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U. Fischer, P. Batistoni, E. Cheng, R. A. Forrest, and T. Nishitani

Citation: *AIP Conf. Proc.* **769**, 1478 (2005); doi: 10.1063/1.1945284

View online: <http://dx.doi.org/10.1063/1.1945284>

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Nuclear Data for Fusion Energy Technologies: Requests, Status and Development Needs

U. Fischer ^a, P. Batistoni ^b, E. Cheng ^c, R. A. Forrest ^d, and T. Nishitani ^e

^a Association FZK-Euratom, Forschungszentrum Karlsruhe, Institut für Reaktorsicherheit, Postfach 3640, D-76021 Karlsruhe, Germany, e-mail: ulrich.fischer@irs.fzk.de

^b Associazione Euratom-ENEA sulla Fusione, ENEA Fusion Division, Via E. Fermi 27, I-00044 Frascati, Italy

^c TSI Research, Inc., P.O. Box 2754, Rancho Santa Fe, CA 92067, USA

^d Euratom/UKAEA Fusion Association, Culham Science Centre, Abingdon, Oxfordshire OX14 3DB, UK

^e Fusion Neutronics Laboratory, JAERI, Tokai-mura, Naka-gun, Ibaraki-ken 319-1195, Japan

Abstract. The current status of nuclear data evaluations for fusion technologies is reviewed. Well-qualified data are available for neutronics and activation calculations of fusion power reactors and the next-step device ITER, the International Thermonuclear Experimental Reactor. Major challenges for the further development of fusion nuclear data arise from the needs of the long-term fusion programme. In particular, co-variance data are required for uncertainty assessments of nuclear responses. Further, the nuclear data libraries need to be extended to higher energies above 20 MeV to enable neutronics and activation calculations of IFMIF, the International Fusion Material Irradiation Facility. A significant experimental effort is required in this field to provide a reliable and sound database for the evaluation of cross-section data in the higher energy range.

INTRODUCTION

The worldwide efforts in fusion energy technology aim at developing, in the long-term, power reactors that can contribute substantially to the supply of electricity. The construction and operation of the experimental fusion device ITER (“International Thermonuclear Experimental Reactor”) [1] and the intense neutron source facility IFMIF (“International Fusion Material Irradiation Facility”) [2] are considered as essential next steps towards this long-term goal. The layout and development of these facilities and their nuclear components rely to a large extent on data provided by neutronics design calculations. The availability of qualified computational tools and nuclear data for the neutron transport simulation and the calculation of relevant nuclear responses is thus a pre-requisite to enable reliable design calculations for these facilities.

This paper provides a brief outline of the current fusion technology long-term strategy and presents an overview of the nuclear data required for related design calculations. The status of the available nuclear

data is reviewed and future development needs are identified with regard to nuclear data for neutron and photon transport, radiation damage, sensitivity/uncertainty and activation/transmutation calculations.

FUSION TECHNOLOGY STRATEGY

The long-term aim of the fusion programme is to make available, as early as possible, fusion power as a source of electric energy [3]. The roadmap leading to a commercial fusion power plant (FPP) around 2050, or some 15 years earlier should a “fast track” be taken [4], assumes the construction and operation of the ITER experimental device as essential next step, followed by a demonstration (DEMO) power plant with no commercial objectives as outlined in Fig. 1. In the case of the fast track approach, the DEMO would be combined with PROTO into one single step that then must be designed as a credible prototype for a power-producing fusion reactor. The IFMIF intense neutron source is assumed to be constructed and operated in parallel to ITER with the objective of

testing and qualifying the materials for the high-neutron fluences anticipated for DEMO and PROTO. Breeding blanket concepts developed for DEMO and FPP will be tested in ITER to check and verify the design concepts and proof their performance at fusion power operation.

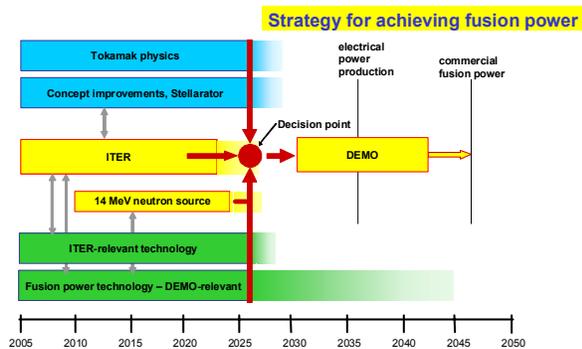


FIGURE 1. Road map to commercial fusion power plants.

