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## Use of Integral Data to Improve the European Activation File

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**Abstract.** The European Activation File is the source of nuclear data for fusion activation calculations that has been developed in Europe. In order to trust the calculations made with the data, validation is essential. A key part of this is the comparison of the EAF data with integral experiments made in fusion relevant neutron spectra on a wide range of materials. A review of the results for the EAF-2001 and -2003 libraries is given, leading on to the recent work on the test library EAF-2004. The latter is innovative in extending the upper energy range from 20 to 60 MeV. Although integral data above 20 MeV are scarce, recent measurements have meant that a start at these energies can be made. Examples of reactions that are considered to be validated are given, which requires that both the integral and differential data are consistent with the EAF data. Cases where integral data are good but differential data are lacking or discrepant are highlighted, as are cases where both types of experimental data differ from EAF. The methodology for the use of measurements of the activity and heat to extract effective cross sections and the use of these to present C/E plots is detailed. This technique has the advantage that the integral data can be used during EAF library development rather than only when the library has been finalised. The improvement of the EAF cross-section data in the various versions of the library is demonstrated.

### INTRODUCTION

Calculations of neutron-induced activation require both libraries of nuclear data and an inventory code. Within Europe the standard data library is the European Activation File (EAF) and the code is FISPACT. Together these comprise 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, for the planned material test facility based on accelerators there is a need to extend the upper energy to 60 MeV [2]. Proof of the adequacy of such data libraries for calculations is necessary and as part of the EFDA technology programme there is work to validate the EAF libraries. This involves the irradiation of fusion relevant materials in various neutron spectra, measurements of the activation and comparison with

activation calculations. The aim is to show agreement between the measurement and the calculations and where possible to use any discrepancies to help improve the library data. This paper will discuss the methodologies of the comparison, the work done on the libraries EAF-2001 and EAF-2003 and the preliminary work on the new EAF libraries with data > 20 MeV. Details of the various data sources mentioned below are given in [1] and references therein.

### VALIDATION METHODOLOGIES

The standard method for comparing measurements and calculations involves the measurement of activity (or heat in some experiments) at various decay times.

The nuclides responsible for most of the activity can be identified and by comparing the calculated (C) value with the measured value (E), the C/E ratio for a set of nuclides can be found. Examples of analyses that follow this approach are those of Sublet [3] for a large set of Japanese measurements analyzed with EAF-2003 and Simakov et al. [4] who analyzed FZK measurements at neutron energies > 20 MeV with IEAF-2001.

An alternative approach that has been used in the validation of EAF libraries employs the pathway method in FISPACT to identify the reaction responsible for producing the measured nuclide. Knowing the C/E ratio for activity and the value of the library cross section averaged in the neutron spectrum allows the measured effective cross section to be found. This value is stored, along with other experimental values, in SAFEPAQ-II [5], the code used for EAF library development. The ratio ( $r$ ) of the calculated to the measured quantity is shown in Eq. (1), where  $Q$  is activity or heat. The ratio ( $k$ ) of the effective cross sections is shown in Eq. (2).

$$r = Q_C / Q_E \quad (1)$$

$$k = \sigma^C / \sigma^E \quad (2)$$

In the case of a single pathway producing the nuclide, then  $k = r$ . If two parallel pathways contribute then it is assumed that the nuclear data for the second pathway are correct (usually the pathway contributing the smaller amount). If  $f$  is the fraction of the nuclide produced by the first pathway then the relationship between  $k$  and  $r$  is shown in Eq. (3). The advantage of this approach is that the integral data can be used in conjunction with the differential data to improve a cross section in the EAF library under development.

$$k = rf / (1 - r(1 - f)) \quad (3)$$

## EAF VALIDATION

### EAF-2001

The report on the validation of EAF-2001 [6] gathered together the measurements from the Technical University of Dresden, ENEA and FZK in fusion peak, moderated, and white neutron spectra on a

variety of materials (vanadium alloys, tritium-generating materials, steels, SiC, and some single elements). As described in the previous section, effective cross sections were calculated for sixty-five reactions. For each reaction the C/E ratios and the EAF  $\sigma(E)$  curve with available EXFOR data were plotted. Figure 1 shows the C/E plot for the  $^{184}\text{W}(n,\alpha)^{181}\text{Hf}$  reaction. The various neutron spectra are identified on the x-axis. The error bars on the points represent the measurement uncertainty, while the band represents the library uncertainty. If the error bars overlap the band then there is satisfactory agreement. It can be seen from the figure that this is not the case for this reaction. For thirty-five reactions there was agreement of the EAF library data with both the integral and differential data and these reactions were validated. Note that in [6] only two of the integral measurements were available for this reaction.

