A Brief Overview of the European Fusion File (EFF) Project

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Abstract: The European Fusion File (EFF) Project is a collaborative project with work funded by the European Fusion Development Agreement (EFDA). The emphasis is on the pooling of resources and removal of duplication of effort, leading to the efficient development of two types of nuclear data libraries for use in fusion power plant design and operation studies. The two branches consist of, on the one hand, a transport file for modelling and design capabilities and, secondly, an activation file for the calculation and simulation of dose rates and energy release during operation of a future power plant. The OECD Nuclear Energy Agency's Data Bank acts as the central repository for the files and all information discussed during twice yearly meetings. It offers its services at no charge to the Project.

1. Introduction

The European Fusion File (EFF) Project forms the main work programme on fusion undertaken under the auspices of the OECD Nuclear Energy Agency's Data Bank. External partners to this project are funded via the European Fusion Development Agreement (EFDA) and their work on nuclear data topics is co-ordinated by two of its members (RAF and PB) who act as task leaders.

The primary tasks include:

nuclear data-file production and verification,
development of calculational methods, and
nuclear data-file validation via integral measurements,

with the aim of producing validated transport and activation libraries for adoption in assessments of materials behaviour in a fusion system.

Basic nuclear data measurements, such as cross sections, are not funded by EFDA, but the EFF Project benefits from the measurements made around the world in several facilities whose experimental data are collected and compiled in the EXFOR (EXchange FORmat) database [1] and disseminated by the NEA Data Bank in conjunction with other partners within the Network of Nuclear Reaction Data Centers (NRDC).[1]

2. Transport Library Production, Verification and Validation

A number of cross section evaluators work within the EFF Project to produce files in the internationally agreed ENDF format [2]. These experts include IRK Vienna who have produced a number of files recently for nickel-58 and -60, and silicon-28. In conjunction with ENEA Bologna they have also produced a new file for iron-56. A collaboration between CEA

[1] The four NRDC core members are the OECD/NEA Data Bank, France; the IAEA NDS in Vienna, Austria; the National Nuclear Data Center at Brookhaven National Laboratory in New York state, USA; the Russian Nuclear Data Centre in Obninsk, Russia with a number of specialised centres in Japan, Russia, Ukraine, Hungary, Korea and China.

Cadarache saw the production of a new chromium-52 file. These files are held at the NEA Data Bank where they are checked using a number of standard checking codes to verify file content and format. Files are subsequently made available to the EFF Project members for the next stage of validation.

Validation of these files involves the comparative analysis of results from the measurements and modelling of various systems. Currently ENEA Frascati, Italy; IPPE Obninsk, Russia and FNS at JAERI, Japan undertake measurements for these studies. Measurements are made of the neutron and gamma-ray emissions within a well-defined geometry following or during irradiation by a known source. A recently completed exercise to validate the new silicon-28 data file involved measurements made at the Oktavia facility, Japan, on a silicon sphere with a 14 MeV neutron source at its centre. These results were modelled using MCNP [3] and the results compared. Inconsistencies in the basic nuclear data file can then be determined and feedback given to the evaluator, thus allowing an iterative approach to correct, modify and improve the recommended nuclear data in the files. Clearly the calculational method employed in the modelling may affect the results and so work is undertaken in order to improve the theories and mathematical techniques used within the modelling codes. Both Monte-Carlo and deterministic methods are used and, where possible, multiple codes of the same type.

A second recent validation exercise involved the measurement and subsequent modelling of the neutron and gamma-ray transport in a silicon-carbide (SiC) block loaned to ENEA Frascati by JAERI. The work highlighted the significant collaboration between Project members, as the measurements were made at Frascati by teams from ENEA and the Technical University of Dresden, with detailed modelling performed by teams from ENEA and FZ Karlsruhe, using the Monte Carlo approach, and IJS Ljubljana using deterministic methods. The calculations [4,5] (see figure 1) confirmed the excellent performance of the new silicon-28 evaluation, but raised questions about the inelastic scattering cross section in the current carbon evaluation. The detector position P1, closest to the source, is more sensitive to the carbon data than the others, hence the poorer agreement. Work is thus being undertaken to improve the carbon evaluation.

