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INDC International Nuclear Data Committee

Summary Report of the Technical Meeting on

Long-term Needs for Nuclear Data Development

IAEA Headquarters, Vienna, Austria

2 – 4 November 2011

Prepared by

A. Plompen, EC-JRC-IRMM, Geel, Belgium

January 2012

IAEA Nuclear Data Section, Vienna International Centre, 1400 Vienna, Austria

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Abstract

The Advisory Group Meeting on Long Term Needs for Nuclear Data Development was held from 2 - 4 November 2011 at IAEA Headquarters, Vienna, Austria. The goal of this meeting was to develop a vision of the work needed over the next decade (2012-2022) on the measurement, calculation and evaluation of improved nuclear data for various applications. Of particular interest were data improvement activities that could be coordinated by the IAEA. The following areas of nuclear data applications were selected for discussion during the Meeting: Medical and Analytical Applications; Energy Production; Data libraries; Basic Science and Tools/Visualisation.

January 2012

Foreword

R. Forrest, Head of the Nuclear Data Section of the IAEA

The IAEA Nuclear Data Section has for many years carried out the mission of providing high quality atomic and nuclear data to Member States. While this mission is not expected to change, it is extremely important that the Section responds both to rapid technological changes and also to differing priorities from the various applications that we have traditionally supported and also consider if new areas of work should be addressed. While we get very valuable guidance on the details of the program from the International Nuclear Data Committee on a two year cycle, it is also important to take a longer term view to identify developing trends so that the Section can plan which areas to concentrate on and also which fields of expertise to target when recruiting new staff.

The last time this was done, at the end of 2000, (details can be found in INDC(NDS)-423) it was realised that the field of charged particles interactions for analytical techniques should be considered and this has led to several CRPs addressing this area and the development of the IBANDL database which has been very well received by the Ion Beam Analysis community. It was deemed the time was again ripe for another long-term look at the Section's work and so the meeting reported on here was held. I would like to thank all the participants for their deliberations and recommendations and particularly A. Plompen as rapporteur who made this report so comprehensive and eloquent.

Contents

Introduction

D. Mohamad, Deputy Director General of the Department of Nuclear Sciences and Applications of the IAEA opened the meeting by welcoming the participants and explaining the importance of this Technical Meeting for the work of the Nuclear Data Section (the Section).

R. Forrest presented the participants with his expectations for this meeting, the meeting's mandate and gave a general survey of the position of the Nuclear Data Section in the IAEA, its organisation, methods of work, competences, staffing, running activities and main achievements in the past twenty years. The participants were to look into the future and give their view on long-term nuclear data needs, seeing well beyond the typical time span of two years covered by the International Nuclear Data Committee with its recommendations to the Section. They should consider the range of topics, the methods of working, the means to deliver the data, the types of the data and the tools of the Section with an aim of maintaining, developing and strenghtening its roles.

M. Herman of the National Nuclear Data Center at Brookhaven National Laboratory was elected chairman of the meeting. A. Plompen of the Institute for Reference Materials and Measurements (Joint Research Centre, European Commission) was elected rapporteur.

The meeting was subdivided into sessions addressing the fields of competence of the Nuclear Data Section: medical and analytical applications, energy production, libraries, basic science, and tools and visualization. For each of these fields the experts were asked to present their vision of long-term developments and give their personal recommendations for future activities of the Section. Within the sessions the contributing participants were asked to address different aspects of the field. Following the presentations the various recommendations were discussed and summarized.

This report follows the structure of the meeting. Summaries of the presentations will be given organized by field including personal recommendations, note that no attempt has been made to standardise the various presentations in editing this report. The meeting summaries and recommendations, agreed upon by all participants, are given in the section "Meeting summaries and recommendations". Much useful information is also available in the various presentations made at the meeting, which are available at the site http://www-nds.iaea.org/nds-technical-meetings/TM%20Long-term%20Needs%202011/.

Participants summaries and recommendations

Medical and analytical applications

Report of recent IAEA-NDS meeting to discuss intermediate-term nuclear data needs in nuclear medicine, 22-26 August 2011

A.L. Nichols, University of Surrey, UK

Cyclotrons and accelerators are used in an increasing number of countries to produce radionuclides for both diagnostic and therapeutic purposes, along with reactors employed to produce specific activation and fission products for applications in nuclear medicine. Nuclear data needs were initially addressed by a Coordinated Research Project (CRP) on "Charged Particle Cross Section Database for Medical Radioisotope Production: Diagnostic Radioisotopes and Monitor Reactions" that concluded with the publication of IAEA-TECDOC-1211 (2001). Equivalent requirements for the production of therapeutic radionuclides were addressed through a further CRP on "Nuclear Data for the Production of Therapeutic Radionuclides" which was completed in 2007. Recommended data from both CRPs are available at: http://www-nds.iaea.org/medportal/

Following from the above studies, a consultants' meeting was held on "High-Precision Beta-Intensity Measurements and Evaluations for Specific PET Radioisotopes" from 3 to 5 September 2008 at IAEA Headquarters, Vienna, Austria. Participants assessed and reviewed the decay data for about 50 positron-emitting radionuclides, and recommended a series of measurements and evaluations. A further consultants' meeting was held on "Improvements in Charged-Particle Monitor Reactions and Nuclear Data for Medical Isotope Production" from 21 to 24 June 2011, at the same venue. Specific recommendations from both of these consultants' meetings were brought together in June 2011 to formulate and agree the scope, work programme and deliverables of a Coordinated Research Project (CRP) designed to focus on improvements in charged-particle monitor reactions and nuclear data for medical radionuclides (see IAEA report INDC(NDS)-0591, August 2011).

Nevertheless, continued developments in medical imaging and therapy utilizing novel diagnostic and therapeutic techniques call for further expansion of the available database over an intermediate timescale of between 5 to 10 years. Therefore, a Technical Meeting on "Intermediate-term Nuclear Data Needs for Medical Applications: Cross Sections and Decay Data" was held at IAEA Headquarters, Vienna, Austria, from 22 to 26 August 2011, in order to assess these requirements. Conclusions and recommendations from this pivotal meeting are given below (see also IAEA report INDC(NDS)-0596 for further detail).

1. Diagnostic γ-ray Emitters

^{99m}Tc: new data requirements have arisen as a consequence of recent efforts to produce this radionuclide by means of charged-particle accelerators rather than fission reactors. Various neutron-, proton-, deuteron-, photofission- and photoneutron-induced reactions need to be experimentally studied. Cross section studies are required, especially with respect to impurities.

^{97}Ru: Cross section measurements and evaluations required for ^{3}He and ^{4}He beams.

^{123}I: Auger emissions may become an issue in the future.

^{147}Gd: Cross section measurements and evaluations required for ^{3}He and ^{4}He beams.

2. Positron Emitters

^{57}Ni, ^{66}Ga, ^{72}As, ^{73}Se, ^{75}Br, ^{76}Br, ^{77}Kr, ^{81}Rb, ^{82m}Rb, ^{83}Sr, ^{89}Zr, ^{94m}Tc and ^{121}I: cross section and decay-data measurements and evaluations required.

^{44}Ti/^{44}Sc, ^{52}Fe/^{52m}Mn, ^{62}Zn/^{62}Cu, ^{72}Se/^{72}As and ^{140}Nd/^{140}Pr generators: cross section and decay-data measurements and evaluations required.

^{86}Y and ^{120g}I: cross section evaluations and decay-data measurements and evaluations required.

^{11}C, ^{13}N, ^{14,15}O, ^{30}P and ^{38}K: cross section measurements and evaluations need extending to a proton energy of 250 MeV.

^{95}Ru: cross section measurements and evaluations required for ^{3}He and ^{4}He beams.

^{34m}Cl, ^{43}Sc, ^{45}Ti, ^{48}V, ^{49}Cr, ^{51}Mn, ^{52}Mn, ^{68}Ga, ^{90}Nb and ^{152}Tb: cross section measurements and evaluations required.

^{68}Ge/^{68}Ga and ^{82}Sr/^{82}Rb generators: cross section measurements and evaluations required.

^{52}Fe, ^{55}Co, ^{61}Cu and ^{110m}In: cross section evaluations required.

3. Therapeutic β^-, X-ray and γ-ray Emitters

^{169}Er and ^{175}Yb: cross section and decay-data measurements and evaluations required.

^{47}Sc, ^{131}Cs, ^{131}Ba and ^{166}Ho: cross section measurements and evaluations required.

^{67}Cu, ^{103}Pd and ^{161}Tb: decay-data measurements and evaluations required.

^{191}Os/^{191m}Ir generator: cross section measurements and evaluations required.

^{191}Pt/^{191m}Ir generator: cross section measurements and evaluations required, along with decay-data measurements and evaluation of ^{191}Pt parent.

4. Therapeutic Auger-electron Emitters

^{125}I is the most commonly used Auger-electron emitter for internal radiotherapy – both reactor-production and decay data are well characterized.

Radionuclides identified as potentially suitable for application with respect to microdosimetry at the molecular and cellular levels would require much improved Auger-electron decay data:

^{71}Ge, ^{178}Ta, ^{193m}Pt, ^{195m}Pt and ^{197}Hg: cross section studies are also required.

^{67}Ga, ^{77}Br, ^{99m}Tc, ^{103}Pd, ^{111}In, ^{123}I and ^{140}Nd.

5. Therapeutic α Emitters

^{149}Tb: cross section measurements and evaluations of spallation and heavy-ion reactions required.

^{211}At/^{211}Po: well-established radionuclide combination for therapeutics.

^{225}Ac/^{213}Bi: cross section measurements and evaluation of spallation reaction on ^{232}Th required.

^{227}Ac/^{223}Ra: require cross section measurements and evaluation of ^{232}Th(p,x) reaction to produce ^{227}Ac.

^{230}U/^{226}Th: cross section and decay-data measurements and evaluations are required.

6. Proton and Heavy-Ion Beam Therapy

Improvements are required with respect to specific cross section data for proton beam therapy:

(1) non-elastic cross sections of the light elements (C, N and O) at proton energies up to 250 MeV; and

(2) activation cross sections for production of residual nuclei, particularly the positron-emitters ^{11}C, ^{13}N, ^{15}O, ^{30}P and ^{38}K.

