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STATUS OF THE EUROPEAN FUSION FILE

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Abstract: The European Fusion File (EFF) is a nuclear data file for application in fusion-reactor blanket design calculations, in particular for neutron and photon transport calculations of the Next European Torus (NET). A first version of the file (EFF-1) has been distributed to European laboratories. Work for the second version (EFF-2) and a separate European Activation File (EAF) is in progress. This paper describes the status of the EFF-1 library, its file handling and processing, progress on the EFF-2 evaluations and adopted nuclear-model codes as well as progress on the EAF. The EFF project is part of the European Fusion Technology programme of the European Community. Various European laboratories contribute to this project. There is a strong link with the Joint Evaluated File (JEF) of the NEA Data Bank. Further international cooperation in the framework of the International Thermonuclear Reactor (ITER) project is discussed.

(Review, Evaluated Nuclear Data Library, Benchmark Calculations, Activation)

1. Introduction

The EFF project is part of the European Fusion Technology Programme of the European Community (EC). The following laboratories are contractors in the EFF project: CEA (Saclay), ECN (Petten), ENEA (Bologna), KfK (Karlsruhe) and the University of Birmingham . Moreover, JRC (Ispra) and CBNM (Geel) are involved as EC institutes. The project is conducted by the NET team (Next European Torus) at Garching and by EC, Brussels. The management and maintanance is performed at ECN (Petten). Other European laboratories are also involved: SCK/CEN (Mol) with an experimental programme performed at CBNM (Geel), IRK (University of Vienna), the UK laboratories at Harwell and Culham (JET), ENEA (Frascati), IKE (Stuttgart), KfA (Jülich) and EIR (Würenlingen). Furthermore, technical support is received from the NEA Data Bank at Gif-sur-Yvette, France.

The main goal of the EFF project is to supply the NET team with reliable evaluated data for neutron and photon transport calculations. There is a related project with the tentative name EAF (European Activation File) to achieve activation cross-sections.

The first version EFF-1 was made to obtain in a relatively short time a data base to replace the currently used ENDF/B-IV evaluation. This file was distributed in early 1986. It consists of materials important to the NET design. These were adopted from the Joint Evaluated File JEF-1, with some important revisions and replacements. The format of the EFF-1 file is ENDF-V with the addition of file MF6 of ENDF-VI to represent double-differential continuum reactions. It is described in more detail in Refs. [1,2] and in Sect. 2. In order to be able to use the data file a conventional ENDF-V processing code, supplemented with the newly developed GROUPXS code [3] is recommended. A multi-group transport library GEFF-1 [4] was made to check the library. At various European laboratories other multi-group libraries were made and applications are forthcoming. An integral data test for lead has already been published, cf. Sect. 2.

In Sect.3 the progress of EFF-2 is discussed. The goal is to obtain an update of EFF-1 with emphasis on the double-differental neutron emission cross-sections and photon-production cross-sections, required in transport calculations. As for EFF-1 the work supplements the activities for the JEF-2 data file. A special effort is made to update the ^{7}Li, ^{9}Be, Al, Si, Fe, Cr, Ni and Pb cross-sections at high energies, relevant for fusion reactors.

The progress with respect to the European Activation File is described in Sect. 4. The main goal of this project is to achieve a complete and yet reliable data file for the assessment of the activation of fusion reactor components, with special emphasis on the study of low-activation materials.

Finally, in Sect. 5 some conclusions are formulated and possible further international cooperation is discussed.

2. The EFF-1 file

Contents and format

The EFF-1 file consists of the materials listed in Table 1. Most of the evaluations are identical to those of JEF-1, except that gas production cross-sections and the parasitic absorption cross-sections were explicitly added. For the materials ^{6}Li, ^{7}Li, ^{9}Be, Al, Si and Pb different or revised evaluations were adopted.

The format of EFF-1 is ENDF-V with the following extensions: the Reich-Moore description in the resonance range, the energy-angle distribution file MF6 of ENDF-VI and the addition of data type MT=10 (continuum particle emission). For most of the light materials the pseudo level representation has been used to store the energy-angle distributions; a further deviation from the official ENDF-V format was adopted for Be by storing the (n,2n) reaction as pseudo inelastic scattering, followed by break-up neutron emission. In addition to the basic EFF-1 file a point-wise given version of the file has been generated.

A somewhat more extensive description of the file has been given in Ref. [2]. Here we discuss only a few features of the file.

For the tritium production cross-sections ^{6}Li(n,t) and ^{7}Li(n,n't) the ENDF/B-V standards and the 1981 Los Alamos evaluation [5] (improvement over ENDF/B-V.1) were adopted. The ^{6}Li(n,t) cross-section is a cross-section standard (upto 100 keV) and the ^{7}Li(n,n't) cross-section is quite accurate at 14.1 MeV: 303 ± 10 mb. A very recent evaluation [7], including the most recent experimental data yielded almost the same value (with smaller uncertainty), confirming the EFF-1

Table 1 Contents of EFF-1

Material	Source	Comment
H	JEF-1	
D	JEF-1	
T	JEF-1	
^{6}Li	ENDF/B-V	
^{7}Li	LASL^{a}	Young [5]
^{9}Be	LASL^{a}	Young and Stewart [6]
^{10}B	JEF-1	
^{11}B	JEF-1	
C	JEF-1	
O	JEF-1	
Al	ENEA	Revised ENDF/B-IV
Si	ENEA	Revised ENDF/B-IV
Ti	JEF-1	
V	JEF-1	
Cr	JEF-1	Reich-Moore
Mn	JEF-1	
Fe	JEF-1	Reich-Moore
Ni	JEF-1	Reich-Moore
Cu	JEF-1	
Zr	JEF-1	
Nb	JEF-1	
Mo	JEF-1	
Ba	JEF-1	Isotopes
W	JEF-1	Isotopes
Pb	ECN	MT=10, file 6
Bi	JEF-1	

^{a}LASL-EFF cooperation.

value. Also at other energies there are no large differences to be expected in EFF-2, except for the energy-angle distributions, cf. Sect. 3.

