implementation on small mobile devices.

The Isotope Browser remains a popular app for small devices, as evidenced by an increasing annual trend in user downloads since 2013. This app has now been downloaded more than 120 000 times to Apple and Android devices and has an excellent rating of 4.7 (the maximum score is 5) from 787 reviews. This project requires a significant amount of effort and time as there are quite a lot of feedback and requests from users, the technology is changing fast, and all the work has to be done for two operating systems. About 70% of ideas come from users and 30% from NDS own initiatives. In order to keep a good rating on this platform, the response to fix errors or implement suggestions must be rapid. In 2019 alone, 13 releases of Isotope Browser were made.

An ambitious development is the progress from Visualization to Visualization + Interaction, which started with the β spectra and the Medical Isotope Brower. It is useful when a user can interact directly with a plot to obtain the underlying and/or related data (and vice versa) and to apply filter techniques. In this regard Verpelli briefly mentioned the idea of what can be called a "Pocket Nuclear Database", having its own data structure (i.e. not working via the Web), tools for extraction & manipulation, and possibilities for Visualisation & Interaction. This gives the potential to put an application like LiveChart on a small mobile device. Visualisation & Interaction capability is also given by JupyterLab, which can run in a browser and give access to Python's Machine Learning tools and interactive graphical engine.

During question time Herman commended the NDS effort. He appreciated the Jupyter access to databases and asked whether the standard plotting is used or whether own choice of plot software is used. Verpelli replied that they use Plotly, which is an interactive, open-source, browser-based Python graphing library. Junghans requested that the Isotope Browser should also be made available with a German language choice. Verpelli replied that the number of downloads from Germany is the second largest after the USA, and that indeed Georg Schnabel is working on a German version, which will be released in due course.

2.3.11 Project Compilation of Nuclear Data Experiments for Radiation Characterization (CoNDERC)

Sublet gave a presentation on the project "Compilation of Nuclear Data Experiments for Radiation Characterization (CoNDERC)". The objectives are as follows:

- To transfer into technology the experimental integral radiation information that can be used as part of the Validation and Verification (V&V) processes of nuclear model and code systems;
- To provide various schema and protocols to perform the V&V processes;
- The aim is to construct several benchmark databases based on extensive and thorough V&V activities, for example data evaluation processes, inventory calculations, source-term and reaction rate simulations, but also outreaching to engineering systems;
- Furthermore, the aim is to provide all experimental and calculational information in such computational ways that it can easily, seamlessly and rapidly be deployed in support of the many scientific systems that need them, such as models, inventories, transport, material sciences, code systems, etc.

Key elements of the project include the following:

- Identify and compile a set of radiation characterization benchmarks (both computational and experimental) that includes spectral indices, reaction rates, decay heat, resonance integrals, particle emissions (source terms), etc.
- Assess and review the data, including quantification of uncertainties, then compile the data into computer format for dissemination;
- Perform simulations of each benchmark with a suitable code system and selected nuclear libraries and produce a database/repository of the necessary input files to repeat those simulations for other nuclear data libraries.

There are many contributing benchmark experiments, across the world, the main ones briefly mentioned below:

1. JAEA time dependent Fusion Neutron Source decay-heat experiments (73 materials, 2 to 3 irradiation campaigns);
2. FZK 6764 (steel) – isotopic composition measurements;
3. Li(p,n) angular neutron yields (up to 150 MeV);
4. Fission pulse decay-heat experiments;
5. Fission delayed neutron experiments;
6. Selected criticality experiments with reaction rates (ICSBEP, IRPhEP, REAL-IAEA);
7. Experimental MACS from KADoNiS;
8. Spectrum-averaged cross sections in reference spectra (e.g. ^{252}Cf, ^{235}U, ACRR, LR-0, BOR, HFR, etc.);
9. Resonance integrals (based on the Atlas, other experiments, compilation);

10. Resonance integrals and thermal cross sections based on kayzero database for NAA;
11. Time-dependent gamma spectral measurements from PNNL (fission) and UK (fusion);
12. (γ, n) experimental data (Laser-Compton scattering from TUNL and New Subaru);
13. Integro-differential benchmark (from EXFOR or otherwise);
14. Shielding and fusion leakage benchmarks from SINBAD and other sources (including models);
15. Reference spectra for computational analysis.

The project has been managed and constructed through one Technical Contract (ending in 2021), a number of small consultant agreements with experts, and generous contributions. The website portal has been designed internally (see also 2.3.9).

Next, relevant information on reference spectra were presented:

- The majority of neutron-application spectra stem from light-water assemblies, mock-ups, piles or reactors where the integral responses are strongly, if not solely, influenced by the energy ranges of the fission spectra, resonance range, and thermal Maxwellian;
- Fusion spectra that have been obtained from magnetic confinement (MCF) or inertial confinement fusion (ICF) present typical D-D 2.5 MeV, or D-T 14 MeV peaks, sometimes accompanied by a higher-energy tail, but also showing rather different slowing-down profiles;
- Accelerator-driven beam spectra are important for their role in nuclear data acquisition and materials research, but also for medical therapeutic and diagnostic applications;
- Some 85 incident particle spectra are provided, mostly including neutron incident spectra but also some charged particle spectra;
- It should be noted that these are provided in the original energy group structures as generated by the code(s) that calculated them. These are often not the same energy group structures as those provided for the nuclear data libraries and may require a flux conversion;
- It should also be noted that while the group conversion can easily be performed, this cannot add structure when moving from a coarse group structure to a more refined multi-group.

The above-mentioned spectra are from all over the world: research reactors, NNP – BWR and PWR, ESS, CERN, Maxwelian, Am-Be, Yayoi, Phenix, etc.

Likewise, resonance integrals and thermal values have been taken from multiple sources and a well-structured table has been compiled (in a style similar to the Atomic Mass Tables):

- Recent publications;
- Data table compiled from EXFOR (up to May 2021);
- S. F. Mughabghab in Atlas of Resonances (Sixth Edition);
- N. E. Holden in Handbook of Chemistry and Physics (99^{th} Edition);
- Dillmann, R. Plag, F. Kappeler and T. Rauscher in KADoNiS v1.0 +;
- J. Kopecky in UKAEA-R(15)30;

Fusion decay-heat benchmark experiments performed at the Fusion Neutron Source (FNS) at JAEA, Japan are very important for CoNDERC. Data have been measured for 83 samples (elements) in two campaigns, 5 min and 7 hrs irradiations, and decay-heat measurements from seconds to a year of cooling time. These data and simulation benchmarks are available with open access in one final portal (https://www-nds.iaea.org/conderc/) with live plots, mouse numerics, and downloadable from GitHub.

For reactor physics fission, of real importance are the following:

- The energy release(s) and fission neutron maps during operation and shortly thereafter (accidental scenarios also);
- The fuel burnup rate, the poisonous fission fragments that capture the neutrons that should induce another fission.

Measurements of fission product energy release rates (decay-heat power) following fast and thermal neutron irradiation of ^{233}U, ^{235}U, ^{238}U, ^{239}Pu, ^{241}Pu, ^{237}Np, and ^{232}Th have been reported for decay times up to 48 hours. Compilation of all the World experiments has been thoroughly scouted and assembled with proper references. The FISPACT-II and ORIGEN code systems have been used to Verify the processes and Validate parts of the data. It should be noted that the website is still evolving.

An ongoing activity is a review of the ICSBEP and IRPhEP handbooks as well as other sources such as IAEA TRS No. 480, which allowed to determine a variety of critical experiments with reaction rates and spectral indices, for which output results are being simulated with ENDF-VIII.0 and TENDL-2019. The latest edition of ICSBEP (International Criticality Safety Benchmark Evaluation Project Handbook) was released in 2020 and for IRPhEP (International Reactor Physics Experiment Evaluation Project) in 2018. Thirteen cases have been identified and there will be more to come. In a sense this can be seen as a "scouting for gems" process. It should be noted that converging reaction rates is much more demanding than traditional K_{eff} simulations. Many sets of experimental data have been gathered, compiled and properly referenced. The MCNP6 and TRIPOLY code systems have been used to Verify the processes and Validate ENDF/B-VIII.0 and TENDL-2019 application data forms. The website is still evolving.

Another activity is gamma transport verification, triggered by the recent releases of new photonuclear libraries. ACE photonuclear data files have been tested for all stable elements/isotopes from Z=3 through Z=83 as well as ^{232}Th and ^{234,235,238}U. There was also a request from a few Member States for radiation shielding benchmarks, which are now also considered in ConDERC. MCNP6 and TRIPOLI-4 input decks have been developed for various contributed experiments or cases (e.g. Oktavian, Aspis, Tiara, Replica, NIST, etc.), building upon the database of shielding experiments (SINBAD) hosted by the RSICC and maintained as a basis for computer codes, models and nuclear data, jointly with the NEA Data Bank.

In conclusion, Sublet mentioned some important objectives/deliverables for the way forward:

- Live web portal, explicit with graphics and tables;
- Deployable data streams, fully downloadable;
- V&V codes inputs & outputs;
- Experimental information in computer forms;
- All data and information computer accessible through GitHub.

During the subsequent discussion, Sublet and Capote exchanged some comments on CoNDERC work that is also relevant for the neutron dosimetry file IRDFF. As these were highly technical issues, they concluded to rather continue the discussion off-line. There were no other questions, concluding the session on Nuclear Data Section Review for 2018–2020.

3. PROGRAMME PLANS FOR 2021−2023

3.1 Continuing and Future Data Development Projects

Capote gave a presentation on ongoing and future DDPs on behalf of the whole Section, stressing that some of them may change later, e.g. becoming future CRPs. Several of these projects are global efforts with coordination residing within the NDS (see also section 2.3.4 for more information on DDPs during the current reporting period):

- Maintaining the International Neutron Standards file and evaluation techniques: this is one of the most important projects at the IAEA. There is concern about rather small uncertainties obtained for the standards in previous evaluations, which led to an ongoing investigation of unknown systematic uncertainties. It was found that in some cases the previous uncertainties were underestimated. This does not only involve unrecognized uncertainties (i.e. a normalization issue) but also uncertainties that can have energy dependence. This was a topic of a CM in July 2020 as well as two preceding meetings, which resulted in a publication describing these difficulties (Capote et al., Unrecognized Sources of Uncertainties (USU) in Experimental Nuclear Data, Nucl. Data Sheets 163 (2020) 191–227). Capote stressed that this publication should be seen as a beginning of an investigation and that progress on new evaluation techniques will be reported at the next INDC meeting.

- Nuclear data for Ion Beam Analysis (IBA) applications: The Ion Beam Analysis Nuclear Data Library (IBANDL) webpage has been maintained and extended (see www-nds.iaea.org/exfor/ibandl.htm). R-matrix evaluations developed by INDEN and the development of R-matrix codes are also relevant for this DDP, as this will help to improve several evaluated data libraries, including IBANDL.

- Charged-Particle Monitor Reactions and Nuclear Data for Medical Isotope Production: This DDP follows the conclusion of several CRPs on this topic, in order to include new experimental data in the evaluations of about 50 radionuclides and provide consistent uncertainty information for all cases. It is expected that this activity will continue at least for two more years. Two papers are in the process of being published, one already available on arxiV and one almost ready for submission:
    - Hermanne et al., Upgrade of IAEA recommended data of selected nuclear reactions for production of PET and SPECT isotopes, arxiV-2006.03125(2020);
    - Hermanne et al., Upgrade of recommended nuclear cross sections for production of therapeutic radionuclides, to be submitted to J. Radioanal. Nucl. Chem.

- R-matrix Codes for Charged-Particle Reactions in the Resolved Resonance Region: Three CMs were held in 2015, 2016 and 2017, followed up by a 4^{th} CM from 27–29 August 2018 and a 5^{th} CM from 13–14 May 2019. Initially the focus was on code inter-comparisons, which led to all codes eventually agreeing to within 1–2%. These codes include AMUR, AZURE, CONRAD, EDA, GECCCOS, SAMMY, SFRESCO, etc. Some of that work for a light nuclear system was published in 2019 (Thompson et al., Verification of R-matrix calculations for charged-particle reactions in the resolved resonance region for the ^{7}Be system, Eur. Phys. J. A 55 (2019) 92.) Subsequent work focused on inter-comparisons of minimization techniques and calculation of covariances by the different codes. Results of a global fitting of ^{7}Be data with the R-matric code RAC were released in a technical report (INDC(NDS)-0791). This work is also important for INDEN evaluations of light elements.

- ACEMAKER: Package to produce ACE-formatted files for Monte Carlo calculations based on PREPRO: This project is done mainly with the aid of a consultant (Daniel López Aldama). The project has strong interaction with the developers of PREPRO. The code prepares ACE-formatted files for incident neutrons for Monte Carlo transport simulations. Current developments and V&V focus on thermal scattering law preparation, dosimetry reaction files, and charged-particle production. It is disseminated as open source and GitHub-based (https://github.com/IAEA-NDS/ACEMAKER). It serves as an alternative for independent IAEA Nuclear Data processing and evaluation, as a benchmarking & evaluation tool.

- Stopping Power Database: Ongoing (see section 2.3.4 for a discussion).
- Gamma-production data for capture and inelastic scattering: This is a new project, necessitated by a reported degraded performance by later ENDF/B releases compared to ENDF/B-VI.3, the latter where experimental data for the gamma spectra which were used in the evaluation (see Technical Report INDC(NDS)-0810, Evaluation of Thermal Neutron Capture Gamma Spectra, published in May 2020). The data are important for many applications, e.g. geology, space applications, forensics, etc. There is a need for these deficiencies to be addressed. In addition, the NDS developed and maintain related databases that may need updating, e.g. Prompt Gamma-Ray Activation Analysis (PGAA) and Evaluated Gamma-ray Activation File (EGAF).
- Decay Data for Monitoring Applications: The objective of this project is to create a library of decay data for radionuclides relevant to the Comprehensive Test-Ban-Treaty Organization Preparatory Commission (CTBTO), which is mainly concerned with detection of nuclear explosions. The duration of the DDP was supposed to be from 2019–2022 but it may extend into 2023. New evaluations are being performed and the goal is to publish the final output in a peer-reviewed journal. A kick-off TM was held from 6–8 May 2019 at the IAEA, followed by four virtual meetings (12 May 2020, 25–27 August 2020, 16 November 2020, and 17 December 2020). The 2nd TM was held virtually from 24–26 March 2021. The identified data needs consist of 42 fission products, 42 activation products, and three Xe isotopes for noble gas detection. About half of the evaluations have been completed and some reviews are underway. The collaborators are from 8 institutes/universities and the IAEA, all members of NSDD.
- Nuclear Data for Decay Heat, antineutrino spectra and other applications: this is a large project which follows from a CM on Updating Data Needs for Total Absorption Gamma-ray Spectrometry (TAGS), which was held from 19–21 February 2018. The CM investigated the impact of TAGS on decay-heat calculations, antineutrino spectra, new emerging data needs, and appropriate recommendations for the future. A TM on Nuclear Data for Decay Heat, antineutrino spectra and other applications was held from 23–26 April 2019. It was attended by 36 participants from 10 countries (Summary Report INDC(NDS)-0786). The meeting made recommendations for antineutrino spectra experiments and data analysis, decay data and reactor data. The objectives include the following:
    - Assess the sensitivity of the observations to uncertainties affecting large and short baseline antineutrino measurements;
    - Address the limitations and uncertainties of the theoretical methods (conversion versus summation);
    - Estimate their dependence on the available data (beta spectra, decay data, fission yields);
    - Make recommendations for the existing measurements, theories and evaluations;
    - Make new proposals for the future where needed, stimulate cross collaborations.