Owing to the complexity of the fragmentation reactions that occur in a carbon beam, data sets that describe these reactions well are extremely difficult to prepare. The best course of action would be the development of more precise models and validated parameter sets to describe the fragmentation processes and the production of light particles and residues. The derivation of better models and validated parameters would also be the ideal approach for proton beam therapy, in order to undertake more precise Monte-Carlo transport calculations of the effects on dose deposition of variations in morphology or in structure arising from bone or implants.

7. Long term perspectives

With regard to longer-term perspectives, the adoption of metallic-based positron emitters can be envisaged to occur as a consequence of developments in organometallic-complex chemistry (Ti, Ga and Cu radionuclides), while the introduction of microdosimetry techniques may require much improved characterisation of suitable low-energy Auger-electron emitters to support the efficacy of this form of therapeutic treatment.

Nuclear data for accelerator technology and accelerator applications: Request for an extended, more user-friendly evaluated proton and deuteron activation data file

F. Tarkanyi, ATOMKI, Debrecen

New experimental results (about one thousand proton and deuteron induced reactions on around 50 target elements) and the predictive capability of theoretical codes and activation data files were presented illustrating the status of the activation database. Charged particle accelerators contribute substantially to nuclear applications first of all in the field of non energy-related but also in energy-related applications. One part of the applications utilizes the accelerated beam directly. Some of the applications are based on the accelerator produced secondary beam and/or activation products.

At present and in the future protons and deuterons remain the most important accelerated particles in the energy range up to 200-300 MeV for protons and 100 MeV for deuterons. They are used in a broad range of applications: medical isotope production, thin layer activation, production of tracer radioisotopes for industrial and biological processes, nuclear analytics, accelerator based neutron production target technology, accelerator shielding, safeguards, etc. They are very important for development of basic knowledge in the field of nuclear reaction theory, astrophysics, etc.

The present status of the activation database for proton and deuteron induced reactions is not satisfactory:

- The quality and the completeness of the experimental database are far from the requirements.
- The predictive capability of a-priori theoretical calculations is poor.

- The adjusted model results in the activation data libraries are also far from the requirements.

- The format of the available activation data libraries are very specific and not very user-friendly. Due to its simplicity the original EXFOR database is used in most cases by researchers.

- Dedicated databases contain only the main reactions without the side reactions that can also be very important in most of the applications.

Considering the importance of the activation data in the established applications and the importance in all candidate applications a more reliable and more complete evaluated charged-particle activation data library is required.

- It should contain activation data of proton and deuteron induced reactions for the full range of candidate targets and materials used in accelerator and target technology.

- New cross section measurements should be made to fill the energy gaps and the missing target elements.

- For different applications, data measurement, and the evolution of experimental data of the basic decay data of reaction products are very important.

- Experimental data published earlier and missing from EXFOR should be compiled as soon as possible.

- In case of disagreements between the theoretical and the experimental data the model results should be normalized to selected experimental data (especially for the widely used TALYS code).

- Taking into account that the activation database in most cases is used by non-data-centre-professionals the activation database should have a more user-friendly version too, parallel with the present one.

Nuclear Data for Ion Beam Analysis

A.F. Gurbich, IPPE, Russian Federation

Ion beam analysis (IBA) is an important family of modern analytical techniques involving the use of MeV ion beams to probe the composition and obtain elemental depth profiles in the near-surface layer of solids. IBA is an area of active research all over the world. The IAEA Physics Section database (http://www-naweb.iaea.org/napc/physics/accelerators/database/datasets/foreword_home.html) contains details of 163 low-energy electrostatic accelerators distributed over 50 Member States. Most of them are used for IBA. All IBA methods are highly sensitive and allow the detection of elements in the sub-monolayer range. The depth resolution is typically in the range of a few nanometers to a few tens of nanometers. The analyzed depth ranges from a few tens of nanometers to a few tens of micrometers. IBA methods are always quantitative with an accuracy of a few percent. The field of IBA application is very wide ranging from the semiconductor industry to cultural heritage studies.

Ion beam analysis methods strongly rely on the available experimental cross section data. These data are needed for planning an experiment and for computer simulation of measured spectra used to derive depth profiles of the elements constituting surface layers of a sample. The required uncertainty for the cross sections should be less than 5%.

IBA uses differential cross sections rather than angle-integrated cross sections and thus data for different angles are needed. Although an officially accepted list of required nuclear data for IBA does not exists it is a safe assumption that such a list should comprise first of all (though not only) the differential cross sections for proton non-Rutherford elastic scattering and nuclear reactions for p, d, and ^{3}He projectiles with energies below 5.0 MeV and for ^{4}He non-Rutherford elastic scattering in the energy range up to about 15 MeV. IBA employs data mainly for elements of natural abundance rather than for separated isotopes and so data acquired previously in nuclear physics studies are often not sufficient.

From the beginning IAEA interests in the field of nuclear data were concentrated on neutron data and it was not until 2000, when an Advisory Group Meeting on Long Term Needs for Nuclear Data was held, that the cross sections for IBA were included in the scope of the IAEA activities. A dramatic improvement has been achieved since then. The most important results were obtained in the course of the implementation of the CRP "Development of a Reference Database for Ion Beam Analysis" (2005 – 2009). The experimental data measured in the framework of the CRP as well as the relevant experimental data found in the literature were incorporated into the Ion Beam Analysis Nuclear Data Library (IBANDL) located at www-nds.iaea.org/ibandl/. All the IBANDL data are in the R33 format developed for communication of reaction cross sections in the IBA community. Every possible effort was made to harmonize IBANDL with EXFOR preserving the advantages of the user friendly IBANDL interface and the simplicity of the R33 format.

In order to elaborate recommended cross sections a standard procedure of evaluation was employed. The evaluated data are provided through the SigmaCalc cross section calculator at www-nds.iaea.org/sigmacalc/ and are integrated into IBANDL. The IBANDL and SigmaCalc resources have become parts of the nuclear data services provided by the IAEA. A new CRP "Development of a Reference Database for Particle-Induced Gamma-ray Emission (PIGE) Spectroscopy" started in 2011 with the aim of providing the data specifically needed for PIGE.

Although significant progress was achieved in the field during the last decade further development is still needed to meet the requirements of the IBA community in nuclear data. The main directions of development are outlined below.

A random search in the literature for IBA relevant cross sections showed that many of the previously acquired results are still missing in IBANDL (and EXFOR). Since it has never been done, a systematic search in the literature is recommended.

Although many of the most needed cross sections were evaluated there is still a need to continue the work. The evaluation of the following cross sections is of primary importance: proton and alpha elastic scattering from ^{6}Li, ^{7}Li, ^{9}Be, ^{10}B, ^{11}B; alpha elastic scattering from ^{19}F, ^{28}Si and natural Si; deuteron induced reactions on ^{9}Be, ^{10}B, ^{11}B; and (p,α)-reactions on ^{15}N, ^{18}O and ^{19}F. As the evaluation of the IBA cross sections is currently made by only one person, attempts to find additional manpower should be made.

The results of the cross section evaluation are potentially useful not only for IBA but also for other applications. Whereas the procedure for incorporation of the evaluated cross sections into the ENDF data base has been developed, so far only a few of the evaluated files for IBA were included in ENDF. It is recommended to upload all the SigmaCalc evaluated cross sections into standard ENDF format.

By a ‘benchmark’ in IBA is understood an integral experiment which consists of a measurement of a charged-particle spectrum from a well characterized uniform thick target followed by a standard direct simulation using microscopic cross section data in order to validate the data. Benchmarking is especially important in cases when theory cannot be applied for the accurate evaluation of the cross section (e.g. in the case of Ericson fluctuations). Only a few cross sections have been benchmarked so far. In principle benchmarking should be performed for all the cross sections for which manufacturing of appropriate targets is feasible. The organization of such work is highly recommended.

Accelerator Technology and Applications

A.J. Kreiner, CNEA, ECyT-UNSAM, CONICET

Nuclear and related data needs for Argentina in different areas

- Boron Neutron Capture Therapy (BNCT) based on Accelerators. Proton and deuteron induced neutron producing light target reactions. Data relevant for estimates of damage to neutron production targets.

- Hadrontherapy and associated Radiobiology (BNCT, Proton and Carbon therapy): damage on soft matter.

- Accelerator development for medical and nuclear applications: 1) Facility for BNCT: 2.5 MeV, 30 mA (75 kW), 2) 200 keV deuteron accelerator for neutron production: T(d,n). Integrity of targets.

- Applications to environmental problems, analytical techniques (HI-PIXE, PIGE,..).

- Argentine Space Program: satellite components, radiation hardness, SEE due to cosmic radiation, 70-500 MeV proton interactions on junctions (nuclear reactions on Si).

- Ion Beam Analysis (IBA) and modification for materials science: HI-RBS, ERDA.

- Microbeam (microanalysis-micromachining).

Why Accelerator Based (AB)-BNCT?

- The advancement of BNCT requires neutron sources suitable for installation in hospital environments. The presence of these devices in specialized cancer centers may be decisive for the future of BNCT: Hospital siting.

- Accelerators offer a number of major advantages over reactor-based sources for clinical applications: The neutron energy spectrum from certain nuclear reactions is much softer than the one coming from fission, which makes it easier to generate the “ideal” epithermal neutron spectrum (needed to treat a deep seated tumor), and hence the quality of the neutron field can be designed to exceed the quality of the neutron field for reactor-based neutron sources: Better quality beams.

Need for cross section and radiation damage data by intense beams (30 mA)

- Lack of recent high-precision (double differential) cross section data for neutron producing reactions: ^{7}Li(p,n), ^{9}Be(p,n), ^{9}Be(d,n), and ^{13}C(d,n).

- Radiation damage in Li, Be and C targets and backing materials (Fe, Zr,..).

- H damage in target and backing materials (blistering).
- High power density: about 1 kW/cm^2 (75 kW on 5 cm radius area).

Recommendations

- Promote/encourage the production of high quality and complete cross section data on low energy (0.1-3 MeV) proton and deuteron induced neutron producing reactions (for intense neutron sources), both for medical (Boron Neutron Capture Therapy, BNCT) and nuclear applications (radiation damage, ADS/injection into subcritical cores).
- Help systematise data for radiobiology, radiotherapy, analytical (IBA) and materials science applications (materials modification, micromachining, radiation damage both induced by charged particle beams and neutrons, radiation hardness, etc).