In view of their importance for ceramic breeder materials revisions of the ENDF/B-IV evaluations for Al and Si have been performed at ENEA-Bologna [8]. These revisions include a better description of the resolved resonance range and updates of the charged-particle emission cross sections.

For the Be neutron multiplier the recent evaluation of LASL [6] using the pseudo-level representation for (n,2n) has been used. This representation guarantees correct energy-angle coupling if the data are processed with the NJOY code [9]. The important neutron emission data fit the experimental results of Drake et al. [10] quite well [6]. Therefore this evaluation is an improvement over the existing ENDF/B-V evaluation.

For the other important neutron multiplier, lead, a revision of the ENDF/B-IV evaluation was made at ECN, Petten [2]. The modifications concern the continuum part of the inelastic scattering, the (n,2n) reaction and the (n,3n) reaction. The energy and angle integrated sum of these reactions (MT=10) was not altered. For these continuum emission reactions the energy-angle distributions were re-evaluated and were stored in file MF6 of the ENDF-VI format, using a rather fine mesh in E'. These distributions are in agreement with recent double-differential measurements at 14 to 15 MeV. The absolute value of the (n,2n) cross-section is about 2100 mb at 14.1 MeV, which is still in agreement with the experimental data of Fréhaut et al. [11]. Very recent studies indicate a 50 to 100 mb higher value, see Sect. 3, but confirm the shape of the neutron emission spectrum, cf. Fig. 5.

For the major structural materials the JEF-1 evaluations have been adopted, which have excellent low-energy cross-sections, based upon recent Reich-Moore analyses. At high energies revisions are needed, cf. Sect. 3.

File handling and processing

In addition to the available ENDF-V and the recently developed ENDF-VI utility routines we have adopted the Japanese version CRECTJ-V for file handling and checking. Furthermore, we have developed some tools to manipulate the energy-angle distributions stored in MF6 of the ENDF-VI format. The code NELIS is used for lumping MF6 files; the code GROUPXS [3] has options to convert MF6 files from the c.m. to the laboratory system, to convert Legendre coefficients to an angular representation and to convert MF6 into MF4 and MF5. The last-mentioned option is not recommended, but may be useful to study the effect of coupled energy-angle distributions or the effect of assuming isotropy in the c.m. system.

The main tool for calculating multi-group constants from the EFF-1 file is the NJOY code [9] or its French version THEMIS. However, this code should at present be supplemented with the code GROUPXS [3] for the processing of continuum reactions stored in the MF6 format. An important part of the code concerns the c.m. to lab. conversion. This part has been tested thoroughly by intercomparisons with a routine made by Bersillon [12] and with a code based upon an analytical method by Shi Xiangjun et al. [13]. In the last mentioned paper an exact expression is given for the transformation of isotropic c.m. angular distributions. In a recent paper [14] we have also indicated a practical method to convert energy-angle distributions of particles emitted from (n,2n) reactions. The results of the conversion for the reduced first-order Legendre coefficient of the total neutron-emisson spectrum of lead at incident neutron energy of 14 to 15 MeV are shown in Fig. 1. The model calculations are in fair agreement with the experimental data of Takahashi et al. [15]. In view of the importance of the P1 term at emission energies from 1 to 5 MeV (cf. Sect. 2) this is an interesting result.

At KfK, Karlsruhe [16] the GROUPXS code has been extended with an option to calculate transfer matrices in a tabulated angular representation, in order to avoid the problems associated with truncated Legendre polynomials. This code prepares multi-group constants for the ANTRA1 code [23].

Multi-group transport libraries

With the above-mentioned tools the GEFF-1 multi-group transport library [4] was constructed. This library is based upon EFF-1 and consists of 175 neutron groups and 42 γ-groups. The group structure is VITAMIN-J, which contains all group boundaries of the VITAMIN-C and VITAMIN-E libraries developed at Oak Ridge. The library was a joint effort of various European laboratories and the NEA Data Bank. The library has been adopted by the European laboratories and the NET team. A larger set of data, in the same group structure (MATXS format), has been made at EIR, Würenlingen [17] by combining the EFF-1 data file with the more extensive JEF-1 data file and by increasing the number of temperatures and σ_p values. Efforts to create a Monte Carlo library for use in the MCNP code are in progress at various laboratories.

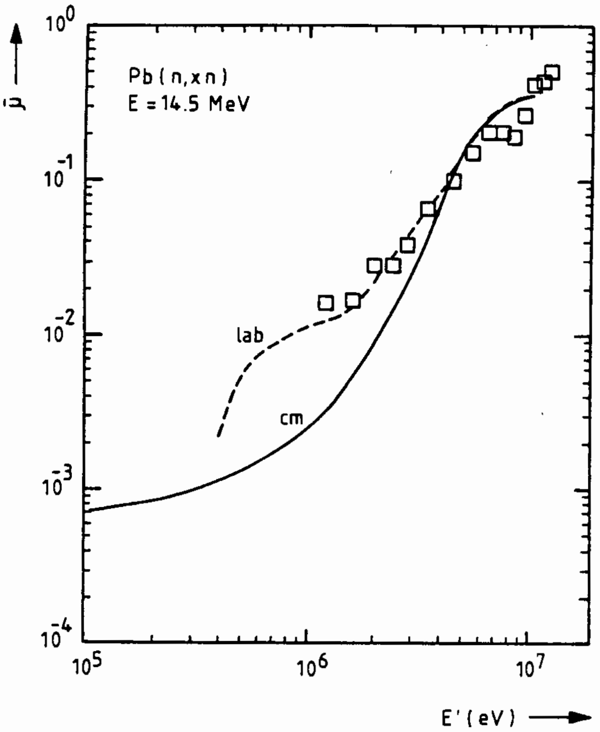

Fig.1 Transformation of the reduced first-order Legendre coefficient $\bar{\mu}$ from c.m. to lab. system. The incident energy of the Pb(n,xn) reaction considered is 15 MeV. The data points were evaluated from the experimental results of Ref.[15].

