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Nuclear Decay Data for Dosimetry Calculation

Revised Data of ICRP Publication 38

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Abstract

New nuclear decay data used for dose calculation have been compiled for 1034 radionuclides, which are significant in medical, environmental and occupational exposures. The decay data were assembled from decay data sets of the Evaluated Nuclear Structure Data File (ENSDF), the latest version as of 2003. Basic nuclear properties in the ENSDF that are particularly important for calculating energies and intensities of radiations were examined and updated by referring to NUBASE2003/AME2003, the database for nuclear and decay properties of nuclides. In addition, modification of incomplete ENSDF was done for their format errors, level schemes, normalization records, and so on. The energies and intensities of emitted radiations by the nuclear decay and the subsequent atomic process were computed from the ENSDF using the computer code EDISTR04. EDISTR04 is an enhanced version of EDISTR used for assembling ICRP Publication 38 (ICRP38), and incorporates updates of atomic data and computation methods for calculating atomic radiations and spontaneous fission radiations. Quality assurance of the compiled data has been made by comparisons with various experimental data and decay databases prepared from different computer codes and data libraries. A package of the data files, called DECDC2 (Nuclear DECay Data for Dosimetry Calculation, Version 2), will succeed ICRP38 that has been used extensively in dose calculation and will be utilized in various fields.

Keywords: DECDC2, Nuclear Decay Data, Radionuclide, Dose Calculation, Internal Exposure, External Exposure, ENSDF, EDISTR04, ICRP Publication 38.

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線量計算用核崩壊データ

ICRP Publication 38の改訂データ

日本原子力研究所東海研究所保健物理部

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(2004年8月27日受理)

要　旨

医療，環境，職業被ばくにおいて重要な1034核種について，線量計算用の新しい核崩壊データを編集した。崩壊データは，2003年時点で最新の評価済み核構造データファイルENSDF (Evaluated Nuclear Structure Data File)から編集した。放射線のエネルギー及び強度を計算する上で特に重要となる基本的な核特性は，核・崩壊特性に関するデータベースNUBASE2003/AME2003を参照し，更新した。また，不完全なENSDFに対しては，フォーマットの誤り，レベルスキーム，規格化定数等の分析を行い，それらの修正を行った。このENSDFから，核の崩壊及びそれに続く原子過程において放出される放射線のエネルギー及び強度を，EDISTR04コードを用いて計算した。EDISTR04は，ICRP Publication 38 (ICRP38)の編集に用いられたEDISTRコードを改良したもので，原子放射線及び自発核分裂放射線の計算のための新しい原子データや計算方法を取り込んでいる。編集されたデータの品質保証は，様々な実験データ，異なる計算コードやデータライブラリから編集されたデータベースとの比較により行った。DECDC2 (Nuclear DECay Data for Dosimetry Calculation, Version 2)と呼ばれるこのデータファイルパッケージは，線量計算に広く利用されているICRP38に置き換わり，様々な分野において活用される。

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1 Introduction

Nuclear decay data, a set of data on half-lives, decay chains, and energies and intensities of radiations emitted by the nuclear transformation and the subsequent atomic process, are required in any evaluation of radiation dose and health risk from internal or external exposure to radionuclides. A nuclear decay database that has been used extensively in dose calculation is that compiled by the Dosimetry Research Team of the Life Sciences Division at Oak Ridge National Laboratory (ORNL). The abridged form of the database was published as Publication 38[1] (ICRP38) of the International Commission on Radiological Protection (ICRP) in 1983. An electronic form of the complete listing along with β particle spectra was published as NUCDECAY.[†,2] The database has been used in the calculation of dose coefficients[3–11] for application to medical, environmental and occupational exposures. ICRP38/NUCDECAY has been also used as a built-in database in several computer codes[12–15] for dose calculation.

Although ICRP38 has played an important role in radiation protection for two decades, an update is necessary for the following reason. Nuclear structure data files, ENSDF[16] (Evaluated Nuclear Structure Data File), used as input in the compilation of ICRP38 were prepared in the 1970s. This information for many nuclides has undergone marked changes during the intervening years.[17,18] In order to adopt the latest information on nuclear structure and decay properties, a new nuclear decay database, DECDC[†,19–21] (Nuclear DECay Data for Dosimetry Calculation), which includes all the nuclides in ICRP38 and 204 additional nuclides not listed in ICRP38, was developed at Japan Atomic Energy Research Institute (JAERI). DECDC was compiled from the ENSDF as of 1997 with the computer code EDISTR,[22] which was used to assemble ICRP38. DECDC has been used for calculating dose coefficients[23–25] based on new dosimetric quantities introduced in ICRP Publication 60,[26] the updated human respiratory tract model[27] and biokinetic models.[4,5,7,8] DECDC has been utilized in a database software relevant to radiation protection developed at ORNL.[28]

For the most part, the needs in dosimetry calculation have been served by information presented in ICRP38/NUCDECAY and DECDC. However, there is increasing interest in the spatial distribution of the dose to cells at risk:[29] particularly the depth dose into the epithelial structure of the airways of the lung, stomach, colon and urinary bladder. Such calculation requires detailed spectra of radiations emitted in the atomic processes. Therefore, further improvement of ICRP38/NUCDECAY and DECDC is required to provide the appropriate level of spatial resolution of the absorbed dose.

The purpose of the present study is to develop a comprehensive and enhanced nuclear decay database that will supersede ICRP38/NUCDECAY and DECDC. The database is aimed at both calculating average doses in organs and tissues and evaluating localized dose distribution in the cellular dimension. Following the **Introduction**, **Section 2** discusses the evaluation of the ENSDF used as input for the compilation of the decay data. The consistency of the ENSDF was established by referring to the latest nuclear parameters and by comparing the computed energies of emitted radiations with total decay energies. **Section 3** describes the computer code EDISTR04, an updated version of EDISTR. EDISTR04 was developed by incorporating into EDISTR new atomic data and methods for calculating the energies and intensities of radiations emitted in the atomic process and spontaneous fission. **Section 4** addresses the quality assurance of the compiled data by comparisons with various experimental data and decay databases prepared from different computer codes and libraries. A package of the data files was named

[†]Both NUCDECAY and DECDC are available from the Radiation Safety Information Computational Center (RSICC), ORNL, and the Nuclear Energy Agency Data Bank (NEA DB), the Organization for Economic Co-operation and Development (OECD).

DECDC2 (DECDC Version 2), an updated version of the previously-published DECDC. The developed nuclear decay files will succeed ICRP38 and will be used extensively for internal and external dose calculation in medical, environmental and occupational exposures.

2 Evaluation of ENSDF

2.1 Selection of Radionuclides for Decay Data Compilation

Figure 2.1 shows the distribution of the number of nuclides, classified by the half-life ($T_{1/2}$) values taken from NUBASE2003/AME2003.[‡,30–32] NUBASE2003/AME2003 is the database for nuclear and decay properties in ground and isomeric states for the mass numbers, A, up to 293. The values of $T_{1/2}$ have not been determined for 132 nuclides, which are classified into "Unknown". Most of these nuclides are transactinides, and the values of $T_{1/2}$ are considered to be on the order of minute or less.

ICRP38 covers the decay data for 820 radionuclides. They consist of (a) 764 nuclides with $T_{1/2} \geq$ 10 min, and (b) 56 nuclides with $T_{1/2} <$ 10 min that are decay products from the nuclides in (a) or that are used for medical applications. From the point of view of updating and reinforcing ICRP38, the nuclides of the following categories were selected as the subjects in the present compilation:

(1) all the nuclides in ICRP38, that is, 820 radionuclides, and

(2) nuclides with $T_{1/2} \geq 10$ min that are not listed in ICRP38 and their decay products.

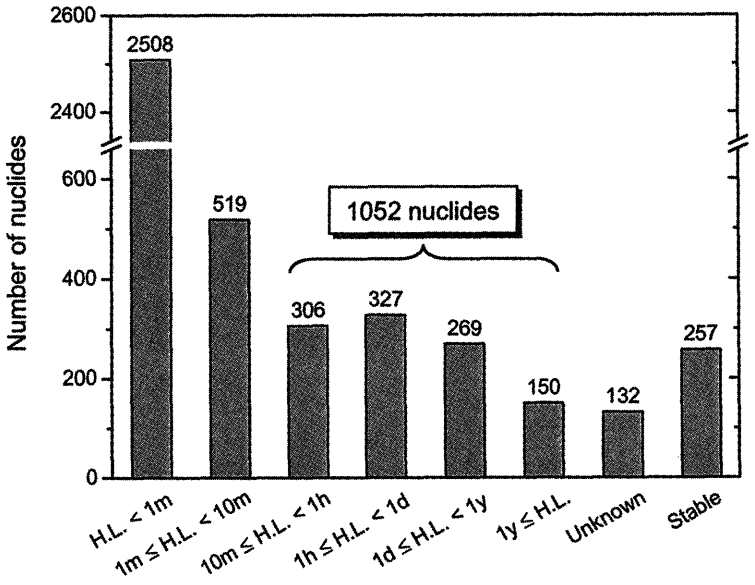


Fig. 2.1 Half-life ($T_{1/2}$) distribution of nuclides. The number of radionuclides with $T_{1/2} \geq 10$ min is 1052.

In the case of spontaneously fissioning (SF) nuclides, the total energy released per fission is of the order of 200 MeV. The dose from the spontaneous fission would be negligible compared with other decay modes, if branching fractions of SF, BF_{SF}, are on the order of 10^{-8} or less. Therefore, the data of radiations from spontaneous fission were included when the values of BF_{SF} are equal to or more than 1×10^{-9}.

Figure 2.2 shows the procedure for the evaluation and compilation of the decay data. The nuclear decay data were compiled from decay data sets of the ENSDF. The ENSDF is a computer-based data file for evaluated data from experiments for half-lives, nuclear ground and excited states, decay γ-rays and other

[‡]NUBASE2003/AME2003 has been developed and maintained in the Atomic Mass Data Center, France.

decay characteristics. The ENSDF has been maintained by the National Nuclear Data Center (NNDC) at Brookhaven National Laboratory (BNL) and regularly updated by the international network for nuclear structure data evaluation under the auspices of the International Atomic Energy Agency (IAEA). A set of ENSDF as of January, 2003, and later versions were used for the present data compilation.

In ICRP38, isomers were defined as the excited states with $T_{1/2} \geq 1$ min. The decay data of isomers were prepared as independent data sets from those of their parent nuclides to consider non-equilibrium conditions of the isomers from the parents. The separation of the decay data were extended for several isomers with shorter $T_{1/2}$ for the following reason. As shown in **Fig. 2.3**, ^{151}Dy transforms by electron capture (EC) plus β^+ decay to ^{151}Tb via ^{151m}Tb of $T_{1/2} = 25$ s. Terbium-151m decays by both isomeric transition (IT) and EC/β^+ decay with BF_i of 0.934 and 0.066, respectively. Since the decay data set of the ENSDF contains the evaluated data for "a single decay mode", the ENSDF of EC/β^+ decay in ^{151}Dy does not include the data of EC/β^+ decay of ^{151m}Tb. Therefore, the treatment for this isomer in ICRP38 misses the radiations from the EC/β^+ decay of ^{151m}Tb. In the present compilation, the decay data of isomers with multiple decay modes were separated from the parent nuclides regardless of the values of $T_{1/2}$; these nuclides are ^{76m}Br, ^{81m}Kr, ^{151m}Tb and ^{193m}Au.

2.2 Evaluation and Process of ENSDF

To achieve unified data expression, fundamental decay properties, such as total decay energies (Q_i values), BF_i, excitation energies of isomers, $T_{1/2}$ and spin (J) and parity (π) values of initial and final states, were referred to those of NUBASE2003/AME2003 and updated. The update for the Q_i values, BF_i, excitation energies, and $T_{1/2}$ were made when these values differ by more than 1 % from those of NUBASE2003/AME2003. The J and π values were revised if any differences were found from NUBASE2003/AME2003. For the revised ENSDF, the values of comparative half-life (log ft) were recalculated using the computer program LOGFT.[33]

After the above procedure, the decay data sets were processed by EDISTR04 in order to calculate the energies, E_i (MeV), and intensities, I_i ([Bq s]$^{-1}$),[§] of α particles, β particles, γ-rays including annihilation photons, internal conversion electrons, X-rays, and Auger, Coster-Kronig (CK) and super CK electrons. For spontaneously fissioning nuclides, the average E_i and I_i of fission fragments, prompt neutrons, prompt γ-rays, delayed γ-rays, and delayed β particles were also computed. A comprehensive description of the theoretical and numerical bases employed in EDISTR is given elsewhere.[22] Several enhancements in EDISTR04 are discussed in **Section 3**.

The consistency of the computed radiation data were checked by the following indices and criteria.

(1) The total intensity from the parent to the ground and isomeric states of the decay product is 100 ± 10 %.

(2) The total intensity from the parent is 100 ± 5 %.

(3) The deviation D_Q between the calculated Q value and the theoretical Q value is equal to or less than ± 5 %.

$$D_Q(\%) = \frac{\text{calculated } Q \text{ value} - \text{theoretical } Q \text{ value}}{\text{theoretical } Q \text{ value}} \times 100 \tag{2.1}$$

[§]The unit (Bq s)$^{-1}$ is given in ICRP38 and is equivalent to the number of events per nuclear transformation.

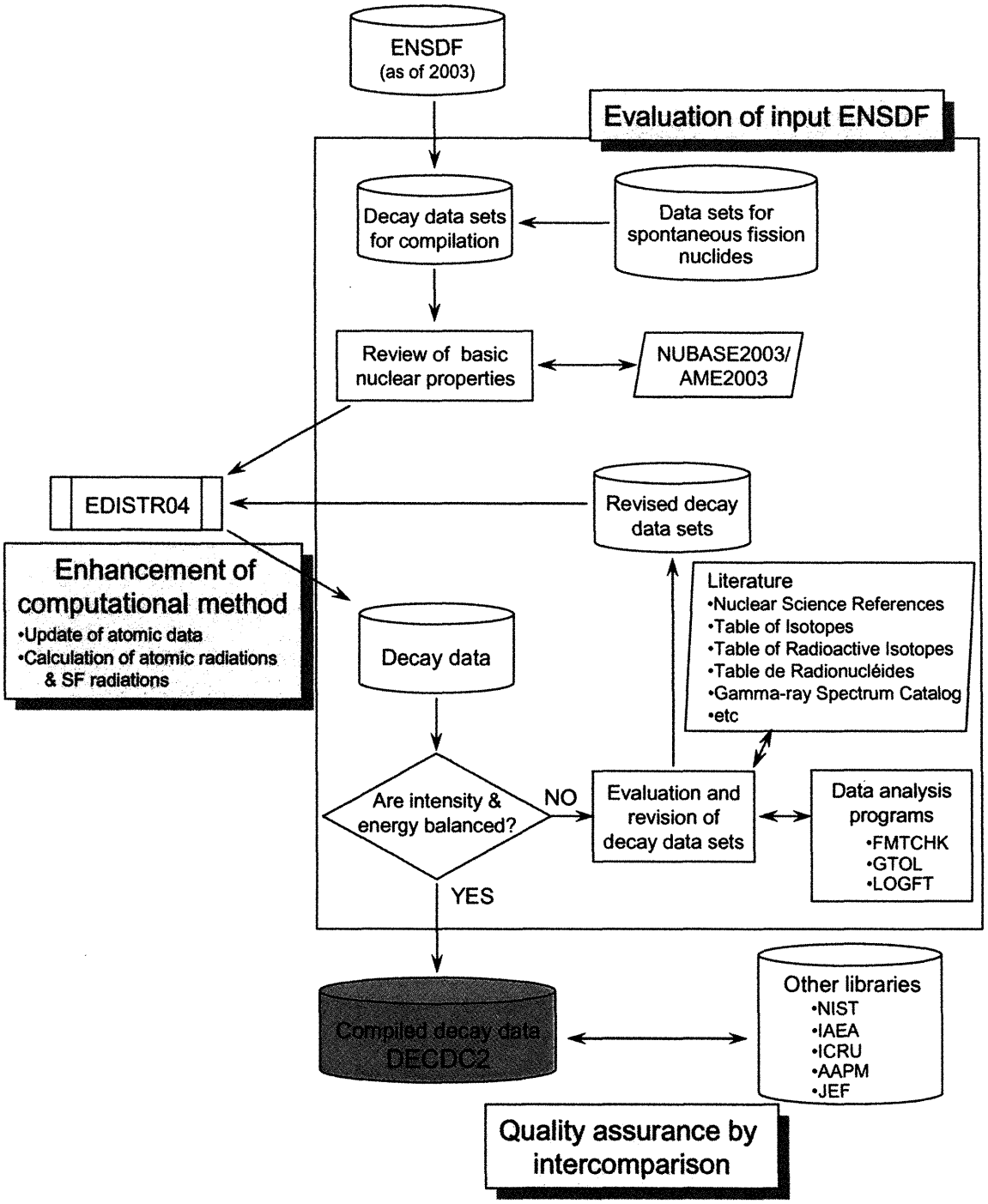


Fig. 2.2 Flow of the compilation of nuclear decay data

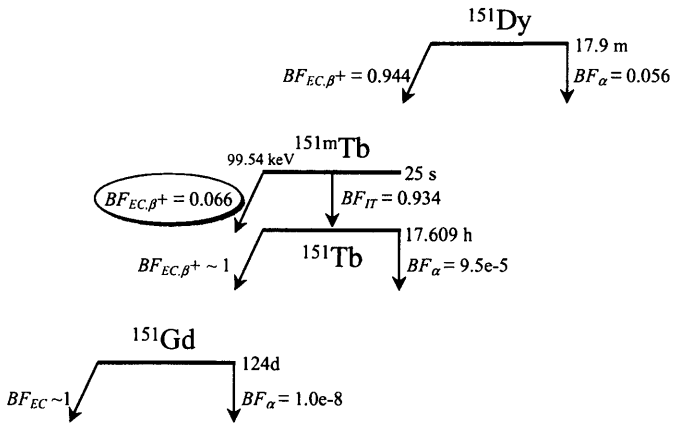


Fig. 2.3 Decay chain of ^{151}Dy. The radiation from EC/β^+ decay of ^{151m}Tb is not included in the ENSDF of ^{151}Dy.

- calculated Q value $= \sum_{i}^{\text{all }\alpha} E_{\alpha_i} I_{\alpha_i} + \sum_{j}^{\text{all }\beta} E_{\beta_j} I_{\beta_j} + \sum_{k}^{\text{all }\gamma} E_{\gamma_k} I_{\gamma_k} + \cdots$

  where E_{α_i}, E_{β_j}, E_{γ_k}, etc. and I_{α_i}, I_{β_j}, I_{γ_k}, etc. are the energies and intensities of i-th α particle, j-th β particle, k-th γ-ray, etc. from the individual decay process in the decay scheme.

- theoretical Q value $= \sum_{i=1}^{\text{all }BF} Q_i BF_i$

  where Q_i and BF_i are the Q value and branching fraction of i-th decay mode.

The criterion of (3) has been adopted in the compilation of nuclear decay database of JEF (Joint Evaluated File).[34,35] In the cases where the compiled data from the ENSDF using EDISTR04 exceed these criteria, the reasons for the deviations were analyzed. The procedures for the evaluation and modification of ENSDF are described in **Section 2.3**.

2.3 Analysis and Modification of ENSDF

While the ENSDF data sets are the compilation of experimental data, some data sets are incomplete due to limitations in the experimental information and are not suitable for calculating E_i and I_i of radiations. Therefore, evaluation, revision, and consistency procedures are required for the ENSDF data sets that exceed the criteria described in **Section 2.2** to produce reliable decay data.

The references used in the preparation of ENSDF were studied to analyze the referred experimental data and the evaluation process of the data sets. The data sets of adopted level and γ-ray transition properties in the ENSDF were used for cross check. Additional literature relating to the nuclides of interest were reflected in the data evaluation. The literature sources were publications listed in the Nuclear Science References,[36] Table of Isotopes,[37] Table of Radioactive Isotopes,[38] Table de Radionucléides[39] and Gamma-ray Spectrum Catalog.[40]

Systematic analysis of the ENSDF was performed using the ENSDF evaluation programs, FMTCHK, GTOL, and LOGFT.[¶] The format and syntax errors of the data sets were analyzed by FMTCHK. Net

[¶]These programs are distributed from WWW of NNDC, BNL.

Table 2.1 Classification of β transitions[41)]

Type of transition	Forbiddenness	ΔJ	π change
Super-allowed		0	no
Allowed		0, ±1	no
Forbidden unique	First	±2	yes
	Second	±3	no
	Third	±4	yes
	Fourth	±5	no
Forbidden non-unique	First	0, ±1	yes
	Second	±2	no
	Third	±3	yes
	Fourth	±4	no

Table 2.2 Log ft for specific transition types[41)]

Type of transition	log ft	Mean log ft
Super-allowed	3.1 – 3.6	3.4
Allowed	3 – 10	~ 5.9
First-forbidden non-unique	5 – 19	7.3
Second-forbidden non-unique	10.5 – 14	12.5
First-forbidden unique	7.5 – 13	9.5
Second-forbidden unique	14 – 18	15.6
Forbiddenness higher than second	> 17	—

feedings at the ground and excited states from the input γ-ray intensities and internal conversion coefficients were calculated with GTOL. Values of log ft for β decay were calculated by LOGFT. LOGFT was also used to compute the partial capture fractions for electron capture, the electron capture to positron ratios in the case of positron decay, and the average β particle energies.

The evaluation of the input net feedings was performed on the basis of extensive review by Singh et al.[41)] **Table 2.1** shows the classification of β transition types. The degree of forbiddenness of transition is determined from J and π changes that occur between the initial and final nuclear states. Singh et al.[41)] reviewed the log ft values for about 3900 transitions in β decay, and tabulated the range of log ft for specific transition types, as shown in **Table 2.2**. The calculated net feeding at each level was compared with the input values of ENSDF, and the validity of input values was studied by referring to the log ft values for respective transitions in **Table 2.2**.

After the above analysis and revision, the ENSDF was processed by EDISTR04 to verify the intensity and energy balances of the revised data sets. The decay data were excluded from the present compilation, if the compiled data exceeded the criteria discussed in **Section 2.2**.

The procedure for evaluation of the incomplete ENSDF is described using an example of ^{131}Ce. **Figure 2.4** shows the latest decay scheme of ^{131}Ce, which was placed in the ENSDF library in 1994. Cerium-

131 transforms via the energy levels shown in **Fig. 2.4** by EC/β^+ decay with $T_{1/2}$ = 10.2 min. However, the net feedings in the excited states and the ground state and the absolute intensities of γ-rays were not evaluated, since the experimental data[42] used for the evaluation of the data set partially mixed with the radiations from ^{131m}Ce ($T_{1/2}$ = 5.0 min). In addition, the data set contained 42 unplaced γ-rays, which could not put in the level scheme.

The data set was modified by the following procedures. The Q value was updated to 4.050 MeV from 4.700 MeV by referring to NUBASE2003/AME2003. The net feeding in each level was estimated on the basis of the selection criteria of β decay. The J and π values of the ground states of ^{131}Ce and ^{131}La are 7/2+ and 3/2+, respectively, and the type of direct transition between the ground states is the second forbidden non-unique. From **Table 2.2**, the values of log ft for the transition of the second forbidden non-unique range from 10.5 to 14, and a typical value is 12.5. It is therefore expected that the direct transition from ^{131}Ce to the ground state of ^{131}La is negligible. Based on the estimation, the normalization record, which converts the relative γ-ray intensities to the absolute intensities, was calculated to give no direct transition to the ground state of ^{131}La by EC/β^+ decay, and was found to be 0.222. Then, the net feedings at the excited states were calculated using GTOL from the absolute intensities of γ-rays and the internal conversion coefficients. The calculated net feedings and log ft were examined and found to be consistent with the selection criteria of **Table 2.2**, and were then put into the data set.

Figure 2.5 shows the revised decay scheme from the above procedures, and **Table 2.3** lists the computed energies of respective radiations from the decay scheme using the computer code EDISTR04. It is shown that the calculated Q value, 4.059 MeV, is consistent with the theoretical Q value, 4.050 MeV, from NUBASE2003/AME2003. The agreement between the two values suggests that the decay scheme modified by applying the selection criteria of β decay is self-consistent. It should be noted from **Table 2.3** that the total energy due to the unplaced γ-rays was calculated to be 0.399 MeV using the evaluated normalization record; the energy corresponds to about 10 % of the theoretical Q value.

For several nuclides, input data sets for EDISTR04 were prepared on the basis of recent publications, which are not still compiled in the ENSDF. For instance, the net feeding to each level and absolute intensities of γ-rays were not determined for β^- decay of ^{215}Bi in the latest ENSDF dated October, 2001. The decay scheme of ^{215}Bi was proposed by Kurpeta et al.[43] in 2003, and the information was used to prepare the input data for EDISTR04 according to the ENSDF format.[16]

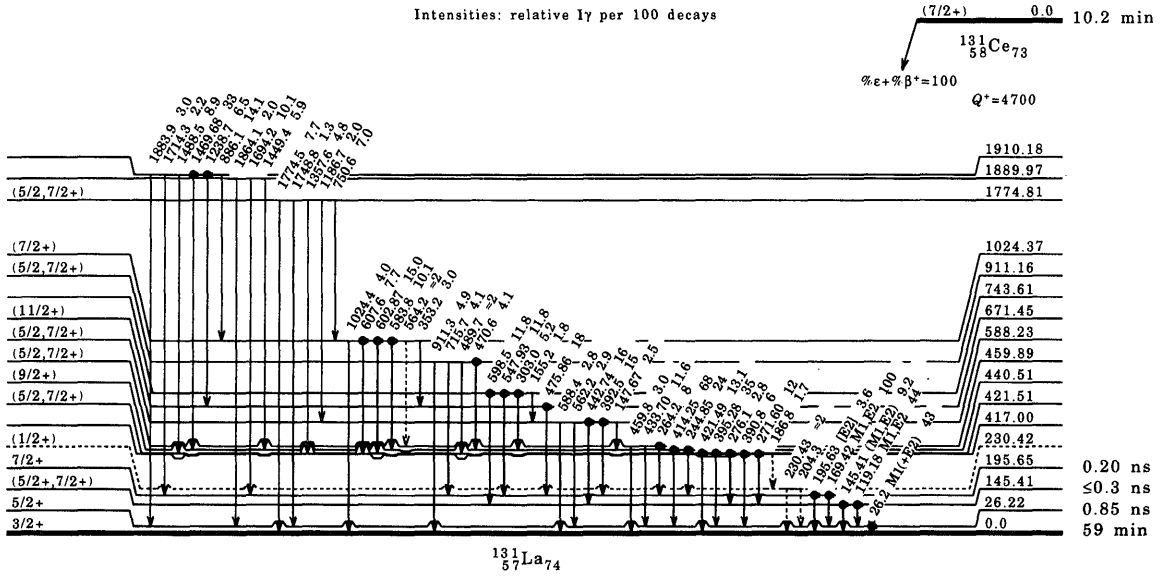


Fig. 2.4 Decay scheme of ^{131}Ce: original. The unit of level energy is keV.

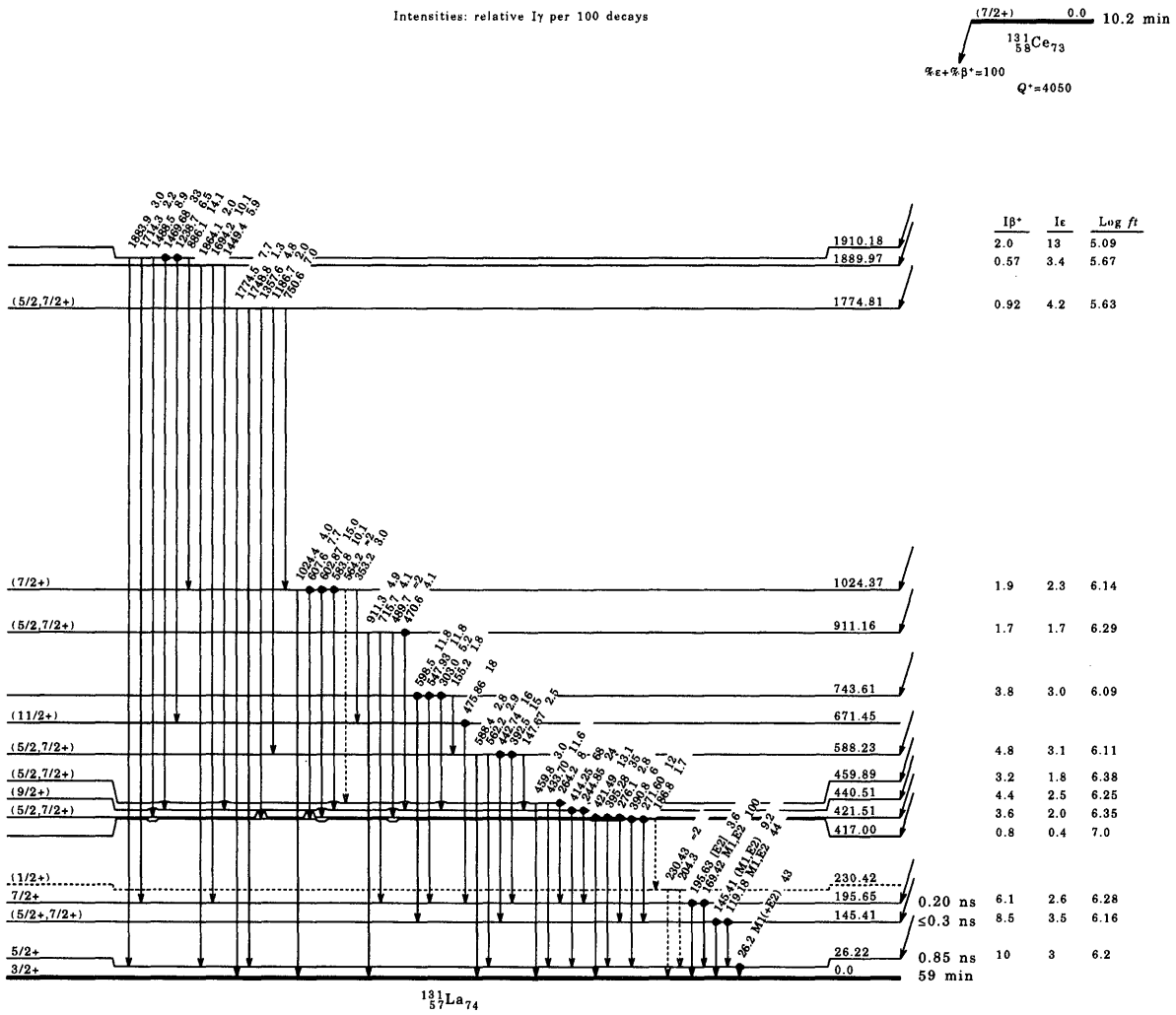


Fig. 2.5 Decay scheme of ^{131}Ce: modified. The unit of level energy is keV.

Table 2.3 Emitted energies from the decay of ^{131}Ce

Emitted energies by radiations from the decay scheme (MeV)	
β^+ particles	5.662×10^{-1}
Annihilation photons	4.923×10^{-1}
γ-rays	7.157×10^{-1}
Internal conversion electrons	4.101×10^{-2}
X-rays	1.965×10^{-2}
Auger and Coster-Kronig electrons	8.122×10^{-3}
Neutrinos	2.216
Calculated Q value	4.059
Theoretical Q value (MeV)	4.050
D_Q (%)	0.22
Energy by unplaced γ-ray (MeV)	3.990×10^{-1}

3 Enhancement of Computer Code EDISTR

The computer code EDISTR[22] was developed at ORNL to compute from the ENSDF the energies and intensities of emitted radiations from nuclear and atomic processes. EDISTR was used for the compilation of both ICRP38/NUCDECAY and DECDC.

In this study, several new capabilities were added to EDISTR in order to compute detailed spectra of X-rays and Auger electrons, which are important in microdosimetry. Methods for calculating energies and intensities of a variety of radiations from spontaneous fission were updated for dosimetry of transuranium nuclides. The revised computer code was named "EDISTR04" as an upgraded version of EDISTR released in 2004. In this section, new features and the validity of EDISTR04 are described.

3.1 Calculation of Energy Spectra of X-rays and Auger Electrons

Electron capture and internal conversion processes produce inner-shell vacancies in electron orbits in the newly formed atom. This excited atom relaxes to the ground state by migration of the initial vacancy to outer shells via the emission of characteristic X-rays, and Auger, Coster-Kronig (CK) and super CK electrons. EDISTR computes X-rays and Auger electrons originating from electron vacancies in the K- and L-shells, but does not consider a series of radiative and nonradiative transitions as the vacancies move to outer subshells, which are important in microdosimetry.[44]

In order to calculate the detailed spectra of X-rays and Auger electrons, EDISTR04 uses extensive bound-state electron radial wavefunctions[45] to assign electron capture subshell ratios and extended internal conversion coefficients.[46,47] These improvements are essential to determine distributions of vacancies produced in various subshells by the electron capture and internal conversion processes. In addition, a method has been introduced into EDISTR04 to calculate X-ray and electron spectra from the atomic process using the relativistic Dirac-Hartree-Slater theory and the evaluated atomic data library EADL.[48,49] These improvements allow calculating detailed spectra of X-rays and electrons emitted by Auger and CK transitions.

3.1.1 Update of Atomic-electron Binding Energies

EDISTR employs atomic-electron binding energies to compute the Fermi function for β decay, and absolute energies of internal conversion electrons, X-rays, and Auger electrons. The atomic-electron binding energies in EDISTR were those mainly from the compilation of Bearden et al.,[50] for the binding energies for K, L_1 through L_3, M_1 through M_5, N_1 through N_5 and O_1 through O_5 shells, or 19 subshells in total.

The atomic-electron binding energies were updated in EDISTR04 using the data from EADL. EADL is the latest theoretical atomic data evaluated at Lawrence Livermore National Laboratory (LLNL). The library includes the theoretical binding energies of 29 subshells from K through Q_1 subshells. **Table 3.1** compares the binding energies of EDISTR04 and EDISTR for the selected elements, argon, tellurium and uranium, from low, intermediate and high atomic numbers. An index D (%) was used to represent the differences in these values,

$$D(\%) = \frac{V_{\mathrm{EDISTR}} - V_{\mathrm{EDISTR04}}}{V_{\mathrm{EDISTR04}}} \times 100 \tag{3.1}$$

where V_{EDISTR} and $V_{EDISTR04}$ are the binding energies in EDISTR and EDISTR04, respectively.

From **Table 3.1**, it is shown in the inner shells that the binding energies are generally in good agreement between EDISTR04 and EDISTR. However, significant differences are found in the outer shells. In the data of EDISTR, the same binding energies are assigned to the outer subshells, as found in the M_2 and M_3 subshells of argon, and the N and O subshells of tellurium. In addition, as shown in the O and P shells of uranium, the data in EDISTR lack the binding energies in several outer subshells in heavy elements. The incorporation of the latest and most comprehensive atomic-electron binding energies from EADL improves the reliability of the energies of internal conversion electrons, X-rays, and Auger electrons. The impact due to the update in the binding energies is discussed in relation to the energies of X-rays and Auger electrons in **Section 3.1.4** for the electron capture of ^{125}I.

Table 3.1 Comparison of atomic-electron binding energies

Ar ($Z = 18$)

	Binding energy (eV)		
Subshell	EDISTR04	EDISTR	D (%)
K	3177.60	3202.90	0.80
L_1	313.43	320.00	2.10
L_2	249.43	247.30	−0.85
L_3	247.09	245.20	−0.76
M_1	28.92	25.30	−12.52
M_2	14.62	12.40	−15.18
M_3	14.43	12.40	−14.07

Te ($Z = 52$)

	Binding energy (eV)		
Subshell	EDISTR04	EDISTR	D (%)
K	31805.00	31813.80	0.03
L_1	4914.20	4939.20	0.51
L_2	4618.20	4612.00	−0.13
L_3	4339.70	4341.40	0.04
M_1	991.08	1006.00	1.51
M_2	867.09	869.70	0.30
M_3	814.85	818.70	0.47
M_4	593.74	582.50	−1.89
M_5	582.74	572.10	−1.83
N_1	174.33	168.30	−3.46
N_2	130.97	110.20	−15.86
N_3	120.92	110.20	−8.87
N_4	50.71	39.80	−21.51
N_5	49.18	39.80	−19.07
O_1	18.45	11.60	−37.13
O_2	9.23	2.30	−75.08
O_3	8.31	2.30	−72.32

Table 3.1 continued from previous page
U ($Z = 92$)

Subshell	Binding energy (eV) EDISTR04	EDISTR	D (%)
K	116110.00	115606.10	−0.43
L_1	21768.00	21757.40	−0.05
L_2	21044.00	20947.60	−0.46
L_3	17182.00	17166.30	−0.09
M_1	5521.30	5548.00	0.48
M_2	5181.50	5182.20	0.01
M_3	4289.60	4303.40	0.32
M_4	3736.80	3727.60	−0.25
M_5	3555.20	3551.70	−0.10
N_1	1419.90	1440.80	1.47
N_2	1264.20	1272.60	0.66
N_3	1030.50	1044.90	1.40
N_4	778.18	780.40	0.29
N_5	735.14	737.70	0.35
N_6	402.09	—	—
N_7	390.75	—	—
O_1	320.65	323.70	0.95
O_2	259.38	259.30	−0.03
O_3	203.39	195.10	−4.08
O_4	112.35	105.00	−6.54
O_5	104.02	96.30	−7.42
O_6	8.91	—	—
O_7	7.95	—	—
P_1	52.23	—	—
P_2	34.09	—	—
P_3	24.57	—	—
P_4	4.74	—	—
P_5	4.13	—	—
Q_1	5.78	—	—

3.1.2 Extension of Electron Capture Subshell Ratios

In electron capture, EDISTR computes capture ratios of orbital electrons from K to M_5 subshells using the Coulomb amplitude for the bound-electron wavefunctions calculated by Behrens et al.,[51] the occupational factors for partially filled shells by Richtmyer et al.[52] and the exchange and overlap correction factors by Martin et al.[53] Additional contributions from capture in the N and higher shells, designated N^+, are estimated from the study of Robinson.[54]

In EDISTR04, calculation of the distribution of capture ratios was extended for higher subshells using the comprehensive data in the Table of Isotopes[37] calculated by Bambynek et al.[45] The data are squared amplitudes of the bound-state electron radial wavefunctions used for calculating the electron capture ratios for 24 subshells from K up to O_8. The occupational factors were also updated by the data from EADL.[48]

Table 3.2 shows distributions of the primary vacancies calculated by EDISTR04 and EDISTR for the electron capture of ^{125}I. The ENSDF evaluated in July, 1999 was used as input in both calculations. Iodine-125 transforms to ^{125}Te through electron capture and the following internal conversion (**Fig. 3.1**). Iodine-125 is highly toxic when incorporated into the DNA of cells, since ^{125}I emits a number of Auger and CK electrons.[44,55,56] Therefore, the evaluation of electron vacancies in the ^{125}I decay is important in the calculation of the Auger and CK electron spectra used for dosimetry calculations.

It is shown from **Table 3.2** that the distributions of vacancies created in the respective subshells are in good agreement between the two codes, except for the M_2 subshell. The value for the M_2 subshell calculated by EDISTR04 is consistent with that by the Monte Carlo method, as discussed in **Section 3.1.4**. The numbers of vacancies are not computed in the N_1 and N_2 subshells by EDISTR due to the limitation of the available atomic data for these subshells. On the other hand, EDISTR04 enables the calculation of vacancies in higher subshells by the extension of Coulomb amplitudes, occupational factors and exchange and overlap correction factors.

Table 3.2 Comparison of the numbers of primary vacancies produced by electron capture of ^{125}I

Subshell	EDISTR04	EDISTR	D (%)
K	7.973E−1	7.963E−1	−0.12
L_1	1.547E−1	1.546E−1	−0.04
L_2	3.974E−3	4.152E−3	4.48
L_3			
M_1	3.491E−2	3.629E−2	3.94
M_2	9.330E−4	8.637E−3	8.3E+2
M_3			
M_4			
M_5			
N_1	8.050E−3		—
N_2	1.803E−4		—

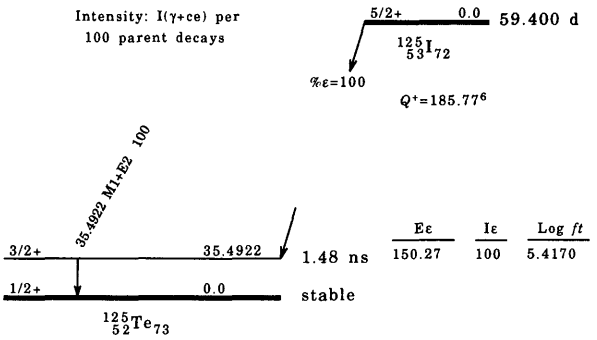


Fig. 3.1 Decay scheme of ^{125}I. The level energy values are in keV.

3.1.3 Extension of Internal Conversion Coefficients

Internal conversion is a process by which the energy of a transition between two nuclear energy levels is transferred to an orbital electron. The orbital electron is ejected from the atom with an energy equal to the transition energy minus the binding energy of the shell from which the electron is ejected. Primary vacancies in the various subshells are produced as a result of the process, and the cascade of the radiative and nonradiative transitions occurs to fill the vacancies in the electron orbits.

EDISTR uses tabulated data from a combination of theoretical internal conversion coefficients (ICC) compiled by Hager and Seltzer,[57] Dragoun et al.[58] and Band et al.[59] to calculate E_i and I_i of internal conversion electrons. The data cover the ICC of K, L, and M shells for γ-rays of multipolarities E1–E4 and M1–M4 and estimates the ICC for the N and higher shells as "N$^+$".

In EDISTR04, the ICC in the range $30 \leq Z \leq 103$ were replaced by comprehensive compilations by Rösel et al.[46] and Band and Trzhaskovskaya.[47] The data by Rösel et al.[46] cover the ICC for multipolarities of E1–E4 and M1–M4 for all subshells from K up to Q_1. The data were further extended by combining the ICC of Band and Trzhaskovskaya[47] for E5 and M5 transitions.

Rösel et al. made a selected comparison of their ICC data with those of Hager and Seltzer[57] and Band et al.[59] that were used in EDISTR. The results of the comparison are summarized as;

(1) The agreement of the ICC between Rösel et al. and Hager and Seltzer is at the 1 % level for the L_1 shell of $Z = 80$ (Hg) (**Fig. 3.2**) except for large multipole orders and near threshold energies, where the discrepancy is remarkably large. The agreement is complete for the L_1 shell of $Z = 30$ (Zn).

(2) The agreement of the ICC between Rösel et al. and Band et al. is within the combined limit of error for the lower multipole orders. However, discrepancies of a few percent were found for the larger multipolarities at low energies.

It was concluded from the comparisons that the data compiled by Rösel et al. are consistent with the other data. By combining the data with those for E5 and M5 multipolarities,[47] EDISTR04 computes the distributions of vacancies produced in all subshells by the internal conversion process.

In order to calculate the distribution of electron vacancies, the procedure for estimating the ICC in EDISTR was revised to be consistent with ENSDF evaluation policy. EDISTR determines the multipolarity of γ transition from the J and π changes evaluated in the ENSDF and refers to the table of ICC. If no information concerning the J or π changes is available, EDISTR assumes an M1 multipole (magnetic dipole) if $Z \leq 50$ and an E2 multipole (electric quadrupole) if $Z > 50$. A previous study,[21]

however, showed that the EDISTR's default assignment can lead to substantial discrepancies in the tabulated emissions of the nuclides including unplaced γ-rays, which could not be placed in the level schemes. In EDISTR04, the procedure was revised so that the default assignment is not applied to the unplaced γ-rays, since the intensity and energy balances of the ENSDF are evaluated excluding the unplaced γ-rays.

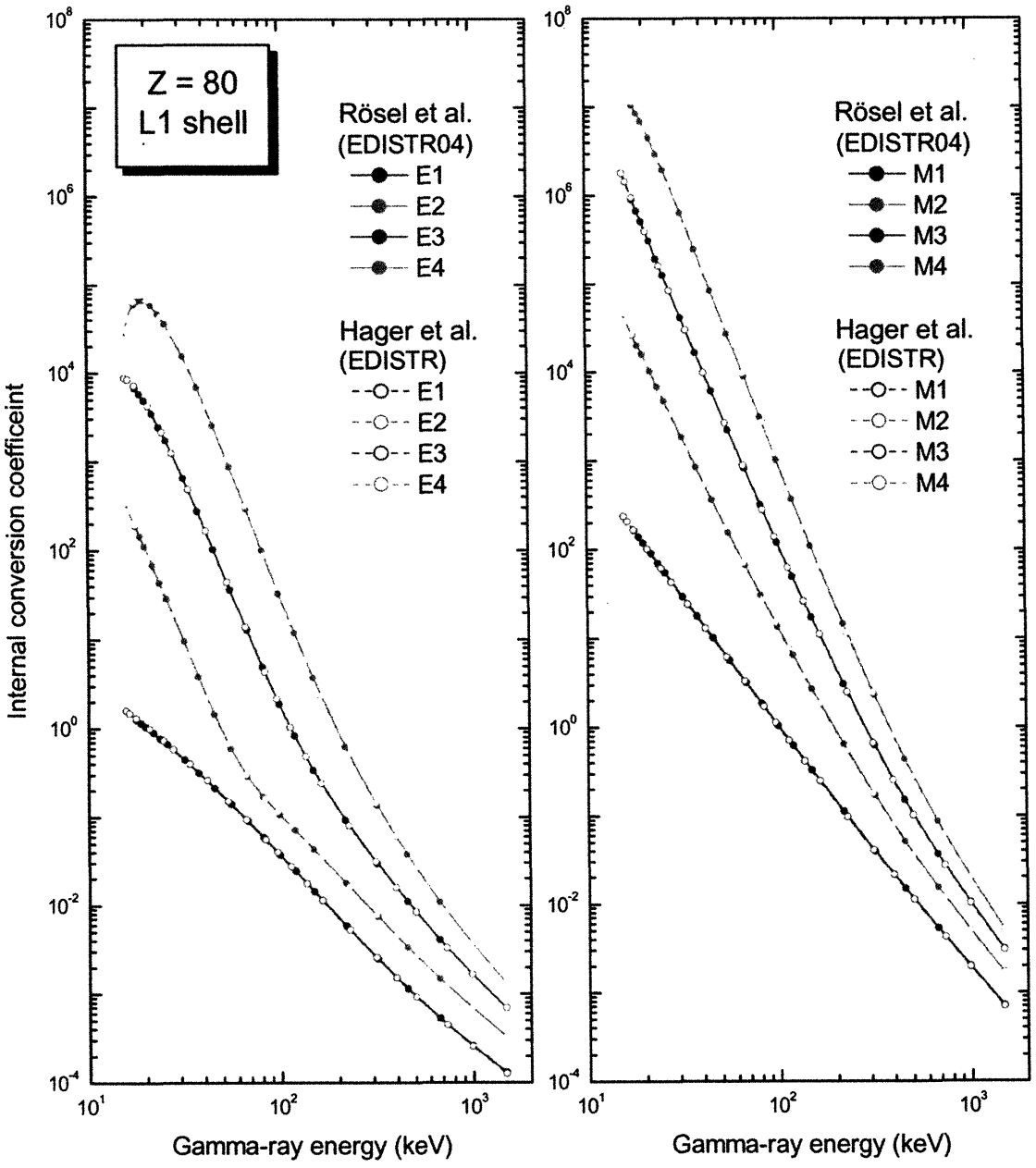


Fig. 3.2 Comparison of internal conversion coefficients in L_1 shell for $Z = 80$ (Hg)

3.1.4 Calculation of Atomic Process

EDISTR calculates E_i and I_i of X-rays and Auger electrons using the atomic-electron binding energies and conventional atomic data for emission rates of X-rays,[60–62] Auger electrons,[63–65] and fluorescence yields.[63] The calculation of EDISTR, however, is limited to the transitions in the K- and L-shells due to the available atomic data.