Energy production

Fission - Current Systems

K. Kozier, AECL

Recommendations to IAEA-NDS:

1. **Encourage Convergence of Evaluated Nuclear Data Libraries**

A trend of regional/national evaluated nuclear data libraries converging toward a single, standard global system is noted – a recent example being ROSFOND, which mainly evaluates and borrows the best segments of other data libraries. This convergence reflects improved communications and greater collaboration between the agencies responsible for nuclear data evaluation, ever-growing computational capabilities and a growing need for enhanced efficiency, due to both budget and resource constraints and to widespread loss of expertise though attrition, with the possible exception of emerging economies, such as China. It is likely that considerable savings could be obtained in the areas of code validation, quality assurance and associated documentation through the adoption of a single global nuclear data library, from which end-users would prepare their own application-specific libraries, as required. Thus, the nuclear power industry would likely benefit significantly from the global adoption of a single evaluated nuclear data library system. Such an outcome might also serve as a model eventually leading to similar harmonization of nuclear safety regulations and standards. Moreover, national nuclear regulators are also nuclear data consumers (sometimes lacking adequate expertise in nuclear data matters) and would also benefit from the adoption of a single authorized data source. The nuclear power industry, therefore, recommends that NDS obtains the resources and takes the steps necessary to accelerate this convergence. It is desirable for NDS to serve as the virtual hub for controlled access to this centralized data library, portions of which would physically reside and be maintained elsewhere around the globe.

2. **Support Emergence of the TALYS/TENDL System as a New Standard**

The TALYS/TENDL system has rapidly evolved to be a likely candidate to form the basis for a single, global evaluated nuclear data library system. In particular, it embodies methodologies to readily propagate physics-measurement-based nuclear-data uncertainties to output parameters in application calculations and, thus, would well serve the needs of end-users who are applying probabilistic methods, such as BEAU (Best Estimate and Analysis of Uncertainty), to reactor safety analysis and licensing assessments. And, it seems to incorporate methods that might be used to determine specific areas whereby new measurements would lead to substantial reductions of uncertainty; this would be a very useful tool for justifying specific new data measurements. In the event that TALYS/TENDL continues to emerge as an unchallenged global contender, it is recommended that NDS provide moral and other support – for example, through CMs and TMs and provision of training forums for new users of the TALYS/TENDL systems. A specific area for future consideration is the adoption of a standard data interface (similar to the SALOME interface in the NEA's NURESIM project) that would allow TALYS/TENDL to serve as a backbone framework into which user application modules could be plugged and which could facilitate communication and coupling with the tools of other disciplines, such as thermalhydraulics.

3. **Facilitate the Adoption of a New Modern Nuclear Data File Format**

The need to replace the archaic, but very successful, ENDF data file format with a modern and humane (i.e., humanly readable) system was very well stated at the meeting and acknowledged by most, if not all, participants. In particular, a linked system, in which portions of a file might reside on different servers, in a modern file format, such as XML, was envisioned. Such an arrangement would partly address the looming need for massive amounts of data storage to treat nuclear data covariances appropriately. It is strongly recommended that the NDS do what it can to facilitate the creation and adoption of a new and universal nuclear data file format through CMs and TMs as needed. The NDS might also ensure that appropriate translation software exists between the new and existing formats and test the efficacy of such translators on the data residing in the NDS's archives.

4. Foster Future Nuclear Data Evaluators and Practitioners

It is recognized that the international nuclear data community is male-dominated (i.e., gender biased) and rapidly aging, especially in developed economies that are increasingly subject to budget constraints. It is recommended that the NDS do what it can to revitalize the international nuclear data community, by encouraging young and, especially, female persons to consider careers in this noble profession. For example, NDS could communicate with existing organizations such as WIN (Women In Nuclear) and YGN (Young Generation Nuclear), host introductory-level training courses and post nuclear data related job advertisements on its website. It could consider starting a quarterly web-based nuclear data newsletter, along the lines of RSICC's (Radiation Safety Information Computational Center) monthly newsletter, with regular feature articles on nuclear data matters in a given topical area (e.g. radiation therapy, astrophysics, GEN-IV reactors, etc.) solicited from global experts, as well as lists of (and links to) new journal articles of potential interest. There should be links on the NDS website to appropriate educational material about nuclear data matters for teachers and students at all levels (perhaps in collaboration with UNESCO); one lesson from Fukushima is the need for an informed public with open access to credible information sources. The NDS could take a leading role in establishing an International Nuclear Data Society or Nuclear Data divisions within existing technical societies (e.g., ANS, ENS). The IAEA-NDS might also consider establishing international awards to recognize and promote the contributions of promising young data achievers or to honour specific outstanding or lifetime achievements of key individuals. In the absence of an international nuclear data society, award selections could be made by a vote of an awards subcommittee reporting to the international advisory committee for the ND series of conferences and presentations made in conjunction with these events. I am confident that nuclear utilities would be willing to contribute financially to the establishment of such awards, especially if we demonstrate what an uncertainty reduction of say 100 pcm or a 0.1% improvement in the calculated power distribution could mean to their bottom lines.

5. Facilitate the Resolution of Nuclear Data Inconsistencies

Examples exist (e.g. ^{16}O) where the thermal-neutron cross section data used in various evaluated nuclear data libraries are not consistent with the values listed in the Atlas of Neutron Resonances; precise measurements on simple compounds (e.g. SiO_2); precise, modern neutron-scattering-length measurements (e.g. ^{16}O); or nuclear-theory calculations (e.g. ^{2}H). In addition, the treatment of angular neutron-elastic-scattering probability distributions is sometimes inadequate (e.g. ^{2}H, ^{56}Fe). Also, concern has been expressed by several Member States about the reliability of the Thermal Scattering Law (TSL; $S(\alpha,\beta)$) data and the loss of key expertise through attrition to support them. It is suggested that the NDS apply its resources, where appropriate and when circumstances permit, to facilitate the resolution of noted data inconsistencies, for example, by convening a CM or TM of interested parties focused on issues and data needs concerning the TSL data.

Perceived problems, challenges and needs in the area: Long term needs of nuclear data of innovative materials for fission energy systems

S. Ganesan, ex-BARC, India

Improved nuclear data are essential to support new initiatives such as the international project on innovative nuclear reactors and fuel cycles (e.g. INPRO of the IAEA) that aim to support the safe, sustainable, economic and proliferation-resistant use of nuclear technology to meet the global energy needs (7 billion population now and growing) of the 21st century. The detailed pursuit of development of Generation IV nuclear energy systems that offer advantages in the areas of economics, safety, reliability and sustainability require significantly improved nuclear data. Design and safe operation of long burnup innovative reactor systems also need improved data and covariances for a larger number of fission products and minor actinides.

Several topics were discussed with interesting examples based upon actual Indian experience. The IAEA-NDS may consider evolving and/or encouraging suitable mechanisms to address issues such as the following:

- The use and influence of recent nuclear data in updating design manuals of reactors in operation, under construction and in the design stage is of relevance to the entire fuel cycle.
- The IAEA-NDS needs to continue to provide guidance and support to Indian EXFOR compilation activities as it has done in the past Indian EXFOR Workshops and follow-ups.
- Use the role model of the FENDL project for thermal and fast innovative nuclear reactors. The ambitious proposal of a reactor physics interface for advanced INPRO/GENIV nuclear power systems modelled on the FENDL project. There is a strong need to address issues of QA in processing.
- Status of quality of thermal scattering law data $S(\alpha,\beta)$, (for materials such as Be in BeO, H in H_2O, D in D_2O and other bound systems); use, applications and assessment of temperature dependence up to the required high temperatures.
- Guidance on nuclear data preparation for radiotoxicity estimations in operating plants.
- Guidance on development of sensitivity tools, validation and their use for nuclear data sensitivity studies for reactor parameters and systems applications.
- Training courses on nuclear data evaluation techniques, processing of ENDF files and intercomparisons. Nuclear data for Monte Carlo applications. Conducting more training courses for Member States on nuclear data topics and interfacing to applications. NDPCI, India offers to host and conduct such courses/workshops.
- Support topics on interesting nuclear physics approaches by way of IAEA-NDS mechanisms to obtain nuclear data for unstable targets using surrogate nuclear reactions.
- Thorium fuel cycle related nuclear data could be improved by having a fresh look at aspects such as decay heat, fission product yield data of isotopes of thorium fuel cycle and higher actinides to benefit innovative reactor developments.

Fission - Innovative Systems

M. Ishikawa, JAEA, Japan

The nuclear data needs of the fission energy application in the future were presented from the user's viewpoint. The fields considered were fast reactors (INPRO, Gen-IV, FaCT), accelerator driven systems (ADS), and next-generation light water reactors (NG-LWR). In fission applications, nuclear data already have an established place in the industry, having moved well beyond the status of an art into nuclear science. This fact implies strong requirements for both the quality and the quantity of nuclear data, leading, in particular, to the need for important aspects such as covariances, and the verification and validation (V&V) system. Typical areas to be improved in fission applications would be: minor actinides, fission products, thermal scattering, and so on.

1) Needs from Fast Reactor

First, the accuracy for *major* isotopes should be further improved from both experimental and theoretical viewpoints to meet the strict requirements of the core design. The important isotopes are: ^{238}U, ^{239,240,241}Pu, ^{241}Am, Na, Fe, Cr, Ni, etc. The data needed for the core design work include the fission neutron spectrum χ, the prompt neutron multiplicity ν_p, inelastic scattering cross sections and their energy transfer matrix, the mean cosine for elastic scattering μ, and the delayed neutron fraction β, besides the standard cross sections. Second, the quantitative reliability of covariances for *major* isotopes is indispensible to allow uncertainty evaluation in the design work, even though the methodology to evaluate covariances has been developed rapidly recently in many countries. And finally, the accuracy and number of evaluated fission products need to be increased, since the core design work needs to treat more than 20 atom% burnup rate, and approximately 1,600 isotopes are needed for detailed burnup chain estimates (e.g. with the ORIGEN code).

2) Needs from ADS

The accuracy for *minor* actinides, and other materials which are specific to ADS must be improved for a realistic design, since there are still very large differences among various libraries. The important isotopes here are: Np, ^{238}Pu, Am, Cm, Pb, Bi, Zr, ^{15}N, etc. Further, spallation and higher energy data are needed in addition to the same reactions that are also needed for fast reactors (for energies of interest to fast reactors). The quantitative reliability of covariances for *minor* actinides is essential for the progress of the ADS study, since a sensitivity and uncertainty analysis might be the only possibility to assure the core design margin, since no mockup experiments for ADS yet exist.

