Chapter 2

THE JEF-2.2 RADIOACTIVE DECAY DATA LIBRARY

Introduction

JEF Report 13, "JEF-2.2 Radioactive Decay Data" (August 1994) summarises the contents of the library and the origins and subsequent modifications of the data for individual isotopes. The library has also been described in a paper by J. Blachot and C. Nordborg to the International Symposium on Nuclear Data Evaluation Methodology (BNL, 1992), and the present summary is an updated and shortened version of this paper.

The JEF Project Radioactive Decay Data Library has resulted from a scientific collaboration between laboratories in France, Germany, Sweden and the United Kingdom. The first version of the library, JEF-1, was completed in 1985 (and edited in 1987, JEF Report 9, NEA Data Bank, July 1987), this file being formed in the main by merging data from the CEA library and the UK libraries (UKFPDD2 for fission products, UKPADD2 for activation products and UKHEDD2 for heavy elements and actinides). The ENDF-6 format [1] has been adopted for the libraries and this has required conversions of format for some of the original sources [2,3].

Following the distribution of the first version of JEF-2 in May 1990 (version 2.1) the library underwent several revisions, with version 2.2.0 being distributed in January 1992, version 2.2.1 in July 1992, version 2.2.2 in February 1993 and version 2.2.3 in July 1993. The JEF-2.2.3 version of the library contains information for 2 346 radioactive nuclides and was compiled at the NEA Data Bank. The data originated from different sources. A selected combination of the UK and the French CEA data files, supplemented with data from ENSDF, constituted the basis for the library. (Examples of the data adopted from the CEA and UK libraries are given in Annex 1.)

Different evaluations and measurements have been used to complement this starter file. A number of average beta and gamma energies obtained from measurements made by G. Rudstam, *et al*. have for example been included, as well as some theoretically calculated average energies and half-lives by H. Klapdor-Kleingrothaus, *et al*.

Most of the delayed neutron branching ratios of precursors (P_n) have been taken from a recent measurement and an evaluation by G. Rudstam, *et al*., and from nuclear theory calculations by H. Klapdor-Kleingrothaus, *et al*. The atomic mass adjustment of G. Audi and A. Wapstra (1988) has been used to update most of the decay energies. A small database (TBRA) was created to follow recent publications not yet entered in the ENSDF database. Great care has been taken to verify the consistency of the data. In particular the ratios between the available energy and the total energies in different spectra were tested and adjusted to be as close as possible to 1. Decay heat calculations have been made as part of the validation of this new library.

The compilation of the JEF-2.2 decay data file

JEF Working Group on Radioactive Decay and Fission Yield Data

A NEA JEF Project Working Group co-ordinated the evaluation work. The summary records of the working group are reported in internal JEF documents.

Problems encountered in the evaluation of decay data

A. Tobias [24], at the time JEF-1 was produced, summarised the problems of evaluation of fission product decay data as follows:

The result of most radioactive decay studies is a decay scheme which describes the relative emission probabilities of gamma transitions that arise in the de-excitation of the daughter nucleus. Occasionally, details of the beta spectrum have also been studied experimentally and the relative branching of the beta transitions to the excited levels of the daughter nucleus determined. In most cases, however, the relative beta branching has been inferred from the measured gamma data. It must be emphasised that, even in many of these cases, the decay scheme data are incomplete from the point of view of decay heat calculations and it is the task of the evaluator to derive the required parameters by suitable deduction.

The average gamma energy release per disintegration may be obtained by summing the products of the gamma energies with their emission probabilities. However, the absolute emission probabilities will not always be known or may be highly uncertain. To this must be added the average energy released in the form of X-rays per disintegration.

There have been relatively few measurements made of the distribution of conversion electrons, Auger electrons and X-rays following the internal conversion of gamma radiation or following electron capture decay. Tabulations of predicted internal conversion coefficients as a function of energy for each atomic number are available for gamma transitions of different multi-polarities. Thus, the distribution of X-rays and electrons arising from internal conversion may be calculated. For the atomic K-shell the calculations are relatively straightforward, but become more complex for the L- and higher electron shells.