A method for calculating detailed atomic radiation has been introduced to EDISTR04 in order to treat the transitions in the outer shells. The method is based on the computer code RELAX[49] and the atomic data library EADL,[48] developed at LLNL. RELAX is designed to calculate X-ray and electron spectra due to bound-bound transitions using the relativistic Dirac-Hartree-Slater theory.[66] RELAX also calculates the spectrum of free-bound transitions assuming that the atom will relax back to its neutral ground state by filling all remaining electron holes through transitions capturing electrons directly from the continuum. EADL includes data for calculating the relaxation process of ionized atoms back to neutrality, during which photons (fluorescence X-rays) and electrons (Auger, Coster-Kronig (CK), and super CK electrons) are emitted. The numbers of photons and electrons treated by the combination of RELAX and EADL reach 154 and 2429, respectively.

RELAX calculates the spectrum for "a single vacancy" in each subshell. Then a new subroutine SRELAX (Simplified RELAX), which contains the computational part for X-ray and electron spectra of RELAX, was developed and incorporated into EDISTR04. SRELAX obtains the distribution of electron vacancies in various subshells produced by the electron capture and internal conversion described in **Sections 3.1.2** and **3.1.3**, and computes E_i and I_i of the atomic radiations.

The X-ray and electron spectra for a single electron vacancy created in the K shell of Hg are compared in **Fig. 3.3**. EDISTR04 calculates a series of radiative and nonradiative transitions as the primary vacancy in the K shell moves to the outer shells ((**a**) and (**b**)), while EDISTR only treats X-rays and Auger electrons from the transitions of the K and L shells ((**c**) and (**d**)).

EDISTR04 calculates E_i and I_i for X-rays, and Auger and CK electrons using EADL, and the number of transitions considered exceeds 2500. Then, these emissions are grouped together in a conventional composite group to keep the tabulated data within appropriate size. Explanation of the notations of the grouping is presented in **Appendix A**.

To examine the reliability of the calculation method in EDISTR04, comparisons of X-ray and electron spectra from ^{125}I were made with those computed by other methods.[44,67–69] **Table 3.3** shows the distributions of electron vacancies in various subshells produced by electron capture and internal conversion in ^{125}I. The present result was calculated from the ENSDF of 1991 using EDISTR04. The calculation by a Monte Carlo method is that of Charlton and Booz.[67] It was found that the present result for the distributions of vacancies in the inner shells agrees with the Monte Carlo calculation. In addition, EDISTR04 calculates extensive vacancies in the outer shells, which are not considered in the Monte Carlo calculation, using the extended data for the electron capture ratios and internal conversion coefficients.

Figures 3.4 and **3.5** show X-ray and electron spectra, respectively. The spectra of Howell[44] and Pomplun et al.[68] were obtained by the Monte Carlo method, and that of Stepanek[69] was calculated from a deterministic method using the computer code IMRDEC.[70] The notations of the respective emission lines are presented according to the IUPAC (International Union of Pure and Applied Chemistry) notation,[71] which is presented in **Appendix A**. For X-ray spectra, the present result is consistent with the other calculations (**Fig. 3.4**). For Auger and CK electron spectra, good agreements are found in E_i and I_i of the emissions from the K- and L-series transitions, as shown in **Fig. 3.5**. However, all spectra show discrepancies in the M- and N-series transitions. It is noted that the disagreement is found in the results

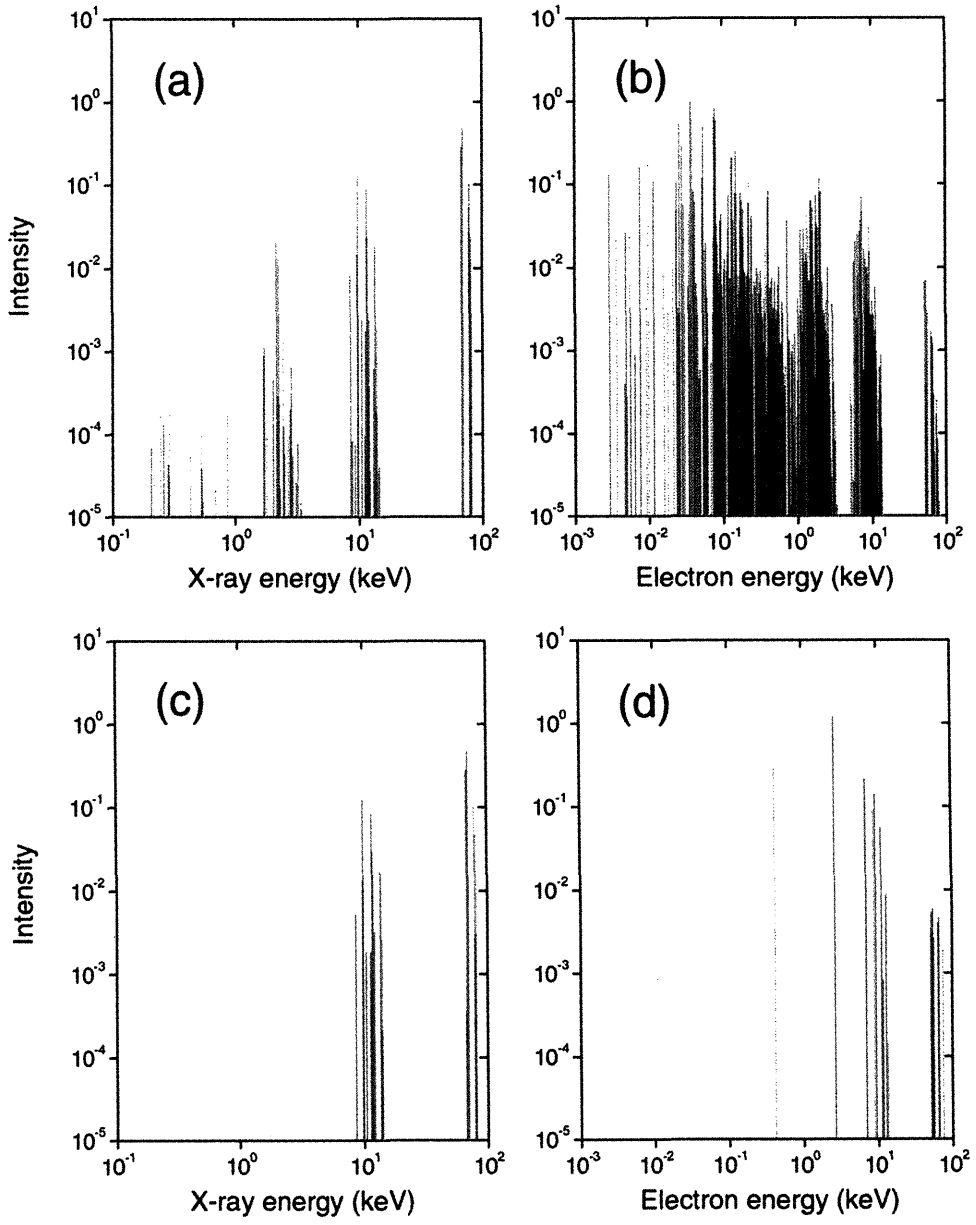


Fig. 3.3 Comparison of spectra of X-rays and Auger and CK electrons produced by a single electron vacancy in the K shell in Hg. (a) and (b) EDISTR04; (c) and (d) EDISTR.

between Howell and Pomplun et al. though both calculations employed the Monte Carlo method. The discrepancies in the four spectra are attributable to the differences of the calculation methods as well as the differences of the atomic data and the nuclear structure data used as input.

Tables 3.4 and **3.5** compare the total intensities and energies and E_i and I_i of individual emissions between the present and Howell's results.[44] In the present result, the value of D_Q defined by Eq. (2.1) was -0.37 %,[‖] which indicates that the calculated Q value is consistent with the theoretical Q value. From **Tables 3.4** and **3.5**, good agreements are found in the total intensities and energies of the emitted

[‖]The theoretical Q value from NUBASE2003/AME2003 was 0.18577 MeV, and the calculated Q value, which is the total energy of all radiation (0.0621 MeV) shown in **Table 3.4** plus neutrino energy, was 0.18508 MeV. Then, D_Q (%) was calculated to be $D_Q = \{(0.18508 - 0.18577)/0.18577\} \times 100 = -0.37$ %.

Table 3.3 Distributions of primary vacancies in subshells by electron capture (EC) and internal conversion (IC) of ^{125}I

	Present method		Monte Carlo method[67]	
Subshell	EC	IC	EC	IC
K	7.973E−1	8.080E−1	8.08E−1	7.95E−1
L_1	1.547E−1	9.686E−2	1.54E−1	9.5E−2
L_2	3.974E−3	8.919E−3	4E−3	7E−3
L_3		3.624E−3		4E−3
M_1	3.491E−2	1.936E−2	3.5E−2	1.9E−2
M_2	9.330E−4	1.880E−3	1E−3	4E−3
M_3		7.595E−4		1E−3
M_4		2.191E−5		
M_5		1.705E−5		
N_1	8.050E−3	4.116E−3		4E−3
N_2	1.803E−4	3.728E−4		1E−3
N_3		1.501E−4		
N_4		3.719E−6		
N_5		2.871E−6		
N_6				
N_7				
O_1		5.489E−4		
O_2		3.492E−5		
O_3		1.327E−5		

radiations and in E_i and I_i of the individual emissions for the K- and L-series transitions between the present and Howell's results. However, the discrepancies at the level of ten percent are found in E_i and I_i of the emissions for the M- and N-series transitions.

The present results were calculated from the latest atomic data and the ENSDF. On the other hand, the calculation by Howell used the atomic-electron binding energies by Sevier,[72] which is the same age with those of EDISTR. The emission rates for X-ray, and Auger and CK electrons were taken from literature sources in 1970s, and the decay scheme and nuclear data were from the Nuclear Data Sheet of 1981.[73] From the comparison in **Table 3.1**, it is considered that the binding energies used in EDISTR04 differ on the order of ten percent or more from those of Sevier in the outer shells. Discrepancies are also expected for the other atomic data. These differences cause the discrepancies in E_i and I_i of X-rays and Auger and CK electrons for the transitions in the outer shells.

Figures 3.6 and **3.7** show X-ray and Auger electron spectra calculated with EDISTR04, EDISTR and RADLST.[74] EDISTR04 resolves the limitation of EDISTR that does not treat a series of X-ray and Auger transitions from the M and higher shells.[44,68] RADLST, developed in NNDC of BNL, calculates the energies and intensities for the nuclear and atomic radiations from the ENSDF; the mathematical and physical bases used in RADLST are similar with those in EDISTR. However, RADLST does not calculate the intensities of the individual X-rays and Auger electrons, and the resolution of these spectra is lower compared with those calculated by EDISTR04 and EDISTR. It is shown from the figures that

EDISTR04 has been greatly enhanced for the compilation of data relating to the atomic process, which is important for microdosimetry studies.

EADL provides the atomic data for $Z = 1 - 100$. Then, EDISTR04 is used for the calculation of the nuclear and atomic radiation data from hydrogen (H) to fermium (Fm), and is not applied to mendelevium (Md) and heavier elements.

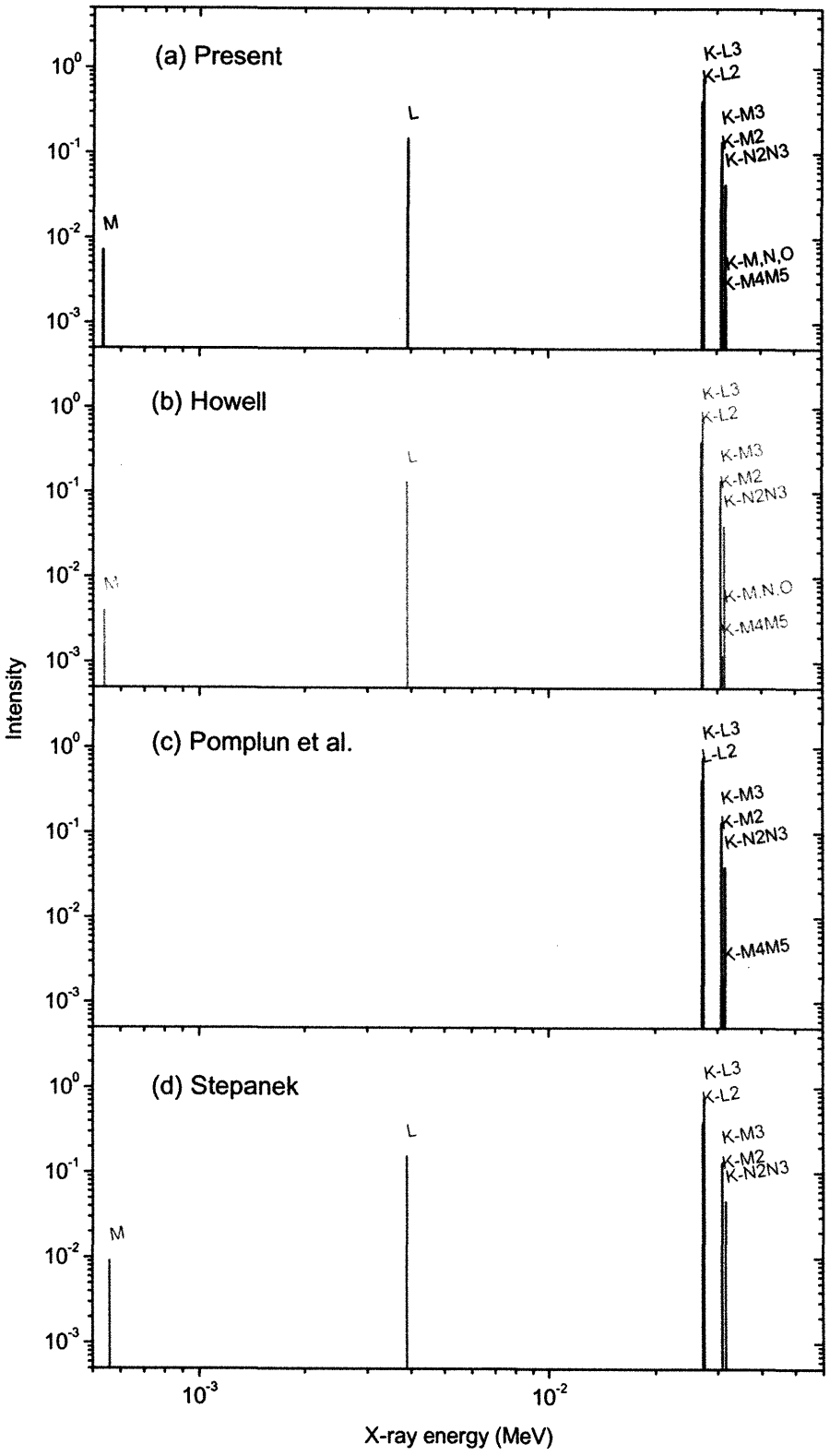


Fig. 3.4 Comparison of X-ray spectra in ^{125}I

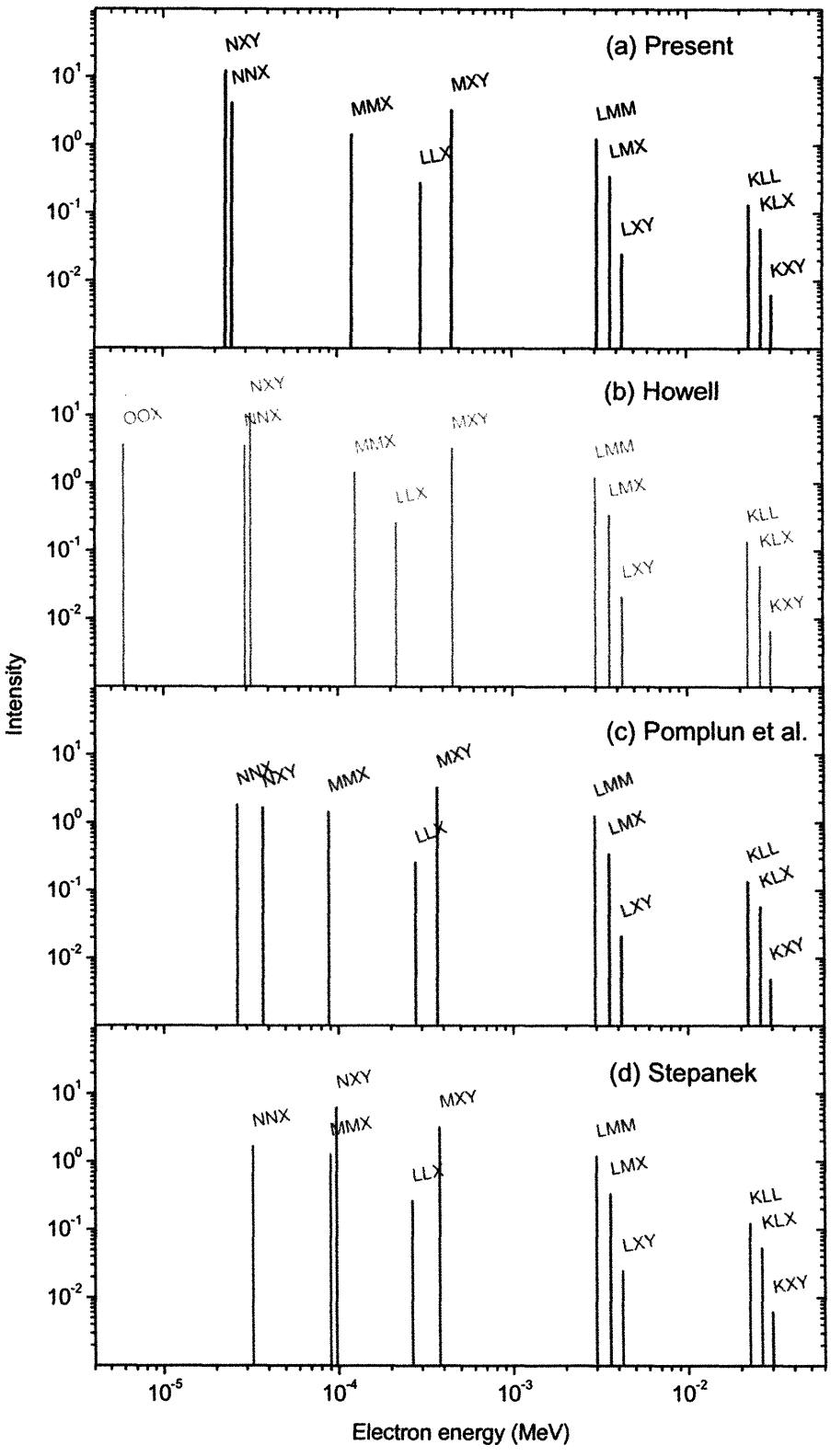


Fig. 3.5 Comparison of Auger and CK electron spectra in ^{125}I

Table 3.4 Comparison of total intensities and energies of radiations emitted by the decay of ^{125}I

	Present result	Howell[44]	D (%)
Total intensity per decay			
γ-ray	6.68E−2	6.50E−2	−2.7
ICE	9.45E−1	9.40E−1	−0.5
X-ray	1.57E+0	1.53E+0	−2.3
Auger and CK electrons	2.30E+1	2.49E+1	8.2
Total energy (MeV) released per decay			
γ-ray	2.37E−3	2.29E−3	−3.2
ICE	7.28E−3	7.24E−3	−0.5
X-ray	4.01E−2	3.97E−2	−1.2
Auger and CK electrons	1.20E−2	1.22E−2	2.3
All radiations	6.21E−2	6.14E−2	−1.0

Table 3.5 Comparison of radiation data in ^{125}I

Radiation	Present result		Howell[44]		D (%)	
	E_i	I_i	E_i	I_i	E_i	I_i
γ-ray	3.55E−2	6.68E−2	3.55E−2	6.47E−2	0.0	3.1
ICE K[1]	3.69E−3	8.08E−1	3.65E−3	7.97E−1	1.0	1.4
ICE L	3.06E−2	1.09E−1	3.06E−2	1.10E−1	0.0	−0.5
ICE M+	3.49E−2	2.72E−2	3.47E−2	2.84E−2	0.5	−4.3
Auger KLL	2.27E−2	1.31E−1	2.24E−2	1.38E−1	1.2	−5.3
Auger KLX	2.65E−2	5.77E−2	2.64E−2	5.90E−2	0.4	−2.3
Auger KXY	3.04E−2	6.08E−3	3.02E−2	6.50E−3	0.5	−6.9
CK LLX	3.00E−4	2.76E−1	2.19E−4	2.64E−1	27.0	4.3
Auger LMM	3.09E−3	1.23E+0	3.05E−3	1.25E+0	1.2	−1.6
Auger LMX	3.68E−3	3.47E−1	3.67E−3	3.40E−1	0.4	2.0
Auger LXY	4.30E−3	2.46E−2	4.34E−3	2.11E−2	−0.9	14.2
CK MMX	1.20E−4	1.42E+0	1.27E−4	1.44E+0	−5.7	−1.4
Auger MXY	4.55E−4	3.24E+0	4.61E−4	3.28E+0	−1.3	−1.2
CK NNX	2.49E−5	4.09E+0	2.99E−5	3.51E+0	−20.1	14.2
Auger NXY	2.29E−5	1.22E+1	3.24E−5	1.09E+1	−41.3	10.7
CK OOX	—	—	6.00E−6	3.66E+0	—	—
X-ray K-L_3	2.75E−2	7.54E−1	2.75E−2	7.51E−1	−0.1	0.4
X-ray K-L_2	2.72E−2	4.05E−1	2.72E−2	3.94E−1	0.0	2.7
X-ray K-M_3	3.10E−2	1.35E−1	3.10E−2	1.38E−1	0.0	−2.2
X-ray K-N_2N_3	3.17E−2	4.27E−2	3.17E−2	4.03E−2	−0.1	5.6
X-ray K-M_2	3.09E−2	6.95E−2	3.09E−2	6.85E−2	0.1	1.4
X-ray K-M_4M_5	3.12E−2	1.47E−3	3.12E−2	1.20E−3	−0.1	18.5
X-ray K-M, N, O	3.19E−2	2.59E−3	3.17E−2	3.00E−3	0.5	−15.8
X-ray L	3.90E−3	1.49E−1	3.93E−3	1.32E−1	−0.7	11.4
X-ray M	5.34E−4	7.15E−3	5.42E−4	4.00E−3	−1.5	44.1

[1] Internal conversion electron in the K shell.

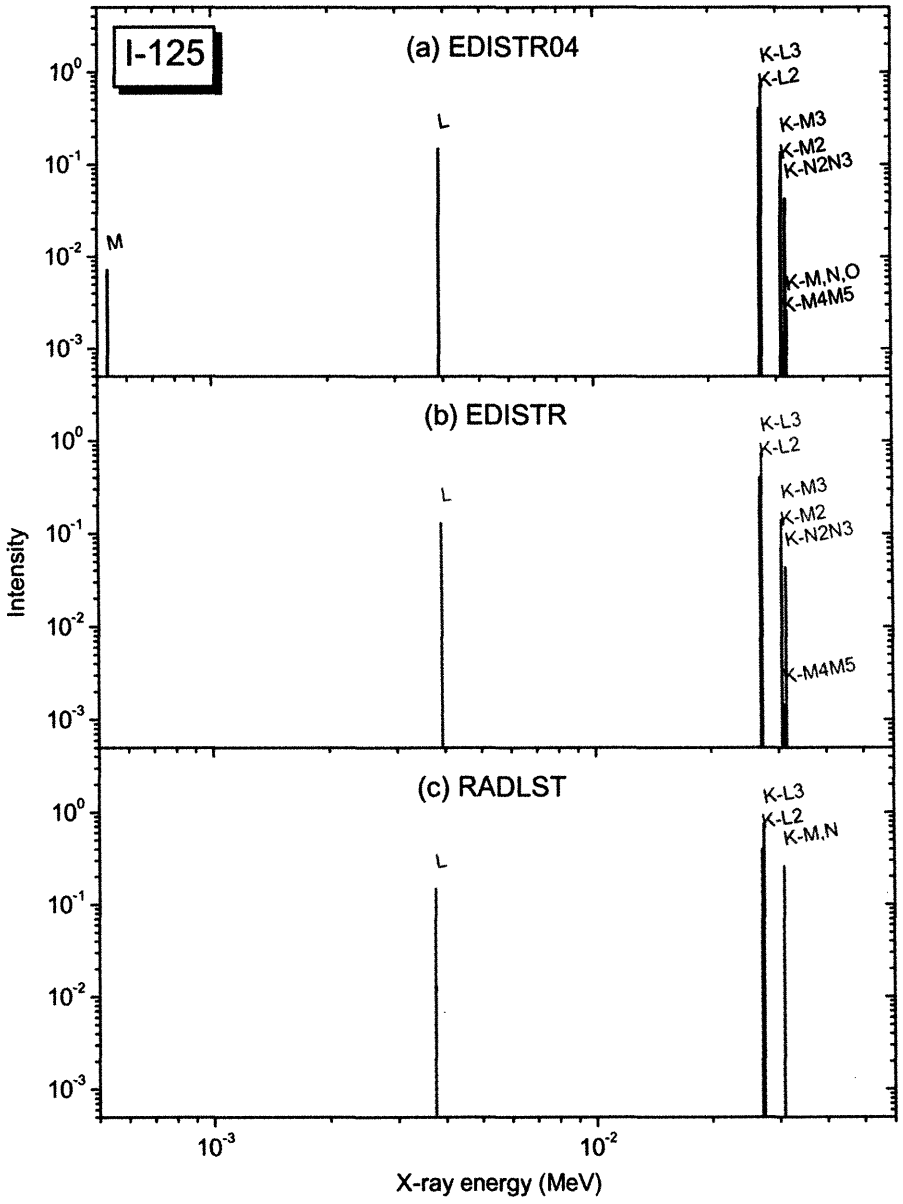


Fig. 3.6 Comparison of X-ray spectra for ^{125}I calculated by (a) EDISTR04, (b) EDISTR, and (c) RADLST

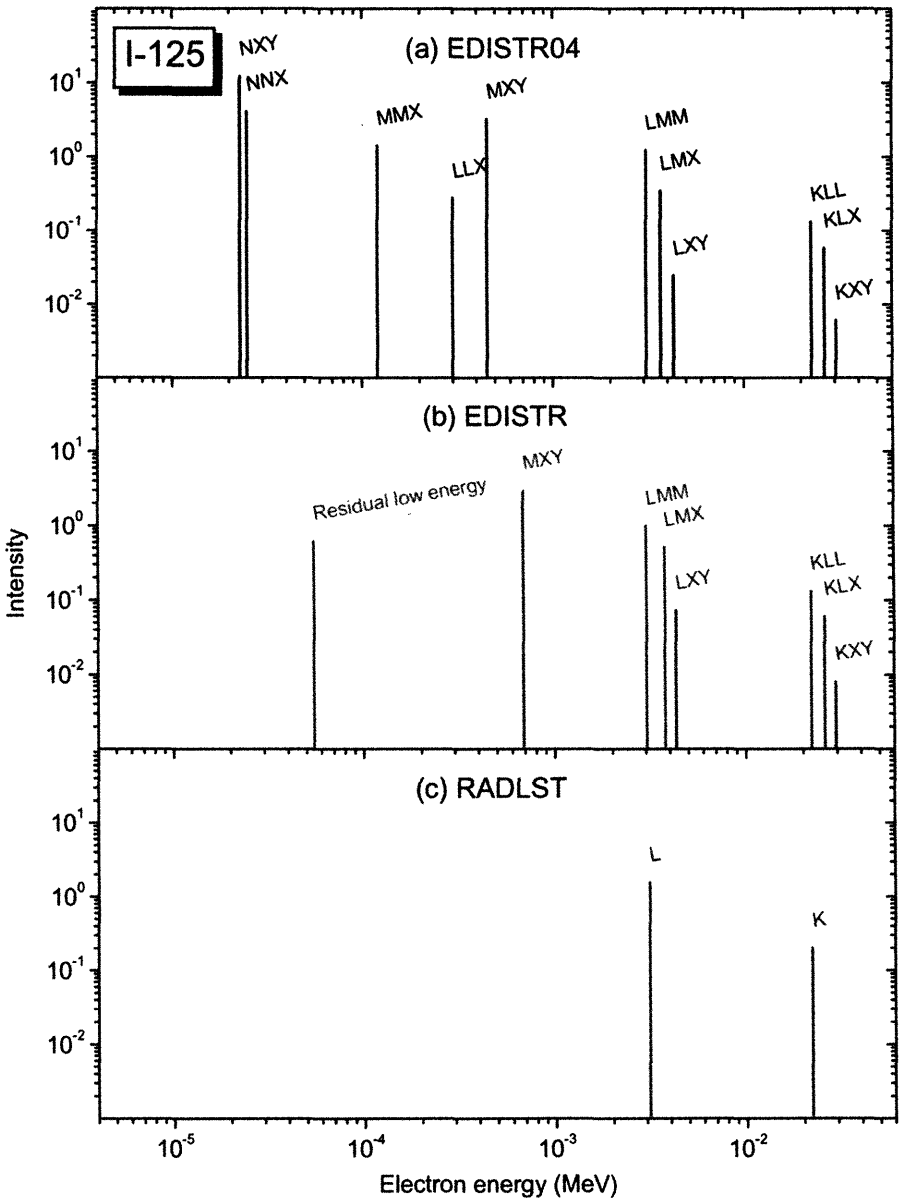


Fig. 3.7 Comparison of Auger and CK electron spectra for ^{125}I calculated by (a) EDISTR04, (b) EDISTR, and (c) RADLST

3.2 Calculation of Energy and Intensity of Spontaneous Fission Radiations

Spontaneous fission (SF) is nuclear fission which occurs without the addition of particles or energy to the nucleus. SF gives rise to a variety of radiations. From a viewpoint of radiation dosimetry, SF nuclides are very important since even if a nuclide decays via SF with the probability of 1 %, the associated dose will be comparable to or larger than the dose due to all other decay modes. Dillman and Jones[75] developed a set of formulas to compute energies and intensities of radiations emitted by SF, and adopted the methods to the EDISTR code.

In this section, methods that supersede those in EDISTR are developed for calculating the energies and intensities of the SF radiations on the basis of the latest studies and adopted in the EDISTR04 code.

3.2.1 Fission Fragments

Dosimetry of fission fragments is significant, especially in internal exposure, since approximately 80 % of the energy emitted in fission occurs as kinetic energy of the fission fragments.[76] Study of the systematics of total kinetic energy of fission fragments, E_{ff}, have shown that E_{ff} can be described by a simple model based on Coulomb repulsion between prolate spheroids. This model predicts that E_{ff} depends linearly on the Coulomb parameters, $Z^2/A^{1/3}$, of the fissioning nucleus, where Z and A are the atomic number and pre-fission mass number, respectively, of the fissioning nuclide. In EDISTR, E_{ff} was computed based on the study by Unik and Gindler.[76] They fitted measured E_{ff} for 7 nuclides (^{231}Pa, ^{233}U, ^{235}U, ^{238}U, ^{237}Np, ^{239}Pu and ^{241}Pu) using the parameter $Z^2/A^{1/3}$, and determined the relation,

$$E_{ff} = 0.139601 \frac{Z^2}{A^{1/3}} - 21.975 . \tag{3.2}$$

Viola et al.[77] reanalyzed the relation between $Z^2/A^{1/3}$ and E_{ff} using recent experimental data and determined the following relation:

$$E_{ff} = 0.1189 \frac{Z^2}{A^{1/3}} + 7.3 . \tag{3.3}$$

Figure 3.8 compares the relation $Z^2/A^{1/3}$ vs. E_{ff} by Eqs. (3.2) and (3.3), along with experimental data.[78] It is shown that both equations predict the experimental data within 5 % in the $Z^2/A^{1/3}$ range of 1350 – 1550. However, Eq. (3.3) can be fitted over the entire range of $Z^2/A^{1/3}$, while Eq. (3.2) gives negative kinetic energies for lighter elements ($Z^2/A^{1/3} = 150 - 180$). Therefore, Eq. (3.3) applicable to a wider range of the Coulomb parameter was adopted in EDISTR04.

It is assumed that E_{ff} is divided equally between the two fragments, and then the average energy, $\bar{E}_{ff}$, and intensity, $\bar{I}_{ff}$, of fission fragments are given using the branching fraction of SF, BF_{SF}, by

$$\bar{E}_{ff} = 0.05945 \frac{Z^2}{A^{1/3}} + 3.65 , \tag{3.4}$$

$$\bar{I}_{ff} = 2BF_{SF} . \tag{3.5}$$

3.2.2 Prompt Neutrons

Prompt neutrons and γ-rays are emitted during the de-excitation of fission fragments. Competition in the emission of prompt neutrons and γ-rays is expected due to the quantum mechanical selection rules for conservation of angular momentum.

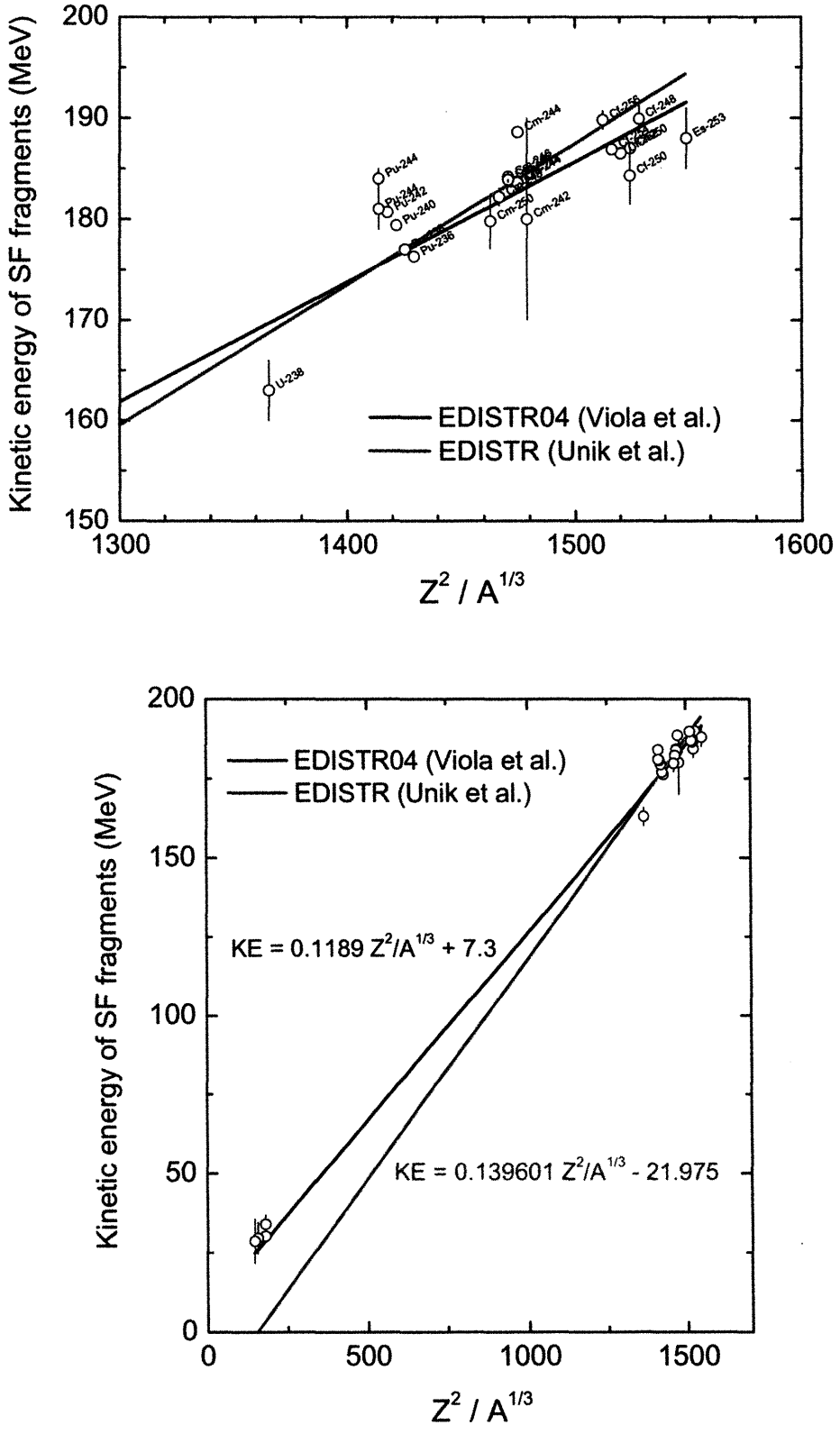


Fig. 3.8 $Z^2/A^{1/3}$ vs. E_{ff} of spontaneous fission nuclides. Black line: EDISTR04; Red line: EDISTR; circle: experimental data reviewed by Hoffman et al.[78)]

In EDISTR, the Maxwellian distribution,[79,80] which is the simplest and most commonly used approximation for fission neutron spectra in the laboratory reference system, was used to calculate the average energy of prompt neutrons, $\bar{E}_{pn}$.

It has been known that the laboratory neutron spectrum shape is well expressed by the Watt spectrum,[81] if it is assumed that all fragments have the same kinetic energy per nucleon. This better approximation has been used as the internal sources for fission spectra in Monte Carlo radiation transport codes MCNP[82] and MCNPX.[83] Thus, the method used in the computer code SOURCE[84] for calculating the SF neutrons based on the Watt spectrum was incorporated into EDISTR04.

In the Watt spectrum, $\bar{E}_{pn}$ is expressed as

$$\bar{E}_{pn} = 0.25a^2b + 1.5a\,, \tag{3.6}$$

where a and b are parameters to express the Watt spectrum. The average intensity of prompt neutrons, $\bar{I}_{pn}$, emitted per decay is given using BF_{SF} by

$$\bar{I}_{pn} = BF_{SF}\bar{\nu}\,, \tag{3.7}$$

where $\bar{\nu}$ is the average number of prompt neutrons emitted per fission. The values of BF_{SF}, $\bar{\nu}$ and the parameters a and b are taken from the internal data library of SOURCE and are tabulated in **Table 3.6**.

Since absorbed doses from neutrons depend strongly on their energy, EDISTR04 was improved to compute spectrum data as well as $\bar{E}_{pn}$ and $\bar{I}_{pn}$, while EDISTR calculates only $\bar{E}_{pn}$ and $\bar{I}_{pn}$. The Watt fission spectrum is approximated using a and b by

$$\chi_{pn}(E) = \bar{I}_{pn}\exp(-E/a)\sinh\sqrt{bE}\,. \tag{3.8}$$

Figure 3.9 shows a calculated spectrum using EDISTR04 for SF neutrons of ^{252}Cf along with the ISO reference data.[85]

The delayed neutrons were not considered in EDISTR04, since the ratio of delayed to prompt neutrons is on the order of 0.005.[76]

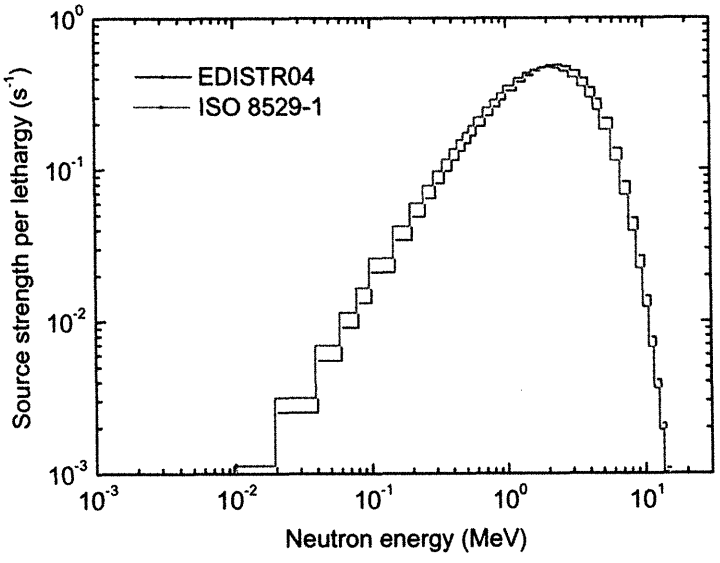


Fig. 3.9 Neutron spectra from spontaneous fission of ^{252}Cf

Table 3.6 Parameters of Watt spectrum for spontaneous fission nuclides

Nuclide	BF_{SF}	$\bar{\nu}$	Watt parameters	
			a	b
^{238}U	5.450E−7	2.010	0.648318	6.81057
^{236}Pu	1.370E−9	2.130	0.988270	3.10386
^{238}Pu	1.850E−9	2.220	0.847833	4.16933
^{240}Pu	5.750E−8	2.160	0.794930	4.68927
^{242}Pu	5.540E−6	2.150	0.819150	4.36668
^{244}Pu	1.210E−3	2.300	0.694716	6.00370
^{240}Cm	3.900E−8	2.390	1.07168	2.69829
^{242}Cm	6.370E−8	2.520	0.887353	3.89176
^{244}Cm	1.371E−6	2.690	0.902523	3.72033
^{245}Cm	6.100E−9	2.870	0.911919	3.62393
^{246}Cm	2.630E−4	3.180	0.878224	3.88585
^{248}Cm	8.390E−2	3.110	0.808387	4.53623
^{250}Cm	7.400E−1[1]	3.310	0.734482	5.43559
^{246}Cf	2.5E−6[2]	3.1[2]	1.026[3]	2.93[3]
^{248}Cf	2.900E−5	3.340	1.027720	2.93228
^{249}Cf	5.020E−9	3.410	1.026[3]	2.93[3]
^{250}Cf	7.7E−4[4]	3.530	1.026[3]	2.93[3]
^{252}Cf	3.092E−2	3.765	1.0250	2.926
^{254}Cf	9.969E−1	3.890	1.026[3]	2.93[3]
^{253}Es	8.900E−8	3.930	0.82[5]	4.6[5]
^{254}Es	3.000E−8	3.950	0.82[5]	4.6[5]
^{254m}Fm	4.500E−4	3.950	0.82[5]	4.6[5]
^{255}Es	4.500E−5	3.970	0.82[5]	4.6[5]
^{252}Fm	2.300E−5	3.9[6]	0.82[5]	4.6[5]
^{254}Fm	5.920E−4	3.960	0.82[5]	4.6[5]
^{255}Fm	2.300E−7	3.730	0.82[5]	4.6[5]
^{256}Fm	9.190E−1	4.010	0.82[5]	4.6[5]
^{257}Fm	2.100E−3	3.850	0.82[5]	4.6[5]

[1] The default value for ^{250}Cm in the SOURCE code, 8.600E−1, was replaced by BF_{SF} from NUBASE2003/AME2003.[30-32]

[2] The values of BF_{SF} and $\bar{\nu}$ were taken from NUBASE2003/AME2003 and the review of Hoffman et al.,[78] respectively, since the data of ^{246}Cf are not evaluated in the SOURCE code.

[3] The parameters a and b were estimated from those for ^{248}Cf and ^{252}Cf.

[4] The default value for ^{250}Cf in the SOURCE code, 3.092E−2, was replaced by BF_{SF} from NUBASE2003/AME2003.

[5] Default values in the SOURCE code.

[6] The value was estimated from the review of Hoffman et al.[78]

3.2.3 Prompt γ-rays

Shortly after the emission of the prompt neutrons, the remaining excitation by the highly excited fission fragments is removed by the rapid emission of γ-rays. The prompt γ-rays are emitted until the fragments reach their ground states or isomeric states.

EDISTR computes average energy, $\bar{E}_{p\gamma}$, and intensity, $\bar{I}_{p\gamma}$, of prompt γ-rays on the basis of the total energy, $E_{p\gamma\,\mathrm{total}}$, and a spectrum of the prompt γ-rays in the fission of ^{235}U. Unik and Gindler[76] evaluated $E_{p\gamma\,\mathrm{total}}$ for the fission of ^{235}U caused by thermal neutrons to be 7.64 ± 0.75 MeV. Dillman and Jones[75] renormalized the prompt γ-ray spectrum evaluated by Peelle and Maienschein[86] to give $E_{p\gamma\,\mathrm{total}}$ of 7.64 MeV. From the normalized spectrum, $\bar{E}_{p\gamma}$ and $\bar{I}_{p\gamma}$ were evaluated to be:

$$\bar{E}_{p\gamma} = 0.8847\,, \tag{3.9}$$

$$\bar{I}_{p\gamma} = 8.636 BF_{SF}\,. \tag{3.10}$$

EDISTR adopted the above equations to all SF nuclides, although these were derived from the data of fission of ^{235}U induced by thermal neutrons.