  A follow-up TM is planned.

- Decay and reaction data for the back-end of the fuel cycle: monitoring, characterization, decommissioning, and disposal of spent-fuel and other irradiated materials: a virtual CM was held from 2–4 November 2020 in Vienna. Various cross sections and decay data, including uncertainty quantification, are vital for both fission and fusion waste management. These include gas-production cross sections. Waste transmutation studies require high-energy neutron and proton-induced reaction data.

- Decay and reaction data for neutron production; the (α,n) reactions: A one-day virtual CM was held in March 2021 within INDEN-LE. Such data are needed as (α,n) reactions and spontaneous fission (SF) are the main neutron terms in spent fuel. This is important for criticality safety as well as long-term storage of spent nuclear fuel. There are also other applications where (α,n) reactions are important, e.g. in astrophysics. A follow-up meeting is planned.

- Development of evaluation methodology and nuclear reaction modelling systems: Various developments were briefly described:
  - Schnabel et al., Conception and software implementation of a nuclear data evaluation pipeline, arxiv.org/abs/2009.00521 (in press);
  - Prototype for EXFOR JSON CouchDB database (https://github.com/IAEA-NDS/exfor-couchdb-docker) for EXFOR to JSON conversion;
  - Prototype website showing a version tracking workflow for libraries;
  - Prototype of AI/ML (artificial intelligence/machine learning) approach to find EXFORable papers;
  - EMPIRE, TALYS and GANDR code developments. GANDR-5.3 was released in 2019 (including a new GUI) as well as the latest version of TALYS;
  - Many technical papers were published on EMPIRE and TALYS applications. These codes are the backbone of practically all evaluations.

During question time, Gilbert observed that many of the (α,n) reactions seem to have thresholds above 5 MeV but that there is a specific need for α-induced reactions with thresholds below 3.5 MeV (the maximum energy of α-particles escaping from a fusion plasma). The idea is to activate monitor foils with the escaping α-particles, followed by γ-ray spectroscopy, measuring γ-ray signals that can distinguish from neutron-induced reactions. Capote replied that the project started merely days ago and that the NDS is still investigating the various data needs, and that this particular need may be one to also consider.

3.2 Other activities

Koning gave the last technical presentation on activities planned for the 2021–2023 period. As his NDS colleagues gave comprehensive and rather detailed presentations on most of the work, this presentation was mostly to summarize a few statements and key areas, and to mention some possibilities.

- The development of a new NDS homepage is a serious project that has become very necessary. It will have a more modern look but still contain a detailed inventory of everything that exists on the current homepage, e.g. historical meetings, data libraries, etc. It will build on consistent metadata for libraries, meetings, documents, etc., and restructure data files for future developments, such as data portals. Important engines e.g. EXFOR-ENDF will remain intact and all historical knowledge will be retained. The top layers will be completed first. A prototype will be ready within a few months and feedback from the INDC will be expected at the next INDC meeting in June 2022.

- EXFOR and/or ENDF GUIs and APIs, which was discussed comprehensively by Zerkin (see section 2.3.8), were again mentioned briefly. Already the EXFOR web interface is very complete and detailed, but also APIs are under development to facilitate automated use of the library. One goal is to release command-line APIs, particularly to satisfy the needs of WPEC SG-50 in a large collaboration with the NEA Databank.

- The TALYS-related software (source codes) and databases will be hosted by the NDS soon and the software will be released. Software for TENDL will follow, e.g. for users who want to create their own TENDL-like libraries but with, say, different parameters. EXFORTABLES contains the entire EXFOR database in a directory structure with one file per dataset. The same philosophy applies for ENDFTABLES. These tools are already contributing to WPEC SG-49 on Reproducibility of Nuclear Data Evaluation, and WPEC SG-50 on Curated Computer-Readable Experimental Database for EXFOR. Direct-access plotting tools are also under development.
- Alternative plotting tools will be made available in addition to general plotting tools already existing, i.e. to be added but not replace the existing tools. LIBRARIES-2020 Data Explorer was demonstrated, which can very rapidly display, for example, cross sections from a selection of experiments and libraries. While it will not have the full functionality of the general plotting software (e.g. renormalization, discarding some data, etc.) this interface will be very easy to use and very quick to provide answers.
- A demonstration was given of “computational steering” in a plotting tool that will probably be called TALYSview. It is still in early development. Users will be able to specify attributes of plots to be generated while running a nuclear model code, able to view the results “live” as the output becomes progressively available with calculations continuing in the background. Eventually, by means of sliders, it will be possible to adjust individual parameters and see the effects/results live while the model code keeps running.
- Medical Isotope Browser is an application that provides an intuitive GUI to calculate production yields of radionuclides. The user specifies characteristics of the accelerator (particle, beam intensity, production energy window) and target to calculate, for example, the produced activity versus bombardment time. Decay time after end of bombardment (EOB) can also be specified. A demonstration was given based on TENDL cross sections (p + ^{100}Mo for producing the medical isotope ^{99m}Tc). The application currently works for any charged-particle production of radionuclides. Evaluated cross-section data established by about 20 years of CRPs are available for about 150 high-quality nuclear reaction channels. In the near future the goal will be to combine the IAEA high-quality evaluations with TENDL-2021 and create IAEA-2021-Medical Isotope Data Library. Next will be to add neutron reactions (for research reactors) and photonuclear production routes also to the Medical Isotope Browser.

In conclusion, Koning briefly summarised some key areas of activity and the direction of key developments, with some questions remaining which need to be further explored:

- In addition to other advanced projects, it is important to work on easy, attractive access of nuclear data, as evidenced by the success of LiveChart and Isotope Browser;
- New NDS homepage under development;
- Nuclear data can be and will remain to be accessible by GUIs, but complete libraries or command-line APIs are needed for versatile use (see e.g. Medical Isotope Browser). This means work on consistently formatted libraries;
- And a final question to the entire Nuclear Data community: Where in nuclear data can Artificial Intelligence/Machine Learning be applied?

As the meeting was running somewhat late at this time, Herman asked for urgent questions only, as there would be time for broad discussions on the entire programme on the last day (Thursday). There were none and the second day of meeting adjourned.

4. NUCLEAR DATA NEEDS

The first two days of the meeting were mainly reserved for technical presentations by NDS staff. Day 3 was largely scheduled for presentations and discussions on nuclear data needs of Member States. Most of the national representatives submitted nuclear data needs summaries and several reports were also received on nuclear data activities and/or ideas for future activities. A presentation was also given on nuclear data activities at the NEA Data Bank. Country reports received are listed in Appendix 6 as working papers to the meeting. Summaries on specific nuclear data needs are presented below:

4.1 Individual Needs of Member States

4.1.1 Argentina

Cantargi had prepared a report on nuclear data activities in Argentina (INDC/P(21)-22). These are mainly related to thermal scattering, heavy ions research, and radioisotope production. No specific requests on nuclear data needs were received.

4.1.2 Australia

Kibédi had prepared a report titled "Proposal to improve the calibration data for conversion electron measurements" (INDC/P(21)-13). Following discussions at the ISTROS 2019 conference, a number of scientists using conversion electron, electron-positron pair and β-ray spectroscopy agreed to participate in an international action to improve the decay data of calibration sources. To date, eleven institutes confirmed to participate. Similar to the X-ray and gamma-ray calibration data, we propose to approach the IAEA, if they are willing to coordinate this effort. At least two meetings, one at the beginning to agree on the policies, and a second to adopt calibration data and summarize the results, would be required. All results, including spectra, should be archived and stored for future reference. It is expected that a large summary paper would be prepared for publication with the recommended calibration data. The main steps of the project are listed below:

(a) Develop procedures for the calibration, measurements with the selected spectrometers, and data analysis. The efficiency calibration of the spectrometers should be based on a combination of experiments, for example using a continuous beta source and detailed simulations with GEANT4, Penelope, etc. Develop form of reports to make sure of histocompatibility.

(b) Review calibration data of potential calibration sources. Some candidates are ^{7}Be, ^{51}Cr, ^{54}Mn, ^{60}Co, ^{88}Y, ^{109}Cd, ^{133}Ba, ^{137}Cs, ^{152}Eu, ^{154}Eu, ^{182}Ta, and ^{203}Hg.

(c) Adopt procedures from (a) and list of radioisotopes (b); agree on work-plan.

(d) All sources should be prepared in a single laboratory.

(e) Carry out experiments and prepare reports.

(f) Prepare summary report and recommended calibration data.

4.1.3 Brazil

Carlson had prepared a report on nuclear data activities and needs in Brazil (INDC/P(21)-10).

- Data for new medical radioisotope production would be of great interest, to increase the range of products available in Brazil. At the moment, the available facilities restrict their interest to radioisotopes produced by proton-induced reactions in low-energy cyclotrons (up to at most 30 MeV). Higher-energy proton-induced reactions could become of interest if the Institute for Energy and Nuclear Research (IPEN) in São Paulo succeeds in its bid to obtain a higher energy cyclotron (e.g. 70 MeV). Interest in reactor production of radioisotopes will also resurge when the Brazilian multipurpose reactor begins operation.

- There is a general consensus that short courses on nuclear data, such as those given at the ICTP in Trieste and at the IAEA headquarters in Vienna, are very important for attracting and preparing young researchers in this area.
- More data on particle production in light-ion-induced reactions might seem to be of purely theoretical interest, but could be of eventual use in measurements using surrogate reactions, as well as for neutron production.
- Nuclear data for particle production in proton-induced reactions in the range of the cosmic ray peak (from about 200 to 600 MeV) as well as more consistent modelling of these reactions is of interest in the area of aerospace dosimetry.
- In this context, implementation of the Generalized Nuclear Database Structure (GNDS) could provide the impetus for an improved description of multiple emission cross sections, appropriate for Monte Carlo calculations and calculations of correlated emissions. This would require further extensions to the allowed formats, however, which still seem to adhere closely to the ENDF philosophy.
- Finally, we emphasize the importance of the EXFOR database and its continued expansion to include charged-particle-induced reaction data as well as new neutron-induced reaction data. The database is known and used by most researchers in nuclear physics and nuclear data in Brazil. Brazilian experimental nuclear physicists at the Open Nuclear Physics Laboratory of the University of São Paulo have also shown great interest in contributing to the database.

4.1.4 China

Ge Zhigang had prepared a report on nuclear data needs in China (INDC/P(21)-12).

- <u>Evaluated completed neutron reaction data file</u>

  a) Actinides: ^{233,234,235,236,238}U, ^{237,238,239}Np, ^{237,239,240,241,242}Pu, ^{241,242,242m,243}Am, $^{242,243,244,245,246, 247,248,250}$Cm, ^{249,250}Bk, ^{249,250,251,252}Cf;

  b) Structural materials: ^{23}Na, ^{27}Al, ^{28,29,30}Si, ^{0,40}Ca, ^{50,51,52,53,54}Cr, ^{46,47,48,49,50}Ti, ^{54,55,56,57,58}Fe, ^{59,60}Co, ^{63,64,65}Cu, ^{90,91,92,93,94,95,96}Zr, ^{93,94,95,96}Nb, ^{204,206,207,208}Pb, ^{0,180,181,182,183,184,185,186}W;

  c) Fission products: ^{154,155,156,157}Gd, ^{101,102,104,106}Ru, ^{103}Rh, ^{121,123}Sb, ^{133,134,135}Cs, ^{142,143,144,147}Nd, ^{148,149,150,151,152}Sm, ^{151,153}Eu;

  d) Light nuclides: n, ^{1,2,3}H, ^{6,7}Li, ^{9}Be, ^{0,12}C, ^{14,15}N, ^{16,17}O, ^{19}F,

  · neutron energy up to 30 MeV, File MF 1-6,12-15,31-40;

  e) Photon reaction data: isotopes of Be, Fe, Cu, Zr, W, Pb, Bi, Th, U, Pu.

- <u>Activation cross sections</u>

  To meet the needs for burn-up analyses and calculations as well as decay-heat calculations, key reactions are as follows: (n,γ) and (n,2n) for ^{147,148}Nd, ^{147,148,148m} Pm, ^{147,148,149,150,151,152}Sm, ^{142,143,150}Nd, ^{152}Eu, ^{141}Pr, ^{124,125}Sn, ^{124,125}Sb, ^{104,105,106}Ru, ^{133,134}Cs.

- <u>Fission yields</u>

Independent and cumulative fission yields of n + ^{235,238}U, ^{239}Pu, the yields of products with masses of 125, 106, 134, 142, 144, 148, 149, 151, 154, are applied to the reactor research such as for fuel consumption benchmark verification, and fundamental scientific research such as elements evolution in nuclear astrophysics. The prompt fission spectrum is applied in reactor design, for calculation of the neutron transport.

- Decay data

  The decay data for ^{105,106}Ru, ^{124,125}Sb, ^{125}Sn, ^{134}Cs, ^{141}Ce, ^{142,144}Pr, ^{144,147,149,151}Nd, ^{147,148,148m,149,151}Pm, ^{151,153}Sm, ^{152,154}Eu, will need to be evaluated.

- GIF reactors and fusion

  The GIF reactors, such as Sodium-cooled Fast Reactor (SFR), Thorium Molten Salt Reactor (TMSR), and Very High Temperature Reactor (VHTR) are being studied and some demonstration and experimental facilities for them are under construction. Also, some of the research on fusion energy (ITER international collaboration) are being performed in China. The requirements of nuclear data have been proposed as follows:

  For the TMSR project research purposes

  a) Photonuclear data: ^{6,7}Li, ^{9}Be, ^{12}C, ^{19}F;
  b) Fission product yields: ^{231,232,233}Pa, ^{242}Am;
  c) Decay data: ^{7}Be, ^{107}Pd, ^{153}Gd, ^{208}Tl, ^{225,226,227}Ac, ^{232,233,234,235}U, ^{230,231,232,233,234,234m}Pa, ^{227,228,229,230,231,232,234}Th, etc.;
  d) Activation cross sections: ^{155,157}Gd(n,γ), ^{155,157}Gd(n,2n), ^{232}Th(n,γ), ^{232}Th(n,2n), ^{233}Pa(n,γ), etc.

  For the SFR project research purposes

  a) Covariances for materials in common use;
  b) Kerma, DPA;
  c) Lumped fission products of ^{232}Th, ^{233,235,238}U, ^{237}Np, ^{238,239,241,242}Pu, ^{241}Am, ^{244}Cm;
  d) Delayed gamma multiplicity and spectrum for gamma heat deposition calculations for ^{238}U, ^{241}Pu;
  e) Photonuclear data: ^{9}Be, ^{12}C;
  f) Decay data: ^{22,24}Na, ^{26}Al, ^{103,106}Ru, ^{106}Rh, ^{103}Pd, ^{108m,110m}Ag, ^{109,113m}Cd, ^{111,113m}In, ^{113}Sn, ^{123,124,125,129,131}I, ^{123m}Te, ^{124,125}Sb, ^{127,131m,133}Xe, ^{131,134,137}Cs, ^{133,140}Ba, ^{139,141,144}Ce, ^{140}La, ^{144}Pr, ^{147}Pm, ^{148,153}Gd, ^{152,154,155}Eu, ^{153}Sm, ^{233,234,235,236,238}U, ^{237}Np, ^{238,239,240,241,242}Pu, ^{241,243}Am, ^{242,243,244}Cm, etc.;
  g) Activation cross sections: ^{24}Na(n,2n), ^{155,157}Gd(n,2n), ^{182,183,184,186}W(n,2n), ^{206,207,208}Pb(n,2n), ^{235,238}U(n,f), ^{239}Pu(n,f), ^{241}Am(n,γ), ^{241}Am(n,2n), etc.