Most measurements of beta decay yield estimates of the beta end point energies and corresponding emission probabilities. What is required for decay heat calculations [30] is the average energy emitted in the form of beta radiation per disintegration. Strictly speaking, this should be derived from the observed distribution of beta particles as a function of energy. Since these data are rarely available it is necessary for the evaluator to calculate the average beta energy of each transition from beta decay theory (Gamow-Teller/FERMI selection rules and systematics of log ft values). This approach is valid for allowed and unique forbidden beta transitions but for non-unique transitions measurements must be made to provide the correct data.

In the absence of this kind of data there is a popular practice of calculating average beta energies of such transitions by treating them as unique transitions of a lower degree, i.e. a first forbidden non-unique transition would be treated as allowed and a second forbidden non-unique transition would be treated as first forbidden unique. However, it must be emphasised that the validity of this approach has yet to be confirmed.

These comments illustrate that even for relatively simple and well-defined decay schemes the evaluators need to provide considerable effort to obtain the required parameters for decay heat calculations. Complex decay schemes, as are found for many fission products (e.g. the case of ^{87}Br, C.W. Reich [31]), give rise to additional problems.

The absolute normalisation of gamma emission probabilities depends upon the magnitude of the beta branch to the ground state of the daughter nucleus. There are many instances where this has not been accurately determined. Also, many experimental studies have concentrated on the most intense radiations at the lower energies. It has been argued that, as a result, in the study of complex decay schemes with large *Q*-values the beta branching to highly excited states may be missed (Hardy, *et al*. [25]. This is because, invariably, the beta branches are deduced from the difference in intensities of gamma rays populating and depopulating the various excited levels. In the construction of the decay scheme certain gamma rays are unplaced while others may remain undetected because of their high energy or relatively low intensity. As a consequence the average beta energy is overestimated with a corresponding underestimate of both the average gamma energy and the combined beta and gamma energy.

Various approaches have been adopted in order to overcome the problems with such nuclides. For example, T. Yoshida [26] has used the gross theory of beta decay to predict the average decay energies of these fission products and extended it to include a number of nuclides with decay schemes, which are believed to be well defined. K. Aleklett and G. Rudstam [27] have measured directly the average beta energies of some fission products with "well known" decay schemes and have used measured beta strength functions, or extrapolations of them, to predict the corresponding average gamma energies. These beta strength functions have also been used by Aleklett and Rudstam to obtain estimates of the average decay energies of short-lived fission products for which little decay data have been measured. Microscopic calculations of the beta strength function have been made by H. Klapdor, *et al*. [33], [34] and corresponding estimates of the average decay energies obtained. Mann, *et al*. [35] have demonstrated the use of a statistical model for the prediction of beta decay properties. However, analysing the recent beta-ray data important to decay heat predictions, Dickens [32] concluded that none of these evaluation/prediction methods is superior in reproducing the experimental data.

Consistency checking

The policy of the JEF Working Group has been to recommend data which is recent and as correct as possible, and also to be careful concerning the consistency of the recommended data. In particular, the ratio between the effective *Q*-value and the calculated *Q*-value was the main criterion:

$$\text{Effective } Q\text{-value} = \Sigma\, Qi\, BRi$$

where *Qi* and *BRi* are the *Q*-value and branching ratio of the i^{th} decay mode.

$$\text{Calculated } Q\text{-value} = \Sigma\, Ea_i\, Pa_i$$

where Ea_i and Pa_i are the energies and emission probabilities of all discrete spectral emissions.

Consistency checks were based on an energy-balance checking procedure developed by A. Tobias (incorporated in the code FIZCON), and comparisons have also been made with the data in other libraries. Decay heat calculations by F. Storrer [21] and A. Tobias [22] have also formed part of the checking procedure which resulted in revisions to intermediate versions of the library. Decay heat

calculations made using JEF-2.2.2 have been presented by F. Storrer (JEF/DOC-441 and thesis) and also by B. Nimal, *et al*. (JEF/DOC-442). An evaluation of the decay heat predictions has also been made by P de Leege, *et al*. [23].

ENSDF and the code RADLST

In a paper presented at the 1990 Nuclear Data Conference in Jülich [4], M. Bhat described the status of the Evaluated Nuclear Structure Data File (ENSDF), the network and the content of the file at the time when the JEF-2 library was being assembled. A description of the file is also given in a BNL report [5]. This file is mainly oriented to nuclear structure data.