According to this long-term strategy, the current efforts of the fusion nuclear data programme focus on the development and qualification of computational tools and nuclear data required for reliable design analyses of ITER, in particular for the layout and optimization of the Test Blanket Modules (TBM), and the IFMIF neutron source facility [5]. This includes a major effort on integral experiments with the objective of providing the experimental database for testing the fusion nuclear data and validating neutronics design calculations.

NUCLEAR DATA FOR FUSION

Nuclear design calculations include neutron and photon transport calculations to provide the neutron/photon flux spectra that then form the basis for the calculation of nuclear responses of interest when convoluted with related nuclear data. Appropriate and qualified computational simulations are required to insure that the calculated nuclear responses are reliable. These in turn require appropriate computational tools for the neutron transport simulation, along with nuclear data both for the neutron transport and nuclear responses.

Neutron cross-section data must be provided for the variety of nuclides constituting the materials to be used in a fusion device, including the breeders, neutron multipliers, coolants, shielding, magnets, and insulators. Special emphasis must be placed on high-quality data around 14 MeV. A major feature is the importance of inelastic neutron reactions, which require the use of double-differential cross-section

data to properly describe the energy-angle distributions of emitted secondary neutrons. Since secondary photons, produced in neutron-induced reactions, contribute significantly to specific nuclear responses, inclusion in the nuclear data libraries photon production and interaction data for use in coupled neutron-photon transport calculations is required. In addition, specific nuclear response data are needed such as tritium production, kerma factors, gas production, and radiation damage data. Activation and transmutation cross-section data must be provided for the isotopes of all stable elements that constitute the materials or may be present as impurities. Also, radio-nuclide targets require cross-section data, as multi-step reactions are also important in the high neutron fluxes. The decay data of all possible nuclides must be available to enable activation calculations to be carried out.

For practical applications, data evaluations must be complete i.e., they must include all data types and nuclear reactions that are required for neutron and photon transport simulations as well as the calculation of relevant nuclear responses. For activation calculations, on the other hand, a full set of data for all potential target nuclides must be available. To allow the preparation of working libraries for use with state-of-the-art transport and activation codes, complete data sets must be prepared in accordance with standard nuclear data format rules such as ENDF-6.

MATERIALS AND DATA NEEDS FOR ITER NUCLEAR ANALYSES

There is a variety of materials present in the complex ITER device (Fig. 2) including materials of the TBM, the plasma facing components, the shield modules, the vacuum vessel, the super-conducting magnets, the bio shield, as well as many other components of minor importance such as special Ni alloy bolts, Ti alloy module support cartridges, and electrical insulators such as $\text{Al}_2\text{O}_3/\text{MgAl}_2\text{O}_4$.

TBM materials include Be (neutron multiplier); Li_4SiO_4 , Li_2TiO_3 , Pb-Li (breeder), the Eurofer low-activation steel (Fe, Cr, W, Ta, V, Mn, C, and minor elements), and the He coolant. Plasma facing components include Be, W, and Cu/Cu alloy (CuCrZr, CuAl25). The shield modules and the vacuum vessel is made of SS-316L (N) with Fe, Cr, Ni, Mo, Mn, C, and N as major constituents, SS 30467 (2w% B) with Fe, Cr, Ni, Mo, Mn, B, C, N, P, S, and H_2O . The

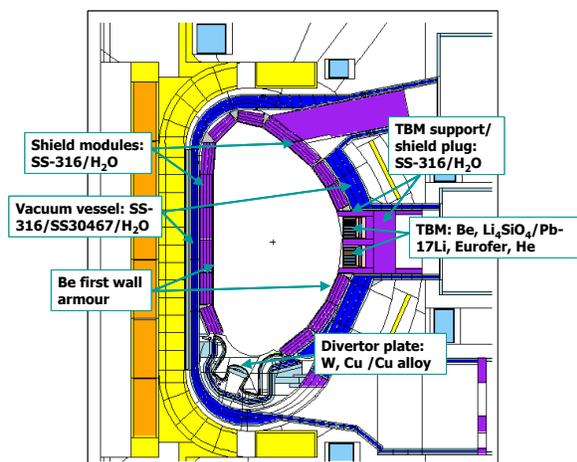


FIGURE 2. MCNP model of the ITER device showing essential components and materials for the nuclear analysis.