  For fusion study purposes

  Nuclear data for light nuclei and structural materials are also needed for fusion studies. Although these data have been included in the FENDL and other evaluated data files, more accuracy and reliability are required, especially for deuterium and tritium.

- For isotope production/medicine and related fields

  For nuclear medicine and isotope production, more accurate information on nuclei, such as half-lives, decay data, Q values, level schemes, etc. are also needed, with updates. This information is also very useful for education, fundamental research, and nuclear technology applications.

  For isotope production purposes

Isotope production with accelerators: More than 30 isotopes need updated excitation functions and production yields for charged-particle induced reactions (p, d, t, etc.) including ^{11}C, ^{13}N, ^{14}N, ^{16}O, ^{24}Mg, ^{30}Si, ^{40}Ar, $^{50,52}Cr$, ^{55}Mn, ^{57}Fe, ^{60}Ni, ^{63}Cu, ^{209}Bi(p,n), (p,2n) and up to ^{203}Tl.

Isotope production with reactors: Data are required, in particular, for ^{3}H, ^{14}C, ^{24}N, and more than 150 isotopes. Targets containing ^{6}Li, ^{14}N, ^{24}Na and more than 150 reaction yields of the type (n,γ), (n,p), (n,α) are needed, including the cross sections, decay data, half-lives, etc.

Isotopes for the medical purposes

The current widely used isotopes: ^{32}P, ^{89}Sr, ^{90}Y, ^{103}Pd, $^{125,131}I$, ^{137}Cs, ^{153}Sm, ^{186}Re, ^{188}Re, ^{192}Ir. The new medical isotopes: ^{47}Sc, ^{67}Cu, ^{91}Y, ^{103}Pd, ^{117m}Sn, ^{166}Ho, ^{186}Re, ^{195m}Pt, ^{213}Bi, ^{225}Ac. Future isotopes of increasing importance include: ^{64}Cu, ^{67}Ga, ^{68}Ga, ^{89}Sr, ^{86}Y, ^{105}Rh, ^{111}In, ^{114m}In, ^{124}I, ^{149}Pm, ^{169}Yb, ^{177}Lu, ^{211}At, ^{225}Ac, ^{209}Po, etc.

For the improvement in analysis of neutrino spectra

The decay data, especially the β-spectra for ^{95}Sr, ^{90}Rb, ^{92}Rb, ^{93}Rb, ^{94}Rb, ^{100}Nb, ^{96}Y, ^{97}Y, ^{98}Y, ^{99}Y, ^{138}I, ^{140}Cs, and ^{142}Cs, should be revised.

For the needs of activation cross sections for SAND-II Library

^{63}Cu, ^{115}In, $^{175,177}Lu$, ^{197}Au(n,γ), ^{235}U, ^{237}Np(n,f), $^{115}In(n,n')^{115m}In$, ^{24}Mg, ^{31}P, ^{32}S, ^{27}Al, $^{47,48,nat}Ti$, $^{54,56}Fe$, ^{59}Co, ^{92}Mo, ^{58}Ni, ^{64}Zn(n,p), ^{27}Al, ^{63}Cu(n,α), ^{55}Mn, ^{58}Ni, ^{89}Y, ^{90}Zr, ^{127}I(n,2n).

4.1.5 France

De Saint Jean had prepared a report on nuclear data activities and needs in France (INDC/P(21)-15). French nuclear data needs are coming mainly from CEA, CNRS and IRSN physicists working on nuclear data evaluation, measurements, benchmarking, or directly from users of nuclear data. Physicists and engineers are involved in fission-related applications (reactors, fuel cycle, nuclear physics, astrophysics, medical applications, etc.) The following needs concern experimental, theoretical and evaluation activities:

Accurate and validated nuclear data are a crucial ingredient of various studies on nuclear system design and related fuel cycle (GEN 2, 3 and 4 concepts, in nominal and accidental conditions), experimental reactors (JHR, CABRI, etc.) and naval propulsion reactors. For improvement of nuclear data precision, reduction of biases in neutronic simulation codes devoted to reactor applications is expected. In reactors, the energy range of interest (for neutron energy and related induced reactions) is from thermal energies up to several tens of MeV. Nuclear data needs in France have not changed much in the last few years. As a result, the following needs are close to previously reported needs at INDC meetings.

Microscopic/Differential/integral measurements

- An improved knowledge of angular distributions is necessary for basic cross-section evaluation and the related nuclear reaction parameters (spin and parity of resonance for example, fission channels decorrelation, etc.) The impact is important for large-size cores (fast and thermal spectrum) as well as heterogeneous cores, where transport effects are crucial.
- Inelastic cross sections (and the related angular distributions) of major fuel components ($^{235,238}U$, $^{239,240,241}Pu$) as well as some structural materials (such as Iron, MgO, etc.) are insufficiently well-known due to a lack of precise measurements; there are still inconsistencies in evaluated files (JEFF, ENDF, JENDL). These uncertainties and biases contribute highly to the uncertainties of neutronic parameters for reactors.

- To validate evaluations in the resolved range, precise time-of-flight experiments are still very much needed, especially in the temperature interval from a few K to 2000 K. Low-temperature measurements could disentangled the effect of crystal lattice on the knowledge of resonance parameters for major isotopes (^{238}U, ^{239,240,241}Pu) and high-temperature measurements could validate models for resonant scattering.
- Neutron-induced capture measurements of fissile isotopes (especially for uranium and plutonium) in the whole energy range are needed, as these cross sections are major contributors to reactor calculations.
- For short-lived isotopes, cross-section measurements are also needed (fission products, isomers). This activity (theory/evaluation/measurement of short-lived isotopes) may be a good candidate for a CRP or TM at the IAEA. In addition, it seems that at the N_TOF installation, a dedicated discussion on isotopes production is required.
- New nubar(E), eta(E), and alpha(E) microscopic measurements in the thermal and epithermal ranges for fissile nuclei are necessary to exhibit fluctuations on nubar as well as temperature effects on cross-section slopes (capture/fission). It should be accompanied with theoretical development explaining observed fluctuations, especially in the (n,γ,f) process.
- New measurements of delayed-neutron data are very much welcomed.
- Thermal data (phonon spectrum, $S_{\alpha\beta}$) for various moderators and structural materials are crucial for a proper knowledge of the light-water reactor spectrum. In addition, resonant scattering of heavy isotope (^{238}U) was proved to be a first-order effect on reactivity of PWR/BWR reactors by having an induced effect on ^{238}U capture and thus ^{239}Pu build-up. Proper modelling of this effect is still a challenge when both resonant scattering and crystal lattice effects are taken into account. A follow-up to WPEC SG-42 and SG-48 was initiated, which is a good idea. Anyway, it could be interesting to have an international and collaborative effort on molecular dynamics models as well as phonon spectrum measurements.
- Neutron-induced reactions suffer in the unresolved resonance range from a lack of both integral and microscopic measurements, even for well-known isotopes (uranium and plutonium).
- DPA data are important for fuel designs using innovative structural materials; Iron is important as well as other steel components (Cr, Ni, etc.). Conclusion of the dedicated CRP is very much welcome on nuclear data as well as proposition of standard DPA calculation and evaluation procedure.
- Prompt neutron and gamma fission spectra and multiplicities are still of major interest for plant lifetime extension considerations, nuclear heating and in terms of uncertainties on reactivity as well as power map tilts on reactor cores. Innovative experiments are needed. In particular, for induced neutron energy between 1 keV and a few MeV, very few experiments are in existence. Furthermore, the reduction of experimental uncertainties is very important for both the low- and high-energy parts of spectra. Breakthroughs in terms of experimental devices are needed.
- For challenging nuclear models, global fission experiments such as fission yields with neutron prompt spectrum and multiplicities, cross sections/fission yields (as proposed in NFS at GANIL by FALSTAFF, FIPPS at ILL and ChiNu in the US) are of principal interest.

Structure data and basic nuclear physics

- Efforts on nuclear structure data are needed for:
  - The interpretation of existing and future inelastic cross sections for heavy isotopes. They appear to be a major source of uncertainties (lack of knowledge).
  - Evaluations of fission observables.
  - Neutrino studies using nuclear reactors or fuel component as sources: need of precise beta and antineutrino spectrum. A collaborative international effort should continue. Specialists of beta-spectrum calculations as well as experimentalists may contribute to establish an evaluated database.
- This effort is related to basic compound nucleus physics (e.g. level densities and spin densities), gamma and x ray intensities for dosimetry analysis, beta spectra, etc.
- Furthermore, decay data evaluation databases as an international effort could be pursued but decay data specialists are lacking.

Theoretical calculations

- For fission yields, neutron/gamma multiplicities and spectra, there is a necessity to have an overview of the state-of-the-art in evaluation and related codes (GEF, FIFRELIN, SPY, Moller propositions, etc.) by a dedicated international effort. For fission yields, there is a major concern to propose a dedicated evaluation database sharing all experimental (old and recent) results with a comprehensive description of the experiments (calibrations to standards or any data that has evolved). The proposed CRP at the IAEA will steer this in a good direction.
- From a general point of view, low-energy nuclear fission breakthroughs in terms of theoretical approaches are needed. The calculation of fission barriers as well as their penetrability factors is based on approximations related to phenomenological theories. Progress is needed and the international experts should continue to collaborate to estimate the state-of-the-art, the potential issues (theoretical as well as experimental) and some hints of what could be feasible in a short/mid/long term.
- Surrogate reactions measurements (aiming at producing a targeted compound nucleus by other entrance channel than neutron) exhibits difficulties in term of theoretical interpretation (Pf, Pγ) due to spin/parity distributions issues. This activity may be part of the previous general physics issue or could be worth discussions in separate or dedicated meetings.
- As for experiments, the unresolved resonance range need real progress in terms of nuclear reaction models and the associated representation in nuclear data files. In particular, its connection to resonance range and fast range is still a puzzling theoretical question.

Uncertainties

Uncertainties for all nuclear data are expected. In this framework, various efforts need to be pursued:

- Full-energy range covariances → correlation between different energy ranges: bridging the gap between thermal and continuum range;
- Multi-observable correlations (spectra/multiplicities/cross sections);
- Model defects: incapacity of phenomenological models to reproduce experimental results.

Deep Learning

In recent times, there is a high interest in deep learning techniques not only for nuclear data evaluation, but also for basic nuclear science (theoretical and experimental). A few workshops took place in France and various international conferences and/or workshops highlighted this growing interest. This very promising activity could be pursued at an international level at the IAEA (follow-up of a 2020 meeting) as well as the NEA, amongst others.

Specific Evaluation

The CRP on Updating the Photonuclear Data library and generating a reference database for photon strength functions is appreciated.

Miscellaneous

With the decommissioning of various experimental reactors in France (EOLE, MINERVE, MASURCA at CEA for example), the status of existing ZPRs and their abilities for proposing analytic experiments (one may think of new integral experiments for inelastic and elastic cross sections of iron, uranium and plutonium) is of great concern for nuclear data physicists in France. Furthermore, there is a real concern related to the shortage of international radio-isotope production capabilities for medical diagnostics. Also, for nuclear medicine, emergent radioisotopes are studied and a need for their related decay data is reported. In conclusion, a general concern is expressed regarding the lack of young physicists working in the nuclear data area. PhD students and post-docs are very hard to find.

4.1.6 Germany

A report titled "Progress Report on Nuclear Data Research in the Federal Republic of Germany for the Period 2018–2020" was compiled by Junghans as a working document to the Committee. Several German research institutions are active in the fields of fission and fusion reactor technology, accelerator facilities including spallation and material irradiation neutron sources, medical physics and astrophysics, as reported in the working paper INDC/P(21)-06. The related activities include nuclear data evaluations with a focus on the needs for fusion technology and accelerator applications (KIT), and, in the experimental field, measurements of neutron cross-section data and fundamental nuclear properties using radioactive ion beams (HZDR, Dresden-Rossendorf; FZJ, Jülich; Goethe University Frankfurt; PTB, Braunschweig; Technical University Darmstadt; Technical University Dresden; Johannes Gutenberg University, Mainz). Education and Training activities of young scientists in the nuclear data field are addressed in the EURATOM project ARIEL which began in September 2019.

Fission technology

Germany is participating in the JEFF project of the OECD where most data needs for fission reactor applications are addressed. There are no specific requests to the NDS at this time. It has to be pointed out, however, that Germany is active in the decommissioning of nuclear facilities. Decay heat, nuclide vectors and source terms of SNF in interim storage are relevant quantities (see e.g. JEFF stakeholders meeting, June 2019, OECD NEA, Paris). The NDS efforts in this field (e.g. data development projects) are welcome.

Fusion technology

Germany is participating in the European programme for the development and experimental validation of fusion nuclear data, which is conducted within the EUROfusion programme. There is also a close cooperation with the JEFF project, to which nuclear data evaluations are provided, both for the general purpose neutron data library as well as specific sub-libraries such as the JEFF-3.3 radiation damage library.

Germany has actively participated in the FENDL-3 project at the IAEA/NDS, which has highest importance to fusion including ITER and the IFMIF/DONES neutron source which is considered of high priority in the European fusion programme. In addition to the regular revisions and corrections applied to the neutron data library, it is recommended to further improve the sub-libraries on neutron, proton and deuteron-induced activation reaction data. Similarly, efforts to define and update reference decay data libraries are suggested. The required strong V&V programme should be further extended under the guidance of IAEA/NDS and synergies with other similar nuclear data and neutronics tools V&V activities, e.g. at ITER, OECD/NEA, are to be pursued.

Fundamental nuclear properties

The ongoing RIPL activities and improvements in nuclear reaction models (codes such as TALYS, EMPIRE, GEF, etc.) that are of general relevance for nuclear applications in science and technology are welcome. The importance of reliable stopping-power databases is recognized. In the short-term future, the knowledge of double-differential cross sections for light charged particles will be essential in assessing the risk of secondary tumours in particle radiation therapy.

4.1.7 Hungary

Tárkányi et al. had prepared a report on nuclear data activities in Hungary (INDC/P(21)-5) that contains the following needs summary:

- Upgrade NUDAT;
- Extend the list of evaluations on nuclear reactions for production of medical isotopes (PET, SPECT, therapy, CP monitor reactions);
- Upgrade of TENDL.

4.1.8 India

Umasankari Kannan had prepared a report on nuclear data activities in India (INDC/P(21)-8) and a needs summary with recommendations. Several gap areas exist in experimentation, evaluation and the use of processed data. Examples are given below to stress the need for interactions with different agencies and international collaboration. This list is not exhaustive.