The decay data in the ENSDF are ordered according to the final nuclide. To combine data from a parent with different decay modes, different data sets have to be merged. For instance, if a nuclide decays via internal transition and beta decay, one data set (*IT* decay) will be found in the *A, Z* and the other (beta) in the *A, Z* + 1 part of the file. Often the data sets are from different evaluators and common parameters, such as half-life, branching etc., might differ. Only the *Q*-values are to a certain extent standardised, as they are always taken from one of the Wapstra-Audi mass evaluations. The ENDSF data are also presented in the Table of Radioactive Isotopes [6] and currently updated (by mass chains) in the Nuclear Data Sheets with a higher degree of uniformity and completeness. No branching for the decay modes, however, are given.

The computer code RADLST [7] was designed to calculate the nuclear and atomic radiations associated with the radioactive decay of nuclei. As its primary input, it uses decay data in the ENSDF format and presents the calculations in a variety of forms. One of the output formats is the ENDF format. The file contains the decay modes, the branching energies and the intensities for various nuclear radiations, conversion electrons, electron-positron pairs from internal pair formation. The energies and intensities of the associated atomic radiations (X-rays and Auger electrons) are also calculated. The program does not output prompt or delayed neutrons nor decay protons. An example of a RADLST calculation is given in the notes of the lecture course given by J. Blachot at the FJ/OH Summer School on Neutron Data Measurements and Evaluation, held at Geel in Belgium, May 1999 [29].

Compilation program

The compilation of the JEF-2.2 decay data file was performed using a semiautomatic computer code, COREDECAY, originally written by T. Nakagawa. The program reads the basic input files stored on the computer and uses an index file, where information on all corrections and additions are stored. It makes the necessary modification to the basic data, performs a number of internal consistency checks and documents all that has been done or found in the comment part of the final data set. Among the items considered for internal checking, and sometimes automatic correction, are included: sum of branching fractions, energy consistencies, *Q*-values, and *FT*-values.

Statistics on the JEF-2.2 file

Some statistics on the JEF-2.2 file are given in Table 1.

Table 1. Status of JEF-2.2

Total number of radioactive nuclides	2 345
Ground state	1 840
First excited state (m)	471
Second excited state (n)	34
Nuclides with spectra	2 144
Total N° of gamma lines	70 614
Total N° of beta lines	7 956
Total N° of beta + lines	8 121
Total N° of alpha lines	1 746
Total N° of electron lines	38 116
Total N° of X-ray lines	6 288

Modifications made to the basic file

Mean beta and gamma energies of short-lived fission products

G. Rudstam, *et al*. [8] have carried out extensive investigations on beta and gamma spectra of individual fission products. The description of the gamma and the beta measurements and the analysis of the data have been published. Some of these data can be compared with mean energies derived from level schemes found in ENSDF. When the level scheme is well known, the agreement in the two data sets is generally good.

For many nuclides with incomplete level schemes, in particular those with high *Q*-beta, the high energy gammas were often not measured. Some nuclides do not have enough data to derive a complete level scheme. Mean beta and gamma energies for 109 nuclides, derived by G. Rudstam, were included in the JEF-2.2 file (see Annex 2) as modified values to some of the ENSDF original data sets together with the associated measured spectra.

It should be noted that, as was well recognised at the time, this procedure can result in discrepancies between the radiation spectra (recorded in ENDF-6 format either in discrete or continuous form, or both), the associated average decay energy and the overall energy balance. Moreover, some atomic and nuclear decay data which are needed to check the internal consistency of the file are lacking in the ENDF-6 format.

P_n values

A number of compilations and evaluations of delayed neutron branchings have been reported during recent years (see for example A. D'Angelo, *et al*. [9]). The values in the ENSDF database often differ from the data in these evaluations, which sometimes use unpublished data or internal reports, not yet referenced in the Nuclear Structure Reference (NSR) file [10].

A recent evaluation by G. Rudstam [11] presents an updated list of delayed neutron branchings. In order to fill the gaps where the existing data are meagre or lacking, an extensive series of measurements has been carried out at the OSIRIS isotope on-line separator facility at Studsvik. As a result of this effort delayed neutron branchings have been measured for 52 precursors, in many cases with a considerable improvement in accuracy. It is always difficult to judge the quality of the different experimental results; a value with a small quoted uncertainty can still be erroneous. G. Rudstam has discarded values which are far outside the bulk of determinations, even if their error estimates are small. If the data are widely discrepant, G. Rudstam has used an unweighted average.