super-conducting magnet encompasses the super-conducting strand with Cu, Nb, Sn, Ta, Ti, and Cr; the normal conducting Cu wire; and the Helium coolant and Epoxy resin insulator with Si, O, B, Al, H, and C as main elements. The bio-shield is made of standard LWR concrete including the elements Si, O, Ca, Al, Na, K, H, Fe, Mg, and S.

According to the priorities of the design tasks in the frame of the fusion programme and the importance of the materials for specific design calculations, there must be available proper nuclear data for the constituting elements. Since the near-term focus of the fusion programme is on the TBM design, the elements Be, Pb, Li, Si, O, Fe, Cr, W, Ta, Cu, and Ti are currently considered as high-priority elements for which well-qualified evaluated data sets are required, including specific reaction data of its natural isotopes. Other elements are currently considered with lower priority.

SPECIFIC NEEDS FOR IFMIF NEUTRONICS

The IFMIF neutron source uses the d-Li stripping reaction to produce neutrons for high-fluence irradiations of FPP candidate materials. A flowing liquid lithium target is bombarded by a high-current deuteron beam accelerated up to 40 MeV energy. The resultant neutron spectrum is fusion-relevant but includes a high-energy tail that extends up to 55 MeV.

Dedicated computational tools and data are required for IFMIF neutronics and activation calculations. These tools must be capable of

simulating the transport of neutrons generated by Li(d,xn) reactions and of photons produced. Cross-section data must be provided over the whole neutron energy range up to 55 MeV. Such data must be evaluated for a variety of nuclides important for transport calculations. The codes for neutronics and activation calculations must be capable of handling all open reaction channels.

Differential experiments are required to provide basic data for the d-Li reactions up to 40 MeV deuteron energy and neutron-induced cross-section data up to 55 MeV neutron energy. Integral benchmark experiments are required to enable the validation of the cross-section data for transport and activation calculations above 20 MeV. In addition, thick lithium target yield data are needed for check-ing and improving the d-Li neutron source term.

The primary mission of IFMIF is to generate a materials irradiation database for the design, construction, licensing, and operation of DEMO. The material of highest importance in this regard is the structural material, which is supposed to be of the reduced activity ferritic-martensitic (RAFM) type such as Eurofer [6]. Accordingly, a variety of Eurofer specimens will be irradiated in the high flux test module (HFTM) of IFMIF up to the target fluence of 150 dpa. Other materials such as SiC, V/V-alloy, divertor materials (e.g., W), ceramic insulators, or breeder/multiplier materials are considered for high-fluence irradiations in IFMIF with lower priority. According to the elemental composition of Eurofer with (in w %) B(0.001), C(0.105), N(0.018), O(0.01), Al(0.008), Si(0.006), P(0.004), S(0.003), Ti(0.008), V(0.20), Cr(9.00), Mn (0.42), Fe(89.98), Co(0.005), Ni(0.005), Cu(0.005), Nb(0.001), Mo(0.001), and Ta(0.07), highest priority is assigned to the data of the main constituents Fe, Cr, W, V, Mn, C, and Ta.

STATUS OF FUSION NUCLEAR DATA

Nuclear Data Evaluations and Libraries

Various efforts have been conducted on the development of dedicated fusion nuclear data libraries, notably in the European Union (European Fusion File, EFF) and in Japan (JENDL-FF, Japanese Evaluated Nuclear Data Library – Fusion File), while in the US and the Russian Federation nuclear data evaluations suitable for fusion applications have been integrated to the general-purpose nuclear data files ENDF/B-VI and BROND, respectively. A major international effort was initiated IAEA/NDS when launching the FENDL

(Fusion Evaluated Nuclear Data Library) project [7]. A first version, FENDL-1, was adopted as the reference library for the ITER project and has been extensively benchmarked [8]. A further update has led to the improved FENDL-2 library [9], currently in use as the standard data library for fusion design applications.