Benchmarking

In the framework of the benchmarking of the JEF-1 library the major shielding materials, also relevant to the NET blanket have been tested. The results were quite satisfactory [18].

In order to test the lead data an international benchmark exercize was defined at the IAEA Specialists' Meeting on Nuclear Data for Fusion Reactor Technology held at Dresden, December 1986 [19]. A calculational benchmark was defined in which the neutron leakage spectrum of lead shells surrounding a 14 MeV neutron source [20,21] had to be calculated. The EFF-1 lead file was distributed [22] in three versions: the original file with energy-angle coupled distributions (MF6), a file with energy-integrated angular distributions (MF4) and angle-integrated energy distributions (MF5) and a file with isotropic angular distributions in the c.m. system. Moreover, the GEFF-1 multi-group constants [4] were included. The results will be discussed at a meeting at the IAEA in Vienna, November 1988.

Fischer et al. [23] has very recently performed some calculations on the Dresden [20] and Osaka [21] integral lead shell experiments. The results are that the EFF-1 data file predicts the shape of the neutron leakage spectra quite well, although there is still a discrepancy with respect to the absolute magnitude, indicating that the (n,2n) cross-section needs to be increased by about 10% to 13%, respectively, cf. Fig. 2. In view of the fact that there are also indications from differential measurements that the (n,2n) cross-section needs to be increased (by 3 to 5%) this is an encouraging result.

An other interesting result is the effect of anisotropic continuum emission spectra as introduced in EFF-1, which is visible in Fig. 2 at the left-hand side of the elastic peak. The assumption of isotropy in the continuum part of the emission spectrum as adopted in ENDF/B-IV and V leads to a lower leakage spectrum at emission energies from 1 to 10 MeV. Since the low-energy range below 5 MeV gives the most important contribution to the total multiplication, the anisotropy effect may be quite important, see also Fig. 1. It is concluded in Ref. [23] that a P1 calculation already gives satisfactory results. However, the main problem of the ENDF/B-IV and -V evaluations for Pb is that the shape of the emission spectrum is not in agreement with experimental data, cf. Fig. 5.

Similar benchmark calculations will be performed for Be-shell experiments at KfK. Preliminary results show that if the EFF-1 evaluation is used the total neutron production is 8 to 14% higher than calculated with ENDF/B-IV [16].

There are also some calculations performed by Pelloni and Cheng [24] for blankets including regions with Li$_{17}$Pb$_{83}$ (30% ^{6}Li enrichment) of different thicknesses. The calculations were performed with ENDF/B-V.2 and EFF-1 libraries in which there are no differences in the cross-sections for ^{6}Li and ^{7}Li. The results indicate differences in the tritium breeding rate (main component due to ^{6}Li), apparently caused by the different energy and angle distributions of lead in the two evaluations (the energy-angle integrated cross-sections are not much different, except perhaps near the threshold). Some of the results, which still need further interpretation, are given in Table 2. Note that in Ref. [24] a version of EFF-1 without angle-energy correlations for the continuum cross-sections was used; still the angular distributions were anisotropic in the c.m. system, in contrast to those of ENDF/B-V.

Table 2. Calculated reaction rates in a LiPb blanket [24]

	20 cm		60 cm	
Reaction	EFF-1	ENDF/B-V^a	EFF-1	ENDF/B-V^a
^{6}Li(n,t)	0.718	0.769	1.225	1.282
^{7}Li(n,n't)	0.014	0.015	0.018	0.018
TBR	0.732	0.784	1.243	1.300
Pb(n,2n)	0.585	0.625	0.714	0.714
Pb(n,γ)	0.027	0.032	0.059	0.064

a) The ^{6}Li and ^{7}Li cross-sections are identical in the two libraries.

It is interesting to note that differences in the energy and angular distributions may cause significantly large changes in the tritium breeding rate (TBR). For thick breeding zones the (n,2n) reaction rates are equal because the cross-sections for (n,2n) are almost the same. Still there are differences in the breeding rate, apparently due to the different scattering distributions. If this preliminary explanation is correct, it demonstrates the importance of a very accurate treatment of double-differential cross-sections. Further benchmarking of the EFF-1 file with Li shells or LiPb shells is recommended.