The P_n values in the JEF-2.2 file have been tested using a summation calculation to derive the delayed nu-bar for the 39 fissile systems [12,13,14]. The results are summarised in the part of this report dealing with documentation (Part II, Chapter 10).

Theoretical calculations for unmeasured parameters

In recent years most calculations of the parameters associated with beta decay have been made using the gross theory [15]. To improve on this calculation method, which essentially ignores nuclear shell model effects, H. Klapdor-Kleingrothaus, *et al*. have calculated the beta decay with a Tamm-Dancoff Approximation (TDA) approach. A description of the model can be found in papers by the Heidelberg group [16,17].

The JEF Working Group decided to use the calculated values of H. Klapdor-Kleingrothaus only when no experimental data were available, 16 values for half-lives, 101 mean beta and gamma energies, and 32 P_n values being adopted (see Annex 2).

The following table compares the types of fission product decay data important for decay heat prediction in the available data files:

	JEF-1	**JEF-2.2**	**JNDC-FP-V2**	**ENDF-B-VI**
Evaluated FPs	700	860	1 227	891
Radioactive FPs	540	730	1 078	764
Stable FPs	120	130	149	127
FPs with exp. known decay energies (a + b)	540	611	536	471
FPs with estimated decay energies (c + d)	0	119	542	420

The *a*, *b*, *c* and *d* categories correspond to:

a) Decay schemes which are constructed from spectroscopic investigations and recorded in an ENSDF type library. In this case, average beta and gamma energies are derived from the level scheme, which may be incomplete at higher energies, leading to a "pandemonium effect".

b) (overestimation of mean beta energy, and underestimation of gamma energy, with a compensation on the total). In JEF-2.2, 2 110 nuclides belong to this category, including around 500 fission products.

c) Average decay energies which are directly evaluated. Rudstam, *et al*. have measured continuous spectra of beta particles and gamma rays for short-lived FPs, from which average energies can be obtained. One hundred and nine (109) nuclides of this type are present in JEF-2.2.

d) Nuclides having incomplete decay schemes. Their evaluation is thus partially based on the Type *a* approach, completed by a Type *b* solution, or a specific evaluation based on systematics (measured spectra augmented by calculated ones are used in ENDF/B-VI and JNDC-FP-V2 but not in JEF-2.2). In fact, six FPs have their spectra modified by Rudstam's evaluation, and 18 have their half-lives obtained from Blachot's systematics (JEF Report 13, August 1994).

e) For nuclides without any experimental information, decay data have been calculated using a theoretical model. In the case of JEF-2.2 this is a nuclear shell model based on the proton-neutron Quasiparticle Random Phase Approximation (p-n QRPA) by Klapdor, *et al.* One hundred and one (101) nuclides of this type are included in JEF-2.2.

Half-lives

A small database, TBRA [18], has been created to contain data for radioactive nuclides more recent than that in the initial JEF-2 file. In the case of metastable isotopes only half-lives greater than one millisecond are included. It contains data for the level energy of the isomer, the spin and parity, the half-life and its uncertainty, the different decay modes and their branchings, the date of the last update and a flag indicating if the data were taken from another source than ENSDF. There are new references in TBRA for 136 nuclides. These new references are only for papers which contain half-life information, mainly on newly identified nuclides. Table 2 presents a comparison with the half-life data in the first version of JEF-2.

Using TBRA, it was possible to update many nuclides in the first version of JEF-2. Only half-lives, decay modes and branchings have been updated using TBRA, a comparison between the two files having been made with a small FORTRAN program.

Table 2. Comparison between TBRA and JEF-2.0 (initial)

Nuclide	T (TBRA)		T (JEF-2A)		DIFF. (%)
$^{32}_{14}$Si	0.1720E+03	y	0.3296E+03	y	-91.6
$^{76}_{29}$Cu	0.3500E+00	s	0.6100E+00	s	-74.2
$^{84}_{31}$Ga	0.1380E+00	s	0.2500E+00	s	-81.1
$^{88}_{33}$As	0.8400E-01	s	0.5600E+00	s	-566.6
$^{89}_{41}$Nb	0.1900E+01	h	0.1100E+01	h	42.1
$^{89m}_{41}$Nb	0.1180E+01	h	0.2030E+01	s	-72.0
$^{90}_{34}$Se	0.3480E+00	s	0.1800E+00	s	48.2
$^{91}_{41}$Nb	0.6800E+03	y	0.9990E+04	y	-1 369.1
$^{102}_{38}$Sr	0.3550E-01	s	0.6800E-01	s	80.8
$^{108}_{49}$In	0.5800E+02	m	0.3967E+02	m	31.6

