The European Activation File, EAF2005

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The European Activation File, EAF-2005

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Abstract. The current version of the European Activation File is EAF-2003. This contains various libraries of nuclear data required for activation calculations. An important component is the neutron-induced cross-section library. Plans to expose fusion components to high neutron fluxes include the IFMIF materials testing facility. This accelerator-based device will produce neutrons with a high-energy tail up to about 55 MeV. In order to carry out activation calculations on materials exposed to such neutrons it is necessary to extend the energy range of the cross-section library. Work on extending the energy range to 60 MeV is nearing completion. A test version (EAF-2004) was produced at the end of 2003 showing the feasibility of the chosen approach. This library required calculated data to extend the existing data from 20–60 MeV and to enlarge it with new classes of reactions with high thresholds. A summary of the new library EAF-2005, which is under development and is planned for distribution at the beginning of 2005, is given. The other files in EAF-2005 are briefly described; these cover cross-section uncertainty information and decay data. Both these have been extended beyond the current version to allow activation calculations at energies up to 60 MeV.

INTRODUCTION

The effects of neutron irradiation on materials are fundamental for fusion technology. Fusion devices generate fluxes of high-energy neutrons; the activation produced by them influences maintenance, safety, and waste disposal issues. Calculations of activation can be made with the European Activation System (EASY) [1]. The current version (EASY-2003) is restricted to neutron energies up to 20 MeV, which is sufficient for fusion devices; however, there are plans for facilities to carry out neutron irradiations to test the materials that will be used in future power plants. The most important of these is the IFMIF device [2], which is an accelerator-based d-Li neutron source able to provide a neutron flux equivalent to 2 MWm^{-2}, in a volume of 500 cm^3. The neutron spectrum is close to that found in a D-T fusion device, except that there is a high-energy tail of neutrons extending up to about 55 MeV. To include such high-energy neutrons in activation calculations it is necessary to develop EASY further: extending the energy range of the cross section libraries, including data for additional radionuclides and enhancing the FISPACT inventory code. This is a major task and it is being carried out over a two-year period. This paper concentrates on the data part of EASY: the European Activation File (EAF), describing the current version, the EAF-2004 test library produced at the end of 2003, and progress with the production of EAF-2005. Note that in this paper when data from EAF-2005 are mentioned, they refer to the current version; this may change prior to the planned release at the beginning of 2005.

SAFEPAQ-II

EAF libraries contain several parts: neutron-induced cross sections, uncertainties, decay data, and charged particle data. To assemble these from multiple sources requires a software tool. SAFEPAQ-II [3] reads data from ENDF files and stores them in relational databases, enabling data manipulation and visualization in an interactive manner. The process of building a library involves choosing a data source for each reaction and constructing a series of modifications based on available experimental data that manipulate the original data. SAFEPAQ-II has been significantly enhanced to enable data > 20 MeV to be treated, new types of validation plots are available, and many new features have been added. A new issue of the User manual [4] will be available as part of the EASY documentation, which can all be downloaded from http://fusion.org.uk/easy2005/. This link will be available from the beginning of 2005.

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EAF LIBRARIES

EAF-2003

EAF-2003 contains cross-section data of neutron-induced reactions for energies between 10^{-5} eV and 20 MeV. It contains data for 98 elements from H to Fm, but excludes data for the short-lived radioactive elements At and Fr. There are 774 target isotopes, including ground, first, and second isomers, which have non-zero cross sections below an energy of 20 MeV. Cross sections to and from isomeric states are listed separately. This leads to a total of 12,617 reaction channels that contain data. An uncertainty file for all reactions is included, enabling uncertainty estimates to be calculated by FISPACT. A summary of the EAF libraries is given in [1], which includes references to the other EASY reports.

Validation

The data libraries need to be validated before the results of activation calculations can be trusted. Validation means that the predictions of the code system are compared with measurements made on fusion-relevant materials in well-characterised neutron fields. Ideally there would be agreement between the two [Experiment (E) and Calculation (C)], but because of uncertainties in the measurements and errors in the data libraries, a range of C/E values is found.

By measuring a range of materials it is possible to cover a large number of reactions, although with the current facilities, it is only possible to validate reactions on stable or long-lived targets giving products with short to medium half-lives. By considering the C/E values it is possible to indicate which reactions are 'validated' – well described in the library and therefore to be relied on when making predictions of activation. Reactions with C/E values far from 1 need to be improved. Such cross-section modifications can be made with confidence if integral results in several complementary neutron spectra are available and if adequate differential data exist.