3) Needs from NG-LWR

The quality assurance system of nuclear data measurement and evaluation should be established, as a part of the V&V policy which is now required from the licensing authority, to sustain the accountability, reproducibility, traceability, and transparency of the plant design. As a special requirement for the LWRs, the thermal scattering law, $S(\alpha,\beta)$ data need to be improved, although this field seems quite difficult because of its interdisciplinary nature, mixing nuclear with material science.

Fusion for Energy – Nuclear Data for Fusion: Goals and Development Needs

U. Fischer, KIT, Germany

The long-term data needs for fusion are driven by the requirements of the international programmes for the development of fusion as a source for electricity production. There are different views of the facilities required to construct and operate a commercial fusion power plant. The major facilities on this development path include, however, the next step device ITER, which is currently under construction as an international project, a fusion material irradiation facility like IFMIF, which is required to develop and qualify materials for high fluence irradiations, and, subsequently, a demonstration power plant (DEMO) proving the feasibility of utilizing the fusion process for the production of electricity. As a consequence, the nuclear data development programme has to focus on the needs of ITER, IFMIF and DEMO.

Recommendations

FENDL nuclear data libraries

The FENDL development efforts need to be continued beyond the end of the FENDL-3 CRP, first of all, to validate the data for fusion reactor and IFMIF applications, secondly to improve and update the data evaluations according to the latest standards, and, eventually to extend the libraries for additional materials/isotopes as required by the fusion programmes. There may also be a need to included actinides to enable analyses of fusion/fission hybrid systems in the future. The sub-libraries for d (and p) induced reactions, which so far are based on automated ("blind") TALYS calculations should also be further developed to improve their quality. There the focus should be on the high priority materials required for IFMIF applications.

Covariance data

All FENDL evaluations should be complemented by covariance data as is now common practice for advanced nuclear data evaluations. The covariance date should account for both model/calculational and experimental uncertainties. (Note - there is already available a calculated "FENDL shadow library" containing TALYS calculated covariance data)

Radiation Damage Data

Radiation damage data are of high importance for evaluating the radiation behaviour of materials at the high fluence levels that are envisaged for DEMO and IFMIF. An advanced simulation approach with better physics modelling, as compared to the standard NRT approximation, is required to predict the radiation induced displacement damage more realistically. Using such an approach, displacement damage cross section data can be evaluated and assembled in special data libraries. Displacement damage data should be made available for neutron and proton induced reactions up to 3 GeV so they can be used for fission and fusion reactors, IFMIF and spallation source applications. This is of high importance to the international fusion programme since all of these facilities are considered (or even are already used) for fusion material irradiations.

Gas production data – H, He

Gas production is another important issue affecting the material properties under high fluence neutron irradiations. The prediction capability of the state-of-the-art nuclear models and codes is in general not sufficient to provide reliable assessments of the gas production and the related charged particle spectra as compared to experimental data. In particular this applies to the IFMIF relevant energy range above 20 MeV incident neutron energy. It is therefore recommended to dedicate some effort to the improvement of the nuclear models describing the emission of charged particles in the nuclear model codes and thus to provide better gas production cross section data for inclusion in the general purpose data libraries such as FENDL.

Complete "all-purpose" Data Libraries

TENDL-like "all-purpose" nuclear data libraries including all relevant data (i.e. secondary energy-angle distributions, photon production and interaction data, covariance data, activation/transmutation cross sections, etc.), all materials/isotopes and covering the full energy range up to about 200 MeV for different applications areas are recommended to be developed in the long-term. Such libraries (particularly for neutron, proton and deuteron induced reactions) can form the basis for the different application purposes (particle transport simulations for e.g. design analyses, nuclide inventory calculations for safety and radwaste related studies, uncertainty assessments, etc.) and then these need to be continuously improved to ensure the highest quality standards.

High energy applications

Y.O. Lee, KAERI, South Korea

From the point of view of high energy applications I would like to make the following recommendations:

- Neutron cross sections from the keV range up to 50 MeV are measured by dedicated mono-energetic fast neutron sources. For the design optimization of fast neutron sources, data files and models of proton and deuteron cross sections and their DDXs on Li and Be isotopes need to be improved utilizing recent experiments and new physics models for E_p <100 MeV and E_d<50 MeV.
- For the engineering stage of accelerator driven systems (ADS), continue the current efforts of the nuclear data community, and in parallel:
  - prepare a recommended stand-alone evaluated library for $E_{n,p}$ < 2 GeV based on up-to-date physics models and available evaluated files,
  - identify target accuracies through sensitivity and uncertainty analyses using the recommended library.
- Inaccurate nuclear data can give rise to engineering margins of a factor 2 to 3 in high energy accelerator shielding design. Improving nuclear data of neutron inelastic scattering as well as activation cross sections for component, structural and shielding materials, such as Na, Al, Mn, Fe, Co, Ni, Cu, Zn for energies up to a few hundreds of MeV, is essential for the reduction of too conservative design margins, which in return would give a huge cost benefit.
- Radiation effects on micro-electronics (soft errors, damage) by cosmic-ray neutrons need to be predicted in a reliable way. Therefore, more reliable nuclear reaction models which can predict neutron-induced light-ion production from silicon in the incident energy range from MeV to GeV are strongly required.

Libraries

Processing Needs

A. Trkov, JSI, Slovenia

Concerning processing needs the following recommendations can be made:

- Encourage and support spectrum-averaged cross section measurements for data validation. For example, measurements of constants for neutron activation analysis (thermal capture and resonance integrals), astrophysics cross sections (MACS, e.g. corresponding to a 30 keV Maxwellian spectrum), ^{252}Cf spontaneous fission spectrum averaged cross sections, etc. The latter could help to resolve many issues related to uncertainties in the capture cross section in the energy region between 100 keV and a few MeV.

- Continue to develop and improve web based and off-line data visualisation tools, striving for generality as well as user-friendliness.

- Continue to support developments for the generation of covariance data of experimental measurements as well as evaluated nuclear data.

- Regarding the issue of independent processing codes, the generally available PREPRO series is highly esteemed and truly valuable, but it lacks, by design the following:

    - a module to generate scattering matrices,
    - a module to generate temperature dependent self-shielded cross sections in the unresolved resonance region,
    - processing of fission neutron multiplicity,
    - treatment of covariances.

- Perhaps Red Cullen might be willing to undertake this work. The details of additional modules to be developed include also treatment of covariances. All these modules should be clearly identified. Enhancement of theprocessing of covariance matrices could be sought by acquiring and making generally available a code that is already developed (e.g. drawing from the experience in Japan).

Experimental data and EXFOR

A. Plompen, EC-JRC-IRMM, European Commission

Nuclear data needs are first of all determined by the applications in which they are used. In the field of nuclear fission energy recent developments have led to re-emphasize nuclear safety and security, including the issue of nuclear waste, and to downplay the importance of energy-sustainability and economic viability of the various options in nuclear energy. In practice, this requires a shift in attention: more emphasis on data needs related to light-water reactors, both currently operating and under construction, continuing emphasis on data related to minimization of high level nuclear waste, and reduced emphasis on innovative options for nuclear energy sustainability such as fast reactors.

The increased emphasis on safety of nuclear systems places high demands on the predictability of their performance and the quality of their safety assessments. Verification and validation schemes for safety assessments and design methods require nuclear data that allow establishment of the margins associated with estimates of diverse quantities such as reactivity and reactivity coefficients, shielding, inventory build-up, and radiation dose. Sensitivity and uncertainty analyses for key nuclear systems parameters point at strict requirements for uncertainties on important nuclear data. In particular, these help prioritize nuclear data development by isotope, reaction and energy range; a key asset in a time where resources for research in the nuclear field are under strain, while the demands for reliability and accuracy are higher than ever.

At IRMM efforts are directed towards improving harmonisation in Europe, a drive that derives from the Europe 2020 initiative to improve economic growth among EU member states. For nuclear data, harmonisation translates to improving the nuclear data libraries used by industry and regulators for their safety and performance analyses. A natural consequence would be to strive for one nuclear data library that is the world's best evaluated and validated library. A recent step in this direction is the adoption of the JEFF-3.1.1 library by certain industrial partners in Europe, but much remains to be done before a unified generally accepted approach is applied throughout the field.

The experimental programme at IRMM in the field of nuclear fission energy (EURATOM activities) and in support of harmonisation in nuclear data concerns neutron-induced nuclear reaction data and radionuclide decay data. Our measurements are prioritized on the basis of needs established through collaborations organised by the OECD Nuclear Energy Agency (the JEFF project, WPEC and the High Priority Request List - HPRL), the International Atomic Energy Agency (e.g. through Coordinated Research Projects), the European Commission's Directorate-General for Research, or by bilateral collaboration agreements.

Our measurements are based on the white neutron time-of-flight facility GELINA, the quasi mono-energetic neutron sources of the van de Graaff laboratory and the radionuclides metrology laboratory. Measurement activities include neutron-induced fission (fission fragment yields, fission neutron spectrum, fission neutron multiplicity, prompt fission gamma-rays, ternary fission), total and capture cross sections by time-of-flight, neutron elastic and inelastic scattering, neutron-induced activation reactions, and neutron-induced light charged particle production. Collaborations at the international level are important to ensure the proper availability of the deliverables of our measurement programme to support improved evaluations on a timely basis, to develop new measurement competences and to contribute to new initiatives from stakeholders and partners in member states and outside the twenty-seven states of the EU.

Concerning the future in nuclear data measurements in general it is important to develop a systematic approach in support of improving the reliability of predictions for systems in nuclear energy (fission, fusion, safety and security). This requires incorporating nuclear data measurements in the developments towards quality assured, verified and validated nuclear data libraries. Prioritization of measurements needs will be key in view of available resources and training and education to support competence in nuclear data measurements will be of utmost importance given the strong requirements for reliable and small uncertainties.

