Part I

EVALUATIONS IN JEF-2.2

Introduction to Part I

The Joint Evaluated File Project, JEF, was started in the early 1980s as a co-operative effort between Member countries of the OECD Nuclear Energy Agency's Data Bank. The project brings together nuclear data evaluators and reactor physicists from Western European countries for the production and validation of libraries of evaluated nuclear data. The first nuclear data library, JEF-1, was distributed to Member countries for validation studies in 1985. Subsequent to the validation studies the library was made generally available. These studies showed that the performance of the library was an improvement over those previously available in the various Member countries, but it was recognised that further improvements were possible and were considered desirable. For this reason the JEF-2 library was developed.

A preliminary version of JEF-2 was produced early in 1990 and improved evaluations for a number of isotopes were included later in 1990 and in 1991. In parallel with this there was a period of processing and benchmark testing, which revealed the need for some corrections. As a result of these studies a revised version, JEF-2.2, was produced in the spring of 1993. This is the version which has been extensively validated.

- The development of JEF-2 has been closely linked to the European Fusion File project, EFF, and the associated European Activation File, EAF. These projects are sponsored by the European Community's Fusion Technology Programme. In particular the evaluations for structural material isotopes have been carried out jointly for the two projects, although differences in time scales of the two projects have resulted in there being some differences between JEF-2.2 and the later library EFF-2.4. JEF and EFF are currently being combined within the framework of the JEFF project to produce the JEFF-3 library, the first version of which (the JEFF-3 Starter File) became available for initial testing in 1999.

The European Activation File is more comprehensive than JEF-2.2 in the number of isotopes and range of reactions which are included. The emphasis is on the requirements for calculations of the activation of fusion reactor structural materials, which can involve a long sequence of transmutation reactions. Secondary energy and angular distributions are not treated, however, and the EAF is not designed for neutron transport calculations.

The JEF libraries are in ENDF-6 format, as are other libraries, such as the American library, ENDF/B-VI, the Japanese Library, JENDL-3.2, the Chinese library, CENDL-3, and the Russian library, BROND-2. This has made it possible to easily include evaluations from these other libraries in JEF, although JEF-2.2 predates the current versions of most of these other libraries. It is the earlier or preliminary versions of these libraries which have been the sources of some of the data included in JEF-2.2. The view has been taken that if there is a satisfactory evaluation in one of the other libraries it is better to adopt it rather than to produce a marginally different evaluation for use in JEF. Nevertheless, independent evaluations have been produced for the major actinide isotopes and structural material isotopes.

The adoption of ENDF-6 format has meant that the checking codes developed at Brookhaven and elsewhere, and the processing codes, NJOY (Los Alamos National Laboratory, LANL) and

LINEAR-RECENT-SIGMA1 (LLNL) can be used, although for some requirements (such as the treatment of resonance shielding effects) additional codes have been developed. Also, some neutronics programs require the preparation of data in forms different from those produced by the above codes and, for these, special purpose codes have been used. The policy has been to use the internationally available codes as much as possible, so as to avoid duplication. An NJOY User Group, co-ordinated and supported by the NEA Data Bank, has been active in validating each new version of the code.

The JEF library is divided into several sections, or tapes:

- *General purpose files*. These contain data for 312 isotopes. The upper energy of the cross-section data is 20 MeV and the lower energy 10^{-5} eV. For studies which require intermediate energy data, reference must be made to other sources at present but it is planned to include this energy range in JEFF-3.
- *Thermal scattering data*. Data is included for five moderating materials, H_2O, D_2O, graphite, beryllium and polyethylene are available in $S(\alpha,\beta)$ and pointwise form.
- *Fission yield data*. Independent and cumulative yield data are included for 21 isotopes (39 fissioning systems).
- *Decay data*. Information for about 2 340 radioactive isotopes are included. Of these isotopes 730 are fission products.

For photon interaction data the evaluation of Cullen, has been adopted.

The validation studies cover the following aspects:

- Thermal reactor neutronics benchmarks and analyses of irradiation experiments.
- Fast reactor neutronics benchmarks and analyses of irradiation experiments.
- Criticality system neutronics studies.
- Neutron and gamma ray shielding calculations.
- Delayed neutron studies.
- Decay heat predictions.

The studies have included calculations of the cross-section adjustments required to improve the predictions of thermal reactor, fast reactor and shielding neutronics properties.

In addition to the data being made available as standard ENDF-6 format files, they have also been incorporated in the JEF-PC system. This includes means for searching for items of data, for displaying the data and for making graphical intercomparisons of data in different evaluated libraries and also with the basic measured data stored in EXFOR. The primary cross-section data are also available in group form, together with standard weighting spectra for condensing the data. The primary cross-section group data can then be output for use elsewhere.

JEF Report 14 presents an intercomparison of simple integral cross-section data from JEF-2.2, ENDF/B-VI, JENDL-3.2, BROND-2 and CENDL-2. The thermal integral values are 2 200 m/s, Maxwellian averages and resonance integrals. The fast spectrum values are the 14 MeV and fission spectrum averages (the fission spectrum being Maxwellian with a temperature of 1.35 MeV). This comparison also permits one to see the materials and reactions treated in the different libraries.

Chapter 1

SUMMARY OF THE SOURCES OF JEF-2.2 EVALUATIONS IN THE GENERAL PURPOSE LIBRARY

Introduction

This chapter is divided into seven sections:

1. Light nuclides; JEF-2.2 Tape1 (Z < 24).
2. Structural materials; Tape 2 (Z = 25 to 30) and (Z = 31 (Ga) and Z = 40 to 42 from Tape 3).
3. Fission products (Z = 32 to 39 and 43 to 65).
4. Heavy materials (Z = 66 to 83).
5. Major actinides.
6. Minor actinides.
7. Standards and dosimetry reactions.

The choice of isotopes for the summary in the section concerning fission is somewhat arbitrary. Radioactive isotopes plus isotopes of elements in the mass ranges 79 to 113 and 123 to 157 have been selected.

The JEF-2.2 General Purpose Library is subdivided into "Tapes"; each Tape approximately corresponds to the sections of the present summary, Tape 1 containing data for the elements $_{1}$H to $_{23}$V.

Data for natural elements and isotopes

When data are given for both the natural element and the isotopes, it should be understood the data for the element should be used in neutron transport calculations in preference to the data summed over the isotopes. In EFF-2.4 there is no ambiguity, data being given for either the natural element or the isotopes. In JEF-2.2 both are given for Zr and Mo. The data for the natural element are potentially more accurate, because there are direct measurements for the element, but the data can be much more complicated to represent (and process) than the data for the isotopes. In some cases data are required for the isotopes as well as for the natural element, for example because they are fission products or important activation products.

Reactions treated in the files

The data are stored in ENDF-6 format, each section of a file being characterised by an MF and an MT number. The MF numbers used in the JEF-2.2 files are as listed in Table 1.

Table 1. MF numbers used in the JEF-2.2 files

MF = 1, MT = 451	Descriptive data*.
MF = 2	Resonance parameter data; in some cases just the scattering radius, MT = 151.
MF = 3	Reaction cross-sections; always present are the total, MT = 1 and the elastic scattering, MT = 2.
MF = 4	Secondary particle angular distribution data; always present for elastic scattering.
MF = 5	Secondary particle energy distribution data.
MF = 6	Coupled energy-angular distribution data for secondary particles.
MF = 7	Thermal neutron scattering law data – these comprise a separate library.
MF = 8, 9, 10	Radioactive nuclide production data.
MF = 12, 13, 14, 15	Photon production data.
MF = 33	Covariances for reaction cross-sections, included in only a few cases, primarily for standard reactions.

* For the fissile isotopes there is also:

MT = 452	Total neutron emission per fission
MT = 455,456	Delayed and prompt neutrons per fission
MT = 458	Components of the energy release in fission

All of the files include MF = 1, 2, 3 and 4, and almost all of the files also include MF = 5 for inelastic scattering to the continuum, MT = 91. In many cases there is also MF = 5, MT = 16 (n,2n), and in some cases also MT = 17 (n,3n), etc.

All files include the total (MT = 1) and the elastic scattering cross-section (MT = 2). All nuclides excepting tritium, ^{3}He and ^{4}He include (n,γ) (MT = 102) cross-sections. In some cases the derived cross-sections MT = 3, total non-elastic (used, in particular, in connection with photon production) and MT = 4, total inelastic (also used in connection with photon production) are included.

In some cases the following derived elastic scattering characteristics are included in the file:

MT = 251	The mean cosine of the scattering in the laboratory system.
MT = 252	The mean logarithm of the energy change in scattering.
MT = 253	The mean square logarithm of the energy change divided by 2 times the mean logarithm.

MF = 6 data

This section of the ENDF-6 format files contains coupled secondary energy-angular distribution data, and the interrelationship of energy and angle is important for fusion neutronics studies. Multi-group codes do not require the two distributions to be separated, the secondary energy distribution being produced for each P_n order. However, some neutronics codes (for example the MONK Monte Carlo code) do require separate data for the energy distributions and the angular distributions. We note that the policy in some data libraries has been to separate the MF = 6 coupled energy/angle data into MF = 4 (angular distributions) and MF = 5 (secondary energy distributions). This separation is not really necessary because there are processing programs available for producing separate files if the separation is required by the reactor physics code.

Another point relates to the inclusion in some EFF files of MF = 6 data for combined reactions; inelastic scattering to the continuum, plus (n,2n), etc. This has been done in two ways:

- First, the primary cross-sections for the separate reactions are given and the MF = 6 data are given for a combined reaction, MT = 10. However, this presents NJOY processing problems.

- Second, in the "users version" of the EFF file the primary cross-sections for the contributing individual reactions are omitted and data are given for a combined reaction, MT = 5.

Some reactor neutronics codes require the secondary distributions to be given for the separate reactions and the use of a combined reaction presents a problem. For neutron flux calculations the separation is not needed, it is only a problem of the data structuring of the codes. The separate reaction data are required for calculating reaction products, and it is convenient to have all of the required data in the same applications library. Separation of the secondary distribution data between the contributing reactions has been preferred for fission reactor applications and this has determined the choice of evaluation for JEF-2.2. This has resulted in some of the evaluations being different in JEF-2.2 from the corresponding EFF-2.4 evaluation.

A further important advantage of the MF = 6 section is that it permits the inclusion of energy distribution data for the emitted charged particles and recoiling nuclei. These can be used to calculate the atomic displacements associated with the reactions, the total energy of recoil being insufficient for this purpose. The angular distribution for these is usually given as isotropic, as it is also usually given for the photon emission.

Sources of the evaluations in JEF-2.2

Many of the evaluations adopted for JEF-2.2 have been carried over from JEF-1, with new evaluations having been produced only for the most important materials. In many cases these JEF-1 evaluations had been adopted from other libraries, such as ENDF/B-V and JENDL-2. However, in many cases they have been improved by the addition of charged particle production cross-sections from the REAC-ECN library, and in a number of cases the thermal and resonance region values have also been revised.

The revision of the resonance region has been made using BNL-325 Edition 3 or 4 [2], or "Neutron Cross-Sections", Vol. 1, Part A and Part B by Mughabghab [3,4].

The cross-sections added from REAC-ECN are for MT = 103 to 107, that is, for (n,p), (n,d), (n,T), (n,He3) and (n,α). In some cases MT = 111, (n,2p), has also been added. (Missing neutron producing reactions, such as (n,2n), (n,3n), (n,n′p) and (n,n′α) have not been added, in general.)

Data for light nuclides, JEF-2.2 Tape 1 (Z < 24)

The elements considered in this section are:

^{1}H, ^{2}He, ^{3}Li, ^{4}Be, ^{5}B, ^{6}C, ^{7}N, ^{8}O, ^{9}F, (^{10}Ne), ^{11}Na, ^{12}Mg, ^{13}Al, ^{14}Si, ^{15}P, ^{16}S, ^{17}Cl, ^{18}Ar, ^{19}K, ^{20}Ca, (^{21}Sc), ^{22}Ti, ^{23}V

Ne and Sc are absent from the library.