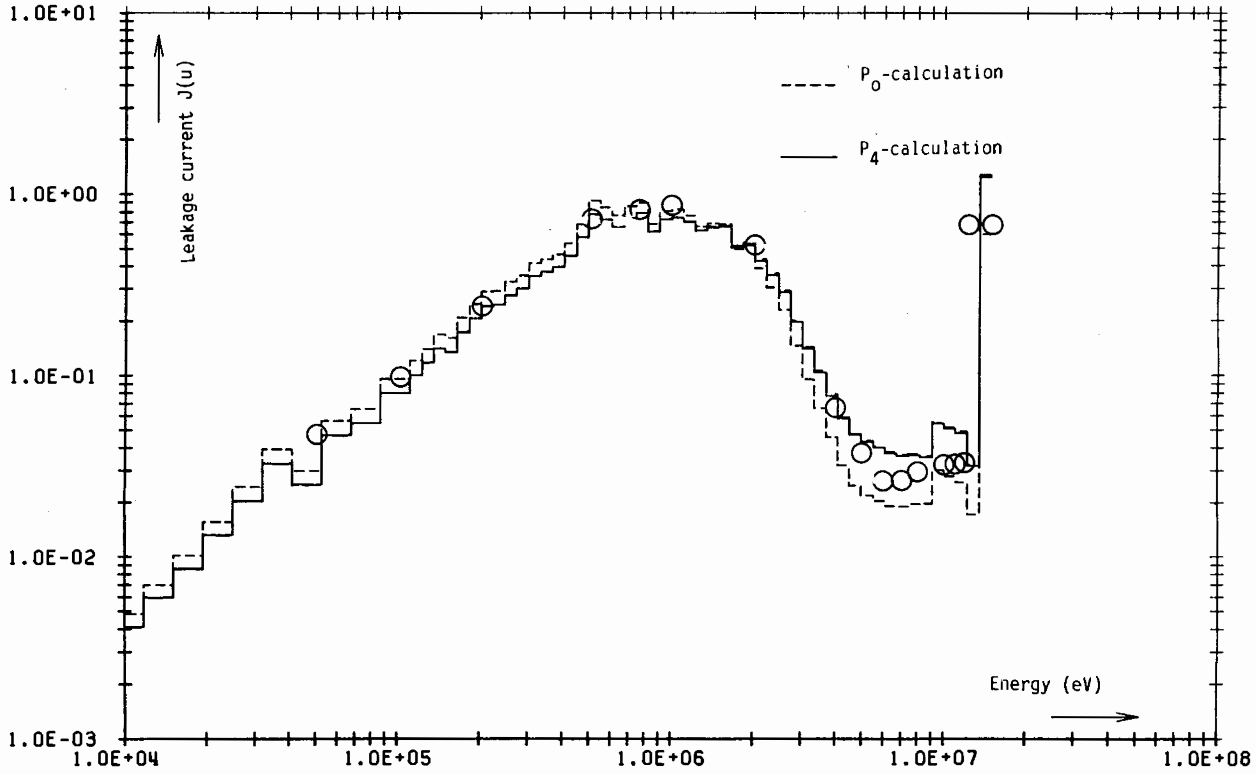

Fig. 2 Calculated and experimental leakage spectrum from a lead shell experiment performed at Dresden [20]. The thickness of the shell is 22.5 cm. Figure taken from Ref. [23].

3. Progress on and plans for EFF-2

The EFF-1 file already means a large improvement as compared to the until recently adopted data files based upon ENDF/B-IV. However, further updating is necessary, in particular with respect to the double-differential neutron emission cross-sections in the continuum and consistent differential photon-production cross-sections.

During the past decade the experimental situation with respect to the double-differential neutron emission spectra has been dramatically improved, at least in the important energy range between 14 and 15 MeV. Our understanding of the neutron emission spectra has been improved as well. The present status is reviewed by Seeliger et al. [25] and in the "horizontal" evaluation report by Vonach et al. [26]. With respect to the light materials new data have become available from the Osaka and Tohoku universities, JAERI, and recently also from CBNM, Geel.

At the same time the nuclear models to calculate these quantities (A > 20) have reached a status in which for practical purposes reliable predictions are possible by employing preequilibrium models incorporated into the code. In the most modern codes a unified description is followed, which means that just one model describes the precompound and the compound phases of the reaction process. With respect to the photon production cross-sections the modern codes calculate these data simulaneously with the neutron cross-sections and provide photon spectra for each reaction component. A new development is the introduction of preequilibrium γ-ray emission in the models and introduction of improved systematics for the E1, M1 and E2 photon strength functions. Recent review papers on this subject are given e.g.in Refs. [27-29] and also at this conference [30,31].

For light masses evaluations could be based upon R-matrix theory fitted to experimental data. For the purpose of the evaluation of coupled energy-angle distributions experimental data are indispensible. However, to interpret these measurements it is necessary to distinguish the various physical processes. One way to do this is the method developed at Birmingham University [32] in which relatively simple assumptions are made to compute the c.m. distributions, which are converted to the laboratory system, resolution-broadened and compared to experimental data. In an iterative process the c.m. quantities are adjusted until finally optimum agreement with the data is reached.

Many of these developments are actively followed or developed at the European laboratories involved in the EFF project.

Contents and format

The contents of the EFF-2 library will be the same as that of EFF-1 (Table 1), with the following extensions requested by the NET team: He, Mg, S, Ca, Co, Sn, Ta and In. The EFF-2 file will be supplementary to the JEF-2 file, with emphasis on evaluations for ^{7}Li, ^{9}Be, Al, Si, Fe, Cr, Ni and Pb. The format will be ENDF-VI with some restrictions on the use of the rather extensive possiblitites. In this respect we hope to benefit from the experiences with the EFF-1 lead file. We intend to allow minimum deviations from the lead example, except that it has been decided to provide the user with MF6 data in the laboratory format. Furthermore, for the light materials the

Legendre-polynomial representation will be replaced by a point-wise representation in the cosine of the scattering angle: (E,E',μ) scheme.

The evaluations for the ENDF/B-VI standard reactions: H(n,n), ^{6}Li(n,t) and ^{10}B(n,α) will be inserted in the EFF-1 evaluations with appropriate adjustments of the cross-sections for the other reactions and translation to the ENDF-VI format. The revised scattering-law data of JEF-2 will be added to the light-element evaluations.