For expressing uncertainties in measurements there are clear guidelines issued by the International Committee for Weights and Measures (CIPM, The guide for the expression of uncertainty in measurements, Sèvres, France). These guidelines are general and harmonised and help improve uncertainty estimates in nuclear data measurements. Besides emphasising methodology an improved effort in reporting is stressed. This level of reporting is not easily accepted by scientific journals, although a few exceptions exist and a special issue of the Nuclear Data Sheets on uncertainty in nuclear data measurements is in preparation. Here lies an important role for EXFOR in reporting with the numerical data sets that constitute the final result, the essential quantities that are of relevance for a meaningful re-evaluation of the experimental results in a future evaluation exercise.

At IRMM considerable progress was made in understanding the level of detail required for time-of-flight measurements when it comes to re-evaluation of the data in the resolved and unresolved resonance range. A template was proposed for reporting time-of-flight data in EXFOR and in collaboration with the Section this template was adopted by the network of Nuclear Reaction Data Centres. The template incorporates a compact format for storing the covariance matrix for such data. This method of storage is facilitated by the use of the AGS (Analysis of Geel Spectra) code system.

Recommendations to the Nuclear Data Section:

1. **Stimulate new experiments**
    a. Advertise the nuclear data challenges (HPRL, conferences, workshops, meetings)
    b. Support studies for relevance of new experiments
    c. Stimulate research for new measurements techniques
    d. Include experimental programmes in your projects as much as possible/practical
2. **Support improved quality of reporting of experiments**
    a. Uncertainties and correlations
    b. Higher benefit for evaluations
    c. Improve quality of EXFOR entries
    d. Improve education (reporting, uncertainties in measurements)
    e. Secure long term professional support for EXFOR compilation
3. **Ensure a position in standardisation of safety and security assessments for nuclear energy**
    a. Output of data development projects: Strive for high quality libraries that merit adoption by regional and world wide library projects in terms of reliability and accuracy.
    b. Support the drive for a world-best verified and validated nuclear data library.
    c. Support modernisation of software (data storage, interfaces, visualisation) to facilitate and improve the use of data libraries both for automated use and for access by individual users.
    d. Educate users of data so that they know the benefits of modern libraries and tools.

Some thoughts on EXFOR

A.L. Nichols, University of Surrey, UK

A strong argument can be made that the most important project within the sub-programme of work undertaken by the IAEA Nuclear Data Section is the work identified with “Data Services, Networks and User Support”. Without the continuous and rigorous pursuit of improvements in database-user communications by means of this project, the effectiveness and value of all data development within the Section would be seriously jeopardized. These particular user-support activities and the sponsorship of the two international nuclear data networks are key to the effectiveness and worth of the Nuclear Data Section.

The Section’s responsibility for the EXFOR database through the establishment and organisation of the work load of the international network of Nuclear Reaction Data Centres is particularly noteworthy. As custodian of the EXFOR master file, the Section must ensure the continued development of suitable database software to attract and assist users, and also ensure that the manual and associated dictionaries are properly maintained. Furthermore, new data must be entered as rapidly as possible (and within no more than 6 to 12 months of detection), and existing errors pursued and corrected within less than 6 months. Any missing neutron and charged-particle cross section data sets also need to be compiled with urgency to achieve the desired "completeness" as a function of time through rigorous systematic scanning and the development of more rapid modes of insertion.

Agreement was reached that there was no obvious long-term need to expand the existing data types, nor extend their ranges within EXFOR (e.g. projectile energies up to 1 GeV, and incident projectiles up to A = 12). The development and introduction of user-friendly output formats must continue, along with further rigorous efforts to detect errors that would reach far beyond the recently useful exercise initiated by WPEC Subgroup-30. Finally, much question-and-answer correspondence exists at the present time in the form of the exchange of letters and PDF files between EXFOR compilers and the authors of cross section publications. All of this material needs to be electronically documented within EXFOR to ensure the provision of readily accessible answers to future users' questions.

General purpose files: Moving to an international ENDF file

M.B. Chadwick, LANL, USA

The following recommendations concern the development of an international file for evaluated nuclear data:

1. The representatives from the various evaluation projects (JEFF, JENDL, BROND, CENDL, KAERI) should consult their project participants and their sponsors on the merits of a collaborative effort to develop a new international evaluated ENDF-format library.
2. Arguments supporting such a transition include:
    a. Improved quality. Increased peer review through bringing together teams of experts around the world to oversee advances, and use best features of current evaluations,
    b. minimize errors. Increased peer review will help mitigate the (many) cases where we have decreasing expertise in each country, and minimize the risk of poor evaluation decisions being made,
    c. pool our resources: especially where we are seeing some retirements and loss of critical expertise, and share talent to continue developing the best files. Also, this collaborative effort could be a stimulating project for young staff for nurturing new expertise in the field,
    d. the various present files already have much overlap, and are converging. (e.g. standards; resonance evaluations; fission products; photonuclear),
    e. we have a previous example from which experiences can be drawn - ENSDF - which has been developed internationally.
3. The IAEA and NEA should discuss the merits of this proposal, including input from the INDC. This could lead to tasking a group of people to meet and work on a proposal of how to proceed, addressing the following questions:
    a. what might a starting best international library look like?
    b. do different national projects take lead responsibilities for different nuclides?
    c. how to use new optimization capabilities being developed (e.g. Total Monte Carlo; bayesian methods) to search for best values matching fundamental and integral data?
    d. how to build in continual validation (e.g. MCNP simulations tested against ICSBEP k-eff) to track progress?

e. how to build on TALYS/TENDL advances?
f. identify some key priority areas to first advance, e.g.
    A) remove compensating errors present in $^{235,238}U$ and ^{239}Pu in existing evaluations
    B) advance C, O, Na, D, Fe evaluations.

Special purpose files, Some Examples of Verification of Nuclear Data in Reactor Physics Calculations

G. Manturov, IPPE, Russian Federation

The recommendations are:

1. Integral measurements of fission reaction rate distributions in zero-power fast reactor facilities (BFS, ZPR, MASURCA) showed the existence of large discrepancies in nuclear data for the structural materials Fe, Cr, Ni. They contradict the differential measurements (so, for example, existing evaluations on chromium data do not explain the observed discrepancy). This situation should be studied and resolved.
2. Integral reactor-physics measurements in zero-power fast reactor facilities and operated reactors are very important and should be widely applied for verification and validation of the existing and new evaluations.
3. I agree with the proposal to translate the ROSFOND documentation to English. It could be very valuable for all.

Basic Science

Astrophysics recommendations

Stephane Goriely, ULB, Belgium

Nuclear astrophysics is the branch of astrophysics which helps understanding the Universe through the knowledge of the microcosm of the atomic nucleus. In the last decades, many advances have been made in nuclear astrophysics thanks to an important effort made in the modelling of the structure and evolution of the stars, in the quality and diversity of the astronomical observations, but also through the significant investment made in our theoretical and experimental understanding of the nucleus. Astrophysics has been, and still is, highly demanding to nuclear physics in both its experimental and theoretical components.

Due to the specific conditions found in astrophysics environments, experiments in nuclear astrophysics have to account for energies far below the Coulomb barrier as well as for a large variety of unstable targets. For this reason, advanced and innovative experimental techniques are being developed and large experimental facilities are being built around the world to determine the structure and interaction properties of stable as well as exotic nuclei. Nuclear astrophysics remains one of their major scientific motivations. With these growing experimental activities, the availability of compilations providing easy access to evaluated and well documented nuclear data is an essential tool for astrophysics modelling. For these reasons, nuclear astrophysicists have built their own specific tools to meet the needs. The existing scattered activities of collection, evaluation and dissemination of experimental data could however be expanded and better coordinated, especially in view of similar efforts being devoted by other nuclear physics communities.

Despite important efforts in the last decades, experimental data only cover a minute fraction of the whole set of data required for nuclear astrophysics applications. Reactions of astrophysics interest often concern unstable or even exotic (neutron-rich, neutron-deficient, superheavy) species for which no experimental data exist and involve a large number (thousands) of unstable nuclei for which many different properties have to be determined. The energy range for which experimental data is available is restricted to the small range reachable by present experimental setups. To fill the gaps, only theoretical predictions can be used. In contrast to many other applications, two major features of nuclear theory must be contemplated here, namely its accuracy, which obviously has always been for most uses of the application the major (and some time unique) criterion in the model selection, but also its reliability. A microscopic description by a physically sound model based on first principles is of paramount importance to ensure a reliable extrapolation away from the experimentally known region. For these reasons, important theoretical efforts have been devoted by nuclear astrophysicists to develop accurate microscopic models for practical applications. These long-standing activities will continue to expand as an active field of research in the decades to come.

Consequently, there is a significant overlap between astrophysics and other nuclear physics applications. The experimental and theoretical efforts made by the astrophysics community can be of direct interest and relevance to nuclear applications and vice-versa the progress made in the various energy or non-energy applications can be of direct relevance for nuclear astrophysics. On this basis, it is recommended to the IAEA:

1. to continuously identify overlap of interest between astrophysics and other nuclear applications and possible cross-fertilization between the various communities,

2. to pro-actively coordinate systematical inclusion of neutron, photon and charged-particle-induced cross sections and rates (compilations and evaluations) from the astrophysics community in the centralized IAEA library (EXFOR). This also includes the IAEA taking a leading role in the future coordination of international evaluation activities for reactions of common interest,
3. to coordinate regularly updates of the experimental Reference Input Parameter Libraries (RIPL) and ensure the proper dissemination of the updates,
4. to coordinate long-term projects for the development and validation of microscopic nuclear models for practical applications and the prediction of relevant nuclear quantities including model uncertainties.

Nuclear Theory Needs

S. Chiba, ASRC-JAEA, Japan

Recommendations to the Section:

1. International evaluated file

M.B. Chadwick has proposed to generate an international evaluated file ENDF/I.

This idea has the danger that financial organizations in each country (or region) may reduce the nuclear data budget arguing that one world-wide library is enough. We must remember that another international file, FENDL, worked well because ITER endorsed FENDL as the reference data library for participants of the project. So we should be cautious on this idea. On the other hand, I would totally agree to make such a library provided that NDS would take an initiative to make this file really internationally authorized. It means that, if an electric power company asks their regulation organization for permission to construct a new nuclear power plant, the nuclear data part causes no problems if they use such an internationally authorized library. Therefore, IAEA should be responsible to make this file internationally authorized. It will involve a considerable amount of benchmarking under IAEA/NDS supervision which must then be accepted and authorized by the regulation organization in each country (or region). It will include a considerable amount of politics as well as technical issues. However, if it is realized, it would benefit the nuclear industry throughout the world.