There are original JEF/EFF evaluations for ^{22}Na and isotopes of Ar, from RCN-2. Several of the evaluations adopted from other libraries have been revised. The only isotopes in this set for which resonance parameters are included are:

^{15}N, ^{22,23}Na, ^{31}P, ^{32,33,34}S, ^{36,38,40}Ar

Sources of the evaluations for the light isotopes

$^{1}_{1}$**H**	B-V capture, with LANL (1989) elastic scattering data (preliminary B-VI standard).
$^{2}_{1}$**H**	B-VI (LANL, 1990).
$^{3}_{1}$**H**	B-IV (LANL, 1967).
$^{3}_{2}$**H**	B-V, with 1989 preliminary B-VI data for (n,p)< 50 keV (preliminary B-VI standard).
$^{4}_{2}$**H**	B-IV (LANL, 1973).
$^{6}_{3}$**Li**	B-V, with 1989 B-VI revised (n,T) < 1 MeV (preliminary B-VI standard).
$^{7}_{3}$**Li**	EFF-1 (LANL, 1981, extended by ECN Petten).
$^{9}_{4}$**Be**	EFF-1 (LANL, 1979, revised and extended by ECN Petten).
$^{10}_{5}$**B**	Preliminary B-VI (LANL, 1989).
$^{11}_{5}$**B**	Preliminary B-VI (LANL, 1989).
$^{nat}_{6}$**C**	^{12}C (B-V) and ^{13}C (B-VI).
$^{14}_{7}$**N**	B-IV (LANL, 1973).
$^{15}_{7}$**N**	JENDL-3 (Fukahori, 1988).
$^{16}_{8}$**O**	B-VI (LANL, 1990).
$^{17}_{8}$**O**	B-VI (1978 evaluation).
$^{18}_{8}$**O**	Absent (a = 0.2%).
$^{19}_{9}$**F**	B-IV (ORNL, 1974).
$^{20}_{10}$**Ne**	Absent (a = 90.51%). *Note: Reaction σ data are included in EAF.*
$^{21}_{10}$**Ne**	Absent (a = 0.27%). *Note: Reaction σ data are included in EAF.*
$^{22}_{10}$**Ne**	Absent (a = 9.21%). *Note: Reaction σ data are included in EAF.*
$^{22}_{11}$**Na**	RCN-2 (Petten, 1982, with updates).
$^{23}_{11}$**Na**	JENDL-3 (Yamakoshi, 1987).
$^{nat}_{12}$**Mg**	B-IV (Drake and Fricke, 1974).
$^{27}_{13}$**Al**	EFF-1 (B-IV with revisions and additions by ENEA and ECN).
$^{nat}_{14}$**Si**	EFF-1 (B-IV with revisions and additions by ENEA and ECN).
$^{31}_{15}$**P**	JENDL-3 (Nakamura, 1987).
$^{32}_{16}$**S**	JENDL-3 (Nakamura, 1987).
$^{33}_{16}$**S**	JENDL-3 (Nakamura, 1987).
$^{34}_{16}$**S**	JENDL-3 (Nakamura, 1987).
$^{36}_{16}$**S**	JENDL-3 (Nakamura, 1987).
$^{nat}_{17}$**Cl**	B-IV (Allen and Drake, 1967).

$^{36}_{18}$**Ar**	RCN-2 (Petten, 1982, with revisions to 1987)
$^{38}_{18}$**Ar**	RCN-2 (Petten, 1982, with revisions to 1987).
$^{40}_{18}$**Ar**	RCN-2 (Petten, 1982, with revisions to 1987).
$^{nat}_{19}$**K**	B-IV (Drake, 1967).
$^{nat}_{20}$**Ca**	B-IV (Fu and Perey, 1971).
$^{45}_{21}$**Sc**	Absent.
$^{nat}_{22}$**Ti**	The evaluation by Phillis, Howerton and Smith (1977) (also adopted in B-V and carried over into B-VI).
$^{nat}_{23}$**V**	B-IV (ORNL, 1972). *Note: ^{nat}V is 99.75% ^{51}V, 0.25% ^{50}V.*

Summary of the reactions represented in the files for the light isotopes

The following tables summarise the reactions represented in the files. The reactions MT = 1 and 2 are in all files and so these are not indicated. The MF = 4 sections are also in all files for the reactions which require angular distribution data. MF = 6 data are only included (in the case of the set of light isotopes) for $^{2}_{1}$H and $^{11}_{5}$B (indicated in bold in the table below) and MF = 33, Covariance Data, only for $^{1}_{1}$H, $^{6}_{3}$Li, $^{7}_{3}$Li, $^{9}_{4}$Be and $^{nat}_{6}$C. The derived quantities, MT = 252-255, are present in a number of the files.

	MF = 3	**MF = 5, 6***	**MF = 12, 13, 14, 15**	**MF = 33**
	Primary σ	**Secondary E distribution**	**Photon production**	**Covariances**
$^{1}_{1}$**H**	102, 251-253		102	1, 2, 102
$^{2}_{1}$**H**	16, 102	**16**	102	
$^{3}_{1}$**H**	16, 251-253	16		
$^{3}_{2}$**H**	103, 104			
$^{4}_{2}$**H**	251-253			
$^{6}_{3}$**Li**	4, 24, 51-81, 102, 103, 105	24	57, 102	1, 2, 105
$^{7}_{3}$**Li**	4, 16, 24, 25, 51-82, 102, 104, 203-205, 207	16, 24, 25	51, 102	All + 851-859
$^{9}_{4}$**Be**	4, 51-83, 102-105, 107, 203-205, 207, 251-253, 700, 701		102, 701	1, 2, 4, 51-83, 102-105, 107
$^{10}_{5}$**B**	4, 51-85, 102-104, 107, 113, 600-603, 800, 801		4, 102, 103, 801	
$^{11}_{5}$**B**	4, 16, 22, 28, 51-60, 91, 102, 103, 105, 107	**16, 22, 28, 91, 102, 103, 107**	4, 102	
$^{nat}_{6}$**C**	4, 51-68, 91, 102, 103, 104, 107, 203, 204, 207	91	51, 102	1, 2, 4, 51-68, 91, 102-104, 107

* Entries in bold indicate MF = 6 data.

	MF = 3	MF = 5	MF = 12, 13, 14, 15
	Primary reactions	**Secondary E distribution**	**Photon production**
$^{14}_{7}$**N**	4, 16, 51-82, 102-105, 107, 108, 251-253, 600-604, 650, 653, 700, 701, 800-810	16	4, 102-105, 107
$^{15}_{7}$**N**	4, 16, 22, 28, 32, 33, 51-66, 91, 102-105, 107, 251	16, 22, 28, 32, 33, 91	3, 51-66, 102-105, 107
$^{16}_{8}$**O**	4, 51-88, 102-104, 107, 800-803		4, 22, 102, 103, 107
$^{17}_{8}$**O**	4, 16, 22, 28, 51-62, 91, 102-104, 107,	16, 22, 28, 91	
$^{19}_{9}$**F**	4, 16, 22, 28, 51-71, 91, 102-105, 107, 251-253	16, 22, 28, 91	3, 4, 102, 107
$^{22}_{11}$**Na**	4, 16, 22, 28, 51-61, 91, 102-104, 107, 108, 251	16, 91	
$^{23}_{11}$**Na**	4, 16, 22, 28, 51-77, 91, 102, 103, 107, 251	16, 22, 28, 91	3, 51-61, 102
$^{nat}_{12}$**Mg**	4, 16, 22, 28, 51-90, 91, 102, 103, 107, 251-253	16, 22, 28, 91	4, 16, 102
$^{27}_{13}$**Al**	3, 4, 16, 51-90, 102-105, 107, 203-205, 207 251-253	16	4, 28, 102, 103
$^{nat}_{14}$**Si**	3, 4, 16, 22, 28, 51-72, 91, 102-104, 107, 203, 204, 207, 251-253, 600-614, 649, 800-811, 849	16, 22, 28, 91, 649, 849	4, 22, 28, 102, 103, 107
$^{31}_{15}$**P**	4, 16, 22, 28, 51-56, 91, 102, 103, 107, 251	16, 22, 28, 91	
$^{32}_{16}$**S**	4, 16, 22, 28, 51-56, 91, 102, 103, 107, 251	16, 22, 28, 91	
$^{33}_{16}$**S**	4, 16, 22, 28, 51-55, 91, 102, 103, 107, 251	16, 22, 28, 91	
$^{34}_{16}$**S**	4, 16, 22, 28, 51-55, 91, 102, 103, 107, 251	16, 22, 28, 91	
$^{36}_{16}$**S**	4, 16, 22, 28, 51-55, 91, 102, 103, 107, 251	16, 22, 28, 91	
$^{nat}_{17}$**Cl**	4, 16, 22, 28, 51-63, 91, 102, 103, 107, 251-253	16, 22, 28, 91	3, 51-61, 91, 102
$^{36}_{18}$**Ar**	4, 16, 22, 28, 51-71, 91, 102-104, 107, 108, 251, 252	16, 91	
$^{38}_{18}$**Ar**	4, 16, 22, 28, 51-69, 91, 102-104, 107, 108, 251, 252	16, 91	
$^{40}_{18}$**Ar**	4, 16, 17, 22, 28, 51-71, 91, 102-104, 107, 108, 251, 252	16, 17, 91	
$^{nat}_{19}$**K**	4, 16, 22, 28, 51-67, 91, 102, 103, 107, 251-253	16, 22, 28, 91	51-56, 91, 102, 103, 107
$^{nat}_{20}$**Ca**	4, 16, 22, 28, 51-73, 91, 102-108, 111, 112, 251-253	16, 22, 28, 91	4, 22, 28, 102, 103, 107
$^{nat}_{22}$**Ti**	4, 16, 17, 22, 28, 51-53, 91, 102-107, 111, 112, 251-253	16, 17, 22, 28, 91	3, 102
$^{nat}_{23}$**V**	3, 4, 16, 22, 28, 51-54, 91, 102-107, 251-253	16, 22, 28, 91	3, 16, 22, 28, 102

The only nuclides which have radioactive decay data for reaction products (MF = 8, 9) are:

$^{2}_{1}$H	MT = 102
$^{6}_{3}$H	MT = 103, 105

Resonance parameter energy ranges

	Resolved range	Unresolved range
	Upper energy	Upper energy
$^{15}_{7}$**N**	5.46076 MeV	No UR range
$^{22}_{11}$**Na**	15 keV	100 keV
$^{23}_{11}$**Na**	350.0 keV	No UR range
$^{31}_{15}$**P**	543.51 keV	No UR range
$^{32}_{16}$**S**	1.56585 MeV	No UR range
$^{33}_{16}$**S**	260.0 keV	No UR range
$^{34}_{16}$**S**	480.0 keV	No UR range
$^{36}_{18}$**Ar**	46.5 keV	1.2 MeV
$^{38}_{18}$**Ar**	300 keV	1.2 MeV
$^{40}_{18}$**Ar**	652.65 keV	No UR range

Data for the structural materials, Z = 24 to 31 and 40 to 42

Materials considered

The materials being considered in this section are the following:

Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Zr, Nb, Mo

Isotopes of elements in the range Z = 32 to 38 are assumed to be primarily of interest as fission or activation products:

^{32}Ge, ^{33}As, ^{34}Se, ^{35}Br, ^{36}Kr, ^{37}Rb, ^{38}Sr, ^{39}Y

General features of JEF-2.2 and EFF-2.4

JEF-2.2 and EFF-2.4 are closely related evaluations. They include data for all of the naturally occurring materials except Zn, for which only an evaluation for the isotope ^{64}Zn is included. In JEF-2.2 photon production data are included for all excepting ^{52,53,54}Cr, ^{57,58}Fe, ^{64}Zn (Zr isotopes), Mo and isotopes. (We note that in EFF-2.4 photon production data have been included for all of the isotopes of Cr, Fe, Ni and Mo.)

Data are given for the natural element in the case of the following multi-isotopic elements: Cu, Ga, Zr (plus the isotopes), Mo (plus the isotopes). (In EFF-2.4 data are given only for the isotopes of Cu, Zr and Mo.)