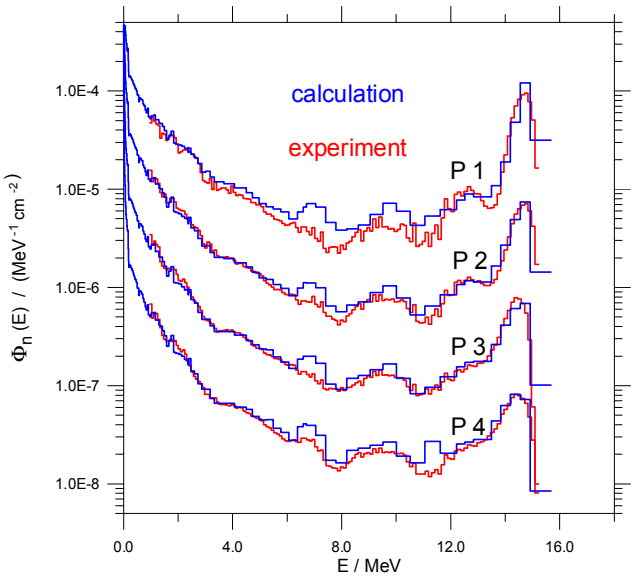

FIG. 1. Calculated and measured neutron flux at four detector positions (P1-P4) [5]

Following their validation, files become generally available, usually this is in the form of a complete library covering all necessary isotopes and reactions. The last complete release of an EFF library was in 1994, designated as EFF-2.4. New EFF evaluations are in use as individual updates to this library and have gone to form part of the recently released Joint Fission and Fusion File (JEFF) version 3.0 [6]. JEFF-3.0 is the first European library, which is designed to cover applications at both fission and fusion relevant energies, with a special intermediate energy library to follow for accelerator driven systems.

3. Activation Library Production, Verification and Validation

The European Activation File (EAF) library falls under the remit of the EFF Project, but is maintained and updated by UKAEA Fusion. This library will be designated as a special purpose file within the JEFF-3.0 suite of libraries and consists of only specific activation reactions that are produced in the same manner as the transport library, i.e. from the evaluation of experimental measurements, followed by validation studies. Comparative studies are initially performed against the available experimental data, generally taken from the EXFOR database. The library is usually updated biennially, following evaluation and validation studies and is supplied to the EFF Project collaborators within the EASY package [7], which contains both the nuclear data to be validated (including decay data) and a tool to allow the irradiation and subsequent decay to be modelled.

Validation studies of the complete library are carried out against measurements of decay heat energy, gamma and neutron spectra, dose rates, etc. in Italy at ENEA Frascati and ENEA Bologna, in Germany at TU Dresden and FZ Karlsruhe and in Greece at NCSR "Demokritos", Attikis. Many candidate fusion device materials have been studied during the course of the last few years, including possible first wall materials and breeder blanket module materials. Figure 2 shows an example of the results of the contact dose rates and contributing radionuclides obtained following the irradiation of a silicon carbide sample, intended for use as an advanced structural material due to its inherently low activation. Results have also been obtained for the various steels intended for use in the construction of a future fusion device [9], i.e. AISI 316 stainless, F82H martensitic, MANET, as well as for EUROFER. Studies have also been completed on Li_4SiO_4, a possible tritium-generating material in the European Helium-Cooled Pebble Bed Blanket design [10].