Gap Area 1: Updating cross sections for new materials and re-evaluating existing data in multi-group cross-section sets

From detailed analysis and review of experimental data available currently, some deviations in evaluated data were found. Also, there is a paucity of data in certain energy domains and certain operating temperatures. A few examples are listed below:

- Updating thermal scattering data library for a larger number of temperatures and for all types of moderating materials: Thermal scattering nuclear data in the evaluated nuclear data libraries are given at definite temperatures which cannot be Doppler broadened by any nuclear data processing code systems like NJOY and PREPRO for a desired temperature. For more precise reactor calculations, it is required to generate the thermal scattering law data for a finer temperature grid as well as for higher temperatures. Thermal scattering data for Be, BeO, and BeF_4 are also required.
- ^{232}Th data still have not converged between evaluated nuclear datasets. Detailed benchmarking and qualification of the new dataset based on ENDF/B-VIII.0 is required.
- Resonance tabulations for all actinides in WIMSD formatted library: The actinides beyond Pu do not have resonance tables. If possible, all actinides should be treated as resonant absorbed and temperature-dilution dependent resonance tables should be given.

- Fast-neutron induced fission of actinides giving information on mass, charge, kinetic energy distributions of fission fragments and neutron multiplicities are required.
- Validated thermal energy data are required for moderating materials like Graphite, Be, and BeO.
- Other isotopes of interest include ^{6}Li, ^{7}Li, ^{nat}Gd, ^{nat}B, ^{nat}Dy, and the Zr isotopes.
- There is a need for a qualified dataset for high-temperature applications. For example, since the Lead-Bismuth eutectic is being considered as coolant in many reactor types (CHTR) the data should be available up to 1500 K.

Gap Area 2: Nuclear data evaluation

The gestation period from EXFOR to evaluation requires to be reduced. From measurement to best estimate evaluation, a qualified procedure needs to be evolved. This is very voluminous work and has to be done collaboratively. Benchmarking and beta testing have to be done simultaneously.

Gap Area 3: More precise experimental techniques required

Better detectors and better instrumentation with cutting edge technologies are required.

Gap Area 4: Alternate neutron sources for experiments

Surrogate reactions are alternatives for neutron sources at required energies and dependence on these have increased. Special attention is required to address the choice of suitable targets. Although the projectile energies can be mono-energetic, the surrogate materials and reactions will have to be chosen carefully for a precise reaction cross-section measurement.

Gap Area 5: Experimental techniques and instruments

Stability of beams for measurement of cross sections is very important. Availability of clean or pure samples is another important aspect of experimentation.

Recommendations

I. Coordinated Research Projects to be taken up (IAEA, International projects) for the following activities:
   a) High-temperature evaluated nuclear data in ACE format (for Monte Carlo and ADS applications) and in multi-group format (for high-temperature reactors).
      - A comprehensive review of the high-temperature data for actinides, fission products, structural materials (similar to the WLUP);
      - Generation and testing of evaluated nuclear data for temperatures up to 2000 K;
      - Generation of multi-group constants for potential application in MSR, HTR;
      - Validation and benchmarking of the multi-group dataset.
   b) Updating the thermal scattering data: The evaluated data files currently have only a few temperatures on a large grid. For a better treatment of thermal phenomena, more temperatures and materials (such as BeO and other moderating materials) are needed.
   c) CRP on update of libraries for point reactor burnup codes: This CRP is required to update the libraries for fuel cycle calculations for several new reactor types. Aim towards recommending a rigorous validated database for a comprehensive fuel cycle analysis for all types of facilities.
   d) A new CRP on evaluated data for the Th-U cycle and its applicability to advanced fuel

cycles, MSRs and Gen-IV systems.

e) CRP on surrogate reactions for neutron-induced fission cross sections for unstable actinide targets and also for exploring possible candidate reactions for fusion energy applications.

f) IAEA workshops on evaluation - Focussed themed workshops on

- Fitting of experimental data – New filtering techniques;
- Improved nuclear models in evaluation;
- Big data management;
- Threshold and high-energy reactions.

II. Collaborative projects for measurements at International Facilities like CERN, through coordination by IAEA:

a) Formation of working groups similar to CSWEG for continuous interactions with experimenters and users;

b) Enhanced beta testing - more participation from different users;

c) Recommend new experiments in uncharted regimes;

d) Improve the frequency of NRDC and other expert group meetings.

III. Inter laboratory and inter code benchmarking for adequacy of resonance energy treatment in thermal reactor systems:

- Investigation of the adequacy of the resonance energy range of multi-group nuclear datasets for thermal reactor systems;
- Revisiting the thermal energy limit in multi-group datasets. Feasibility to bring down to 1.85 eV to be investigated. Up-scattering below 4 eV is important for many moderators like H_2O, D_2O, Be and C.

IV. Creation of Joint Evaluated IAEA File: International collaborative efforts to reduce the deviations between evaluations. Revisit the files and their use every 10 years; recommend comprehensive evaluated file and disseminate updated data through IAEA-NDS:

a) Expand the evaluators domain – the evaluation procedures and methods should be open to a larger workforce who can effectively contribute;

b) Encourage the development of newer methods for evaluation procedure.

4.1.9 Japan

Iwamoto had prepared a report on nuclear data needs in Japan (INDC/P(21-18). Needs related to the nuclear energy programmes in Japan are not so much changed from the previous report in 2018. Developments concerning treatments of nuclear wastes are still important and transmutation of high-level radioactive waste is a possible candidate. Development of an accelerator-driven system (ADS) for burning transuranic nuclides is in progress. For the design of ADS, there is a need to improve current nuclear data accuracy on

- Neutron cross sections of ^{15}N and Fe, Pb, Bi, Pu, Am and Cm;
- Fission spectrum of Pu, Am and Cm.

Regarding light-water reactors and fast reactors, for prediction accuracy improvement on nuclear characteristics of the reactors including data assimilation technics, accurate cross sections and their covariances are still needed, especially for

- Neutron cross sections and covariances of actinides (U, Np, Pu, Am, Cm) and neutron absorbers (Gd, Ag, In, Cd, W) for thermal reactors,
- Neutron cross sections for C and O isotopes, and structure material for fast reactors.

For fusion technology and neutron shielding calculations, the completeness of nuclear data in the library is requested, especially for covariances and energy emission of structural materials, such as

- Covariance data of H, Li, Be, F, Si, Cr, Ti, Fe, Cu, Pb, W, Nb, Sn;
- Gamma-ray emission and recoil spectra for all nuclei for estimation of kerma factors.

In the nuclear sensing field, nuclear data are required for development of various methods of non-destructive assay:

- Neutron-induced gamma-ray emission spectra: actinides, structural materials, O, B, Gd, etc.;
- Accurate resonance parameters for neutron resonance transmission analysis: actinides, structure materials, etc.;
- Beta-delayed gamma-ray spectrum of fission products.

4.1.10 Republic of Korea

Lee had prepared a report on nuclear data needs in Korea (INDC/P(21)-9). The KAERI nuclear data group now belongs to the Nuclear Physics Application Research Division, where the fusion engineering and the nuclear data teams merged since KAERI's 2020 restructuring. The mission and size of the group are unchanged, but priority is slightly shifted towards the neutron sources, nuclear detectors, and accelerator applications.

Deuteron-induced neutron double differential cross sections are in need for improving the accuracy of the RAON Nuclear Data Production System (NDPS), scheduled to be completed next year. One of the NDPS neutron sources uses a thick carbon target bombarded by 98 MeV deuterons, where a good accuracy of neutron-emitting spectra is inevitable for the engineering design of the target, collimator, TOF, and detection systems.

- *SNF management* has been, and will be one of the national high-priority problems to be coped with since the number of NPPs to be shut down will start to increase sharply in several tens of years. Budget decrease in SFR and pyro projects deepens this issue. A challenging proposal is under review to precisely predict the pellet-wise discharge burnups in SNF assemblies through an ultra-fine grid numerical model with highly reliable M&S and nuclear data. Target accuracies of the isotopic densities in SNF are set, and corresponding uncertainties of the neutron nuclear data well as fission yields and decay data of actinides and fission products are being estimated.
- Nuclear data needs in Korea are still mostly from the field of the *SFR linked with the pyro-process* despite the shrinking situation. The SFR project is at the stage of the prototype design, and needs to quantify the cross-section uncertainties in the validation and verification of the neutronics calculations.
- Small Modular Reactors (SMR) are being developed in Korea, where a number of new materials are under study. Thermal scattering laws are especially to be improved, properly processed, or newly evaluated for the thermal SMR using such new materials.
- The Korean ITER neutronics team requires reliable fast neutron nuclear data of the key materials for its neutronics performance, shielding design and activation analyses. The ITER neutronics team mainly uses the FENDL 2.1 library implemented in MCNPX 2.5 while the KAERI nuclear data centre is improving the nuclear data of some key structural isotopes in parallel.

4.1.11 Russian Federation

Khryachkov had prepared a report on nuclear data needs in Russia (INDC/P(21)-20), informing that there is interest to refine data in several fields:

For thermonuclear reactors and hybrid nuclear systems with a thermonuclear neutron source

- Various nuclear reactions, e.g. (n,p), (n,α), (n,2n), (n,3n), etc., on structural materials (isotopes Fe, Cr, Ni, Mo, Al, V, Ti, C, Si, O) in the neutron energy range 8–16 MeV;
- Various nuclear reactions leading to tritium production, especially ^{6}Li(n,α)t and ^{7}Li(n,n)αt in the neutron energy range 8–14 MeV;
- Data for ^{232}Th and ^{238}U are required for reactions leading to additional neutron production (e.g. for (n,2n) and (n,3n) reactions, neutron multiplicity and of prompt fission neutron spectra).

For classic fission reactors

- Improvement of neutron standards (prompt neutron spectra of ^{252}Cf(sf) fission, ^{6}Li(n,t) and ^{10}B(n,α) reactions);
- Measurements of the prompt fission neutron spectrum shape in the energy range $10 < E_n < 500$ keV and above 6 MeV for ^{235}U fission by thermal neutrons;
- Accumulation of gases in structural materials, in particular (n,p) and (n,α) reactions for isotopes Fe, Cr, Ni, etc.

For the production of medical isotopes

- Refinement of the photonuclear reaction cross sections for the production of medical radioisotopes: ^{226}Ra(γ,p)^{225}Fr, ^{226}Ra(γ,n)^{225}Ra, ^{100}Mo(γ,n)^{99}Mo, ^{187}Re(γ,n)^{186}Re, etc.
- Systematization of nuclear data obtained at bremsstrahlung gamma sources.

4.1.12 South Africa

Steyn had submitted a report on nuclear data activities and needs (INDC/P(21)-19) as received from the Radioactivity Standards Laboratory of the National Metrology Institute of South Africa (NMISA), the South African Nuclear Energy Corporation (Necsa) and iThemba LABS. Only two items of specific nuclear data needs were received:

- TENDL-2019 data, processed into the ACE format and bundled with the code MCNP6 as shipped by the RSICC, do not currently include (α,n) cross-section sets for a range of isotopes. There is a need for complete (α,n) cross sections in ACE format.
- Continued support for the 709-neutron energy group structure of FISPACT-II in addition to the newer 1102-group format, especially for TENDL data.

4.1.13 Spain

Gonzalez Romero had prepared a report on nuclear data activities and needs in Spain (INDC/P(21)-14). Nuclear data needs in Spain had been identified from scientists in various fields of research and applications, including nuclear fission technology, fusion research, health applications, astrophysics, and basic nuclear physics. Most requests had been identified by CIEMAT, CSIC, CNA and several Universities (USC, UPM, UPC, USE, UCM, and UGR) working on nuclear data measurement and validation, physics research and, on the other hand, by users of evaluated data for the design and safety analysis of nuclear fission reactors, optimization of fuel cycles, including nuclear waste minimization by partitioning and transmutation, research for ITER, IFMIF and other options for fusion, optimized nuclear medical techniques for diagnosis and treatment, as well as shielding and radioprotection. Some of the identified nuclear data needs include:

- To continue providing a generalized improvement of the uncertainties and covariance data for cross sections and other nuclear data relevant for simulation applications, and particularly for those related to safety parameters;
- Clarification of capture cross sections for main nuclear fuel actinides, including ^{239}Pu;
- Fission, capture and other absorption reaction cross sections for the characterization and prediction of the open cycle inventories and for the optimization of advanced fuel cycles, including medium-lived Pu, Am and Cm isotopes (e.g. ^{238}Pu, ^{241}Am, ^{243}Am, ^{243}Cm, ^{244}Cm, ^{245}Cm, etc.);
- Continue the improvement of nuclear data on the delayed neutron emission and decay heat from fission fragments;
- Data for new radioisotope production, in particular by proton-induced reactions;
- Data for hadron therapy, including double-differential proton-induced reaction cross sections with production of neutrons;
- Data for neutron-induced charged-particle reactions that could complement B(n,α) for cancer therapy;
- Improving the models and cross-section values of deuteron-induced reactions related to IFMIF and other fusion-related applications;
- Automated computer access (API) to the main libraries (EXFOR, ENDF, ENSDF) for open access to the data.

4.1.14 United Kingdom

Gilbert had prepared a report on nuclear data activities and needs in the UK (INDC/P(21)-11). The United Kingdom Atomic Energy Authority (UKAEA) have recently identified the critical experimental capability needs for fusion (as part of discussions on a new neutron source in the UK). These include:

- Alpha reaction cross sections at 3.5 MeV to support efforts to develop diagnostics for alpha-losses from fusion plasmas. Examples include Ge(n,α) cross sections, but we would encourage a dedicated effort to explore the availability of alpha-induced reaction data across the periodic table to enable feasibility and optioneering studies of alpha-diagnostics.
- Gas-production measurements under neutron irradiation. Needed in general, but particularly, for example, on ^{12}C where (n,n3α) competes with (n,α) at 14 MeV and might have significant impact on the viability for fusion materials containing carbon (e.g. carbides such as WC and SiC).
- Transmutation measurements for direct comparison to the outputs of inventory codes such as FISPACT-II. Irradiations and then measurement of composition changes using mass spectroscopy or advanced techniques such as Energy-dispersive X-ray spectroscopy (EDX) and Atom-probe tomography (APT).

The UK had a strong involvement in the recent IAEA consultants meeting on the new and improved nuclear data forms needed for the monitoring, characterization, dismantling, decommissioning and disposal (McDDD) of the current and future generations of nuclear systems. Rolls-Royce has an ongoing need to improve modelling of advanced fuel systems to support the development of the compact reactors of the future, while UKAEA needs reduced uncertainty in nuclear code predictions to enable realistic design engineering of the next generation of fusion reactor experiments and power plants, particularly for decommissioning and maintenance planning

4.1.15 United States of America

Herman had prepared a report on US nuclear data needs (INDC/P(21)-21). In recent years, a custom was established that members of the US Nuclear Data Program meet with the managers of various government agencies and of industry who have interest in nuclear data. These meetings are called WANDA (Workshop for Applied Nuclear Data Activities) and serve to shape the US nuclear data program in a way to match the needs of the country. This summary is in large part based on the topics discussed during the WANDA 2021 meeting held virtually from 25 January to 3 February, and to which funding is likely to be provided.

Predictive codes for isotope production

- Improving the predictive power of nuclear reaction codes, especially at higher incident energies, is essential to support isotope production. It has also been recognized to be a general necessity. There is a consensus that nuclear level densities are the most critical and relatively poorly understood ingredient of the model calculations. These are responsible for large uncertainties in the calculations at high energies. It is partially due to the very uncertain dumping of the collective enhancements at higher excitation energies, lack of the D_0 (average spacing of s-wave resonances) data out of the stability line, and uncertain spin distributions.
- On the reaction modelling side, a multi-step pre-equilibrium (PE) mechanism, as well as multiple PE particle emission, are needed for incident energies above 30 MeV. The area of composite particle emission is largely unexplored. In general, quantum mechanical models should be developed and implemented in the reaction codes, especially away from the line of stability.
- More ‘validated’ experimental data at higher energies are needed to calibrate model parameters.