Data are given for the constituent isotopes only (and not for the natural element) in the case of Cr, Fe, Ni. The monoisotopic elements ^{55}Mn, ^{59}Co, ^{93}Nb are also included.

There are original JEF-2.2 evaluations for the Cr isotopes, Fe isotopes, ^{58}Co (radioactive), ^{59}Ni (radioactive), ^{64}Zn, several Zr and Mo isotopes and ^{95}Nb (radioactive). The evaluations for Ga, Zr and Mo element and several isotopes, and ^{93}Nb have been adopted from other evaluations but extensively revised. The data for ^{55}Mn, ^{59}Co and ^{58,60,61,62,64}Ni have been adopted from other libraries. The Bologna evaluations for the Cr isotopes, and for the Fe isotopes in the higher energy ranges, have been described in a series of JEF/DOCs (for example, JEF/DOC-255, JEF/DOC-256, JEF/DOC-276, JEF/DOC-297, JEF/DOC-336). The Petten evaluations for the Ni isotopes are described in JEF/DOC-189, JEF/DOC-257, JEF/DOC-272 and JEF/DOC-302. These were adopted in EFF but not in JEF-2.2 because the use of the combined reaction, MT = 10, presented problems in some reactor physics codes, which require the data to be for the individual component reactions.

JEF-2.2 Tape 2 materials

$^{50}_{24}$**Cr**	ENEA Bologna (1989).
$^{52}_{24}$**Cr**	ENEA Bologna (1989).
$^{53}_{24}$**Cr**	ENEA Bologna (1989/90).
$^{54}_{24}$**Cr**	ENEA Bologna (1989).
$^{55}_{25}$**Cr**	B-IV (Takahashi, 1974). *Note: The (n,γ) cross-section is a dosimetry reaction.*
$^{54}_{26}$**Fe**	KfK Karlsruhe (resonance region) and ECN Bologna (1990).
$^{56}_{26}$**Fe**	KfK Karlsruhe (resonance region) and ECN Bologna (1991).
$^{57}_{26}$**Fe**	KfK Karlsruhe (resonance region) and ECN Bologna (1990).
$^{58}_{26}$**Fe**	KfK Karlsruhe (resonance region) and ECN Bologna (1989).
$^{58}_{27}$**Co (radioactive)**	RCN-2 (Petten).
$^{59}_{27}$**Co**	The ANL evaluation by A.D. Smith, *et al*. (ANL/NDM-107). *Note: The (n,γ) cross-section is a dosimetry reaction.*
$^{58}_{28}$**Ni**	B-VI (Hetrick, Fu and Larson, 1989) Rev. 1, 1991.
$^{59}_{28}$**Ni (radioactive)**	NEA/ECN (1987).
$^{60}_{28}$**Ni**	B-VI (Hetrick, Fu and Larson, 1989) Rev. 1, 1991.
$^{61}_{28}$**Ni**	B-VI (Hetrick, Fu and Larson, 1989) Rev. 1, 1991.
$^{62}_{28}$**Ni**	B-VI (Hetrick, Fu and Larson, 1989) Rev. 1, 1991.
$^{64}_{28}$**Ni**	B-VI (Hetrick, Fu and Larson, 1989) Rev. 1, 1991.
$^{nat}_{29}$**Cu**	B-IV (Drake and Fricke, 1973).
$^{nat}_{30}$**Zn**	Absent.
$^{64}_{30}$**Zn (48.6% abundance)**	RCN-2 (Petten, 1983, plus revisions).

Selected JEF-2.2 Tape 3 materials

$^{nat}_{31}$**Ga**	ENDL-78 plus charged particle production cross-sections from the ECN library.
$^{nat}_{40}$**Zr**	ENDL-78 with revision of the resonance region, based on BNL-325 4th Edition, plus charged particle production cross-sections from REAC-ECN-4.
$^{90}_{40}$**Zr**	JENDL-1 revised. Resonance parameters from BNL-325 4th Edition, and missing charged particle reaction data from REAC-ECN-4.
$^{91}_{40}$**Zr**	ENEA/CEA revised. Resonance parameters from BNL-325 4th Edition, and missing charged particle reaction data from REAC-ECN-4.
$^{92}_{40}$**Zr**	JENDL-1 revised. Resonance parameters from BNL-325 4th Edition, and missing charged particle reaction data from REAC-ECN-4.
$^{93}_{40}$**Zr (radioactive)**	ENEA/CEA revised. Resonance parameters from BNL-325 4th Edition, and missing charged particle reaction data from REAC-ECN-4.
$^{94}_{40}$**Zr**	ENEA/CEA revised. Resonance parameters from BNL-325 4th Edition, and missing charged particle reaction data from REAC-ECN-4.
$^{95}_{40}$**Zr (radioactive)**	ENEA/CEA revised. Resonance parameters from BNL-325 4th Edition, and missing charged particle reaction data from REAC-ECN-4.
$^{96}_{40}$**Zr**	JENDL-1 revised. Resonance parameters from BNL-325 4th Edition, and missing charged particle reaction data from REAC-ECN-4.
$^{93}_{41}$**Nb**	B-V with revised resonance parameters from BNL [3], and missing charged particle reaction data from REAC-ECN-4. *Note: The (n,n') ^{93m}Nb cross-section is used as a dosimetry reaction*.
$^{94}_{41}$**Nb (radioactive)**	B-V with revised resonance parameters from BNL-325 3rd Edition and missing charged particle reaction data from REAC-ECN-4.
$^{95}_{41}$**Nb (radioactive)**	ENEA/CEA with revised resonance parameters and missing charged particle reaction data from REAC-ECN-4.
$^{nat}_{42}$**Mo**	RCN-3 revised. Resonance parameters from BNL-325 4th Edition.
$^{92}_{42}$**Mo**	B-V revised. Resonance parameters from BNL-325 4th Edition, and missing charged particle reaction data from REAC-ECN-4.
$^{94}_{42}$**Mo**	B-V revised. Resonance parameters from BNL-325 4th Edition, and missing charged particle reaction data from REAC-ECN-4.
$^{95}_{42}$**Mo**	JENDL-1 revised. Resonance parameters from BNL-325 4th Edition, and missing charged particle reaction data from REAC-ECN-4.
$^{96}_{42}$**Mo**	B-V revised. Resonance parameters from BNL-325 4th Edition, and missing charged particle reaction data from REAC-ECN-4.
$^{97}_{42}$**Mo**	JENDL-1 revised. Resonance parameters from BNL-325 4th Edition, and missing charged particle reaction data from REAC-ECN-4.
$^{98}_{42}$**Mo**	ENEA/CEA revised. Resonance parameters from BNL-325 4th Edition, and missing charged particle reaction data from REAC-ECN-4.
$^{99}_{42}$**Mo (radioactive)**	B-V plus missing charged particle reaction data from REAC-ECN-4.
$^{100}_{42}$**Mo**	ENEA/CEA revised. Resonance parameters from BNL-325 4th Edition, and missing charged particle reaction data from REAC-ECN-4.

It should be noted that the Mo isotope data in EFF-2.4 are more recent than those in JEF-2.2 being from JENDL-3, with the addition of photon production data and a new evaluation of the MF = 6 data (secondary energy-angle distributions) by ENEA Bologna. Also, the Mo evaluations in B-VI are the same as B-V and date from 1980, which predates the JEF-2.2 evaluations.

Reactions represented in the evaluations

	MF = 3	MF = 5, 6*	MF = 12, 13, 14, 15	MF = 33
	Primary σ	**Secondary E distribution**	**Photon production**	**Covariances**
$^{50}_{24}$**Cr**	4, 16, 22, 28, 51-68, 91, 102-105, 107, 251	16, 22, 28, 91	4, 16, 102, 103, 107	
$^{52}_{24}$**Cr**	4, 16, 22, 28, 51-65, 91, 102-105, 107, 251	16, 22, 28, 91	4, 16, 102, 103, 107	
$^{53}_{24}$**Cr**	4, 16, 22, 28, 51-73, 91, 102-105, 107, 251	16, 22, 28, 91	4, 16, 102, 103, 107	
$^{54}_{24}$**Cr**	4, 16, 22, 28, 51-66, 91, 102-105, 107, 251	16, 22, 28, 91	4, 16, 102, 103, 107	
$^{55}_{25}$**Mn**	3, 4, 16, 17, 22, 28, 51-55, 91, 102-104, 106, 107, 251-253	16, 17, 22, 28, 91	3, 51-55, 102,	
$^{54}_{26}$**Fe**	4, 16, 22, 28, 51-57, 91, 102-105, 107	16, 22, 28, 91	4, 16, 102, 103, 107	
$^{56}_{26}$**Fe**	4, 16, 22, 28, 51-82, 91, 102-105, 107, 251	16, 22, 28, 91	4, 16, 102, 103, 107	
$^{57}_{26}$**Fe**	4, 16, 22, 28, 51-65, 91, 102-105, 107, 251	16, 22, 28, 91	4, 16, 102, 103, 107	
$^{58}_{26}$**Fe**	4, 16, 22, 28, 51-67, 91, 102-105, 107, 251	16, 22, 28, 91	4, 16, 102, 103, 107	
$^{58}_{27}$**Co**	4, 16, 22, 28, 51-62, 91, 102-104, 107, 251	16, 91		
$^{59}_{27}$**Co**	4, 16, 22, 28, 32, 33, 51-69, 91, 102-108, 111, 112	16, 22, 28, 32, 33, 91	3, 102	1, 16, 103, 107
$^{58}_{28}$**Ni**	3, 4, 16, 22, 28, 51-58, 91, 102-104, 107	**16, 22, 28, 51-58, 91, 103, 107**	51-58, 102	All
$^{59}_{28}$**Ni**	3, 16, 22, 28, 32, 34, 102-107, 111		3, 102	
$^{60}_{28}$**Ni**	3, 4, 16, 22, 28, 51-61, 91, 102-104, 107	**16, 22, 28, 51-61, 91, 103, 107**	51-61, 102	All
$^{61}_{28}$**Ni**	3, 4, 16, 28, 51-58, 91, 102, 103, 107, 111	**16, 28, 51-58, 91, 103, 107**	51-58, 102	All
$^{62}_{28}$**Ni**	3, 4, 16, 22, 28, 51-54, 91, 102-104, 107	**16, 22, 28, 51-54, 91, 103, 107**	51-54, 102	All
$^{64}_{28}$**Ni**	3, 4, 16, 22, 28, 51-52, 91, 102-104, 107	**16, 22, 28, 51-52, 91, 103, 107**	51-52, 102	All
$^{nat}_{29}$**Cu**	4, 16, 17, 22, 28, 51-61, 91, 102-104, 106, 107, 251-253	16, 17, 22, 28, 91	3, 102,	
$^{64}_{30}$**Zn**	4, 16, 22, 28, 51-67, 91, 102, 103, 107, 251	16, 91		

* Entries in bold indicate MF = 6 data.