Relative importance of the different sources of decay energies in JEF-2.2 decay heat calculations

Considering the total decay heat for a ^{235}U fission pulse, F. Storrer [21] shows that for cooling times longer than about 3×10^6 seconds the calculated heat is determined by the data evaluated on the basis of detailed spectroscopic measurements, while for times shorter than 3×10^5 seconds the largest contribution is from isotopes having data evaluated by G. Rudstam. For a cooling time shorter than about 10 seconds the theoretical data of H. Klapdor-Kliengrothaus, *et al*. makes its maximum contribution of about 25%.

Yoshida, *et al*. [28] have compared JEF-2.2 calculations of the gamma energy for a ^{239}Pu fission burst with measurements by Dickens, *et al*. [36] and by Akiyama [37], and also with calculations made using JNDC-V-2 and ENDF/B-VI. All three data libraries underestimate the gamma energy in the 300 to 3 000 seconds interval, but for JEF-2.2 the underestimation is larger (about 10%) and extends down to about 30 seconds. The authors attribute this to the JEF policy of not augmenting measured gamma spectra to take account of theoretical estimates of the total gamma energy yield and that thus the data suffer from the so-called "pandemonium effect". As a consequence it is expected that the beta component of the decay heat in this time interval will be overestimated. Yoshida, *et al*. also identify isotopes for which the differences between the data in JEF-2.2 and in JNDC-V-2 have significant effects in the time interval 300 to 3 000 seconds mainly due to beta branching inversion between isomeric and ground states (and spin assignment).

The data for the heavy elements (^{206}Hg to ^{253}Es)

A re-evaluation of the decay data for 126 heavy elements and actinides (^{206}Hg to ^{253}Es) has been made by A. Nichols, *et al*. [19]. This re-evaluation includes lists of the references used to produce the proposed decay schemes and comments identifying their deficiencies. Particular care was applied in testing the consistency of data.

Documentation of the JEF-2.2 decay data library

The report documenting the library (JEF Report 13, August 1994) contains the following information:

- A list of the origin of the data for all isotopes and the reference for any modifications to half-lives, average energies, P_n values, and inclusion of continuum spectra.

- A table containing, for each isotope, the most important decay parameters, such as average energies, half-lives, *Q*-values, spin and parity, branching and number of spectral lines.

- A section showing graphically the decay schemes for the mass-chains from $A = 71$ to $A = 170$, including cumulative and chain yields for the most important fissionable systems.

- A comparison of the main decay parameters from the JEF-2.2, ENDF/B-VI, and JNDC-2.0 libraries.

The computer code JEF-PC (version 2.0, OECD/NEA, 1997), which has been developed for use on personal computers, contains information such as half-lives, *Q*-values, average decay energies, as well as detailed gamma and alpha spectra for all isotopes in the JEF-2.2 decay data file.

Suggested requirements for improvements

Studies have been made to identify the required improvements to the JEF-2.2 decay data library. These include requested modifications to the ENDF-6 format. Reference should be made to several JEF/DOCs, in particular the following document:

- JEF/DOC-661, by F Storrer, *et al.*, "General Comments on the Nuclear Decay Data Requirements for JEFF-3 and the Evaluation Procedure".

A number of deficiencies and discrepancies have been detected in the JEF-2.2 file, as has been described in the following JEF documents:

- JEF/DOC-465 by Hoogenboom, "Data Missing".

- JEF/DOC-603 by C.J. Dean, C.R. Eaton and A.L. Nichols, "Assessment of Decay Data Files for Selected Radionuclides – Interim Report April 1996".

- JEF/DOC-676 by B. Nimal, J. Blachot and C.H. Diop, "Consistency Checks on the JEF-2.2 Decay Data File".

Decay data checking methods are reviewed in:

- JEF/DOC-813 by C.J. Dean and M.J. Grimstone, "Review of Decay Data Checking Methods".