Expanded benchmarks & validation for nuclear data

- The need for reconciliation of the reaction (ENDF/B-VIII.0) and the structure (ENSDF) databases was brought to our attention. Currently, there are many discrepancies for the same quantities between these two libraries.
- There is a need for improved gamma-production cross sections for priority isotopes for validation of the modelling. Existing gamma-production cross sections should be reviewed for validity.

Advanced computing for nuclear data

- There is a general interest in Machine Learning and Artificial Intelligence that can augment existing physics models by providing emulators and diagnostic tools, or unveil hidden patterns in data.
- Natural Language Processing is of interest, e.g., for nuclear data compilation.

Nuclear data for space applications

Large amounts of nuclear data are needed for space exploration, including prompt neutrons and gammas from fission, gamma emissions from fission-product decay, material activation and decay, and neutron and gamma attenuation. Damage cross sections are requested to be included in the ENDF libraries. Nuclear propulsion systems might approach temperatures of 3000 K for fuel and structural materials with H_2 as internal propellant. In addition, planetary nuclear spectroscopy needs (n,n′γ) and (n,γ) gamma-ray production cross sections.

Nuclear data for advanced reactors

Even more specific requirements come from the advanced reactors. Terra Power's Molten Chloride Reactor needs tighter uncertainties for ^{239}Pu, and is very sensitive to ^{35}Cl(n,p). Kairos Power's Fluoride-salt-cooled High Temperature Reactor needs thermal scattering data for graphite and FLiBe and cross sections for ^{19}F, ^{9}Be, ^{6}Li, and ^{7}Li. Molten salt reactors require (α,n) data for light elements, in particular ^{19}F(α,n) and ^{17,18}O(α,n), along with the related neutron energy spectra.

Charged-particle production reactions

It was reported that there were two requests to IAEA-NDS from the US nuclear data community, where data science across the borders of nuclear data experiment, evaluation, and processing might be involved.

Advanced techniques for nuclear data measurement often require precise particle transport simulations to characterize the detector characteristics, such as the efficiency. Although such efforts are sort of experimental apparatus specific, issues in utilization of current nuclear data libraries and techniques for performing the Monte Carlo code simulations are common, since each of the experiments usually perform their own Monte Carlo simulations with MCNP, Geant4, PHITS, etc. As an example, LANL recently published a paper on the importance of energy and angular distributions for measurements of charged-particle production reactions [H. I. Kim et al., Nucl. Instrum. Methods A 963 (2020) 163699], where missing information of such angular distributions in the evaluated nuclear data library may cause large uncertainties in the deduced experimental data. We believe the NDS is an ideal place to offer opportunities to bring together scientists in different areas – measurement, evaluation, and transport simulation – to discuss such common issues residing in understanding experimental techniques. We foresee experimental groups in many countries are interested in participating in such activities if NDS decides to proceed.

Interconnection among different areas of nuclear data

Similarly, stronger interconnection among theoretical nuclear physics, production of evaluated nuclear data files, and data processing has also become important nowadays to produce reliable nuclear data for applications. In March 2021, NDS organized an online consultants' meeting of "model code output and application nuclear data form structure", where experts in these different areas were invited and discussed on what is the most reasonable way to preserve and transfer information given by theoretical calculations to actual application codes. We believe such meetings are very unique and useful activities organized by NDS, besides on-going CRPs that focus on more specific topics. We request that NDS keeps providing opportunities for nuclear data scientists in different areas to interact with each other. This is particularly important to maintain high quality nuclear data.

4.2 Nuclear Data Activities and Services of the NEA Data Bank

Michael Fleming (Acting Head, NEA Data Bank) gave a presentation on Nuclear Data activities and services by the NEA Data Bank. The NEA represents 34 OECD Member Countries and a number of Strategic Partners (e.g. China and India) seeking excellence in nuclear safety, technology and policy. It has 8 standing committees and more than 70 working parties and expert groups. The task of the NEA Data Bank is to provide nuclear data codes and validation services. It has a global relationship with industry and universities. Currently the NEA countries operate about 90% of the world's installed nuclear capacity. The NEA has a narrower mandate than the IAEA with main focus to serve the above-mentioned installed nuclear capacity.

Fleming briefly discussed the NEA structure, which will not be discussed here in detail, but the various committees are responsible for matters related to nuclear regulatory activities, nuclear law, nuclear safety, radioactive waste management, decommissioning, radiological protection, technical and economic studies on nuclear energy, etc. The NEA and IAEA have a long history of collaboration and coordination to maximize impact on international nuclear data activities. The IAEA Nuclear Data Section engagement has been a key ingredient to the success of the NEA nuclear data programme of work. The NEA and IAEA organizational instruments are complimentary and offer options for the nuclear data community in launching collaborations. The IAEA Staff on Loan within the Data Bank also provides distribution services to non-OECD members of the IAEA.

The Joint Evaluated Fission and Fusion (JEFF) Nuclear Data Library Project has been a long-standing collaboration since the original JEF-1 library released in 1986. The library is used across the world for nuclear energy, science, technology and other applications. The JEFF collaboration is responsible for the development and testing of a general-purpose nuclear data library, including neutron and other incident particle data, decay data and fission yields. Multiple sub-groups operate on either a long-term or ad-hoc basis to address various aspects of the JEFF development process. The JEFF project meets twice a year, in spring and fall, during the NEA Nuclear Data Week, in a 4 to 5-day technical programme, with the aim to promote cooperation between experimentalists, evaluators, producers and end-users of nuclear data. Due to the pandemic, recent meetings were hosted virtually. The next meeting is scheduled for 26–30 April 2021. The latest release of the library is JEFF-3.3, a paper of which has been published recently (Plompen et al., The Joint Evaluated Fission and Fusion Nuclear Data Library, JEFF-3.3, Eur. Phys. J. A 56 (2020) 181). It has over 70 co-authors from 30 organizations, including the NDS. This project leverages IAEA-NDS project outputs, including the Neutron Standards and contributions to other projects such as CIELO. The current chair of JEFF is Arjan Plompen (JRC-Geel, EC).

In 2018 the NEA implemented a GitLab system with core functionality that has been used for projects such as EXFOR compilation and the GNDS specifications. The implementation of an upgraded service has been in planning since 2019, providing more computational resources in runners, full docker container registries, GitLab pages, and other features. Since February/March 2021 the NEA is rolling out a new GitLab instance with more sophisticated architecture to accommodate these functionalities. The migration is expected in the second quarter of 2021. This is one of the technologies implemented by the NEA to streamline collaborations and make them more efficient. GitLab will be a key platform for current and future cross-database and cross-NEA work.

An example of GitLab for JEFF was shown. This system offers a powerful collaboration tool with built-in, automated processes including processing, testing and benchmarking. It replaces and/or integrates previous scripts and processes such as NDEC. A Proof-of-Concept using cloud-based solutions is under development and will be migrated (with the first NEA instance) in 2021.

The NEA Data Bank continues to play a central role in the EXFOR project within the NRDC. It contributes approximately 300 new or revised entries per year. There is a strong collaboration with the IAEA through the NRDC. Ongoing development and enhancements are also met through work within WPEC SG-50, "Developing an Automatically Readable, Comprehensive and Curated Experimental Reaction Database" (see more detailed discussion below). The NEA EXFOR compilation work was migrated to GitLab in 2018. Processes are now increasingly captured within the system, including preservation of entry development and quality assurance (QA).

JANIS (Java-based nuclear information software) version 4.1 was released in September 2020, which is the first new release since version 4.0 was released in 2013. It facilitates the visualisation and manipulation of nuclear data. The new version includes updates to webstart version, books, applications, libraries, supported data, and much more. A wide range of features are documented in the "What's new in 4.1" page.

Fleming briefly discussed the Working Party on International Nuclear Data Evaluation Co-operation (WPEC). Over a period of 31 years it created 50 subgroups (SG), of which 8 were active during the current reporting period (2 closed in 2020). In addition, two expert groups (EG) have been established to address long-term high-priority needs and establish an international standard data format. The 32nd WPEC Meeting (with associated meetings of its subgroups) was held from 11–15 May as a virtual event. It had a record 130 participants in 10 sessions. Subgroup meetings were also held from 9–16 November 2020 and 7 December 2020. The 33rd WPEC Meeting is to be held from 10–14 May 2021, and a possible hybrid meeting is planned for 6–10 December 2021, depending on the status of the pandemic at that time. The current chair of WPEC is Osamu Iwamoto (JAEA, Japan).

The objective of the EG on High Priority Request List (HPRL) is to maintain a point of reference for nuclear data priorities, including a rigorous process to review and add new entries. The HPRL is an online database of experimental and/or evaluation needs. Each entry requires a detailed justification with quantification of impact, including sensitivity/uncertainty calculations with modern data libraries. The list is continuously updated/reviewed with progress and new requests. The HPRL also provides reviewed data that funding decision-takers need to determine what research to support. Examples are WPEC SG-41 and WPEC SG-40/CIELO, which were direct responses to needs expressed through the HPRL. A new HPRL system (based on Java Content Management System – JCMS) is under development with the new NEA website, to be made public in 2021. The current chair of EG-HPRL is Emmeric DuPont (CEA, France).

The EG on Generalized Nuclear Data Structure (GNDS) was established to create and maintain a modern international standard for the storage on nuclear data. A replacement of ENDF-6 format was required, as the fixed-column width and other Byzantine legacy features created challenges for extensibility. Subgroup 38 was created to establish the requirements for an international replacement format for ENDF-6 and to start with its specifications. That endeavor was successful. The EG-GNDS was formed as an official body to finalize the first specifications and create the process for continual updates. GNDS version 1.9 was published in May 2020 (ISBN 978-92-6490-197-1; https://doi.org/10.1787/94d5e451-en) providing detailed technical specifications as well as a policy brief for high level/general audience. The current chair of EG-GNDS is David Brown (BNL, Brookhaven, USA).

WPEC SG-45, Validation of Nuclear Data Libraries (VaNDaL) Project, was established to collect, review and provide quality assurance (QA) inputs for nuclear data validation with integral experiments (primarily ICSBEP). ICSBEP contains thousands of experiments, but simulation inputs (if they exist) are not designed for nuclear data validation and verification (V&V). The nuclear data community makes extensive use of these experiments, duplicating effort and introducing errors with modelling. Thousands of inputs have been shared in SG-45 (using NEA GitLab) and are used in cross-comparisons, complemented by data stored in NEA DICE databases and other output, sensitivity and verification data generated by participants. A new meta-format for serialization has been drafted, which can be used for serialization into code-specific inputs (e.g. the Monte Carlo code MCNP). The SG-45 coordinator is Wim Haeck (LANL, Los Alamos, USA) and the monitor is Andrej Trkov (JSI, Slovenia).

WPEC SG-46, Efficient and Effective Use of Integral Experiments for Nuclear Data Validation, was launched to update Target Accuracy Requirements (TARs) for nuclear systems and develop methods for integral nuclear data feedback. An important motivation is the need to define updated target accuracies for design, operation and fuel cycle parameters, and to assess the impact of present covariance data on accuracy requirements. The current SG-46 coordinators are Óscar Cabellos (UPM, Spain) and Mathieu Hursin (PSI, Switzerland). The monitors are Arjan Plompen (JRC-Geel) and Andrej Trkov (JSI, Slovenia).

WPEC SG-47, Use of Shielding Integral Benchmark Archive and Database for Nuclear Data Validation, has as objective the identification and development of shared resources for SINBAD benchmarks to aid in nuclear data validation and evaluation. Many SINBAD experiments are (or could be) used for nuclear data testing, validation, and integral feedback. Models are often limited in terms of overall description, therefore supplementary information is valuable for nuclear data (e.g. Monte Carlo weight window meshes for CAD geometries or virtual reality (VR), more detailed source terms, code modifications, etc.) Many SINBAD entries are complex and additional model information greatly improves the potential value for nuclear data and other users. The SG-47 coordinator is Ivan-Alexander Kodeli (UKAEA, UK) and monitors are Óscar Cabellos (UPM, Spain) and Luiz Leal (IRSN, France).

WPEC SG-48, Validation of Thermal Scattering Laws (TSL) for Light Water at Elevated Temperatures with Diffusion Experiments, has as objective to advance the state-of-the-art in thermal scattering law, processing and validation. Following the success of SG-42, which re-invigorated the field, many new advances are now possible. Uncertainties are better handled in the new GNDS format. Approximations applied in legacy formats and processing are being removed and a modern, open-source processing scheme for new TSL data has emerged. More communities are engaging, some with unique needs such as spallation source facilities (e.g. SNS, ESS, ILL, ISIS, CNS, etc.) Better links with NRDC/EXFOR have been established to improve stored experimental differential data. New TSL validation methods are being investigated, involving new types of integral measurements. A kick-off meeting was held on 13 May 2020, attended by 47 participants. The SG-48 coordinator is Gilles Noguère (CEA, France) and the monitor is Ayman Hawari (NCSU, North Carolina, USA).

WPEC SG-49, Reproducibility in Nuclear Data Evaluation, was established to improve reproducibility in evaluation by documenting processes and developing tools to store knowledge. A problem in much of the evaluation work done over the years is that many evaluations are difficult or even impossible to reproduce. This is counter to basic principles of scientific work. It is also a looming challenge due to the demographics of the workforce. Technology cannot solve the problem – but it can help. SG-49 is establishing guidance for information required in the evaluation process. Building of version-controlled systems that capture the details of models, codes, scripts, data/databases, etc., will assist in ensuring reproducibility. These will be used by library projects and coupled with automated testing systems. Examples are the ENDF and JEFF GitLab projects. One important gain of this approach is that re-evaluation at a later stage can be significantly simplified, e.g. an evaluator can include subsequent measurements to a previous evaluation and much more rapidly produce an updated evaluation. The SG-49 coordinators are Michal Herman (LANL, Los Alamos, USA) and Dimitri Rochman (PSI, Switzerland). The monitors are David Brown (BNL, Brookhaven, USA), Osamu Iwamoto (JAEA, Japan), and Arjan Koning (IAEA, Vienna).

WPEC SG-50, Developing an Automatically Readable, Comprehensive and Curated Experimental Reaction Database, has been established to develop derived databases from EXFOR that incorporate unofficial corrections and evaluator judgements. EXFOR is a uniquely successful database that contains experimental data as published. Quite often not all uncertainties are available in the original works. Corrections are made as necessary by evaluators (who are not normally the original experimentalists). Sometimes data types are required for evaluations which are not part of EXFOR. Ultimately, evaluators weigh many data and information, including judgement, which may be subjective and not unique. These *ex post facto* data are outside the scope of EXFOR but fundamental to nuclear data evaluation – hitherto often unrecorded. SG-50 has therefore been created to formulate a strategy so that such knowledge is not lost. Several exploratory meetings have been held in 2020/21, followed by a coordination meeting on 6 April 2021. Essentially the real work is only now starting. The SG-50 coordinators are Amanda Lewis (NNL, USA) and Denise Neudecker (LANL, Los Alamos, USA). The monitor is Arjan Koning (IAEA, Vienna).