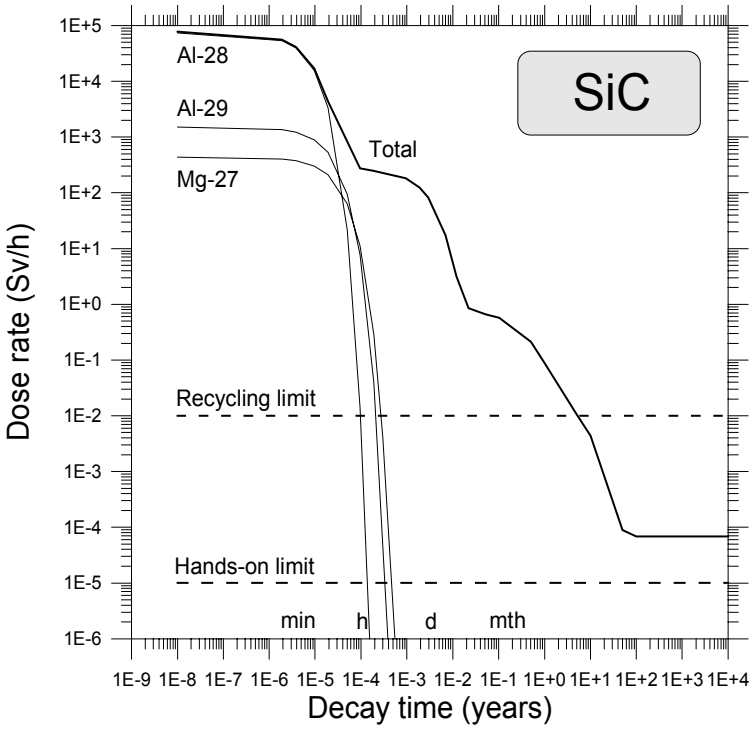

FIG. 2. Contact dose rates from the gamma emitting radionuclides after irradiation with 14-MeV neutrons of 1.0 MW power for one year as a function of the decay time [8]

Owing to the impurities, which are inherently present in many of the proposed materials, studies have been carried out on "pure" elements to measure the contribution of individual radionuclides produced. This allows the validation of specific reaction cross sections and decay data within EASY. Figure 3 is an example of an EASY calculation showing the number of radionuclides identified and their percentage contribution to the total dose rate, shown in this example for the irradiation of a pure tungsten sample. These results were then compared to the measured activities of the individual radionuclides in order to validate EASY. A short irradiation (~10 mins) led to the measurements made in the range of time ts and two longer

irradiations of ~14 hours each allowed measurements to be taken at times t1, t2 and t3 (shown on the figure by the vertical dashed lines.)

Experimental data on electron and photon decay heat were also obtained for several pure materials irradiated with 14 MeV neutrons at ENEA Frascati and used to validate the EASY-2001 code and the activation and decay data files EAF-2001 [11]. These data help to assess activation in fusion relevant materials and lead to the identification of problem materials and/or impurities with regards to dose rates during operation and at shutdown. This information feeds back to the overall materials development project within EFDA, helping to identify the changes required to meet the target dose rates for a future fusion device.

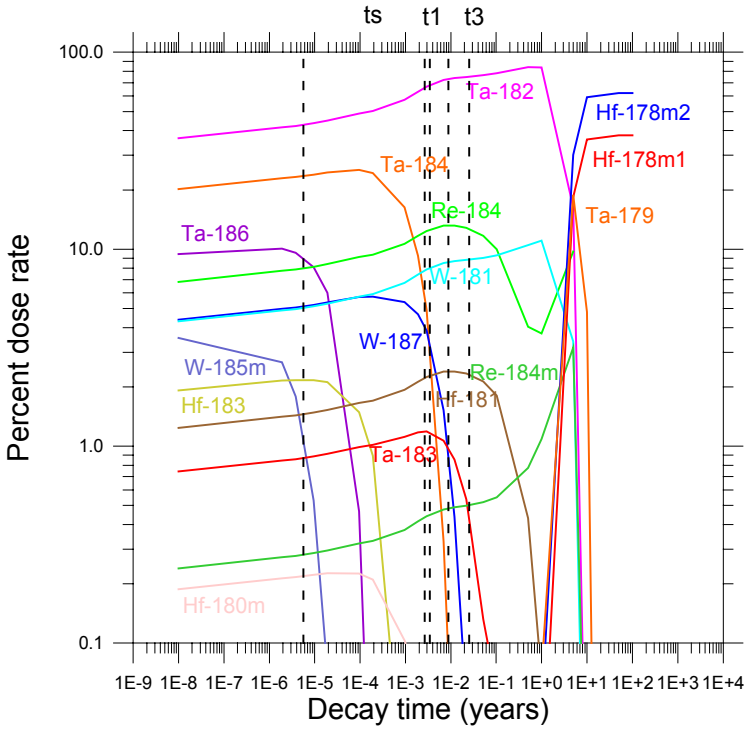

FIG. 3. Calculated contribution of different radionuclides following the irradiation of a pure tungsten sample [12]

4. Improvement of Calculational Methods

Within both branches of the EFF Project, work is undertaken to improve the mathematical tools used in modelling radiation transport and activation in fusion systems. Work has been undertaken by FZ Karlsruhe in collaboration with both the IJS Ljubljana, Slovenia and the Hebrew University of Jerusalem, Israel to improve both Monte Carlo and deterministic code sensitivity analysis. This allows data problems to be highlighted more easily rather than modelling deficiencies. In particular, work on the sensitivity analysis capabilities of the MCNP code are now well established for cross section excitation functions, using the differential operator approach [13]. More recent work has included the ability to apply this to secondary neutron angular distributions and work is in progress for secondary energy distributions. A combined code system has successfully been developed at FZ Karlsruhe which couples MCNP with FISPACT (part of EASY) to allow a full three dimension calculation of the activation inventory and decay heat in a fusion device.