Resonance parameter data

	Resolved resonance range	Unresolved range
	Upper energy (in keV)	Upper energy
$^{50}_{24}$**Cr**	595.0	No UR
$^{52}_{24}$**Cr**	637.0	No UR
$^{53}_{24}$**Cr**	248.0	No UR
$^{54}_{24}$**Cr**	400.0	No UR
$^{55}_{25}$**Mn**	80.0	No UR
$^{54}_{26}$**Fe**	500.0	No UR
$^{56}_{26}$**Fe**	862.0	3.0 MeV
$^{57}_{26}$**Fe**	200.0	No UR
$^{58}_{26}$**Fe**	370.0	3.0 MeV
$^{58}_{27}$**Co**	596.41	No UR
$^{59}_{27}$**Co**	100.0	No UR
$^{58}_{28}$**Ni**	812.0	No UR
$^{59}_{28}$**Ni**	10.0	No UR
$^{60}_{28}$**Ni**	450.0	No UR
$^{61}_{28}$**Ni**	70.0	No UR
$^{62}_{28}$**Ni**	600.0	No UR
$^{64}_{28}$**Ni**	600.0	No UR
$^{nat}_{29}$**Cu**	30.0	No UR
$^{64}_{30}$**Zn**	75.0	200 keV

	MF = 3	MF = 5, 6*	MF = 12, 13, 14, 15	MF = 2
	Primary σ	**Secondary E distribution**	**Photon production**	**Resonance range Resolved/UR (in keV)**
$^{nat}_{31}$**Ga**	4, 16, 91, 102, 103, 107	16, 91	3, 102	None
$^{nat}_{40}$**Zr**	4, 16, 17, 51-58, 91, 102, 103, 251-253	16, 17, 91	3, 102	Isotope dependent
$^{90}_{40}$**Zr**	4, 51-64, 91, 102-107, 111, 251	91		131.4/No UR
$^{91}_{40}$**Zr**	4, 16, 28, 51-64, 91, 102-107, 111, 251, 252	16, 28, 91		17.0/100.0
$^{92}_{40}$**Zr**	4, 51-66, 91, 102-107, 111, 251	91		34.0/No UR
$^{93}_{40}$**Zr**	4, 16, 22, 28, 51-62, 91, 102-107, 111, 251, 252	16, 22, 28, 91		117.0/50.0
$^{94}_{40}$**Zr**	4, 51-60, 91, 102-107, 111, 251	91		67.7/No UR
$^{95}_{40}$**Zr**	4, 16, 51-64, 91, 102-107, 111, 251, 252	16, 91		3.0/50.0
$^{96}_{40}$**Zr**	4, 16, 28, 51-53, 91, 102-107, 111, 251	16, 91		56.2/100.0
$^{93}_{41}$**Nb**	4, 16, 17, 22, 51-62, 91, 102-107, 111, 251-253	16, 17, 22, 91	3, 102	7.351/100.0
$^{94}_{41}$**Nb**	4, 51-58, 91, 102-107, 111, 251-253	91		61.649/No UR
$^{95}_{41}$**Nb**	4, 16, 51-55, 91, 102-107, 111, 251, 252	16, 91		1.0/50.0
$^{nat}_{42}$**Mo**	4, 16, 51-70, 91, 102, 103, 107, 251	16, 91		Isotope dependent
$^{92}_{42}$**Mo**	4, 51-56, 91, 102-107, 111, 251-253	91		31.57/No UR
$^{94}_{42}$**Mo**	4, 51-57, 91, 102-107, 111, 251-253	91		8.08/No UR
$^{95}_{42}$**Mo**	4, 51-64, 91, 102-107, 111, 251	91		2.1684/No UR
$^{96}_{42}$**Mo**	4, 51-56, 91, 102-107, 111, 251-253	91		8.161/No UR
$^{97}_{42}$**Mo**	4, 51-64, 91, 102-107, 111, 251	91		1.9568/No UR
$^{98}_{42}$**Mo**	4, 16, 51-69, 91, 102-107, 111, 251, 252	16, 91		12.214/No UR
$^{99}_{42}$**Mo**	4, 51-56, 91, 102-107, 111	91		None
$^{100}_{42}$**Mo**	4, 16, 51-62, 91, 102-107, 111, 251, 252	16, 91		15.398/50.0

Fission products and activation products

The fission and activation products in this group are isotopes of the following elements:

JEF-2.2 Tape 3, Fission Products I	^{32}Ge, ^{33}As, ^{34}Se, ^{35}Br, ^{36}Kr, ^{37}Rb, ^{38}Sr, ^{39}Y, ^{43}Tc, ^{44}Ru, ^{45}Rh, ^{46}Pd, ^{47}Ag

This tape also includes ^{31}Ga, ^{40}Zr, ^{41}Nb and ^{42}Mo, reviewed in the previous section.

JEF-2.2 Tape 4, Fission Products II	^{48}Cd, ^{49}In, ^{50}Sn, ^{51}Sb, ^{52}Te, ^{53}I, ^{54}Xe, ^{55}Cs, ^{56}Ba, ^{57}La, ^{58}Ce, ^{59}Pr

JEF-2.2 Tape 5, Fission Products III	^{60}Nd, ^{61}Pm, ^{62}Sm, ^{63}Eu, ^{64}Gd, ^{65}Tb

The 169 isotopes included

$^{72,73,74,76}_{32}$Ge	$^{121,123,124,125,126}_{51}$Sb
$^{75}_{33}$As	$^{120,122,123,124,125,126,127m,128,129m,130,132}_{52}$Te
$^{74,76,77,78,80,82}_{34}$Se	$^{127,129,130,131,135}_{53}$I
$^{79,81}_{35}$Br	$^{124,126,128,129,130,131,132,133,134,135,136}_{54}$Xe
$^{78,80,82,83,84,85,86}_{36}$Kr	$^{133,134,135,136,137}_{55}$Cs
$^{85,86,87}_{37}$Rb	$^{134,135,136,137,138,140}_{56}$Ba
$^{84,86,87,88,89,90}_{38}$Sr	$^{139,140}_{57}$La
$^{89,90,91}_{39}$Y	$^{140,141,142,143,144}_{58}$Ce
$^{99}_{43}$Tc	$^{141,142,143}_{59}$Pr
$^{96,98,99,100,101,102,103,104,105,106}_{44}$Ru	$^{142,143,144,145,146,147,148,150}_{60}$Nd
$^{103,105}_{45}$Rh	$^{147,148,148m,149,151}_{61}$Pm
$^{102,104,105,106,107,108,110}_{46}$Pd	$^{144,147,148,149,150,151,152,153,154}_{62}$Sm
$^{107,109,111}_{47}$Ag	$^{151,152,153,154,155,156,157}_{63}$Eu
$^{nat,106,110,111,112,113,114,115m,116}_{48}$Cd	$^{154,155,156,157,158,160}_{64}$Gd
$^{113,115}_{49}$In	$^{159,160}_{65}$Tb
$^{112,114,115,116,117,118,119,120,122,123,124,125,126}_{50}$Sn	

In all of the evaluations missing charged particle reaction data were added (in 1989) from the REAC-ECN-4 library, so that the reactions complete the range MT = 102-107, plus 111. Where necessary, spin values have been randomly assigned using the code RNDSPIN. The resonance flag has been set to MLBW. In most cases where resonance parameters are included they are based on Refs. [2,3].

The capture cross-sections of a number of isotopes have been adjusted at ECN Petten to take account of the results of the analyses of fast reactor integral measurements.

The evaluations are considered in two groups, those based on ENDF/B-V (or B-IV in the case of ^{nat}Cd and three isotopes of Gd) and those from other sources.

This second group comprises evaluations based on the RCN (Petten), ENEA (Bologna) and ENEA/CEA evaluations. Two evaluations have been based on JENDL-1 (^{128}Te and ^{157}Gd) and one on JENDL-2 (^{155}Gd). The file for ^{89}Y is based on an evaluation by A.B. Smith (ANL). Petten revisions to the inelastic scattering data are described in JEF/DOC-195 by H. Gruppelaar and G.J.M. Janssen [5] and other revisions in JEF/DOC-275 by H. Gruppelaar [6].

The files for the following isotopes are based on RCN evaluations:

^{99}Tc, ^{101}Ru, ^{103}Rh, ^{104,106,107,108,109}Pd, ^{109}Ag, ^{112}Sn, ^{129}I, ^{133}Cs, ^{139}La, ^{141}Pr, ^{144,145,146,148}Nd, ^{147}Pm, ^{147,149,152}Sm

The files for the following isotopes are based on ENEA/CEA evaluations:

^{103}Ru, ^{111}Cd, ^{137}Cs, ^{138,140}Ba, ^{141,142,144}Ce, ^{155}Eu, ^{156}Gd, ^{159}Tb

The files for the following isotopes are based on ENEA evaluations:

^{105}Pd, ^{135}Cs, ^{143}Nd, ^{151}Sm

A number of natural isotopes are missing from JEF-2.2. These are as follows:

$^{109}_{46}$Pd (26.8%)
$^{108}_{48}$Cd (0.885%)
$^{132}_{56}$Ba (0.097%)
$^{138}_{57}$La (0.089%)
$^{136}_{58}$Ce (0.19%)
$^{138}_{58}$Ce (0.25%)
$^{152}_{64}$Gd (0.2%)

Characteristics of the first group of evaluations, based on B-V (or B-IV)

For all excepting the isotopes ^{78,80,82,83,84,86}Kr, ^{107}Ag, ^{113}Cd, ^{129}I, ^{124,126,128,129,130,131,132,134,136}Xe, ^{151,152,153,154}Eu the reactions are limited to elastic and inelastic scattering plus the range MT = 102-107, and 111. The elastic and inelastic scattering are isotropic and the inelastic scattering continuum secondary energy distribution (MF = 5, MT = 91) is an evaporation spectrum.

The isotopes ^{78,80,82,83,84,86}Kr, ^{107}Ag, ^{113}Cd, ^{129}I, ^{124,126,128,129,130,131,132,134,136}Xe, ^{151,152,153,154}Eu include (n,2n) (MT = 16). $^{83\text{-}86}$Kr, ^{129}I, ^{124,126,128,129,130,131,132,134,136}Xe, ^{151,152,153,154}Eu also include (n,3n), (MT = 17). ^{129}I also includes MT = 22 and 28.

Some evaluations also include the derived parameters MT = 251-253.

There are unresolved resonance ranges only for ^{154}Sm, ^{151,152,153,154}Eu.

There are no resonance parameters for the following isotopes:

^{85}Kr, ^{86}Rb, ^{89,90}Sr, ^{90,91}Y, ^{96,98,105,106}Ru, ^{105}Rh, ^{111}Ag, ^{nat}Cd, ^{115m}Cd,
^{125,126}Sn, ^{124,125,126}Sb, ^{120,127m,129m,132}Te, ^{130,131,135}I, ^{133,135}Xe,
^{140}La, ^{143}Ce, ^{142,143}Pr, ^{148,149,151}Pm, ^{144,148,153}Sm, ^{156,157}Eu, ^{160}Tb

Evaluations based on other sources than B-V (or B-IV)

$^{89}_{39}$Y is based on A.B. Smith (ANL) with resonance parameters added at ECN, Petten. The reactions include MT = 16, 22, 28, 102-107. Photon production data (MF = 12-15) are included for MT = 3, 102. Covariance data MF = 33 are included for MT = 1, 2, 4, 16, 91, 102, 103, 107.

The files for the following isotopes are based on RCN evaluations:

^{99}Tc, ^{101}Ru, ^{103}Rh, ^{104,106,107,108,109}Pd, ^{109}Ag, ^{112}Sn, ^{129}I,
^{133}Cs, ^{139}La, ^{141}Pr, ^{144,145,146,148}Nd, ^{147}Pm, ^{147,149,152}Sm

The evaluations include (n,2n) and reaction data MT = 102-107, plus 111. Both resolved and unresolved resonance parameter data are included based (in most cases) on the 4th Edition of BNL-325 [2]. The evaluation for ^{101}Ru also includes reactions MT = 17, 22, 28 and resonance data based on [3]. ^{112}Sn includes MT = 22, 28.

The files for the following isotopes are based on ENEA/CEA evaluations:

^{103}Ru, ^{111}Cd, ^{137}Cs, ^{138,140,141,142,144}Ba, ^{155}Eu, ^{156}Gd, ^{159}Tb

The files include (n,2n) and reaction data MT = 102, 107, 111. Both resolved and unresolved resonance parameters are included. Angular distributions for non-elastic cross-sections are isotropic in the laboratory system for ^{103}Ru, ^{111}Cd, ^{141,142,144}Ce, ^{155}Eu, ^{156}Gd and ^{159}Tb. MT = 17, (n,3n), is included for ^{140}Ba, ^{144}Ce.

The files for the following isotopes are based on ENEA evaluations:

^{105}Pd, ^{135}Cs, ^{143}Nd, ^{151}Sm

The files include (n,2n) and reaction data MT = 102, 107, 111. Both resolved and unresolved resonance parameters are included. Angular distributions for non-elastic cross-sections are isotropic in the laboratory system for ^{105}Pd and ^{151}Sm. The resonance parameters for ^{143}Nd are based on [3] and those for ^{151}Sm on the 4th Edition of BNL-325 [2].