2. Theory

Nuclear theory will be a vital tool for all future nuclear data work. Arjan Koning is really doing a fantastic job in the development of the TALYS code. However, there are some other fields where his current method will not work. One field is the dynamical description of the nuclear reactions which are necessary to understand fission and surrogate reactions. Namely, the fission fragment distributions depending on the excitation energy and spin, their excitation energies at the scission, and the number of pre- and post-scission neutrons which can be understood in a unified way by such a dynamical model. Surrogate reactions also need help from such a theory. Furthermore, there are more theories needed in the light nuclei where the cluster breakup reactions are the major part of the reaction mechanisms. Right now, there is no good interface between the cluster-physics community and nuclear energy community. NDS should take a leadership role to close the gap.

3. Experiments

The demand for nuclear data is becoming more and more complicated. Data for many unstable nuclei are becoming necessary. Therefore, good international collaboration must be organized to facilitate the use of capabilities of the various participating organizations. NDS should establish such data needs clearly, and take a leadership role in any international collaboration.

Parameter libraries

Z. Ge, CIAE, China

Recommendations for future parameter libraries:

1. The existing parameter library should be updated, extended and corrected regularly based on the latest measurements, evaluations and theoretical studies by international collaborations (through CRPs or other activities). What parts of the parameter library to be updated and corrected should be taken into account in setting up the activity.
2. New parameters should be added according to the new mechanisms or approaches introduced in the nuclear reaction model code and the updated results from nuclear theory studies.
3. Information on the range of parameters, especially for nuclear reaction model parameters used for covariance evaluations and sensitivity studies of nuclear data should be recommended. The information which can be used for this purpose should be considered based on the nuclear reaction models such like OM, DWBA, H-F and exciton model, etc. which are popular in the nuclear reaction model codes.
4. The model parameters (global and local) and related information for the unstable nuclei model calculations should be recommended and the uncertainties from the parameters for the model calculations of unstable nuclei should be studied and analyzed.
5. If some parameter systematics could be provided, it would help the nuclear data evaluators and nuclear data users to perform the model calculations.
6. CRPs and collaborations should be considered to address the above items.

Covariances : a personal view

E. Bauge, CEA DAM DIF, France

Since the field of the covariance/uncertainties of nuclear data is in its infancy, there are many different views on the subject. Nevertheless, the output of WPEC SG24 [1] and the September 2011 IAEA Technical meeting on covariances [2] are available and present an overview of the current state of the art in the field.

The views presented here are based on the practices in use at CEA DAM DIF for nuclear data evaluations. First, at CEA DAM DIF, nuclear data are evaluated using the model based approach where the evaluated data is the result of a model code for which parameters are adjusted in order to account for the relevant experimental data (both differential and integral).

The method used to evaluate covariances must reflect the method used to evaluate central values. This leads to a multitude of covariance evaluation methods among which the Backward-Forward Monte-Carlo (BFMC) is the one that closely matches the evaluation method of CEA DAM DIF.

That BFMC method is based on the Monte-Carlo sampling of the physical model parameters, where the calculation/experiment mismatch is quantified by a generalized chi-square which is used to construct a weighting function that is used to weight each sample [3].

Use of generalized chi-square points to the necessity of obtaining a covariance matrix of the entire experimental data set (including systematic errors derived from the original papers, and correlations stemming from standards for relative measurements). EXFOR should make the process of experimental data covariance evaluation easier and tools to assist the evaluator in that task should be developed.

Application of the BFMC method to the n+^{239}Pu cross sections highlights the inability of the model used to account for some of the data ((n,2n) above 14 MeV). The effect of such model defects must be quantified into the covariance of the data. Another way to deal with model defects would be to improve the models, but that is a longer term (but more satisfying for nuclear physicists) solution.

Application of the BFMC to the Y and Zr region illustrates that the physical model parameter distributions adjusted for ^{89}Y are relevant in the neighboring nuclide region. That produces a few interesting consequences:

- Common physical model parameters distributions introduce cross-isotopes correlations: by evaluating not an isotope but a nuclide region, thus using a larger, more comprehensive set of experimental constraints, produces a set of consistent evaluated covariances that includes cross-isotopes correlations, even if the ENDF format does not allow such correlations to be stored.
- The reusability of experimentally weighted model parameter distributions shows that they constitute the core of the information (the crown jewels) that are needed to produce an evaluation and the associated uncertainties. This points to the possibility of storing parameter distributions (mean vectors and covariance matrices) instead of storing the cross sections that are derived from them. This is already the case for resonance parameters in MF=2. In this case processing or simulation codes need to somehow include the calculational routines of model codes such as TALYS or EMPIRE.
- Information on parameter range of confidence should be available. This points to an update of RIPL including covariance matrices of model parameters (RIPCL).

One of the standing issues on covariances is that there is no way yet to assess the quality of the content of a covariance file by itself. One can compare the methodologies used to produce the covariance file on toy models, one can check the facts that it reflects the experimental data used to constrain the covariance (tests of confidence levels) but there is no real benchmark of covariance in the sense that the file can be tested on its own without any outside information (methods or experimental data used as constraints). Work should be done in that direction.

Finally, combining BFMC with NRG's Total Monte Carlo (TMC) [4] will allow the evaluation of important isotopic regions (Pu isotopes) in a consistent manner, making use of all the available relevant experimental constraints (differential and integral), producing high quality cross correlated evaluated data files for central values and covariance at the same time. With that TMC+BFMC combination, given a set of experimental constraints (differential and integral, including experimental data covariance), joint evaluation of central values and covariance matrices of nuclear data proceeds in an automated and reproducible way.

[1] M. Herman et al., Covariance Data in the Fast Neutron Region**,** WPEC Subgroup 24 final report, NEA OECD report, 2011.

[2] A. Tkov, D.L. Smith, R. Capote-Noy, Summary Report Technical Meeting on Neutron Cross Section Covariances, IAEA report INDC(NDS)-0582 2011**.**

[3] E. Bauge, P. Dossantos-Uzarrlade J. Korean Phys. Soc., Vol. 59, No. 2, August 2011, pp. 1218-1223.

[4] D. Rochman, A. Koning, S. Van der Mark, Annals of Nuclear Energy, vol **36**, p 810 (2009).

What Users Need – Complete Libraries

A. Koning, NRG, The Netherlands

An entirely new way of producing nuclear data libraries was presented. It is entirely based on the notion of *reproducibility*: the essential elements of a nuclear data evaluation are much more compact than an ENDF-data library, and contain, for example, several selected experimental data sets, a nuclear model input file, and an additional nuclide-specific shell script. Once this information is safely stored, nuclear data libraries can be produced over and over again, leading to novelties such as (1) the TENDL data library, (2) Total Monte Carlo uncertainty propagation, and (3) automatic optimization to differential and integral data. If this is to become the future method of data evaluation and validation, several developments are required to contribute to its success. The recommendations are:

- To shorten the life cycle of evaluation, processing and validation, it is essential that integral benchmarks are easily accessible in directly usable form. This means that for future efficient data evaluation, the three main databases ICSBEP, SINBAD and IRPHE should be brought to a high level of quality (for ICSBEP this is the case already), including the provision of input files for codes such as MCNP. This is mostly an OECD/NEA coordinated task, but the IAEA could contribute as well.

- The quality and automatic retrieval of EXFOR data is essential, and NRDC is strongly advised to continue the quality improvement path initiated by WPEC SG-30. Recent initiatives taken by the IAEA, such as expanding the EXFOR format to accommodate covariance data, optional normalization entries, etc. should also be continued.

- To increase the efficiency of evaluation of libraries, which tend to increase in size both in terms of nuclides and reaction channels, visualisation tools need to be developed which can efficiently test huge libraries.

- The IAEA should take the lead in a world-wide initiative to come to a more modern nuclear data format, along the lines presented by Mike Herman (XML) or as recently suggested by LLNL. A real leap into the 21st century, which would get rid of ENDF's out-of-date reaction channel categorization ("MT-numbers") and other limitations requires however a larger agreement which includes processing and reactor code developers. This may be too ambitious, but the step to a more flexible format should definitely be investigated.

- Maintain and expand the capability of nuclear modeling, as was done by the RIPL projects. Especially the theoretical description of actinides requires development. Another possibility would be the extension of the RIPL format to complete nuclear model inputs, e.g. entire TALYS or EMPIRE input files which reproduce the experimental data as well as possible.

- Further development of covariance methodologies.

Formats and data storage

M. Herman, BNL, USA

Formats

The currently used ENDF-6 format has a number of shortcomings that originate from the punch-card legacy. Some, such as redundancy, counting lines, too short MAT number and too many options could be resolved within the current format. The more critical issues, such as rigidity to extensions, limited accuracy due to fixed number of digits, difficulty of reading by humans, lack of native software support, and lack of integration with EXFOR and ENSDF libraries, would require such considerable efforts that migration to a new and modern format, offering additional advantages, is a more attractive option. Actually, such an option is even more justified by the existence of the well advanced General Nuclear Data (GND) format being developed by LLNL. This XML based framework is easily extensible, its numerical precision is not fixed, it is easier to edit, can store additional information (e.g. renormalized experimental data used in the evaluation), allows for storing various versions side by side (e.g. reconstructed data, group-wise data, alternative evaluations), it may include hyperlinks to documentation or another set of data (e.g. covariances). Two additional advantages are the possibility of using native Python support software and already available conversion (in both directions) to the binary HDF5 format which allows to organize, store, access, analyze, share, and preserve data huge in both size and complexity.

The GND format comes with the processing software FUDGE, whose class structure mirrors the GND format. It provides for arbitrary alteration of the data, energy deposition/kermas, data checking, translation to different format (ENDF-6, HDF5, ENDL), grouping, resonance reconstruction, visualization and sampling from covariances.

It is deemed advantageous to the Nuclear Data community to adopt this new system and develop interfaces to the currently used processing codes and retrieval systems to take full advantage of the evolving technology. Such modernization is needed to allow for the storage of large covariances, ensuring evolution of the stored data, and for attracting to the field young experts.