Results from the integral measurements have been used with various versions of EAF to validate data relevant for particular materials; also they have provided feedback to aid in the production of EAF libraries. Summary reports detailing the validation of EASY-2001 and EASY-2003 has been produced [5,6]. Together they present all the integral measurements made as part of the European Technology programme, the analysis of Japanese measurements, and list all available experimental data for historical measurements in the ^{252}Cf spontaneous fission spectrum. In total 287 reactions are considered, of which 171 are considered validated. An example of the C/E results for a validated reaction is shown in Fig. 1; the shaded band represents the library uncertainty (typically based on the spread of available differential measurements) and the error bars show the experimental uncertainty for each integral measurement.

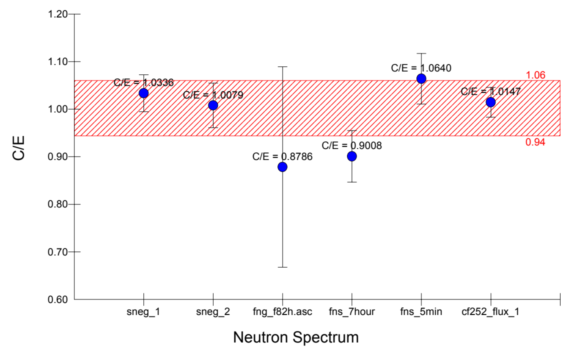

FIGURE 1. Integral C/E comparison for $^{51}V(n,\alpha)^{48}Sc$ using data from EAF-2005.

An example of the use of EAF-2003 is the calculation of activation of all elements exposed to various neutron spectra. This extensive handbook [7] contains 543 pages of tabular and graphical data and gives results without running an inventory code.

EAF-2004

This section discusses the approach followed to generate EAF libraries with data > 20 MeV. The most important question is the source of such data. Although there are some measurements and evaluated libraries with data > 20 MeV, these are rather sparse and it is necessary to rely on calculation for a source of cross-section data at high energies. The major code development project led by Koning involves the TALYS code system [8]. This is a very versatile system enabling the production of a wide range of data using a unified set of models. The data library termed TALYS-4 was read into SAFEPAQ-II and was used as the basis for the production of EAF-2004.

The decision was made to retain the same method of reaction description as used in earlier EAF libraries – use of MT numbers. Because of the new reaction types some unofficial extension of the ENDF MT numbering system was required and 49 new MT values were defined (with unassigned values between 152 and 200) and used by both TALYS and

SAFEPAQ-II. This approach is feasible for energies up to 60 MeV but would probably be too complicated for libraries extending to higher energies.

SAFEPAQ-II has required significant changes to allow the new data to be viewed and to enable the TALYS data to be automatically 'joined' at 20 MeV to the existing data. Many other new features have also been introduced to make the handling of the high-energy data easier.

The additional reactions mean that new nuclides can be formed, and these require entries in the decay data library. The number of nuclides has increased from 1,917 in EAF-2003 to 2,195 in EAF-2004. The number of uncertainty groups has increased with a new group covering 20-60 MeV.

EAF-2004 consists of a point-wise library extending to 60 MeV; however this requires processing into multi-group form before it can be used in applications such as FISPACT. Existing group structures extend up to 20 MeV, so an extension was required for the new data. The existing 175 and 315 group structures have been extended by adding groups of width 1 MeV up to 55 MeV.

The basic method of production of EAF-2004 has involved the addition of new reactions (generally with thresholds > 20 MeV) taken directly from TALYS-4. For the reactions already present in EAF-2003, the TALYS-4 data above 20 MeV were scaled to smoothly fit the existing data < 20 MeV. In some cases very large factors were required and for many of these it is unphysical to use the very limited data in EAF-2003 as a basis, and it is preferable to take data at all energies from TALYS-4.

EAF-2005

Production of EAF-2005 has followed the same philosophy as for EAF-2004. However, data from the latest TALYS library, version 5, have been used. Figure 2 shows data for $^{59}Co(n,3n)^{57}Co$, which illustrates the improvement in TALYS-5. The experimental points are from EXFOR, Final in the key means data from EAF-2005. This is an example of a reaction with a threshold that is near to 20 MeV and while present in EAF-2003, only had 2 data points and was of no significance.

A major improvement has been the introduction of low-energy data for (n,p) and (n,α) reactions based on the 'Low energy approximation' (LEA). This uses data

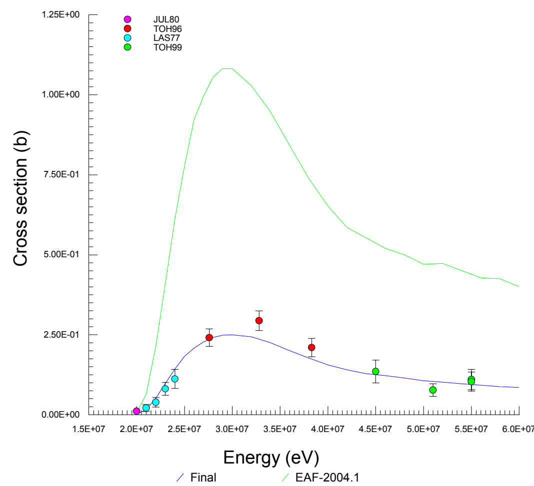

FIGURE 2. Data for $^{59}Co(n,3n)^{57}Co$ from EAF.

for the corresponding (n,γ) reaction scaled to pass through the thermal value for (n,α). This approach is based on the fact that the ratio of these cross sections is approximately constant at energies below the end of the resonance region. An example is shown in Fig. 3 for $^{39}K(n,\alpha)^{36}Cl$, which contains resonances for EAF-2005, but not in the earlier EAF-2003 data.