The evaluations based on JENDL-1 or JENDL-2 are:

^{128}Te, ^{157}Gd (JENDL-1), ^{155}Gd (JENDL-2)

The files include reaction data MT = 102, 107, 111. There are resolved resonance parameters. There are unresolved resonance parameters only for ^{155}Gd. The file for ^{157}Gd includes (n,2n). The resonance parameters for ^{128}Te are based on the 3rd Edition of BNL-325 [2].

Evaluations for heavy nuclides (Z = 66 to 83)*

Evaluations for the elements (or for the naturally occurring isotopes of the following elements) are absent from the library: $_{69}$Tm, $_{70}$Yb, $_{76}$Os, $_{77}$Ir, $_{78}$Pt, $_{80}$Hg, $_{81}$Tl.

Characteristics of the evaluations

The elements represented are: $_{66}$Dy, $_{67}$Ho, $_{68}$Er, $_{71}$Lu, $_{72}$Hf, $_{73}$Ta, $_{74}$W, $_{75}$Re, $_{79}$Au, $_{82}$Pb, $_{83}$Bi.

For most elements the evaluations have been adopted from B-IV or B-V, with revisions to the resonance parameter representations (change of flag from SLBW to MLBW and random spin assignments). The evaluations for Hf, Pb and Bi are from independent sources and the ^{197}Au (n,γ) reaction data has been updated using B-VI standards data.

$^{160,161,162,163,164}_{66}$Dy	B-V (resonance parameters changed to MLBW with random spin assignment). Resolved resonance regions but no unresolved regions. ^{164}Dy includes the reactions MT = 16, 17, 103 and 107. Minor isotopes ^{156}Dy (0.06%) and ^{158}Dy (0.10%) are absent from JEF-2.2.
$^{165}_{67}$Ho (100%)	B-V (1974) (R.P. changed to MLBW with random spin assignment). The reactions are limited to elastic, inelastic and (n,γ) and scattering is isotropic. No unresolved resonance region.
$_{68}$Er isotopes	The naturally occurring isotopes are ^{162,164,166,167,168,170}Er. JEF-2.2 includes only the isotopes ^{166,167}Er, adopted from B-V. R.P. changed to MLBW with random spin assignment. No unresolved resonance regions.
$^{175,176}_{71}$Lu	B-V (R.P. changed to MLBW with random spin assignment). JEF-2.2 and B-VI are essentially the same, being based on the B-III (1967) evaluations. MT = 16, 17, 103 and 107 are included. There are no unresolved resonance regions.
$^{174,176,177,178,179,180}_{72}$Hf	UKNDL-81 resonance region data and JENDL-2. The reactions MT = 16, 17, 103 and 107 are included. MF = 5 secondary energy distributions are evaporation spectra. There are no unresolved resonance region data.
$^{181}_{73}$Ta (99.988%)	B-IV (1972/74). The resonance parameters are from B-III, resolved to 330 eV and unresolved to 5 keV. Reactions MT = 16, 17, and 103, and photon production data are included. Inelastic scattering angular distributions are isotropic (in cm co-ordinates for the 10 discrete levels, in laboratory co-ordinates for the continuum). B-VI is also based on B-IV.
$^{182}_{73}$Ta (114.5 day)	B-IV. The resonance parameters are resolved to 35.0 eV and unresolved to 10 keV. Reactions MT = 16, 17, and 107 are included.
^{180m}Ta (0.012%)	Absent.
$^{182,183,184,186}_{74}$W	B-IV (1973). Include resolved and unresolved resonance regions to 100 keV (to 45 keV for ^{183}W). The reactions treated include MT = 16, 17, 28, 103 and 107. Inelastic scattering to the first one or two of the eight or nine levels is anisotropic. Photon production data are included for MT = 4 and 102.

* Note: The elements Z = 84-89 have no stable isotopes.

^{180}**W (0.122%)**	Absent.
$^{185,187}_{75}$**Re**	B-IV (1968) (R.P. flag changed to MLBW). The evaluations include the reactions MT = 16 and 17. There are resolved and unresolved resonance regions (to 100 keV) with a varying background cross-section in the resolved range.
$^{197}_{79}$**Au (100%)**	B-V (1977); B-VI (n,γ) cross-section between 0.5 and 2.5 MeV. The (n,γ) cross-section is a standard (0.5 to 2.5 MeV). Resolved region resonance parameters to 5 keV; no unresolved region data. Radioactive decay data, MF = 8 and 10 (for MT = 16) and covariance data (MF = 33, MT = 102) are included. The secondary angular distributions for inelastic scattering, (n,2n), (n,3n) are isotropic and continuum energy distributions use a temperature model.
$^{nat}_{82}$**Pb**	EFF-1 (ECN, Petten, evaluation). Resonance parameters are not included explicitly. Reactions MT = 16, 17 and 101 are included, together with MT = 10. Photon production and MF = 6 coupled energy-angular distribution data are included.
$^{209}_{83}$**Bi (100%)**	Bersillon, *et al*., Proc. Antwerp Conf. (1984) p. 665. Based on a resonance region analysis to 265 keV and nuclear model calculations at higher energies. (Resonance parameters are not given explicitly in the file.) Reactions MT = 16, 17, 103 and 107 are included. (In the original evaluation reactions MT = 22 and 28 were included but these lacked secondary energy distributions and so they were combined into other reactions.) There are 29 discrete inelastic levels and detailed angular distributions are included for these. MT=16, 17 and 91 are treated as isotropic. Photon production data are included.

Data for the major actinide isotopes

Introduction

The major actinide isotopes are defined here as those for which it is necessary to have good scattering cross-sections (in addition to the reaction cross-sections (capture, fission, (n,2n), (n,3n)) which are sufficient to determine the production and transmutation of the minor actinides). In other words they are the actinides which might be present in sufficient density to influence the neutron spectrum. Also, resonance shielding effects could be important for these isotopes. Consequently both resolved and unresolved resonance region data are desirable. The isotopes considered are the following:

^{232}Th, ^{233,235,236,238}U, ^{237}Np, ^{238,239,240,241,242}Pu, ^{241,243}Am

However, we should note that ^{232}Th and ^{233}U were not updated, being the ENDF/B-IV evaluations adopted for JEF-1. Also, we note that the evaluation for ^{236}U was adopted from ENDF/B-V. The evaluations for ^{240}Pu and ^{242}Pu were adopted from JENDL-2.

We can also note that there are more recent (i.e. post JEF-2.2) resonance region evaluations, by Derrien, *et al*. for ^{233}U, ^{235}U, ^{239}Pu, ^{240}Pu and ^{241}Pu.

Particular reaction types to be noted in these evaluations are:

MT = 3	Total non-elastic (used for photon production)	
MT = 4	Total inelastic (used for photon production)	
MT = 16	(n,2n)	
MT = 17	(n,3n)	
MT = 18	(n,f total)	Total fission
MT = 19	(n,f)	First chance fission
MT = 20	(n,nf)	Second chance fission
MT = 21	(n,2nf)	Third chance fission
MT = 37	(n,4n)	
MT = 38	(n,3nf)	Fourth chance fission
MT = 51, 52, etc.	Inelastic scattering to discrete levels	
MT = 91	Continuum inelastic scattering	
MT = 452	Nubar total	
MT = 455	Nubar delayed	
MT = 456	Nubar prompt	
MT = 458	Energy release in fission	

All the JEF-2.2 evaluations include MT = 16, 17, 18, 51-91, 452. For most of the isotopes the inelastic scattering (n,2n) and (n,3n) are treated as isotropic and the secondary distributions for 16, 17 and 91 are simple evaporation spectra. For several of the isotopes a Maxwellian prompt fission spectrum (MF = 5, MT = 18) with a temperature derived by systematics is adopted. The energy dependence of ν is treated simply for several of the isotopes, in terms of a dependence of the form $a + b.E$, with the values of a and b being given in the file. The energy dependence of the delayed neutron yield is also given simply for most isotopes, in the form of a value at zero energy, a value at 4 MeV (in the case of threshold fission the same value), and a value above 7 MeV (or thereabouts). The energy yield in fission, MF = 1, MT = 458, is given only for ^{236}U. There are no delayed neutron yield data for ^{236}U, ^{237}Np, ^{238}Pu, ^{242}Pu, ^{241}Am and ^{243}Am.

It should be noted that the time dependent delayed neutron yield data included in these evaluations is not recommended for use.

The total delayed neutron yields have been evaluated for some isotopes but not the time dependent data. In particular, the ^{235}U and ^{239}Pu relative yields and decay constants for the six time groups are not consistent, having been adopted from different (inconsistent) sources. The data recommended by the Delayed Neutron Subgroup of the Working Party on International Evaluation Co-operation is considered to be the correct choice for the JEF Project.

Sources of the evaluations for the most important actinide isotopes

^{232}Th	B-IV (1966) with Cox delayed neutron data (1973). The evaluation includes resolved resonance region data to 3.94 keV and unresolved resonance region data to 50 keV. A smooth background is included in the resolved region to compensate for missing p-wave resonances. Anisotropy of elastic scattering is treated but inelastic scattering, (n,2n) and (n,3n) are treated as isotropic. There are eight discrete inelastic levels. The fission spectrum is represented by a Maxwellian with the temperature derived by Barnard (1965), T = 1.2558 MeV, increasing with neutron energy. The total ν is 1.854 + 0.156 E (MeV) giving ν = 2.166 at 2 MeV. The delayed neutron yield is 0.0527 up to 4 MeV and 0.03 above 7 MeV. These compare with Tuttle's values of 0.0531 ± 0.0023 (fast) and 0.0285 ± 0.0013 (14 MeV) and so they are broadly consistent. There are no photon production or covariance data.
^{233}U	B-IV (1965/69). Includes resolved resonance region data to 60 eV, plus a complicated background cross-section. There are no unresolved resonance region data. There are seven discrete inelastic levels. Anisotropy of elastic scattering is treated but inelastic scattering (n,2n) and (n,3n) are treated as isotropic. The fission spectrum is represented by three evaporation spectra, corresponding to 10% scission neutrons and the emissions from the light and heavy mass fission products. The energy distributions for MT = 16, 17 and 91 are Maxwellian. The total ν is 2.498 at thermal energy. The delayed neutron yield is 0.0074 up to 4.5 MeV and 0.0047 from 6 to 14 MeV. There are no unresolved region, photon production or covariance data.
^{235}U	B-VI with a revised evaluation below 0.15 eV (to take into account the IRMM, Geel, and Oak Ridge measurements of thermal eta and alpha, see JEF/DOC-446 by C. Raepsaet and H. Tellier) and the evaluation of ν, prompt and delayed, by E. Fort and P. Long is adopted over the whole energy range (for the delayed neutron yield see JEF/DOC-286). Reactions treated include MT = 19, 20, 21, 37, 38. There are 44 discrete inelastic levels. Angular and energy distributions of scattered neutrons and (n,2n), etc. are analysed using the codes ECIS, GNASH, COMNUC and DWUCK. Thus anisotropy of inelastic scattering and (n,2n) are treated and there are MF = 6 data for MT = 16, 17, 37 (n,4n) and 91. Unresolved region data (2.25 to 100 keV) were analysed using the FITACS code of F. Froehner. The capture widths are 49.5 meV and 47.6 meV respectively for the s-wave and p-wave channels, l = 0 and l = 1. These values appear to be too high relative to the value of about 38 meV obtained in the ORNL resolved resonance region analysis. There are photon production data, MF = 12 to 15, and covariance data, MF = 33, are included for MT = 18 and 102.
^{236}U	B-V, (1978). Includes MT = 19, 20, 21, with six discrete inelastic scattering levels. The resolved resonance range extends to 4.11 keV and the unresolved range to 100 keV. It adopts the elastic angular distributions of ^{232}Th and isotropic distributions for other processes. The continuum inelastic scattering energy distribution is represented by an evaporation spectrum temperature (Gilbert and Cameron, 1965) and the energy distributions for MT = 16 and 17 are Maxwellian, as are the distributions for the pre-fission neutrons emitted in (n,nf) and (n,2nf), with the fission neutron spectrum being a Maxwellian with T = 1.2955 MeV at thermal energy and 1.4923 MeV at 15 MeV. The total ν is 2.317 + 0.131 E (MeV) giving a value of 2.579 at 2 MeV. There are MF = 8 data for MT = 16, 17 and 102. There are no delayed neutron data, photon production or covariance data.