During question time, Umasankari Kannan enquired how scientists from non-OECD countries can become members of and/or contribute to WPEC subgroups. Fleming replied that India and China are strategic partners of the NEA although not officially OECD Member States. This complicates nominations to NEA structures somewhat. The chair of a subgroup, however, can invite a person from a non-OECD country on a discretionary basis. Should a person from a non-OECD country want to contribute, the correct way is to contact the chair of a subgroup directly.

5. INDC SURVEY and DISCUSSION

Koning gave a presentation on the "INDC Survey of August 2020". A questionnaire was sent to the INDC members and observers in August 2020 to advise on the future programme of the NDS. This survey was used as input for planning of the 2022–2023 biennium. There were 20 questions covering 5 categories:

- IAEA/NDS networks: NRDC, NSDD, and INDEN;
- Coordinated Research Projects (CRPs);
- Data Development Projects (DDPs) and related meetings;
- Computers: website, data handling and distributions;
- New ideas and other topics.

Following this presentation, the survey was used as a template for the discussion, which consumed most of the 4^{th}-day session of the meeting. The questions are in bold font below, followed by a summary of responses as bulleted items. The NDS replies to the responses received and aspects of the discussion are presented in italics font.

<u>Question 1:</u> NRDC network – EXFOR compilation: Do you have any suggestions for improvements of the EXFOR compilation?

- Investigate automatic input from publishers also for EXFOR, as has recently been shown to be successful for XUNDL. The use of artificial intelligence (AI) may be useful for prescreening the literature.
- Reconsider keywords and identifiers to improve searching. Some specialized data are not so easy to search for.
- Consider a more modern project management system for EXFOR.
- Evaluation tasks would benefit from having a *scoring system* in EXFOR to help filter anomalous data and outliers.
- Provide access to the articles which have not yet been compiled. If the article is not open access, consider a sub-library that provides relevant information, such a title, authors, reference, type of data, etc., prior to the full compilation.
- Arranging EXFOR compilation workshops/meetings should continue, as this has been very successful in recent years.

WPEC SG-50 was mentioned as a major new effort to make EXFOR more useful, by providing derivative databases that contain normalizations, corrections, implementation of quality scoring, etc. The NDS is already actively engaged within the NRDC with such development *efforts.*

The use of a modern maintenance system like GitLab has been discussed at NRDC meetings. Such an implementation is foreseen in the future.

The NDS will continue to support international and regional training events for EXFOR compilers.

It was pointed out that the data in EXFOR are very diverse and that unifying keywords and identifiers is not a simple task, especially taken into consideration the freedom given to evaluators over the years to handle this diversity. On the matter of anomalous data and outliers, care must be taken as sometimes good data may appear to be outliers due to a wrong identifier, i.e. there are still errors in EXFOR. The EXFOR library is not yet automatically accessible to applications (e.g. codes like MCNP) but work should continue to make it more accessible to applications via APIs. There are initiatives within the NRDC to make this a reality, not within the original EXFOR but certainly within derivative databases.

<u>Question 2:</u> NRDC Network – EXFOR: Do you have any suggestions on how EXFOR should be delivered to users in a more diverse way? (Note that we are not talking about the format of EXFOR database itself. Rather about OUTPUT formats, GUIs, APIs, etc. Note also there is a newly started WPEC SG-50 related to this. This may generate subsequent IAEA projects in 2-3 years from now.)

- NEA WPEC SG-50 on an automatically readable, curated and validated experimental reaction database (based on EXFOR) is seen as a good initiative to make EXFOR even more useful. (Note that a number of INDC members responded on SG-50 in various ways, not all of which are summarized here.) The recently added JSON format in the retrieval system is a timely extension.
- Several comments indicated that a more user-friendly EXFOR web interface will be appreciated. The web interface needs to be modernized. In particular, care must be taken to avoid specialized jargon that only nuclear data experts will understand. Too-small fonts should also be avoided.
- Aim to integrate EXFOR seamlessly into evaluation systems, including AI approaches, which in future will also form part of validation and verification of nuclear data.
- Aim for formats suitable for whole-library validation. Non-user interface recall of data would be useful to allow codes to automatically interface with EXFOR (via APIs).
- A more rapid response GUI will also be appreciated, similar to JANIS.

Some of the ideas mentioned in Question 1 were further explored, especially with regards to WPEC SG-50. The NDS is already playing an important role in SG-50. An investigation into an API-based interface next to the current interface has already been initiated. There was a comment by Capote that it is important to remember that EXFOR is continuing to be developed and that the idea is not to change the way that this is done. The correction system of SG-50 is seen as a back-end of EXFOR and the derived database is strongly connected to EXFOR, i.e. not developing independently but actually developing as EXFOR develops. There was some discussion on the completeness of charged-particle reaction data, which still requires a considerable effort. It was mentioned that individual evaluation projects actually contribute to EXFOR in the sense of finding data that can and should be compiled if not in the library already, and also finding mistakes. Thus, there is a healthy interaction between projects and the NRDC/EXFOR effort.

It was mentioned by Kawano that there are still some entries of evaluated data within EXFOR, for historical reasons, which strictly should not be there. It was suggested that the NRDC should *be made aware of such entries and that they should be removed. This aspect was discussed at length and the general consensus was in favour of the elimination of such non-experimental data to avoid confusion. EXFOR should also not contain any data contaminated by model calculations. The INDC recommends that the NDS discusses this point within the NRDC and facilitate the necessary actions to clean up EXFOR.*

INDC members expressed their strong support for the development of APIs for EXFOR, as well as for other libraries like ENSDF. There was consensus that this point should be a pertinent recommendation by the INDC to the IAEA.

<u>Question 3:</u> NSDD Network – Evaluations: In your opinion, what should be the role of the IAEA in the NSDD network?

- The IAEA should continue organizing decay data evaluations.
- The IAEA should strengthen its role in coordinating the network by hiring a qualified and experienced person, like when this function was performed by Vivian Dimitriou.
- A good balance between reactor and medical applications should be maintained.
- Outreach to as many good quality new evaluators as possible.

Vivian Dimitriou has been re-appointed, as suggested. The NSDD is responsible for the ENSDF database, which is not applications oriented, as this database covers all measured structure and decay data. Decay data for specific applications are being catered for by CRPs and DDPs, and there is a balance between projects for medical and reactor applications. Outreach meetings/workshops similar to ICTP are in the future plans.

Note that questions 4 and 5 are also related to NSDD work.

<u>Question 4:</u> What do you think of the development of the LiveChart and the Isotope Browser? Do you have suggestions for new features to be added?

- Provision of links to original research articles will be useful.
- Adding the mass defect in addition to the binding energy would be very useful.
- Would it be possible to get faster online response for LiveChart? Perhaps this particular web application is also in need of modernization.

Many of the responses from INDC members commended the NDS for these two excellent developments. Both LiveChart and the Isotope Browser are widely used by the broader scientific community.

<u>Question 5:</u> There is the recurring issue of the ever-decreasing number of data evaluators for structure and decay data. What are possible initiatives that the Section could take in order to foster the creation of new evaluators?

- The problem may be that member countries may not see a pressing need for nuclear data, hence they do not employ full-time data evaluators.
- The NDS should continue sponsoring individual evaluators in part-time jobs.
- Continue ICTP training. As the ICTP programme is often over-subscribed, consider hosting dedicated IAEA training schools.
- Use other IAEA tools, e.g. CRPs, yearly Technical Meetings, etc.

Kibédi expressed his concern about the preservation of knowledge, especially as older evaluators are reaching retirement age. This started a discussion to which many people contributed. It was noted that similar discussions were held at previous INDC meetings over *many years as scarcity of evaluators remain a perpetual issue. Dimitriou explained that while the USA has a clear funding possibility for nuclear structure and decay data evaluations, the same is not the case in Europe and Japan. While the IAEA is indeed funding some mentorships for young evaluators, it is difficult to keep them in the network as there is a lack of long-term career paths. It remains hard to convince large research centres and experimental facilities that their help is needed. Funding remains the key issue. Recently, instead of trying the top-down approach, the NSDD is trying a bottom-up approach, i.e. training students in nuclear data and hoping that some of them may convince their superiors as to its value and necessity. Ultimately, what is needed is for senior management to invest in nuclear data and to promote its growth.*

Several comments were made about what to do to keep young evaluators in the network. Training in nuclear data will help them in their research projects. Modernization of ENSDF may also attract young scientists. It is necessary for them to see the benefits of nuclear data training in their own careers.

An opportunity may be opening to train/assist experimental groups as the tools required for evaluation may be useful to these groups for publication purposes, in view of the recent introduction by some journals of nuclear data checking prior to reviewing (e.g. Phys. Rev. C; EPJ, etc.) There was consensus that the NDS and NSDD explore this possibility further.

Cantargi suggested that virtual introductory courses, prior to attending a hands-on workshop in Trieste, may be useful to introduce young scientists to the nuclear data field. Dimitriou agreed that this may be useful as an initial exposure but pointed out that it takes time to train a new evaluator to maturity, which may take several years of working with an experienced tutor. Training can be done but it is essential that at least some of the newly trained evaluators remain in the network on the longer term.

Capote explained that CRPs and TMs are not suitable vehicles for training as they have been tailored specifically for data development work.

<u>Question 6:</u> In 2018 we started the International Nuclear Data Evaluation Network (INDEN), with yearly efforts and meetings, on light nuclides, structural materials and actinides. Three meetings/year were held in 2018 and 2019, similarly planned for 2020–2023. The focus is on discussing existing challenges and in-depth technical and methodological issues. Eventually new evaluations will be produced: evaluation of light elements (connected to the R-matrix DDP); evaluation of structural materials (Fe, Cu, Ni, etc.); evaluation of actinides with focus on the resonance region (Pu isotopes, revisiting ^{235}U, ^{233}U). Do you have any additions or suggestions?

- Focus on reproducibility of evaluations, which require rigorous documentation and storage of all required inputs.
- The INDEN activities are currently limited to only a few selected people and institutes. It should be open to more parties in the world. An outcome of INDEN should be to guide a larger number of evaluators and eventually promote relevant projects in member countries.
- More focus on covariance evaluation of cross sections is needed. The isotopes of Zr can be added to structural materials, and issues with accuracy of minor actinides should be addressed.
- A serious effort needs to be made to evaluate data in a form useful for transport simulations. The multi-emission cross sections, spectra and DXXs in ENDF format do not contain the sequential emission information needed to describe these processes correctly. As the evaluated data don't contain the necessary information, global

descriptions of sequential pre-equilibrium and equilibrium emissions must be used in their place. But these usually can't describe the peculiarities of individual nuclei that make evaluation necessary in the first place.

There is still a lot of effort needed on ^{56}Fe and ^{235}U evaluation. Extension to Zr and minor actinides has not yet been done. INDEN, as a follow-up of the CIELO project, has a current focus on only a few selected isotopes. Capote explained that the INDEN network is not going to produce an INDEN library, which is not its goal. In that regard it differs from the other nuclear data networks. The goal of INDEN is to converge on evaluation methods, which necessitates also converging on evaluation data, but for selected isotopes only. Those evaluations, however, are available and can be used by projects.

<u>Question 7:</u> Completed CRPs: Photonuclear data library and database of gamma-ray strength functions (two peer-reviewed publications, webpage); Beta-delayed neutron emission (one publication still with Editor, webpage); Particle-Induced Gamma ray Emission (PIGE) (published a TECDOC, IBANDL webpage); Primary radiation damage cross sections (one peer-reviewed paper, webpage); Charged-particle cross section database for medical radioisotope production and beam monitor reactions (four peer-reviewed papers, webpage); Do you have any comments on completed projects or suggestions for follow-up?

- Photonuclear data library needs follow-up meetings and input from data processing experts to improve the quality.
- Documentation needs to be in sync with CRP webpages and related databases.

Koning agreed that there are still some issues with the Photonuclear Data Library as in a sense it is still an old-style library, and the NDS has to deal with contributions from many contributors, all in different styles. An intern worked on the format and tested the file, and there is good progress. The gamma-ray strength functions also require some attention. Webpage modernization and upgrades are under construction.

The discussion was very short on this question. Herman commended the NDS on the large amount of quality work done but added that once a project has been completed, there is often not much one can do anymore, except that there is an understanding that some maintenance and updating may be required. Koning explained that small updates can be handled by the NDS internally. Depending on the size of future updates, future consultant's meetings may be required for larger tasks. It is not unusual for that to happen, say, 2 or 3 years after completion of a CRP, followed by an updated release of a database.

<u>Question 8:</u> On-going CRPs: RIPL for fission nuclear model codes. Do you have any comments on this ongoing CRP?

- The existing Reference Input Parameter Library (RIPL) is very successful, widely used, saves a great deal of time when setting up calculations, thus a CRP to find better fission parameters should follow the success of previous CRPs on RIPL.
- Compilation and systemization are important.

Koning explained that during previous RIPL CRPs, it was realized that the development of fission parameters was lacking behind work on other reactions. Parameters for fission calculations are the least mature and most difficult to establish. There is a need for a consistent parameter database for fission calculations. The idea of this CRP is to provide a good starting point for code developers. Unfortunately, this CRP is particularly hurt by travel restrictions to and from the IAEA. It now requires a big push forward by the main code developers and their coordinators, four of which were highlighted: CoH_3 (Kawano), CCONE (Iwamoto), EMPIRE

(Capote, Herman), TALYS (Koning).

Herman commented that there is a small issue with the old-style format of RIPL, which has a fixed-column, old Fortran structure. This is not appealing to the younger generation. Koning suggested that the RIPL CRP should investigate modernizing the format, perhaps converting to or adding JSON.

<u>Question 9:</u> Starting CRPs: Fission Yields (FY) of neutron induced fission of major actinides (1st RCM held in August 2020). Do you have any comments on related starting projects or suggestions for additional activities?

- Integrate the FY CRP in a full nuclear data pipeline, from differential reaction measurements to reactor calculations, including SFCOMBO. (SFCOMPO 2.0 is a Spent Fuel Isotopic Composition Database developed by the NEA in close collaboration with Oak Ridge National Laboratory - ORNL).
- Proposal for new CRP: Consider a CRP on proton and alpha-induced reactions, with focus on nuclear data for fusion applications.
- Proposal for new CRP: After the success of the CRP on monitor reactions and cross sections for medical radioisotopes, a new CRP on ionizing radiation from decay of medical radioisotopes can be considered, including X-rays, β-particles and Auger electrons. Together with the improvement of medical imaging, these developments pave the way for cancer treatment on the nanoscale, thus such a CRP may have significant impact. The CRP should especially focus on emissions at lower energies.

Koning remarked that covering the entire FY data pipeline would be very challenging. The NDS is not equipped, nor mandated to provide a full nuclear pipeline, but should deliver as many components as possible. Initially the main isotopes requiring high-quality evaluations will be ^{252}Cf, ^{235}U and ^{238}U, with appropriate model developments. The general discussion supported the view that the entire pipeline would perhaps be too ambitious, taking into consideration that FY are important for many applications and not only reactors. Similar arguments were made for (α,n) reactions, which are important for many applications and not only fusion. Capote remarked that many of the nuclear data projects have a wide scope, benefitting both fusion and fission as well as other applications. There was some discussion on a planned future TM on (α,n) reactions later in 2021. Dimitriou confirmed that this will be advertised widely, also extending the invitation to the fusion community. She also mentioned that exploratory discussions on (α,n) reactions took place at a recent INDEN meeting on light elements.