5. Conclusions

The EFF Project brings together all available expertise in Europe, relating to the nuclear data requirements of existing and future fusion systems. To date the Project has produced an internationally recognised nuclear data library for fusion applications, EFF-2.4, and has participated significantly in the successful release of the new JEFF-3.0 library.

The Project continues to improve the quality of nuclear data and, in particular, strives to reduce the uncertainties involved in the calculation of various parameters relevant to the successful running of existing fusion devices and the future construction of the Next Step fusion experiment. Specifically these include the particle transport modelling within the

system and the determination of the dose rates during operation and after shutdown for safe operation.

All the nuclear data libraries mentioned in this paper are available free of charge from the OECD NEA's website (http://www.nea.fr/html/dbdata). All documents presented within the EFF Project meetings are held at the NEA and are available to Project members. Individual requests from non-members are treated on a case-by-case basis, but in general most documents can be supplied upon request.

6. Acknowledgements

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References

[1] MCLANE, V, "EXFOR Basics A Short Guide to the Neutron Reaction Data Exchange Format", BNL-NCS-63380-2001/05-Rev., Brookhaven National Laboratory, NY (2001)

[2] MCLANE, V. (editor), "ENDF-102 Data Formats and Procedures for the Evaluated Nuclear Data File ENDF-6", BNL-NCS-44945-01/04-Rev., Brookhaven National Laboratory, NY (2001)

[3] BRIESMEISTER, J. F. (editor), "MCNP - A General Monte Carlo N-Particle Transport Code", LA-13709-M, Los Alamos National Laboratory, NM (2000)

[4] ANGELONE, M., et al., "Benchmark analysis of neutronics performances of a SiC block irradiated with 14 Mev neutrons", presented at the 6th International Symposium on Nuclear Technology (ISFNT-6), accepted for publication in Fus. Eng. Design

[5] FREIESLEBEN, H., et al., "Measurement and analysis of neutron and γ-ray flux spectra in SiC", EFFDOC-822, Technische Universität Dresden (2002), (available from the NEA upon request)

[6] OECD NEA Data Bank, "The JEFF-3.0 Nuclear Data Library", JEFF Report 19, to be published December 2002 (available from the NEA upon request)

[7] FORREST, R. A., "The European Activation System: EASY-2001 Overview", UKAEA-FUS-449, UKAEA Culham, UK (2001), (available from http://www.fusion.org.uk/easy2001)

[8] SEIDEL, K., et al., "Experimental investigation of radioactivity induced in the fusion power plant structural material SiC and in the breeder material Li4SiO4 by 14-MeV neutrons", Proceedings of the 21st Symposium on Fusion Technology, Madrid, Sept. 11-15, 2000

[9] PILLON, M.,et al., "Benchmark Experiments on Fusion Neutron induced gamma-ray radioactivity in various structural materials", Journal of Radioanalytical and Nuclear Chemistry, Vol 244, No.2, (2000), 441-445

[10] BOCCACCINI, L. V., "The European HCPB Test Blanket Module to be irradiated in ITER", Proceedings of the Symposium on Fusion Technology, Marseille, Sept. 7-11, 1998, p. 1255

[11] PILLON, M., et al., "Measurements of decay heat and validation of the European Activation Code System for Power Plant Applications", presented at the 6th International Symposium on Nuclear Technology (ISFNT-6), accepted for publication in Fus. Eng. Design

[12] SEIDEL, K., et al., "Activation experiment with Tungsten in fusion peak neutron field", EFFDOC-821, Technische Universität Dresden (2002), (available from the NEA upon request)

[13] CHEN, Y., et al., "Sensitivity and uncertainty analyses of 14 MeV neutron benchmark experiment on Silicon Carbide", SOFT 2002