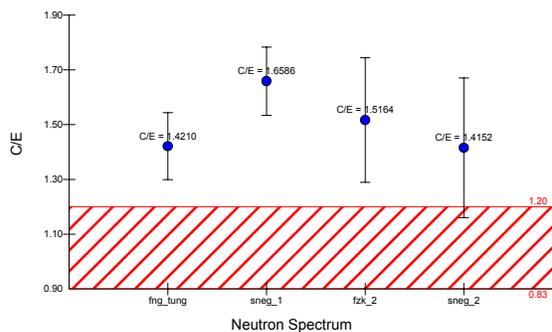


FIGURE 1. Integral data for  $^{184}\text{W}(n,\alpha)^{181}\text{Hf}$  using data from EAF-2001.

### EAF-2003

The report on the validation of EAF-2003 [7] used the data from [6] plus additional measurements from the European groups, the data from the JAERI Fusion Neutron Source (FNS), and data for the  $^{252}\text{Cf}$  spontaneous fission spectrum. Effective cross sections were calculated for two hundred and eighty-seven reactions. Figure 2 shows the C/E plot for the same reaction as Fig. 1, but using data from EAF-2003. It can be seen that due to an improvement in the EAF library data, the agreement with the integral data is improved. Consequently this reaction is now validated.

The number of reactions considered is significantly larger than for EAF-2001 and it is judged that one hundred and seventy-one reactions are validated.

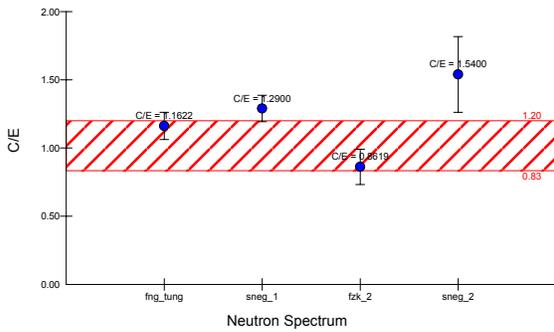


FIGURE 2. Integral data for  $^{184}\text{W}(n,\alpha)^{181}\text{Hf}$  using data from EAF-2003.

### EAF-2004 and EAF-2005

As discussed in [2], work on EAF over the last two years has concentrated on extending the energy range from 20 to 60 MeV. To demonstrate that the approach taken was feasible the test library EAF-2004 was constructed. This library has not been distributed to users and will be superseded by EAF-2005. Although the latter library is not finalised it is possible to use the current data to show examples of validation. New integral data are available since [7]. These include results for Y, and data for neutrons with energy > 20 MeV from Rež and FZK.

As an example of the new results at higher energies, the measurements made at FZK on four materials in a white neutron spectrum [8] were analysed using EAF-2004. Figure 3 shows data for  $^{52}\text{Cr}(n,2n)^{51}\text{Cr}$ , where it can be seen that three additional points from FZK are present (spectrum fzk\_ss316). There is good agreement of these integral data with the previous data and the status of the reaction remains 'validated'. Note that the current EAF-2005 data are used in Fig. 3.

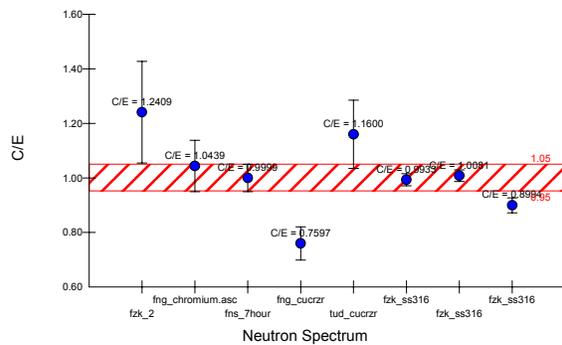


FIGURE 3. Integral data for  $^{52}\text{Cr}(n,2n)^{51}\text{Cr}$  using data from EAF-2005.

In EAF-2004 no change was made to the data for charged particle reactions used for calculation of sequential charged particle reaction products (SCPR) [9]. The analysis presented in [4] used the charged particle data below 20 MeV and the results suggested that the contribution of SCPR for neutrons with energies > 20 MeV may be enhanced. Consequently current work on EAF-2005 is underway to extend the charged particle data so that this contribution can be included when analyzing integral data.

Figure 4 shows C/E for a reaction not previously considered.  $^{50}\text{Cr}(n,3n)^{48}\text{Cr}$  has a threshold of 24.06 MeV and so was not present in EAF-2003. The new integral data from FZK suggests that although the current library uncertainty is large, there is satisfactory agreement with the library data. There are no differential data (a single EXFOR point exists but as the energy is below threshold, this should be ignored), so the reaction cannot be validated at this time.

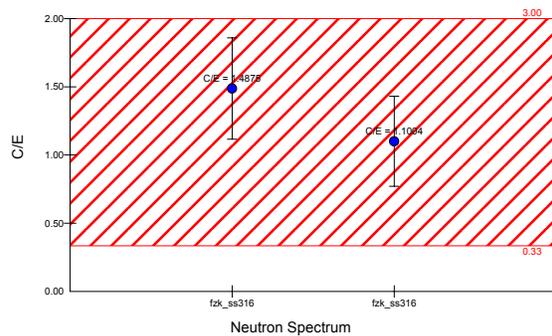


FIGURE 4. Integral data for  $^{50}\text{Cr}(n,3n)^{48}\text{Cr}$  using data from EAF-2005.