The two suggestions for new CRPs were well received and can be the basis for further discussions on what CRPs should be pursued in the future. The choice on new CRPs need to be made. Future projects on alpha-particle induced reactions, fusion, medical, etc. are planned, though not all as CRPs.

<u>Question 10:</u> Nuclear data for medical applications: NDS aims to continue developing and updating nuclear data for medical applications. Amongst others, we have developed: A web Interface for efficient estimation of medical isotope production (nds.iaea.org/mib); A Medical Portal showing all cross section and decay data (nds.iaea.org/medportal). Can you give us some preferences and priorities for improvement of the medical isotope data? For reactions? For decay data?

- Continue evaluations of charged-particle cross sections for radionuclide production and update the database accordingly.
- Continue decay data evaluations for medical applications.
- Investigate general nuclear data needs for medical applications.

Koning commented that the various requests for future medical efforts are well noted. The development of a computer-readable medical isotopes data library for charged-particle reactions is in progress, aimed for the end of 2021. This library will contain all past high-quality IAEA evaluations as well as TENDL data. Evaluation work needs to continue as there are some promising production routes that have not yet been evaluated.

Herman commented on the fact that this activity supports an important peaceful use of nuclear technology and is good for the image of the NDS. Kibédi made a general comment on the use of nuclear data in modern codes and the fact that the latest data are not always implemented and/or used. He gave the example of Geant4-DNA, where recent Auger simulations employed quite old data.

<u>Question 11:</u> Data Development Projects: [on-going] Analysis and evaluation codes for nuclear structure and decay; [on-going] Decay data for monitoring; [on-going] Neutron data standards; [on-going] Nuclear data processing (includes inter-comparison of processing codes); [on-going] R-matrix codes; [on-going] IBANDL; [on-going] Thermal scattering; [on-going] Total Absorption Gamma-Ray Spectroscopy (TAGS) data; [on-going] FENDL, data for fusion; [on-going] Antineutrino data; [completed] Maintenance of Electron and Photon interaction data library (EPICS). What is your opinion on the development, prioritization, and expansion of the scope of various DDPs?

- Prioritize code development.
- Modernization of FENDL required. FENDL is widely used in fusion but feels more archaic compared to modern nuclear data efforts. A different approach, e.g. more of a "live library" may be considered, accessible in real time by modern codes.
- Sequential particle emission below 30 MeV for medical applications.
- The impressive list of projects seems rather complete.

The NDS noted the comments. Georg Schnabel has taken over the coordination of FENDL and there are plans to modernize the library. The problem with FENDL is that it contains files from a large number of volunteers, each with their own ideas of how a nuclear data file should be built. Better streamlining of the library is needed.

<u>Question 12</u>: NDS website: Do you have any recommendation for the modernization of the NDS website? Are you currently missing anything from our website?

- A complete redesign is necessary. The current website is too packed with information and its appearance is rather old. The new page should be scrollable.
- The current website is fine and doesn't need changing.
- All relevant information is there but needs reorganization.
- Layout of sub-pages should be unified.
- More APIs instead of click-to-download options only.
- Improvement of the in-site search function.

Koning reported that the feedback was rather diverse in that some people are happy with the existing website, while many feel that a redesign/modernization is necessary. The NDS agrees with the latter view and initiatives for a new website have started. An aim is to report a prototype/alternative website at the next INDC meeting in June 2022.

A very lengthy discussion ensued. Gilbert mentioned that currently the search function on CRPs takes one to a global list of CRPs of the whole IAEA, making it difficult to find the relevant *information for only the NDS. He could not find a way that only targets the NDS projects. Capote welcomed this comment, confirming that he was aware of the issue and that it will be streamlined. Kawano made the point that the best way to test a new website was to get user feedback. Koning replied that they will open the new website to some users for testing and that initially there will be a period of overlap with both the old and new websites available. This overlap period cannot be too long, however, as then it becomes costly in terms of manpower to maintain two websites. Several people made comments on levels of abstraction, reducing the amount of information on the top page, reducing acronyms and code names that only experts will be familiar with, providing the full titles of databases and projects, well-defined links in appropriate places, etc. NDS staff promised that the new website will be made friendlier for less experienced users. Herman strongly suggested that the graphical design of the Apple website BIG SUR should be studied as a prime example of what a modern website should look like. It was also mentioned by several attendees that attention should be given to portable devices, as an increasing number of users are using cell phones/tablets for Web browsing. NDS staff agreed that new webpages, by design, should be usable on all popular portable devices and computer systems.*

In summary, Koning suggested that a definite goal might be to open a prototype website in about half-a-year, then inviting a group of users to test it, followed by a meeting to discuss the experience, problems, suggestions for improvement, etc. This idea was welcomed by several INDC members and observers.

Question 13: Mirror sites: Is the current set of mirror sites (China, India, Russia) sufficient and useful? Do we need a revision of NDS policy on mirror sites?

- Five of the responses questioned the need for mirror sites and three more indicated that they never use them.
- The mirror site at CNDC is important for China.

Koning commented that the mirror site issue needs a firm decision, which may be country dependent. In former times, it was often the case that the local internet speed was much faster than the international internet speed, which was a main motivation for some countries to having mirror sites. Unfortunately, in some cases the support was lacking at a mirror site, with updates falling behind up to several months. But now, with cloud-based services, internet speed is becoming less of an issue. Herman wanted to know how much time/work was required for the NDS to manage mirror sites. Zerkin explained that, in contrast to former times, nowadays it was in fact very little, as the work was similar to staging and updating the virtual servers in the cloud. This is typically done once a week and takes less than one hour. Repeating this for the mirror sites was not a time-consuming task. The members from India and China expressed views on the usefulness of having mirror sites in their countries.

It was concluded that should there be good commitment at a mirror site, this service should be continued. The INDC therefore endorses mirror sites in such locations.

Question 14: If IAEA allows, should we make code/software available via Git platforms (GitHub, GitLab)? If yes, can you give some examples? Do you recommend other services/workflows that should be handled via a Git platform?

- Git was advocated for CRPS, research networks and EXFOR.
- Distribution of code packages should be done via GitHub or GitLab.
- Git seems to be more useful for codes than for data.

Koning reminded the meeting that the IAEA is not a science-oriented organization but rather Microsoft dominated administrative, therefore with Git the NDS will be largely on their own.

Nevertheless, GitLab is already used for more projects now and several codes are disseminated via GitHub.

GitLab and GitHub seem to be taking over from SVN and is becoming very popular. It is excellent for project development, information sharing, updating, editing, version control, etc. It may be better for CRPs, DDPs and code development than for working with large databases, primarily because of cost of storage, data transfers and data-transfer speeds. There may also be security constraints. These potential issues, however, need to be fully explored. It may be that GitLab is the best for project development but data retrieval still predominantly from a website, at least at the present time. It is important to follow the development of these technologies as the current situation may change.

The INDC fully endorses the implementation of Git platforms.

<u>Question 15</u>: Do you see a need for some of our data to be also accessible programmatically, via APIs? If yes, can you give us some examples of data and possible usage? (Note: this is already underway for EXFOR and ENDF).

- Yes, for EXFOR and ENDF (many replies).
- Virtually all data could/should have APIs although the priority should be determined by the total user need. APIs for ENSDF and LiveChart should be considered.
- APIs should include JSON format.
- API and JSON format should be considered for RIPL.

Koning commented that ENSDF has not yet been discussed in the context of APIs. There still is a sense with some developers that these libraries are fine with whatever is done on the back-end but a resistance to changes to the internal structure and format. Several attendees commented that this will ultimately have to change. Herman commented that ENDF is also approaching a stage where the transition will be forced as there will be more possibilities in GNDS than in ENDF-6 format. Dimitriou commented that the NNDC already started modernizing the ENSDF format and structure. Comments were made that WPEC SG-50 may lead to a similar process for EXFOR.

The INDC fully endorses the development of APIs alongside existing interfaces.

<u>Question 16</u>: Are you satisfied with, or do you require more, full database distributions? (e.g. "XC4 of full EXFOR", "EXFOR for Applications", etc.)

- Generally, INDC members are satisfied with the present distribution (8 responses).

There was almost no discussion on this question. Some of the responses and discussion to questions 1 & 2 may also apply here.

<u>Question 17:</u> ICTP Workshop: What would be your preference for a topic for an ICTP Workshop?

- Revive the nuclear reaction workshops.
- Nuclear data for medical isotope production.
- Covariance and uncertainty evaluation.
- AI/ML for nuclear reactions and structure.
- Monte Carlo transport simulation physics.
- Antineutrino detection.

- Thermal scattering law and TSL library generation.
- ENSDF evaluation.

Almost every topic on nuclear data were suggested. Some ideas can be merged into one workshop. There is room for only one or two nuclear data workshops per year. Artificial Intelligence (AI) and Machine Learning (ML) is an interesting idea.

Cantargi suggested a workshop associated with the ND Conferences as many experts will be present who may be able to be presenters. This can be several days either before or after the conference. There was some enthusiasm for this idea. There was also a suggestion for a virtual workshop prior to a ND Conference. The problem with this suggestion is that this is normally the time when people are preparing their presentations for the conference, therefore, perhaps it will not be well received.

Question 18: Artificial Intelligence and Machine Learning is also entering nuclear science now and nuclear data is an obvious branch where it should be introduced over the whole breadth of the field. We want to start with a Consultancy Meeting to advise us on several ND projects. One application is efficient compilation and more efficient testing and use of EXFOR. Do you have any further AI/ML ideas for us?

- EXFOR compilation and testing.
- ENSDF evaluation, including translation of old codes.
- Several respondents would like an invitation to the CM.

For EXFOR this is underway, starting with automatic identification of articles to be compiled. For ENSDF this needs to be put on the agenda of the NSDD. Programs already started at the NNDC and also LANL. It is a rising field with expectations to have impact in many fields of science. Young scientists are more familiar with these new techniques but perhaps less familiar than older scientists on the topics of nuclear data – the idea would be to bring them together.

Question 19: Nuclear data for back-end of the fuel cycle We could invest more effort in nuclear data for the safe monitoring, dismantling, decommissioning and disposal of nuclear fuels and waste materials, including n-p-g cross sections, particle emission spectra and decay data in unison. Do you have a particular interest or suggestions for data needs?

- Provision of neutron sources for irradiated fuel – source terms and simulations.
- The need for nuclear data for minor elements/isotopes of spent fuel is very high, both for nuclear reactions and structure.
- Update data for the Th-U and U-Pu cycles.
- Reduction of uncertainty of nuclear waste production in structural materials, for both fission and fusion.

There is definite interest in nuclear data for the back-end of the fuel cycle as many reactors are reaching end of life. Decommissioning aspects have different nuclear data needs, e.g. nuclear waste in structural materials, which is also important from the outset in next generation fission and fusion infrastructures. It was mentioned that the main impact of the CIELO project was on criticality safety, a topic that will further benefit from INDEN.

Question 20: Any additional comments

- Easier access to data like TENDL on the NDS website.
- Extend the Medical Isotope Browser

- More nuclear structure data experts in the INDC.

TENDL is currently hosted by PSI in Switzerland but will in future also be hosted by die NDS. Access will be available in more than one way from the new NDS website.

Zerkin reminded Herman about his commitment to pen a letter to US laboratories, asking permission to open access for laboratory reports in PDF format.

There was some discussion on the issue of correct referencing of databases and computer codes. This is important for authors as it affects the scores of h-indices. Digital Object Identifiers (DOIs) can be a great help, not only for reports but also for databases. Marian commented that there is an initiative to establish official IAEA DOIs and that this still requires legal issues to be straightened out by the IAEA's legal department.

In conclusion of the discussion and the survey, Koning assured the meeting that the NDS takes note of all the comments and suggestions.

6. OTHER BUSINESS and ADJOURNMENT

Koning thanked the INDC members, advisors, observers and NDS staff for their participation. The date for the 34th INDC Meeting will be communicated soon as it has not yet been programmed into the IAEA calendar, but it is likely to be in the middle of June 2022.

The Chairman closed the meeting.

Appendix 1

International Atomic Energy Agency

33rd International Nuclear Data Committee Meeting

Virtual Event

29 March–1 April 2021

AGENDA

Monday, 29 March

14:0014:30 CEST **Opening**

Opening statements – Melissa Denecke, DIR-NAPC
Arjan Koning, SH-NDS

Announcements

Statements of INDC members

Adoption of Agenda

Adoption of Minutes of 32nd INDC Meeting (INDC/P(18)-15)

Actions from previous meeting

14:30–17:00 CEST	**Section Review (2018–2020)**	
14:30–14:40	Global Overview of the Nuclear Data Section	*Koning*
14:40–14:50	Staffing and Budget	*Koning*
	Nuclear Data Section Activities (2018–2020)	
14:50–15:10	Network coordination (NRDC)	*Otsuka*
15:10–15:30	Network coordination (NSDD)	*Dimitriou*
15:30–15:50	INDEN: International Nuclear Data Evaluation Network	*Capote*
15:50–16:00	*Break*	
16:00–16:30	Nuclear data development (CRPs and DDPs)	*Capote*
16:30–16:40	CRP Evaluation Primary Radiation Damage Cross Sections	*Sublet*
16:40–16:50	Training and Workshops (ICTP, Trieste)	*Capote*

Tuesday, 30 March

14:00–17:00 CEST	**Nuclear Data Section Activities (2018–2020) – continued**	
14:00–14:20	Project Nuclear Data Services Dissemination – Deployment	*Sublet*

14:20–14:40	User services for nuclear reaction data	*Zerkin*
14:40–15:00	Computing Infrastructure	*Marian*
15:00–15:20	Software support for Structure & Decay Data	*Verpelli*
15:20–15:40	Project Compilation of Nuclear Data Experiments for Radiation Characterization (CoNDERC)	*Sublet*
15:40–15:50	*Break*	
	2021–2023 Programme Plans	
15:50–16:20	Continuing and future Data Development Projects	*Capote*
16:20–16:40	Other activities	*Koning*

Wednesday, 31 March

14:00–17:00 CEST	**Nuclear Data Needs**	
14:00–14:20	INDC Survey	*Koning*
14:20–15:20	INDC members: statements on data needs	
15:20–15:40	WPEC and JEFF activities	
15:40–16:00	INDC Membership (outgoing, new and renewals)	
16:00–17:00	Discussion	

Thursday, 1 April

14:00–17:00 CEST	**Discussion, Summary and Concluding Activities**
14:00–16:40	Discussion
16:40–17:00	Other business – date of 34th INDC Meeting
17:00	Adjournment

LIST OF PARTICIPANTS

(in addition to NDS Staff)

ARGENTINA
Florencia Cantargi
Neutron Physics Group
Centro Atómico Bariloche
8400 – S.C. de Bariloche – Rió Negro
Tel.: +54 2944 445216
E-mail: cantargi@cab.cnea.gov.ar

AUSTRALIA
Tibor Kibédi
Department of Nuclear Physics
Research School of Physical Sciences and Engineering
Australian National University
Canberra, A.C.T. 0200
Tel.: +61 2 6125 2093
E-mail: tibor.kibedi@anu.edu.au

BRAZIL
Brett V. Carlson
Instituto Technológico de Aeronáutica (ITA)
Praça Mal. Eduardo Gomes, 50
Vila das Acácias
12228-900 SÃO JOSÉ DOS CAMPOS
SP BRAZIL
Tel.: +55 12 3947-6881
E-mail: brett@ita.br