^{7}Li

For ^{7}Li a completely new evaluation will be made in a cooperative effort of Birmingham University, CBNM-Geel, ECN-Petten and Los Alamos National Laboratory. The energy-angle integrated data are based upon the very recent re-evaluation by Young [7] based upon a least-squares analysis including the newest data. The results are not much different from those of EFF-1. However, the uncertainty has been significantly reduced for the important tritium production reaction ^{7}Li(n,n't). Its cross-section at 14.1 MeV is 300.7 mb with an uncertainty of only 2.5%. For the other important reaction, the total neutron emission, the cross-section at 14.1 MeV is 411 mb, close to the evaluation of Vonach [33]: 413 ± 14 mb.

Table 3 Important 14.1 MeV cross-sections

Reaction	EFF-1	Vonach [33]	EFF-2PR
$^{7}\mathrm{Li}(n,n_1\gamma)$	66.3	-	66.3
$^{7}\mathrm{Li}(n,n_2)t\alpha$	128.0	-	111.3
$^{7}\mathrm{Li}(n,n_3)t\alpha$	-	-	-
$^{7}\mathrm{Li}(n,n')t\alpha$	302.6	300 ± 10	300.7
$^{7}\mathrm{Li}(n,2n)^{6}\mathrm{Li}$	30.8	53 ± 5	31.6
$^{7}\mathrm{Li}(n,2n)d\alpha$	20.1		20.1
$^{7}\mathrm{Li}(n,d)^{6}\mathrm{He}$	10.2	7 ± 3.5	7
$^{7}\mathrm{Li}(n,np)^{6}\mathrm{He}$	-	7 ± 3.5	7
$^{7}\mathrm{Li}(n,nem)$	404	413 ± 14	411

The first two reactions proceed through the 0.4776, 4.63 and 6.68 MeV excited states and will be stored in MT51, 52 and 53, respectively. Their neutron angular distributions are given in MT4, as usual, because the reactions represent sequential two-body scattering through a compound ^{8}Li* state. The neutron angular distribution of the (n,n'γ) reaction has been deduced by Liskien [34] from Doppler shift measurements of the photons. The distributions of the t and α break-up particles will be given in MF6. The $(n,n_3)t\alpha$ reaction component needs to be seperated from the (n,n')tα reaction in which it has been included in Table 3.

The main improvement of the evaluation should come from revised continuum neutron emission cross-sections of which the main component is the $(n,n_c)t\alpha$ reaction (MT91). The energy-angle distributions of the neutrons and the break-up products will be stored in MF6 (lab. system). The reason for storing most of the inelastic scattering cross-sections in MF3 and MF6 under MT=91, rather than in MF3 and MF4 under MT= 51-90 is that the main process is not inelastic scattering followed by break-up of ^{7}Li*, but rather tritium emission from the compound state ^{8}Li*, followed by α decay of the ^{5}He ground state, leaving a fast neutron: (n,t)^{5}He → α,n. The kinematics of this reaction and (thus) the laboratory distributions are different from the usual two-body compound inelastic scattering. An additional difficulty is that due to the finite lifetime of the ^{5}He ground state, it has a width of about 1 MeV, causing additional broadening of the particle distributions. There are still two other processes contributing to MT=91, i.e. sequential two-body break-up through the ^{5}He first-excited state: (n,t)^{5}He* → α,n ,and three-body direct break-up: (n,n'αt). These three processes have different kinematics and will be distinguished in MF6 by utilizing the LIP parameter (LIP = 1,2,3). The lumped result will be stored in a derived file under LIP = 0. This procedure closely follows the physical ideas given in Refs. [32,35, 36].

The five different processes contributing to the tritium production mentioned above are indicated schematically in Fig. 3, taken from Ref. [34]. The splitting into components is necessary because of the different particle distributions of the components. As constraints the values such as given in Table 3 (last column) will be adopted.

A preliminary result of a calculation of the double-differential neutron emission including elastic scattering, inelastic scattering followed by γ-ray emission or ^{7}Li* break-up and sequential two-body scattering through the ^{5}He ground state is given by Beynon and Sim [36], who have compared their data with experimental results of Chiba et al. [37] at incident energies of 5.4, 6.0 and 14.2 MeV. At the first two energies there is good agreement, at higher energies more processes should be included. The results are only indicative, as a proper resolution broadening is still necessary for a good comparison with the experimental data. Furthermore, the recent data measured at CBNM [38] at incident energies between 1.6 and 13.8 MeV will be included.

Be

For ^{9}Be the plans are very similar to those for ^{7}Li. Here the important cross-section is the (n,2n) cross-section and its coupled energy-angle distributions. More precisely: the reaction is denoted as ^{9}Be(n,2n)2α. However there are many different physical processes that can be distinguished. The most convenient way to store these data is in MF3 and MF6 under MT = 16. Again the different processes could be distinguished by means of the LIP parameter. All processes show continuum spectra or broad levels except for the following one proceeding through the second excited state of ^{9}Be:

$$
\begin{array}{llllll}
{}^{9}\mathrm{Be}+n & \rightarrow {}^{10}\mathrm{Be}^{*} & \rightarrow {}^{9}\mathrm{Be}^{*}_{*}+n_2 & & & \\
 & & {}^{9}\mathrm{Be} & \rightarrow {}^{8}\mathrm{Be}^{*}_{*}+n' & & \\
 & & & {}^{8}\mathrm{Be} & \rightarrow 2\alpha. &
\end{array}
$$

Since the first-emitted neutron has a fixed energy a sharp peak will appear in the neutron emission spectrum. Therefore, it is more convenient to store this process as an inelastic scattering (MT=52) to the second-excited state, followed by break-up into a second neutron and two α paricles. File MF4 should be added to describe the first-emitted neutron, whereas MF6 should be used to describe the second neutron distributions and the distributions of the α-particles. It is not certain whether this representation is allowed according to the ENDF-VI rules, but it seems to be the most physical description. The other pro-