Valentine[87] has developed equations for predicting $E_{p\gamma\,\mathrm{total}}$, $\bar{E}_{p\gamma}$ and $\bar{I}_{p\gamma}$ of prompt γ-rays from fission. It was postulated that $E_{p\gamma\,\mathrm{total}}$ is a function of both the pre-fission mass and $\bar{\nu}$ and is given by

$$E_{p\gamma\,\mathrm{total}}(\bar{\nu},Z,A) = \varphi(Z,A)\bar{\nu} + 4.0\,. \tag{3.11}$$

The function $\varphi(Z,A)$ was determined to fit with measured values for ^{235}U, ^{239}Pu and ^{252}Cf as

$$\varphi(Z,A) = 2.51 - 1.13 \times 10^{-5}\, Z^2\sqrt{A}\,. \tag{3.12}$$

Next, $\bar{E}_{p\gamma}$ was expressed using the measured data from ^{235}U, ^{239}Pu and ^{252}Cf by

$$\bar{E}_{p\gamma} = -1.33 + 119.6\,\frac{Z^{1/3}}{A}\,. \tag{3.13}$$

Consequently, $\bar{I}_{p\gamma}$ was derived using Eqs. (3.11) and (3.13) by

$$\bar{I}_{p\gamma} = \frac{E_{p\gamma\,\mathrm{total}}(\bar{\nu},Z,A)}{\bar{E}_{p\gamma}}\,. \tag{3.14}$$

Table 3.7 shows calculated $\bar{E}_{p\gamma}$, $\bar{I}_{p\gamma}$ and $E_{p\gamma\,\mathrm{total}}$ from Eqs. (3.13), (3.14) and (3.11) for ^{233}U, ^{235}U, ^{239}Pu and ^{252}Cf along with measured data. The calculated values show agreement with the measurements. The results indicate the equations developed by Valentine[87] can be used to predict the properties of prompt γ-rays depending on A and Z. Thus, Eqs. (3.13) and (3.14) were adopted in EDISTR04.

3.2.4 Delayed γ-rays and β Particles

After reaching the ground states or isomeric states, the fission fragments shift by β decay toward to stable states. Delayed γ-rays and β particles are emitted during the radioactive decay of the fission fragments.

Exact treatment of energy spectra of delayed γ-rays and β particles requires one to calculate yield of the fission fragments and to follow time-dependent nuclide compositions. However, it is difficult to apply these data to dose calculations, especially to internal exposure, since a variety of radionuclides having different biokinetic behavior should be considered at once. For instance, the number of fission products

Table 3.7 Comparison of average energies and intensities and total energies of prompt γ-rays per fission

Nuclide	Calculation			Measurement		
	$\bar{E}_{p\gamma}$ (MeV)	$\bar{I}_{p\gamma}$	$E_{p\gamma\,\mathrm{total}}$ (MeV)	$\bar{E}_{p\gamma}$ (MeV)	$\bar{I}_{p\gamma}$	$E_{p\gamma\,\mathrm{total}}$ (MeV)
^{233}U	0.98	6.76	6.61	1.06	6.31	6.69
^{235}U	0.96	6.82	6.54	0.97	6.60	6.53
^{239}Pu	0.94	7.25	6.78	0.95	7.06	6.78
^{252}Cf	0.85	8.18	6.94	0.87	7.98	6.95

from SF of ^{252}Cf reaches over 700 radionuclides consisting of about 50 elements.[88] Therefore, Dillman and Jones[75] developed equations for predicting E_i and I_i of delayed γ-rays and β particles based on "chain length"** by assuming all the energy from delayed γ-rays and β particles to be emitted at the time of fission.

Due to the difficulty of the exact treatment of time-dependent nuclide composition in dosimetry calculation, the concept of "chain length" was followed in EDISTR04 for predicting E_i and I_i of delayed γ-rays and β particles. Although the method might cause some errors to the estimated E_i and I_i of emissions, it is within a permissible range since the energy emitted by delayed γ-rays and β particles is about 10 % or less of the total energy of all emissions from SF.

· **Delayed γ-rays**

EDISTR computes the average energy of delayed γ-rays, $\bar{E}_{d\gamma}$, with the same method as that for prompt γ-rays. Unik and Gindler[76] analyzed published data on the total energy released in the delayed γ-rays, $E_{d\gamma\,\mathrm{total}}$, by ^{236}U from 10^{-3} s after fission to infinity, and concluded that 7.2 ± 1.3 MeV is the best value for $E_{d\gamma\,\mathrm{total}}$. Dillman and Jones[75] renormalized the delayed γ-ray spectrum[89,90] to give $E_{d\gamma\,\mathrm{total}}$ of 7.2 MeV, and evaluated $\bar{E}_{d\gamma}$ to be 0.9578 MeV.

The average intensity of delayed γ-rays, $\bar{I}_{d\gamma}$, was derived using the chain length. On the basis of study by James[91] and Griffin,[92] Unik and Gindler[76] proposed that $E_{d\gamma\,\mathrm{total}}$ is approximately proportional to the square of the total chain length, $N_{\beta T}$, of both fission fragments. An expression for the ratio of $E_{d\gamma\,\mathrm{total}}$ for any fissioning nuclide to the corresponding energy release for ^{236}U is

$$R = \frac{(N_{\beta T})^2}{[N_{\beta T}(^{236}\mathrm{U})]^2} . \tag{3.15}$$

An empirical expression for $N_{\beta T}$ is given by

$$N_{\beta T} = N_{\beta T}(^{236}\mathrm{U}) + A\left(\frac{92}{236} - \frac{Z}{A}\right) , \tag{3.16}$$

where Z and A are the atomic and mass numbers of the fissioning nuclide, respectively. By combining Eqs. (3.15) and (3.16) and substituting an experimental value of 5.98[76] for $N_{\beta T}(^{236}\mathrm{U})$, $\bar{I}_{d\gamma}$ was expressed as

$$\bar{I}_{d\gamma} = 0.2102\left(5.98 + \frac{92}{236}A - Z\right)^2 BF_{SF} . \tag{3.17}$$

**The chain length corresponds to the number of β decay to reach a stable nuclide.

· **Delayed β particles**

Similarly to the case of delayed γ-rays, the total energy of β particles, $E_{d\beta\,\mathrm{total}}$, emitted following fission is proportional to $N_{\beta T}^2$. Unik and Gindler[76] adopted a value of 7.36 MeV for $E_{d\beta\,\mathrm{total}}$ released by ^{236}U. By substituting numerical values into Eq. (3.16), $E_{d\beta\,\mathrm{total}}$ is expressed using ^{236}U as a reference by

$$E_{d\beta\,\mathrm{total}} = 0.2058\left(5.98+\frac{92}{236}A-Z\right)^2 . \tag{3.18}$$

From the chain length and Eq. (3.18), the average energy, $\bar{E}_{d\beta}$, and intensity, $\bar{I}_{d\beta}$, of delayed β particles were given by

$$\bar{E}_{d\beta} = 0.2058\left(5.98+\frac{92}{236}A-Z\right) , \tag{3.19}$$

$$\bar{I}_{d\beta} = \left(5.98+\frac{92}{236}A-Z\right)BF_{SF} . \tag{3.20}$$

Table 3.8 shows comparisons of $E_{d\gamma\,\mathrm{total}}$ and $E_{d\beta\,\mathrm{total}}$ by the method of Dillman and Jones[75] with published values for the fission of ^{235}U by thermal neutrons.[88,93–95] The values based on the SF yields and fission product (FP) decay data were calculated using the latest evaluated SF yields[88] and JENDL FP Decay Data File 2000 (JENDL FP 2000).[95] The results indicate that $E_{d\gamma\,\mathrm{total}}$ and $E_{d\beta\,\mathrm{total}}$ of Dillman and Jones adopted in both EDISTR/EDISTR04 agree with the other estimates within 15 %.

Table 3.8 Comparison of total energies of delayed γ-rays and β particles in the fission of ^{235}U by thermal neutrons

	Energy (MeV)	
Source of data	Delayed γ-rays	β particles
Dillman and Jones[75] (EDISTR/EDISTR04)	7.2	7.36
Sher[93]	6.33	6.50
Yoshida et al.[94]	6.42	—
SF yield[88] and FP decay data[95]	6.21	6.40

3.3 Data Diagnostic Function

EDISTR computes energy and intensity balances of the ENSDF data sets in order to diagnose their self-consistency. These diagnoses are based on the transition intensities between the levels. From the diagnostic functions, the contributions of respective types of radiations (e.g. γ-rays, X-rays, $\beta^{\pm}$ particles, Auger electrons, α particles, etc.) and of the unplaced radiations to the theoretical Q value are not evaluated.

The data diagnostic function was enhanced by referring to the computer codes RADLST[74] and IMRDEC[69,70] to produce the energies of respective types of radiations, the energy of unplaced γ-rays, and the ratio of the calculated Q value to the theoretical Q value. **Figure 3.10** shows an example of diagnostic listing, which is printed at the end of EDISTR04's output. By combining the functions of EDISTR

and new features shown in **Fig. 3.10**, the diagnostic capability in EDISTR04 was greatly enhanced for checking the consistency of the ENSDF data sets and the validity of the computational method.

```
*****************************************************
*                  Radiation Summary                *
*****************************************************

Energy released by
  Gamma-ray                          (MeV) =   1.31239E-02
  X-ray                              (MeV) =   1.18725E-02
  Free-bound X-ray                   (MeV) =   1.86933E-03
  Annihilation photon                (MeV) =   0.00000E+00
  Beta+ particle                     (MeV) =   0.00000E+00
  Neutrino                           (MeV) =   0.00000E+00
  Beta- particle                     (MeV) =   7.68921E-02
  Neutrino-                          (MeV) =   2.01264E-01
  Internal conv. electron            (MeV) =   6.85059E-02
  Auger and CK electron              (MeV) =   1.68108E-02
  Alpha particle                     (MeV) =   0.00000E+00
  Recoil nucleus                     (MeV) =   0.00000E+00
E-total (except unplaced radiat.)    (MeV) =   3.90339E-01
E-unplaced radiation                 (MeV) =   1.11393E-07
Q-value from ENSDF data              (MeV) =   3.89500E-01
Ratio of E-total/Q-value             ( % ) =   1.00215E+02
Ratio of E-unplaced radi./Q-value    ( % ) =   2.85989E-05


Total yield of
  Gamma-ray                                =   2.52195E-01
  X-ray                                    =   8.18275E-01
  Free-bound X-ray                         =   2.44327E+01
  Annihilation photon                      =   0.00000E+00
  Beta+ particle                           =   0.00000E+00
  Beta- particle                           =   1.00000E+00
  Internal conv. electron                  =   2.32699E+00
  Auger and CK electron                    =   2.21168E+01
  Alpha particle                           =   0.00000E+00
Yield of unplaced radiation                =   6.27000E-07
```

Fig. 3.10 Output of the energies of respective types of radiations by EDISTR04 for the decay data of ^{231}Th

4 Compiled Data and Quality Assurance

4.1 Compiled Data

4.1.1 Summary Information of Compiled Data

The compiled data from the ENSDF using the EDISTR04 code, discussed in **Sections 2** and **3**, were prepared in two types of format, ICRP38 and NUCDECAY formats, and are available as ASCII files. The data package was named DECDC2 (DECDC Version 2), which is an updated version of DECDC.[19–21] The data in ICRP38 format are tabulated data of the nuclide name, half-life, decay modes, radiation types and respective E_i and I_i, decay chains and branching fractions. The data of NUCDECAY are the computer readable format containing the nuclide name, half-life, and radiation records. The radiation records are composed of an integer code, which identifies the type of radiation, and E_i and I_i. Further details are found in the respective references.[1,2]

Table 4.1 shows summary information on the nuclear transformation compiled in DECDC2. The total number of nuclides included in DECDC2 is 1034, which consist of 922 radionuclides with $T_{1/2} \geq$ 10 min. The proportion that covers the radionuclides with $T_{1/2} \geq 10$ min was extended up to 88 % of the radionuclides in this half-life range, while ICRP38 was limited to 73 %. The decay data of 130 radionuclides with $T_{1/2} \geq 10$ min were not included in DECDC2 because of the limitation of the available ENSDF data sets.

Table 4.1 contains the following information.

Nuclide : Nuclide name: element symbol and mass number ($A = N + Z$). Isomers are identified in order of increasing excitation energy by appending "m" and "n" to the mass number.

$T_{1/2}$: Physical half-life of the nuclide. Units are abbreviated as follows: y = year, d = day, h = hour, m = minute, and s = second. 1 y is equivalent to 365.2422 d.

Decay mode : The symbols are: A = α decay, B– = β^- decay, EC = electron capture, B+ = β^+ decay, IT = isomeric transition, and SF = spontaneous fission.

Branching fraction : Branching fraction of the corresponding decay mode.

Product : Nuclide name produced from the decay of the corresponding parent nuclide: element symbol and mass number.

Energy : Energies in MeV of radiations emitted per nuclear transformation (n.t.). Types of radiations are:

- Alpha : α particles.
- Electron : $\beta^{\pm}$ particles, internal conversion electrons, and Auger and Coster-Kronig (CK) electrons.
- Photon : Gamma-rays, annihilation photons, and X-rays.

ENSDF date : The date (month-year) when the data set was placed in the ENSDF library.

The summation of BF_i is not unity for several nuclides with multiple decay modes due to the following reasons. In NUBASE2003/AME2003, the decay modes and corresponding BF_i are assigned to individual nuclides. However, the assigned values of BF_i in NUBASE2003/AME2003 have some uncertainty. In addition, the ENSDF data sets were not available for several decay modes with small BF_i values, since the decay schemes have not been established. The decay data of such small BF_i were not included in the present compilation, when the contribution to doses from these decay modes is considered to be negligible. From the above reasons, the sum of BF_i is not unity for ^{205}Po, ^{217}At, ^{219}At, ^{223}Ac, ^{228}U, ^{236}Np, ^{244m}Am, ^{240}Cm, ^{250}Es and ^{254m}Es.

Table 4.1 Summary information of the nuclear transformation of the radionuclides (1/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.)			ENSDF date
						Alpha	Electron	Photon	
Hydrogen									
H-3	12.32y	B-	1.000E+0	He-3	stable		5.680E-3		Jul-2000
Beryllium									
Be-7	53.22d	EC	1.000E+0	Li-7	stable		3.639E-8	4.986E-2	May-2001
Be-10	1.51E+6y	B-	1.000E+0	B-10	stable		2.525E-1		Feb-1999
Carbon									
C-11	20.39m	EC,B+	1.000E+0	B-11	stable		3.847E-1	1.020E+0	Jun-2000
C-14	5.70E+3y	B-	1.000E+0	N-14	stable		4.945E-2		Oct-2001
Nitrogen									
N-13	9.965m	EC,B+	1.000E+0	C-13	stable		4.909E-1	1.020E+0	Jun-2000
Oxygen									
O-14	70.606s	EC,B+	1.000E+0	N-14	stable		7.763E-1	3.320E+0	Oct-2001
O-15	122.24s	EC,B+	1.000E+0	N-15	stable		7.347E-1	1.021E+0	Apr-2002
O-19	26.464s	B-	1.000E+0	F-19	stable		1.761E+0	9.397E-1	Jul-1996
Fluorine									
F-18	109.77m	EC,B+	1.000E+0	O-18	stable		2.416E-1	9.886E-1	Nov-1996
Neon									
Ne-19	17.22s	EC,B+	1.000E+0	F-19	stable		9.624E-1	1.021E+0	Jul-1996
Sodium									
Na-22	2.6019y	EC,B+	1.000E+0	Ne-22	stable		1.941E-1	2.193E+0	Apr-2000
Na-24	14.9590h	B-	1.000E+0	Mg-24	stable		5.538E-1	4.123E+0	Apr-2000
Magnesium									
Mg-28	20.915h	B-	1.000E+0	Al-28	2.2414m		1.610E-1	1.370E+0	Mar-2001
Aluminum									
Al-26	7.17E+5y	EC,B+	1.000E+0	Mg-26	stable		4.444E-1	2.675E+0	Apr-2000
Al-28	2.2414m	B-	1.000E+0	Si-28	stable		1.242E+0	1.779E+0	Mar-2001
Silicon									
Si-31	157.3m	B-	1.000E+0	P-31	stable		5.949E-1	8.863E-4	Mar-2001
Si-32	132y	B-	1.000E+0	P-32	14.263d		6.863E-2		Mar-2001
Phosphorus									
P-30	2.498m	EC,B+	1.000E+0	Si-30	stable		1.439E+0	1.022E+0	Mar-2001
P-32	14.263d	B-	1.000E+0	S-32	stable		6.948E-1		Mar-2001
P-33	25.34d	B-	1.000E+0	S-33	stable		7.643E-2		Mar-2001
Sulfur									
S-35	87.51d	B-	1.000E+0	Cl-35	stable		4.872E-2		Mar-2001
S-38	170.3m	B-	1.000E+0	Cl-38	37.24m		4.898E-1	1.695E+0	Mar-2001
Chlorine									
Cl-34	1.5264s	EC,B+	1.000E+0	S-34	stable		2.051E+0	1.021E+0	Mar-2001
Cl-34m	32.00m	EC,B+	5.540E-1	S-34	stable		4.596E-1	2.113E+0	Mar-2001
		IT	4.460E-1	Cl-34	1.5264s				Mar-2001
Cl-36	3.01E+5y	B-	9.810E-1	Ar-36	stable		2.732E-1	1.460E-4	Mar-2001
		EC,B+	1.900E-2	S-36	stable				Mar-2001
Cl-38	37.24m	B-	1.000E+0	Ar-38	stable		1.550E+0	1.443E+0	Mar-2001
Cl-39	55.6m	B-	1.000E+0	Ar-39	269y		8.246E-1	1.451E+0	Mar-2001
Argon									
Ar-37	35.04d	EC	1.000E+0	Cl-37	stable		2.267E-3	2.806E-4	Mar-2001
Ar-39	269y	B-	1.000E+0	K-39	stable		2.188E-1		Mar-2001

Table 4.1 continued from previous page (2/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.)			ENSDF date
						Alpha	Electron	Photon	
Ar-41	109.61m	B-	1.000E+0	K-41	stable		4.637E-1	1.284E+0	Jan-2002
Ar-42	32.9y	B-	1.000E+0	K-42	12.360h		2.325E-1		Mar-2001
Ar-44	11.87m	B-	1.000E+0	K-44	22.13m		5.245E-1	1.938E+0	Nov-1999
Potassium									
K-38	7.636m	EC,B+	1.000E+0	Ar-38	stable		1.211E+0	3.187E+0	Mar-2001
K-40	1.251E+9y	B-	8.914E-1	Ca-40	stable		5.218E-1	1.567E-1	No date
		EC,B+	1.086E-1	Ar-40	stable				Nov-2002
K-42	12.360h	B-	1.000E+0	Ca-42	stable		1.430E+0	2.787E-1	Mar-2001
K-43	22.3h	B-	1.000E+0	Ca-43	stable		3.097E-1	9.641E-1	May-2001
K-44	22.13m	B-	1.000E+0	Ca-44	stable		1.457E+0	2.385E+0	Nov-1999
K-45	17.3m	B-	1.000E+0	Ca-45	162.67d		9.959E-1	1.836E+0	Jun-1995
Calcium									
Ca-41	1.02E+5y	EC	1.000E+0	K-41	stable		2.733E-3	5.011E-4	Jan-2002
Ca-45	162.67d	B-	1.000E+0	Sc-45	stable		7.720E-2	1.391E-8	Jun-1995
Ca-47	4.536d	B-	1.000E+0	Sc-47	3.3492d		3.521E-1	1.052E+0	Mar-1995
Ca-49	8.718m	B-	1.000E+0	Sc-49	57.2m		8.693E-1	3.168E+0	Dec-1995
Scandium									
Sc-43	3.891h	EC,B+	1.000E+0	Ca-43	stable		4.195E-1	9.841E-1	May-2001
Sc-44	3.97h	EC,B+	1.000E+0	Ca-44	stable		5.961E-1	2.137E+0	Nov-1999
Sc-44m	58.61h	IT	9.880E-1	Sc-44	3.97h		3.278E-2	2.743E-1	Nov-1999
		EC	1.200E-2	Ca-44	stable				Nov-1999
Sc-46	83.79d	B-	1.000E+0	Ti-46	stable		1.121E-1	2.010E+0	Feb-2001
Sc-47	3.3492d	B-	1.000E+0	Ti-47	stable		1.624E-1	1.089E-1	Mar-1995
Sc-48	43.67h	B-	1.000E+0	Ti-48	stable		2.216E-1	3.353E+0	Nov-1993
Sc-49	57.2m	B-	1.000E+0	Ti-49	stable		8.177E-1	1.043E-3	Dec-1995
Titanium									
Ti-44	60.0y	EC	1.000E+0	Sc-44	3.97h		1.081E-2	1.396E-1	Nov-1999
Ti-45	184.8m	EC,B+	1.000E+0	Sc-45	stable		3.728E-1	8.703E-1	Nov-1993
Vanadium									
V-47	32.6m	EC,B+	1.000E+0	Ti-47	stable		8.027E-1	9.951E-1	Mar-1995
V-48	15.9735d	EC,B+	1.000E+0	Ti-48	stable		1.526E-1	2.914E+0	Nov-1993
V-49	330d	EC	1.000E+0	Ti-49	stable		3.538E-3	9.185E-4	Dec-1995
V-50	1.50E+17y	EC	8.300E-1	Ti-50	stable		1.581E-2	1.424E+0	Sep-1995
		B-	1.700E-1	Cr-50	stable				Sep-1995
Chromium									
Cr-48	21.56h	EC,B+	1.000E+0	V-48	15.9735d		8.564E-3	4.363E-1	Nov-1993
Cr-49	42.3m	EC,B+	1.000E+0	V-49	330d		6.047E-1	1.054E+0	Dec-1995
Cr-51	27.7025d	EC	1.000E+0	V-51	stable		3.824E-3	3.290E-2	Feb-2001
Manganese									
Mn-51	46.2m	EC,B+	1.000E+0	Cr-51	27.7025d		9.344E-1	9.977E-1	Jun-1997
Mn-52	5.591d	EC,B+	1.000E+0	Cr-52	stable		7.505E-2	3.458E+0	May-2000
Mn-52m	21.1m	EC,B+	9.825E-1	Cr-52	stable		1.132E+0	2.409E+0	May-2000
		IT	1.750E-2	Mn-52	5.591d				May-2000
Mn-53	3.7E+6y	EC	1.000E+0	Cr-53	stable		3.989E-3	1.356E-3	Oct-1999
Mn-54	312.12d	EC,B+	1.000E+0	Cr-54	stable		4.205E-3	8.360E-1	Jul-2001
		B-	2.900E-6	Fe-54	stable				Jul-2001
Mn-56	2.5789h	B-	1.000E+0	Fe-56	stable		8.299E-1	1.692E+0	Apr-1999
Iron									
Fe-52	8.275h	EC,B+	1.000E+0	Mn-52m	21.1m		1.917E-1	7.405E-1	May-2000
Fe-55	2.737y	EC	1.000E+0	Mn-55	stable		4.169E-3	1.665E-3	Aug-2001
Fe-59	44.495d	B-	1.000E+0	Co-59	stable		1.179E-1	1.188E+0	Apr-2002
Fe-60	1.5E+6y	B-	1.000E+0	Co-60m	10.467m		6.473E-2		Jul-1993

Table 4.1 continued from previous page (3/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.)			ENSDF date
						Alpha	Electron	Photon	
Cobalt									
Co-55	17.53h	EC,B+	1.000E+0	Fe-55	2.737y		4.312E-1	1.996E+0	Aug-2001
Co-56	77.23d	EC,B+	1.000E+0	Fe-56	stable		1.198E-1	3.640E+0	Apr-1999
Co-57	271.74d	EC	1.000E+0	Fe-57	stable		1.864E-2	1.252E-1	Dec-1998
Co-58	70.86d	EC,B+	1.000E+0	Fe-58	stable		3.395E-2	9.749E-1	Sep-2000
Co-58m	9.04h	IT	1.000E+0	Co-58	70.86d		2.287E-2	2.016E-3	May-1997
Co-60	5.2713y	B-	1.000E+0	Ni-60	stable		9.686E-2	2.504E+0	Sep-2000
Co-60m	10.467m	IT	9.976E-1	Co-60	5.2713y		5.648E-2	6.688E-3	Jul-1993
		B-	2.400E-3	Ni-60	stable				Jul-1993
Co-61	1.650h	B-	1.000E+0	Ni-61	stable		4.664E-1	9.697E-2	Nov-1999
Co-62	1.50m	B-	1.000E+0	Ni-62	stable		1.634E+0	1.605E+0	Jan-2001
Co-62m	13.91m	B-	1.000E+0	Ni-62	stable		1.097E+0	2.692E+0	Jan-2001
Nickel									
Ni-56	6.075d	EC,B+	1.000E+0	Co-56	77.23d		7.346E-3	1.721E+0	Apr-1999
Ni-57	35.60h	EC,B+	1.000E+0	Co-57	271.74d		1.571E-1	1.938E+0	Dec-1998
Ni-59	1.01E+5y	EC,B+	1.000E+0	Co-59	stable		4.537E-3	2.366E-3	Apr-2002
Ni-63	100.1y	B-	1.000E+0	Cu-63	stable		1.742E-2		Mar-2001
Ni-65	2.51719h	B-	1.000E+0	Cu-65	stable		6.277E-1	5.583E-1	Aug-1993
Ni-66	54.6h	B-	1.000E+0	Cu-66	5.120m		7.336E-2		May-1998
Copper									
Cu-57	0.1963s	EC,B+	1.000E+0	Ni-57	35.60h		3.599E+0	1.141E+0	Dec-1998
Cu-60	23.7m	EC,B+	1.000E+0	Ni-60	stable		8.975E-1	3.911E+0	Jul-1993
Cu-61	3.333h	EC,B+	1.000E+0	Ni-61	stable		3.090E-1	8.237E-1	Nov-1999
Cu-62	9.673m	EC,B+	1.000E+0	Ni-62	stable		1.284E+0	1.007E+0	Jan-2001
Cu-64	12.700h	EC,B+	6.100E-1	Ni-64	stable		1.248E-1	1.855E-1	Sep-1996
		B-	3.900E-1	Zn-64	stable				Sep-1996
Cu-66	5.120m	B-	1.000E+0	Zn-66	stable		1.066E+0	9.781E-2	May-1998
Cu-67	61.83h	B-	1.000E+0	Zn-67	stable		1.504E-1	1.154E-1	Dec-1991
Zinc									
Zn-62	9.186h	EC,B+	1.000E+0	Cu-62	9.673m		3.265E-2	4.431E-1	Jan-2001
Zn-63	38.47m	EC,B+	1.000E+0	Cu-63	stable		9.204E-1	1.097E+0	Mar-2001
Zn-65	244.06d	EC,B+	1.000E+0	Cu-65	stable		6.877E-3	5.819E-1	Sep-2000
Zn-69	56.4m	B-	1.000E+0	Ga-69	stable		3.216E-1	6.000E-6	Jun-2000
Zn-69m	13.76h	IT	9.997E-1	Zn-69	56.4m		2.261E-2	4.162E-1	Jun-2000
		B-	3.300E-4	Ga-69	stable				Jun-2000
Zn-71	2.45m	B-	1.000E+0	Ga-71	stable		1.047E+0	3.150E-1	May-1993
Zn-71m	3.96h	B-	1.000E+0	Ga-71	stable		5.430E-1	1.561E+0	May-1993
Zn-72	46.5h	B-	1.000E+0	Ga-72	14.10h		1.021E-1	1.519E-1	Jan-1995
Gallium									
Ga-65	15.2m	EC,B+	1.000E+0	Zn-65	244.06d		8.158E-1	1.165E+0	Aug-2000
Ga-66	9.49h	EC,B+	1.000E+0	Zn-66	stable		9.634E-1	2.494E+0	May-1998
Ga-67	3.2612d	EC	1.000E+0	Zn-67	stable		3.634E-2	1.595E-1	Dec-1991
Ga-68	67.71m	EC,B+	1.000E+0	Zn-68	stable		7.379E-1	9.487E-1	Nov-2002
Ga-70	21.14m	B-	9.959E-1	Ge-70	stable		6.441E-1	7.288E-3	Apr-1993
		EC	4.100E-3	Zn-70	stable				Apr-1993
Ga-72	14.10h	B-	1.000E+0	Ge-72	stable		5.060E-1	2.707E+0	Jan-1995
Ga-73	4.86h	B-	1.000E+0	Ge-73	stable		4.999E-1	3.520E-1	Aug-2002
Germanium									
Ge-66	2.26h	EC,B+	1.000E+0	Ga-66	9.49h		9.836E-2	6.780E-1	May-1998
Ge-67	18.9m	EC,B+	1.000E+0	Ga-67	3.2612d		1.169E+0	1.425E+0	Dec-1991
Ge-68	270.95d	EC	1.000E+0	Ga-68	67.71m		4.956E-3	4.110E-3	Nov-2002
Ge-69	39.05h	EC,B+	1.000E+0	Ga-69	stable		1.203E-1	9.505E-1	Jun-2000
Ge-71	11.43d	EC	1.000E+0	Ga-71	stable		5.013E-3	4.168E-3	May-1993
Ge-75	82.78m	B-	1.000E+0	As-75	stable		4.206E-1	3.524E-2	Jul-1999
Ge-77	11.30h	B-	1.000E+0	As-77	38.83h		6.493E-1	1.079E+0	Aug-1997
Ge-78	88m	B-	1.000E+0	As-78	90.7m		2.273E-1	2.781E-1	Aug-1991

Table 4.1 continued from previous page (4/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.)			ENSDF date
						Alpha	Electron	Photon	
Arsenic									
As-69	15.23m	EC,B+	1.000E+0	Ge-69	39.05h		1.218E+0	1.143E+0	Jun-2000
As-70	52.6m	EC,B+	1.000E+0	Ge-70	stable		8.799E-1	4.253E+0	Apr-1993
As-71	65.28h	EC,B+	1.000E+0	Ge-71	11.43d		1.167E-1	5.765E-1	May-1993
As-72	26.0h	EC,B+	1.000E+0	Ge-72	stable		1.041E+0	1.783E+0	Oct-1997
As-73	80.30d	EC	1.000E+0	Ge-73	stable		6.063E-2	1.591E-2	Aug-2002
As-74	17.77d	EC,B+	6.600E-1	Ge-74	stable		2.658E-1	7.582E-1	Jun-1995
		B-	3.400E-1	Se-74	stable				Jun-1995
As-76	1.0778d	B-	1.000E+0	Se-76	stable		1.067E+0	4.166E-1	Mar-1995
As-77	38.83h	B-	1.000E+0	Se-77	stable		2.258E-1	8.324E-3	Aug-1997
As-78	90.7m	B-	1.000E+0	Se-78	stable		1.246E+0	1.307E+0	Aug-1991
Selenium									
Se-70	41.1m	EC,B+	1.000E+0	As-70	52.6m		2.375E-1	7.211E-1	Apr-1993
Se-72	8.40d	EC	1.000E+0	As-72	26.0h		2.275E-2	3.432E-2	Jan-1995
Se-73	7.15h	EC,B+	1.000E+0	As-73	80.30d		3.871E-1	1.092E+0	Apr-1998
Se-73m	39.8m	IT	7.260E-1	Se-73	7.15h		1.642E-1	2.633E-1	Jan-2003
		EC,B+	2.740E-1	As-73	80.30d				Nov-1993
Se-75	119.779d	EC	1.000E+0	As-75	stable		1.444E-2	3.890E-1	Jul-1999
Se-77m	17.36s	IT	1.000E+0	Se-77	stable		7.369E-2	8.885E-2	Aug-1997
Se-79	2.95E+5y	B-	1.000E+0	Br-79	stable		5.292E-2		Jun-2002
Se-81	18.45m	B-	1.000E+0	Br-81	stable		6.108E-1	8.010E-3	Feb-1997
Se-81m	57.28m	IT	9.995E-1	Se-81	18.45m		8.711E-2	1.834E-2	Feb-1997
		B-	5.200E-4	Br-81	stable				Feb-1997
Se-83	22.3m	B-	1.000E+0	Br-83	2.40h		4.528E-1	2.625E+0	May-2001
Bromine									
Br-74	25.4m	EC,B+	1.000E+0	Se-74	stable		1.062E+0	4.613E+0	Jun-1995
Br-74m	46m	EC,B+	1.000E+0	Se-74	stable		1.275E+0	4.147E+0	Jun-1995
Br-75	96.7m	EC,B+	1.000E+0	Se-75	119.779d		5.283E-1	1.198E+0	Jul-1999
Br-76	16.2h	EC,B+	1.000E+0	Se-76	stable		6.497E-1	2.793E+0	Mar-1995
Br-76m	1.31s	IT	9.970E-1	Br-76	16.2h		6.902E-2	4.329E-2	Mar-1995
		EC,B+	3.000E-3	Se-76	stable				Mar-1995
Br-77	57.036h	EC,B+	1.000E+0	Se-77	stable		9.379E-3	3.209E-1	Aug-1997
Br-77m	4.28m	IT	1.000E+0	Br-77	57.036h		8.763E-2	1.968E-2	Aug-1997
Br-80	17.68m	B-	9.170E-1	Kr-80	stable		7.247E-1	7.607E-2	Aug-1992
		EC,B+	8.300E-2	Se-80	stable				Aug-1992
Br-80m	4.4205h	IT	1.000E+0	Br-80	17.68m		6.174E-2	2.416E-2	Aug-1992
Br-82	35.30h	B-	1.000E+0	Kr-82	stable		1.454E-1	2.639E+0	Dec-1995
Br-83	2.40h	B-	1.000E+0	Kr-83m (9.985E-1)[1]	1.83h		3.258E-1	6.876E-3	May-2001
				Kr-83 (1.552E-3)[1]	stable				
Br-84	31.80m	B-	1.000E+0	Kr-84	stable		1.236E+0	1.759E+0	Jun-1997
Krypton									
Kr-74	11.50m	EC,B+	1.000E+0	Br-74	25.4m		6.006E-1	1.058E+0	Jun-1995
Kr-76	14.8h	EC	1.000E+0	Br-76m (8.114E-3)	1.31s		1.540E-2	4.276E-1	Mar-1995
				Br-76 (9.919E-1)	16.2h				
Kr-77	74.4m	EC,B+	1.000E+0	Br-77m (9.614E-2)	4.28m		6.744E-1	1.038E+0	Aug-1997
				Br-77 (9.039E-1)	57.036h				
Kr-79	35.04h	EC,B+	1.000E+0	Br-79	stable		2.373E-2	2.549E-1	Jun-2002
Kr-81	2.29E+5y	EC	1.000E+0	Br-81	stable		5.184E-3	7.198E-3	Feb-1997
Kr-81m	13.10s	IT	1.000E+0	Kr-81	2.29E+5y		5.961E-2	1.309E-1	Feb-1997
		EC	2.500E-5	Br-81	stable				Feb-1997
Kr-83m	1.83h	IT	1.000E+0	Kr-83	stable		3.881E-2	2.752E-3	May-2001
Kr-85	10.756y	B-	1.000E+0	Rb-85	stable		2.507E-1	2.231E-3	Apr-1991

1 The values in the parentheses are branching fractions to the respective states.

Table 4.1 continued from previous page (5/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.)			ENSDF date
						Alpha	Electron	Photon	
Kr-85m	4.480h	B-	7.860E-1	Rb-85	stable		2.549E-1	1.574E-1	Apr-1991
		IT	2.140E-1	Kr-85	10.756y				Apr-1991
Kr-87	76.3m	B-	1.000E+0	Rb-87	4.923E+10y		1.328E+0	7.919E-1	May-2002
Kr-88	2.84h	B-	1.000E+0	Rb-88	17.78m		3.689E-1	1.954E+0	Aug-1988
Rubidium									
Rb-77	3.77m	EC,B+	1.000E+0	Kr-77	74.4m		1.687E+0	1.545E+0	Aug-1997
Rb-78	17.66m	EC,B+	1.000E+0	Kr-78	stable		1.289E+0	4.092E+0	Aug-1991
Rb-79	22.9m	EC,B+	1.000E+0	Kr-79	35.04h		8.099E-1	1.449E+0	Jun-2002
Rb-80	33.4s	EC,B+	1.000E+0	Kr-80	stable		2.045E+0	1.190E+0	Aug-1992
Rb-81	4.576h	EC,B+	1.000E+0	Kr-81m (9.569E-1)	13.10s		1.222E-1	5.081E-1	Feb-1997
				Kr-81 (4.309E-2)	2.29E+5y				
Rb-81m	30.5m	IT	9.760E-1	Rb-81	4.576h		8.170E-2	3.028E-2	Feb-1997
		EC,B+	2.400E-2	Kr-81m (2.136E-4)	13.10s				Feb-1997
				Kr-81 (2.379E-2)	2.29E+5y				
Rb-82	1.273m	EC,B+	1.000E+0	Kr-82	stable		1.411E+0	1.108E+0	Aug-2000
Rb-82m	6.472h	EC,B+	1.000E+0	Kr-82	stable		9.352E-2	2.921E+0	Dec-1995
Rb-83	86.2d	EC	1.000E+0	Kr-83m (7.429E-1)	1.83h		8.308E-3	4.914E-1	May-2001
				Kr-83 (2.571E-1)	stable				
Rb-84	32.77d	EC,B+	9.620E-1	Kr-84	stable		1.633E-1	9.077E-1	Jun-1997
		B-	3.800E-2	Sr-84	stable				Jun-1997
Rb-84m	20.26m	IT	1.000E+0	Rb-84	32.77d		8.134E-2	3.831E-1	Jun-1997
Rb-86	18.642d	B-	1.000E+0	Sr-86	stable		6.680E-1	9.305E-2	Dec-2001
		EC	5.200E-5	Kr-86	stable				Dec-2001
Rb-87	4.923E+10y	B-	1.000E+0	Sr-87	stable		1.154E-1		May-2002
Rb-88	17.78m	B-	1.000E+0	Sr-88	stable		2.072E+0	6.370E-1	Aug-1988
Rb-89	15.15m	B-	1.000E+0	Sr-89	50.53d		9.528E-1	2.243E+0	Nov-1998
Strontium									
Sr-80	106.3m	EC,B+	1.000E+0	Rb-80	33.4s		4.184E-2	4.371E-1	Aug-1992
Sr-81	22.3m	EC,B+	1.000E+0	Rb-81m (1.442E-3)	30.5m		9.743E-1	1.387E+0	Feb-1997
				Rb-81 (9.986E-1)	4.576h				
Sr-82	25.36d	EC	1.000E+0	Rb-82	1.273m		5.356E-3	7.883E-3	Dec-1995
Sr-83	32.41h	EC,B+	1.000E+0	Rb-83	86.2d		1.604E-1	8.213E-1	May-2001
Sr-85	64.84d	EC	1.000E+0	Rb-85	stable		8.910E-3	5.001E-1	Apr-1991
Sr-85m	67.63m	IT	8.660E-1	Sr-85	64.84d		1.296E-2	2.177E-1	Apr-1991
		EC,B+	1.340E-1	Rb-85	stable				Apr-1991
Sr-87m	2.815h	IT	9.970E-1	Sr-87	stable		6.724E-2	3.202E-1	May-2002
		EC	3.000E-3	Rb-87	4.923E+10y				May-2002
Sr-89	50.53d	B-	1.000E+0	Y-89	stable		5.845E-1	8.690E-5	Nov-1998
Sr-90	28.79y	B-	1.000E+0	Y-90	64.10h		1.957E-1		Jan-1998
Sr-91	9.63h	B-	1.000E+0	Y-91m (5.825E-1)	49.71m		6.549E-1	7.072E-1	Feb-1999
				Y-91 (4.175E-1)	58.51d				
Sr-92	2.66h	B-	1.000E+0	Y-92	3.54h		2.025E-1	1.337E+0	Jan-2001
Yttrium									
Y-84m	39.5m	EC,B+	1.000E+0	Sr-84	stable		1.225E+0	3.975E+0	Jun-1997
Y-85	2.68h	EC,B+	1.000E+0	Sr-85m	67.63m		4.881E-1	1.079E+0	Apr-1991
Y-85m	4.86h	EC,B+	1.000E+0	Sr-85m (4.000E-2)	67.63m		5.765E-1	1.324E+0	Apr-1991
				Sr-85 (9.600E-1)	64.84d				
Y-86	14.74h	EC,B+	1.000E+0	Sr-86	stable		2.179E-1	3.578E+0	Dec-2001

Table 4.1 continued from previous page (6/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.)			ENSDF date
						Alpha	Electron	Photon	
Y-86m	48m	IT	9.931E-1	Y-86	14.74h		2.431E-2	2.203E-1	Dec-2001
		EC,B+	6.900E-3	Sr-86	stable				Dec-2001
Y-87	79.8h	EC,B+	1.000E+0	Sr-87m	2.815h		7.152E-3	4.462E-1	May-2002
Y-87m	13.37h	IT	9.843E-1	Y-87	79.8h		7.941E-2	3.072E-1	May-2002
		EC,B+	1.570E-2	Sr-87	stable				May-2002
Y-88	106.65d	EC,B+	1.000E+0	Sr-88	stable		6.743E-3	2.695E+0	Aug-1988
Y-90	64.10h	B-	1.000E+0	Zr-90	stable		9.331E-1	1.232E-6	Jan-1998
Y-90m	3.19h	IT	1.000E+0	Y-90	64.10h		4.697E-2	6.354E-1	Jan-1998
		B-	1.800E-5	Zr-90	stable				Jan-1998
Y-91	58.51d	B-	1.000E+0	Zr-91	stable		6.032E-1	3.132E-3	Feb-2001
Y-91m	49.71m	IT	1.000E+0	Y-91	58.51d		2.794E-2	5.283E-1	Feb-1999
Y-92	3.54h	B-	1.000E+0	Zr-92	stable		1.449E+0	2.517E-1	Jan-2001
Y-93	10.18h	B-	1.000E+0	Zr-93	1.53E+6y		1.172E+0	9.610E-2	Mar-1997
Y-94	18.7m	B-	1.000E+0	Zr-94	stable		1.813E+0	7.725E-1	May-1992
Y-95	10.3m	B-	1.000E+0	Zr-95	64.032d		1.429E+0	1.108E+0	Apr-1994
Zirconium									
Zr-86	16.5h	EC,B+	1.000E+0	Y-86	14.74h		3.103E-2	2.952E-1	Dec-2001
Zr-87	1.68h	EC,B+	1.000E+0	Y-87m (9.970E-1)	13.37h		8.218E-1	9.271E-1	May-2002
				Y-87 (2.964E-3)	79.8h				
Zr-88	83.4d	EC	1.000E+0	Y-88	106.65d		1.603E-2	3.918E-1	Aug-1988
Zr-89	78.41h	EC,B+	1.000E+0	Y-89	stable		1.019E-1	1.158E+0	Nov-1998
Zr-89m	4.161m	IT	9.377E-1	Zr-89	78.41h		3.184E-2	6.344E-1	Nov-1998
		EC,B+	6.230E-2	Y-89	stable				Nov-1998
Zr-93	1.53E+6y	B-	1.000E+0	Nb-93m (9.750E-1)	16.13y		1.942E-2		Mar-1997
				Nb-93 (2.500E-2)	stable				
Zr-95	64.032d	B-	1.000E+0	Nb-95m (1.080E-2)	3.61d		1.185E-1	7.321E-1	Sep-2000
				Nb-95 (9.892E-1)	34.991d				
Zr-97	16.744h	B-	1.000E+0	Nb-97	72.1m		7.212E-1	8.792E-1	Mar-1998
Niobium									
Nb-88	14.5m	EC,B+	1.000E+0	Zr-88	83.4d		1.456E+0	4.219E+0	Aug-1988
Nb-89	2.03h	EC,B+	1.000E+0	Zr-89m (1.228E-2)	4.161m		1.086E+0	1.367E+0	Nov-1998
				Zr-89 (9.877E-1)	78.41h				
Nb-89m	66m	EC,B+	1.000E+0	Zr-89m	4.161m		7.855E-1	1.306E+0	Nov-1998
Nb-90	14.60h	EC,B+	1.000E+0	Zr-90	stable		4.032E-1	4.214E+0	Jan-1998
Nb-91	680y	EC,B+	1.000E+0	Zr-91	stable		5.789E-3	1.182E-2	Feb-2001
Nb-91m	60.86d	IT	9.660E-1	Nb-91	680y		9.630E-2	3.399E-2	Feb-1999
		EC,B+	3.400E-2	Zr-91	stable				Feb-2001
Nb-92	3.47E+7y	EC	1.000E+0	Zr-92	stable		7.855E-3	1.505E+0	Jan-2001
Nb-92m	10.15d	EC,B+	1.000E+0	Zr-92	stable		6.477E-3	9.689E-1	Jan-2001
Nb-93m	16.13y	IT	1.000E+0	Nb-93	stable		2.944E-2	2.004E-3	Mar-1997
Nb-94	2.03E+4y	B-	1.000E+0	Mo-94	stable		1.684E-1	1.558E+0	Jul-1997
Nb-95	34.991d	B-	1.000E+0	Mo-95	stable		4.456E-2	7.645E-1	Sep-2000
Nb-95m	3.61d	IT	9.440E-1	Nb-95	34.991d		1.800E-1	6.968E-2	Sep-2000
		B-	5.600E-2	Mo-95	stable				Sep-2000
Nb-96	23.35h	B-	1.000E+0	Mo-96	stable		2.535E-1	2.461E+0	Apr-1993
Nb-97	72.1m	B-	1.000E+0	Mo-97	stable		4.683E-1	6.650E-1	Nov-1993
Nb-98m	51.3m	B-	1.000E+0	Mo-98	stable		7.636E-1	2.818E+0	Aug-1998
Molybdenum									
Mo-90	5.56h	EC,B+	1.000E+0	Nb-90	14.60h		2.107E-1	8.331E-1	Jan-1998
Mo-91	15.49m	EC,B+	1.000E+0	Nb-91m (3.423E-4)	60.86d		1.451E+0	9.773E-1	Feb-1999
				Nb-91 (9.997E-1)	680y				