The radionuclides which are currently being re-evaluated are given in:

- JEF/DOC-671 by J.S. Kent and A.L. Nichols, "Assessment and Evaluation of Decay Data for Nuclear Reactor Applications" (also Ref. [20]).

Progress with the re-evaluation work is given in Part IV, Chapter 14, also issued as:

- JEF/DOC-793 by A.L. Nichols and C.J. Dean, "UK Work Undertaken after BNFL/CEA and UKAEA Reviews of JEF-2.2 Decay Data – 1996-2000".

REFERENCES

[1] P.F. Rose and C.L. Dunford, ENDF-102 BNL-NCS-44945.

[2] B. Nimal and B. Duchemin, Ecriture en ENDF de la bibliothèque, CEA/SERMA/LEPF/86-744 (1986).

[3] A. Tobias, COGEND, RD/B/N4147 (1977) and RD/B/N4309 (1978).

[4] M.R. Bhat, "Evaluated Nuclear Structure Decay Data File (ENSDF)", in Proc. Conf. on Nuclear Data for Science and Technology, S.M. Qaim, ed. (Springer-Verlag, 1991), p. 817.

[5] J.K. Tuli "Evaluated Nuclear Structure Data File", A manual for preparation of data sets, BNL-NCS-51655 - Rev. 87.

[6] E. Browne and R.B. Firestone, Eighth Edition of the Table of Radioactive Isotopes. A Wiley-Interscience Publication (1996).

[7] T.W. Burrows, The Program RADLST, BNL-NCS-52142 (1988).

[8] G. Rudstam, *et al*., *At. Nuc. Data Tables* 45 (1990), p. 239 and 53 (1993), p. 1.

[9] A. D'Angelo, *et al*., WPEC Sub-Group 6 – final report to be published Sept. 1999. See also: S. Das, "The Importance of Delayed Neutrons in Nuclear Research", *Progress in Nuclear Energy*, Vol. 28, No. 3, pp. 209-264, 1994.

[10] S. Ramavataram and C.L. Dunford, Nuclear Structure, References BNL-NCS-51800.

[11] G. Rudstam, "P_n-Values and Half-Lives of Delayed-Neutron Precursors", Research Report NFL-70/Rev, The Studsvik Neutron Research Laboratory, University of Uppsala, S611 82 Nykoping Sweden, (1991).

[12] J. Blachot, *et al*., "Delayed Neutron Yields for 39 Fissile Systems", idem to [4], p. 89.

[13] R.W. Mills, M.F. James and D.R. Weaver, "Study of the Delayed Neutron Yield and its Time Dependence", idem to [4], p. 86.

[14] J. Blachot, *et al*., NEANDC-299 "U".

[15] K. Takahashi and M. Yamada, *Prog. Theor. Phys*. 41 (1969), 1470.

[16] M. Hirsch, A. Staudt, K. Muto and H. Klapdor-Kleingrothaus, idem to [4], p. 539.

[17] Staudt, *et al*. *At. Nuc. Data Tables*, 44 (1990), 79.

[18] O. Bersillon and J. Blachot, CEA N 2643 (1990).

[19] A.L. Nichols, "Heavy Element and Actinide Decay Data: UKHEDD-2 Data Files", AEA Technology Report AEA-RS-5219, Dec. 1991.

[20] J.S. Backhouse and A.L. Nichols, "Assessment and Evaluation of Decay Data for Nuclear Reactor Applications" *Appl. Radiat. Isot*., Vol. 49, No. 9-11, pp. 1393-1396, 1998.

[21] F. Storrer, "Contribution à l'élaboration et la qualification de la bibliothèque DARLING", Thesis, University Paris-XI, Orsay, 1993, and paper to the 1994 Gatlinburg Nuclear Data Conference, Vol. 2, p. 819.

[22] A. Tobias, "Decay Heat Testing of the Preliminary JEF-2.2.1 Data Files", TD/NS/MEM.0390 (Nov. 1992).

[23] P. de Leege, J. Hoogenboom and J. Kloosterman, "Validation of Decay Heat Data from ENDF/B-VI. JEF-2.2, and JNDC FP V2 Nuclear Data Libraries".

[24] A. Tobias, "Decay Heat Predictions Using JEF-1", JEF/DOC-166 (1986).

[25] J.C. Hardy, *et al*., *Phys. Letts*. 136B, p. 331 (1984).