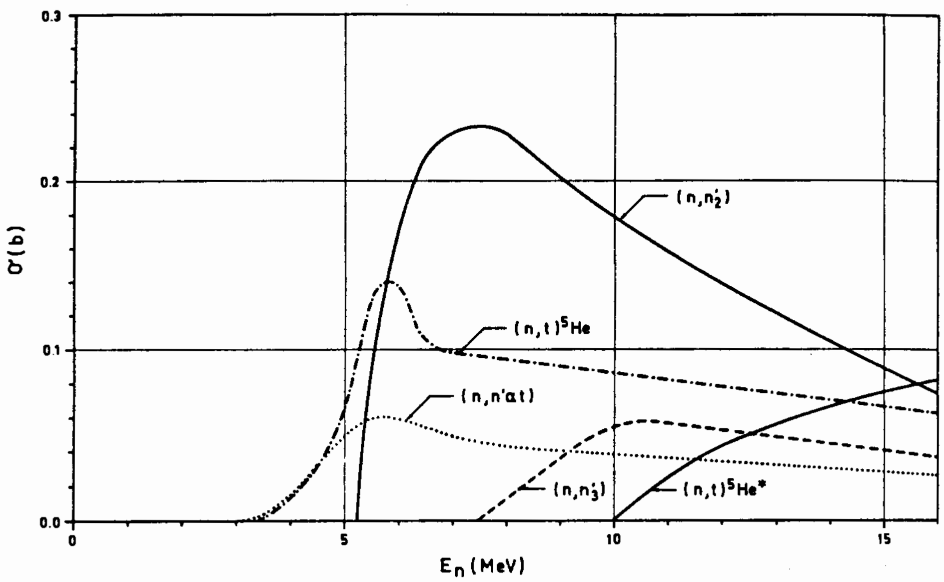

Fig. 3. Estimated size if the five processes contributing to the tritium production cross-section [34].

cesses yield continuous neutron emission spectra due to break-up and/or intermediate broad states, always yielding two neutrons and two α particles. According to Beynon and Sim [39] there is also a pure inelastic scattering cross-section: the ^{9}Be(n,n$_1\gamma$)^{9}Be reaction contributing to the total neutron emission cross-section (MT=51).

As in the case for ^{7}Li the main emphasis of the re-evaluation will be on the neutron-emission energy-angle distributions. For the angle-energy integrated data existing new evaluations (EFF-1 or the forthcoming Lawrence Livermore evaluation [40]) will be adopted. Some new data which need to be inserted are the results from the ^{9}Be(n,t) measurements performed at CBNM [41]. Using these data as constraints the method of Beynon [32,39] will be applied with iterative adjustments to the existing experimental results [10,20,42] and the forthcoming CBNM measurements.

Al and Si

For Al the new evaluation of ENEA-Bologna will be used, combined with the low-energy range of EFF-1. The new evaluation is based upon model calculations with the IDA code system [43]. With this system unified pre-equilibrium and equilibrium calculations, using realistic exciton state densities [44] have been performed. The energy-angle correlated angular distributions were obtained from the leading particle model, with the Kikuchi-Kawai scattering kernel adopted for emission from the initial exciton state. Angular-momentum conservation has been considered throughout the calculations. As an example of these calcultions Fig. 4 is shown [45]. For the direct inelastic scattering coupled-channel calculations have been performed. Although the evaluation has been completed, there is still some effort required to create a file in ENDF-VI format. This work is presently performed at Bologna.

For Si the EFF-1 evaluation will be compared with the evaluation of Hermsdorf [46], included in the BROND file. Probably the high-energy range of this evaluation is better than the present EFF-1 data. At ENEA-Bologna the two evaluations are intercompared at present.

Structural materials

For the structural materials Fe, Cr and Ni the revisions are made in a joint JEF-2 and EFF-2 effort. The new evaluations will be made for the isotopes rather than for the elements. The resolved-resonance ranges, extending to energies between 0.5 and 1.0 MeV have already been reevaluated in the framework of the JEF-2 programme. The laboratories responsible for these low-energy re-evaluations are: KfK-Karlsruhe (Fe), ENEA-Bologna (Cr) and jointly CEA-Cadarache, ECN-Petten and the NEA Data Bank (Ni). For Fe and Cr the Reich-Moore description is folllowed.

At higher energies the revisions fit into the EFF-2 programme. For Fe there is a cooperation between KfK-Karlsruhe and ENEA-Bologna; for Cr progress is made at Bologna and for Ni there is a cooperation between ECN-Petten and M. Uhl from IRK-Vienna. In all evaluations the double-differential neutron-emission cross-sections are considered as well as the photon-production cross-sections. In the cases of ^{58}Ni and ^{60}Ni the evaluations of Uhl [47] at energies above 1 MeV are already available. Work is in progress at ECN-Petten to reformat the library and to connect the data with the resolved-resonance range evaluated by Derrien [48]. For the minor Ni-isotopes adjustments of existing evaluations will be made. Additional effort is required to combine the isotopic evaluations for the purpose of a check of the experimental data available for the natural element. This is of particular interest for the double-differential neutron emisson cross-sections which should agree with the results of the recent "horizontal" evaluation of Vonach et al. [26] at 14.5 MeV.