Table 4.1 continued from previous page (7/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.)			ENSDF date
						Alpha	Electron	Photon	
Mo-93	4.0E+3y	EC	1.000E+0	Nb-93m (8.800E-1)	16.13y		5.558E-3	1.070E-2	Mar-1997
				Nb-93 (1.200E-1)	stable				
Mo-93m	6.85h	IT	9.988E-1	Mo-93	4.0E+3y		1.045E-1	2.318E+0	Mar-1997
		EC	1.200E-3	Nb-93	stable				Mar-1997
Mo-99	65.94h	B-	1.000E+0	Tc-99m (8.773E-1)	6.015h		3.929E-1	1.484E-1	Jul-2001
				Tc-99 (1.227E-1)	2.111E+5y				
Mo-101	14.61m	B-	1.000E+0	Tc-101	14.2m		5.524E-1	1.471E+0	Feb-1998
Mo-102	11.3m	B-	1.000E+0	Tc-102	5.28s		3.509E-1	1.854E-2	Apr-1998
Technetium									
Tc-93	2.75h	EC,B+	1.000E+0	Mo-93	4.0E+3y		4.359E-2	1.569E+0	Mar-1997
Tc-93m	43.5m	IT	7.660E-1	Tc-93	2.75h		1.015E-1	9.522E-1	Mar-1997
		EC,B+	2.340E-1	Mo-93	4.0E+3y				Mar-1997
Tc-94	293m	EC,B+	1.000E+0	Mo-94	stable		4.754E-2	2.661E+0	Jul-1997
Tc-94m	52.0m	EC,B+	1.000E+0	Mo-94	stable		7.543E-1	1.957E+0	Jul-1997
Tc-95	20.0h	EC	1.000E+0	Mo-95	stable		6.850E-3	7.965E-1	Apr-1994
Tc-95m	61d	EC,B+	9.612E-1	Mo-95	stable		1.544E-2	6.887E-1	Apr-1994
		IT	3.880E-2	Tc-95	20.0h				Apr-1994
Tc-96	4.28d	EC	1.000E+0	Mo-96	stable		8.874E-3	2.503E+0	Apr-1993
Tc-96m	51.5m	IT	9.800E-1	Tc-96	4.28d		2.689E-2	4.799E-2	Apr-1993
		EC,B+	2.000E-2	Mo-96	stable				Apr-1993
Tc-97	2.6E+6y	EC	1.000E+0	Mo-97	stable		5.550E-3	1.137E-2	Nov-1993
Tc-97m	90.1d	IT	1.000E+0	Tc-97	2.6E+6y		8.686E-2	9.555E-3	Nov-1993
Tc-98	4.2E+6y	B-	1.000E+0	Ru-98	stable		1.415E-1	1.413E+0	Aug-1998
Tc-99	2.111E+5y	B-	1.000E+0	Ru-99	stable		1.013E-1	7.025E-7	Jan-1995
Tc-99m	6.015h	IT	1.000E+0	Tc-99	2.111E+5y		1.619E-2	1.266E-1	Jul-2001
		B-	3.700E-5	Ru-99	stable				Jan-1995
Tc-101	14.2m	B-	1.000E+0	Ru-101	stable		4.725E-1	3.367E-1	Feb-1998
Tc-102	5.28s	B-	1.000E+0	Ru-102	stable		1.944E+0	8.077E-2	Apr-1998
Tc-104	18.3m	B-	1.000E+0	Ru-104	stable		1.601E+0	2.245E+0	Feb-2000
Ruthenium									
Ru-94	51.8m	EC,B+	1.000E+0	Tc-94m	52.0m		8.467E-3	5.197E-1	May-1992
Ru-95	1.643h	EC,B+	1.000E+0	Tc-95m (2.613E-2)	61d		8.308E-2	1.242E+0	Apr-1994
				Tc-95 (9.739E-1)	20.0h				
Ru-97	2.9d	EC	1.000E+0	Tc-97m (4.218E-4)	90.1d		1.318E-2	2.408E-1	Nov-1993
				Tc-97 (9.996E-1)	2.6E+6y				
Ru-103	39.26d	B-	1.000E+0	Rh-103m (9.876E-1)	56.114m		6.605E-2	4.962E-1	Aug-2001
				Rh-103 (1.245E-2)	stable				
Ru-105	4.44h	B-	1.000E+0	Rh-105	35.36h		4.406E-1	7.480E-1	May-1993
Ru-106	373.59d	B-	1.000E+0	Rh-106	29.80s		1.003E-2		Aug-1994
Rhodium									
Rh-97	30.7m	EC,B+	1.000E+0	Ru-97	2.9d		5.211E-1	1.445E+0	Nov-1993
Rh-97m	46.2m	EC,B+	9.440E-1	Ru-97	2.9d		1.992E-1	2.202E+0	Nov-1993
		IT	5.600E-2	Rh-97	30.7m				Nov-1993
Rh-98	8.7m	EC,B+	1.000E+0	Ru-98	stable		1.337E+0	1.812E+0	Aug-1998
Rh-99	16.1d	EC,B+	1.000E+0	Ru-99	stable		6.115E-2	5.627E-1	Jan-1995
Rh-99m	4.7h	EC,B+	1.000E+0	Ru-99	stable		3.675E-2	6.511E-1	Jan-1995
Rh-100	20.8h	EC,B+	1.000E+0	Ru-100	stable		4.943E-2	2.743E+0	May-1997
Rh-101	3.3y	EC	1.000E+0	Ru-101	stable		2.666E-2	2.878E-1	Feb-1998
Rh-101m	4.34d	EC	9.360E-1	Ru-101	stable		1.993E-2	2.877E-1	Feb-1998
		IT	6.400E-2	Rh-101	3.3y				Feb-1998

Table 4.1 continued from previous page (8/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.)			ENSDF date
						Alpha	Electron	Photon	
Rh-102	207d	EC,B+	7.800E-1	Ru-102	stable		1.717E-1	5.060E-1	Apr-1998
		B-	2.200E-1	Pd-102	stable				Apr-1998
Rh-102m	3.742y	EC,B+	9.977E-1	Ru-102	stable		1.249E-2	2.154E+0	Apr-1998
		IT	2.330E-3	Rh-102	207d				Apr-1998
Rh-103m	56.114m	IT	1.000E+0	Rh-103	stable		3.769E-2	1.723E-3	Aug-2001
Rh-105	35.36h	B-	1.000E+0	Pd-105	stable		1.533E-1	7.727E-2	May-1993
Rh-106	29.80s	B-	1.000E+0	Pd-106	stable		1.411E+0	2.061E-1	Aug-1994
Rh-106m	131m	B-	1.000E+0	Pd-106	stable		3.492E-1	2.853E+0	Aug-1994
Rh-107	21.7m	B-	1.000E+0	Pd-107	6.5E+6y		4.407E-1	3.133E-1	Feb-2000
Palladium									
Pd-98	17.7m	EC,B+	1.000E+0	Rh-98	8.7m		4.548E-2	4.154E-1	Aug-1998
Pd-99	21.4m	EC,B+	1.000E+0	Rh-99m (9.665E-1)	4.7h		4.498E-1	1.283E+0	Jan-1995
				Rh-99 (3.353E-2)	16.1d				
Pd-100	3.63d	EC	1.000E+0	Rh-100	20.8h		4.547E-2	1.231E-1	May-1997
Pd-101	8.47h	EC,B+	1.000E+0	Rh-101m	4.34d		3.278E-2	3.518E-1	Feb-1998
Pd-103	16.991d	EC	1.000E+0	Rh-103m (9.988E-1)	56.114m		5.820E-3	1.458E-2	Aug-2001
				Rh-103 (1.251E-3)	stable				
Pd-107	6.5E+6y	B-	1.000E+0	Ag-107	stable		9.582E-3		Feb-2000
Pd-109	13.7012h	B-	1.000E+0	Ag-109	stable		4.380E-1	1.178E-2	May-1999
Pd-111	23.4m	B-	1.000E+0	Ag-111m (9.976E-1)	64.8s		8.409E-1	4.780E-2	Apr-1996
				Ag-111 (2.437E-3)	7.45d				
Pd-112	21.03h	B-	1.000E+0	Ag-112	3.130h		8.999E-2	5.086E-3	No date
Silver									
Ag-101	11.1m	EC,B+	1.000E+0	Pd-101	8.47h		8.396E-1	1.570E+0	Feb-1998
Ag-102	12.9m	EC,B+	1.000E+0	Pd-102	stable		8.430E-1	3.409E+0	Apr-1998
Ag-103	65.7m	EC,B+	1.000E+0	Pd-103	16.991d		1.973E-1	8.440E-1	Aug-2001
Ag-104	69.2m	EC,B+	1.000E+0	Pd-104	stable		9.166E-2	2.707E+0	Feb-2000
Ag-104m	33.5m	EC,B+	9.993E-1	Pd-104	stable		7.331E-1	1.805E+0	Feb-2000
		IT	7.000E-4	Ag-104	69.2m				Feb-2000
Ag-105	41.29d	EC	1.000E+0	Pd-105	stable		1.916E-2	5.138E-1	May-1993
Ag-105m	7.23m	IT	9.966E-1	Ag-105	41.29d		2.521E-2	1.261E-3	May-1993
		EC,B+	3.400E-3	Pd-105	stable				May-1993
Ag-106	23.96m	EC,B+	9.900E-1	Pd-106	stable		4.967E-1	6.996E-1	Aug-1994
		B-	1.000E-2	Cd-106	stable				Aug-1994
Ag-106m	8.28d	EC	1.000E+0	Pd-106	stable		1.312E-2	2.809E+0	Aug-1994
Ag-108	2.37m	B-	9.715E-1	Cd-108	stable		6.071E-1	1.855E-2	Dec-2000
		EC,B+	2.850E-2	Pd-108	stable				Dec-2000
Ag-108m	418y	EC	9.130E-1	Pd-108	stable		1.591E-2	1.621E+0	Dec-2000
		IT	8.700E-2	Ag-108	2.37m				Dec-2000
Ag-109m	39.6s	IT	1.000E+0	Ag-109	stable		7.696E-2	1.108E-2	May-1999
Ag-110	24.6s	B-	9.970E-1	Cd-110	stable		1.181E+0	3.070E-2	Mar-2000
		EC	3.000E-3	Pd-110	stable				Mar-2000
Ag-110m	249.76d	B-	9.864E-1	Cd-110	stable		7.577E-2	2.761E+0	Mar-2000
		IT	1.360E-2	Ag-110	24.6s				Mar-2000
Ag-111	7.45d	B-	1.000E+0	Cd-111	stable		3.539E-1	2.648E-2	Apr-1996
Ag-111m	64.8s	IT	9.930E-1	Ag-111	7.45d		5.678E-2	7.867E-3	Apr-1996
		B-	7.000E-3	Cd-111	stable				Apr-1996
Ag-112	3.130h	B-	1.000E+0	Cd-112	stable		1.354E+0	6.905E-1	Jan-1997
Ag-113	5.37h	B-	1.000E+0	Cd-113m (1.739E-2)	14.1y		7.614E-1	7.195E-2	Apr-1998
				Cd-113 (9.826E-1)	7.7E+15y				
Ag-115	20.0m	B-	1.000E+0	Cd-115m (9.782E-1)	44.6d		1.093E+0	4.831E-1	Feb-1999
				Cd-115 (2.177E-2)	53.46h				

Table 4.1 continued from previous page (9/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.)			ENSDF date
						Alpha	Electron	Photon	
Cadmium									
Cd-104	57.7m	EC	1.000E+0	Ag-104m	33.5m		3.059E-2	2.513E-1	Feb-2000
Cd-105	55.5m	EC,B+	1.000E+0	Ag-105m	7.23m		2.167E-1	1.299E+0	May-1993
				(8.296E-1)					
				Ag-105	41.29d				
				(1.704E-1)					
Cd-107	6.50h	EC,B+	1.000E+0	Ag-107	stable		8.697E-2	3.371E-2	Feb-2000
Cd-109	461.4d	EC	1.000E+0	Ag-109	stable		8.270E-2	2.653E-2	May-1999
Cd-111m	48.50m	IT	1.000E+0	Cd-111	stable		1.066E-1	2.843E-1	Apr-1996
Cd-113	7.7E+15y	B-	1.000E+0	In-113	stable		9.260E-2		Apr-1998
Cd-113m	14.1y	B-	9.986E-1	In-113	stable		1.847E-1	7.293E-5	Apr-1998
		IT	1.400E-3	Cd-113	7.7E+15y				Apr-1998
Cd-115	53.46h	B-	1.000E+0	In-115m	4.486h		3.182E-1	1.926E-1	Feb-1999
Cd-115m	44.6d	B-	1.000E+0	In-115m	4.486h		6.045E-1	3.292E-2	Feb-1999
				(1.058E-4)					
				In-115	4.41E+14y				
				(9.999E-1)					
Cd-117	2.49h	B-	1.000E+0	In-117m	116.2m		4.379E-1	1.080E+0	May-2002
				(9.151E-1)					
				In-117	43.2m				
				(8.493E-2)					
Cd-117m	3.36h	B-	1.000E+0	In-117m	116.2m		2.279E-1	2.044E+0	May-2002
				(9.983E-3)					
				In-117	43.2m				
				(9.900E-1)					
Cd-118	50.3m	B-	1.000E+0	In-118	5.0s		1.614E-1		Sep-1995
Indium									
In-107	32.4m	EC,B+	1.000E+0	Cd-107	6.50h		3.263E-1	1.531E+0	Feb-2000
In-108	58.0m	EC,B+	1.000E+0	Cd-108	stable		1.620E-1	3.916E+0	Dec-2000
In-108m	39.6m	EC,B+	1.000E+0	Cd-108	stable		7.021E-1	2.765E+0	Dec-2000
In-109	4.2h	EC,B+	1.000E+0	Cd-109	461.4d		3.345E-2	6.441E-1	May-1999
In-109m	1.34m	IT	1.000E+0	In-109	4.2h		4.159E-2	6.085E-1	May-1999
In-110	4.9h	EC,B+	1.000E+0	Cd-110	stable		1.222E-2	3.097E+0	Mar-2000
In-110m	69.1m	EC,B+	1.000E+0	Cd-110	stable		6.283E-1	1.578E+0	Mar-2000
In-111	2.8047d	EC	1.000E+0	Cd-111m	48.50m		3.482E-2	4.061E-1	Oct-2000
				(5.000E-5)					
				Cd-111	stable				
				(1.000E+0)					
In-111m	7.7m	IT	1.000E+0	In-111	2.8047d		6.746E-2	4.706E-1	Apr-1996
In-112	14.97m	EC,B+	5.600E-1	Cd-112	stable		2.452E-1	2.675E-1	Jan-1997
		B-	4.400E-1	Sn-112	stable				Jan-1997
In-112m	20.56m	IT	1.000E+0	In-112	14.97m		1.217E-1	3.474E-2	Jan-1997
In-113m	1.6579h	IT	1.000E+0	In-113	stable		1.361E-1	2.606E-1	Oct-2000
In-114	71.9s	B-	9.950E-1	Sn-114	stable		7.740E-1	2.330E-3	Jan-2003
		EC,B+	5.000E-3	Cd-114	stable				Jan-2003
In-114m	49.51d	IT	9.675E-1	In-114	71.9s		1.450E-1	8.041E-2	Jan-2003
		EC	3.250E-2	Cd-114	stable				Jan-2003
In-115	4.41E+14y	B-	1.000E+0	Sn-115	stable		1.526E-1		Feb-1999
In-115m	4.486h	IT	9.500E-1	In-115	4.41E+14y		1.748E-1	1.627E-1	Feb-1999
		B-	5.000E-2	Sn-115	stable				Feb-1999
In-116m	54.41m	B-	1.000E+0	Sn-116	stable		3.128E-1	2.469E+0	Apr-2001
In-117	43.2m	B-	1.000E+0	Sn-117m	13.76d		2.673E-1	6.939E-1	May-2002
				(3.532E-3)					
				Sn-117	stable				
				(9.965E-1)					
In-117m	116.2m	B-	5.290E-1	Sn-117	stable		4.344E-1	9.100E-2	May-2002
		IT	4.710E-1	In-117	43.2m				May-2002
In-118	5.0s	B-	1.000E+0	Sn-118	stable		1.879E+0	7.783E-2	Sep-1995
In-119	2.4m	B-	1.000E+0	Sn-119m	293.1d		6.148E-1	7.701E-1	Feb-2000
				(9.477E-3)					
				Sn-119	stable				
				(9.905E-1)					
In-119m	18.0m	B-	9.440E-1	Sn-119	stable		1.022E+0	6.604E-2	Feb-2000
		IT	5.600E-2	In-119	2.4m				Feb-2000

Table 4.1 continued from previous page (10/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.)			ENSDF date
						Alpha	Electron	Photon	
Tin									
Sn-108	10.30m	EC,B+	1.000E+0	In-108m	39.6m		2.693E-2	6.847E-1	Dec-2000
Sn-109	18.0m	EC,B+	1.000E+0	In-109m (2.827E-1)	1.34m		5.711E-2	2.206E+0	May-1999
				In-109 (7.173E-1)	4.2h				
Sn-110	4.11h	EC	1.000E+0	In-110m	69.1m		1.518E-2	2.918E-1	Mar-2000
Sn-111	35.3m	EC,B+	1.000E+0	In-111m (2.075E-3)	7.7m		1.915E-1	4.903E-1	Apr-1996
				In-111 (9.979E-1)	2.8047d				
Sn-113	115.09d	EC	1.000E+0	In-113m (1.000E+0)	1.6579h		6.269E-3	2.370E-2	Jan-1999
				In-113 (2.235E-5)	stable				
Sn-113m	21.4m	IT	9.110E-1	Sn-113	115.09d		5.880E-2	1.368E-2	Apr-1998
		EC	8.900E-2	In-113	stable				Apr-1998
Sn-117m	13.76d	IT	1.000E+0	Sn-117	stable		1.616E-1	1.581E-1	May-2002
Sn-119m	293.1d	IT	1.000E+0	Sn-119	stable		7.809E-2	1.509E-2	Feb-2000
Sn-121	27.03h	B-	1.000E+0	Sb-121	stable		1.156E-1		May-2000
Sn-121m	43.9y	IT	7.760E-1	Sn-121	27.03h		3.539E-2	5.152E-3	May-2000
		B-	2.240E-1	Sb-121	stable				May-2000
Sn-123	129.2d	B-	1.000E+0	Sb-123	stable		5.227E-1	6.892E-3	Feb-1994
Sn-123m	40.06m	B-	1.000E+0	Sb-123	stable		4.788E-1	1.407E-1	Feb-1994
Sn-125	9.64d	B-	1.000E+0	Sb-125	2.75856y		8.037E-1	3.346E-1	Jul-1999
Sn-126	2.30E+5y	B-	1.000E+0	Sb-126m	19.15m		1.380E-1	5.686E-2	Jan-2003
Sn-127	2.10h	B-	1.000E+0	Sb-127	3.85d		5.199E-1	1.908E+0	Jan-1996
Sn-128	59.07m	B-	1.000E+0	Sb-128m	10.4m		2.457E-1	6.041E-1	Dec-2001
Antimony									
Sb-114	3.49m	EC,B+	1.000E+0	Sn-114	stable		1.218E+0	2.689E+0	Jan-2003
Sb-115	32.1m	EC,B+	1.000E+0	Sn-115	stable		2.342E-1	8.894E-1	Feb-1999
Sb-116	15.8m	EC,B+	1.000E+0	Sn-116	stable		5.138E-1	2.279E+0	Apr-2001
Sb-116m	60.3m	EC,B+	1.000E+0	Sn-116	stable		1.408E-1	3.103E+0	Apr-2001
Sb-117	2.80h	EC,B+	1.000E+0	Sn-117	stable		2.982E-2	1.864E-1	May-2002
Sb-118	3.6m	EC,B+	1.000E+0	Sn-118	stable		8.730E-1	8.039E-1	Sep-1995
Sb-118m	5.00h	EC,B+	1.000E+0	Sn-118	stable		3.737E-2	2.613E+0	Sep-1995
Sb-119	38.19h	EC	1.000E+0	Sn-119	stable		2.583E-2	2.342E-2	Feb-2000
Sb-120	15.89m	EC,B+	1.000E+0	Sn-120	stable		3.077E-1	4.521E-1	Sep-2002
Sb-120m	5.76d	EC	1.000E+0	Sn-120	stable		4.493E-2	2.466E+0	Sep-2002
Sb-122	2.7238d	B-	9.759E-1	Te-122	stable		5.618E-1	4.453E-1	Jul-1994
		EC,B+	2.410E-2	Sn-122	stable				Jul-1994
Sb-124	60.20d	B-	1.000E+0	Te-124	stable		3.831E-1	1.853E+0	May-1997
Sb-124m	93s	IT	7.500E-1	Sb-124	60.20d		1.157E-1	4.401E-1	Aug-1998
		B-	2.500E-1	Te-124	stable				May-1997
Sb-124n	20.2m	IT	1.000E+0	Sb-124m	93s		2.561E-2	3.726E-4	Aug-1998
Sb-125	2.75856y	B-	1.000E+0	Te-125m (2.314E-1)	57.40d		1.010E-1	4.373E-1	Jul-1999
				Te-125 (7.686E-1)	stable				
Sb-126	12.35d	B-	1.000E+0	Te-126	stable		3.545E-1	2.755E+0	Jan-2003
Sb-126m	19.15m	B-	8.600E-1	Te-126	stable		6.322E-1	1.548E+0	Jan-2003
		IT	1.400E-1	Sb-126	12.35d				Jan-2003
Sb-127	3.85d	B-	1.000E+0	Te-127m (1.768E-1)	109d		3.160E-1	6.934E-1	Jan-1996
				Te-127 (8.232E-1)	9.35h				
Sb-128	9.01h	B-	1.000E+0	Te-128	stable		4.999E-1	3.093E+0	Dec-2001
Sb-128m	10.4m	B-	9.640E-1	Te-128	stable		9.580E-1	1.906E+0	Dec-2001
		IT	3.600E-2	Sb-128	9.01h				Dec-2001
Sb-129	4.40h	B-	1.000E+0	Te-129m (2.262E-1)	33.6d		3.953E-1	1.460E+0	May-1996
				Te-129 (7.738E-1)	69.6m				

Table 4.1 continued from previous page (11/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.)			ENSDF date
						Alpha	Electron	Photon	
Sb-130	39.5m	B-	1.000E+0	Te-130	stable		7.579E-1	3.272E+0	Jul-2001
Sb-131	23.03m	B-	1.000E+0	Te-131m (8.207E-2)	30h		5.867E-1	2.073E+0	Dec-1994
				Te-131 (9.179E-1)	25.0m				
Tellurium									
Te-114	15.2m	EC,B+	1.000E+0	Sb-114	3.49m		1.551E-1	1.282E+0	Jan-2003
Te-116	2.49h	EC,B+	1.000E+0	Sb-116	15.8m		6.178E-2	1.122E-1	Apr-2001
Te-117	62m	EC,B+	1.000E+0	Sb-117	2.80h		2.139E-1	1.549E+0	May-2002
Te-118	6.00d	EC	1.000E+0	Sb-118	3.6m		6.094E-3	1.994E-2	Sep-1995
Te-119	16.05h	EC,B+	1.000E+0	Sb-119	38.19h		1.430E-2	7.679E-1	Feb-2000
Te-119m	4.70d	EC,B+	1.000E+0	Sb-119	38.19h		1.802E-2	1.506E+0	Feb-2000
Te-121	19.16d	EC	1.000E+0	Sb-121	stable		9.786E-3	5.775E-1	May-2000
Te-121m	154d	IT	8.860E-1	Te-121	19.16d		8.168E-2	2.176E-1	May-2000
		EC	1.140E-1	Sb-121	stable				May-2000
Te-123	6.00E+14y	EC	1.000E+0	Sb-123	stable		2.752E-3	3.569E-4	Feb-1994
Te-123m	119.25d	IT	1.000E+0	Te-123	6.00E+14y		9.900E-2	1.477E-1	Feb-1994
Te-125m	57.40d	IT	1.000E+0	Te-125	stable		1.091E-1	3.598E-2	Jul-1999
Te-127	9.35h	B-	1.000E+0	I-127	stable		2.246E-1	4.880E-3	Jan-1996
Te-127m	109d	IT	9.760E-1	Te-127	9.35h		8.238E-2	1.133E-2	Jan-1996
		B-	2.400E-2	I-127	stable				Jan-1996
Te-129	69.6m	B-	1.000E+0	I-129	1.57E+7y		5.436E-1	6.254E-2	May-1996
Te-129m	33.6d	IT	6.300E-1	Te-129	69.6m		2.709E-1	3.758E-2	May-1996
		B-	3.700E-1	I-129	1.57E+7y				May-1996
Te-131	25.0m	B-	1.000E+0	I-131	8.02070d		7.122E-1	4.200E-1	Dec-1994
Te-131m	30h	B-	7.780E-1	I-131	8.02070d		1.870E-1	1.454E+0	Dec-1994
		IT	2.220E-1	Te-131	25.0m				Dec-1994
Te-132	3.204d	B-	1.000E+0	I-132	2.295h		1.108E-1	2.345E-1	Mar-1992
Te-133	12.5m	B-	1.000E+0	I-133	20.8h		6.897E-1	1.201E+0	Oct-1995
Te-133m	55.4m	B-	8.250E-1	I-133	20.8h		3.880E-1	1.860E+0	Oct-1995
		IT	1.750E-1	Te-133	12.5m				Oct-1995
Te-134	41.8m	B-	1.000E+0	I-134	52.5m		2.266E-1	8.714E-1	Jul-1994
Iodine									
I-118	13.7m	EC,B+	1.000E+0	Te-118	6.00d		1.965E+0	2.016E+0	Sep-1995
I-119	19.1m	EC,B+	1.000E+0	Te-119m (9.542E-3)	4.70d		5.116E-1	9.110E-1	Feb-2000
				Te-119 (9.905E-1)	16.05h				
I-120	81.6m	EC,B+	1.000E+0	Te-120	stable		1.168E+0	2.661E+0	Sep-2002
I-120m	53m	EC,B+	1.000E+0	Te-120	stable		9.070E-1	3.525E+0	Sep-2002
I-121	2.12h	EC,B+	1.000E+0	Te-121m (2.863E-3)	154d		6.649E-2	3.995E-1	May-2000
				Te-121 (9.971E-1)	19.16d				
I-122	3.63m	EC,B+	1.000E+0	Te-122	stable		1.106E+0	9.619E-1	Jul-1994
I-123	13.27h	EC	1.000E+0	Te-123m (4.442E-5)	119.25d		2.819E-2	1.730E-1	Feb-1994
				Te-123 (1.000E+0)	6.00E+14y				
I-124	4.1760d	EC,B+	1.000E+0	Te-124	stable		1.943E-1	1.113E+0	May-1997
I-125	59.400d	EC	1.000E+0	Te-125	stable		1.924E-2	4.284E-2	Jul-1999
I-126	12.93d	EC,B+	5.270E-1	Te-126	stable		1.606E-1	4.354E-1	Jan-2003
		B-	4.730E-1	Xe-126	stable				Jan-2003
I-128	24.99m	B-	9.310E-1	Xe-128	stable		7.463E-1	6.762E-2	Dec-2001
		EC,B+	6.900E-2	Te-128	stable				Dec-2001
I-129	1.57E+7y	B-	1.000E+0	Xe-129	stable		6.507E-2	2.518E-2	May-1996
I-130	12.36h	B-	1.000E+0	Xe-130	stable		2.786E-1	2.137E+0	Jul-2001
I-131	8.02070d	B-	1.000E+0	Xe-131m (1.176E-2)	11.84d		1.918E-1	3.828E-1	Dec-1994
				Xe-131 (9.882E-1)	stable				
I-132	2.295h	B-	1.000E+0	Xe-132	stable		4.930E-1	2.265E+0	Mar-1992

Table 4.1 continued from previous page (12/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.) Alpha	Electron	Photon	ENSDF date
I-132m	1.387h	IT	8.600E-1	I-132	2.295h		1.614E-1	3.403E-1	Mar-1992
		B-	1.400E-1	Xe-132	stable				Mar-1992
I-133	20.8h	B-	1.000E+0	Xe-133m (2.885E-2)	2.19d		4.142E-1	6.120E-1	Oct-1995
				Xe-133 (9.712E-1)	5.243d				
I-134	52.5m	B-	1.000E+0	Xe-134	stable		5.776E-1	2.595E+0	Jul-1994
I-135	6.57h	B-	1.000E+0	Xe-135m (1.657E-1)	15.29m		3.465E-1	1.581E+0	Jun-1998
				Xe-135 (8.343E-1)	9.14h				
Xenon									
Xe-120	40m	EC,B+	1.000E+0	I-120	81.6m		4.611E-2	4.015E-1	Sep-2002
Xe-121	40.1m	EC,B+	1.000E+0	I-121	2.12h		5.819E-1	1.472E+0	May-2000
Xe-122	20.1h	EC	1.000E+0	I-122	3.63m		1.000E-2	6.840E-2	Jul-1994
Xe-123	2.08h	EC,B+	1.000E+0	I-123	13.27h		1.875E-1	6.411E-1	Feb-1994
Xe-125	16.9h	EC,B+	1.000E+0	I-125	59.400d		3.505E-2	2.723E-1	Jul-1999
Xe-127	36.4d	EC	1.000E+0	I-127	stable		3.251E-2	2.806E-1	Jan-1996
Xe-127m	69.2s	IT	1.000E+0	Xe-127	36.4d		1.293E-1	1.685E-1	Jan-1996
Xe-129m	8.88d	IT	1.000E+0	Xe-129	stable		1.844E-1	5.173E-2	May-1996
Xe-131m	11.84d	IT	1.000E+0	Xe-131	stable		1.470E-1	2.058E-2	Dec-1994
Xe-133	5.243d	B-	1.000E+0	Cs-133	stable		1.379E-1	4.744E-2	Oct-1995
Xe-133m	2.19d	IT	1.000E+0	Xe-133	5.243d		1.924E-1	4.097E-2	Oct-1995
Xe-135	9.14h	B-	1.000E+0	Cs-135	2.3E+6y		3.208E-1	2.483E-1	Jun-1998
Xe-135m	15.29m	IT	9.940E-1	Xe-135	9.14h		1.008E-1	4.249E-1	Jun-1998
		B-	6.000E-3	Cs-135	2.3E+6y				Jun-1998
Xe-138	14.08m	B-	1.000E+0	Cs-138	33.41m		6.596E-1	1.122E+0	Jul-1993
Cesium									
Cs-124	30.8s	EC,B+	1.000E+0	Xe-124	stable		1.991E+0	1.161E+0	May-1997
Cs-125	45m	EC,B+	1.000E+0	Xe-125	16.9h		3.524E-1	7.550E-1	Jul-1999
Cs-126	1.64m	EC,B+	1.000E+0	Xe-126	stable		1.319E+0	1.155E+0	Jan-2003
Cs-127	6.25h	EC,B+	1.000E+0	Xe-127	36.4d		2.935E-2	4.334E-1	Jan-1996
Cs-128	3.640m	EC,B+	1.000E+0	Xe-128	stable		8.734E-1	8.916E-1	Dec-2001
Cs-129	32.06h	EC,B+	1.000E+0	Xe-129	stable		1.753E-2	2.802E-1	May-1996
Cs-130	29.21m	EC,B+	9.840E-1	Xe-130	stable		3.869E-1	5.026E-1	Jul-2001
		B-	1.600E-2	Ba-130	stable				Jul-2001
Cs-131	9.689d	EC	1.000E+0	Xe-131	stable		6.350E-3	2.316E-2	Dec-1994
Cs-132	6.479d	EC,B+	9.813E-1	Xe-132	stable		1.431E-2	7.151E-1	Mar-1992
		B-	1.870E-2	Ba-132	stable				Mar-1992
Cs-134	2.0648y	B-	1.000E+0	Ba-134	stable		1.639E-1	1.555E+0	Jul-1994
		EC	3.000E-6	Xe-134	stable				Jul-1994
Cs-134m	2.903h	IT	1.000E+0	Cs-134	2.0648y		1.122E-1	2.725E-2	Jul-1994
Cs-135	2.3E+6y	B-	1.000E+0	Ba-135	stable		8.938E-2		Jun-1998
Cs-135m	53m	IT	1.000E+0	Cs-135	2.3E+6y		3.607E-2	1.597E+0	Jun-1998
Cs-136	13.16d	B-	1.000E+0	Ba-136	stable		1.449E-1	2.128E+0	Jun-2002
Cs-137	30.1671y	B-	1.000E+0	Ba-137m (9.440E-1)	2.552m		1.884E-1	1.653E-6	Aug-1997
				Ba-137 (5.601E-2)	stable				
Cs-138	33.41m	B-	1.000E+0	Ba-138	stable		1.246E+0	2.361E+0	Jan-1998
Barium									
Ba-124	11.0m	EC,B+	1.000E+0	Cs-124	30.8s		1.743E-1	5.728E-1	May-1997
Ba-126	100m	EC,B+	1.000E+0	Cs-126	1.64m		1.784E-2	5.803E-1	Jan-2003
Ba-127	12.7m	EC,B+	1.000E+0	Cs-127	6.25h		5.971E-1	7.282E-1	Jan-1996
Ba-128	2.43d	EC	1.000E+0	Cs-128	3.640m		8.625E-3	6.651E-2	Dec-2001
Ba-129	2.23h	EC,B+	1.000E+0	Cs-129	32.06h		1.270E-1	3.331E-1	May-1996
Ba-129m	2.16h	EC,B+	1.000E+0	Cs-129	32.06h		4.186E-2	1.583E+0	May-1996
Ba-131	11.50d	EC	1.000E+0	Cs-131	9.689d		4.551E-2	4.763E-1	Dec-1994
Ba-131m	14.6m	IT	1.000E+0	Ba-131	11.50d		1.102E-1	7.734E-2	Dec-1994
Ba-133	10.52y	EC	1.000E+0	Cs-133	stable		5.532E-2	4.030E-1	Oct-1995

Table 4.1 continued from previous page (13/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.) Alpha	Electron	Photon	ENSDF date
Ba-133m	38.9h	IT	9.999E-1	Ba-133	10.52y		2.259E-1	6.856E-2	Oct-1995
		EC	9.600E-5	Cs-133	stable				Oct-1995
Ba-135m	28.7h	IT	1.000E+0	Ba-135	stable		2.080E-1	6.023E-2	Jun-1998
Ba-137m	2.552m	IT	1.000E+0	Ba-137	stable		6.534E-2	5.963E-1	Aug-1997
Ba-139	83.06m	B-	1.000E+0	La-139	stable		9.012E-1	4.574E-2	Apr-2001
Ba-140	12.752d	B-	1.000E+0	La-140	1.6781d		3.202E-1	1.826E-1	Jan-1995
Ba-141	18.27m	B-	1.000E+0	La-141	3.92h		9.624E-1	9.271E-1	Mar-2001
Ba-142	10.6m	B-	1.000E+0	La-142	91.1m		4.141E-1	1.047E+0	Mar-2000
Lanthanum									
La-129	11.6m	EC,B+	1.000E+0	Ba-129m (7.616E-2)	2.16h		6.135E-1	9.212E-1	May-1996
				Ba-129 (9.238E-1)	2.23h				
La-130	8.7m	EC,B+	1.000E+0	Ba-130	stable		1.111E+0	2.232E+0	Jul-2001
La-131	59m	EC,B+	1.000E+0	Ba-131	11.50d		1.963E-1	6.633E-1	Dec-1994
La-132	4.8h	EC,B+	1.000E+0	Ba-132	stable		5.693E-1	1.995E+0	Mar-1992
La-132m	24.3m	IT	7.600E-1	La-132	4.8h		1.126E-1	6.706E-1	Mar-1992
		EC,B+	2.400E-1	Ba-132	stable				Mar-1992
La-133	3.912h	EC,B+	1.000E+0	Ba-133	10.52y		5.034E-2	1.605E-1	Oct-1995
La-134	6.45m	EC,B+	1.000E+0	Ba-134	stable		7.647E-1	7.196E-1	Jul-1994
La-135	19.5h	EC,B+	1.000E+0	Ba-135	stable		6.692E-3	3.607E-2	Jun-1998
La-137	6.0E+4y	EC	1.000E+0	Ba-137	stable		6.484E-3	2.503E-2	Aug-1997
La-138	1.02E+11y	EC	6.640E-1	Ba-138	stable		3.772E-2	1.232E+0	Jan-1998
		B-	3.360E-1	Ce-138	stable				Jul-1993
La-140	1.6781d	B-	1.000E+0	Ce-140	stable		5.346E-1	2.308E+0	Jan-1995
La-141	3.92h	B-	1.000E+0	Ce-141	32.508d		9.876E-1	2.679E-2	Mar-2001
La-142	91.1m	B-	1.000E+0	Ce-142	stable		8.697E-1	2.374E+0	Mar-2000
La-143	14.2m	B-	1.000E+0	Ce-143	33.039h		1.299E+0	2.631E-1	Jan-2002
Cerium									
Ce-130	22.9m	EC,B+	1.000E+0	La-130	8.7m		7.380E-2	5.003E-1	Jul-2001
Ce-131	10.2m	EC,B+	1.000E+0	La-131	59m		6.153E-1	1.627E+0	Dec-1994
Ce-132	3.51h	EC	1.000E+0	La-132	4.8h		1.804E-2	2.727E-1	Mar-1992
Ce-133	97m	EC,B+	1.000E+0	La-133	3.912h		3.817E-1	5.430E-1	Oct-1995
Ce-133m	4.9h	EC,B+	1.000E+0	La-133	3.912h		7.393E-2	1.737E+0	Oct-1995
Ce-134	3.16d	EC	1.000E+0	La-134	6.45m		7.196E-3	2.810E-2	Jul-1994
Ce-135	17.7h	EC,B+	1.000E+0	La-135	19.5h		2.960E-2	8.237E-1	Jun-1998
Ce-137	9.0h	EC,B+	1.000E+0	La-137	6.0E+4y		1.648E-2	3.883E-2	Nov-1994
Ce-137m	34.4h	IT	9.922E-1	Ce-137	9.0h		2.067E-1	5.578E-2	Nov-1994
		EC	7.800E-3	La-137	6.0E+4y				Nov-1994
Ce-139	137.641d	EC	1.000E+0	La-139	stable		3.551E-2	1.599E-1	Apr-2001
Ce-141	32.508d	B-	1.000E+0	Pr-141	stable		1.710E-1	7.680E-2	Mar-2001
Ce-143	33.039h	B-	1.000E+0	Pr-143	13.57d		4.364E-1	2.796E-1	Jan-2002
Ce-144	284.91d	B-	1.000E+0	Pr-144m (9.770E-3)	7.2m		9.162E-2	1.937E-2	Aug-2001
				Pr-144 (9.902E-1)	17.28m				
Praseodymium									
Pr-134	11m	EC,B+	1.000E+0	Ce-134	3.16d		1.080E+0	3.150E+0	Jul-1994
Pr-134m	17m	EC,B+	1.000E+0	Ce-134	3.16d		1.527E+0	2.310E+0	Jul-1994
Pr-135	24m	EC,B+	1.000E+0	Ce-135	17.7h		5.793E-1	8.741E-1	Feb-1988
Pr-136	13.1m	EC,B+	1.000E+0	Ce-136	stable		7.545E-1	2.146E+0	Jun-2002
Pr-137	1.28h	EC,B+	1.000E+0	Ce-137	9.0h		1.947E-1	3.693E-1	Nov-1994
Pr-138	1.45m	EC,B+	1.000E+0	Ce-138	stable		1.162E+0	8.153E-1	Jul-1993
Pr-138m	2.12h	EC,B+	1.000E+0	Ce-138	stable		2.208E-1	2.478E+0	Jul-1993
Pr-139	4.41h	EC,B+	1.000E+0	Ce-139	137.641d		4.783E-2	1.298E-1	Apr-2001
Pr-140	3.39m	EC,B+	1.000E+0	Ce-140	stable		5.516E-1	5.467E-1	Jan-1995
Pr-142	19.12h	B-	9.998E-1	Nd-142	stable		8.098E-1	5.811E-2	Mar-2000
		EC	1.640E-4	Ce-142	stable				Mar-2000
Pr-142m	14.6m	IT	1.000E+0	Pr-142	19.12h		3.623E-3	1.066E-4	Mar-2000
Pr-143	13.57d	B-	1.000E+0	Nd-143	stable		3.150E-1	8.907E-9	Jan-2002

Table 4.1 continued from previous page (14/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.)			ENSDF date
						Alpha	Electron	Photon	
Pr-144	17.28m	B-	1.000E+0	Nd-144	2.29E+15y		1.208E+0	2.886E-2	Aug-2001
Pr-144m	7.2m	IT	9.993E-1	Pr-144	17.28m		4.747E-2	1.335E-2	Aug-2001
		B-	7.000E-4	Nd-144	2.29E+15y				Aug-2001
Pr-145	5.984h	B-	1.000E+0	Nd-145	stable		6.757E-1	1.862E-2	May-1993
Pr-146	24.15m	B-	1.000E+0	Nd-146	stable		1.328E+0	1.010E+0	Dec-1997
Pr-147	13.4m	B-	1.000E+0	Nd-147	10.98d		8.896E-1	4.887E-1	Aug-1992
Neodymium									
Nd-135	12.4m	EC,B+	1.000E+0	Pr-135	24m		1.055E+0	1.262E+0	Jun-1998
Nd-136	50.65m	EC,B+	1.000E+0	Pr-136	13.1m		8.046E-2	2.793E-1	Jun-2002
Nd-137	38.5m	EC,B+	1.000E+0	Pr-137	1.28h		3.247E-1	1.179E+0	Nov-1994
Nd-138	5.04h	EC	1.000E+0	Pr-138	1.45m		8.187E-3	4.383E-2	Jul-1993
Nd-139	29.7m	EC,B+	1.000E+0	Pr-139	4.41h		2.084E-1	4.431E-1	Apr-2001
Nd-139m	5.50h	EC,B+	8.820E-1	Pr-139	4.41h		7.951E-2	1.585E+0	Apr-2001
		IT	1.180E-1	Nd-139	29.7m				Apr-2001
Nd-140	3.37d	EC	1.000E+0	Pr-140	3.39m		6.936E-3	2.875E-2	Jan-1995
Nd-141	2.49h	EC,B+	1.000E+0	Pr-141	stable		1.649E-2	7.648E-2	Mar-2001
Nd-141m	62.0s	IT	9.997E-1	Nd-141	2.49h		6.219E-2	6.947E-1	Mar-2001
		EC,B+	3.200E-4	Pr-141	stable				Mar-2001
Nd-144	2.29E+15y	A	1.000E+0	Ce-140	stable	1.852E+0			May-1998
Nd-147	10.98d	B-	1.000E+0	Pm-147	2.6234y		2.702E-1	1.408E-1	Aug-1992
Nd-149	1.728h	B-	1.000E+0	Pm-149	53.08h		5.042E-1	3.713E-1	Jan-1995
Nd-151	12.44m	B-	1.000E+0	Pm-151	28.40h		6.195E-1	8.518E-1	Mar-1997
Nd-152	11.4m	B-	1.000E+0	Pm-152	4.12m		3.314E-1	1.644E-1	Jan-1997
Promethium									
Pm-140	9.2s	EC,B+	1.000E+0	Nd-140	3.37d		2.043E+0	1.051E+0	Jan-1995
Pm-141	20.90m	EC,B+	1.000E+0	Nd-141m (1.665E-3)	62.0s		6.054E-1	7.349E-1	Mar-2001
				Nd-141 (9.983E-1)	2.49h				
Pm-142	40.5s	EC,B+	1.000E+0	Nd-142	stable		1.312E+0	8.561E-1	Mar-2000
Pm-143	265d	EC	1.000E+0	Nd-143	stable		8.277E-3	3.157E-1	Jan-2002
Pm-144	363d	EC	1.000E+0	Nd-144	2.29E+15y		1.713E-2	1.563E+0	Aug-2001
Pm-145	17.7y	EC	1.000E+0	Nd-145	stable	6.322E-9	1.258E-2	3.151E-2	May-1993
		A	2.800E-9	Pr-141	stable				Mar-2001
Pm-146	5.53y	EC	6.600E-1	Nd-146	stable		9.410E-2	7.512E-1	Dec-1997
		B-	3.400E-1	Sm-146	1.03E+8y				Dec-1997
Pm-147	2.6234y	B-	1.000E+0	Sm-147	1.060E+11y		6.193E-2	4.390E-6	Aug-1992
Pm-148	5.368d	B-	1.000E+0	Sm-148	7E+15y		7.284E-1	5.743E-1	Apr-2000
Pm-148m	41.29d	B-	9.580E-1	Sm-148	7E+15y		1.699E-1	1.992E+0	Apr-2000
		IT	4.200E-2	Pm-148	5.368d				Apr-2000
Pm-149	53.08h	B-	1.000E+0	Sm-149	stable		3.650E-1	1.189E-2	Jan-1995
Pm-150	2.68h	B-	1.000E+0	Sm-150	stable		8.101E-1	1.470E+0	Apr-1996
Pm-151	28.40h	B-	1.000E+0	Sm-151	90y		3.048E-1	3.289E-1	Mar-1997
Pm-152	4.12m	B-	1.000E+0	Sm-152	stable		1.328E+0	2.866E-1	Jan-1997
Samarium									
Sm-140	14.82m	EC,B+	1.000E+0	Pm-140	9.2s		1.710E-1	5.677E-1	Jan-1995
Sm-141	10.2m	EC,B+	1.000E+0	Pm-141	20.90m		7.126E-1	1.409E+0	Mar-2001
Sm-141m	22.6m	EC,B+	9.969E-1	Pm-141	20.90m		3.995E-1	1.949E+0	Mar-2001
		IT	3.100E-3	Sm-141	10.2m				Mar-2001
Sm-142	72.49m	EC,B+	1.000E+0	Pm-142	40.5s		4.459E-2	1.105E-1	Mar-2000
Sm-145	340d	EC	1.000E+0	Pm-145	17.7y		3.072E-2	6.424E-2	May-1993
Sm-146	1.03E+8y	A	1.000E+0	Nd-142	stable	2.460E+0			Mar-2000
Sm-147	1.060E+11y	A	1.000E+0	Nd-143	stable	2.248E+0			Jan-2002
Sm-148	7E+15y	A	1.000E+0	Nd-144	2.29E+15y	1.932E+0			Aug-2001
Sm-151	90y	B-	1.000E+0	Eu-151	stable		1.997E-2	1.573E-5	Mar-1997
Sm-153	46.50h	B-	1.000E+0	Eu-153	stable		2.699E-1	6.426E-2	Apr-1998
Sm-155	22.3m	B-	1.000E+0	Eu-155	4.7611y		5.674E-1	1.029E-1	Jul-1994
Sm-156	9.4h	B-	1.000E+0	Eu-156	15.19d		2.093E-1	1.150E-1	Mar-1992