Use of servers for performing calculations

The Nuclear Data centers should support and promote use of their servers to perform small and medium scale calculations by remote users. Typical applications currently available are Q-value calculators and operations on the evaluated files (e.g. the NNDC SIGMA interface). Further steps in this direction include a more extensive use of the servers to perform nuclear data processing and checking (e.g. the myENSDF and myENDF applications developed by V. Zerkin). This alleviates users from the necessity of installing codes on their computers, keeping them up-to-date and, to some extent, from preparing the input for the calculations.

Better help system

The Nuclear Data web servers usually offer textual help, which is cumbersome to prepare and difficult to follow for the users. It would be much more efficient to change to animated screen shots accompanied with a registered voice that explains steps needed for retrieving specific quantities or performing the requested operation. Software for preparing such help is easily available, inexpensive (less that $100), and very easy to use. The help files could also be posted on You-Tube thereby also increasing visibility of nuclear data to the general public.

Nuclear data applications for mobile devices

Mobile devices such as smartphones and tablets are becoming increasingly popular and capable of running relatively complex applications. There are nuclear databases, e.g. the Wallet Cards that would greatly benefit from being distributed through mobile applications. They would be more accessible, understandable, interactive, and would reach much larger groups of users than current paper editions. They would be also ‘at hand’ in emergency situations.

Archiving of data and codes

It is equally important that legacy codes, nuclear data libraries, and experimental data be secured on the Nuclear Data centre servers and backup systems. These constitute a precious heritage, worth billions, that must be preserved.

Visualisation tools

E. Dupont, NEA, OECD

E. Dupont proposed that visualisation tools should be extended to Nuclear Data (ND) Information Systems in order to cover all data (and formats), all users and all needs. In particular, these ND Information Systems could both serve as an interface between data and users, as well as between data and codes (processing codes or nuclear reaction codes). It is expected that these systems will combine the advantages of processing codes and visualisation tools, as well as serving as a Tool Box to support various ND projects.

Meeting summaries and recommendations

Under the following headings the meeting is summarized and the main recommendations are presented. These summaries and recommendations emerged from the contributions of and the discussions between the participants and were generally agreed upon. The recommendations serve the Nuclear Data Section as guidance for future initiatives. For context and substance the Section may further draw on the participants contributions presented in the previous chapter.

Medical applications

There are two major fields within nuclear medicine that require improved nuclear data. The first concerns diagnosis and therapeutic treatment − there is a strong need for more precise excitation functions in order to produce the optimum yields and high purity of specific medical radioisotopes, along with the derivation of accurate decay data for their well-defined use. The second concerns accelerator-based therapy, in particular hadron-therapy with proton, alpha and carbon beams, and neutron-capture therapy (accelerator-based boron neutron capture therapy (BNCT)) − nuclear data are needed to optimize the irradiation conditions and improve the assessment of the delivered dose. Of the various aspects of importance within these two areas of concern, the NDS should focus on nuclear data related issues.

Medical applications are a key field of interest to the IAEA. NDS involvement in this field is important, well recognized, and should continue. Meeting participants indicated a significant range of possible activities. Based on earlier CRPs and recent Consultants' Meetings, the Section should further develop a list of *prioritized* needs to guide future CRP and DDP initiatives in this important field of application for the IAEA.

Accelerator applications

Charged particle accelerators provide a broad range of nuclear applications: ion beam analysis, medical isotope production, thin layer activation, production of tracer radioisotopes for industrial and biological processes, accelerator based neutron production (quasi mono-energetic neutron sources and Accelerator Driven Systems), accelerator dose rates and shielding, safeguards and radiation effects on micro-electronics. The many available and required experimental data are also important for the development of basic knowledge in the field of nuclear reaction theory, and also astrophysics. Current nuclear data libraries, both evaluated and experimental (EXFOR) are incomplete and evaluations and the available data often lack the required accuracy or completeness. Improved evaluations along with new measurements are required to advance this important and diverse field of application. The Section should seek to prioritize the needs in these very diverse sub-fields and establish the projects that would maximize its impact in accelerator applications. Possible synergies with medical, fusion and astrophysics applications provide important guidance.

Energy production

An important interest in nuclear data development arises from the large field of energy production. Here current and near-term needs affect a large number of industrial and governmental users concerned with the operation and monitoring of present day and next generation light and heavy water reactors, since nuclear data libraries are deployed throughout for planning, safety, and performance assessments, as well as for planning of evolutionary innovation. Large science and engineering studies tackle the development of truly innovative options such as a fusion reactor, fast reactors, Accelerator Driven Systems, or the development and implementation of the Th/U fuel cycle. The driving forces for the latter four are sustainability of nuclear energy and the minimization of high level waste output to long term storage.

General recommendations

Despite the breadth of the field a few key requirements for nuclear data development can be identified that are common to these different sub-fields of energy production.

Requirements for safety and security on the one hand and economy of operation and cost of design and development on the other hand all boil down to 1) tight uncertainty requirements and 2) reliability of performance and safety assessments. For nuclear data this implies an emphasis on accuracy and reliability of evaluated libraries in terms of central values and covariance matrices. This accuracy and reliability has to be demonstrated through verification and validation (V&V) by benchmark exercises. The quality assurance system of nuclear data measurement and evaluation should be established, as a part of the V&V policy which is now required from the licensing authority, to sustain the accountability, reproducibility, traceability, and transparency of plant design. The Section is recommended to maintain the highest standards of quality assurance for the central values and covariances of the evaluations that it produces through its data development projects. This recommendation implies the delivery of the appropriate covariances with new evaluations.

In view of the large range of nuclear data that may play a role in the various operating and foreseen systems for nuclear energy production and in view of the pressure on resources for nuclear data development it is essential that activities in this field, whether measurements, evaluation, validation or otherwise are properly motivated and prioritised. The Section is well placed to advertise and list priorities. In particular it should encourage nuclear data sensitivity studies and facilitate their dissemination in collaboration with the OECD-Nuclear Energy Agency (High priority request list for nuclear data - HPRL).

The Section is recommended to play a key role in nuclear data for safety assessments, e.g. involving radioactivity inventory, radiation dose estimates, decay heat, shielding, dispersion and mitigation-of-dispersion of radioactivity and dosimetry. A recognised role in nuclear safety will be an important driver for the Section's continuity.

Recommendations specific to the sub-fields[1]

Operating and next-generation nuclear power plants

It is suggested that the Section apply its resources, where appropriate and when circumstances permit, to facilitate the resolution of noted data inconsistencies, for example, by convening a CM or TM of interested parties focused on the issues and data needs. Examples were identified by the experts in the meeting for secondary angle and energy distributions of scattered neutrons and low energy data, including the thermal scattering law. Nuclear data issues for operating and next-generation reactors typically have a high impact and therefore often require direct action. The Section should therefore remain alert and responsive to such issues when they arise.

Advanced reactors and fuel cycles

Improved nuclear data are essential to support new initiatives such as the international projects on innovative nuclear reactors and fuel cycles (INPRO, Generation-IV) that aim to support the safe, sustainable, economic and proliferation-resistant use of nuclear technology to meet the global energy needs of the 21st century. For fast reactors and accelerator driven systems prioritized lists of nuclear data needs exist that are backed-up by sensitivity analyses. For fast reactors the first priority is the

[1] The high energy recommendations are found in the section on accelerator applications.

major isotopes while for accelerator driven systems dedicated to waste transmutation there is an additional emphasis on data for minor actinides. Both concepts in addition require data for the innovative materials in their designs. Finally, high burn-up innovative reactor systems need better completeness and better accuracies for fission products. In all cases the reliability of covariances is indispensible. Advanced fuel cycles scenarios include the recycling of minor actinides for minimization of high level waste and the use of the Th/U fuel cycle. The Section should maintain an active role in data development for advanced reactor and fuel cycle initiatives.

Fusion

The Section's nuclear data development programme has to focus on the needs of ITER, IFMIF and DEMO as served by its FENDL library. The FENDL development efforts need to be continued beyond the FENDL-3 CRP, to validate the data for fusion reactor and IFMIF applications, and to improve the data evaluations according to the latest standards. Eventually the libraries should be extended for additional materials/isotopes as required by the fusion programmes. All FENDL evaluations should be complemented by covariance data accounting for both modelling and experimental uncertainties. In view of the high foreseen doses in fusion devices radiation damage data are of high importance. An advanced simulation approach with better physics modelling is required to predict the radiation induced displacement damage and gas production more realistically. A wide neutron and proton energy range should be covered enabling material damage studies at all foreseen facilities.

Basic Science

Basic nuclear science is an important lifeline in nuclear data development. The awareness and large scale use of consistent physics modeling for nuclear data development was advanced tremendously over the past decade and the first data library entirely based on model codes was released in 2008 and has been updated on a yearly basis[2]. The Section has supported basic nuclear science with the development of three generations of reference input parameter libraries (RIPL-1, -2, -3) which have been a tremendous success. The Section has also been instrumental in developing various aspects of nuclear modeling and model codes, in particular, but not only, in the field of neutron-induced reactions on actinides.

Nuclear theory and basic science, including experiments, play a key role in advancing the quality of nuclear data evaluations, uncertainties and their correlations. They also help attract bright new students that are often educated in astrophysics and high energy physics, and maintain an interest in high quality low-energy experiments whether neutron-induced or for instance by the surrogate technique. It is also in this domain that important cross fertilization is possible. For instance, a large body of work carried out for astrophysics is directly relevant for nuclear data development and vice versa.

Recommendations include monitoring, stimulating and adopting of theoretical and experimental results in fields of basic science of interest to data development, to regularly update the reference input parameter libraries, to support developments and adopt new insights in the generation of covariances and, in particular, consider relevant extensions of RIPL in support of model-based covariance generation, to consider nuclear modeling developments for light nuclei (e.g. cluster theory, R-matrix) and unstable nuclei and to encourage experiments allowing guidance for understanding reactions on unstable (excited) nuclei and other basic science interests. This broad scope of activities naturally asks for a careful selection of the Section's activities, e.g. by dedicated Technical or Consultants' Meetings.