In addition to the new integral results discussed above, new differential measurements have been made, specifically to try and resolve some of the discrepancies found during the validation of EAF-2003. Filatenkov [10] measured cross sections for a set of reactions where the integral data showed satisfactory agreement with EAF-2003 but the differential data were poor or absent. An example of how the new data have been used during the preparation of EAF-2005 concerns the reaction  $^{120}\text{Sn}(n,2n)^{119\text{m}}\text{Sn}$ . Figure 5 shows that the new results (KRI04m) are significantly different from the existing EXFOR point from 1968. The current EAF-2005 data (shown as Final in the legend) is obtained by changing the data source from ADL-3 to TALYS-5 and renormalizing so that it passes through the new differential data. The change in C/E for the integral data is an improvement, for EAF-2003 C/E = 1.608, while for EAF-2005 C/E = 1.389.

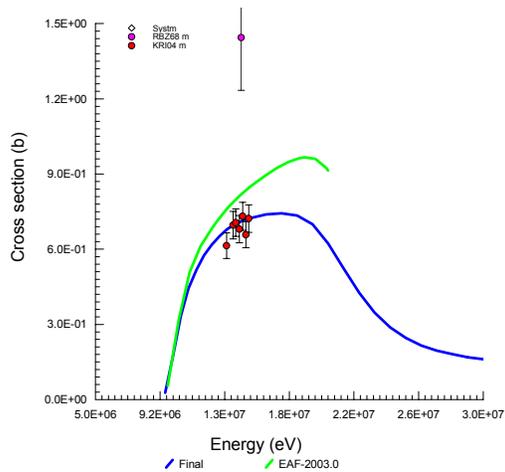


FIGURE 5. Data for  $^{120}\text{Sn}(n,2n)^{119m}\text{Sn}$  from EAF.

An example where the agreement of the integral data in EAF-2003 has been improved by changing the data source for EAF-2005 is given by the reaction  $^{186}\text{W}(n,\alpha)^{183}\text{Hf}$ . Figure 6 shows that the agreement of EAF-2003 with the differential data is reasonable; however, the integral C/E values were low (0.895, 0.796, 0.890). The data source was changed from JENDL-3.2/A to TALYS-5. An experimental data point was used for renormalization, and the overall fit to the data is improved. The improvement in integral agreement is significant with C/E values of 0.962, 0.990, 0.978. The lack of any data above 15 MeV means that the library data around 20 MeV, which is about twice the EAF-2003 value, remains untested. Note that the systematic value at 20 MeV is of no help with the two curves passing above and below the value. This shows the need for more high-energy data.

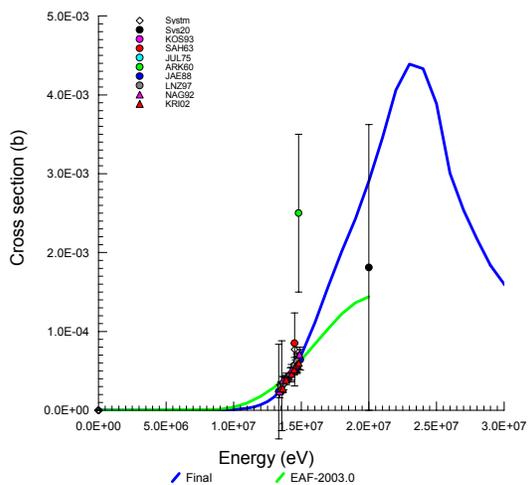


FIGURE 6. Data for  $^{186}\text{W}(n,\alpha)^{183}\text{Hf}$  from EAF.

A final example that illustrates that the current EAF-2005 needs further improvement is shown in Fig. 7. The data source has been changed from ADL-3 to TALYS-5; this has made the fit to both differential and integral data worse, and as can be seen from Figure 7, an increase in the cross section by a factor of about 5 is called for.

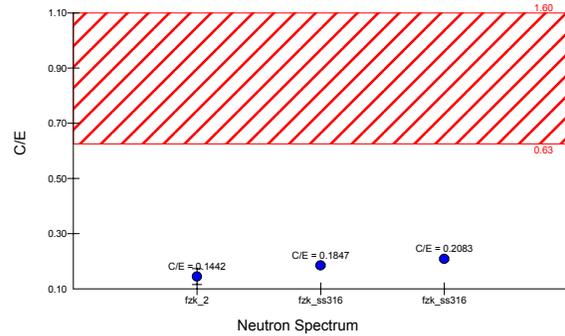


FIGURE 7. Integral data for  $^{54}\text{Fe}(n,t)^{52}\text{Mn}$  using data from EAF-2005.

## ACKNOWLEDGMENTS

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