Table 4.1 continued from previous page (15/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.)			ENSDF date
						Alpha	Electron	Photon	
Europium									
Eu-145	5.93d	EC,B+	1.000E+0	Sm-145	340d		2.539E-2	1.280E+0	Aug-2002
Eu-146	4.61d	EC,B+	1.000E+0	Sm-146	1.03E+8y		4.551E-2	2.401E+0	Dec-1997
Eu-147	24.1d	EC,B+	1.000E+0	Sm-147	1.060E+11y	6.399E-5	4.309E-2	4.721E-1	Aug-1992
		A	2.200E-5	Pm-143	265d				Jan-2002
Eu-148	54.5d	EC,B+	1.000E+0	Sm-148	7E+15y	2.465E-8	2.241E-2	2.229E+0	Apr-2000
		A	9.400E-9	Pm-144	363d				Aug-2001
Eu-149	93.1d	EC	1.000E+0	Sm-149	stable		2.411E-2	6.612E-2	Jan-1995
Eu-150	36.9y	EC,B+	1.000E+0	Sm-150	stable		2.847E-2	1.555E+0	Aug-1996
Eu-150m	12.8h	B-	8.900E-1	Gd-150	1.79E+6y		3.122E-1	4.936E-2	Apr-1996
		EC,B+	1.100E-1	Sm-150	stable				Oct-1995
Eu-152	13.537y	EC,B+	7.210E-1	Sm-152	stable		1.286E-1	1.176E+0	Jan-1997
		B-	2.790E-1	Gd-152	1.08E+14y				Jan-1997
Eu-152m	9.3116h	B-	7.200E-1	Gd-152	1.08E+14y		5.060E-1	2.963E-1	Jan-1997
		EC,B+	2.800E-1	Sm-152	stable				Jan-1997
Eu-152n	96m	IT	1.000E+0	Eu-152	13.537y		6.665E-2	7.527E-2	Jan-1997
Eu-154	8.593y	B-	9.998E-1	Gd-154	stable		2.730E-1	1.249E+0	Dec-1998
		EC	2.000E-4	Sm-154	stable				Dec-1998
Eu-154m	46.0m	IT	1.000E+0	Eu-154	8.593y		7.450E-2	7.061E-2	Dec-1998
Eu-155	4.7611y	B-	1.000E+0	Gd-155	stable		6.471E-2	6.118E-2	Jul-1994
Eu-156	15.19d	B-	1.000E+0	Gd-156	stable		4.579E-1	1.234E+0	Aug-2003
Eu-157	15.18h	B-	1.000E+0	Gd-157	stable		3.961E-1	2.930E-1	Aug-1996
Eu-158	45.9m	B-	1.000E+0	Gd-158	stable		8.920E-1	1.298E+0	Apr-1996
Eu-159	18.1m	B-	1.000E+0	Gd-159	18.479h		8.923E-1	3.032E-1	Aug-1994
Gadolinium									
Gd-145	23.0m	EC,B+	1.000E+0	Eu-145	5.93d		3.456E-1	2.424E+0	May-1993
Gd-146	48.27d	EC	1.000E+0	Eu-146	4.61d		1.274E-1	2.526E-1	Dec-1997
Gd-147	38.1h	EC,B+	1.000E+0	Eu-147	24.1d		6.166E-2	1.403E+0	Aug-1992
Gd-148	74.6y	A	1.000E+0	Sm-144	stable	3.183E+0			Aug-1989
Gd-149	9.28d	EC,B+	1.000E+0	Eu-149	93.1d		6.859E-2	5.292E-1	Jan-1995
Gd-150	1.79E+6y	A	1.000E+0	Sm-146	1.03E+8y	2.734E+0			Dec-1997
Gd-151	124d	EC	1.000E+0	Eu-151	stable	2.582E-8	3.938E-2	7.078E-2	Mar-1997
		A	1.000E-8	Sm-147	1.060E+11y				Jun-1997
Gd-152	1.08E+14y	A	1.000E+0	Sm-148	7E+15y	2.147E+0			Apr-2000
Gd-153	240.4d	EC	1.000E+0	Eu-153	stable		4.376E-2	1.057E-1	Apr-1998
Gd-159	18.479h	B-	1.000E+0	Tb-159	stable		3.096E-1	5.388E-2	Aug-1994
Terbium									
Tb-147	1.64h	EC,B+	1.000E+0	Gd-147	38.1h		2.810E-1	2.185E+0	Aug-1992
Tb-148	60m	EC,B+	1.000E+0	Gd-148	74.6y		8.411E-1	2.359E+0	Apr-2000
Tb-149	4.118h	EC,B+	8.330E-1	Gd-149	9.28d	6.627E-1	8.706E-2	1.361E+0	Nov-2000
		A	1.670E-1	Eu-145	5.93d				May-1993
Tb-150	3.48h	EC,B+	1.000E+0	Gd-150	1.79E+6y	2.444E-5	2.890E-1	2.440E+0	Apr-1996
		A	7.000E-6	Eu-146	4.61d				Dec-1997
Tb-151	17.609h	EC,B+	1.000E+0	Gd-151	124d	3.234E-4	7.997E-2	9.941E-1	Mar-1997
		A	9.500E-5	Eu-147	24.1d				Jun-1997
Tb-151m	25s	IT	9.340E-1	Tb-151	17.609h		7.927E-2	8.080E-2	Mar-1997
		EC,B+	6.600E-2	Gd-151	124d				Mar-1997
Tb-152	17.5h	EC,B+	1.000E+0	Gd-152	1.08E+14y		2.503E-1	1.493E+0	Jan-1997
Tb-153	2.34d	EC,B+	1.000E+0	Gd-153	240.4d		4.811E-2	3.318E-1	Apr-1998
Tb-154	21.5h	EC,B+	1.000E+0	Gd-154	stable		6.809E-2	2.283E+0	Dec-1998
Tb-155	5.32d	EC	1.000E+0	Gd-155	stable		4.341E-2	1.777E-1	Jul-1994
Tb-156	5.35d	EC	1.000E+0	Gd-156	stable		8.352E-2	1.937E+0	Aug-2003
Tb-156m	24.4h	IT	1.000E+0	Tb-156	5.35d		1.706E-2	3.696E-2	Aug-2003
Tb-156n	5.3h	IT	1.000E+0	Tb-156	5.35d		8.739E-2	4.768E-3	Aug-2003
Tb-157	71y	EC	1.000E+0	Gd-157	stable		5.734E-3	5.655E-3	Sep-1997
Tb-158	180y	EC	8.340E-1	Gd-158	stable		1.117E-1	8.048E-1	Apr-1996
		B-	1.660E-1	Dy-158	stable				Apr-1996
Tb-160	72.3d	B-	1.000E+0	Dy-160	stable		2.593E-1	1.126E+0	Jan-1997
Tb-161	6.906d	B-	1.000E+0	Dy-161	stable		2.025E-1	3.652E-2	Oct-2000
Tb-163	19.5m	B-	1.000E+0	Dy-163	stable		3.597E-1	7.887E-1	Feb-2000

Table 4.1 continued from previous page (16/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.)			ENSDF date
						Alpha	Electron	Photon	
Dysprosium									
Dy-151	17.9m	EC,B+	9.440E-1	Tb-151m (4.102E-1)	25s	2.279E-1	6.527E-2	1.372E+0	Mar-1997
				Tb-151 (5.338E-1)	17.609h				
		A	5.600E-2	Gd-147	38.1h				Jun-1997
Dy-152	2.38h	EC	9.990E-1	Tb-152	17.5h	3.629E-3	1.295E-2	2.867E-1	Jan-1997
		A	1.000E-3	Gd-148	74.6y				Apr-2000
Dy-153	6.4h	EC,B+	1.000E+0	Tb-153	2.34d	3.258E-4	9.012E-2	8.746E-1	Apr-1998
		A	9.400E-5	Gd-149	9.28d				Nov-2000
Dy-154	3.0E+6y	A	1.000E+0	Gd-150	1.79E+6y	2.870E+0			May-1998
Dy-155	9.9h	EC,B+	1.000E+0	Tb-155	5.32d		2.723E-2	6.687E-1	Jul-1994
Dy-157	8.14h	EC	1.000E+0	Tb-157	71y		1.378E-2	3.472E-1	Aug-1996
Dy-159	144.4d	EC	1.000E+0	Tb-159	stable		1.307E-2	4.562E-2	Aug-1994
Dy-165	2.334h	B-	1.000E+0	Ho-165	stable		4.473E-1	2.674E-2	Mar-1992
Dy-166	81.6h	B-	1.000E+0	Ho-166	26.80h		1.667E-1	4.333E-2	Nov-1992
Holmium									
Ho-154	11.76m	EC,B+	9.998E-1	Dy-154	3.0E+6y	7.477E-4	1.093E+0	1.882E+0	Dec-1998
		A	1.900E-4	Tb-150	3.48h				Oct-1995
Ho-155	48m	EC,B+	1.000E+0	Dy-155	9.9h		2.176E-1	6.142E-1	Jul-1994
Ho-156	56m	EC,B+	1.000E+0	Dy-156	stable		6.655E-1	2.106E+0	Aug-2003
Ho-157	12.6m	EC,B+	1.000E+0	Dy-157	8.14h		9.289E-2	5.835E-1	Aug-1996
Ho-159	33.05m	EC,B+	1.000E+0	Dy-159	144.4d		5.759E-2	3.857E-1	Aug-1994
Ho-160	25.6m	EC,B+	1.000E+0	Dy-160	stable		7.028E-2	1.695E+0	Jan-1997
Ho-161	2.48h	EC	1.000E+0	Dy-161	stable		3.360E-2	5.821E-2	Oct-2000
Ho-162	15.0m	EC,B+	1.000E+0	Dy-162	stable		5.985E-2	1.640E-1	Sep-1999
Ho-162m	67.0m	IT	6.200E-1	Ho-162	15.0m		7.394E-2	5.614E-1	Sep-1999
		EC,B+	3.800E-1	Dy-162	stable				Sep-1999
Ho-163	4570y	EC	1.000E+0	Dy-163	stable		5.160E-4	6.255E-5	Feb-2000
Ho-164	29m	EC	6.000E-1	Dy-164	stable		1.470E-1	2.974E-2	Jul-2001
		B-	4.000E-1	Er-164	stable				Jul-2001
Ho-164m	38.0m	IT	1.000E+0	Ho-164	29m		9.264E-2	4.724E-2	Jul-2001
Ho-166	26.80h	B-	1.000E+0	Er-166	stable		6.963E-1	3.007E-2	Nov-1992
Ho-166m	1.20E+3y	B-	1.000E+0	Er-166	stable		1.497E-1	1.625E+0	Nov-1992
Ho-167	3.1h	B-	1.000E+0	Er-167	stable		2.329E-1	3.661E-1	Aug-2000
Erbium									
Er-156	19.5m	EC	1.000E+0	Ho-156	56m		9.432E-2	6.782E-2	Aug-2003
Er-159	36m	EC,B+	1.000E+0	Ho-159	33.05m		7.380E-2	9.635E-1	Aug-1994
Er-161	3.21h	EC,B+	1.000E+0	Ho-161	2.48h		5.222E-2	9.905E-1	Oct-2000
Er-163	75.0m	EC,B+	1.000E+0	Ho-163	4570y		8.090E-3	4.032E-2	Feb-2000
Er-165	10.36h	EC	1.000E+0	Ho-165	stable		7.991E-3	3.788E-2	Mar-1992
Er-167m	2.269s	IT	1.000E+0	Er-167	stable		1.111E-1	9.667E-2	Aug-2000
Er-169	9.40d	B-	1.000E+0	Tm-169	stable		1.035E-1	6.033E-5	Dec-1991
Er-171	7.516h	B-	1.000E+0	Tm-171	1.92y		4.205E-1	3.731E-1	Sep-2002
Er-172	49.3h	B-	1.000E+0	Tm-172	63.6h		1.387E-1	5.166E-1	Sep-1995
Thulium									
Tm-161	30.2m	EC,B+	1.000E+0	Er-161	3.21h		2.308E-1	1.299E+0	Oct-2000
Tm-162	21.70m	EC,B+	1.000E+0	Er-162	stable		5.648E-1	1.916E+0	Sep-1999
Tm-163	1.810h	EC,B+	1.000E+0	Er-163	75.0m		7.161E-2	1.320E+0	Feb-2000
Tm-164	2.0m	EC,B+	1.000E+0	Er-164	stable		5.994E-1	7.760E-1	Jul-2001
Tm-165	30.06h	EC,B+	1.000E+0	Er-165	10.36h		6.372E-2	5.625E-1	Mar-1992
Tm-166	7.70h	EC,B+	1.000E+0	Er-166	stable		8.919E-2	1.977E+0	Nov-1992
Tm-167	9.25d	EC	1.000E+0	Er-167	stable		1.332E-1	1.482E-1	Aug-2000
Tm-168	93.1d	EC,B+	9.999E-1	Er-168	stable		8.471E-2	1.243E+0	Jul-1994
		B-	1.000E-4	Yb-168	stable				Jul-1994
Tm-170	128.6d	B-	9.987E-1	Yb-170	stable		3.280E-1	4.146E-3	Nov-2002
		EC	1.310E-3	Er-170	stable				Nov-2002
Tm-171	1.92y	B-	1.000E+0	Yb-171	stable		2.548E-2	6.244E-4	Sep-2002
Tm-172	63.6h	B-	1.000E+0	Yb-172	stable		5.327E-1	4.744E-1	Sep-1995

Table 4.1 continued from previous page (17/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.)			ENSDF date
						Alpha	Electron	Photon	
Tm-173	8.24h	B-	1.000E+0	Yb-173	stable		3.103E-1	3.885E-1	Sep-1995
Tm-175	15.2m	B-	1.000E+0	Yb-175	4.185d		5.196E-1	1.085E+0	Nov-1993
Ytterbium									
Yb-162	18.87m	EC,B+	1.000E+0	Tm-162	21.70m		3.736E-2	2.519E-1	Sep-1999
Yb-163	11.05m	EC,B+	1.000E+0	Tm-163	1.810h		2.718E-1	7.277E-1	Jan-1997
Yb-164	75.8m	EC	1.000E+0	Tm-164	2.0m		9.455E-3	5.420E-2	Jul-2001
Yb-165	9.9m	EC,B+	1.000E+0	Tm-165	30.06h		1.518E-1	3.390E-1	Mar-1992
Yb-166	56.7h	EC	1.000E+0	Tm-166	7.70h		4.174E-2	8.676E-2	Nov-1992
Yb-167	17.5m	EC,B+	1.000E+0	Tm-167	9.25d		9.520E-2	2.696E-1	Aug-2000
Yb-169	32.026d	EC	1.000E+0	Tm-169	stable		1.471E-1	3.302E-1	Dec-1991
Yb-175	4.185d	B-	1.000E+0	Lu-175	stable		1.308E-1	3.910E-2	Nov-1993
Yb-177	1.911h	B-	1.000E+0	Lu-177	6.647d		4.358E-1	1.952E-1	May-1993
Yb-178	74m	B-	1.000E+0	Lu-178	28.4m		1.925E-1	3.813E-2	Aug-1994
Lutetium									
Lu-165	10.74m	EC,B+	1.000E+0	Yb-165	9.9m		3.751E-1	1.110E+0	Mar-1992
Lu-167	51.5m	EC,B+	1.000E+0	Yb-167	17.5m		1.109E-1	1.692E+0	Aug-2000
Lu-169	34.06h	EC,B+	1.000E+0	Yb-169	32.026d		4.769E-2	1.317E+0	Dec-1991
Lu-170	2.012d	EC,B+	1.000E+0	Yb-170	stable		5.847E-2	2.564E+0	Nov-2002
Lu-171	8.24d	EC,B+	1.000E+0	Yb-171	stable		9.278E-2	6.503E-1	Sep-2002
Lu-172	6.70d	EC,B+	1.000E+0	Yb-172	stable		1.154E-1	1.956E+0	Sep-1995
Lu-172m	3.7m	IT	1.000E+0	Lu-172	6.70d		4.039E-2	1.514E-3	Sep-1995
Lu-173	1.37y	EC	1.000E+0	Yb-173	stable		5.260E-2	1.834E-1	Sep-1995
Lu-174	3.31y	EC,B+	1.000E+0	Yb-174	stable		4.583E-2	1.163E-1	Aug-1999
Lu-174m	142d	IT	9.938E-1	Lu-174	3.31y		1.188E-1	6.260E-2	Aug-1999
		EC	6.200E-3	Yb-174	stable				Aug-1999
Lu-176	3.85E+10y	B-	1.000E+0	Hf-176	stable		3.026E-1	4.799E-1	Jul-1998
Lu-176m	3.635h	B-	9.991E-1	Hf-176	stable		4.783E-1	1.461E-2	Jul-1998
		EC	9.500E-4	Yb-176	stable				Jul-1998
Lu-177	6.647d	B-	1.000E+0	Hf-177	stable		1.479E-1	3.510E-2	May-1993
Lu-177m	160.4d	B-	7.830E-1	Hf-177	stable		2.687E-1	1.000E+0	May-1993
		IT	2.170E-1	Lu-177	6.647d				May-1993
Lu-178	28.4m	B-	1.000E+0	Hf-178	stable		7.561E-1	1.256E-1	Aug-1994
Lu-178m	23.1m	B-	1.000E+0	Hf-178	stable		4.907E-1	1.048E+0	Aug-1994
Lu-179	4.59h	B-	1.000E+0	Hf-179	stable		4.869E-1	2.977E-2	Dec-1994
Hafnium									
Hf-170	16.01h	EC	1.000E+0	Lu-170	2.012d		6.871E-2	4.403E-1	Nov-2002
Hf-172	1.87y	EC	1.000E+0	Lu-172m	3.7m		8.284E-2	1.062E-1	Sep-1995
Hf-173	23.6h	EC,B+	1.000E+0	Lu-173	1.37y		5.236E-2	3.970E-1	Sep-1995
Hf-174	2.0E+15y	A	1.000E+0	Yb-170	stable	2.437E+0			Nov-2002
Hf-175	70d	EC	1.000E+0	Lu-175	stable		4.503E-2	3.534E-1	Nov-1993
Hf-177m	51.4m	IT	1.000E+0	Hf-177	stable		5.078E-1	2.286E+0	May-1993
Hf-178m	31y	IT	1.000E+0	Hf-178	stable		2.113E-1	2.238E+0	Aug-1994
Hf-179m	25.05d	IT	1.000E+0	Hf-179	stable		1.897E-1	9.207E-1	Dec-1994
Hf-180m	5.5h	IT	9.970E-1	Hf-180	stable		1.437E-1	9.884E-1	Apr-1994
		B-	3.000E-3	Ta-180m	stable				Apr-1994
Hf-181	42.39d	B-	1.000E+0	Ta-181	stable		2.052E-1	5.324E-1	Jan-1992
Hf-182	9E+6y	B-	1.000E+0	Ta-182	114.43d		6.325E-2	2.397E-1	Mar-1995
Hf-182m	61.5m	B-	5.800E-1	Ta-182	114.43d		2.441E-1	9.135E-1	Mar-1995
		IT	4.200E-1	Hf-182	9E+6y				Aug-1988
Hf-183	1.067h	B-	1.000E+0	Ta-183	5.1d		4.478E-1	7.749E-1	Jul-1991
Hf-184	4.12h	B-	1.000E+0	Ta-184	8.7h		4.787E-1	2.387E-1	Feb-1990
Tantalum									
Ta-172	36.8m	EC,B+	1.000E+0	Hf-172	1.87y		5.513E-1	1.697E+0	Sep-1995
Ta-173	3.14h	EC,B+	1.000E+0	Hf-173	23.6h		1.686E-1	5.824E-1	Sep-1995
Ta-174	1.14h	EC,B+	1.000E+0	Hf-174	2.0E+15y		4.670E-1	9.767E-1	Aug-1999
Ta-175	10.5h	EC,B+	1.000E+0	Hf-175	70d		6.633E-2	1.113E+0	Nov-1993
Ta-176	8.09h	EC,B+	1.000E+0	Hf-176	stable		8.493E-2	2.232E+0	Jul-1998

Table 4.1 continued from previous page (18/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.)			ENSDF date
						Alpha	Electron	Photon	
Ta-177	56.56h	EC	1.000E+0	Hf-177	stable		2.396E-2	6.775E-2	May-1993
Ta-178	9.31m	EC,B+	1.000E+0	Hf-178	stable		3.912E-2	1.218E-1	Aug-1994
Ta-178m	2.36h	EC	1.000E+0	Hf-178	stable		1.616E-1	1.156E+0	Aug-1994
Ta-179	1.82y	EC	1.000E+0	Hf-179	stable		7.800E-3	2.561E-2	Dec-1994
Ta-180	8.152h	EC	8.600E-1	Hf-180	stable		5.651E-2	4.825E-2	Apr-1994
		B-	1.400E-1	W-180	stable				Apr-1994
Ta-182	114.43d	B-	1.000E+0	W-182	stable		2.105E-1	1.292E+0	Aug-1988
Ta-182m	15.84m	IT	1.000E+0	Ta-182	114.43d		2.665E-1	2.659E-1	Aug-1988
Ta-183	5.1d	B-	1.000E+0	W-183	stable		3.537E-1	2.963E-1	Jul-1991
Ta-184	8.7h	B-	1.000E+0	W-184	stable		5.426E-1	1.573E+0	Feb-1990
Ta-185	49.4m	B-	1.000E+0	W-185	75.1d		7.416E-1	1.547E-1	Mar-1995
Ta-186	10.5m	B-	1.000E+0	W-186	stable		1.071E+0	1.420E+0	Apr-1999
Tungsten									
W-177	132m	EC,B+	1.000E+0	Ta-177	56.56h		9.698E-2	9.185E-1	May-1993
W-178	21.6d	EC	1.000E+0	Ta-178	9.31m		7.499E-3	1.638E-2	Aug-1994
W-179	37.05m	EC	1.000E+0	Ta-179	1.82y		3.257E-2	5.540E-2	May-2000
W-179m	6.40m	IT	9.972E-1	W-179	37.05m		1.661E-1	5.606E-2	Dec-1994
		EC	2.800E-3	Ta-179	1.82y				May-2000
W-181	121.2d	EC	1.000E+0	Ta-181	stable		1.289E-2	4.042E-2	Feb-1991
W-185	75.1d	B-	1.000E+0	Re-185	stable		1.270E-1	5.176E-5	Mar-1995
W-187	23.72h	B-	1.000E+0	Re-187	4.12E+10y		2.995E-1	4.483E-1	Feb-1991
W-188	69.78d	B-	1.000E+0	Re-188	17.0040h		9.967E-2	1.895E-3	Apr-2002
W-190	30.0m	B-	1.000E+0	Re-190	3.1m		4.771E-1	1.511E-1	Dec-1990
Rhenium									
Re-178	13.2m	EC,B+	1.000E+0	W-178	21.6d		6.192E-1	1.709E+0	Aug-1994
Re-179	19.5m	EC,B+	1.000E+0	W-179m (2.392E-1)	6.40m		6.683E-2	1.084E+0	Dec-1994
				W-179 (7.608E-1)	37.05m				
Re-180	2.44m	EC,B+	1.000E+0	W-180	stable		1.720E-1	1.203E+0	Apr-1994
Re-181	19.9h	EC,B+	1.000E+0	W-181	121.2d		1.360E-1	8.044E-1	Feb-1991
Re-182	64.0h	EC	1.000E+0	W-182	stable		2.045E-1	1.798E+0	Jun-1997
Re-182m	12.7h	EC,B+	1.000E+0	W-182	stable		9.223E-2	1.221E+0	Jun-1997
Re-183	70.0d	EC	1.000E+0	W-183	stable		1.093E-1	1.575E-1	Jul-1991
Re-184	38.0d	EC,B+	1.000E+0	W-184	stable		5.620E-2	8.919E-1	Feb-1990
Re-184m	169d	IT	7.540E-1	Re-184	38.0d		1.413E-1	3.836E-1	Feb-1990
		EC	2.460E-1	W-184	stable				Feb-1990
Re-186	3.7183d	B-	9.253E-1	Os-186	2.0E+15y		3.362E-1	2.080E-2	Nov-1997
		EC	7.470E-2	W-186	stable				Apr-1999
Re-186m	2.00E+5y	IT	1.000E+0	Re-186	3.7183d		1.267E-1	2.068E-2	Nov-1997
Re-187	4.12E+10y	B-	1.000E+0	Os-187	stable		6.177E-4		Feb-1991
Re-188	17.0040h	B-	1.000E+0	Os-188	stable		7.793E-1	6.125E-2	Apr-2002
Re-188m	18.59m	IT	1.000E+0	Re-188	17.0040h		9.762E-2	7.154E-2	Apr-2002
Re-189	24.3h	B-	1.000E+0	Os-189m (1.221E-1)	5.8h		3.260E-1	5.565E-2	Oct-1991
				Os-189 (8.779E-1)	stable				
Re-190	3.1m	B-	1.000E+0	Os-190	stable		6.863E-1	1.338E+0	Dec-1990
Re-190m	3.2h	B-	5.440E-1	Os-190	stable		4.456E-1	9.257E-1	Jun-2003
		IT	4.560E-1	Re-190	3.1m				Jun-2003
Osmium									
Os-180	21.5m	EC,B+	1.000E+0	Re-180	2.44m		2.984E-2	1.265E-1	Apr-1994
Os-181	105m	EC,B+	1.000E+0	Re-181	19.9h		9.183E-2	1.384E+0	Feb-1991
Os-182	22.10h	EC	1.000E+0	Re-182m	12.7h		5.649E-2	4.317E-1	Mar-1995
Os-183	13.0h	EC,B+	1.000E+0	Re-183	70.0d		7.923E-2	6.288E-1	Sep-1997
Os-183m	9.9h	EC,B+	8.500E-1	Re-183	70.0d		4.164E-2	1.006E+0	Jul-1991
		IT	1.500E-1	Os-183	13.0h				Jul-1991
Os-185	93.6d	EC	1.000E+0	Re-185	stable		1.840E-2	6.917E-1	Mar-1995
Os-186	2.0E+15y	A	1.000E+0	W-182	stable	2.761E+0			May-1998

Table 4.1 continued from previous page (19/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.) Alpha	Electron	Photon	ENSDF date
Os-189m	5.8h	IT	1.000E+0	Os-189	stable		2.861E-2	2.253E-3	Oct-1991
Os-190m	9.9m	IT	1.000E+0	Os-190	stable		1.166E-1	1.589E+0	Dec-1990
Os-191	15.4d	B-	1.000E+0	Ir-191	stable		1.372E-1	8.431E-2	Jun-1995
Os-191m	13.10h	IT	1.000E+0	Os-191	15.4d		6.636E-2	8.040E-3	Jun-1995
Os-193	30.11h	B-	1.000E+0	Ir-193m (3.476E-3)	10.53d		3.797E-1	6.743E-2	May-1998
				Ir-193 (9.965E-1)	stable				
Os-194	6.0y	B-	1.000E+0	Ir-194	19.28h		4.533E-2	4.514E-3	Nov-1996
Os-196	34.9m	B-	1.000E+0	Ir-196	52s		3.807E-1	8.049E-2	Nov-1995
Iridium									
Ir-182	15m	EC,B+	1.000E+0	Os-182	22.10h		1.047E+0	1.412E+0	May-1995
Ir-183	58m	EC,B+	1.000E+0	Os-183m (7.097E-1)	9.9h		1.516E-1	1.189E+0	Sep-1998
				Os-183 (2.903E-1)	13.0h				
Ir-184	3.09h	EC,B+	1.000E+0	Os-184	stable		3.194E-1	1.964E+0	Feb-1990
Ir-185	14.4h	EC,B+	1.000E+0	Os-185	93.6d		1.228E-1	8.581E-1	Mar-1995
Ir-186	16.64h	EC,B+	1.000E+0	Os-186	2.0E+15y		1.453E-1	1.665E+0	Nov-1997
Ir-186m	1.92h	EC,B+	7.500E-1	Os-186	2.0E+15y		1.103E-1	1.252E+0	Nov-1997
		IT	2.500E-1	Ir-186	16.64h				Nov-1997
Ir-187	10.5h	EC,B+	1.000E+0	Os-187	stable		5.677E-2	3.325E-1	Jan-1992
Ir-188	41.5h	EC,B+	1.000E+0	Os-188	stable		5.085E-2	2.097E+0	Apr-2002
Ir-189	13.2d	EC	1.000E+0	Os-189m (7.426E-2)	5.8h		4.578E-2	7.933E-2	Oct-1991
				Os-189 (9.257E-1)	stable				
Ir-190	11.78d	EC	1.000E+0	Os-190	stable		7.456E-2	1.477E+0	Dec-1990
Ir-190m	1.120h	IT	1.000E+0	Ir-190	11.78d		2.398E-2	2.373E-3	Jan-1996
Ir-190n	3.087h	EC	9.140E-1	Os-190m	9.9m		2.892E-2	5.774E-2	Jun-2003
		IT	8.600E-2	Ir-190	11.78d				Jun-2003
Ir-191m	4.94s	IT	1.000E+0	Ir-191	stable		9.708E-2	7.644E-2	Jun-1995
Ir-192	73.827d	B-	9.513E-1	Pt-192	stable		2.177E-1	8.165E-1	Sep-1998
		EC	4.870E-2	Os-192	stable				Sep-1998
Ir-192n[2]	241y	IT	1.000E+0	Ir-192	73.827d		1.617E-1	6.573E-3	Sep-1998
Ir-193m	10.53d	IT	1.000E+0	Ir-193	stable		7.761E-2	2.664E-3	May-1998
Ir-194	19.28h	B-	1.000E+0	Pt-194	stable		8.105E-1	9.108E-2	Nov-1996
Ir-194m	171d	B-	1.000E+0	Pt-194	stable		1.422E-1	2.334E+0	Nov-1996
Ir-195	2.5h	B-	1.000E+0	Pt-195	stable		3.803E-1	5.932E-2	May-1999
Ir-195m	3.8h	B-	9.500E-1	Pt-195m (4.369E-1)	4.02d		2.606E-1	3.766E-1	May-1999
				Pt-195 (5.131E-1)	stable				
		IT	5.000E-2	Ir-195	2.5h				May-1999
Ir-196	52s	B-	1.000E+0	Pt-196	stable		1.174E+0	2.322E-1	Feb-1998
Ir-196m	1.40h	B-	1.000E+0	Pt-196	stable		3.844E-1	2.468E+0	Feb-1998
Platinum									
Pt-184	17.3m	EC,B+	1.000E+0	Ir-184	3.09h	7.653E-5	2.004E-1	7.266E-1	Feb-1990
		A	1.700E-5	Os-180	21.5m				May-1998
Pt-186	2.08h	EC	1.000E+0	Ir-186m (8.194E-1)	1.92h	4.232E-6	4.513E-2	6.844E-1	May-1998
				Ir-186 (1.806E-1)	16.64h				
		A	1.000E-6	Os-182	22.10h				May-1998
Pt-187	2.35h	EC,B+	1.000E+0	Ir-187	10.5h		1.549E-1	6.183E-1	Feb-1991
Pt-188	10.2d	EC	1.000E+0	Ir-188	41.5h	1.137E-6	8.235E-2	2.055E-1	Apr-2002
		A	2.900E-7	Os-184	stable				May-1998

2 There are two isomers for Ir-192, e.g., Ir-192m (half-life = 1.45m) for the first isomeric state and Ir-192n (241y) for the second isomeric state. The second isomer, Ir-192n, directly transforms to the ground state of Ir-192. Therefore, the decay data for Ir-192m is not included in the present compilation.

Table 4.1 continued from previous page (20/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.)			ENSDF date
						Alpha	Electron	Photon	
Pt-189	10.87h	EC,B+	1.000E+0	Ir-189	13.2d		9.962E-2	4.870E-1	Oct-1991
Pt-190	6.50E+11y	A	1.000E+0	Os-186	2.0E+15y	3.181E+0			Nov-1997
Pt-191	2.802d	EC	1.000E+0	Ir-191	stable		7.486E-2	2.960E-1	Mar-1996
Pt-193	50y	EC	1.000E+0	Ir-193	stable		7.146E-3	2.580E-3	May-1998
Pt-193m	4.33d	IT	1.000E+0	Pt-193	50y		1.377E-1	1.322E-2	May-1998
Pt-195m	4.02d	IT	1.000E+0	Pt-195	stable		1.845E-1	7.717E-2	May-1999
Pt-197	19.8915h	B-	1.000E+0	Au-197	stable		2.552E-1	2.563E-2	Jan-1996
Pt-197m	95.41m	IT	9.670E-1	Pt-197	19.8915h		3.250E-1	8.390E-2	Jan-1996
		B-	3.300E-2	Au-197	stable				Jan-1996
Pt-199	30.80m	B-	1.000E+0	Au-199	3.139d		5.455E-1	1.995E-1	Aug-1994
Pt-200	12.5h	B-	1.000E+0	Au-200	48.4m		2.321E-1	6.052E-2	Oct-1995
Pt-202	44h	B-	1.000E+0	Au-202	28.8s		6.537E-1		Apr-1997
Gold									
Au-186	10.7m	EC,B+	1.000E+0	Pt-186	2.08h		1.075E+0	1.498E+0	Nov-1997
Au-190	42.8m	EC,B+	1.000E+0	Pt-190	6.50E+11y		2.129E-1	2.381E+0	Dec-1990
Au-191	3.18h	EC,B+	1.000E+0	Pt-191	2.802d		8.650E-2	5.946E-1	Jun-1995
Au-192	4.94h	EC,B+	1.000E+0	Pt-192	stable		9.045E-2	1.939E+0	Sep-1998
Au-193	17.65h	EC	1.000E+0	Pt-193	50y		5.751E-2	1.673E-1	May-1998
Au-193m	3.9s	IT	9.997E-1	Au-193	17.65h		9.040E-2	1.979E-1	May-1998
		EC	3.000E-4	Pt-193m	4.33d				May-1998
Au-194	38.02h	EC,B+	1.000E+0	Pt-194	stable		4.207E-2	1.039E+0	Nov-1996
Au-195	186.098d	EC	1.000E+0	Pt-195	stable		5.202E-2	8.386E-2	May-1999
Au-195m	30.5s	IT	1.000E+0	Au-195	186.098d		1.172E-1	2.014E-1	May-1999
Au-196	6.183d	EC	9.280E-1	Pt-196	stable		3.718E-2	4.734E-1	Feb-1998
		B-	7.200E-2	Hg-196	stable				Feb-1998
Au-196m	9.6h	IT	1.000E+0	Au-196	6.183d		3.760E-1	2.473E-1	Feb-1998
Au-198	2.69517d	B-	1.000E+0	Hg-198	stable		3.277E-1	4.029E-1	Mar-2002
Au-198m	2.27d	IT	1.000E+0	Au-198	2.69517d		2.748E-1	5.332E-1	Mar-2002
Au-199	3.139d	B-	1.000E+0	Hg-199	stable		1.451E-1	9.615E-2	Aug-1994
Au-200	48.4m	B-	1.000E+0	Hg-200	stable		7.303E-1	2.737E-1	Oct-1995
Au-200m	18.7h	B-	8.200E-1	Hg-200	stable		2.433E-1	1.984E+0	Oct-1995
		IT	1.800E-1	Au-200	48.4m				Oct-1995
Au-201	26m	B-	1.000E+0	Hg-201	stable		4.259E-1	3.464E-2	Jul-1994
Au-202	28.8s	B-	1.000E+0	Hg-202	stable		1.075E+0	1.720E-1	Apr-1997
Mercury									
Hg-190	20.0m	EC,B+	1.000E+0	Au-190	42.8m		5.388E-2	2.018E-1	Jun-2003
Hg-191m	50.8m	EC,B+	1.000E+0	Au-191	3.18h		1.378E-1	1.490E+0	Jun-1995
Hg-192	4.85h	EC	1.000E+0	Au-192	4.94h		6.360E-2	2.749E-1	Sep-1998
Hg-193	3.80h	EC,B+	1.000E+0	Au-193m (3.541E-2)	3.9s		7.401E-2	8.377E-1	May-1998
				Au-193 (9.646E-1)	17.65h				
Hg-193m	11.8h	EC,B+	9.290E-1	Au-193m (8.920E-1)	3.9s		4.696E-2	1.024E+0	Feb-1997
				Au-193 (3.703E-2)	17.65h				
		IT	7.100E-2	Hg-193	3.80h				Feb-1997
Hg-194	440y	EC	1.000E+0	Au-194	38.02h		7.847E-3	2.714E-3	Nov-1996
Hg-195	10.53h	EC,B+	1.000E+0	Au-195	186.098d		6.504E-2	2.008E-1	May-1999
Hg-195m	41.6h	IT	5.420E-1	Hg-195	10.53h		1.480E-1	2.047E-1	May-1999
		EC,B+	4.580E-1	Au-195	186.098d				May-1999
Hg-197	64.94h	EC	1.000E+0	Au-197	stable		7.025E-2	7.399E-2	Jan-1996
Hg-197m	23.8h	IT	9.140E-1	Hg-197	64.94h		2.170E-1	9.775E-2	Jan-1996
		EC	8.600E-2	Au-197	stable				Jan-1996
Hg-199m	42.66m	IT	1.000E+0	Hg-199	stable		3.487E-1	1.836E-1	Aug-1994
Hg-203	46.612d	B-	1.000E+0	Tl-203	stable		9.896E-2	2.380E-1	Nov-1993
Hg-206	8.15m	B-	1.000E+0	Tl-206	4.200m		4.211E-1	1.215E-1	Oct-1999
Thallium									
Tl-194	33.0m	EC,B+	1.000E+0	Hg-194	440y		5.972E-1	9.143E-1	Nov-1996
Tl-194m	32.8m	EC,B+	1.000E+0	Hg-194	440y		3.037E-1	2.522E+0	Nov-1996

Table 4.1 continued from previous page (21/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.)			ENSDF date
						Alpha	Electron	Photon	
Tl-195	1.16h	EC,B+	1.000E+0	Hg-195m	41.6h		7.402E-2	1.225E+0	May-1999
				(3.436E-3)					
				Hg-195	10.53h				
				(9.966E-1)					
Tl-196	1.84h	EC,B+	1.000E+0	Hg-196	stable		1.782E-1	1.873E+0	Feb-1998
Tl-197	2.84h	EC,B+	1.000E+0	Hg-197	64.94h		5.437E-2	4.587E-1	Jan-1996
Tl-198	5.3h	EC,B+	1.000E+0	Hg-198	stable		4.142E-2	2.011E+0	Mar-2002
Tl-198m	1.87h	EC,B+	5.400E-1	Hg-198	stable		2.006E-1	1.217E+0	Mar-2002
		IT	4.600E-1	Tl-198	5.3h				Mar-2002
Tl-199	7.42h	EC,B+	1.000E+0	Hg-199	stable		5.998E-2	2.520E-1	Aug-1994
Tl-200	26.1h	EC,B+	1.000E+0	Hg-200	stable		4.077E-2	1.311E+0	Oct-1995
Tl-201	72.912h	EC	1.000E+0	Hg-201	stable		4.470E-2	9.382E-2	Jul-1994
Tl-202	12.23d	EC	1.000E+0	Hg-202	stable		2.329E-2	4.658E-1	Apr-1997
Tl-204	3.78y	B-	9.710E-1	Pb-204	stable		2.372E-1	1.274E-3	Nov-1994
		EC	2.900E-2	Hg-204	stable				Nov-1994
Tl-206	4.200m	B-	1.000E+0	Pb-206	stable		5.398E-1	1.060E-4	Oct-1999
Tl-207	4.77m	B-	1.000E+0	Pb-207	stable		4.952E-1	2.352E-3	Feb-1994
Tl-208	3.053m	B-	1.000E+0	Pb-208	stable		6.113E-1	3.360E+0	May-1986
Tl-209	2.161m	B-	1.000E+0	Pb-209	3.253h		6.875E-1	2.143E+0	Nov-1991
Tl-210	1.30m	B-	1.000E+0	Pb-210	22.20y		1.270E+0	2.763E+0	Mar-1992
Lead									
Pb-194	12.0m	EC,B+	1.000E+0	Tl-194	33.0m	3.387E-7	8.445E-2	1.083E+0	Nov-1996
		A	7.300E-8	Hg-190	20.0m				May-1998
Pb-195m	15m	EC,B+	1.000E+0	Tl-195	1.16h		3.167E-1	1.655E+0	May-1999
Pb-196	37m	EC,B+	1.000E+0	Tl-196	1.84h		9.688E-2	4.940E-1	Feb-1998
Pb-197	8m	EC,B+	1.000E+0	Tl-197	2.84h		8.177E-2	1.532E+0	Jan-1996
Pb-197m	43m	EC,B+	8.100E-1	Tl-197	2.84h		2.477E-1	1.173E+0	Jan-1996
		IT	1.900E-1	Pb-197	8m				Jan-1996
Pb-198	2.4h	EC	1.000E+0	Tl-198	5.3h		7.814E-2	4.385E-1	Mar-2002
Pb-199	90m	EC,B+	1.000E+0	Tl-199	7.42h		5.841E-2	1.039E+0	Aug-1994
Pb-200	21.5h	EC	1.000E+0	Tl-200	26.1h		9.966E-2	2.086E-1	Oct-1995
Pb-201	9.33h	EC,B+	1.000E+0	Tl-201	72.912h		5.938E-2	7.562E-1	Jul-1994
Pb-201m	61s	IT	1.000E+0	Pb-201	9.33h		2.633E-1	3.658E-1	Oct-2003
Pb-202	5.25E+4y	EC	9.900E-1	Tl-202	12.23d	2.547E-2	6.146E-3	2.498E-3	Apr-1997
		A	1.000E-2	Hg-198	stable				Mar-2002
Pb-202m	3.53h	IT	9.050E-1	Pb-202	5.25E+4y		1.321E-1	1.993E+0	Apr-1997
		EC	9.500E-2	Tl-202	12.23d				Apr-1997
Pb-203	51.873h	EC	1.000E+0	Tl-203	stable		5.296E-2	3.143E-1	Nov-1993
Pb-204m	67.2m	IT	1.000E+0	Pb-204	stable		1.030E-1	2.063E+0	Nov-1994
Pb-205	1.53E+7y	EC	1.000E+0	Tl-205	stable		6.220E-3	2.529E-3	Oct-1993
Pb-209	3.253h	B-	1.000E+0	Bi-209	stable		1.974E-1		Nov-1991
Pb-210	22.20y	B-	1.000E+0	Bi-210	5.013d	7.067E-8	4.039E-2	5.343E-3	Mar-1992
		A	1.900E-8	Hg-206	8.15m				Oct-1999
Pb-211	36.1m	B-	1.000E+0	Bi-211	2.14m		4.543E-1	6.442E-2	Aug-1991
Pb-212	10.64h	B-	1.000E+0	Bi-212	60.55m		1.766E-1	1.450E-1	May-1992
Pb-214	26.8m	B-	1.000E+0	Bi-214	19.9m		2.948E-1	2.533E-1	Nov-1995
Bismuth									
Bi-200	36.4m	EC,B+	1.000E+0	Pb-200	21.5h		2.469E-1	2.436E+0	Oct-1995
Bi-201	108m	EC,B+	1.000E+0	Pb-201m	61s		6.117E-2	1.730E+0	Jul-1994
				(4.517E-1)					
				Pb-201	9.33h				
				(5.483E-1)					
Bi-202	1.72h	EC,B+	1.000E+0	Pb-202	5.25E+4y		1.515E-1	2.756E+0	Apr-1997
Bi-203	11.76h	EC,B+	1.000E+0	Pb-203	51.873h		8.090E-2	2.385E+0	Nov-1993
Bi-204	11.22h	EC,B+	1.000E+0	Pb-204m	67.2m		8.066E-2	2.916E+0	Nov-1994
				(9.853E-2)					
				Pb-204	stable				
				(9.015E-1)					
Bi-205	15.31d	EC,B+	1.000E+0	Pb-205	1.53E+7y		3.460E-2	1.691E+0	Oct-1993
Bi-206	6.243d	EC,B+	1.000E+0	Pb-206	stable		1.379E-1	3.280E+0	Oct-1999
Bi-207	32.9y	EC,B+	1.000E+0	Pb-207	stable		1.193E-1	1.537E+0	Feb-1994