^{238}U	Evaluation by F. Froehner, M. Moxon and M. Sowerby (1990), plus JENDL-3. It includes resonance parameters to 10 keV (evaluation of Moxon and Sowerby, JEF/DOC-270 and JEF/DOC-288) and unresolved region data to 300 keV (evaluation of Froehner, JEF/DOC-271). Above 308.502 keV the data are from JENDL-3, except for the total cross-section (Smith), and the fission (Poenitz, B-VI standards) and capture (below 2.2 MeV, Poenitz). The angular and energy distribution data are from JENDL-3. There are 26 discrete inelastic levels. Anisotropy of scattering is treated for the elastic scattering and inelastic scattering to discrete levels. Reactions MT = 16, 17 and 91 (continuum inelastic, above 1.5 MeV) are isotropic with evaporation energy spectra. The delayed neutron data are from JENDL-3T, the spectra being from Saphier, 1977. The file includes photon production data (JENDL-3 with modifications). Covariance data, MF = 33, are included for MT = 1, 2, 4, 18, 51, 52, 102.
^{237}Np	H. Derrien, *et al*. (1980) and B-V angular and energy distribution data. There are 33 discrete levels. There are (1985) modifications to the (n,2n) data. The resolved resonance range extends to 150 eV, the data being based on Paya (1962) and Plattard (1976), with the spins of Keyworth (1973) and modifications to the fission widths below 3.86 eV. There is no unresolved region. Inelastic scattering and (n,2n), (n,3n) data are isotropic. The elastic angular distributions are in the name of H. Alter (Atomics International). The fission spectrum is Maxwellian with Terrel's (1965) temperature, T = 1.315 MeV. The total ν is 2.534 + 0.1561 E (MeV), giving a value of 2.8462 at 2 MeV. The continuum inelastic scattering is Goldman (1964). MF = 8 and 9 are given for MT = 16 (energy dependent branching ratios). There are no unresolved resonance region, delayed neutron, photon production or covariance data.
^{238}Pu	H. Derrien *et al*. (1981) with B-V angular and energy distribution data. There are resolved resonance data from 1.05 to 412.5 eV but no unresolved parameters. There are 13 discrete inelastic levels. Inelastic scattering and (n,2n), (n,3n) data are isotropic, the elastic angular distributions being anisotropic. The fission spectrum is a Maxwellian with Howerton's (1977) temperature, T = 1.33 MeV. The continuum inelastic scattering and (n,2n) energy distributions are represented in terms of energy dependent nuclear temperatures (Parker, 1964). The total ν is 2.895 + 0.148 E (MeV). There are no unresolved resonance range, delayed neutron data, photon production or covariance data.
^{239}Pu	H. Derrien and G. de Saussure (resonance region, to 30 keV, JEF/DOC-241, JEF/DOC-246, JEF/DOC-247, JEF/DOC-291, JEF/DOC-292), E. Fort (>30 keV), JEF/DOC-174 et seq. (1990). The resolved range is to 1 keV and unresolved resonance range to 30 keV. The evaluation of E. Fort is adopted at higher energies (1990). Reactions treated include MT = 19, 20, 21, 37 and 38. There are 21 discrete inelastic levels. Elastic scattering and inelastic scattering to the first four levels are treated as anisotropic, all other secondary neutron distributions being isotropic. The energy distribution for fission is Madland (1984), as in B-V Rev. 2 and the distributions for MT = 16, 17, 37 and 91 are evaporation spectra (England 1989). There are no photon production or covariance data. However the text contains some information about fission gamma spectra.

^{240}Pu	JENDL-2 (1979/83). There is a modification to the value of theta in the energy spectra of delayed neutrons (MF = 5, MT = 455). The evaluation includes MT = 37, and 29 discrete inelastic levels. Resolved resonance parameters are given to 4 keV and a background cross-section is included. The unresolved range extends to 40 keV. Elastic angular distributions are from JENDL-1 and all other distributions are isotropic. For MT = 16, 17, 37 and 91 the energy distributions are evaporation spectra and the fission spectrum is a Maxwellian with temperature derived from Z^2/A systematics, T = 1.346 MeV, increasing with energy, being 1.377 MeV at a neutron energy of 2 MeV. The prompt neutron data are from Frehaut (1974) renormalised to ^{252}Cf. The total ν value is 2.7838 + 0.1498 E (MeV) up to 4 MeV, giving a value of 3.0834 at 2 MeV. The delayed neutron yield (from B-IV) is 0.009 below 4 MeV and 0.00615 above 7 MeV. There are no photon production or covariance data.
^{241}Pu	H. Derrien and G. de Saussure (1988, JEF/DOC-248) in the resolved resonance range, to 300 eV, F. Froehner (1989/91) in the unresolved range, to 162 keV, and JENDL-2 (1979) at higher energies. There is a modification to the JENDL-2 value of theta in the energy distribution of delayed neutrons (MF = 5, MT = 455). The evaluation includes MT = 37, and 11 discrete inelastic levels. Elastic angular distributions are anisotropic and all other distributions are isotropic. For MT = 16, 17, 37 and 91 the energy distributions are evaporation spectra and the fission spectrum is a Maxwellian with temperature derived from Z^2/A systematics, T = 1.3597 MeV at thermal (increasing with energy). The total ν is 2.9323 at thermal. The delayed neutron yield data are from Benedetti (0.0157 to 4 MeV, 0.0084 above 7 MeV) and the spectra are from B-IV. There are no photon production or covariance data.
^{242}Pu	JENDL-2 Rev. 1 (1981/83). Modifications are the addition of a negative energy resonance to reproduce the thermal value and a change to the effective radius. The evaluation includes MT = 37, and 17 discrete inelastic levels. Resolved resonance parameters are given to 1.29 keV and there is no unresolved range. Elastic angular distributions are the values for ^{240}Pu and all other distributions are isotropic. For MT = 16, 17, 37 and 91 the energy distributions are evaporation spectra and the fission spectrum is a Maxwellian with temperature derived from Z^2/A systematics, T = 1.33974 MeV. The total ν is 2.808 + 0.142 E (MeV). There are no unresolved resonance region, delayed neutron, photon production or covariance data.
^{241}Am	KEDAK-4 resolved resonance range and CEA Cadarache (1981) above 150 eV. The thermal capture is 579 barns. There is no unresolved region treatment. Energy distribution data, MF = 5, are from B-V and have simple forms. There are 40 discrete levels. Only elastic scattering is anisotropic. The fission spectrum is a Maxwellian with T = 1.33 MeV. The value of ν is 3.33 +0.159071 E (MeV) the value at 2 MeV being 3.648. There are no unresolved resonance region, delayed neutron, photon production or covariance data.
^{243}Am	UKNDL-2 (1980) with energy distribution data, MF = 5, from B-V. There are resolved resonance parameters to 250 eV and unresolved data to 40 keV. The prompt neutron yield data are from Howerton to which a delayed neutron contribution has been added to give a total ν at thermal energy of 3.0616 and 3.4176 at 2 MeV. The fission spectrum is a Maxwellian with T = 1.33 MeV. The elastic scattering is anisotropic (Parker, ^{238}U, 1964) but other neutron emissions are isotropic, and the B-V continuum energy distributions have a simple form. There are no delayed neutron data, photon production or covariance data.

The minor actinides

Introduction

There are 42 actinide isotopes in JEF-2.2. Those treated in the section entitled *Data for the most important actinide isotopes* are the following 13:

^{232}Th, ^{233,235,236,238}U, ^{237}Np, ^{238,239,240,241,242}Pu, ^{241,243}Am

The additional 29 represented in JEF-2.2 are the following:

^{230}Th, ^{231,233}Pa, ^{232,234,237}U, ^{238,239}Np, ^{236,237,243,244}Pu, ^{242,242m}Am, ^{241,242,243,244,245,246,247,248}Cm, ^{249}Bk, ^{249,250,251,252,253}Cf, ^{253}Es

The evaluation for ^{253}Es only includes capture (MT = 102) and elastic scattering (MT = 2) and no fission, inelastic scattering or (n,2n). The evaluation for ^{253}Cf does not include inelastic scattering or (n,2n).

The evaluations for these 29 isotopes were adopted from B-V with the exception of the following eight:

^{238}Np	B-V + ENDL-84
^{239}Np, ^{242}Am	JENDL-2
^{242m}Am, ^{244}Cm	KEDAK-4
^{242,243,245}Cm	ENEA

The JENDL-2 evaluation for ^{239}Np was also adopted in B-VI but with revised cross-sections below 4 eV to fit the thermal values found in [4]. The evaluations for ^{239}Np and ^{242}Am are essentially unchanged in JENDL-3.2, apart from ν prompt and delayed for ^{239}Np.

Several evaluations adopted from B-V were combined evaluations, with data other than the resolved and unresolved resonance region parameters being taken from the Lawrence Livermore library ENDL-78. In particular, those evaluations with photon production data have adopted this section from ENDL-78.

Some minor modifications were made to some of the B-V evaluations adopted in JEF-2.2, such as randomisation of resonance J-values for some isotopes and the adoption of MLBW formalism. In some cases the fission angular distribution, MF = 4, MT = 18, or 19, had not been specified (isotropic) and this was added later to both B-V and JEF.

In B-VI the evaluations have remained the same as in B-V except for new evaluations for ^{249}Bk (1986) and ^{249}Cf (1989), by Zhou Delin, *et al*. (also included in CENDL-2.1). Delayed neutron data have also been added in B-VI, from Brady and England [7].

We can note that JENDL-3.2 contains data for several additional isotopes:

^{227,228,229,233,234}Th, ^{232}Pa, ^{236}Np, ^{244,244m}Am, ^{249,250}Cm, ^{250}Bk, ^{254}Cf, ^{254,255,255m}Es

Evaluations for the following additional isotopes, not in JENDL-3.2, are given in the ENDL library:

^{231}Th, ^{239,240}U, ^{235}Np

General features of the evaluations

The aspects of primary interest in the evaluations for the minor actinide isotopes are the transmutation cross-sections, capture, fission, (n,2n) and (n,3n). In most cases the measured data are very sparse, only thermal values and resonance integrals (together with some fission cross-section measurements) being available, and so the energy dependence is in most cases approximate and based on theory. Capture cross-sections above the resonance region are generally based on theory.

The inelastic scattering, (n,2n), etc. secondary distributions are treated as isotropic in all 29 evaluations, except for the first three discrete inelastic scattering levels in the ENEA evaluations for ^{242,243,245}Cm (the first level in the case of ^{243}Cm, the comments section being incorrect in this respect).

The continuum secondary distributions are evaporation spectra in all evaluations excepting for the following (adopted from the LLL evaluations) for which detailed tabular spectra are given:

^{237}U, ^{238}Np, ^{249}Bk, ^{249,251,252}Cf

In all cases the fission spectra are represented by a Maxwellian, in many cases with the value of T = 1.33 MeV, but in several cases with energy dependent temperatures.

Photon production data (MF = 12, 13, 14, 15; MT = 3, 18, 102) are included for:

^{237}U, ^{243}Pu, ^{246,247,248}Cm, ^{249}Bk, ^{249,250,251,252}Cf

Energy production in fission, MT = 458, is included for:

^{233}Pa, ^{234}U, ^{236,237,244}Pu, ^{241,248}Cm

Delayed neutron data are included only in the case of the evaluation adopted from JENDL-2 for ^{242g}Am, and this does not include the delayed neutron spectra.

(n,3n) is included for ^{243,244}Pu, ^{246,247,248}Cm, ^{249}Bk, ^{249,250,251,252}Cf.