[26] T. Yoshida, *et al*., Proc. NEANDC Specialists Meeting on Yields and Decay Properties of Fission Product Nuclei, p. 227 (1983).

[27] K. Aleklett and G. Rudstam, *Nucl. Sci. and Eng*. 80, p. 74 (1982).

[28] T. Yoshida, *et al*., "Possible Origin of the Gamma-Ray Discrepancy in the Summation Calculations of Fission Product Decay Heat", *Nucl. Sci. Technol*. 36, p. 135 (1999).

[29] J. Blachot, "Evaluation of Fission Product Decay Data", Lecture Notes to the Frédéric Joliot/Otto Hahn Summer School on Neutron Data Measurement and Evaluation, held at Geel, Belgium, May 1999.

[30] C.W. Reich, "Review of Nuclear Data of Relevance for the Decay Heat Problem", Proc. Specialists Meeting on Data for Decay Heat Predictions, Studsvik, Sweeden, 1987, NEACRP-302 'L', NEANDC-245 'U'.

[31] C.W. Reich, "Nuclear Decay Data: Some Applications and Needs", Proc. International Conference on Nuclear Data for Science and Technology, Santa Fe, New Mexico, May 1985.

[32] J.K. Dickens, "Analysis of Beta-Ray Data Important to Decay Heat Predictions", *Nuclear Science and Engineering*, 109, 92-102 (1991).

[33] H.V Klapdor, "The shape of the beta strength function and consequences for nuclear physics and astrophysics", *Prog. Part. Nucl. Phys*. 10, 131(1983).

[34] H.V. Klapdor and J. Metzinger, “New Results on the Decay Heat of Nuclear Reactors”, Proc. Intern. Conf. on Nuclear Power Plant Ageing, Availability Factor and Reliability Analysis, San Diego, July 1985.

[35] F.M. Mann C. Dunn and R.E. Schenter, “Beta Decay properties using a statistical model”, *Physical Review C* - Volume 25, number 1 (January 1982).

[36] J.K. Dickens, T.A. Love, J.W. Mc Connell and R.Peellee “Fission-Product Energy Release for imes Following Thermal-Neutron Fission of Plutonium-239 and Plutonium-241 Between 2 and 14,000 s”. *Nucl. Sci. Eng*., 78(2): 126-146 (June 1981).

[37] M. Akiyama and S. An “Measurements of Fission-Product Decay heat for Fast Reactors” Proc. Of the 1982 Antwerp Int. Conf. on Nuclear Data for Science and Technology, p. 237, K. H. Böckhoff ed. (1983).

Annex 1

Examples of data adopted from the CEA and UK libraries

An example of data adopted from the CEA library is given in Table A.1. Summary and test results were written into the comment part of the file. Table A.2 shows data adopted from the UK library.

Table A.1. Example of data for an isotope adopted from the CEA library

35-BR- 85 NEADB RCOM-JUL83 JEF DECAY DATA WORKING GROUP
----JEF-2 MATERIAL 3552

JEF-2
DATA WERE TAKEN FROM THE FRENCH LIBRARY

**** 35 BR 85

***DECAY DATA EVALUATION CEA OCT. 1984
***J. BLACHOT – B. DUCHEMIN – C. FICHE – B. NIMAL

MEAN BETA ENERGY	1 042.15	keV
MEAN GAMMA ENERGY	66.03	keV
EFFECTIVE Q-VALUE	2 566.17	keV
CALCULATED Q-VALUE	2 577.82	keV
% DEVIATION	0.45	

COMMENTS

07.08.80 ENSDF; 85 BR B-DECAY
75NU03, 75HU02, 71ER15 80 NDS

73KR06 KRATZ J.V. ET AL. J. INORG. NUCL. CHEM. 35 (1973) 1407.
73NU03 NUH M.F. SLAUGHTER D.R. NUCL. PHYS. A 250 (1975) P1.