Table 4.1 continued from previous page (22/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.)			ENSDF date
						Alpha	Electron	Photon	
Bi-208	3.68E+5y	EC	1.000E+0	Pb-208	stable		1.437E-2	2.646E+0	May-1986
Bi-210	5.013d	B-	1.000E+0	Po-210	138.376d	6.150E-6	3.889E-1	3.095E-7	Mar-1992
		A	1.320E-6	Tl-206	4.200m				Oct-1999
Bi-210m	3.04E+6y	A	1.000E+0	Tl-206	4.200m	4.911E+0	4.750E-2	2.607E-1	Oct-1999
Bi-211	2.14m	A	9.972E-1	Tl-207	4.77m	6.549E+0	1.003E-2	4.727E-2	Feb-1994
		B-	2.760E-3	Po-211	0.516s				Aug-1991
Bi-212	60.55m	B-	6.406E-1	Po-212	2.99E-7s	2.175E+0	5.046E-1	1.038E-1	May-1992
		A	3.594E-1	Tl-208	3.053m				May-1992
Bi-213	45.59m	B-	9.791E-1	Po-213	4.2E-6s	1.222E-1	4.440E-1	1.277E-1	May-1992
		A	2.090E-2	Tl-209	2.161m				Nov-1991
Bi-214	19.9m	B-	9.998E-1	Po-214	1.643E-4s	1.147E-3	6.631E-1	1.479E+0	Nov-1995
		A	2.100E-4	Tl-210	1.30m				Mar-1992
Bi-215	7.6m	B-	1.000E+0	Po-215	1.781E-3s		6.694E-1	2.534E-1	Jan-2004
Polonium									
Po-203	36.7m	EC,B+	9.989E-1	Bi-203	11.76h	5.921E-3	1.672E-1	1.635E+0	Nov-1993
		A	1.100E-3	Pb-199	90m				Dec-2001
Po-204	3.53h	EC	9.934E-1	Bi-204	11.22h	3.549E-2	1.839E-1	1.165E+0	Nov-1994
		A	6.600E-3	Pb-200	21.5h				May-1998
Po-205	1.66h	EC,B+	9.990E-1	Bi-205	15.31d	2.088E-3	6.602E-2	1.585E+0	Oct-1993
		A	4.000E-4	Pb-201	9.33h				Jul-1994
Po-206	8.8d	EC	9.455E-1	Bi-206	6.243d	2.847E-1	1.655E-1	1.193E+0	Oct-1999
		A	5.450E-2	Pb-202	5.25E+4y				May-1998
Po-207	5.80h	EC,B+	9.998E-1	Bi-207	32.9y	1.074E-3	4.897E-2	1.285E+0	Feb-1994
		A	2.100E-4	Pb-203	51.873h				Nov-1993
Po-208	2.898y	A	1.000E+0	Pb-204	stable	5.115E+0	3.805E-6	2.137E-5	May-1986
		EC	2.230E-5	Bi-208	3.68E+5y				May-1986
Po-209	102y	A	9.952E-1	Pb-205	1.53E+7y	4.858E+0	3.032E-3	6.294E-3	Oct-1993
		EC	4.800E-3	Bi-209	stable				Nov-1991
Po-210	138.376d	A	1.000E+0	Pb-206	stable	5.304E+0	9.374E-8	9.725E-6	Oct-1999
Po-211	0.516s	A	1.000E+0	Pb-207	stable	7.442E+0	1.803E-4	8.172E-3	Feb-1994
Po-212	2.99E-7s	A	1.000E+0	Pb-208	stable	8.785E+0			May-1998
Po-213	4.2E-6s	A	1.000E+0	Pb-209	3.253h	8.377E+0	1.234E-6	3.749E-5	Nov-1991
Po-214	1.643E-4s	A	1.000E+0	Pb-210	22.20y	7.687E+0	8.214E-7	8.301E-5	May-1998
Po-215	1.781E-3s	A	1.000E+0	Pb-211	36.1m	7.386E+0	6.316E-6	1.764E-4	May-1992
Po-216	0.145s	A	1.000E+0	Pb-212	10.64h	6.778E+0	1.469E-7	1.531E-5	May-1992
Po-218	3.10m	A	9.998E-1	Pb-214	26.8m	6.001E+0	1.427E-5		May-1998
		B-	2.000E-4	At-218	1.5s				Jan-1996
Astatine									
At-205	26.2m	EC,B+	9.000E-1	Po-205	1.66h	5.903E-1	2.575E-1	1.144E+0	Oct-1993
		A	1.000E-1	Bi-201	108m				Jul-1994
At-206	30.6m	EC,B+	9.911E-1	Po-206	8.8d	5.072E-2	3.324E-1	2.481E+0	Oct-1999
		A	8.900E-3	Bi-202	1.72h				Apr-1997
At-207	1.80h	EC,B+	9.140E-1	Po-207	5.80h	4.951E-1	1.298E-1	2.014E+0	Feb-1994
		A	8.600E-2	Bi-203	11.76h				Nov-1993
At-208	1.63h	EC,B+	9.945E-1	Po-208	2.898y	3.102E-2	1.598E-1	3.041E+0	May-1986
		A	5.500E-3	Bi-204	11.22h				Nov-1994
At-209	5.41h	EC,B+	9.590E-1	Po-209	102y	2.315E-1	1.172E-1	2.285E+0	Nov-1991
		A	4.100E-2	Bi-205	15.31d				Oct-1993
At-210	8.1h	EC,B+	9.983E-1	Po-210	138.376d	9.521E-3	7.963E-2	2.962E+0	Mar-1992
		A	1.750E-3	Bi-206	6.243d				Oct-1999
At-211	7.214h	EC	5.820E-1	Po-211	0.516s	2.452E+0	5.945E-3	3.667E-2	Aug-1991
		A	4.180E-1	Bi-207	32.9y				Feb-1994
At-215	1.00E-4s	A	1.000E+0	Bi-211	2.14m	8.026E+0	3.042E-5	1.716E-4	May-1992
At-216	3.00E-4s	A	1.000E+0	Bi-212	60.55m	7.794E+0	1.341E-3	2.510E-3	May-1992
At-217	3.23E-2s	A	9.999E-1	Bi-213	45.59m	7.068E+0	8.156E-5	2.446E-4	May-1992
At-218	1.5s	A	9.990E-1	Bi-214	19.9m	6.679E+0	1.095E-3		Nov-1995
		B-	1.000E-3	Rn-218	3.5E-2s				Jan-1996
At-219	56s	A	9.700E-1	Bi-215	7.6m	6.022E+0			Oct-2001

Table 4.1 continued from previous page (23/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.)			ENSDF date
						Alpha	Electron	Photon	
Radon									
Rn-209	28.5m	EC,B+	8.300E-1	At-209	5.41h	1.027E+0	1.167E-1	1.195E+0	Nov-1991
		A	1.700E-1	Po-205	1.66h				Oct-1993
Rn-210	2.4h	A	9.600E-1	Po-206	8.8d	5.799E+0	9.067E-3	6.096E-2	Oct-1999
		EC	4.000E-2	At-210	8.1h				Mar-1992
Rn-211	14.6h	EC,B+	7.260E-1	At-211	7.214h	1.590E+0	6.628E-2	1.873E+0	Nov-1996
		A	2.740E-1	Po-207	5.80h				Feb-1994
Rn-212	23.9m	A	1.000E+0	Po-208	2.898y	6.264E+0	4.882E-6	3.384E-4	May-1998
Rn-216	4.5E-5s	A	1.000E+0	Po-212	2.99E-7s	8.048E+0			May-1998
Rn-217	5.40E-4s	A	1.000E+0	Po-213	4.2E-6s	7.740E+0			May-1992
Rn-218	3.5E-2s	A	1.000E+0	Po-214	1.643E-4s	7.129E+0	1.401E-5	7.571E-4	Nov-1995
Rn-219	3.96s	A	1.000E+0	Po-215	1.781E-3s	6.754E+0	6.837E-3	5.860E-2	Oct-2001
Rn-220	55.6s	A	1.000E+0	Po-216	0.145s	6.288E+0	1.453E-5	6.285E-4	Mar-1997
Rn-222	3.8235d	A	1.000E+0	Po-218	3.10m	5.489E+0	1.064E-5	3.890E-4	Jan-1996
Rn-223	24.3m	B-	1.000E+0	Fr-223	22.00m		6.283E-1	3.444E-1	Oct-2001
Francium									
Fr-212	20.0m	EC,B+	5.700E-1	Rn-212	23.9m	2.721E+0	1.294E-1	1.142E+0	May-1992
		A	4.300E-1	At-208	1.63h				May-1992
Fr-219	2.0E-2s	A	1.000E+0	At-215	1.00E-4s	7.308E+0	4.393E-4	3.579E-3	Oct-2001
Fr-220	27.4s	A	9.965E-1	At-216	3.00E-4s	6.619E+0	1.627E-2	1.047E-2	Mar-1997
		B-	3.500E-3	Ra-220	1.79E-2s				Mar-1997
Fr-221	4.9m	A	1.000E+0	At-217	3.23E-2s	6.304E+0	8.908E-3	2.941E-2	Aug-1991
Fr-222	14.2m	B-	1.000E+0	Ra-222	38.0s		7.145E-1	1.806E-1	Jan-1996
Fr-223	22.00m	B-	1.000E+0	Ra-223	11.43d	3.277E-4	3.829E-1	5.826E-2	Oct-2001
		A	6.000E-5	At-219	56s				Oct-2001
Fr-224	3.33m	B-	1.000E+0	Ra-224	3.66d		8.751E-1	5.523E-1	Mar-1997
Radium									
Ra-220	1.79E-2s	A	1.000E+0	Rn-216	4.5E-5s	7.452E+0	1.724E-4	4.675E-3	Mar-1997
Ra-221	28s	A	1.000E+0	Rn-217	5.40E-4s	6.669E+0	6.898E-2	3.901E-2	Sep-2003
Ra-222	38.0s	A	1.000E+0	Rn-218	3.5E-2s	6.551E+0	8.502E-4	9.194E-3	Jan-1996
Ra-223	11.43d	A	1.000E+0	Rn-219	3.96s	5.667E+0	7.810E-2	1.413E-1	Oct-2001
Ra-224	3.66d	A	1.000E+0	Rn-220	55.6s	5.673E+0	2.329E-3	1.039E-2	Mar-1997
Ra-225	14.9d	B-	1.000E+0	Ac-225	10.0d		1.050E-1	1.446E-2	Aug-1990
Ra-226	1600y	A	1.000E+0	Rn-222	3.8235d	4.774E+0	3.911E-3	7.400E-3	Jan-1996
Ra-227	42.2m	B-	1.000E+0	Ac-227	21.772y		4.511E-1	1.508E-1	Oct-2001
Ra-228	5.75y	B-	1.000E+0	Ac-228	6.15h		1.320E-2	3.061E-3	Apr-1997
Ra-230	93m	B-	1.000E+0	Ac-230	122s		2.201E-1	7.944E-2	Jul-1993
Actinium									
Ac-223	2.10m	A	9.900E-1	Fr-219	2.0E-2s	6.552E+0	2.536E-2	1.904E-2	Oct-2001
Ac-224	2.78h	EC	9.090E-1	Ra-224	3.66d	5.561E-1	4.901E-2	2.325E-1	Mar-1997
		A	9.100E-2	Fr-220	27.4s				Mar-1997
Ac-225	10.0d	A	1.000E+0	Fr-221	4.9m	5.787E+0	2.476E-2	1.709E-2	Dec-1990
Ac-226	29.37h	B-	8.300E-1	Th-226	30.57m	3.239E-4	2.914E-1	1.327E-1	Apr-1996
		EC	1.700E-1	Ra-226	1600y				Apr-1996
		A	6.000E-5	Fr-222	14.2m				Jan-1996
Ac-227	21.772y	B-	9.862E-1	Th-227	18.68d	6.805E-2	1.502E-2	1.051E-3	Oct-2001
		A	1.380E-2	Fr-223	22.00m				Oct-2001
Ac-228	6.15h	B-	1.000E+0	Th-228	1.9116y		4.495E-1	8.671E-1	Apr-1997
Ac-230	122s	B-	1.000E+0	Th-230	7.538E+4y		9.229E-1	5.440E-1	Jul-1993
Thorium									
Th-224	1.05s	A	1.000E+0	Ra-220	1.79E-2s	7.134E+0	1.291E-2	2.319E-2	Mar-1997
Th-226	30.57m	A	1.000E+0	Ra-222	38.0s	6.308E+0	2.112E-2	8.908E-3	Jan-1996
Th-227	18.68d	A	1.000E+0	Ra-223	11.43d	5.883E+0	7.547E-2	1.317E-1	Oct-2001
Th-228	1.9116y	A	1.000E+0	Ra-224	3.66d	5.399E+0	2.102E-2	3.607E-3	Mar-1997
Th-229	7.34E+3y	A	1.000E+0	Ra-225	14.9d	4.872E+0	1.217E-1	9.705E-2	Aug-1990
Th-230	7.538E+4y	A	1.000E+0	Ra-226	1600y	4.671E+0	1.460E-2	1.776E-3	Apr-1996
Th-231	25.52h	B-	1.000E+0	Pa-231	3.276E+4y		1.622E-1	2.687E-2	Oct-2001
Th-232	1.405E+10y	A	1.000E+0	Ra-228	5.75y	3.999E+0	1.262E-2	1.486E-3	Apr-1997

Table 4.1 continued from previous page (24/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.)			ENSDF date
						Alpha	Electron	Photon	
Th-233	22.3m	B-	1.000E+0	Pa-233	26.967d		4.140E-1	3.748E-2	Aug-1990
Th-234	24.10d	B-	1.000E+0	Pa-234m	1.17m		6.224E-2	1.052E-2	Apr-1994
Th-236	37.5m	B-	1.000E+0	Pa-236	9.1m		3.671E-1	3.463E-2	Aug-1991
Protactinium									
Pa-227	38.3m	A	8.500E-1	Ac-223	2.10m	5.467E+0	2.262E-2	2.336E-2	Oct-2001
		EC	1.500E-1	Th-227	18.68d				Dec-2003
Pa-228	22h	EC,B+	9.800E-1	Th-228	1.9116y	1.195E-1	1.320E-1	1.369E+0	Apr-1997
		A	2.000E-2	Ac-224	2.78h				Mar-1997
Pa-229	1.50d	EC	9.952E-1	Th-229	7.34E+3y	2.689E-2	1.314E-2	6.657E-2	Feb-1990
		A	4.800E-3	Ac-225	10.0d				Aug-1990
Pa-230	17.4d	EC	9.160E-1	Th-230	7.538E+4y	1.699E-4	6.679E-2	6.708E-1	Jul-1993
		B-	8.400E-2	U-230	20.8d				Jul-1993
		A	3.200E-5	Ac-226	29.37h				Apr-1996
Pa-231	3.276E+4y	A	1.000E+0	Ac-227	21.772y	4.972E+0	5.380E-2	4.496E-2	Oct-2001
Pa-232	1.31d	B-	1.000E+0	U-232	68.9y		1.738E-1	9.393E-1	Aug-1991
		EC	3.000E-5	Th-232	1.405E+10y				Aug-1991
Pa-233	26.967d	B-	1.000E+0	U-233	1.592E+5y		2.151E-1	2.229E-1	Aug-1990
Pa-234	6.70h	B-	1.000E+0	U-234	2.455E+5y		4.037E-1	1.472E+0	Apr-1994
Pa-234m	1.17m	B-	9.984E-1	U-234	2.455E+5y		8.171E-1	1.624E-2	Apr-1994
		IT	1.600E-3	Pa-234	6.70h				Apr-1994
Pa-235	24.5m	B-	1.000E+0	U-235m (9.999E-1)	26m		4.886E-1	7.998E-4	May-2003
				U-235 (1.011E-4)	7.04E+8y				
Pa-236	9.1m	B-	1.000E+0	U-236	2.342E+7y		8.049E-1	9.148E-1	Aug-1991
Uranium									
U-228	9.1m	A	9.750E-1	Th-224	1.05s	6.489E+0	2.313E-2	5.589E-3	Mar-1997
U-230	20.8d	A	1.000E+0	Th-226	30.57m	5.864E+0	2.157E-2	3.239E-3	Apr-1996
U-231	4.2d	EC	1.000E+0	Pa-231	3.276E+4y	2.176E-4	8.467E-2	8.964E-2	Oct-2001
		A	4.000E-5	Th-227	18.68d				Oct-2001
U-232	68.9y	A	1.000E+0	Th-228	1.9116y	5.302E+0	1.638E-2	2.311E-3	Apr-1997
U-233	1.592E+5y	A	1.000E+0	Th-229	7.34E+3y	4.817E+0	5.905E-3	1.300E-3	Feb-1990
U-234	2.455E+5y	A	1.000E+0	Th-230	7.538E+4y	4.760E+0	1.365E-2	2.018E-3	Jul-1993
U-235	7.04E+8y	A	1.000E+0	Th-231	25.52h	4.393E+0	5.301E-2	1.669E-1	Oct-2001
U-235m	26m	IT	1.000E+0	U-235	7.04E+8y		7.650E-5	7.65E-15	Nov-2003
U-236	2.342E+7y	A	1.000E+0	Th-232	1.405E+10y	4.482E+0	1.138E-2	1.785E-3	Aug-1991
U-237	6.75d	B-	1.000E+0	Np-237	2.144E+6y		1.991E-1	1.442E-1	May-1995
U-238	4.468E+9y	A	1.000E+0	Th-234	24.10d	4.192E+0	9.171E-3	1.430E-3	Apr-1994
		SF	5.450E-7						Dec-2003
U-239	23.45m	B-	1.000E+0	Np-239	2.3565d		4.108E-1	5.185E-2	May-2003
U-240	14.1h	B-	1.000E+0	Np-240m	7.22m		1.276E-1	9.864E-3	Nov-1996
U-242	16.8m	B-	1.000E+0	Np-242	2.2m		3.859E-1	4.130E-2	Jun-2002
Neptunium									
Np-232	14.7m	EC,B+	1.000E+0	U-232	68.9y		1.073E-1	1.197E+0	Aug-1991
Np-233	36.2m	EC	1.000E+0	U-233	1.592E+5y	5.533E-5	1.436E-2	9.106E-2	Aug-1990
		A	1.000E-5	Pa-229	1.50d				Feb-1990
Np-234	4.4d	EC,B+	1.000E+0	U-234	2.455E+5y		5.742E-2	1.109E+0	Apr-1994
Np-235	396.1d	EC	1.000E+0	U-235m (3.993E-3)	26m	1.301E-4	1.055E-2	7.105E-3	Aug-1993
				U-235 (9.960E-1)	7.04E+8y				
		A	2.600E-5	Pa-231	3.276E+4y				Oct-2001
Np-236	1.54E+5y	EC	8.730E-1	U-236	2.342E+7y	7.251E-3	2.372E-1	1.594E-1	Aug-1991
		B-	1.250E-1	Pu-236	2.858y				Aug-1991
		A	1.600E-3	Pa-232	1.31d				Aug-1991
Np-236m	22.5h	EC	5.200E-1	U-236	2.342E+7y		8.803E-2	5.066E-2	Aug-1991
		B-	4.800E-1	Pu-236	2.858y				Aug-1991
Np-237	2.144E+6y	A	1.000E+0	Pa-233	26.967d	4.768E+0	6.810E-2	3.495E-2	Aug-1990
Np-238	2.117d	B-	1.000E+0	Pu-238	87.7y		2.519E-1	5.879E-1	Nov-2002
Np-239	2.3565d	B-	1.000E+0	Pu-239	2.411E+4y		2.623E-1	1.846E-1	Aug-1992

Table 4.1 continued from previous page (25/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.)			ENSDF date
						Alpha	Electron	Photon	
Np-240	61.9m	B-	1.000E+0	Pu-240	6564y		5.095E-1	1.054E+0	Nov-1996
Np-240m	7.22m	B-	9.989E-1	Pu-240	6564y		6.779E-1	3.225E-1	Nov-1996
		IT	1.100E-3	Np-240	61.9m				Dec-2003
Np-241	13.9m	B-	1.000E+0	Pu-241	14.35y		4.341E-1	3.954E-2	Aug-1994
Np-242	2.2m	B-	1.000E+0	Pu-242	3.75E+5y		9.027E-1	2.654E-1	Jun-2002
Np-242m	5.5m	B-	1.000E+0	Pu-242	3.75E+5y		7.551E-1	9.194E-1	Jun-2002
Plutonium									
Pu-232	33.7m	EC	7.700E-1	Np-232	14.7m	1.514E+0	8.689E-3	6.334E-2	Aug-1991
		A	2.300E-1	U-228	9.1m				May-1998
Pu-234	8.8h	EC	9.400E-1	Np-234	4.4d	3.711E-1	1.138E-2	6.934E-2	Apr-1994
		A	6.000E-2	U-230	20.8d				May-1998
Pu-235	25.3m	EC	1.000E+0	Np-235	396.1d	1.569E-4	2.279E-2	9.572E-2	Aug-1993
		A	2.700E-5	U-231	4.2d				Oct-2001
Pu-236	2.858y	A	1.000E+0	U-232	68.9y	5.753E+0	1.283E-2	2.244E-3	Aug-1991
		SF	1.370E-9						Dec-2003
Pu-237	45.2d	EC	1.000E+0	Np-237	2.144E+6y	2.257E-4	1.714E-2	5.365E-2	May-1995
		A	4.200E-5	U-233	1.592E+5y				Aug-1990
Pu-238	87.7y	A	1.000E+0	U-234	2.455E+5y	5.486E+0	1.068E-2	2.054E-3	Apr-1994
		SF	1.850E-9						Dec-2003
Pu-239	2.411E+4y	A	1.000E+0	U-235m (9.781E-1)	26m	5.148E+0	7.455E-3	1.078E-3	May-2003
				U-235 (2.189E-2)	7.04E+8y				
Pu-240	6564y	A	1.000E+0	U-236	2.342E+7y	5.156E+0	1.051E-2	1.935E-3	Aug-1991
		SF	5.750E-8						Dec-2003
Pu-241	14.35y	B-	1.000E+0	Am-241	432.2y	1.199E-4	5.238E-3	1.781E-6	Aug-1994
		A	2.450E-5	U-237	6.75d				May-1995
Pu-242	3.75E+5y	A	1.000E+0	U-238	4.468E+9y	4.892E+0	8.912E-3	1.655E-3	Nov-2002
		SF	5.540E-6						Dec-2003
Pu-243	4.956h	B-	1.000E+0	Am-243	7.37E+3y		1.729E-1	2.587E-2	Oct-1993
Pu-244	8.00E+7y	A	9.988E-1	U-240	14.1h	4.575E+0	7.193E-3	1.364E-3	May-1998
		SF	1.210E-3						Dec-2003
Pu-245	10.5h	B-	1.000E+0	Am-245	2.05h		3.190E-1	4.027E-1	Oct-1993
Pu-246	10.84d	B-	1.000E+0	Am-246m	25.0m		1.159E-1	1.431E-1	Sep-1998
Americium									
Am-237	73.0m	EC	9.998E-1	Pu-237	45.2d	1.512E-3	8.016E-2	3.714E-1	May-1995
		A	2.500E-4	Np-233	36.2m				Aug-1990
Am-238	98m	EC,B+	1.000E+0	Pu-238	87.7y	5.938E-6	4.852E-2	9.023E-1	Nov-2002
		A	1.000E-6	Np-234	4.4d				Apr-1994
Am-239	11.9h	EC	9.999E-1	Pu-239	2.411E+4y	5.767E-4	1.709E-1	2.436E-1	Aug-1992
		A	1.000E-4	Np-235	396.1d				Aug-1993
Am-240	50.8h	EC	1.000E+0	Pu-240	6564y	1.021E-5	7.576E-2	1.035E+0	Nov-1996
		A	1.900E-6	Np-236	1.54E+5y				Aug-1991
Am-241	432.2y	A	1.000E+0	Np-237	2.144E+6y	5.479E+0	3.730E-2	2.933E-2	May-1995
Am-242	16.02h	B-	8.270E-1	Cm-242	162.8d		1.806E-1	1.882E-2	Jun-2002
		EC	1.730E-1	Pu-242	3.75E+5y				Jun-2002
Am-242m	141y	IT	9.955E-1	Am-242	16.02h	2.344E-2	4.389E-2	5.623E-3	Jun-2002
		A	4.500E-3	Np-238	2.117d				Nov-2002
Am-243	7.37E+3y	A	1.000E+0	Np-239	2.3565d	5.270E+0	2.338E-2	5.852E-2	Aug-1992
Am-244	10.1h	B-	1.000E+0	Cm-244	18.10y		3.330E-1	8.052E-1	Feb-1987
Am-244m	26m	B-	9.996E-1	Cm-244	18.10y		5.187E-1	1.720E-2	Feb-1987
Am-245	2.05h	B-	1.000E+0	Cm-245	8.5E+3y		2.874E-1	3.242E-2	Oct-1993
Am-246	39m	B-	1.000E+0	Cm-246	4.76E+3y		7.241E-1	7.498E-1	Sep-1998
Am-246m	25.0m	B-	1.000E+0	Cm-246	4.76E+3y		5.033E-1	9.799E-1	Sep-1998
Am-247	23.0m	B-	1.000E+0	Cm-247	1.56E+7y		5.683E-1	1.348E-1	Oct-1993

Table 4.1 continued from previous page (26/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.)			ENSDF date
						Alpha	Electron	Photon	
Curium									
Cm-238	2.4h	EC	9.616E-1	Am-238	98m	2.494E-1	1.166E-2	8.287E-2	Nov-2003
		A	3.840E-2	Pu-234	8.8h				May-1998
Cm-239	2.9h	EC,B+	1.000E+0	Am-239	11.9h		2.907E-2	2.593E-1	Aug-1992
Cm-240	27d	A	9.970E-1	Pu-236	2.858y	6.259E+0	1.082E-2	2.214E-3	May-1998
		SF	3.900E-8						Dec-2003
Cm-241	32.8d	EC	9.900E-1	Am-241	432.2y	5.930E-2	1.342E-1	5.034E-1	Aug-1994
		A	1.000E-2	Pu-237	45.2d				May-1995
Cm-242	162.8d	A	1.000E+0	Pu-238	87.7y	6.101E+0	9.557E-3	1.983E-3	Nov-2002
		SF	6.370E-8						Dec-2003
Cm-243	29.1y	A	9.976E-1	Pu-239	2.411E+4y	5.796E+0	1.342E-1	1.353E-1	Aug-1992
		EC	2.400E-3	Am-243	7.37E+3y				Oct-1993
Cm-244	18.10y	A	1.000E+0	Pu-240	6564y	5.795E+0	7.926E-3	1.699E-3	Nov-1996
		SF	1.371E-6						Dec-2003
Cm-245	8.5E+3y	A	1.000E+0	Pu-241	14.35y	5.358E+0	8.240E-2	1.084E-1	Aug-1994
		SF	6.100E-9						Dec-2003
Cm-246	4.76E+3y	A	9.997E-1	Pu-242	3.75E+5y	5.377E+0	6.606E-3	1.353E-3	Jun-2002
		SF	2.630E-4						Dec-2003
Cm-247	1.56E+7y	A	1.000E+0	Pu-243	4.956h	4.948E+0	1.136E-2	3.138E-1	Oct-1993
Cm-248	3.48E+5y	A	9.161E-1	Pu-244	8.00E+7y	4.645E+0	6.186E-3	1.279E-3	May-1998
		SF	8.390E-2						Dec-2003
Cm-249	64.15m	B-	1.000E+0	Bk-249	330d		2.835E-1	2.000E-2	Nov-1999
Cm-250	8300y	A	1.800E-1	Pu-246	10.84d	9.135E-1	2.508E-3	3.428E-4	Nov-1998
		B-	8.000E-2	Bk-250	3.212h				Dec-2003
		SF	7.400E-1						Dec-2003
Cm-251	16.8m	B-	1.000E+0	Bk-251	55.6m		4.545E-1	1.112E-1	Nov-1999
Berkelium									
Bk-245	4.94d	EC	9.988E-1	Cm-245	8.5E+3y	7.341E-3	1.326E-1	2.352E-1	Oct-1993
		A	1.200E-3	Am-241	432.2y				Aug-1994
Bk-246	1.80d	EC	1.000E+0	Cm-246	4.76E+3y		5.544E-2	8.546E-1	Sep-1998
Bk-247	1.38E+3y	A	1.000E+0	Am-243	7.37E+3y	5.611E+0	6.911E-2	1.468E-1	Oct-1993
Bk-248m	23.7h	B-	7.000E-1	Cf-248	334d		1.910E-1	5.593E-2	Aug-1999
		EC	3.000E-1	Cm-248	3.48E+5y				Aug-1999
Bk-249	330d	B-	1.000E+0	Cf-249	351y	7.840E-5	3.240E-2	6.713E-7	Nov-1999
		A	1.450E-5	Am-245	2.05h				Oct-1993
Bk-250	3.212h	B-	1.000E+0	Cf-250	13.08y		2.949E-1	8.983E-1	Dec-2001
Bk-251	55.6m	B-	1.000E+0	Cf-251	900y		3.693E-1	9.150E-2	Nov-1999
Californium									
Cf-244	19.4m	A	1.000E+0	Cm-240	27d	7.200E+0	7.502E-3	2.049E-3	May-1998
Cf-246	35.7h	A	1.000E+0	Cm-242	162.8d	6.741E+0	5.969E-3	1.426E-3	Jun-2002
		SF	2.000E-6						Dec-2003
Cf-247	3.11h	EC	9.997E-1	Bk-247	1.38E+3y	2.210E-3	4.635E-2	1.050E-1	Oct-1993
		A	3.500E-4	Cm-243	29.1y				Oct-1993
Cf-248	334d	A	1.000E+0	Cm-244	18.10y	6.249E+0	7.328E-3	1.704E-3	May-1998
		SF	2.900E-5						Dec-2003
Cf-249	351y	A	1.000E+0	Cm-245	8.5E+3y	5.831E+0	3.995E-2	3.282E-1	Oct-1993
		SF	5.020E-9						Dec-2003
Cf-250	13.08y	A	9.992E-1	Cm-246	4.76E+3y	6.019E+0	5.590E-3	1.307E-3	Sep-1998
		SF	7.700E-4						Dec-2003
Cf-251	900y	A	1.000E+0	Cm-247	1.56E+7y	5.787E+0	1.705E-1	1.245E-1	Oct-1993
Cf-252	2.645y	A	9.691E-1	Cm-248	3.48E+5y	5.922E+0	5.608E-3	1.295E-3	Aug-1999
		SF	3.092E-2						Dec-2003
Cf-253	17.81d	B-	9.969E-1	Es-253	20.47d	1.853E-2	9.076E-2	4.832E-3	Nov-1999
		A	3.100E-3	Cm-249	64.15m				Nov-1999
Cf-254	60.5d	A	3.100E-3	Cm-250	8300y	1.806E-2	1.841E-5	4.355E-6	Dec-2001
		SF	9.969E-1						Dec-2003
Cf-255	85m	B-	1.000E+0	Es-255	39.8d		2.178E-1		Nov-1999

Table 4.1 continued from previous page (27/27)

Nuclide	$T_{1/2}$	Decay mode	Branching fraction	Product	$T_{1/2}$	Energy (MeV/n.t.)			ENSDF date
						Alpha	Electron	Photon	
Einsteinium									
Es-249	102.2m	EC,B+	9.943E-1	Cf-249	351y	3.862E-2	4.369E-2	4.129E-1	Nov-1999
		A	5.700E-3	Bk-245	4.94d				Oct-1993
Es-250	8.6h	EC	9.850E-1	Cf-250	13.08y		3.281E-1	1.224E+0	Dec-2001
Es-250m	2.22h	EC,B+	1.000E+0	Cf-250	13.08y		3.425E-2	5.549E-1	Dec-2001
Es-251	33h	EC	9.950E-1	Cf-251	900y	3.241E-2	5.221E-2	1.016E-1	Nov-1999
		A	5.000E-3	Bk-247	1.38E+3y				Apr-1994
Es-253	20.47d	A	1.000E+0	Bk-249	330d	6.627E+0	2.209E-3	8.476E-4	Nov-1999
		SF	8.900E-8						Dec-2003
Es-254	275.7d	A	1.000E+0	Bk-250	3.212h	6.422E+0	7.267E-2	2.080E-2	Dec-2001
		B-	1.740E-6	Fm-254	3.240h				Dec-2001
		SF	3.000E-8						Dec-2003
Es-254m	39.3h	B-	9.800E-1	Fm-254	3.240h	2.049E-2	2.374E-1	4.693E-1	Dec-2001
		A	3.200E-3	Bk-250	3.212h				Dec-2001
		EC	7.600E-4	Cf-254	60.5d				Dec-2001
		SF	4.500E-4						Dec-2003
Es-255	39.8d	B-	9.200E-1	Fm-255	20.07h	5.036E-1	7.329E-2		Nov-1999
		A	8.000E-2	Bk-251	55.6m				Nov-1999
		SF	4.500E-5						Dec-2003
Es-256	25.4m	B-	1.000E+0	Fm-256	157.6m		5.822E-1	3.158E-3	Aug-1999
Fermium									
Fm-251	5.30h	EC,B+	9.820E-1	Es-251	33h	1.232E-1	3.370E-2	1.588E-1	Nov-1999
		A	1.800E-2	Cf-247	3.11h				Oct-1993
Fm-252	25.39h	A	1.000E+0	Cf-248	334d	7.031E+0	6.291E-3	1.582E-3	Aug-1999
		SF	2.300E-5						Dec-2003
Fm-253	3.00d	EC	8.800E-1	Es-253	20.47d	8.220E-1	1.084E-1	7.130E-2	Nov-1999
		A	1.200E-1	Cf-249	351y				Nov-1999
Fm-254	3.240h	A	9.994E-1	Cf-250	13.08y	7.181E+0	6.439E-3	1.595E-3	Dec-2001
		SF	5.920E-4						Dec-2003
Fm-255	20.07h	A	1.000E+0	Cf-251	900y	7.017E+0	9.541E-2	1.696E-2	Nov-1999
		SF	2.300E-7						Dec-2003
Fm-256	157.6m	A	8.100E-2	Cf-252	2.645y	5.597E-1	4.502E-4	1.078E-4	Aug-1999
		SF	9.190E-1						Dec-2003
Fm-257	100.5d	A	9.979E-1	Cf-253	17.81d	6.512E+0	1.307E-1	1.220E-1	Nov-1999
		SF	2.100E-3						Dec-2003

4.1.2 Comparison with NUCDECAY

To see the differences in the decay data by the update in the ENSDF and the improvement of computational methods, the values of $T_{1/2}$ and the energies of radiations ($\sum E_i I_i$) were compared between DECDC2 and NUCDECAY. The comparisons were made for 832 radionuclides in NUCDECAY, except for the following 6 radionuclides;

(1) The decay data of ^{177}Re and ^{176}W were not included in DECDC2, since the ENSDF data sets for these nuclides were incomplete.

(2) Tantalum-180m was excluded in DECDC2, since the nuclide was assigned to be the stable one in NUBASE2003/AME2003.

(3) The decay data of ^{257}Md and ^{258}Md were not compiled in DECDC2 due to the limitation of available atomic data in EADL.

(4) The comparison of ^{97m}Nb ($T_{1/2}$ = 60 s) in NUCDECAY was not made, since the nuclide was included into the decay data of ^{97}Zr in DECDC2 due to the update of $T_{1/2}$ of ^{97m}Nb ($T_{1/2}$ = 52.7 s); $T_{1/2}$ of 52.7 s is less than the criterion of isomers in ICRP38.

An index D (%) defined in Eq. (3.1) was used to represent the differences in these values. **Figure 4.1** shows distributions of D for $T_{1/2}$ and $\sum E_i I_i$, and **Table 4.2** lists the nuclides for which the values of D exceed ± 25 %. The reasons of these discrepancies are analyzed as follows.

Table 4.2 Radionuclides with large D values

$T_{1/2}$				$\sum E_i I_i$ of all radiations			
Nuclide	D (%)	Nuclide	D (%)	Nuclide	D (%)	Nuclide	D (%)
^{115}In	1.1E+3	^{123}Te	−98.3	^{190n}Ir[1]	1.8E+3	^{80}Sr	−97.2
^{202}Pb	4.7E+2	^{60}Fe	−93.3	^{123}Te	7.4E+2	^{202}Pb	−75.1
^{32}Si	2.4E+2	^{79}Se	−78.0	^{135}Ce	1.4E+2	^{250}Es	−73.0
^{157}Tb	1.1E+2	^{250}Es	−75.6	^{238}Cm	1.1E+2	^{193}Hg	−72.7
^{41}Ca	37.3	^{108m}Ag	−69.6	^{70}Se	55.2	^{81m}Rb	−72.1
^{218}At	33.3	^{126}Sn	−56.5	^{120m}I	47.6	^{126}Ba	−69.4
^{138}La	32.4	^{194}Hg	−40.9	^{195m}Ir	43.2	^{194}Tl	−46.4
^{121m}Sn	25.3	^{59}Ni	−25.7	^{250}Cm	41.6	^{162}Yb	−42.2
		^{236}Np	−25.3	^{199}Pb	39.4	^{180}Os	−40.8
				^{81}Kr	35.7	^{189}Pt	−35.2
				^{133m}Te	34.3	^{104m}Ag	−33.7
				^{89m}Nb	31.9	^{174}Ta	−31.1
				^{234}Np	29.6	^{173}Lu	−29.7
				^{234}Pa	28.7	^{194}Os	−29.4
				^{170}Hf	25.8	^{116}Te	−27.7
				^{173}Ta	25.5	^{185}Ir	−27.0
						^{153}Tb	−26.8

[1] Isomers are identified in order of increasing excitation energy by appending "m" and "n" to the mass number.

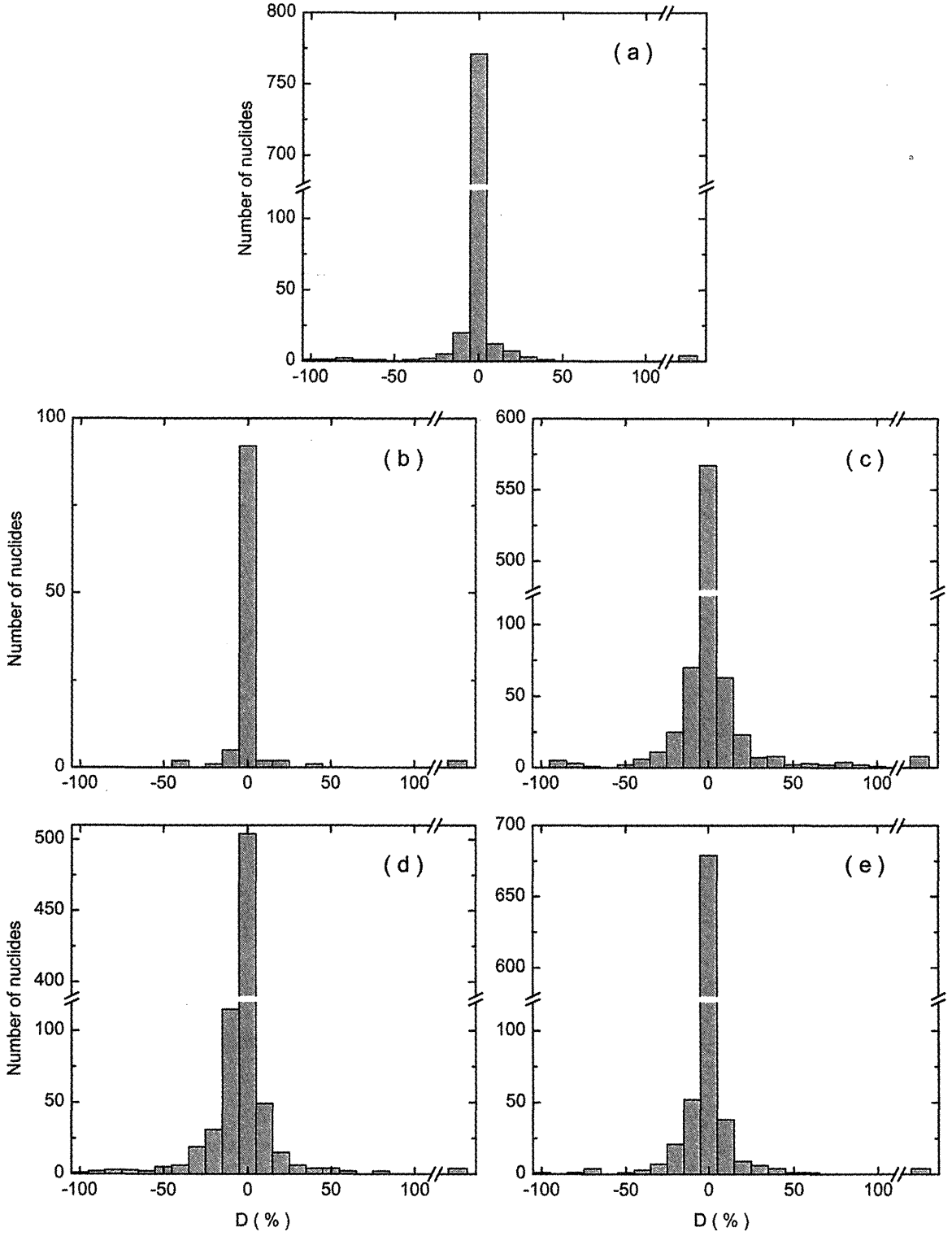
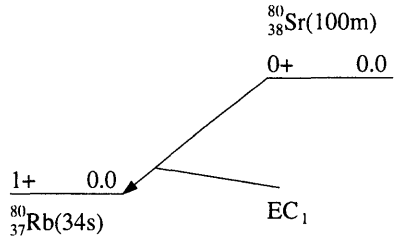


Fig. 4.1 Histograms of D for (a) $T_{1/2}$, (b) $\sum E_i I_i$ of α particles, (c) $\sum E_i I_i$ of electrons, (d) $\sum E_i I_i$ of photons, and (e) $\sum E_i I_i$ of all radiations

(a) NUCDECAY



(b) DECDC2

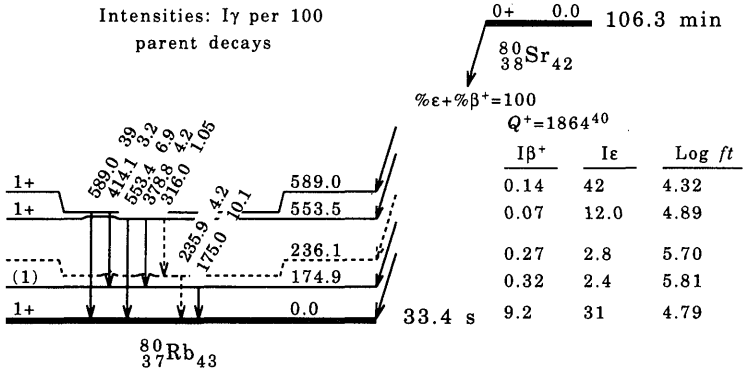


Fig. 4.2 Decay schemes of ^{80}Sr in (a) NUCDECAY and (b) DECDC2. The energy of the levels is in keV.

· **Half-life values**

Figure 4.1(a) shows the distribution of D for $T_{1/2}$. In most nuclides, the values of $T_{1/2}$ show good agreement between DECDC2 and NUCDECAY, and the D values are within ± 25 % for 816 nuclides. However, the values of D exceed ± 50 % in the long-lived nuclides, as listed in **Table 4.2**, whose accurate measurement of $T_{1/2}$ is difficult: ^{115}In (NUCDECAY 5.1E+15 y → DECDC2 4.41E+14 y); ^{202}Pb (3E+5 y → 5.25E+4 y); ^{123}Te (1E+13 y → 6.00E+14 y); ^{60}Fe (1E+6 y → 1.5E+6 y).

· **Total energy of radiations**

Figures 4.1(b)–(e) shows the distributions of D for $\sum E_i I_i$ of emitted radiations. The values of $\sum E_i I_i$ of DECDC2 generally agree with those in NUCDECAY, but significant differences are found for several nuclides. The differences in $\sum E_i I_i$ are mainly attributable to the revision of the decay scheme. For instance, as shown in **Fig. 4.2**, ^{80}Sr decays by electron capture with 100 % and transfers to the ground state of ^{80}Rb in NUCDECAY. On the other hand, the decay scheme was revised to transfer to the four excited states (174.9, 236.1, 553.5 and 589.0 keV) of ^{80}Rb, as well as the ground state. The γ-rays from the excited states and the associated radiations consequently increased the value of $\sum E_i I_i$.

Other updates which affect the difference of $\sum E_i I_i$ are the alpha decay branch in ^{202}Pb, and the revision of the electron capture to positron ratio of electron capture decay in ^{135}Ce. The update of Q_i values also contributes to the increase in $\sum E_i I_i$.

A significant discrepancy in $\sum E_i I_i$ of ^{190n}Ir is attributable to the difference in the treatment of isomer. **Figure 4.3** shows the decay scheme of ^{190n}Ir. Iridium-190n transforms 91.4 % through electron capture

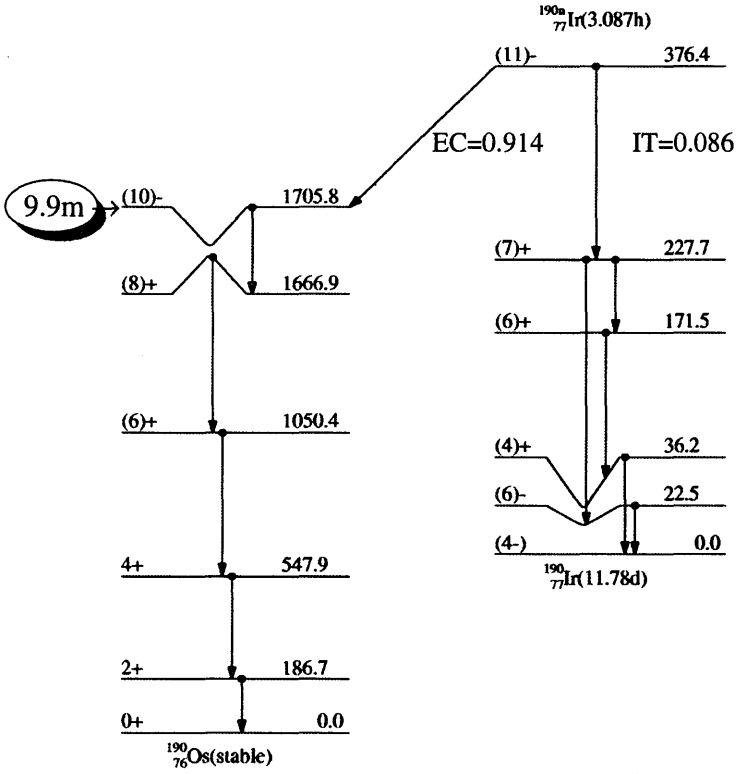


Fig. 4.3 Decay scheme of ^{190n}Ir. The energy of levels is in keV.