[2] TENDL-2008, -2009, -2010, -2011

International Evaluated Nuclear Data File

It was observed that the various evaluation projects (JEFF, JENDL, BROND, CENDL, KAERI) tend to converge, the demands on quality of an evaluation strongly increase, while the resources for development tend to decrease, and that some essential expertise from the 'golden era' of nuclear development is fading. Therefore, a new initiative establishing the world's best nuclear data library appears to be of great current interest. In particular, this would be the case if it could act as a well-recognised reference for nuclear data users in key areas of societal interest, such as nuclear safety. The development of such a library will be a major challenge with unique benefits and a few potentially important downsides. On the side of the benefits is the new impetus given to a capable pool of available experts that are currently taking over from the previous generation of data developers. Along with other innovations emerging from this Technical Meeting this may provide a stimulating environment for technical staff in the early stage of their career. This also appears to be the logical next step in view of the recent developments in nuclear data library production technology. Of the possible downsides are potential difficulties due to lack of diversity in libraries (for robustness testing), lack of competition (for best quality), and lack of funding from regional authorities (for lack of visibility and control over output).

The Section is recommended to review the pertinent suggestions brought forward by the meeting and engage in the discussion with the various file projects over the goals, the benefits, the disadvantages, the means and the organisation of such an international evaluated nuclear data library.

Complete libraries, data development methodology

An entirely new way of producing nuclear data libraries is currently within reach. While the inclusion of full experimental covariances is still outstanding, methodologies to solve this technical problem are available. With a limited amount of information (summarised in model codes, input files and experimental data) and the highest degree of automation, it is possible to generate complete libraries with an evaluation methodology that is entirely reproducible. The potential of this approach is illustrated by (1) the TENDL data library, (2) Total Monte Carlo uncertainty propagation, and (3) automatic optimization to differential and integral data. One of the tremendous benefits, or perhaps the largest benefit, is the short turn-around time from new developments (modelling improvements, integral or differential data) to a validated nuclear data library. Given the power of this new methodology the Section is recommended to support essential initiatives to facilitate its implementation by improving automated access to as many experimental data including experimental covariances as are available, to stimulate the quality of the compilation of such experimental data, and to ease the way to large scale automated retrieval, comparison, testing and visualisation of data.

EXFOR

The leading role of the Section among the International Network of Nuclear Reaction Data Centres for the compilation of experimental data in EXFOR should be considered as one of the Section's most noteworthy and important obligations. EXFOR compilation and dissemination are key services to many users of the Section's data facilities. Any new evaluation effort will need to access and make extensive use of all relevant data compiled in EXFOR. Therefore, strong agreement prevailed that the Section should continue to provide leading support to the compilation and dissemination of data in EXFOR, and should consider the changes required to adjust to and profit from software and hardware developments so that high-level services can be maintained to EXFOR users in the future.

At the technical level, agreement was reached that there was no obvious long-term need to expand the existing data types within EXFOR, nor extend their ranges (e.g. defined as projectile energies up to 1

GeV, and incident projectiles up to A = 12). The development and introduction of user-friendly output formats must continue, along with further rigorous efforts to detect errors that would reach far beyond the recent, useful exercise initiated by WPEC Subgroup-30. Finally, much question-and-answer correspondence exists at the present time in the form of the exchange of letters and PDF files between EXFOR compilers and the authors of cross section publications. All of this material needs to be electronically documented within EXFOR to ensure the provision of readily accessible answers to future users' questions. Furthermore, EXFOR compilations should include improved support to evaluators with respect to uncertainties and covariance matrices. More complete compilations of the experimental details are required along the lines of the recent IRMM template, along with improved tracking of linked data sets (e.g. through normalization, an on-going project of the Section) and an interface for covariance generation from the EXFOR entry.

Data format

The Section should seriously consider moving the formats in which data are stored (evaluated data and experimental data) to a format that takes full advantage of the available current day software technology. The current format for evaluated files (ENDF) was developed over 40 years ago and was implemented on the basis of punch-card technology. Having survived for so long shows the good sense and foresight of the original format developers, however, nowadays there are considerable limitations identified that warrant a thorough revision. One possible development was recently proposed at LLNL and is based on the XML data structure. It has the advantage that storage is in ASCII, a format easily portable across platforms, that the generic hierarchic and field structure of ENDF and EXFOR can be directly reflected in it and expanded upon, and last but not least that there are well developed software interfaces that allow the data to be available in several formats, formats to be converted and the data to be processed and visualised.

There are considerable hurdles to overcome. All users will require adapted interfaces to process the new format. Thus processing codes will need modifications as will the visualisation and web retrieval tools. These changes are inevitable to take nuclear data technology to the 21st century. In view of the implications a concerted effort is required by all nuclear data developers. Therefore the NRDC and all important file projects should be involved and support such a radical new development. The Section should consider taking a leadership role in pushing forward this suggestion, provided a sufficient consensus is reached to make the effort successful.

Processing

Processing codes provide an essential interface between evaluated data libraries, today still stored in the ENDF format and users' applications codes. Certain processed libraries and the PREPRO processing tool were supported/developed at the Section and are available and disseminated through its web interface. Such files and the processing code serve a very important role between nuclear data producers and users and its support is appreciated by this community. Concerning PREPRO there are significant features that make it complementary to the other processing codes in common use by the various file projects, thus allowing independent cross checks that are of interest to validation of nuclear data. The Section should maintain support for processed libraries and its processing tools considering developments to better handle uncertainties and covariances. An extension of the PREPRO system or a development of a new processing code is encouraged. The extended/developed code should include modules to generate scattering matrices, to generate temperature dependent self-shielded cross sections in the unresolved resonance region, to process fission neutron multiplicity, and to treat covariances.

Naturally, the abovementioned fundamental overhaul of the data format will require a strong concurrent and integrated effort for the development of processing interfaces. This may require a major effort on behalf of the Section, since the success/acceptance of the new data format depends on the quality of the processing tools. Such future Section activities are recommended provided sufficient support for the development of the new data format materialises.

Visualisation

The value of high quality user-friendly visualisation and user data access tools for evaluated and experimental nuclear data cannot be overestimated. This was stressed in several contexts. Individual users from beginners to professionals need quick easy access to all the plots and data that they require for their queries, in an easy self-explanatory format. Simple operations and comparisons with user defined data sets should be supported. Besides web-based services, services for common portable devices should be considered in the future. For professional evaluators heavy-duty large scale visualisations of evaluated data in comparison with other evaluations and experimental data should be facilitated. The Section is strongly encouraged to continue development of its visualisation and interactive data retrieval tools in order to keep improving its services to users.

Dissemination, education, and training

Education and training are crucial to high quality development of nuclear data libraries in all its aspects, to the correct use of data in applications and to heighten the awareness of the role of nuclear data in large and small scale systems modelling. The Section has an important role not only in the dissemination of nuclear data but also in raising the awareness and competence of the users requiring these data. It is therefore recommended that the Section continue to organise nuclear data related courses for the user community.

Conclusion

A Technical Meeting on Long Term Nuclear Data Needs was held at the IAEA in Vienna from 2 to 4 November 2011. Twenty-one experts, nuclear data developers and nuclear data users participated and expressed their opinions addressing the fields of competence of the Nuclear Data Section: Medical and analytical applications, energy production, libraries, basic science, and tools and visualization. Following discussions a valuable comprehensive set of recommendations emerged. These recommendations were generally backed by all the participants to the meeting and therefore provide excellent support and guidance to the Nuclear Data Section in developing new initiatives. The Nuclear Data Section is an important point of reference in the nuclear data developers and user communities and the participants strongly endorse that it continues to act in ways that will guarantee its reference role in the future.

IAEA Advisory Group Meeting on

"LONG TERM NEEDS FOR NUCLEAR DATA DEVELOPMENT"

Room A07-42, IAEA Headquarters, Vienna, Austria

2 – 4 November 2011

AGENDA

Wednesday, 2 November

08:30 - 09:30 Registration (IAEA Registration desk, Gate 1)

09:30 - 10:30 Opening Session

- Welcoming address — D. Mohamad – DDG-NA
- Introduction - *Future challenges for the NDS* — R.A. Forrest - Head, NDS

10:30 – 11:00 Break for administrative matters

11:00 – 12:30 Presentations (approx. 20' each) **and discussions**

MEDICAL AND ANALYTICAL APPLICATIONS

- *Intermediate- and Longer-term Nuclear Data Requirements for Medical Applications* — A. Nichols
- *Systematic study of activation cross sections of proton and deuteron induced reactions for accelerator applications* — F. Tarkanyi
- *Nuclear Data for Ion Beam Analysis* — A. Gurbich

12:30 - 14:00 Lunch break

14:00 - 17:30 Presentations and discussions - cont'd

ENERGY PRODUCTION

- *Data Needs for Fission – Current Systems* — K. Kozier
- *Perceived problems, challenges and needs in the area: Long term needs of nuclear data of innovative materials for fission energy systems* — S. Ganesan
- *Energy Production: Fission – Innovative Systems* — M. Ishikawa
- *Fusion for Energy – Nuclear Data for Fusion: Goals and Development Needs* — U. Fischer
- *High Energy Applications* — Y.-O. Lee

(Coffee break as appropriate)

Thursday, 3 November

9:00 - 12:30 Presentations and discussions - cont'd

LIBRARIES

- *Long-term Needs for Nuclear Data Development - Processing Needs* A. Trkov
- *Experimental data – EXFOR* A. Plompen
- *Long-term Nuclear Data Requirements* A. Nichols
- *An Alternative Future: An International Evaluated Nuclear Database ("ENDF/I" or "WENDF" or "WEF or …")* M. Chadwick
- *Some Examples of Verification of Nuclear Data in Reactor Physics Calculations* G. Manturov

(Coffee break as appropriate)

12:30 - 14:00 Lunch break

14:00 - 17:30 Presentations and discussions - cont'd

BASIC SCIENCE

- *Future Challenges in Nuclear Physics for Astrophysics Applications* S. Goriely
- *Nuclear Theory Needs* S. Chiba
- *Parameter Libraries for Nuclear Data Model Calculations* Z. Ge
- *Covariances: A personal view* E. Bauge
- *Accelerator Technology and Applications* A. Kreiner

(Coffee break as appropriate)

19:00 Social event

Friday, 4 November

9:00 - 12:30 Presentations and discussions - cont'd

TOOLS/VISUALISATION

- *What users need – complete libraries* A. Koning
- *Formats and data storage* M. Herman
- *Some thoughts on Visualisation tools* E. Dupont

(Coffee break as appropriate)

12:30 – 13:30 Lunch break

13:30 – 15:00 Report Summary

15:00 Closing

IAEA Advisory Group Meeting on

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