Some features of the resonance region data

Table 1 summarises the energy ranges of the resolved and unresolved resonance regions and notes the isotopes which have background contributions in the resolved region and also those which give the infinite dilute values (as well as average parameters) in the unresolved region (only ^{242m}Am). The sources of the data are also given.

The format is MLBW in all cases excepting for ^{243,245}Cm for which the RM formalism is used.

The resonance parameters for the following isotopes (adopted from B-V) were generated statistically in the resolved region using the GENRPAR code and fitted to the thermal and resonance integral data:

^{237}U, ^{238}Np, ^{236}Pu, ^{243,244}Pu, ^{247}Cm, ^{249}Bk, ^{250,251,252,253}Cf

However, we can note that resonance parameters are given for the following isotopes in Mughabghab [4]:

^{244}Pu	Auchampaugh (1971) ([2] but additional data).
^{247}Cm	Moore (1971), de Saussure (1973), Belanova (1979) ([2] with additional data < 20 eV).
^{249}Bk	Benjamin 1977/79/83 (no data in [2]).
^{252}Cf	Moore 1970/71 > 24 eV ([2] with two postulated resonances).

The additional measured resonance region data since the B-V evaluations were produced are very few.

In some cases there are no resonance parameters given in the evaluations (^{239}Np, ^{237}Pu, ^{242}Am and ^{241}Cm) and no alternative sources have been found.

The only evaluation for which no unresolved region parameters are specified but resolved region data are given is ^{230}Th.

Table 6.1. Resonance region and inelastic scattering data for the minor actinide isotopes

Isotope	Resolved range (eV)	Unresolved range (keV)	Inelastic levels	Resonance region data source
^{230}Th	251	X	17 levels	B-V (BNL-325, 1973 + -ve)
^{231}Pa	14.3	1	12 levels	B-V (BNL-325, 1973 + -ve)
^{233}Pa	38.5	10	5 levels	B-V (BNL-325, 1973)
^{232}U	53	1	13 levels	B-V (BNL-325, 1973, RM)
^{234}U	1500	100	6 levels	B-V (1978; James, *et al*. 77)
^{237}U	102.5	10	No levels	B-V (G) (1976) (+ Smooth B)
^{238}Np	100.2	10	No levels	B-V (G) (1975)
^{239}Np	X	X	8 levels	JENDL-2 (1976)
^{236}Pu	163.3	10	4 levels	B-V (G) (1978)
^{237}Pu	X	X	10 levels	B-V (1978)
^{243}Pu	101.7	10	No levels	B-V (G) (1976)
^{244}Pu	249.2	10	5 levels	B-V (G) (1978)
^{242}Am	X 20	X 50 σinf	22 levels 13 levels	J-2 (1980) KEDAK-4 (1989/data 1983)
^{241}Cm	X	X	14 levels	B-V (1978)
^{242}Cm	280	10	3 levels	ENEA (1982) (+ Smooth B)

X Denotes that there are no resonance parameter data.
B-V (G) Denotes that these ENDF/B-V parameters were generated using the GENRPAR code and fitted to the thermal values and resonance integrals.
Smooth B Denotes that there is a smooth background cross-section.
Complex B Denotes that the background cross-section has a complex energy variation.
σinf Denotes that both the infinite dilution cross-sections and the average resonance parameters are given in the unresolved range (only for ^{242m}Am).

Table 6.1. Resonance region and inelastic scattering data for the minor actinide isotopes (*cont.*)

Isotope	Resolved range (eV)	Unresolved range (keV)	Inelastic levels	Resonance region data source
^{243}Cm	26	10	12 levels	ENEA (1982)
^{244}Cm	1000	10	22 levels	KEDAK-4 (1982) (+ Complex B)
^{245}Cm	61	10	16 levels	ENEA (1982)
^{246}Cm	385	10	11 levels	B-V (1976)
^{247}Cm	61.7	10	No levels	B-V (G) (1976)
^{248}Cm	2400	10	7 levels	B-V (1978)
^{249}Bk	100.8	10	No levels	B-V (G) (1976) (+ Smooth B)
^{249}Cf	70	10	No levels	B-V (1976)
^{250}Cf	286.1	10	No levels	B-V (G) (1976) (+ Smooth B)
^{251}Cf	163.9	10	No levels	B-V (G) (1976) (+ Smooth B)
^{252}Cf	366.5	10	No levels	B-V (G) (1976)
^{253}Cf	100.4	10	No inelastic	B-V (G) (1975)
^{253}Es	101.2	10	No inelastic	B-V (G) (1976)

X Denotes that there are no resonance parameter data.
B-V (G) Denotes that these ENDF/B-V parameters were generated using the GENRPAR code and fitted to the thermal values and resonance integrals.
Smooth B Denotes that there is a smooth background cross-section.
Complex B Denotes that the background cross-section has a complex energy variation.
σinf Denotes that both the infinite dilution cross-sections and the average resonance parameters are given in the unresolved range (only for ^{242m}Am).

Some characteristics of the evaluations*

^{230}Th	B-V (1977) Includes resolved resonance parameters to 251 eV, from [2], plus a negative energy resonance and a modification to the neutron width of the first resonance. The fission cross-section is based on the bomb-shot measurements of Muir and Vesser (1971) from 300 keV to 3 MeV. The remaining data are based on nuclear model calculations. There are 17 discrete inelastic levels, all non-elastic being isotropic. Continuum spectra are evaporation spectra and the fission spectrum a Maxwellian. There are no unresolved resonance region data.
^{231}Pa	B-V (1977) Includes resolved resonance parameters to 14.3 eV, from [2], plus a negative energy resonance and unresolved resonance region data to 1 keV. The fission cross-section is based on the bomb-shot measurements of Muir and Vesser (1971) from 0.1 to 3 MeV. The remaining data are based on nuclear models. There are 12 discrete inelastic levels, all non-elastic being isotropic. Continuum spectra are evaporation spectra and the fission spectrum a Maxwellian.

* Unless otherwise stated, there are no photon production, delayed neutron, fission energy components nor covariance data in the files.

^{233}Pa (27.0 day)	B-V (1978) = B-IV (1970/74/78). Includes resolved resonance parameters to 38.5 eV, from [2], plus a negative energy resonance and modifications to give the required thermal capture and a resonance integral, with unresolved resonance region data to 10 keV. The fission cross-section is based on a scaling of the ^{238}U fission cross-section. The remaining data are based on nuclear model calculations. There are five discrete inelastic levels, all non-elastic being isotropic. Continuum spectra are evaporation spectra and the fission spectrum a Maxwellian, T = 1.33 MeV. = 2.29 + 0.118.E (Howerton systematics, 1977). Sher (1977) fission energy data are included.
^{232}U	B-V (1977). Includes resolved resonance parameters to 53 eV, from [2], plus a negative energy resonance, and unresolved resonance region data to 1 keV. In the resonance range the fission cross-section is based on the data of Auchampaugh, *et al*. (1968) and Farrel (1970). The capture cross-section above the resonance range and the remaining data are based on nuclear model calculations. There are 13 discrete inelastic levels, all non-elastic being isotropic. Continuum spectra are evaporation spectra and the fission spectrum a Maxwellian, T = 1.33 MeV. ν= 3.13 + 0.107.E (Howerton systematics, 1977).
^{234}U	B-V (1978). Includes resolved resonance parameters to 1.499 keV, from James, *et al*. (1977) and normalisation to [2], plus a negative energy resonance. There is unresolved resonance region data to 100 keV. The fission cross-section above 100 keV is based on the measurement of Behrens and Carlson (1977). The remaining data are based on nuclear models. There are six discrete inelastic levels, all non-elastic being isotropic. Continuum spectra are evaporation spectra and the fission spectrum a Maxwellian. The value of ν is based on Mather (1965). There are fission energy data, MT = 458, of Sher (1976).
^{237}U (6.75 day)	B-V (1976) Includes resolved resonance parameters to 102.7 eV (plus a smooth background), generated using the GENRPAR code and data of McNally, *et al*. (1974). There is unresolved resonance region data to 10 keV. The remaining data are based on nuclear models. There are no discrete inelastic levels, all non-elastic being isotropic. Continuum spectra are evaporation spectra and the fission spectrum a Maxwellian. The ν value is based on the systematics of Manero and Konshin (1972). Photon production data are included.
^{238}Np (2.117 day)	ENDL-84 above 10 keV and B-V below. The resolved resonance region data (to 100.2 eV) were generated using the GENRPAR code to give the required thermal and resonance integral values. There is no description of the ENDL-84 section in the file. There are no discrete inelastic levels, all non-elastic being isotropic. Continuum spectra are evaporation spectra and the fission spectrum is a Maxwellian. The ν value is based on the systematics of Manero and Konshin (1972) plus Howerton (1971) energy dependence, ν = 2.79 + 0.148.E.
^{239}Np	JENDL-2 (1976 +). This evaluation is the same as JENDL-1 apart from the extension in energy to 20 MeV. The fission is zero below 40 keV. The capture has 1/v form below 4 eV being normalised to the thermal value (37 barns) of Stoughton and Halperin (1959).

^{236}Pu	B-V (1978). Includes resonance parameters to 163.4 eV, generated using the GENRPAR code, and fitted to the fission data of Hulet (1961) assuming that the capture is equal to the fission. There is unresolved resonance region data to 10 keV. The remaining data are based on nuclear models. There are four discrete inelastic levels, non-inelastic being treated as isotropic, with continuum distributions represented by evaporation spectra and a Maxwellian for fission. There are fission energy data, MT = 458, based on the systematics of Sher (1976).
^{237}Pu	B-V (1978). There are no resonance parameters. There are 10 inelastic levels.
^{243}Pu	B-V (1976). The resonance region treatment is based on parameters generated using the GENRPAR code, resolved to 101.7 eV and unresolved to 10 keV. There are no inelastic levels.
^{244}Pu	B-V (1978). The resonance region treatment is based on parameters generated using the GENRPAR code, resolved to 249.2 eV and unresolved to 10 keV. There are five inelastic levels.
^{242}Am (16.1 hr)	JENDL-2 (1977/80). Contains no resonance parameter data, the evaluation being based on nuclear models. There are no discrete inelastic levels, inelastic continuum, (n,2n), (n,3n) all being treated as isotropic, with continuum distributions represented by evaporation spectra and a Maxwellian for fission with T derived using Z^2/A systematics. There are delayed neutron yields but no spectra.
^{242m}Am	KEDAK-4. Includes resonance parameters to 20 eV (revised 1989) and unresolved resonance region data to 50 keV (revised 1991). The list of references includes Browne, *et al*. (1984), Dabbs, *et al*. (1983) and Moore (1978). There are 13 discrete inelastic levels, inelastic continuum, (n,2n), (n,3n) all being treated as isotropic, with continuum distributions represented by evaporation spectra and a Maxwellian for fission, T = 1.33 MeV. The total ν value is 3.21 + 0.1335 E.
^{241}Cm (32.8 day)	B-V (1977). Contains no resonance parameter data. All cross-sections are based on statistical model calculations. There are four discrete inelastic levels, all non-elastic being treated as isotropic, with continuum distributions represented by evaporation spectra and a Maxwellian for fission, T = 1.33 MeV. Fission energy production data are included (Sher, 1976).
^{242}Cm (162.8 day)	ENEA (1982) (Reference INDC(ITY)-7). The evaluation includes resonance parameters to 280 eV and unresolved resonance region data to 10 keV. The remaining data are based on nuclear models. There are three discrete inelastic levels, treated as anisotropic. The inelastic continuum and (n,2n) are treated as isotropic, with continuum distributions represented by evaporation spectra and a Maxwellian for fission. There are no (n,3n) data.
^{243}Cm	ENEA (1982) (Reference RT/FI(81)23, 1981). Includes resonance parameters to 26 eV and unresolved resonance region data to 10 keV. The remaining data are based on nuclear models. There are 12 discrete inelastic levels, the first being treated as anisotropic, the remaining non-elastic being isotropic, with continuum distributions represented by evaporation spectra and a Maxwellian, T(E), for fission.The total ν value is 3.39 + 0.178 E. There are no (n,3n) data.