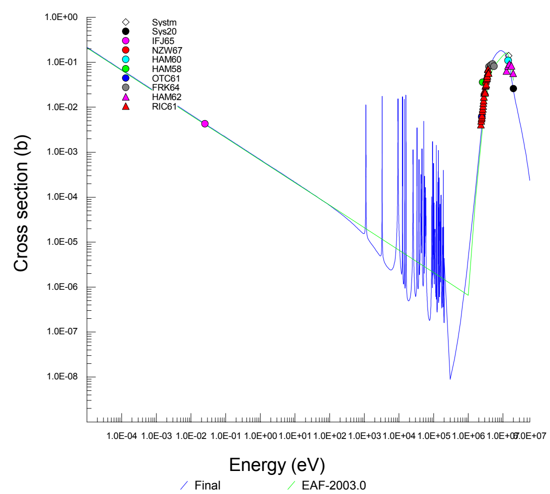

FIGURE 3. Data for $^{39}K(n,\alpha)^{36}Cl$ from EAF.

New differential measurements have been measured recently by Filatenkov [9]. The reactions studied had been shown by the previous validation to be discrepant. The new data are useful in making improvements. Figure 4 shows that for EAF-2005 the data source has been changed to TALYS-5 and renormalized to pass through the new experimental data. This is now a better representation than the EAF-2003 data that came from JEF-2.2.

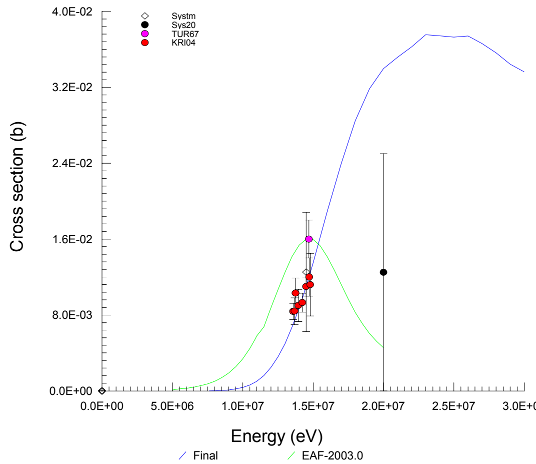

FIGURE 4. Data for $^{80}Se(n,p)^{80}As$ from EAF.

An example of a reaction where changes have improved the agreement with integral data is $^{93}Nb(n,\alpha)^{90m}Y$. Figure 5 shows the differential data, the EAF-2005 curve agrees better with the recent experimental data than EAF-2003. The two integral measurements have C/E values of 1.0518 and 1.1279 for EAF-2003; these improve to 1.0010 and 1.0704 with the new data. This illustrates the principle of changing data to get the best compromise between improving the integral and differential fits. A further example is $^{120}Sn(n,2n)^{119m}Sn$ where the changes mean that the integral C/E improves from 1.6080 to 1.3894.

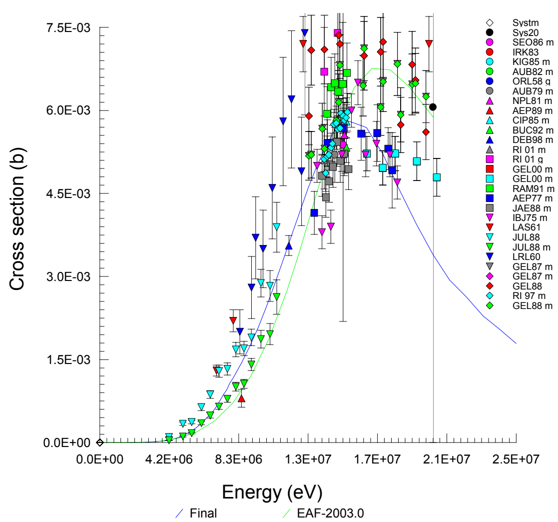

FIGURE 5. Data for $^{93}Nb(n,\alpha)^{90m}Y$ from EAF.

The current statistics for EAF-2005 are: 2192 nuclides and 62,637 reactions. Work over the next few months will involve checking the data and comparing with the integral data used for EAF-2003 and new data generated since the previous report [6]. Updating of the other components of EASY will also be carried out. The EASY package of data, codes, and documentation will be released at the start of 2005.

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