Pb

For EFF-2 some modifications will be applied to the present EFF-1 evaluation. The main improvement is an increase of the (n,2n) cross-section at 14.1 MeV by about 5%, based upon a careful re-evaluation of Vonach [49]. This re-evaluation is based upon an analysis of the accurate value of the non-elastic cross-section and a determination of the inelastic scattering cross-section from the high-energy end of the neutron emisson spectrum as evaluated in Ref.[16]. The result is σ(n,2n) = 2193 ± 71 mb, which is close to the value of Fréhaut after a correction of about 10%: 2150 ± 160 mb. The correction of 10% is based

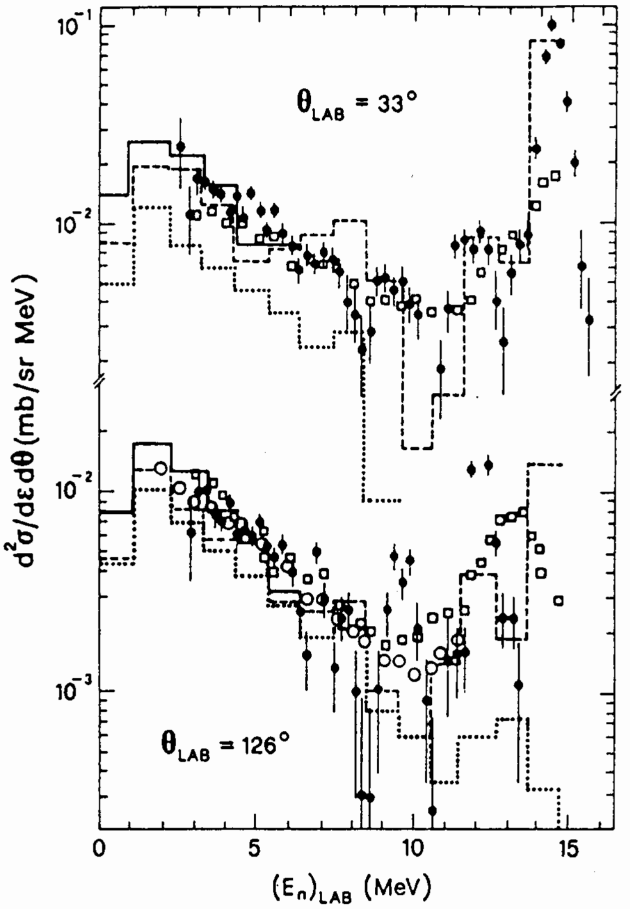

Fig. 4. Total 14.5 MeV neutron emission spectrum for Al at 33° and 126° (dotted curve: equilibrium component; dashed curve: eq.+ preeq. components from (n,n') and (n,2n); full curve includes additional processes as well). Figure taken from Ref. [45].

upon a systematical difference between activation data with the results of Fréhaut for many targets. The region near the threshold of the (n,2n) cross-section needs also some inspection.

The shape of the EFF-1 neutron emission cross-section spectrum at about 14.5 MeV is quite close to the recommended curve of Vonach [26], cf. Fig. 5. Still, some slight improvements are possible. In view of the importance of the low-energy range upto about 5 MeV we will concentrate on that region, guided by the results of both differential and integral measurements (Sect. 2). Recently, our understanding of the shape of neutron emission spectra has been greatly improved [25,26], It is by now clear that direct-collective effects give important contributions, in addition to the preequilibrium exciton contribution. The effect is that the high-energy end of the spectrum is much higher than predicted by the preequilibrium model. This was already realized during the EFF-1 evaluation of the neutron-emission spectra for lead, resulting in a horizontal extrapolation of the emission spectra at the highest emission energies, guided by the experimental data at 14.5 MeV. At other incident energies similar corrections were applied [2]. From the work of Seeliger [25], it is evident that these direct collective contributions are relatively more important at low incident energies, because the total collective contribution appears almost independent of incident energy (in the case of Nb). In EFF-2 we will concentrate on making improvements to the neutron-emisssion spectra at lower incident energies. A possible method to include direct-collective effects is to increase the number of levels for which (n,n') cross-sections are given. Since already 40 MT numbers (MT=51 to 90) are used in EFF-1, some lumping of levels is necessary to create vacant MT numbers. The extension of the discrete level excitation energy range requires additional statistical-model and DWBA calculations, This work is planned for EFF-2.

Some other minor changes will be applied, such as the addition of (n,p) and (n,α) reactions, the addition of a direct component to (n,γ) and adjustment of the photon production cross-section in order to correct the energy balance. Furthermore, a resolved-resonance range should be added in order to allow the user to perform proper self-shielding calculations. A comparison with other recent lead evaluations (ENDF/B-V,VI, BROND) is in progress. The next step (after EFF-2) would be to make evaluations for the individual isotopes rather than for the element.

4. European Activation File

The EFF-1 and -2 files are useful for neutron and photon transport calculations. Files may also be derived for damage, kinetic energy release and gas-production for the most important fusion reactor materials. However, for the calculation of activation and transmutation the number of materials in EFF-1,2 is much too low. This is due to the fact that a small contaminant may cause a large activation problem. Therefore a separate file, if possible consistent with EFF-2, is needed. The recent interest in low-activation materials in view of recycling or simple waste disposal (like shallow land burial) has accelerated the project to achieve such a file. The requirements of the European Activation File are: a complete data base for all stable isotopes ($A \leq 210$) and isotopes (including isomers) with half lifes longer than about 1 day, including uncertainty estimates. For the most important activation reactions detailed evaluations are necessary.

Important steps in the direction of a European Activation File have been made at ECN-Petten (supported by JRC-Ispra) and by AERE-Harwell. The results are presented in two contributions to this meeting [50,51]. The two laboratories have made libraries that are based upon the REAC data file of Mann et al. [52], with extensions and important renormalizations at 14.5 MeV to experimental data or results from systematics. In particular with respect to the systematics of cross-sections [53] and of isomer ratios [54] important progress has been made. As a by-product of the systematics uncertainty estimates are available for all reactions that have been normalized to the systematics. The REAC-ECN-3 data file [50] contains over 8000 reactions. There are 51 reactions that were completely re-evaluated to obtain reliable predictions of long-lived products, including uncertainty information. The current UK library is based upon REAC-ECN-2 with extensions and improvements. It also contains a consistent decay library. Because of intense cooperation the REAC-ECN-3 and the current UK activation library are very similar. The practice is that revisions are exchanged.