CHINA
Ge Zhigang
China Nuclear Data Center
China Institute of Atomic Energy
P.O. Box 275
Beijing 102413
Tel.: +86 10 6935 7275
E-mail: gezg@ciae.ac.cn

JAPAN
Osamu Iwamoto
Nuclear Data Center
Japan Atomic Energy Agency
2-4 Shirakata, Tokai-mura, Naka-gun
Ibaraki-ken 319-1195
Tel.: +81-29-282-5480
E-mail: iwamoto.osamu@jaea.go.jp

FRANCE
Cyrille De Saint Jean
DEN/DER/SPRC/LEPh
Commissariat à l'Energie Atomique
Centre de Cadarache, Bat. 230A
F-13108 Saint-Paul-lez-Durance Cedex
Tel.: +33 4422 54101
E-mail: cyrille.de-saint-jean@cea.fr

GERMANY
Arnd Junghans
Helmholtz Zentrum Dresden Rossenhof (HZRD)
Bautzner Landstr. 400
01328 Dresden
Tel.: +49 351 260 3589
E-mail: a.junghans@hzdr.de

HUNGARY
Ferenc Tárkányi
Institute of Nuclear Research of the Hungarian Academy of Sciences (ATOMKI)
Bem ter 18/c, P.O. Box 51
H-4001 Debrecen
Tel.: +36 52-509-200
E-mail: tarkanyi@atomki.hu

INDIA
Umasankari Kannan
Reactor Physics Division
Bhabha Atomic Research Centre
Trombay, Mumbai 400 085
Tel.: +91 22 25505050
E-mail: uma_k@barc.gov.in

SPAIN
Enrique M. Gonzalez Romero
Division de Fision Nuclear
CIEMAT
Avda. Complutense, 40 (Edif. 17)
28040 Madrid
Tel.: +34 913466120
E-mail: enrique.gonzalez@ciemat.es

KOREA
Young-Ouk Lee
Nuclear Data Centre
Korea Atomic Energy Research Institute
P.O. Box 105
Yusong, Daejon 305-600
Tel: +82-42-868-2964
E-mail: yolee@kaeri.re.kr

RUSSIAN FEDERATION
Vitaly Khryachkov
Institute for Physics and Power Engineering
Bondarenko Sq. 1
249 033 Obninsk, Kaluga Region
Tel.: +7 494 399 4827
E-mail: bgg1999@mail.ru

SOUTH AFRICA
Deon Steyn
NRF iThemba Laboratory for Accelerator
Based Sciences (NRF iThemba LABS)
PO Box 772
Somerset West 7129
Tel.: +27-21-8431000
E-mail: deon@tlabs.ac.za

UNITED KINGDOM
Mark Gilbert
Culham Centre for Fusion Energy
United Kingdom Atomic Energy Authority
Culham Science Centre
OX14 3DB Abington, Oxfordshire
Tel.: +44-1235-466400
E-mail: Mark.Gilbert@ukaea.uk

UNITED STATES OF AMERICA
Michal W. Herman
Los Alamos National Laboratory
P.O. Box 1663
Los Alamos NM 87545
Tel.: +1 505-664-0580
E-mail: mwherman@lanl.gov

OBSERVERS and ADVISORS

Michael Fleming
OECD Nuclear Energy Agency (NEA)
NEA Data Bank
46, Quai Alphonse le Gallo
92100 Boulogne-Billancourt
FRANCE
Tel.: +33-1-4524-1099
E-mail: michael.fleming@oecd-new.org

Arjan Plompen
Standards for Nuclear Safety, Security and
Safeguards (SN3S) Unit, EC, JRC, IRMM
Retieseweg 111
B-2440 Geel
BELGIUM
Tel.: +32-14-571-381
E-mail: arjan.plompen@ec.europa.eu

Dipanwita Dutta
Bhabha Atomic Research Centre
Trombay, Mumbai 400 085
INDIA
Tel.: +91 22 25505050
E-mail: ddutta@barc.gov.in

Anek Kumar
Bhabha Atomic Research Centre
Trombay, Mumbai 400 085
INDIA
Tel.: +91 22 25505050
E-mail: kanek@barc.gov.in

Toshihiko Kawano
Los Alamos National Laboratory
P.O. Box 1663
Los Alamos NM 87545
UNITED STATES OF AMERICA
Tel.: +1 505-664-0513
E-mail: kawano@lanl.gov

Ashwani Kumar
Bhabha Atomic Research Centre
Trombay, Mumbai 400 085
INDIA
Tel.: +91 22 25505050
E-mail: kashwani@barc.gov.in

Sadhana Mukerji
Bhabha Atomic Research Centre
Trombay, Mumbai 400 085
INDIA
Tel.: +91 22 25505050
E-mail: mukherjis@barc.gov.in

Devesh Raj
Bhabha Atomic Research Centre
Trombay, Mumbai 400 085
INDIA
Tel.: +91 22 25505050
E-mail: draj@barc.gov.in

Anindata Sarkar
Bhabha Atomic Research Centre
Trombay, Mumbai 400 085
INDIA
Tel.: +91 22 25505050
E-mail: anindata@barc.gov.in

Sandor Takács
Institute of Nuclear Research of the Hungarian
Academy of Sciences (ATOMKI)
Bem ter 18/c, P.O. Box 51
H-4001 Debrecen
HUNGARY
Tel.: +36 52-509-200
E-mail: stakacs@atomki.mta.hu

Alejandro Sonzogni
National Science and Technology Department
Brookhaven National Laboratory
Upton, NY 11973
UNITED STATES OF AMERICA
Tel.: +1 631 344-5334
E-mail: sonzogni@bnl.gov

TERMS OF REFERENCE OF THE INTERNATIONAL NUCLEAR DATA COMMITTEE

(Updated version of January 2020)

FUNCTIONS

1. The International Nuclear Data Committee (INDC) will advise the Agency on its programmatic activities in the field of nuclear data for applications. In particular, it will:

    (a) provide feedback on current activities in the Agency's subprogramme on Nuclear and Atomic Data ("the subprogramme") in order to ensure that the important data needs of Member States are being met;

    (b) make specific recommendations regarding future programmatic activities of the Agency in this field and for the efficient and effective implementation of those activities; and

    (c) facilitate the exchange of information on nuclear data programmes in Member States.

MEMBERSHIP

2. Members of the INDC will be appointed by the Deputy Director General responsible for the subprogramme, in consultation with their Governments, for an initial term of 4 years, which can be renewed up to a maximum of 12 years.

3. The INDC will include a maximum of 15 members, each selected from a Member State which maintains a major nuclear data programme, which provides particular technical expertise, or which offers a needed regional perspective.

4. Each member of the Committee will be a senior expert in the field of nuclear data having broad responsibilities for the direction of nuclear data programmes or widely recognized for accomplishments in this field.

5. Each member of the INDC will be requested to serve on the Committee in his personal capacity and will not represent his or her Government.

CHAIRMAN

6. The Chairman of the INDC will be selected from Committee members, after consultations, and appointed by the Deputy Director General responsible for the subprogramme.

SECRETARIAT AND ADMINISTRATIVE SUPPORT

7. The Agency Secretariat will provide administrative support for INDC meetings. A member of the Agency's Secretariat will also serve as Scientific Secretary of the INDC, to assist the INDC in its work and to facilitate communications between the Committee and the Secretariat.

METHODS OF WORK

8. The Committee will determine its own methods of work.

9. The Committee will consider issues submitted by the Deputy Director General responsible for the subprogramme, and by its members.

10. Observers from Member States or other international organizations may be invited by the Deputy Director General responsible for the subprogramme to attend INDC meetings, or particular sessions during such meetings.

11. The Deputy Director General responsible for the subprogramme and representatives nominated by him will be entitled to participate in the meetings of INDC.

12. The INDC will record its recommendations in a biennial report submitted to the Deputy Director General responsible for the subprogramme.

MEETINGS

13. The INDC will meet, normally in Vienna, at intervals of at least once every 2 years, with each meeting lasting up to 5 working days. Meetings will be conducted in English.

14. Members may be accompanied to INDC meetings by advisors.

15. All travel costs associated with the participation in INDC meetings of members, advisors and observers are expected to be borne by the respective sponsoring organizations. However, where possible, support will be provided by the IAEA for the participation of all INDC members excluding advisors and observers.

Appendix 4

ACTIONS ARISING FROM 32nd INDC MEETING

No.	Respondent	Action	Status
1	NDS	Support international efforts to improve light-nuclide data, including relevant EXFOR compilation and integral experiments.	Continuing R-matrix Meetings and INDEN light elements meetings. An intensive compilation may be arranged if an article list or data specification (target, projectile, quantity, energy) is provided.
2	NDS	Remain involved in WPEC SG-42 on TSL.	NDS made available the TSL interpolator nds.iaea.org/TSL_LibGen/. Discussions are continuing on TSL-related issues in the INDEN network. Retroactive compilation of articles listed in the 2015 CM was done except for 6 articles.
3	NDS	Release a new IRDFF library.	IRDFF-II was released in January 2020 (see nds.iaea.org/IRDFF).
4	NDS	Resolve the issue of code distribution to non-OECD countries by the NEA.	Distribution of codes to non-NEA (but IAEA) countries is again available.
5	NDS	Extend the graphical capabilities for decay data.	LiveChart is continuously improved; β^+ / β^- spectra are now available, gamma intensities from EC/beta+ are split, and X-ray intensities can be split according to each parent gamma ray. Medical Portal offers similar interactive features as LiveChart for decay data; new beta-delayed-neutron database offers plotting, search engine and numerical file for applications.
6	NDS	Give more priority to the EXFOR compilation of photonuclear data.	NDS started compilation of photonuclear data articles when there is a request and/or no responsible centre (e.g., new and old data from European countries like U. Ghent, FZD, GSI).
7	NDS	Make available the displacement damage cross-section data of the CRP	Done (see https://www-nds.iaea.org/CRPdpa/)

No.	Respondent	Action	Status
8	NDS	Investigate a new initiative on nuclear data for back end of the fuel cycle.	Done (see https://www-nds.iaea.org/index-meeting-crp/CM-McDDD)
9	NDS	Enlarge the output options of EXFOR regarding C5M, XC5 and covariance formats.	Done (see https://www-nds.iaea.org/public/zvview/ Zerkin2SG50/c5dev-2020-11-10/)
10	NDS	Organize training workshop, possibly with ICTP, on nuclear data for multi-scale materials modelling.	Two virtual events planned in 2021; One A&M only, and one with Physics Section. Proposal for "Bohr to Young" ICTP workshop in 2022, as workshops had been cancelled in 2021 due to Covid-19.

Appendix 5

ACTIONS ARISING FROM 33rd INDC MEETING

No.	Respondent	Action
1	NDS	Create APIs for EXFOR and possibly other libraries/databases.
2	NDS	Clean EXFOR from "data contaminated by model calculations", evaluated data, etc.
3	NDS	Expand and open X4Lite Pilot Project
4	NDS	NSDD single document repository. Improvement of documentation, protocols and procedures relevant to evaluations, not only on codes but also on how data should be evaluated - need to have a single location for such information. Discuss this inside NSDD. Perhaps other networks and/or projects can also benefit from such an action.
5	NDS	Extend the graphical capabilities for decay data
6	NDS	German version of the Isotope Browser
7	NDS	Release a new version of the Stopping Power database
8	NDS	Nuclear Data for Medical applications: expansion of the existing database established by several completed CRPs
9	NDS	Support international efforts to improve light- nuclide data, including relevant EXFOR compilation and integral experiments.
10	NDS	Investigating AI/ML for nuclear data applications
11	NDS	New ND website "test period", followed by organizing a meeting to discuss the experience, identify problems, suggestions, etc.
12	NDS	Opening up PDF collection further. (Mike Herman, in his capacity as departing INDC Chairman, to pen a letter to US laboratories to ask necessary permissions.)
13	NDS	ICTP Workshops Joint IAEA-ICTP Workshop on the Evaluation of Nuclear Reaction Data for Application (last one in 2017) Nuclear data for multi-scale materials modeling.

Appendix 6

LIST OF WORKING PAPERS

(Also available online from http://www-nds.iaea.org/indc/)

No.	Author	Title
INDC/P(18)-15	G. F. Steyn	Minutes of the 32nd Meeting of the International Nuclear Data Committee.
INDC/P(21)-01	NDS Staff	Meetings, Scientific Visits and Special Service Agreements 2018–2020.
INDC/P(21)-02	NDS Staff	NDS Staff Scientific Papers and Publications 2018–2020.
INDC/P(21)-03	NDS Staff	NDS Technical Publications 2018–2020.
INDC/P(21)-04	NDS Staff	Joint ICTP-IAEA School and Workshops 2018–2020.
INDC/P(21)-05	F. Tárkányi et al.	Progress Report on Nuclear Data Research in Institute for Nuclear Research (ATOMKI), Hungary.
INDC/P(21)-06	A. Junghans	Progress Report on Nuclear Data Research in the Federal Republic of Germany for the Period 2018–2020.
INDC/P(21)-07	NDS Staff	List of actions from 32nd INDC Meeting.
INDC/P(21)-08	U. Kannan	Nuclear Data Activities in India 2018–2020.
INDC/P(21)-09	Y. -O. Lee	Nuclear Data Needs in Korea.
INDC/P(21)-10	B. V. Carlson	Report on Brazilian nuclear data needs and activities.
INDC/P(21)-11	M. Gilbert et al.	UK country report.
INDC/P(21)-12	Ge Zhigang	Nuclear Data Needs in China.
INDC/P(21)-13	T. Kibédi et al.	Proposal to improve the calibration data for conversion electron measurements.
INDC/P(21)-14	E. Gonzalez	Spanish report on nuclear data needs and activities.
INDC/P(21)-15	C. De Saint Jean	Statement on French nuclear data needs and activities for the period May 2018 – March 2020.
INDC/P(21)-16	A. Junghans	German Nuclear Data Needs.
INDC/P(21)-17	M. Fleming	NEA Nuclear Data Activities.
INDC/P(21)-18	O. Iwamoto	Nuclear Data Needs in Japan.
INDC/P(21)-19	G. F. Steyn	Nuclear Data Activities and Needs in South Africa.
INDC/P(21)-20	V. Khryachkov	Nuclear Data Needs in Russia.
INDC/P(21)-21	M. Herman	US Data Needs.
INDC/P(21)-22	F. Cantargi	Progress Report on Nuclear Data Research in Argentina.
INDC/P(21)-23	G.F. Steyn	Minutes of the 32nd Meeting of the International Nuclear Data Committee.

Appendix 7

Work Programme Proposals

Proposals submitted for joint ICTP-IAEA Workshops (2020-2022)

Joint ICTP-IAEA Workshop on Radiation Damage in Nuclear Systems: from Bohr to Young (smr 3443) (2020/1)

Joint ICTP-IAEA Virtual Workshop on Atomistic Modelling of Radiation Damage in Nuclear Systems (smr 3573) (2021/1)

Joint ICTP-IAEA Workshop on Atomic Processes in Plasmas: Data-driven Research (smr 3638) (2021/2)

Joint ICTP-IAEA Workshop on Nuclear Structure and Decay Data: Experiment, Theory and Evaluation (smr 3740) (2022/1)