In the EU, a continuous effort is being conducted on the development of nuclear data for fusion technology applications. This effort has led to genuine EFF-3 general-purpose data evaluations for ${}^7\text{Li}$, ${}^9\text{Be}$, ${}^{27}\text{Al}$, ${}^{28}\text{Si}$, ${}^{\text{nat}}\text{V}$, ${}^{52}\text{Cr}$, ${}^{56}\text{Fe}$, and ${}^{58,60}\text{Ni}$ [10]. These data evaluations are also included in the JEFF-3.0 data library [11].

The JENDL Fusion File 99 [12] is a rather comprehensive data library for fusion applications. It comprises full data evaluations for 79 isotopes and 13 natural elements relevant to fusion applications including ${}^1\text{H}$, ${}^6,7\text{Li}$, ${}^9\text{Be}$, ${}^{12}\text{C}$, ${}^{14}\text{N}$, ${}^{16}\text{O}$, ${}^{19}\text{F}$, ${}^{27}\text{Al}$, ${}^{28-30}\text{Si}$, ${}^{\text{nat}}\text{Si}$, ${}^{40,42-44,46,48}\text{Ca}$, ${}^{\text{nat}}\text{Ca}$, ${}^{46-50}\text{Ti}$, ${}^{\text{nat}}\text{Ti}$, ${}^{51}\text{V}$, ${}^{50,52-54}\text{Cr}$, ${}^{\text{nat}}\text{Cr}$, ${}^{55}\text{Mn}$, ${}^{54,56-58}\text{Fe}$, ${}^{\text{nat}}\text{Fe}$, ${}^{59}\text{Co}$, ${}^{58,60-62,64}\text{Ni}$, ${}^{\text{nat}}\text{Ni}$, ${}^{63,65}\text{Cu}$, ${}^{\text{nat}}\text{Cu}$, ${}^{69,71}\text{Ga}$, ${}^{\text{nat}}\text{Ga}$, ${}^{75}\text{As}$, ${}^{90-92,94,96}\text{Zr}$, ${}^{\text{nat}}\text{Zr}$, ${}^{93}\text{Nb}$, ${}^{92,94-98,100}\text{Mo}$, ${}^{\text{nat}}\text{Mo}$, ${}^{112,114-120,122,124}\text{Sn}$, ${}^{121,123}\text{Sb}$, ${}^{\text{nat}}\text{Sb}$, ${}^{182-184,186}\text{W}$, ${}^{\text{nat}}\text{W}$, ${}^{204,206-208}\text{Pb}$, ${}^{\text{nat}}\text{Pb}$, and ${}^{209}\text{Bi}$. Most of these evaluations are based on updates of JENDL-3.1 data by including double-differential cross sections for the secondary particles. They were also adopted in the later JENDL-3.2 and 3.3 libraries.

Activation Cross-Section Data

A major evaluation effort on the development of a qualified activation data library for fusion inventory calculations has been conducted in the frame of the EU fusion technology programme. This has led to various versions of the European Activation File (EAF) with the current version EAF-2003 [13]. An earlier version, EAF-97, was a major contributor to the international FENDL-2 activation library [14]. The EAF-2003 activation file contains cross-section data of 12,617 neutron-induced reactions in the energy range between 10^{-5} eV and 20 MeV for 774 targets up to fermium ($Z=100$). A major effort has been devoted to increase the accuracy the EAF data by a process of validation with a series of integral measurements. EAF-2003 is thus considered the best validated activation data library for fusion activation and transmutation analyses. A new version EAF-2005 with an extended energy range up to 60 MeV is currently underway [15].

Nuclear Data for IFMIF Neutronics

A complete set of $d + {}^6,7\text{Li}$ cross-section data up to 50 MeV deuteron energy was evaluated for use with the McDeLicious Monte Carlo code [16], an extension to MCNP [17] with the capability of sampling in the transport calculation the generation of d-Li source neutrons on the basis of tabulated $d + {}^6,7\text{Li}$ cross-section data.