For the definition of a European Activation Library the starting point will be the current REAC-ECN-3 library. It will be extended with a number of reactions to obtain a very complete data base. In particular the (n,γ) data will be

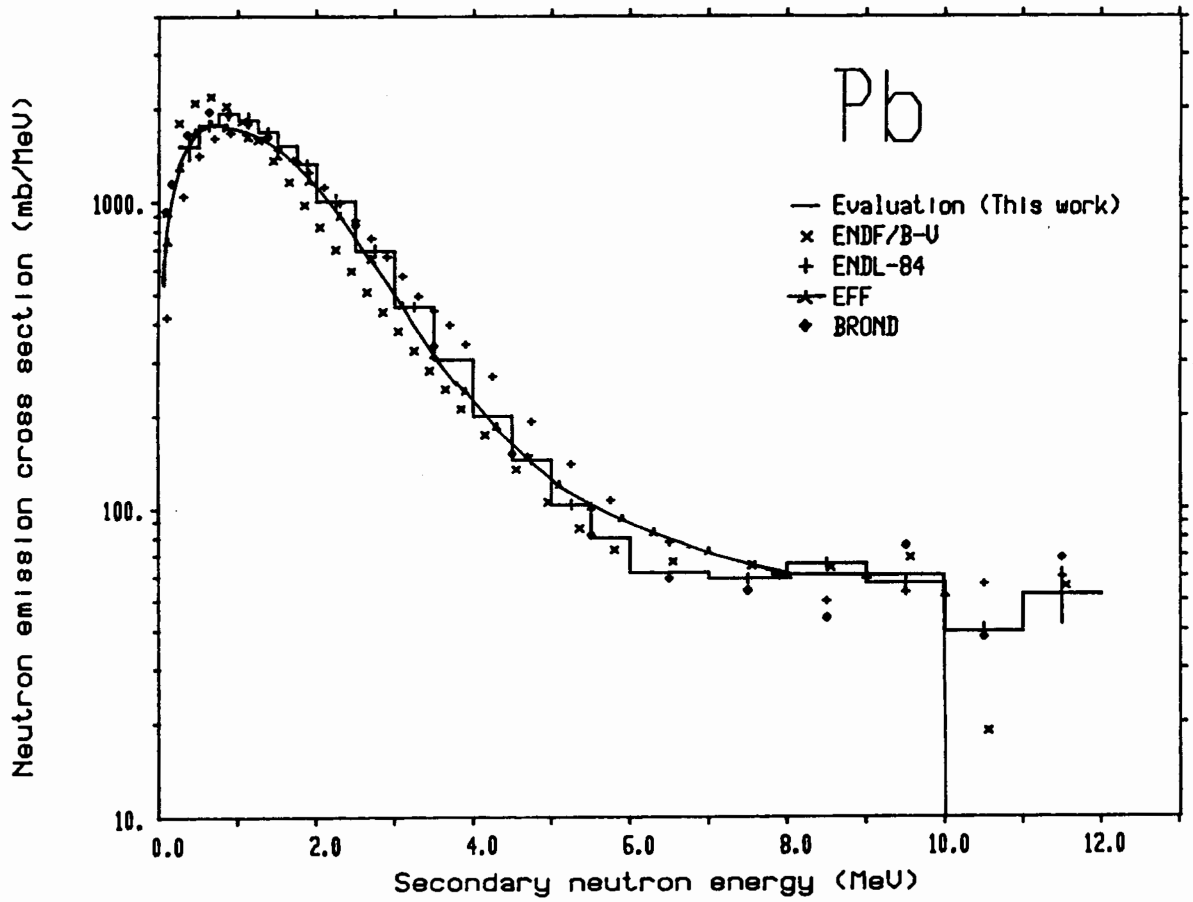

Fig. 5. Evaluated neutron emission spectra for Pb at 14 to 15 MeV. Figure taken from Ref. [26]. The histogram represents the evaluation of Vonach [26].

updated. These reactions are important at relatively low energies and therefore also the thermal and resonance ranges will be reconsidered. This is of importance in "thermal" blankets and the NET water-cooled reactor. Thus, EAF will become a general activation file, applicable in fission and fusion reactor technology. It is aimed to include evaluations of various European groups (e.g. AERE-Harwell, IRK-Vienna and ECN-Petten). A further development is an agreed tripartite cooperation with the U.S. (Dr. F.M. Mann, Richland, U.S.) to create a joint European-U.S. activation file.

5. Conclusions

The status of the EFF-project has been discussed. The EFF-1 library has been checked with integral experiments and benchmark calculations. Multigroup transport libraries based upon EFF-1/JEF-1 are being introduced for routine calculations of fission and fusion reactor systems in Europe. Their performance is expected to be much better than the previously used libraries based upon ENDF/B-IV. Meanwhile, work for EFF-2/JEF-2 is in good progress. Detailed plans for EFF-2 have been presented. Work for a supplementary, large activation file was also discussed.

As has already been mentioned the success of the project is partly due to international cooperation within Europe, due to the projects supported by the EC and the NEA Data Bank. However, further international cooperation is needed, and actually has already been established for many parts of the project: e.g. the cooperation with LASL on ^{7}Li and the recent tripartite agreement on the creation of a joint European-U.S. activation file. Due to the need to achieve one data file for ITER design calculations strong international cooperation is highly stimulated and it is hoped that this will lead to unrestricted distribution of the major regional data files in order to be able to intercompare, check and select the best possible data source for the design of future fusion reactors.

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