^{244}Cm	KEDAK-4. (No details of the evaluation in the comments section.) There are resonance parameters to 1 keV (plus a complex background probably associated with the conversion from KEDAK, in which $g\Gamma_n$ is specified), and unresolved resonance region data to 215 keV. There are 22 discrete inelastic levels, all non-elastic being treated as isotropic, with continuum distributions represented by evaporation spectra and a Maxwellian for fission, T = 1.33 MeV. The total ν value is 3.24 + 0.184 E.
^{245}Cm	ENEA (1982) (CNEN Report RT/FI(81)24). Includes resonance parameters to 61 eV and unresolved resonance region data to 10 keV. The remaining data are based on nuclear models. There are 16 discrete inelastic levels, three being treated as anisotropic. The remaining inelastic and (n,2n) are isotropic, with continuum distributions represented by evaporation spectra and a Maxwellian, T(E), for fission. There are no (n,3n) data.
^{246}Cm	B-V (1976). Contains resonance parameters to 385 eV, based on Berreth, *et al*. (1972), Benjamin, *et al*. (1974), Moore and Keyworth (1971) and the integral measurements of Benjamin, *et al*. (1971), (1972) and Halperin and Druschel (1971). There are unresolved parameters to 10 keV. The fission cross-section involves a fit to the measurements of Moore and Keyworth. The remaining data are based on nuclear models. There are 11 discrete inelastic levels, all non-elastic being isotropic, with continuum distributions represented by detailed energy spectra and a Maxwellian, T(E), for fission. (n,4n) data are included. The neutron yield is based on Manero and Konshin systematics. Photon production data are included.
^{247}Cm	B-V (1976). Includes resonance parameters to 61.7 eV, generated using the GENRPAR code. The parameters of the lowest energy resonances are chosen to fit the integral measurements made by Benjamin, *et al*. (1972) and (1975). The measurements of Moore and Keyworth (1971) are used at higher energies. There is unresolved resonance region data to 10 keV. The fission cross-section above the resonance range makes use of Moore and Keyworth. The remaining data are based on nuclear model calculations. There are no discrete inelastic level data, all non-elastic being isotropic, with continuum distributions represented by evaporation spectra and a Maxwellian, T(E), for fission. (n,4n) data are included. The total neutron yield is based on the systematics of Manero and Konshin with the energy dependence of Howerton. There are photon production data from Howerton, LLL.
^{248}Cm	B-V (1976). Includes resonance parameters to 2.4 keV, based on Benjamin, *et al*. (1974) and Moore and Keyworth (1971), together with the integral measurements of Benjamin, *et al*. (1972) and Druschel, *et al*. There are unresolved resonance region data to 10 keV. The fission cross-section is based on Moore and Keyworth, other cross-sections being obtained using nuclear models. There are no discrete inelastic levels, all non-elastic reactions being isotropic, with continuum distributions represented by evaporation spectra and a Maxwellian for fission, T = 1.33 MeV. (n,4n) data are included. The total neutron yield is derived using Manero and Konshin. There are photon production (Howerton) and fission energy data, MT = 458.

^{249}Bk (311 day)	B-V (1977). Includes resonance parameters to 100.8 eV (with a smooth background), generated using the GENRPAR code and unresolved resonance region data to 10 keV. The remaining data are from the Lawrence Livermore library, ENDL-78, being based on nuclear model calculations. There are no discrete inelastic level data, all non-elastic being treated as isotropic, with continuum distributions represented by tabular spectra and a Maxwellian, T(E), for fission. (n,4n) data are included. There are photon production data.
^{249}Cf	B-V (1977). Includes resonance parameters to 70 eV and unresolved resonance region data to 10 keV. The remaining data are from the Lawrence Livermore library and are based on nuclear models. There are no discrete inelastic levels, all non-elastic being isotropic, with continuum distributions represented by tabular spectra and a Maxwellian, T(E), for fission. (n,4n) data are included. There are photon production data.
^{250}Cf	B-V (1977). Includes resonance parameters to 286.1 eV (plus a smooth background), generated using the GENRPAR code, plus unresolved resonance region data to 10 keV. The integral measurements of Benjamin, *et al*. (1975) and Halperin, *et al*. (1971) are used to select the parameters. The remaining data are based on nuclear models. There are no discrete inelastic levels, all non-elastic being treated as isotropic, with continuum distributions represented by tabular spectra and a Maxwellian, T(E), for fission. (n,4n) data are included. There are photon production data.
^{251}Cf	B-V (1976). Includes resonance parameters to 163.9 eV (plus a smooth background), generated using the GENRPAR code plus unresolved resonance region data to 10 keV. The integral measurements of Benjamin, *et al*. (1975) and Halperin, *et al*. (1971) are used. The remaining data are based on nuclear models. There are no discrete inelastic levels, all non-elastic being treated as isotropic, with continuum distributions represented by tabular spectra and a Maxwellian, T(E), for fission. There are photon production data.
^{252}Cf	B-V (1976). Includes resonance parameters to 366.5 eV, generated using the GENRPAR code plus unresolved resonance region data to 10 keV. The integral measurements of Benjamin, *et al*. (1975) and Halperin, *et al*. (1971) and (1969), are used. The remaining data are based on nuclear models. There are no discrete inelastic levels, all non-elastic being treated as isotropic, with continuum distributions represented by tabular spectra and a Maxwellian, T(E), for fission. There are also (n,4n) data. There are photon production data.
^{253}Cf	B-V. Does not include inelastic scattering or (n,2n). The resonance region treatment is based on parameters generated using the GENRPAR code, resolved to 100.4 eV and unresolved to 10 keV.
^{253}Es	B-V. Includes only capture (MT = 102) and elastic scattering (MT = 2) and no fission, inelastic scattering or (n,2n). The resonance region treatment is based on parameters generated using the GENRPAR code, resolved to 101.2 eV and unresolved to 10 keV.

Cross-section standards and dosimetry reactions

Introduction

The nuclear cross-section standards are those relative to which other cross-sections are measured. They comprise:

- ^{1}H (n,nθ), ^{3}He (n,p), ^{6}Li (n,t), ^{10}B (n,α), ^{12}C (n,nθ), ^{197}Au (n,γ), ^{235}U (n,f).
- ^{252}Cf spontaneous fission X(E) and ν.
- The 2 200 m/s cross-sections of ^{233,235}U, ^{239,241}Pu.

The cross-sections are not standards over the whole energy range, only over the range for which they are well-known. The choice of data for the standards is the responsibility of a subgroup of the IAEA International Nuclear Data Committee (and previously also of the NEA Nuclear Data Committee before it was discontinued). In practice, the data chosen have been the ENDF/B standards (currently ENDF/B-VI) except for the ^{252}Cf fission spectrum, for which the IAEA recommended standard is the evaluation by Mannhart [8]. The standards are described in the handbook NEANDC-311 [9].

The cross-sections in JEF-2.2 are the ENDF/B-VI evaluations, except for the 2 200 m/s values for ^{233}U, ^{239}Pu and ^{241}Pu. In addition, we note that the thermal values for ^{235}U are currently being re-evaluated. Also we should note that for C it is the evaluation for the element, rather than the isotope, ^{12}C, which is in the libraries. For ^{252}Cf it is the spontaneous fission data which is the standard and this is not included in the cross-section file for ^{252}Cf (although the spontaneous fission spectrum is included in the ENDF/B-VI Decay Data Library as Mat 9861).

The International Reactor Dosimetry File, IRDF-90 version 2 [10] contains data recommended by an IAEA advisory group. The contents of the 1990 version are described by Zsolnay and Nolthenius [11]. For some applications the use of an international standard dosimetry reaction is preferred. For example, for characterising irradiation damage effects, or irradiation conditions, the use of a standard set of reactions, and their interpretation using an internationally agreed set of data and procedures, is recommended. In other cases one would wish to use the best available data.

The list of dosimetry reactions includes the standards reactions. In addition to these we have:

^{19}F (n,2n), ^{23}Na (n,γ), ^{24}Mg (n,p), ^{27}Al (n,p) (n,α), ^{31}P (n,p), ^{32}S (n,p), ^{45}Sc (n,γ), ^{46}Ti (n,p), ^{47}Ti (n,p)* (n,np)*, ^{48}Ti (n,p) (n,np)*, V (n,α), ^{52}Cr (n,2n), ^{55}Mn (n,γ)* (n,2n)*, ^{56}Fe (n,p)*, ^{58}Fe (n,γ)*, ^{59}Co (n,γ)* (n,α)* (n,2n), ^{58}Ni (n,p)* (n,2n), ^{60}Ni (n,p)*, ^{63}Cu (n,γ)* (n,α)* (n,2n), ^{65}Cu (n,2n)*, ^{64}Zn (n,p), ^{89}Y (n,2n)*, ^{90}Zr (n,2n), ^{93}Nb (n,γ) (n,n′)m (n,2n), ^{103}Rh (n,n′)m, ^{109}Ag (n,γ), Cd (n,γ)*, ^{115}In (n,n′)m* (n,2n), ^{127}I (n,2n), Gd (n,γ)**, ^{232}Th (n,f)* (n,γ)*, ^{238}U (n,f)* (n,γ)*, ^{237}Np (n,f)*, ^{239}Pu (n,f)*

* Denotes that the data in the International Reactor Dosimetry File, IRDF-90/93 were adopted from ENDF/B-VI.

** Denotes that the data were obtained by summing the isotopic data in ENDF/B-VI.

For reactions that have a resonance structure, such as the (n,γ) reaction, detailed point energy data are required, both for the reaction and for the total and scattering cross-sections, so that resonance shielding and scattering effects can be calculated. For threshold reactions at high keV and MeV energies the use of fine group data for the reaction alone can be acceptable and data could be taken directly from the IRDF library in such cases. When the data used differ from the IRDF data, and the results of the analysis are to be published, a comparison between the data used and the IRDF data (at the group level) would be helpful to the international community.

For the (n,γ) and (n,f) cross-sections it is always best to use the cross-sections in a complete evaluation. The data for these cross-sections given in JEF-2.2 should be used in the analysis of dosimetry measurements even if different from the recommended dosimetry file data because it is more important to have consistency between the cross-sections used to calculate the flux and the dosimetry reaction because of resonance shielding effects. For threshold reactions which do not have a resonance structure requiring a resonance shielding treatment it is not essential that the cross-sections used for the flux calculation and to calculate the dosimetry reaction rate be the same.

Evaluations in JEF-2.2

We note that there are different evaluations in JEF-2.2, from those in the IRDF library, for the following:

Al, V, ^{32}S, ^{52}Cr, ^{56}Fe, ^{58}Fe, ^{127}I (adjusted in JEF-2.2), ^{238}U, ^{239}Pu

There are no evaluations for the isotopes of Mg and Ti in JEF-2.2.

^{89}Y and ^{103}Rh

In JEF-2.2 the B-VI evaluation for ^{89}Y by Howerton and Smith [12] was adopted, with modifications made to the resonance region data by Gruppelaar et al.. This includes the recommended (n,2n) dosimetry reaction.

The JEF-2.2 evaluation for ^{103}Rh is based on the RCN-3 evaluation with the addition of resonance parameters from [3] and charged particle reaction data from REAC-ECN-4. The evaluation makes no specific reference to the (n,n′)m cross-section, the evaluation of the inelastic scattering being based on nuclear model calculations. One could not recommend the use of this file for dosimetry applications without further study. The evaluation is mainly aimed at meeting the requirements for fission product applications.

Concluding remarks concerning the dosimetry reactions

The JEF-2.2 evaluations, in common with other current general purpose libraries, do not provide dosimetry reaction data consistent with the international recommendations in most cases. The reactions in the JEF-2.2 files should be compared with the recommended dosimetry evaluations, and when the difference is significant the reaction data in the internationally recommended dosimetry library, IRDF-90 (or, when available, a more recent recommended library) should be adopted. This will not be practicable for (n,γ) cross-sections or other reactions in the resonance range, but should be possible for (n,p), (n,α) and (n,2n) reactions at MeV energies, in most cases.

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