For activation and transmutation calculations, the Intermediate Energy Activation File IEAF-2001 has been recently developed [18]. IEAF-2001 contains neutron-induced activation cross sections for 679 target nuclides from $Z=1$ (hydrogen) to 84 (polonium) in the energy range 10^{-5} eV to 150 MeV. The IEAF-2001 data library has been prepared in standard ENDF-6 data format making use of the MT=5 (neutron, anything) option with the excitation functions stored in file section MF=3 and the product nuclide vectors in MF=6. Two different working libraries with 256 group data in different data formats have been derived for application calculations [19]. One of them, the G-IEAF-2001/XS-256 group library, can be used by activation codes capable of handling an arbitrary number of reaction channels such as ALARA (Analytical and Laplacian Adaptive Radioactivity Analysis) [20]. The other IEAF-2001 working library, denoted as G-IEAF-2001/PY-256, uses pseudo fission product yields to describe the generation of transmutation products and can be used with standard activations codes such as FISPACT [21].

The evaluation effort on general-purpose neutron cross-section data focused in the frame of the IFMIF project on selected important nuclides such as ${}^1\text{H}$, ${}^{56}\text{Fe}$, ${}^{23}\text{Na}$, ${}^{39}\text{K}$, ${}^{28}\text{Si}$, ${}^{12}\text{C}$, ${}^{52}\text{Cr}$, and ${}^{51}\text{V}$ up to 50 MeV neutron incidence energy and, more recently, ${}^6,7\text{Li}$ and ${}^9\text{Be}$ up to 150 MeV [22]. Cross-section data for other nuclides such as ${}^{16}\text{O}$, ${}^{14}\text{N}$, ${}^{27}\text{Al}$, ${}^{28-30}\text{Si}$, ${}^{31}\text{P}$, ${}^{40}\text{Ca}$, ${}^{50,52-54}\text{Cr}$, ${}^{54,56-58}\text{Fe}$, ${}^{58,60-62,64}\text{Ni}$, ${}^{63,65}\text{Cu}$, ${}^{93}\text{Nb}$, and ${}^{182-184,186}\text{W}$ are available from the LANL 150-MeV evaluations [23] and are included in release 6 of the ENDF/B-VI nuclear data library. More recently, new NRG evaluations up to 200 MeV became available for ${}^{40,42-44,46,48}\text{Ca}$, ${}^{45}\text{Sc}$, ${}^{46-50}\text{Ti}$, ${}^{54,56-58}\text{Fe}$, ${}^{70,72-74,76}\text{Ge}$, ${}^{204,206-208}\text{Pb}$, and ${}^{209}\text{Bi}$ [24]. JAERI has released as well JENDL High Energy data (up to 3 GeV) for ${}^1\text{H}$, ${}^{12,13}\text{C}$, ${}^{14}\text{N}$, ${}^{16}\text{O}$, ${}^{24-26}\text{Mg}$, ${}^{27}\text{Al}$, ${}^{28-30}\text{Si}$, ${}^{39,41}\text{K}$, ${}^{40,42-46,48}\text{Ca}$, ${}^{46-50}\text{Ti}$, ${}^{51}\text{V}$, ${}^{50,52-54}\text{Cr}$, ${}^{55}\text{Mn}$, ${}^{54,56-58}\text{Fe}$, ${}^{59}\text{Co}$, ${}^{58,60-62,64}\text{Ni}$, ${}^{63,65}\text{Cu}$, ${}^{64,66-68,70}\text{Zn}$, ${}^{90-92,94,96}\text{Zr}$, ${}^{93}\text{Nb}$, ${}^{180,182-184,186}\text{W}$, and ${}^{196,198-202,204}\text{Hg}$ [25]. In the frame of the EFF project, 150-MeV data evaluations are underway for the tungsten isotopes [26]. Thus a variety of intermediate energy data evaluations is available including the high-priority nuclides for IFMIF neutronics analyses.

VALIDATION EXPERIMENTS AND ANALYSES

Testing and validation are essential in the process of assuring the quality assurance of the nuclear data evaluations for application calculations. This is achieved through integral benchmark experiments and their computational analyses both for transport and activation experiments.

Neutron Transport

Numerous 14-MeV neutron transport benchmark experiments on a variety of fusion-relevant materials have been performed in the past decade. For an overview on the achievements see the review [27] and the summary of integral experiments performed at JAERI [28]:

Recent neutron transport benchmark experiments have been performed on assemblies of SiC and W, both at the Frascati Neutron Generator (FNG) [29,30] and the Fusion Neutron Source (FNS) facility of JAERI [31,32]. In the Russian Federation, a transport benchmark experiment on Vanadium has been concluded in the frame of an ISTC-project [33]. Figure 3 shows, as an illustrative example, the high-energy ($E > 12.5$ MeV) neutron flux profile as calculated and measured across the W assembly in the FNG experiment [30]. Through a sensitivity analysis it was found that the underestimation observed with FENDL-2 data is caused by an overestimated (n,2n) cross section. This is in agreement with measurements of the differential (n,2n) cross-section data.