(EC) and 8.6 % through isomeric transition (IT). The electron capture of ^{190n}Ir transfers the excited state (1705.8 keV) in ^{190}Os; $T_{1/2}$ of the level is 9.9 min. According to the definition of ICRP38 discussed in **Section 2.1**, the radiations of the transition from this level should be excluded from the decay data of ^{190n}Ir. While DECDC2 follows the definition of ICRP38, NUCDECAY includes the radiations from the transition in the decay data of ^{190n}Ir. It caused the difference in $\sum E_i I_i$ of ^{190n}Ir between DECDC2 and NUCDECAY.

4.1.3 Influence of Update of Decay Data on Dose Calculation

To reveal the influence of the decay data revision, effective dose due to inhalation of ^{80}Sr was calculated using the decay data of DECDC2 and NUCDECAY. Strontium-80 was chosen for this comparison since the significant change in $\sum E_i I_i$ was found in this nuclide (**Fig. 4.2**). The summary of the decay data for ^{80}Sr is listed in **Table 4.3**.

The calculation was carried out using the computer program LUDEP[13] for the conditions of inhalation of a 5 μm AMAD (Activity Median Aerodynamic Diameter) aerosol by a normal nose-breathing adult male worker performing light work. Type S (slow) was selected for the rate of particle dissolution and subsequent uptake in the blood. The integration time following inhalation was 50 y. Strontium-80 produces the radioactive decay product ^{80}Rb. In this calculation, however, the dose from ^{80}Rb was not taken into account in order to determine the discrepancy of the dose due to the update of decay data in ^{80}Sr.

The result is shown in **Table 4.3**. The effective dose integrated over 50 y, $E(50)$, per unit activity of ^{80}Sr calculated using DECDC2 is 6.9 times that calculated using NUCDECAY. It is found that the effective dose is obviously increased by the update of the decay data of ^{80}Sr.

Table 4.3 Comparison of effective dose for ^{80}Sr

	Source of decay data	
	DECDC2	NUCDECAY
$T_{1/2}$	106.3 m	100 m
$\sum E_i I_i$ (MeV) of		
· γ-rays, annihilation photons and X-rays	4.37×10^{-1}	8.00×10^{-3}
· $\beta^{\pm}$ particles, internal conversion electrons and Auger electrons	4.18×10^{-2}	5.40×10^{-3}
$E(50)$ (Sv per Bq)	2.5×10^{-11}	3.6×10^{-12}
Ratio $\frac{E(50)_{\mathrm{DECDC2}}}{E(50)_{\mathrm{NUCDECAY}}}$	6.9	

4.2 Comparison with Experimental Data and Evaluated Libraries for Quality Assurance

Quality assurance of the compiled data in DECDC2 is a significant issue relating to the reliability of dose calculation. Eq. (2.1) provides the index for checking internal consistency of the ENSDF data sets. In addition, comparisons with experimental data and evaluated libraries are useful for the validation of the compiled data in the present study. In this section, the comparisons with the data from selected sources are made for the verification of reliability of the data in DECDC2.

4.2.1 Half-life Values

The measurement and evaluation of $T_{1/2}$ values have been conducted to assure the quality of radioactivity standards. The values of $T_{1/2}$ of several radionuclides have been measured in the Radioactivity Group[96] of the US National Institute of Standards and Technology (NIST). The critical evaluation of $T_{1/2}$, as well as energies and intensities of X-rays and γ-rays, has been made for selected radionuclides for detector calibration by a Co-ordinated Research Project (CRP)[97,98] of IAEA. The $T_{1/2}$ values from DECDC2 are compared with those in the two compilations.

The first evaluation by the IAEA-CRP, TECDOC-619,[97] included $T_{1/2}$ and X-ray and γ-ray data for 39 radionuclides. Update of TECDOC-619, which is considering 62 radionuclides, is now being carried out and a new set of recommended data is being prepared for publication. Of these evaluations, the $T_{1/2}$ values were published in 2003,[98] and are used for the present comparison.

Table 4.4 compares $T_{1/2}$ of DECDC2 with the evaluated values at NIST and IAEA-CRP. It is noted for the NIST measurement that the two values of $T_{1/2}$ for ^{99m}Tc reflect the influence of the different valence states of the technetium in acid and saline solution.[96] For most radionuclides, the values of $T_{1/2}$ in DECDC2 are in reasonable agreement with the those of NIST and IAEA-CRP. Discrepancies beyond the uncertainties are found for several nuclides, such as ^{177}Lu and ^{207}Bi; the maximum difference is 4 % in ^{207}Bi.

Table 4.4 Comparison of half-life values with the NIST and IAEA data

Nuclide	DECDC2	NIST measurement	IAEA evaluation
^{3}H	12.32 y (4500 d)[1]	4500 ± 8 d	
^{18}F	109.77 m (1.8295 h)	1.82951 ± 0.00034 h	
^{22}Na	2.6019 y (950.32 d)	950.97 ± 0.15 d	950.57 ± 0.23 d
^{24}Na	14.9590 h (0.62329 d)	14.9512 ± 0.0032 h	0.62329 ± 0.00009 d
^{32}P	14.263 d	14.263 ± 0.003 d	
^{40}K	1.251E+9 y (4.569E+11 d)[2]		4.563E+11 ± 1.3E+9 d
^{46}Sc	83.79 d	83.831 ± 0.066 d	83.79 ± 0.04 d
^{51}Cr	27.7025 d	27.7010 ± 0.0012 d	27.7009 ± 0.0020 d
^{54}Mn	312.12 d	312.028 ± 0.034 d	312.29 ± 0.26 d
^{55}Fe	2.737 y (999.7 d)		1002.7 ± 2.3 d
^{56}Mn	2.5789 h (0.10745 d)		0.107449 ± 0.000019 d
^{56}Co	77.23 d		77.20 ± 0.08 d
^{57}Co	271.74 d	272.11 ± 0.26 d	271.80 ± 0.05 d
^{58}Co	70.86 d	70.77 ± 0.11 d	70.86 ± 0.06 d
^{59}Fe	44.495 d	44.5074 ± 0.0072 d	44.494 ± 0.013 d
^{60}Co	5.2713 y (1925.4 d)	1925.20 ± 0.25 d	1925.23 ± 0.27 d
^{62}Cu	9.673 m	9.6725 ± 0.0080 m	
^{64}Cu	12.700 h (0.52917 d)		0.52929 ± 0.00018 d
^{65}Zn	244.06 d	244.164 ± 0.099 d	243.86 ± 0.20 d
^{66}Ga	9.49 h (0.395 d)		0.3909 ± 0.0025 d
^{67}Ga	3.2612 d	3.26154 ± 0.00054 d	3.2614 ± 0.0004 d
^{68}Ga	67.71 m (0.04702 d)		0.04703 ± 0.00007 d
^{75}Se	119.779 d	119.809 ± 0.066 d	119.778 ± 0.029 d
^{85}Kr	10.756 y (3928.5 d)	3935.7 ± 1.2 d	3927 ± 8 d
^{85}Sr	64.84 d	64.8530 ± 0.0081 d	64.851 ± 0.005 d
^{88}Y	106.65 d	106.626 ± 0.044 d	106.625 ± 0.024 d
^{93m}Nb	16.13 y (5892 d)		5.74E+3 ± 2.2E+2 d
^{94}Nb	2.03E+4 y (7.41E+6 d)		7.3E+6 ± 9E+5 d
^{95}Nb	34.991 d		34.985 ± 0.012 d
^{99}Mo	65.94 h (2.748 d)	65.9239 ± 0.0058 h	2.7490 ± 0.0010 d
^{99m}Tc	6.015 h (0.2506 d)	6.00718 ± 0.00087 h[3]	0.250281 ± 0.000022 d
		6.0123 ± 0.0032 h[4]	
^{103}Ru	39.26 d	39.310 ± 0.044 d	39.247 ± 0.013 d
^{106}Ru	373.59 d		371.8 ± 1.8 d
^{106}Rh	29.80 s (0.0003449 d)		0.000348 ± 0.000004 d
^{109}Cd	461.4 d	463.26 ± 0.63 d	461.4 ± 1.2 d
^{110m}Ag	249.76 d	249.950 ± 0.024 d	249.85 ± 0.10 d
^{111}In	2.8047 d	2.80477 ± 0.00053 d	2.8049 ± 0.0006 d
^{113}Sn	115.09 d	115.079 ± 0.080 d	115.09 ± 0.04 d
^{117m}Sn	13.76 d	14.00 ± 0.05 d	
^{123}I	13.27 h (0.5529 d)	13.2235 ± 0.0019 h	0.55095 ± 0.00015 d

[1] The values in the parentheses were calculated using: 1 d = 24 h, 1 y = 365.2422 d.

[2] Read as 4.569×10^{11} d.

[3] Normal saline solution.

[4] Acid.

Table 4.4 continued from previous page

Nuclide	DECDC2	NIST measurement	IAEA evaluation
^{123m}Te	119.25 d		119.45 ± 0.25 d
^{125}Sb	2.75856 y (1007.54 d)	1007.56 ± 0.10 d	1007.48 ± 0.21 d
^{125}I	59.400 d	59.49 ± 0.13 d	59.402 ± 0.014 d
^{127}Xe	36.4 d	36.3446 ± 0.0028 d	
^{129}I	1.57E+7 y (5.73E+9 d)		5.87E+9 ± 2.2E+8 d
^{131}I	8.02070 d	8.0197 ± 0.0022 d	8.0230 ± 0.0022 d
^{131m}Xe	11.84 d	11.934 ± 0.021 d	
^{133}Ba	10.52 y (3842 d)	3854.7 ± 2.8 d	3848.7 ± 1.2 d
^{133}Xe	5.243 d	5.24747 ± 0.00045 d	
^{134}Cs	2.0648 y (754.15 d)	753.88 ± 0.15 d	753.5 ± 1.0 d
^{137}Cs	30.1671 y (11018.6 d)	11018.3 ± 0.5 d	1.099E+4 ± 4E+1 d
^{139}Ce	137.641 d	137.734 ± 0.091 d	137.642 ± 0.020 d
^{140}Ba	12.752 d	12.7527 ± 0.0023 d	
^{140}La	1.6781 d (40.274 d)	40.293 ± 0.012 h	
^{141}Ce	32.508 d	32.510 ± 0.024 d	32.503 ± 0.014 d
^{144}Ce	284.91 d	284.534 ± 0.032 d	285.1 ± 0.6 d
^{152}Eu	13.537 y (4944.3 d)	4947.2 ± 1.1 d	4941 ± 5 d
^{153}Gd	240.4 d	239.472 ± 0.069 d	
^{153}Sm	46.50 h (1.938 d)	46.2853 ± 0.0014 h	1.938 ± 0.010 d
^{154}Eu	8.593 y (3139 d)	3145.2 ± 1.1 d	3138.1 ± 1.4 d
^{155}Eu	4.7611 y (1739.0 d)	1739.06 ± 0.45 d	1736 ± 6 d
^{166}Ho	26.80 h (1.117 d)	26.794 ± 0.023 h	1.1165 ± 0.0013 d
^{166m}Ho	1.20E+3 y (4.38E+5 d)		4.4E+5 ± 7E+4 d
^{169}Yb	32.026 d	32.0147 ± 0.0093 d	32.016 ± 0.006 d
^{170}Tm	128.6 d		127.8 ± 0.8 d
^{177}Lu	6.647 d	6.64 ± 0.01 d	
^{181}W	121.2 d	121.095 ± 0.064 d	
^{186}Re	3.7183 d (89.239 h)	89.248 ± 0.069 h	
^{188}Re	17.0040 h	17.001 ± 0.022 h	
^{188}W	69.78 d	69.783 ± 0.048 d	
^{192}Ir	73.827 d	73.810 ± 0.019 d	73.826 ± 0.010 d
^{195}Au	186.098 d	186.098 ± 0.047 d	
^{198}Au	2.69517 d	2.69517 ± 0.00021 d	2.6950 ± 0.0007 d
^{201}Tl	72.912 h (3.0380 d)	3.0456 ± 0.0015 d	3.0422 ± 0.0017 d
^{202}Tl	12.23 d	12.466 ± 0.081 d	
^{203}Hg	46.612 d	46.619 ± 0.027 d	46.594 ± 0.012 d
^{203}Pb	51.873 h	51.923 ± 0.037 h	
^{207}Bi	32.9 y (12020 d)	11523. ± 15. d	1.18E+4 ± 3E+2 d
^{226}Ra	1600 y (5.844E+5 d)		5.862E+5 ± 2.2E+3 d
^{228}Th	1.9116 y (698.20 d)	698.60 ± 0.36 d	698.60 ± 0.23 d
^{234m}Pa	1.17 m (0.000813 d)		0.000805 ± 0.000011 d
^{241}Am	432.2 y (1.579E+5 d)		1.582E+5 ± 4E+2 d
^{243}Am	7.37E+3 y (2.69E+6 d)		2.692E+6 ± 8E+3 d

4.2.2 X-ray and γ-ray Data

The IAEA-CRP has been evaluating a recommended set of data for specific radionuclides that are identified as appropriate for the calibration of equipment used to measure X-ray and γ-ray emissions.[97,99,100] As mentioned in **Section 4.2.1**, the update of X-ray and γ-ray data in TECDOC-619[97] is now under progress.[100] Thus, the data in the first compilation of TECDOC-619 are used in the present comparison.

Table 4.5 shows comparisons for K and L X-ray data. The notation of X-rays is presented in **Appendix A**. Agreement was found in E_i of X-ray between DECDC2 and the IAEA data. The E_i of X-ray in DECDC2 were calculated using EADL from the difference in the atomic-electron binding energies of the two states, where the electron transition occurs. The agreement suggests the reliability of atomic-electron binding energies of EADL.

The values of I_i of X-ray are generally in good agreement between DECDC2 and the IAEA evaluation for elements of low and intermediate atomic numbers, and the disagreement is less than 10 %. However, it should be noted that a discrepancy of about 25 % was found in the L X-ray data of ^{241}Am. It has been pointed out[101] that theoretical calculation and experimental data show some discrepancies for I_i of L X-rays of ^{241}Am. The reason identified is that the theoretical internal conversion coefficients (ICC) do not reproduce distributions of vacancies in electron orbits that satisfy I_i of the experimental L X-ray data for ^{241}Am.

Schönfeld et al.[102] studied the values of ICC that reproduce the measured I_i of ^{241}Am. **Tables 4.6** and **4.7** compare the data used in the present and Schönfeld's calculations for significant transitions for the emission of L X-rays. Reasonable agreements are found for E_γ, I_γ, multipolarities, and mixing ratios used in the two calculations. However, critical differences are identified in the ICC of three L subshells, α_L, for the γ transition of 59.5409 keV. The α_L values in **Table 4.6** were calculated from the built-in theoretical data by Rösel et al.[46] while those in **Table 4.7** were evaluated from experimental data. This is the basis[101] for the difference in I_i of L X-ray in ^{241}Am between the theoretical calculation and the experiment data.

The latest compilation for α_L were published by Band et al.[103] in 2002. The values of α_{L1}, α_{L2} and α_{L3} for Np, which are used for the calculation of L X-ray data in the α decay of ^{241}Am, are consistent with those of Rösel et al.[46] and are different from the values of **Table 4.7**. It indicates that the agreement between the theoretical and experimental values of I_i for the L X-ray from ^{241}Am remains inadequate. Although it might not be significant for organ dose calculation, the above discrepancy should be considered when applying the calculated data to quantitative assay of radionuclide content by photon spectroscopy.

Table 4.8 shows comparison of the γ-ray data between DECDC2 and IAEA-TECDOC-619. Good agreements are found in E_i and I_i in most γ-rays. Disagreement that exceeds the level of 1 % are observed in several emissions with small I_i values.

Table 4.5 Comparison of energies and intensities of X-rays

		DECDC2		IAEA-TECDOC-619	
Nuclide	Transition	E_i (keV)	I_i	E_i (keV)	I_i
^{51}Cr	V K_α	4.91	0.194	4.95	0.201
	V K_β	5.39	0.022	5.43	0.027
^{54}Mn	Cr K_α	5.37	0.217	5.41	0.226
	Cr K_β	5.91	0.025	5.95	0.030
^{55}Fe	Mn K_α	5.86	0.240	5.89	0.249
	Mn K_β	6.45	0.029	6.49	0.034
^{57}Co	Fe K_α	6.36	0.489	6.40	0.510
	Fe K_β	7.02	0.059	7.06	0.069
^{58}Co	Fe K_α	6.36	0.227	6.40	0.235
	Fe K_β	7.02	0.027	7.06	0.032
^{65}Zn	Cu K_α	8.00	0.336	8.03–8.05	0.341
	Cu K_β	8.86	0.041	8.91	0.046
^{75}Se	As K_α	10.49	0.480	10.51–10.54	0.493
	As K_β	11.69	0.066	11.72–11.95	0.075
^{85}Sr	Rb K_α	13.33	0.501	13.34–13.40	0.500
	Rb K_β	14.94	0.080	14.96–15.29	0.087
^{88}Y	Sr K_α	14.10	0.511	14.10–14.17	0.522
	Sr K_β	15.82	0.085	15.83–16.19	0.094
^{93m}Nb	Nb K_α	16.55	0.0945	16.52–16.62	0.0925
	Nb K_β	18.63	0.0173	18.62–19.07	0.0179
^{109}Cd	Ag K_α	22.08	0.842	21.99–22.16	0.821
	Ag K_β	25.00	0.171	24.93–25.60	0.173
^{111}In	Cd K_α	23.08	0.690	22.98–23.17	0.684
	Cd K_β	26.16	0.141	26.09–26.80	0.146
^{113}Sn	In K_α	24.12	0.809	24.00–24.21	0.796
	In K_β	27.35	0.168	27.27–28.02	0.172
^{125}I	Te K_α	27.37	1.160	27.20–27.47	1.135
	Te K_β	31.10	0.249	30.98–31.88	0.255
^{137}Cs	Ba K_α	32.07	0.0582	31.82–32.19	0.0566
	Ba K_β	36.52	0.0129	36.36–37.45	0.0134

Table 4.5 continued from previous page

		DECDC2		IAEA-TECDOC-619	
Nuclide	Transition	E_i (keV)	I_i	E_i (keV)	I_i
^{133}Ba	Cs K_α	30.85	0.989	30.63–30.97	0.980
	Cs K_β	35.12	0.218	34.97–36.01	0.230
^{139}Ce	La K_α	33.31	0.668	33.03–33.44	0.643
	La K_β	37.96	0.150	37.78–38.93	0.154
^{152}Eu	Sm K_α	39.95	0.594	39.52–40.12	0.591
	Gd K_α	42.81	0.00707	42.31–43.00	0.00648
	Sm K_β	45.64	0.139	45.38–46.82	0.149
	Gd K_β	48.95	0.00167	48.65–50.21	0.00176
^{154}Eu	Gd K_α	42.81	0.206	42.31–43.00	0.205
	Gd K_β	48.95	0.049	48.65–50.21	0.051
^{198}Au	Hg K_α	70.34	0.0220	68.89–70.82	0.0219
	Hg K_β	80.84	0.0057	80.12–82.78	0.0061
^{203}Hg	Tl L	11.40	0.056	8.95–14.40	0.060
	Tl $K_{\alpha 2}$	71.05	0.039	70.83	0.038
	Tl $K_{\alpha 1}$	73.14	0.066	72.87	0.064
	Tl $K_{\beta' 1}$	82.71	0.022	82.43	0.022
	Tl $K_{\beta' 2}$	85.16	0.0052	85.19	0.0063
^{207}Bi	Pb L	11.69	0.338	9.19–14.91	0.325
	Pb $K_{\alpha 2}$	73.04	0.218	72.80	0.226
	Pb $K_{\alpha 1}$	75.25	0.366	74.97	0.382
	Pb $K_{\beta' 1}$	85.08	0.122	84.79	0.130
	Pb $K_{\beta' 2}$	87.62	0.029	87.63	0.039
^{241}Am	Np L_ℓ	11.91	0.0103	11.871	0.0085
	Np L_α	13.94	0.162	13.927	0.132
	Np $L_{\beta\eta}$	17.52	0.166	17.611	0.194
	Np L_γ	21.12	0.036	20.997	0.049

Table 4.6 Data used for calculating L X-ray intensities from ^{241}Am in DECDC2

E_γ (keV)	I_γ	Multipolarity and mixing ratio	α_{L1}	α_{L2}	α_{L3}	$\Sigma\alpha_L$
59.5409	0.3578	E1	0.306	0.279	0.283	0.868
33.1963	0.00121	M1 + 1.7 % E2	93	28.2	17.5	139
26.3446	0.024	E1	1.07	2.10	2.75	5.92

Table 4.7 Data used for calculating L X-ray intensities from ^{241}Am in Schönfeld's calculation[102)]

E_γ (keV)	I_γ	Multipolarity and mixing ratio	α_{L1}	α_{L2}	α_{L3}	$\Sigma\alpha_L$
59.5409	0.3578	E1	0.227	0.443	0.124	0.794
33.1963	0.00121	M1 + 1.7 % E2	94	26.6	18	138.6
26.3446	0.024	E1	1.23	2.44	1.48	5.15

Table 4.8 Comparison of energies and intensities of γ-rays

	DECDC2		IAEA-TECDOC-619		D (%)	
Nuclide	E_i (keV)	I_i	E_i (keV)	I_i	E_i	I_i
^{22}Na	1274.53	0.99944	1274.542	0.99935	0.00	0.01
^{24}Na	1368.63	1.00000	1368.633	0.999936	0.00	0.01
	2754.03	0.99944	2754.030	0.99855	0.00	0.09
^{46}Sc	889.277	0.999838	889.277	0.999844	0.00	0.00
	1120.55	0.999908	1120.545	0.999874	0.00	0.00
^{51}Cr	320.082	0.0992	320.0842	0.0986	0.00	0.63
^{54}Mn	834.848	0.999755	834.843	0.999758	0.00	0.00
^{56}Co	846.771	0.99935	846.764	0.99933	0.00	0.00
	1037.84	0.1417	1037.844	0.1413	0.00	0.28
	1175.10	0.02288	1175.099	0.02239	0.00	2.19
	1238.28	0.6690	1238.287	0.6607	0.00	1.26
	1360.22	0.04290	1360.206	0.04256	0.00	0.80
	1771.35	0.1547	1771.350	0.1549	0.00	−0.13
	2015.18	0.03040	2015.179	0.03029	0.00	0.36
	2034.75	0.07890	2034.759	0.07771	0.00	1.53
	2598.46	0.1730	2598.460	0.1696	0.00	2.00
	3201.96	0.0332	3201.954	0.0313	0.00	6.07
	3253.42	0.0812	3253.417	0.0762	0.00	6.56
	3272.99	0.0193	3272.998	0.0178	0.00	8.43
	3451.15	0.0097	3451.154	0.0093	0.00	4.52
	3547.93	0.00200	3548.27	0.00178	−0.01	12.36
^{57}Co	14.4129	0.0916	14.4127	0.0916	0.00	0.00
	122.061	0.8560	122.0614	0.8560	0.00	0.00
	136.474	0.1068	136.4743	0.1068	0.00	0.00
^{58}Co	810.759	0.9945	810.775	0.9945	0.00	0.00
^{60}Co	1173.23	0.99850	1173.238	0.99857	0.00	−0.01
	1332.49	0.99983	1332.502	0.99983	0.00	0.00
^{65}Zn	1115.54	0.5060	1115.546	0.5060	0.00	0.00
^{75}Se	96.7340	0.0342	96.7344	0.0341	0.00	0.30
	121.116	0.172	121.1171	0.171	0.00	0.58
	136.000	0.583	136.0008	0.588	0.00	−0.93
	264.658	0.5890	264.6580	0.590	0.00	−0.17
	279.542	0.250	279.5431	0.250	0.00	−0.03
	400.657	0.115	400.6593	0.115	0.00	−0.28
^{85}Sr	514.007	0.957	514.0076	0.984	0.00	−2.73
^{88}Y	898.042	0.937	898.042	0.940	0.00	−0.34
	1836.06	0.9924	1836.063	0.9936	0.00	−0.12

Table 4.8 continued from previous page

	DECDC2		IAEA-TECDOC-619		D (%)	
Nuclide	E_i (keV)	I_i	E_i (keV)	I_i	E_i	I_i
^{94}Nb	702.622	0.9790	702.645	0.9979	0.00	−1.89
	871.091	0.9990	871.119	0.9986	0.00	0.04
^{95}Nb	765.803	0.9981	765.807	0.9981	0.00	0.00
^{109}Cd	88.0336	0.0359	88.0341	0.0363	0.00	−0.98
^{111}In	171.28	0.9065	171.28	0.9078	0.00	−0.14
	245.35	0.9409	245.35	0.9416	0.00	−0.07
^{113}Sn	391.698	0.6494	391.702	0.6489	0.00	0.08
^{125}Sb	176.314	0.0689	176.313	0.0685	0.00	0.54
	380.452	0.01527	380.452	0.01518	0.00	0.59
	427.874	0.298	427.875	0.297	0.00	0.34
	463.365	0.1056	463.365	0.1048	0.00	0.80
	600.597	0.1777	600.600	0.1773	0.00	0.21
	606.713	0.0502	606.718	0.0500	0.00	0.31
	635.950	0.1129	635.954	0.1121	0.00	0.75
^{125}I	35.4922	0.0668	35.4919	0.0658	0.00	1.52
^{134}Cs	475.365	0.0149	475.364	0.0149	0.00	−0.27
	563.246	0.0835	563.240	0.0836	0.00	−0.12
	569.331	0.1538	569.328	0.1539	0.00	−0.06
	604.721	0.9762	604.720	0.9763	0.00	−0.01
	795.864	0.855	795.859	0.854	0.00	0.15
	801.953	0.0869	801.948	0.0869	0.00	0.00
	1038.61	0.00988	1038.610	0.00990	0.00	−0.20
	1167.97	0.01789	1167.968	0.01792	0.00	−0.17
	1365.19	0.03014	1365.185	0.03016	0.00	−0.07
^{137}Cs	661.657	0.847	661.660	0.851	0.00	−0.45
^{133}Ba	80.997	0.3406	80.998	0.3411	0.00	−0.15
	276.400	0.07164	276.398	0.07147	0.00	0.24
	302.851	0.1833	302.853	0.1830	0.00	0.16
	356.013	0.6205	356.017	0.6194	0.00	0.18
	383.848	0.08940	383.851	0.08905	0.00	0.39
^{139}Ce	165.858	0.7894	165.857	0.7987	0.00	−1.17
^{152}Eu	121.782	0.2867	121.7824	0.2837	0.00	1.05
	244.698	0.0761	244.6989	0.0753	0.00	1.02
	344.279	0.2656	344.2811	0.2657	0.00	−0.05
	411.116	0.02237	411.126	0.02238	0.00	−0.03
	443.965	0.03158	443.965	0.03125	0.00	1.04
	778.904	0.1296	778.903	0.1297	0.00	−0.07
	867.373	0.04258	867.390	0.04214	0.00	1.05
	964.079	0.1465	964.055	0.1463	0.00	0.13

continued to next page

Table 4.8 continued from previous page

Nuclide	DECDC2		IAEA-TECDOC-619		D (%)	
	E_i (keV)	I_i	E_i (keV)	I_i	E_i	I_i
^{152}Eu	continued from previous page					
	1085.87	0.1024	1085.842	0.1013	0.00	1.07
	1089.74	0.01730	1089.767	0.01731	0.00	−0.07
	1112.07	0.1369	1112.087	0.1354	0.00	1.07
	1212.95	0.01426	1212.970	0.01412	0.00	1.01
	1299.14	0.01625	1299.152	0.01626	0.00	−0.04
	1408.01	0.2107	1408.022	0.2085	0.00	1.05
^{154}Eu	123.071	0.406	123.071	0.412	0.00	−1.56
	247.930	0.0691	247.930	0.0695	0.00	−0.51
	591.762	0.0496	591.762	0.0499	0.00	−0.56
	692.425	0.0179	692.425	0.0180	0.00	−0.46
	723.305	0.201	723.305	0.202	0.00	−0.46
	756.804	0.0454	756.804	0.0458	0.00	−0.83
	873.190	0.1220	873.190	0.1224	0.00	−0.31
	996.262	0.1053	996.262	0.1048	0.00	0.50
	1004.72	0.1791	1004.725	0.182	0.00	−1.62
	1274.44	0.350	1274.436	0.350	0.00	−0.02
	1494.05	0.0070	1494.048	0.0071	0.00	−1.43
	1596.50	0.0179	1596.495	0.0181	0.00	−1.21
^{198}Au	411.802	0.9558	411.8044	0.9557	0.00	0.01
^{203}Hg	279.197	0.8146	279.1967	0.8148	0.00	−0.02
^{207}Bi	569.698	0.9776	569.702	0.9774	0.00	0.02
	1063.66	0.746	1063.662	0.745	0.00	0.13
	1770.23	0.0687	1770.237	0.0687	0.00	0.00
^{228}Th	84.3730	0.01220	84.373	0.01222	0.00	−0.16
	238.632	0.433	238.632	0.435	0.00	−0.46
	240.986	0.0410	240.987	0.0410	0.00	0.00
	277.358	0.0227	277.358	0.0230	0.00	−1.45
	300.087	0.0328	300.094	0.0325	0.00	0.86
	510.77	0.0813	510.77	0.0818	0.00	−0.67
	583.191	0.304	583.191	0.306	0.00	−0.77
	727.330	0.0658	727.330	0.0669	0.00	−1.66
	860.564	0.0447	860.564	0.0450	0.00	−0.77
	1620.50	0.0149	1620.735	0.0149	−0.01	−0.26
	2614.53	0.3564	2614.533	0.3586	0.00	−0.62
^{239}Np	106.123	0.272	106.123	0.267	0.00	1.87
	228.167	0.1127	228.183	0.1112	−0.01	1.35
	277.599	0.1438	277.599	0.1431	0.00	0.49
^{241}Am	26.345	0.024	26.345	0.024	0.00	0.00
	59.541	0.359	59.537	0.360	0.01	−0.28
^{243}Am	43.53	0.0593	43.53	0.0594	0.00	−0.11
	74.66	0.682	74.66	0.674	0.00	1.19

4.2.3 Beta Particle Spectra

The International Commission on Radiation Units and Measurements (ICRU) provided in its report No. 56[104] (ICRU56) β particle spectra of selected nuclides for β-particle dosimetry in radiation protection. In ICRU56, the relative number of β particles per MeV, $N(W)$, was calculated by the following equation:[105]

$$N(W) = p \cdot W \cdot (W_0 - W)^2 \cdot F(Z,W) \cdot a_n(Z,W), \tag{4.1}$$

where p is the electron momentum in units of $m_e c^2$ (m_e is the electron mass, and c is the velocity of light), W is the total energy of the electron (kinetic energy + $m_e c^2$) in units of $m_e c^2$, W_0 is the corresponding value at the maximum electron energy, $F(Z,W)$ is the Fermi factor (Z is the atomic number of the daughter nucleus), and $a_n(Z,W)$ is a shape factor for a transition of order of forbiddenness n.

Figure 4.4 compares β particle spectra between DECDC2 and those listed in Appendix D of ICRU56. The β particle spectra in DECDC2, denoted as "Present", are in good agreement with those of ICRU56, except for ^{137}Cs, ^{204}Tl and ^{210}Bi. The discrepancy in the three radionuclides is attributed to shape correction of spectra.

Beta particle spectra are classified into various degrees of forbiddenness depending on the J and π changes that occur between the initial and final nuclear levels, as listed in **Table 2.1**. **Figure 4.5** shows the decay scheme of ^{137}Cs. The discrepancy found in the β particle spectra of ^{137}Cs in **Fig. 4.4** is due to the transition of β_1^- in **Fig. 4.5**. The transition is $\Delta J = 2$ and $\Delta\pi$ = yes, and is therefore assigned to the first forbidden unique. **Figure 4.6** compares β particles spectra of DECDC2, ICRU56, Cross et al.[106] and Mantel.[107] The spectra of DECDC2, Cross et al., and Mantel were calculated by applying $a_n(Z,W)$ for the first forbidden unique transition. It is obvious that the β particle spectrum in DECDC2 is consistent with those by Cross et al. and Mantel; it indicates that $a_n(Z,W)$ adopted for the spectrum of DECDC2 is correct. The appropriateness of $a_n(Z,W)$ for ^{137}Cs in DECDC2 is further supported by the evidence that the discrepancies in the spectral shapes between DECDC2 and ICRU56 are not found in the first forbidden unique transition in other nuclides, such as ^{89}Sr, ^{90}Sr, ^{90}Y, and ^{91}Y. It was found that the β particle spectrum of ^{137}Cs in ICRU56 could be reproduced by applying the shape factor of the allowed transition, that is, $a_n(Z,W) = 1$. From the above analysis, it is considered that the β particles spectrum of ^{137}Cs in ICRU56 was calculated using a different shape factor for the first forbidden unique transition.

It has been known for many nuclides that measured β particle spectra for both allowed and forbidden transitions show some deviations from the theoretical shapes.[108] For ^{204}Tl and ^{210}Bi where the deviations are relatively large, $a_n(Z,W)$ derived from measured spectra were used for the calculation in ICRU56. On the other hand, EDISTR04 adopts $a_n(Z,W)$ theoretically derived by Gove and Martin.[33] The discrepancies in the β particle spectra for ^{204}Tl and ^{210}Bi are caused by the difference of the shape factors.