Table A.2. Example of data for an isotope adopted from the UK library

35-BR- 80 M NEADB RCOM-JUL83 JEF DECAY DATA WORKING GROUP

* JEF-2
* DATA WERE TAKEN FROM THE UK LIBRARY

35 BR-80 M DECAY SCHEME EVALUATION A. TOBIAS SEP-80
DECAY DATA FROM ENSDF-EXTRACTION PROGRAM BY B.S.J. DAVIES

MEAN GAMMA ENERGY	= 14.6203	keV
MEAN X-RAY ENERGY	= 9.5408	keV
MEAN AUGER ELECTRON ENERGY	= 8.0464	keV
MEAN CONVERSION ELECTRON ENERGY	= 53.9239	keV
EFFECTIVE Q-VALUE	= 85.9499	keV
UNCERTAINTY IN EFFECTIVE Q (%)	= 0.4654	keV
CALCULATED Q-VALUE	= 86.1314	keV
% DEVIATION	= -0.2111	

ENDF/B-V DATA PRODUCED BY COGEND (A. TOBIAS JAN-1984)

Annex 2

Isotopes for which the decay energies are from the measurements of G. Rudstam or the theoretical estimates of H. Klapdor-Kleingrothaus, *et al*.

Nuclides for which the mean beta and gamma energies derived by G. Rudstam have been adopted

$^{79,80,81,82}_{31}$Ga
$^{79,80,81,82,83}_{32}$Ge
$^{79,80,81,82,82m,83,84,85,86}_{33}$As
$^{83,83m,85}_{34}$Se
$^{84,85,86,88,89,90}_{35}$Br
$^{87,89,90,91}_{36}$Kr
$^{89,90m,91,92,93,94,95,96,97}_{37}$Rb
$^{92,93,94,96,97,98,99}_{38}$Sr
$^{94,95,96,97,97m,98,99,100}_{39}$Y
$^{99}_{40}$Zr
$^{98,99}_{41}$Nb
$^{129,130,130m,131,132,133}_{50}$Sn
$^{131,133,135,136,137}_{51}$Sb
$^{133,133m,135,136,137}_{52}$Te
$^{135,136,136m,137,138,139,140}_{53}$I
$^{137,139,141}_{54}$X
$^{138m,139,140,141,142,143,144,145,146}_{55}$Cs
$^{141,142,143,144,145,146,147}_{56}$Ba
$^{143,144,145,146,147}_{57}$La
$^{145,146,147}_{58}$Ce
$^{147}_{59}$Pr

Additional isotopes for which the continuum spectrum from measurements by G. Rudstam was adopted

$^{87}_{35}$Br
$^{88,90}_{37}$Rb
$^{95}_{38}$Sr
$^{99m}_{41}$Nb
$^{134m}_{51}$Sb

Isotopes for which the mean energies evaluated by G. Rudstam were adopted but not the continuum spectra

$^{81}_{33}$As
$^{96}_{39}$Y
$^{129}_{50}$Sn
$^{133m}_{52}$Te
$^{139}_{55}$Cs
$^{146}_{56}$Ba

Nuclides for which the theoretical estimates of mean energies, calculated by H. Klapdor-Kleingrothaus, *et al*., have been adopted

$^{74,75,76}_{29}$Cu
$^{77,83,84}_{31}$Ga
$^{84,85,86}_{32}$Ge
$^{87,88}_{33}$As
$^{87,88,89,90,91}_{34}$Se
$^{91}_{35}$Br
$^{98,99,100}_{37}$Rb
$^{100,101}_{38}$Sr
$^{101,102}_{39}$Y
$^{100,101,102,103,104}_{40}$Zr
$^{100,101,102,103,104,105,106}_{41}$Nb
$^{103,105,106,107,110}_{42}$Mo
$^{109,110,112}_{43}$Tc
$^{110,111,112,113}_{44}$Ru
$^{111,113}_{45}$Rh
$^{117,118,119,120}_{46}$Pd
$^{121,123,124,125}_{47}$Ag
$^{122,123,125,127,128}_{48}$Cd
$^{134,135,136}_{50}$Sn
$^{138}_{51}$Sb
$^{138,139,140}_{52}$Te
$^{141}_{53}$I
$^{142,143,144}_{54}$Xe
$^{148}_{55}$Cs
$^{148}_{56}$Ba
$^{149,150}_{57}$La
$^{149,150,151}_{58}$Ce
$^{150,151,152,153}_{59}$Pr
$^{153,154,155}_{60}$Nd
$^{155,156,157,158}_{61}$Pm
$^{158,159}_{62}$Sm
$^{161,162}_{63}$Eu
$^{163,164}_{64}$Gd
$^{165,166}_{65}$Tb
$^{169}_{67}$Ho