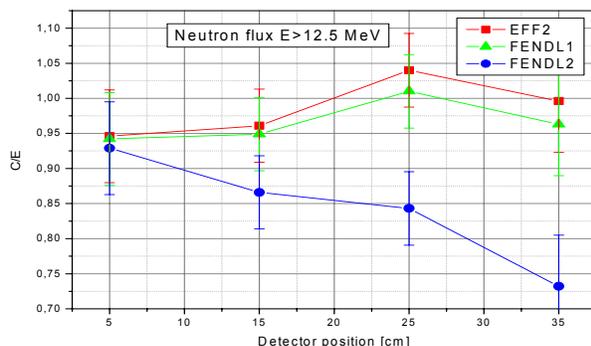


FIGURE 3. C/E (calculation/experiment) ratio of high-energy neutron flux across the W assembly in the FNG experiment [30].

The current focus of the experimental activities is on design-oriented breeder blanket experiments. The objective of these experiments is to check and validate the Tritium breeding performance of the considered blanket concepts as predicted by calculations. In the

EU, such an experiment is presently in preparation for a mock-up of the Helium-Cooled Pebble Bed (HCPB) Test Blanket Module (TBM) [34]. At FNS, such types of mock-up experiments have been recently performed for the JAERI pebble bed blanket consisting of layers of lithium titanate enriched in ^6Li , Beryllium, and the F82H steel [35]. Measured and calculated Tritium production rates were shown to agree within the combined uncertainty of the calculation and the experiment of 15%. A C/E (calculation/experiment) ratio close to 1.0 was obtained for a ^6Li -enrichment of 95 at. % and $C/E \cong 1.10$ for 40 at. %. Figure 4 shows the C/E ratios obtained in two 12-mm thick layers of Li_2TiO_3 embedded in Beryllium. To reduce the uncertainty of the Tritium measurement in these experiments, advanced techniques have been developed [37]. An international benchmark campaign is currently underway to benchmark them [38].

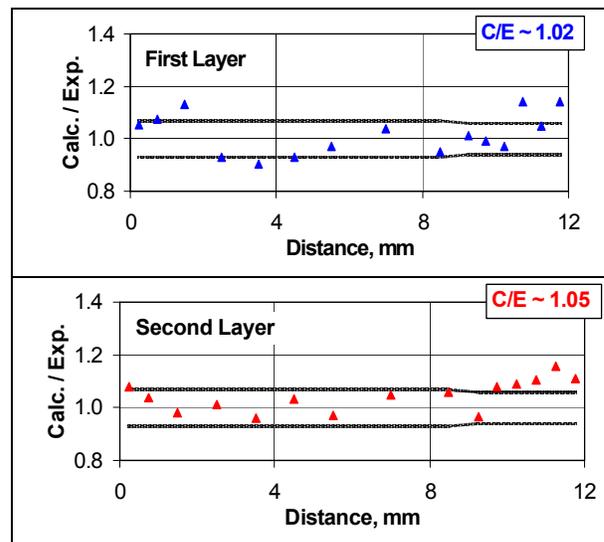


FIGURE 4. C/E ratios of Tritium production rates in two 12-mm thick layers of Li_2TiO_3 embedded in Beryllium (Calculations: MCNP4C with JENDL-3.3 data) [35].

Activation

At the Fusion Neutron Source (FNS) of JAERI, a series of decay heat measurements was conducted [41,42] on a variety of materials samples (all naturally existing elements, but excluding very light elements and the noble gases) following the irradiation by 14-MeV neutrons for 5 minutes and 7 hours. The decay heat values were measured over a wide cooling time range: from a few tens of seconds up to 400 days. These measurements were extensively used to validate the EAF cross-section data [43].

In the EU the experimental benchmark effort has focused on the validation of activation cross-section data. Samples of various fusion candidate materials such as the steels SS-316, MANET, F82H and Eurofer, different vanadium alloys, pure elements (Al, V, Ni, Cu, Cr, Fe, Hf, Nb, Y, W), CuCrZr, SiC, and the Li₄SiO₄ breeder ceramics have been irradiated with 14-MeV neutrons at the Frascati Neutron Generator (FNG) and the SNEG-13 high-intensity neutron generator at Serгиеv Posad. Some material samples were also activated in the white neutron field of the Karlsruhe d-Be neutron source. Computational analyses were performed with FISPACT using both EAF-2001 and EAF-2003 data [43,44]. An example of a validated reaction is shown in Fig. 5. Here, C/E is the ratio of the library to experimental cross section averaged in the neutron spectrum. The band indicates the uncertainty of the EAF-2003 data. The same plot for EAF-2001 data is shown in Fig. 6; a significant improvement can be seen. A further example of data improved between EAF-2001 and EAF-2003 is for ⁶²Ni(n,α)⁵⁹Fe, which has C/E=0.7993 and 0.9590, respectively.

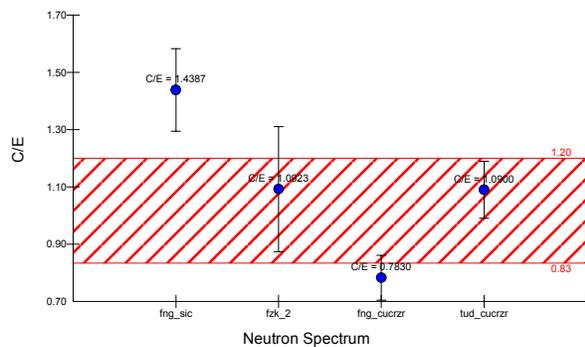


FIGURE 5. Integral data for ⁶⁵Cu(n,n'α)⁶¹Co using data from EAF-2003.

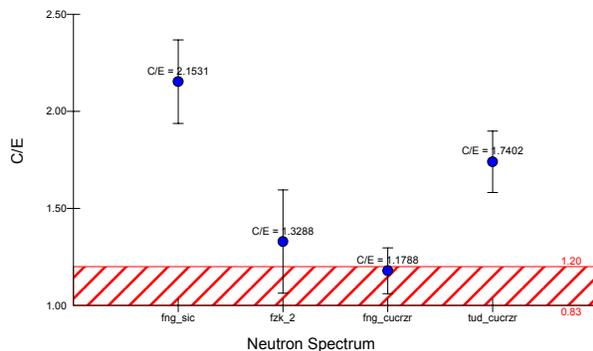


FIGURE 6. Integral data for ⁶⁵Cu(n,n'α)⁶¹Co using data from EAF-2001.

The McDeLicious approach for simulating the generation of D-Li source neutrons on the basis of evaluated d + ^{6,7}Li cross-section data was extensively tested against available experimental thick lithium target neutron yield data. As an example, Fig. 7 shows a comparison of measured and calculated forward neutron yields as a function of the deuteron incidence energy up to 40 MeV. Based on the results of such analyses, it was concluded that McDeLicious can predict the D-Li neutron generation with considerably better accuracy than its precursor McDeLi [45] and the MCNPX code [46] using the built-in ISABEL intra-nuclear cascade model. Further improvements of the d + ^{6,7}Li cross-section data evaluations were, however, indicated when comparing energy-angle spectra both for thick and thin Lithium targets [39].

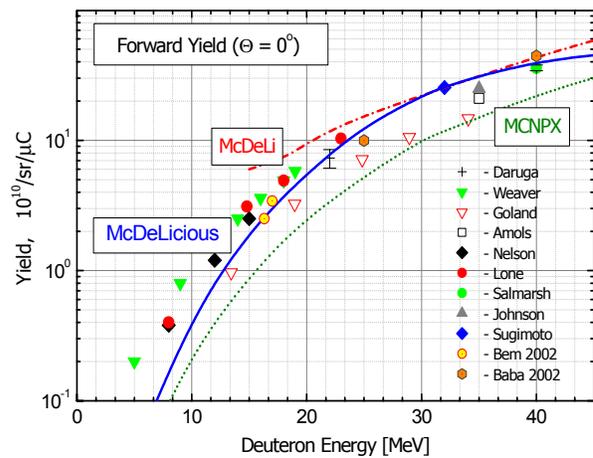


FIGURE 7. Thick Lithium target forward neutron yield data: comparison of calculations and measurements.

IEAF-2001 activation cross-section data were tested against results of an integral activation experiment performed previously at FZK [39]. Samples of SS-316 and F82H steels, V, and V-4Ti-4Cr alloy were activated in an IFMIF-like neutron field produced by a 40-MeV deuteron beam on a thick lithium target [40]. Results of the activation analyses for SS-316 and F82H steel samples are shown in Fig. 8 in terms of C/E ratios of the resulting γ-activities. For SS-316, the ALARA/ IEAF-2001 calculations agree with the measurements within the experimental uncertainty of typically 10-30% for half of the measured radio-nuclides. This includes the main contributors to the total activity and the contact dose rate such as ⁵⁶Mn, ⁵⁷Ni, ⁵⁸Co, ⁵⁴Mn, and ⁶⁰Co. For other radio-isotopes of minor importance, C/E ratios between 0.03 and 5 were obtained. In particular, this

applies for activation reactions with reaction thresholds above 20 MeV such as $^{92}\text{Mo}(n,3n)^{86}\text{Zr}$.

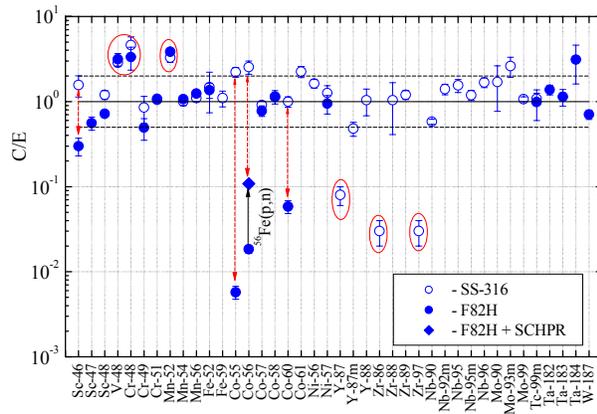


FIGURE 8. Comparison of calculated and measured radioactivities induced by irradiating SS-316 and F82H steel samples in an IFMIF-like white neutron field [39].

FURTHER DEVELOPMENT NEEDS FOR FUSION NUCLEAR DATA

The requirements for the further development of fusion nuclear data follow directly from the needs of the long-term fusion programme. Following this guideline, there is first the need to extend the general-purpose data evaluations to higher energies for all isotopes required for IFMIF. A variety of intermediate energy data evaluations is already available from different sources including the high-priority nuclides for IFMIF. These evaluations need to be qualified through benchmark analyses and complemented by data evaluations for the minor isotopes. The EAF activation data libraries will similarly require extension to higher energies. Many more experimental cross-section data are needed to make sure the extended data library is not entirely based on model calculations. In particular, this is essential for the Helium production cross sections above 20 MeV neutron energy where measured data are scarce. The Helium gas production, on the other hand, is one of the most important quantities needed for qualifying the material behaviour at high neutron fluences.

A further major medium-term goal of the fusion programme is to provide the tools and data for assessing the uncertainties of nuclear responses in ITER. To this end covariance data for all nuclides and nuclear reactions of interest in the design calculations are needed. This is a huge and demanding task that requires a strong effort on a long-time scale. Co-

variance data are currently available only for a limited number of nuclide evaluations and reaction types.

CONCLUSIONS AND OUTLOOK

The current status of nuclear-data evaluations for fusion technologies has been reviewed. Well-qualified data are available for neutronics and activation calculations of fusion power reactors and the next-step devices ITER. Major challenges for the further development of fusion nuclear data arise from the needs of the of the long-term fusion programme. In particular, co-variance data are required for uncertainty assessments of nuclear responses. Further, the nuclear data libraries need to be extended to higher energies above 20 MeV to enable neutronics and activation calculations of the IFMIF intense neutron source facility. A significant experimental effort is required in this field to provide a reliable and sound database for the evaluation of cross-section data in the higher energy range.

ACKNOWLEDGMENTS

This work has been performed in the framework of the nuclear fusion programme of Forschungszentrum Karlsruhe and is supported by the European Union within the European Fusion Technology Programme.

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