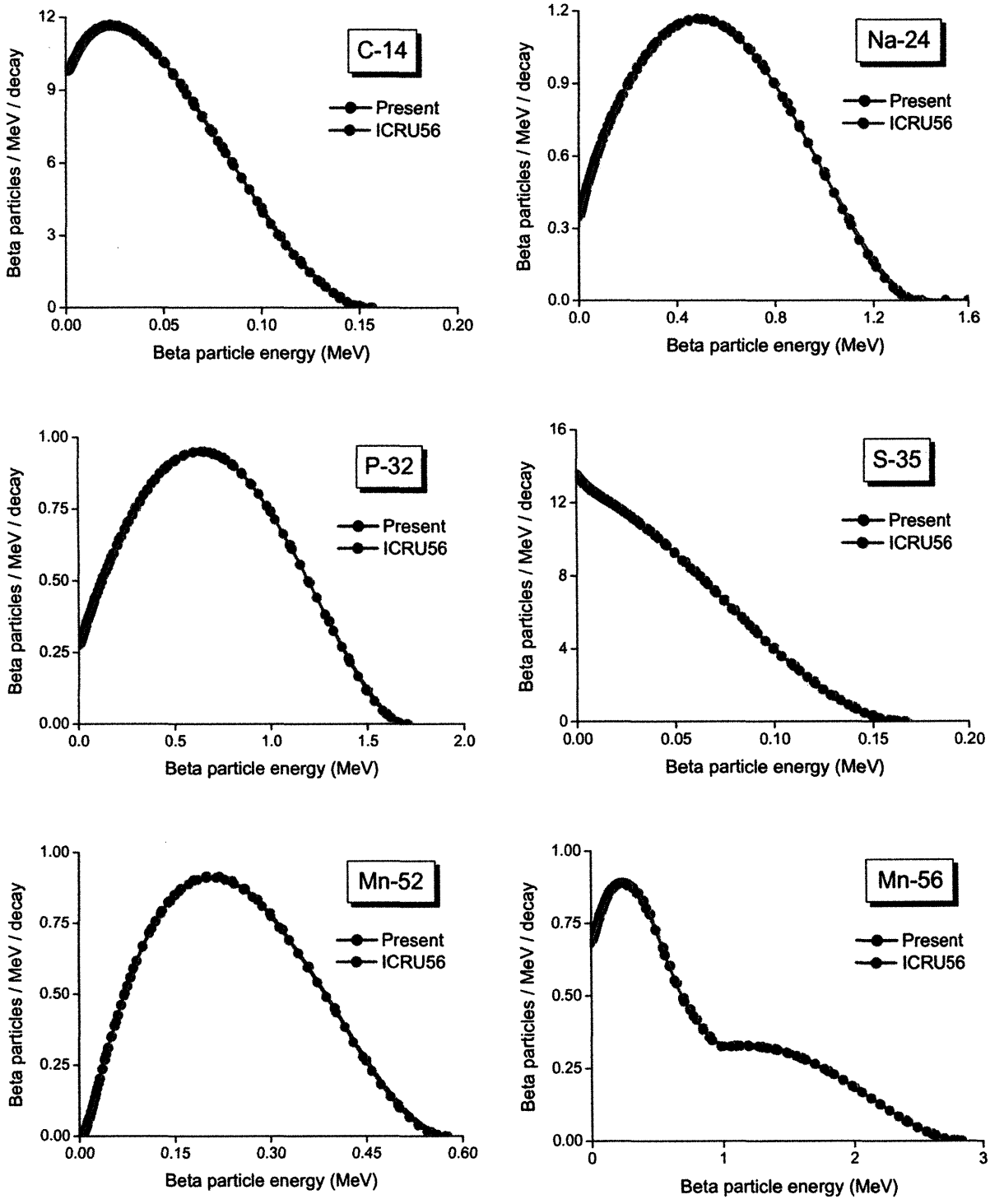


Fig. 4.4 Comparison of β particle spectra

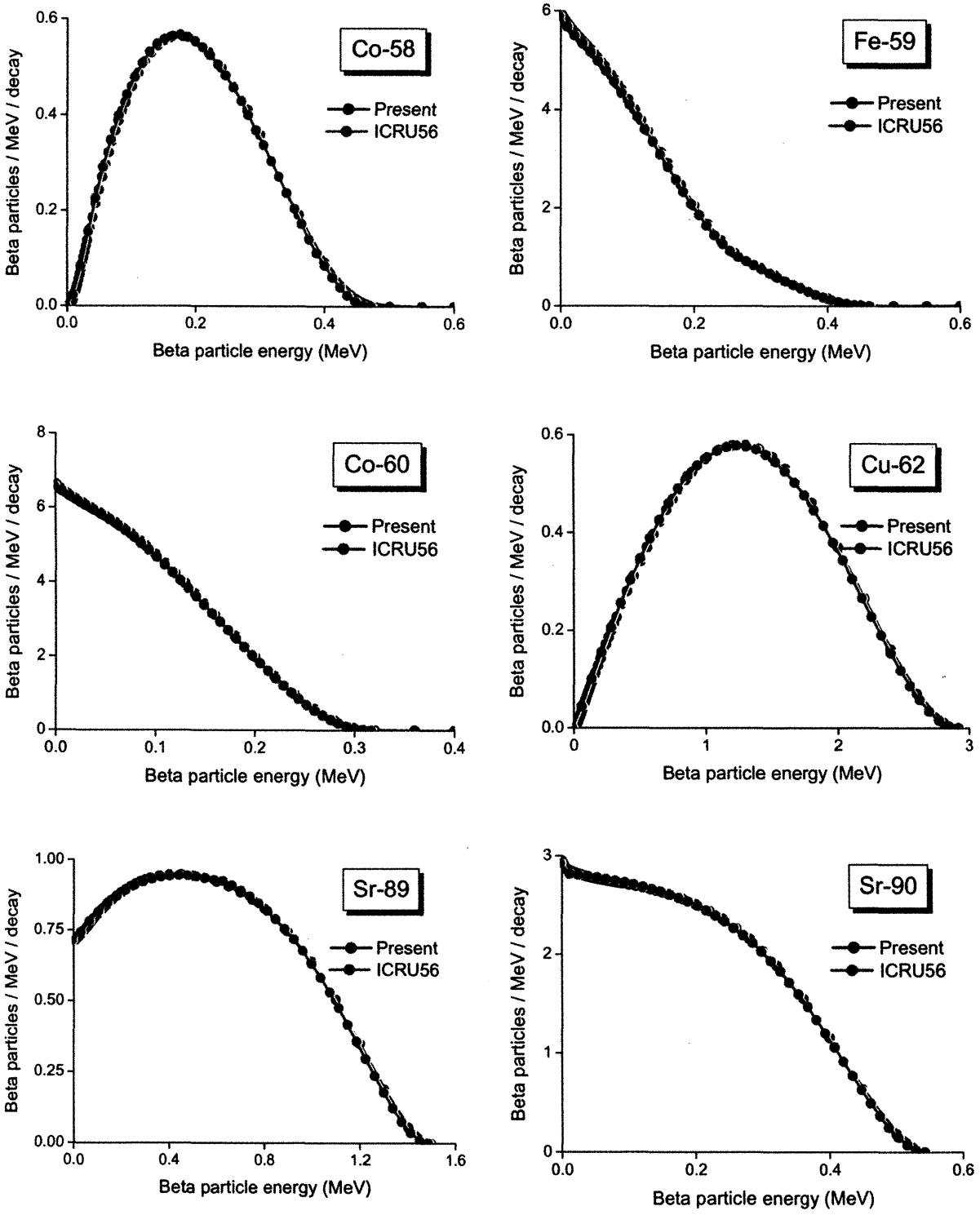


Fig. 4.4 continued

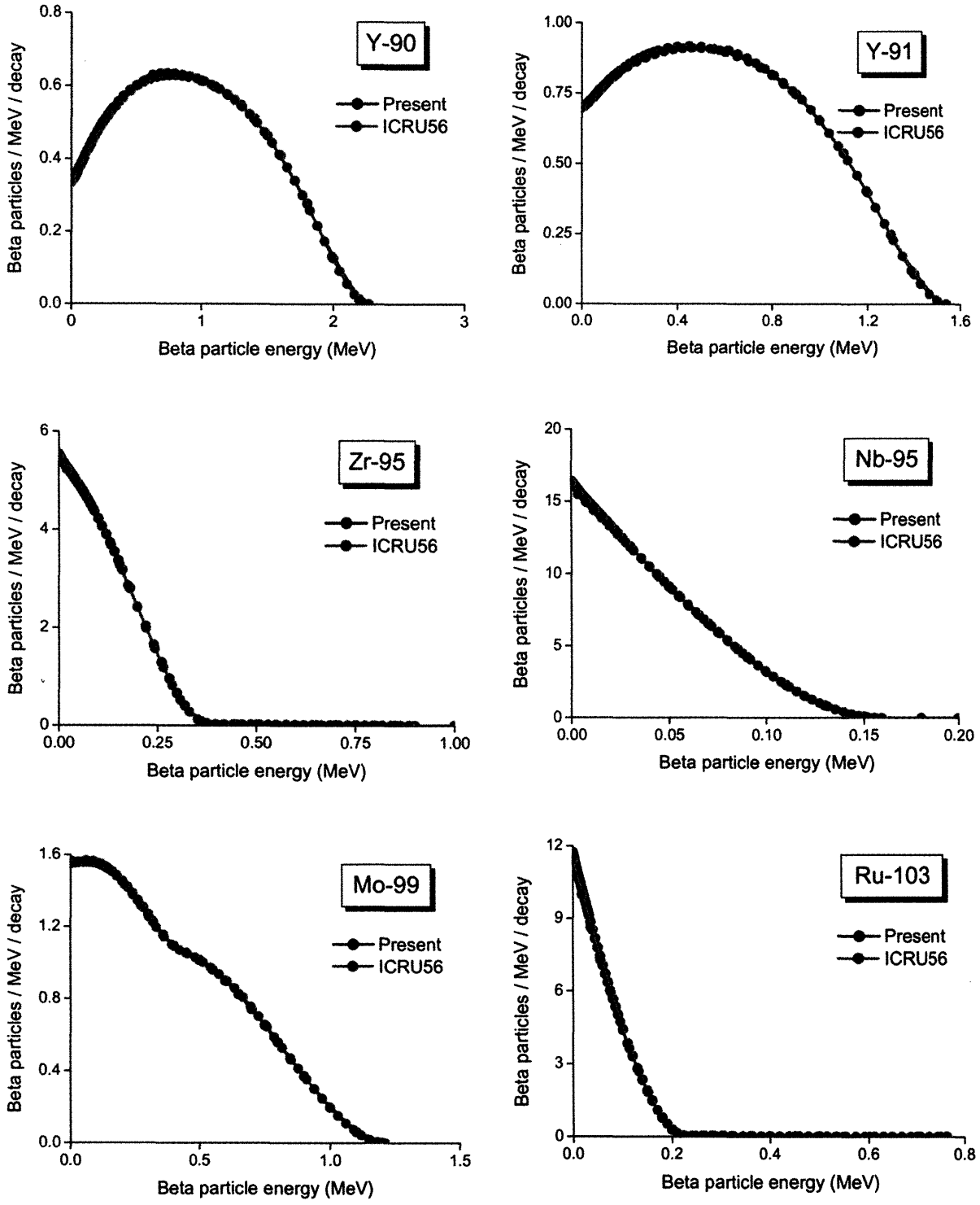


Fig. 4.4 continued

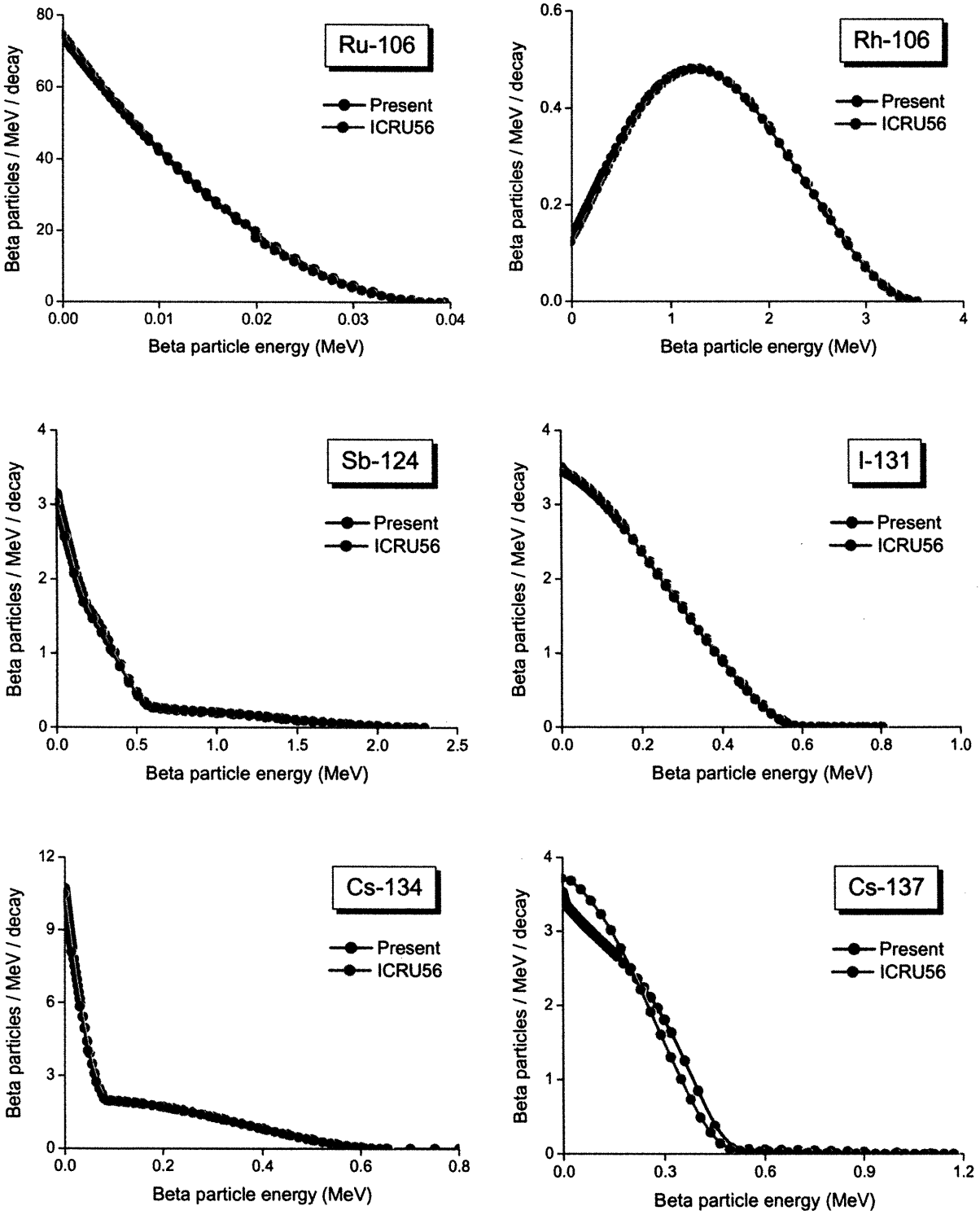


Fig. 4.4 continued

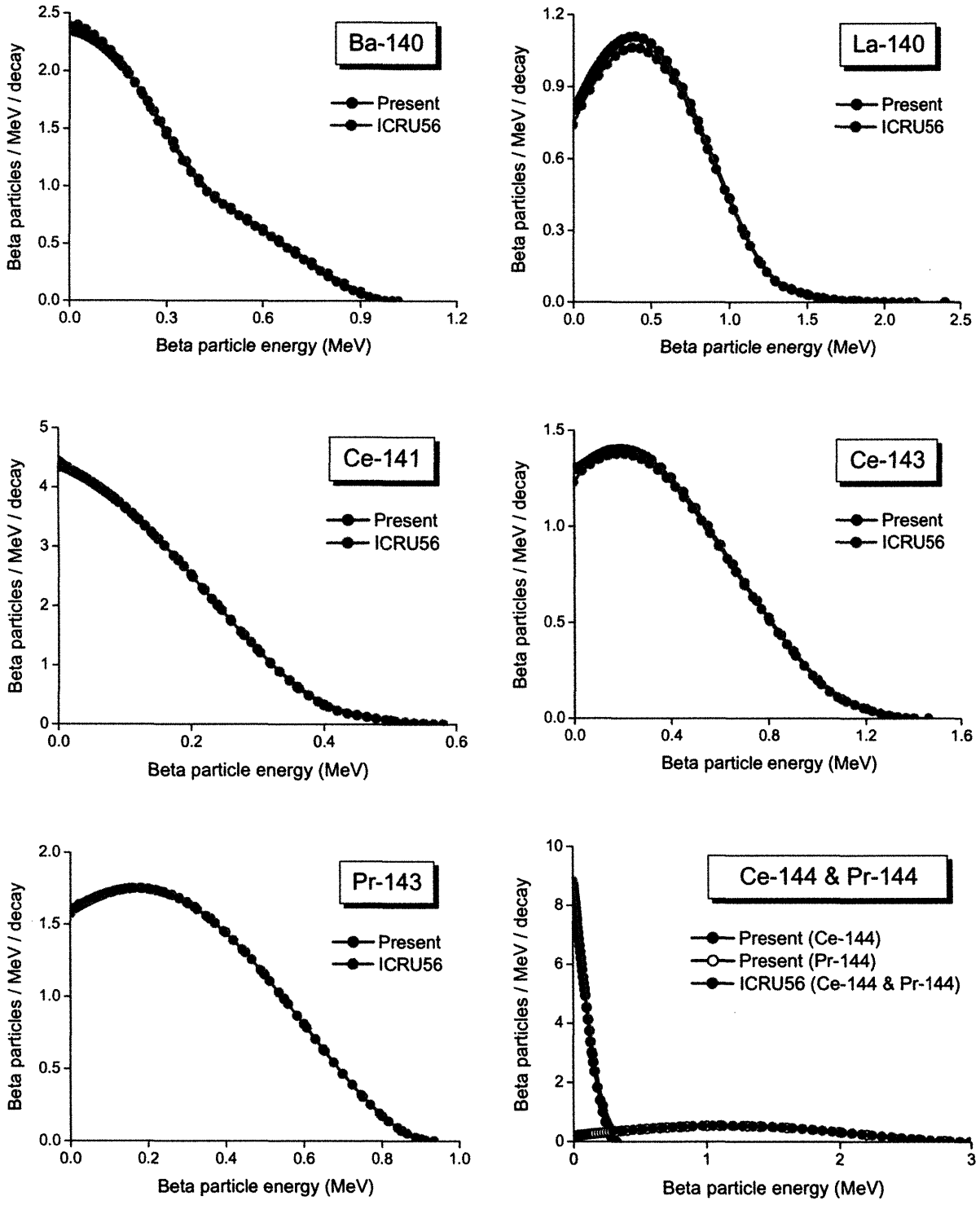


Fig. 4.4 continued

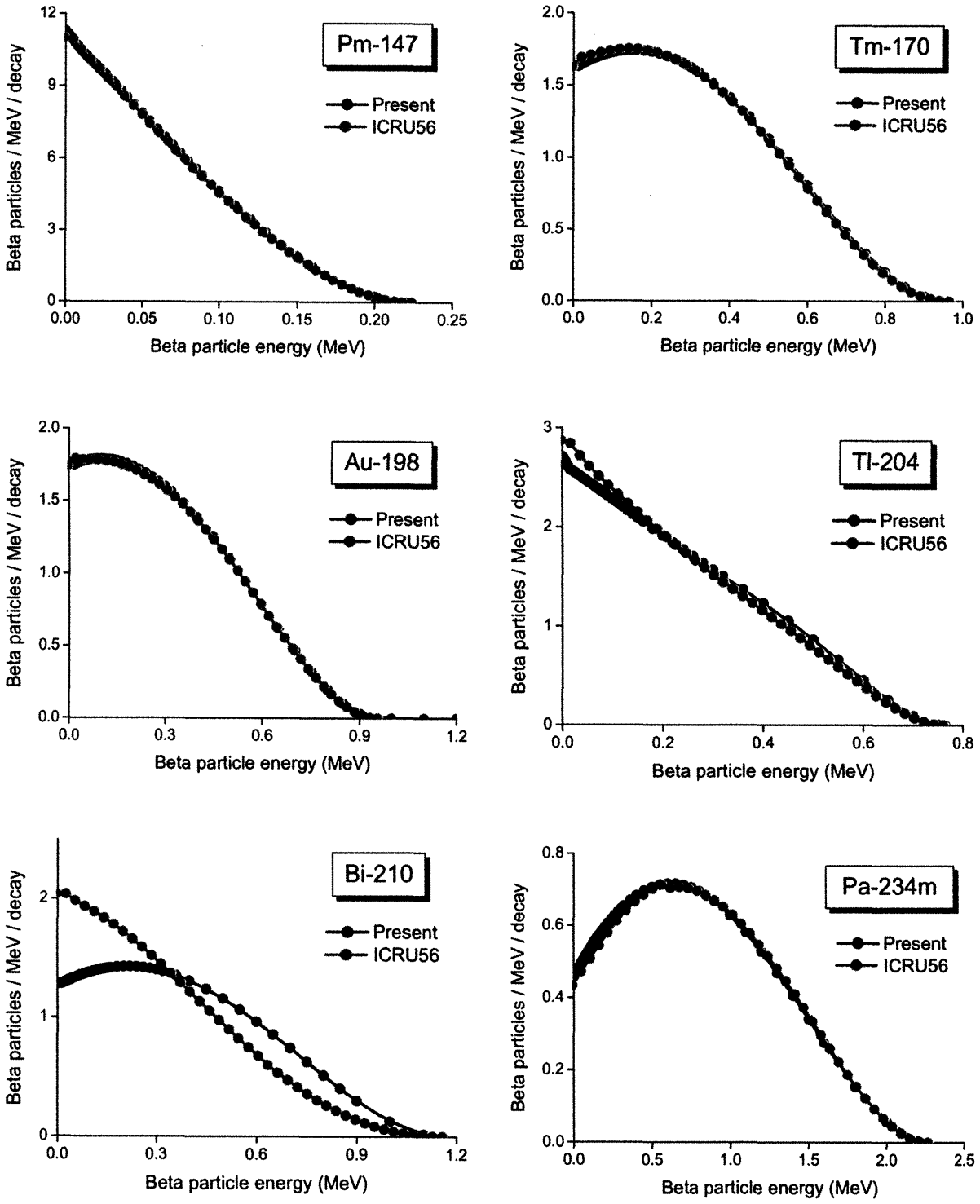


Fig. 4.4 continued

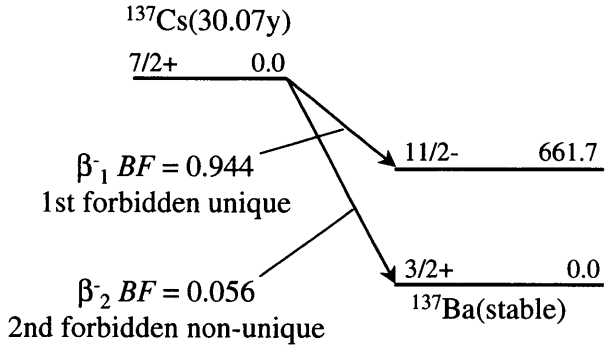


Fig. 4.5 Decay scheme of ^{137}Cs. The unit of level energy is keV.

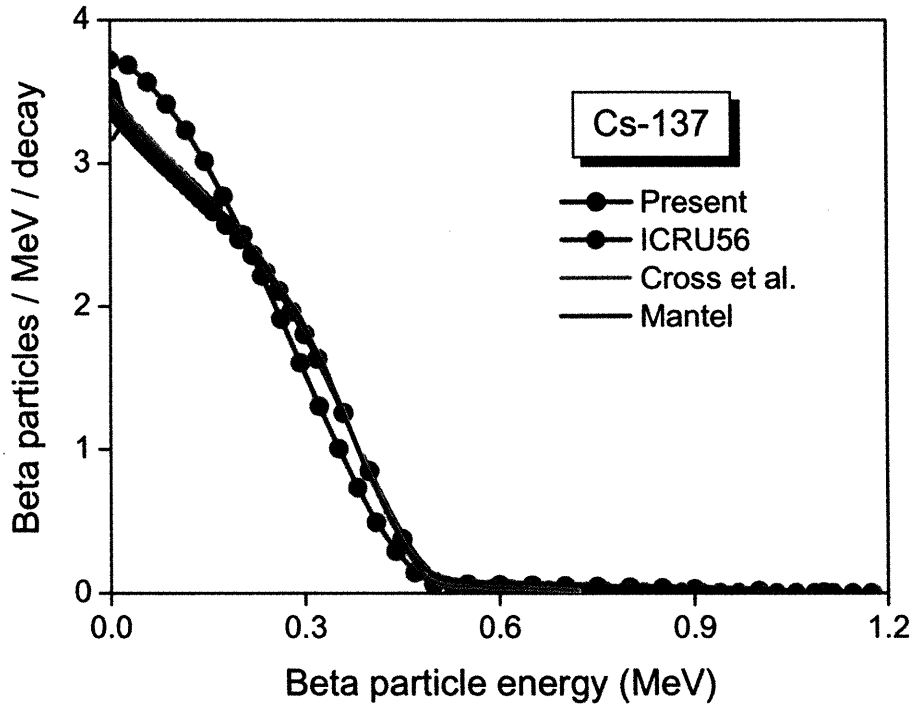


Fig. 4.6 Comparison of β particle spectra of ^{137}Cs

4.2.4 X-ray and Auger Electron Spectra

The Nuclear Medicine Task Group No. 6 of the American Association of Physicists in Medicine (AAPM) provided X-ray and Auger electron spectra for commonly used 12 radionuclides of medical and environmental significance.[44] The calculation was performed by the Monte Carlo method. **Figure 4.7** compares spectra of X-rays and Auger and Coster-Kronig (CK) electrons for 11 radionuclides in DECDC2 with the compilation by AAPM. Comparison of an additional nuclide, ^{125}I, was presented in **Figs. 3.4 – 3.5** and **Table 3.5**.

Generally, X-ray and Auger and CK electron spectra of DECDC2 are corresponded with those of AAPM. However, differences in E_i and I_i of emissions are found in the transitions in the outer shells. As discussed in **Section 3.1.4** for ^{125}I, the discrepancies in E_i and I_i are attributable to the differences in the calculation methods, the atomic data, and the ENSDF used as input. The deviations are emphasized for E_i and I_i in the N- and O-series transitions, since uncertainties in the atomic-electron binding energies and other atomic data are increased in the outer shells. It has been confirmed for the 12 nuclides that the total intensities and energies of the emitted radiations of DECDC2 are consistent with those of AAPM, as indicated for ^{125}I in **Section 3.1.4**, and that calculated Q values agree with theoretical Q values.

The Monte Carlo technique adopted for the compilation of AAPM data is the most reliable method for calculating X-ray and electron spectra from the atomic process. However, the Monte Carlo calculation requires extensive computation time. On the other hand, the deterministic method using EADL adopted for EDISTR04 results in much shorter computation, and the effectiveness of the method has been demonstrated by Stepanek.[69,70] Therefore, the method is convenient for data compilation of a large number of nuclides.

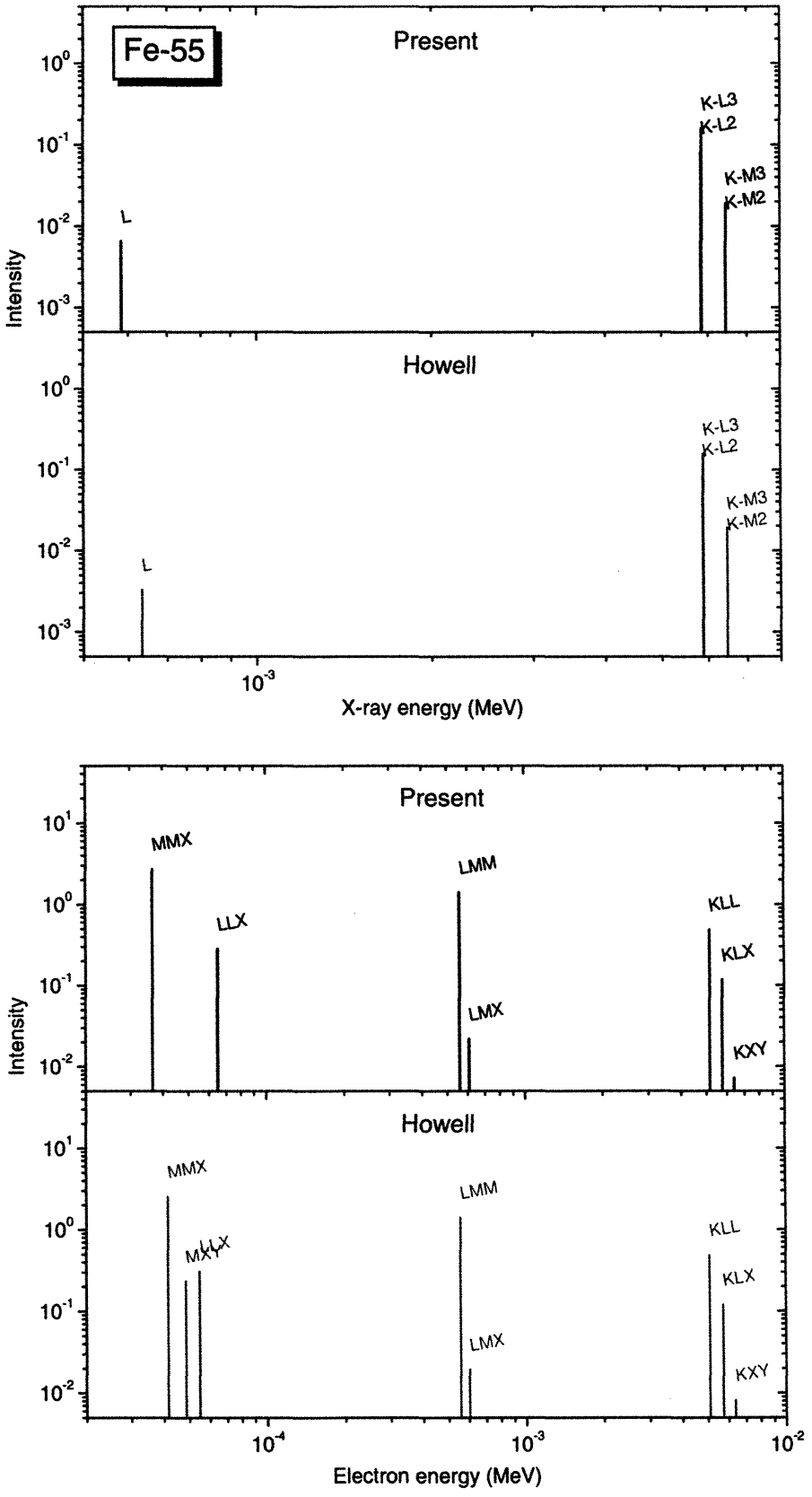


Fig. 4.7 Comparison of X-ray and Auger and CK electron spectra: ^{55}Fe

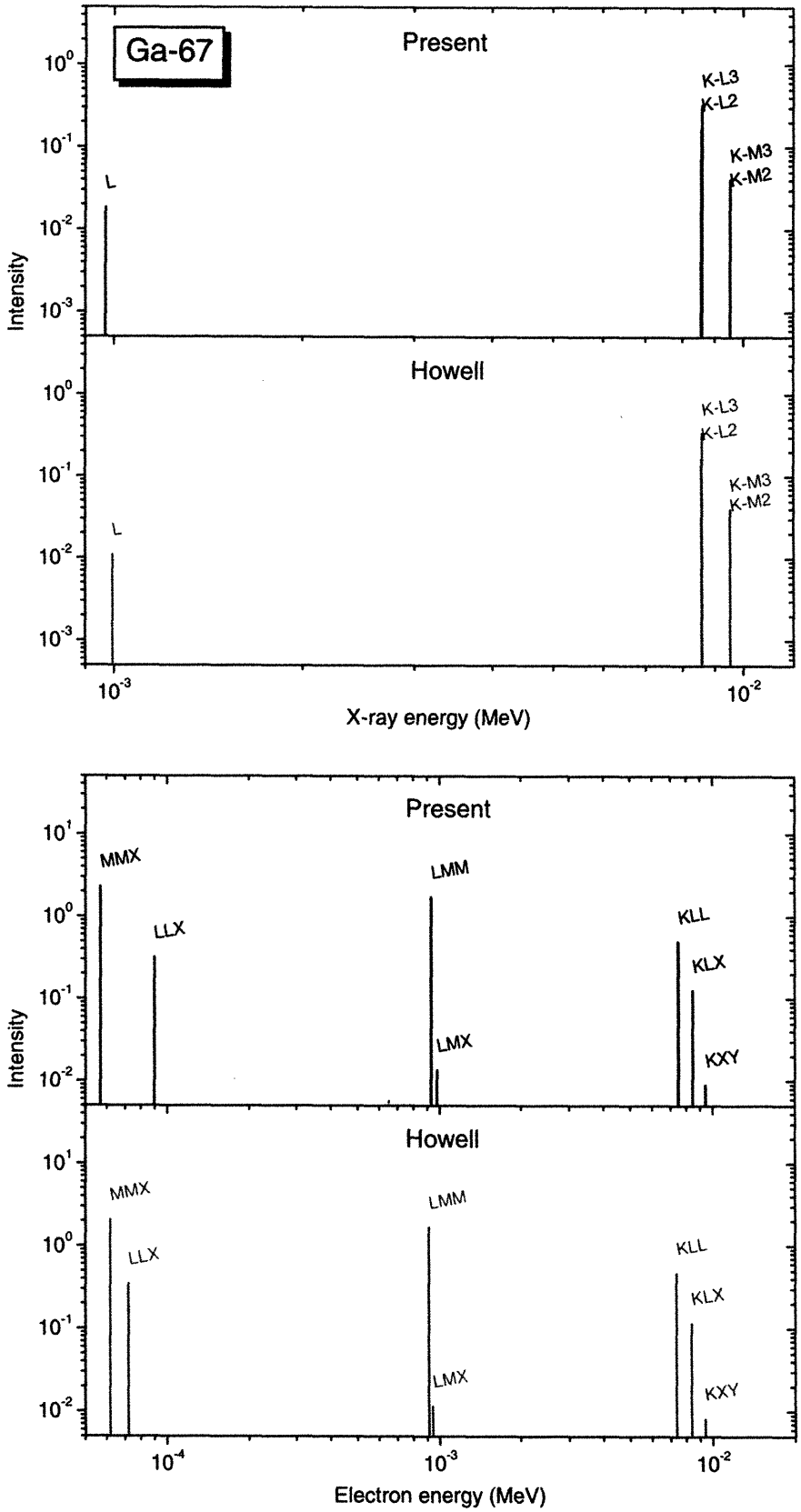


Fig. 4.7 continued: ^{67}Ga

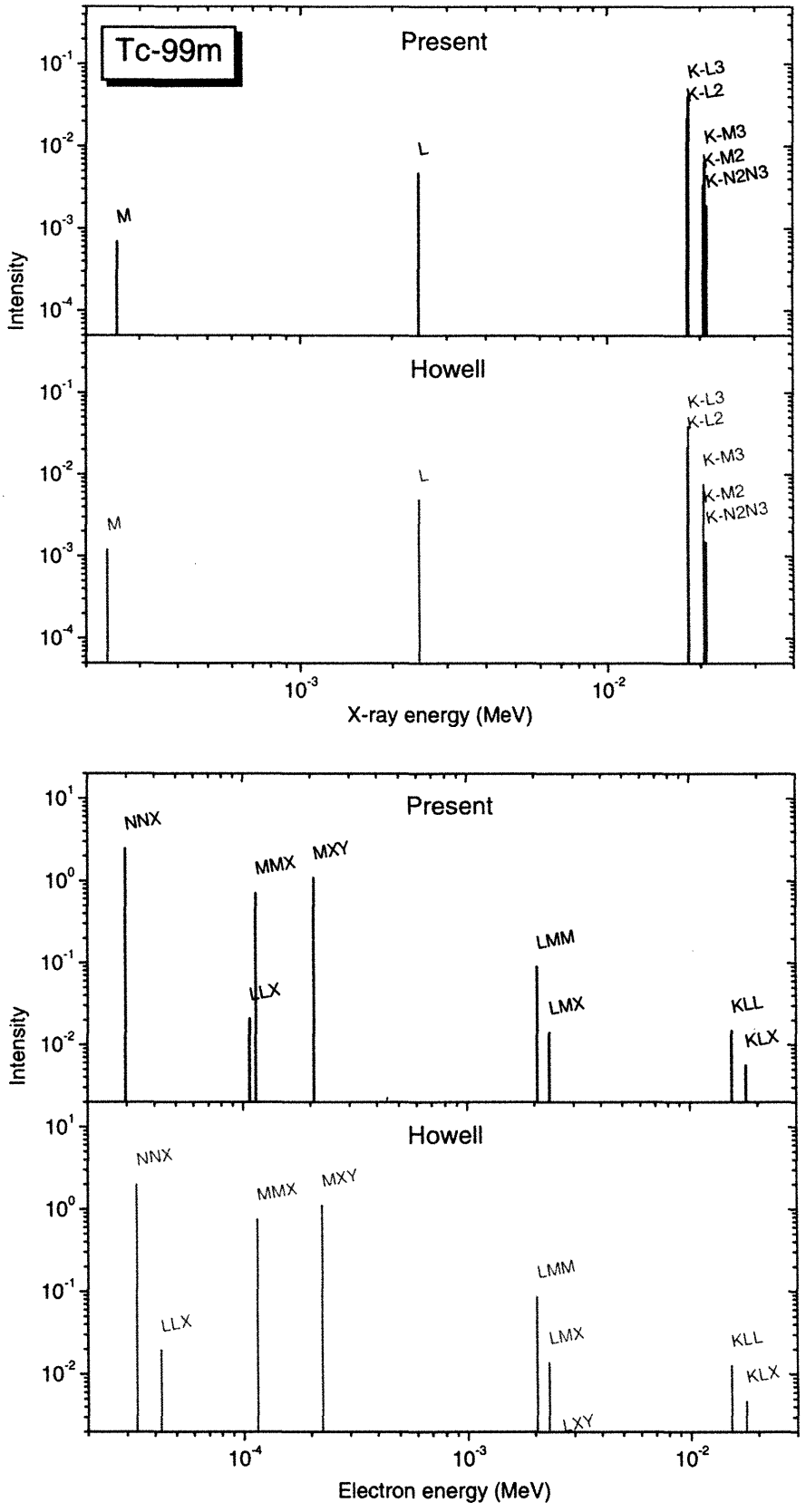


Fig. 4.7 continued: ^{99m}Tc

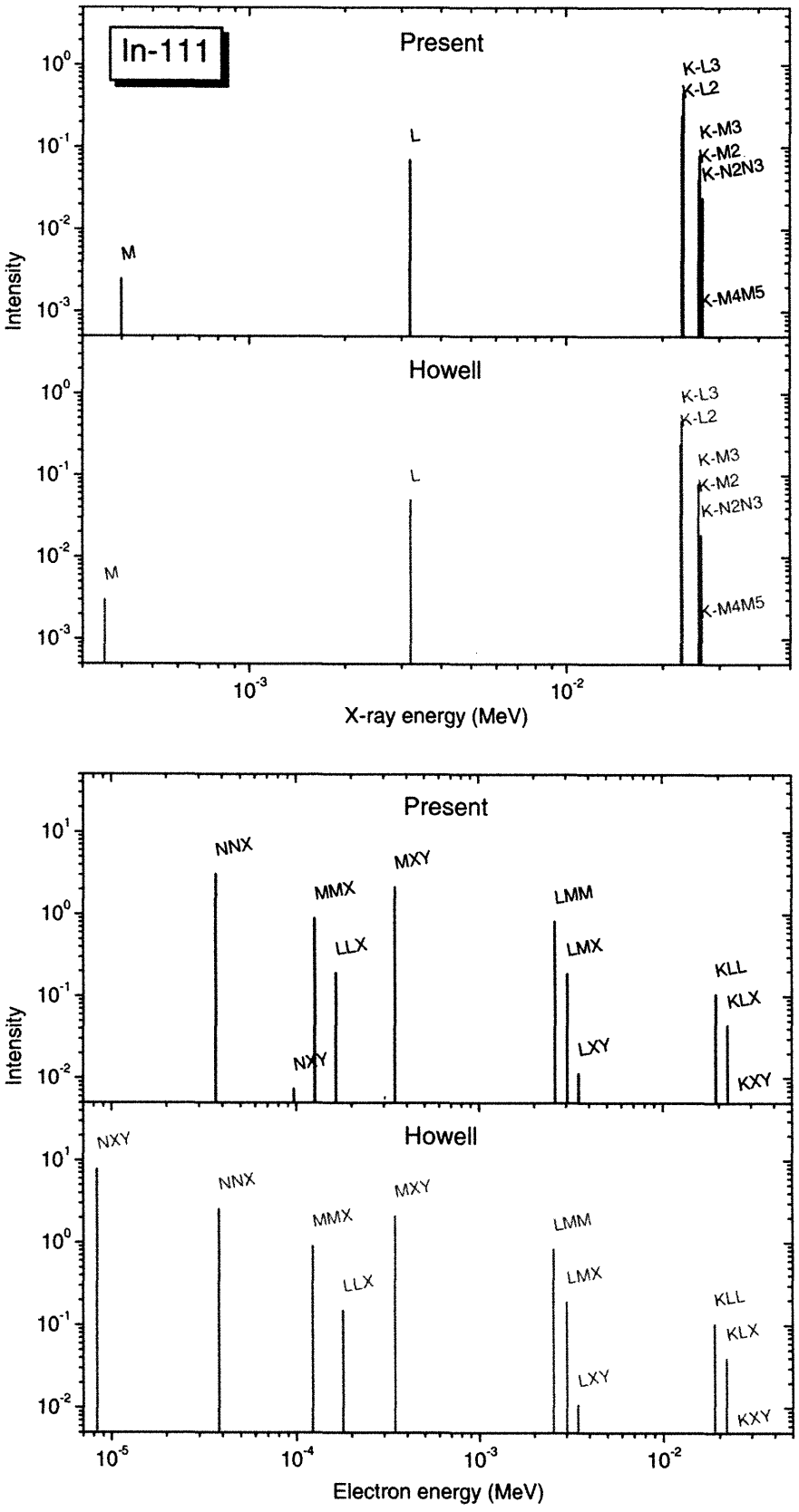


Fig. 4.7 continued: ^{111}In

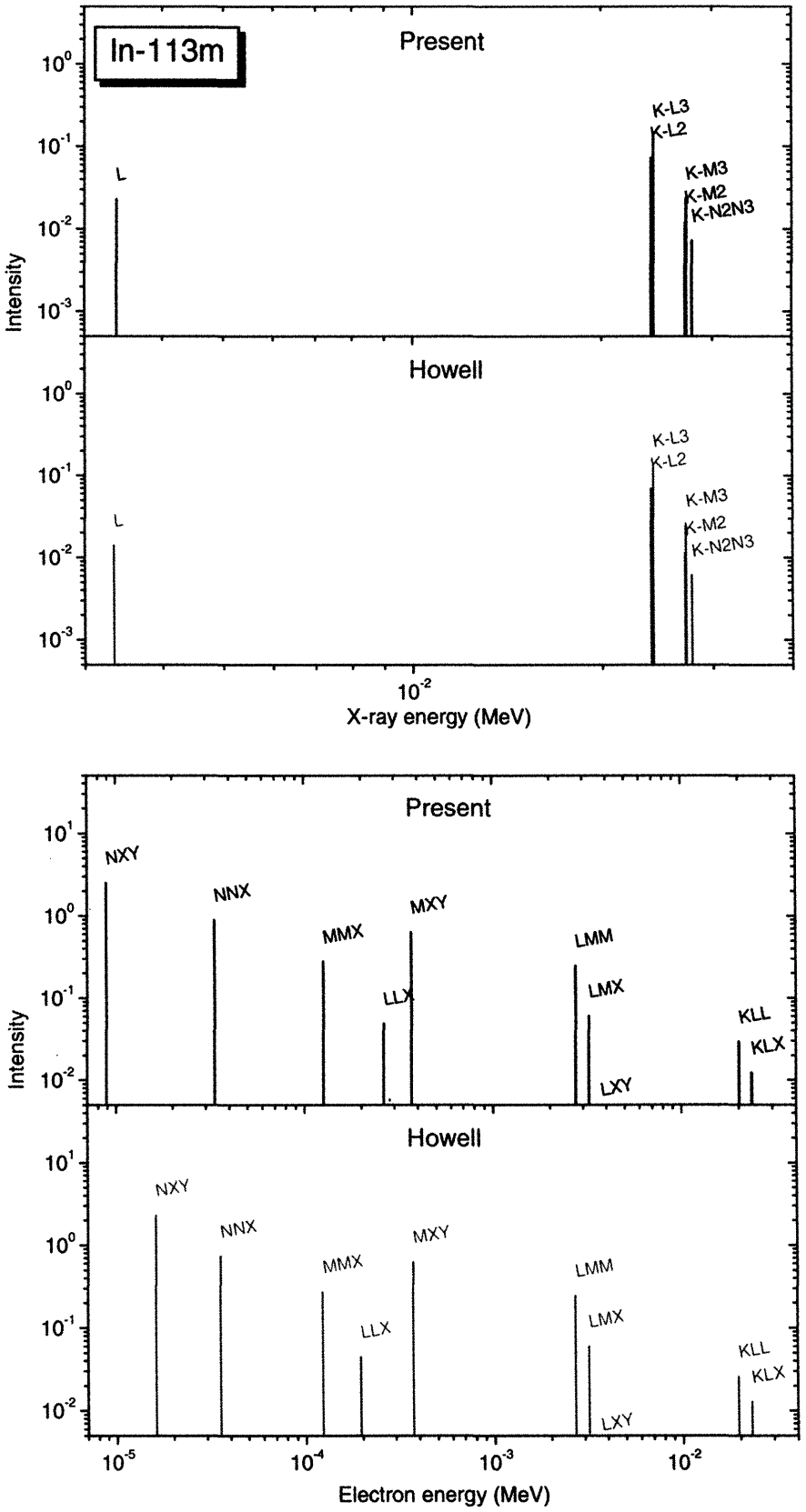


Fig. 4.7 continued: ^{113m}In

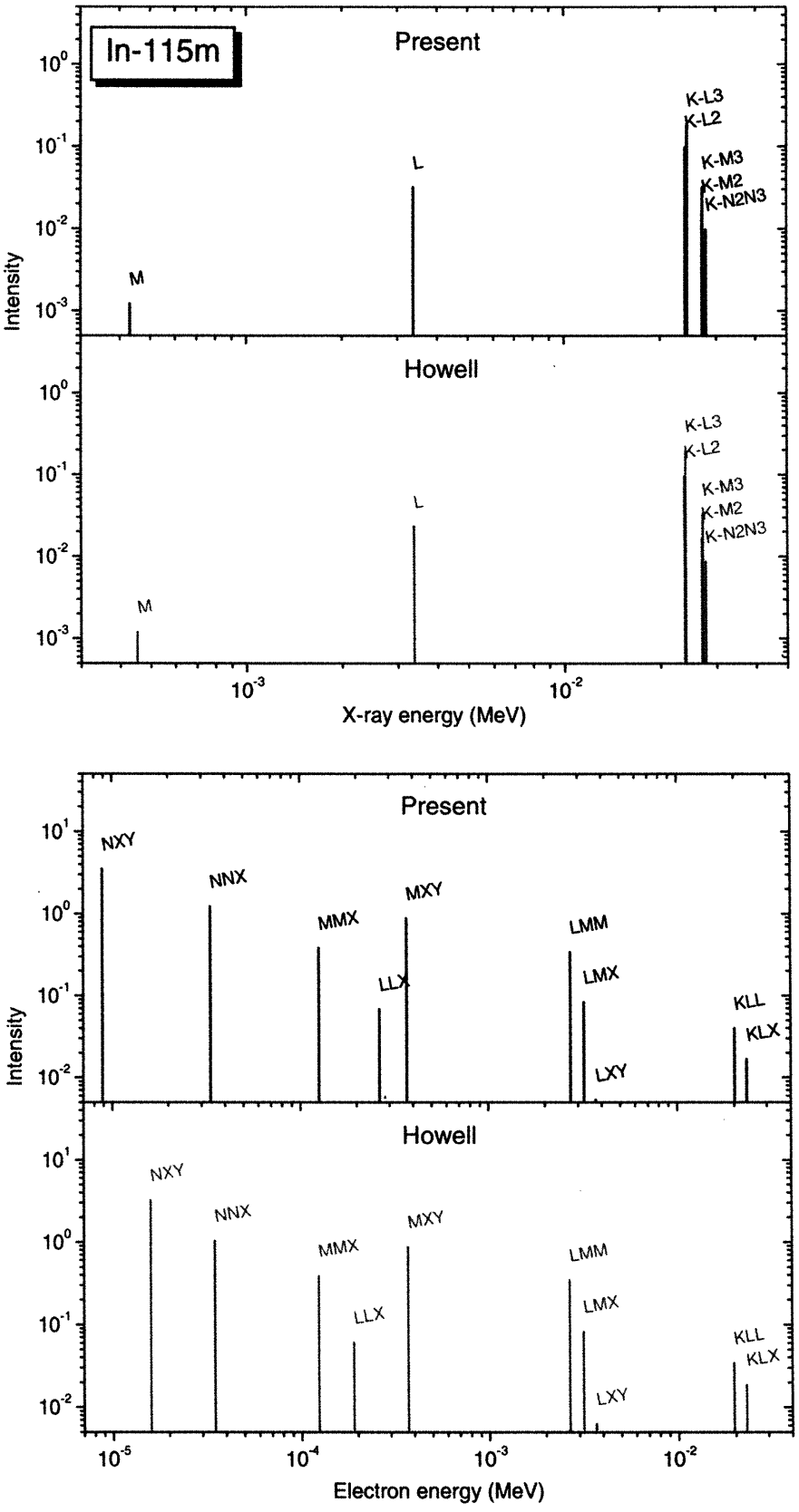


Fig. 4.7 continued: ^{115m}In

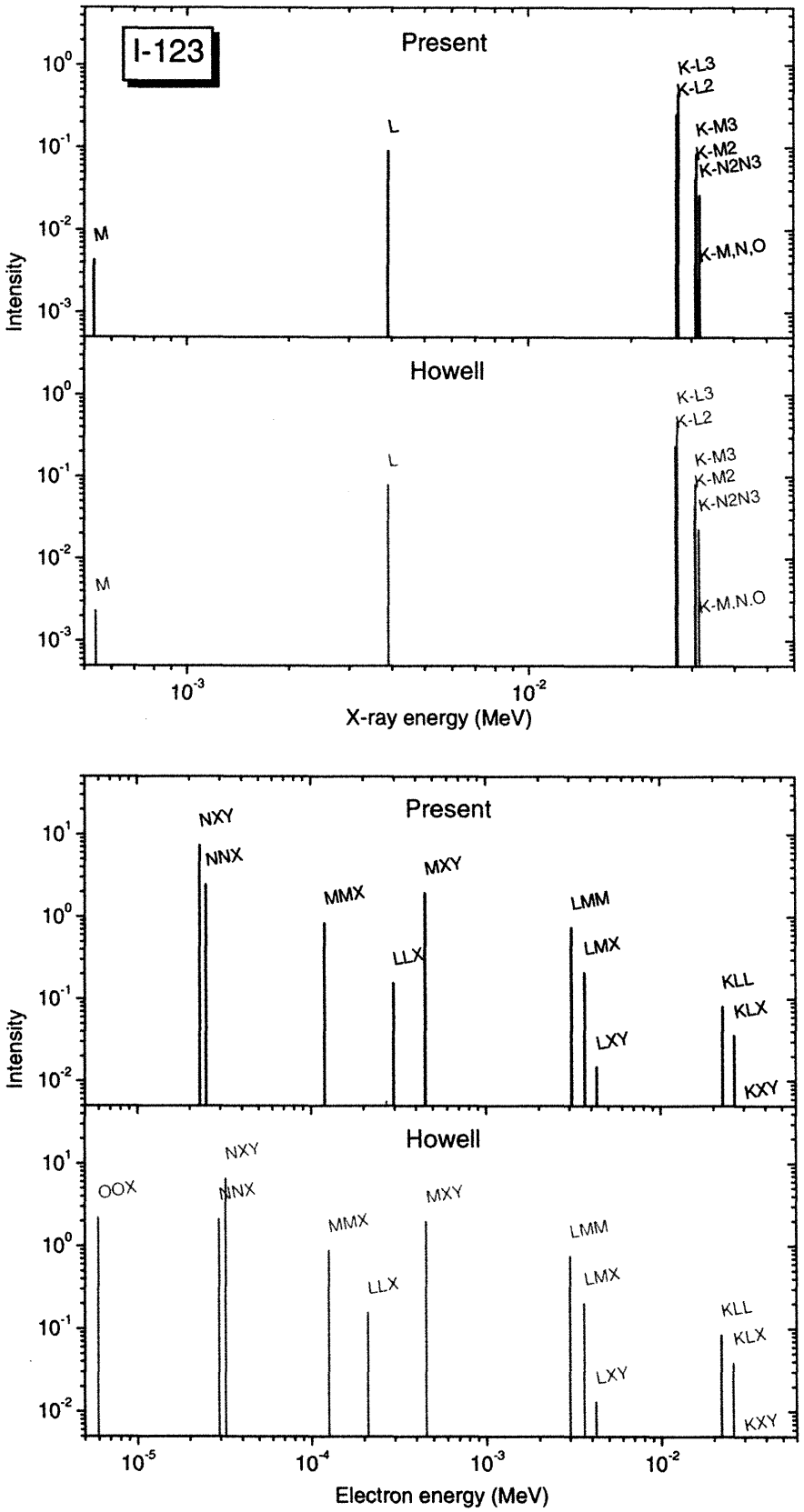


Fig. 4.7 continued: ^{123}I

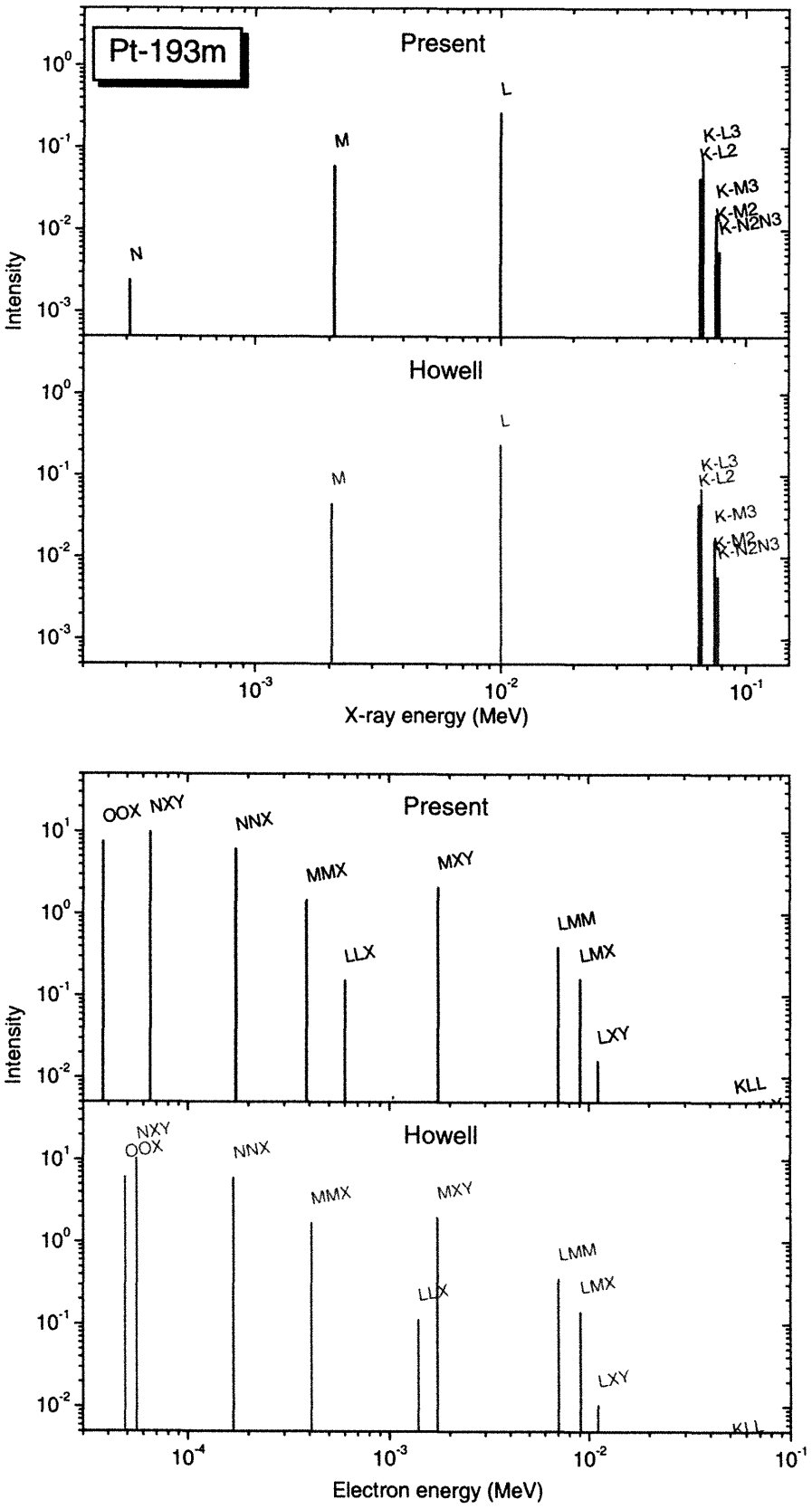


Fig. 4.7 continued: ^{193m}Pt

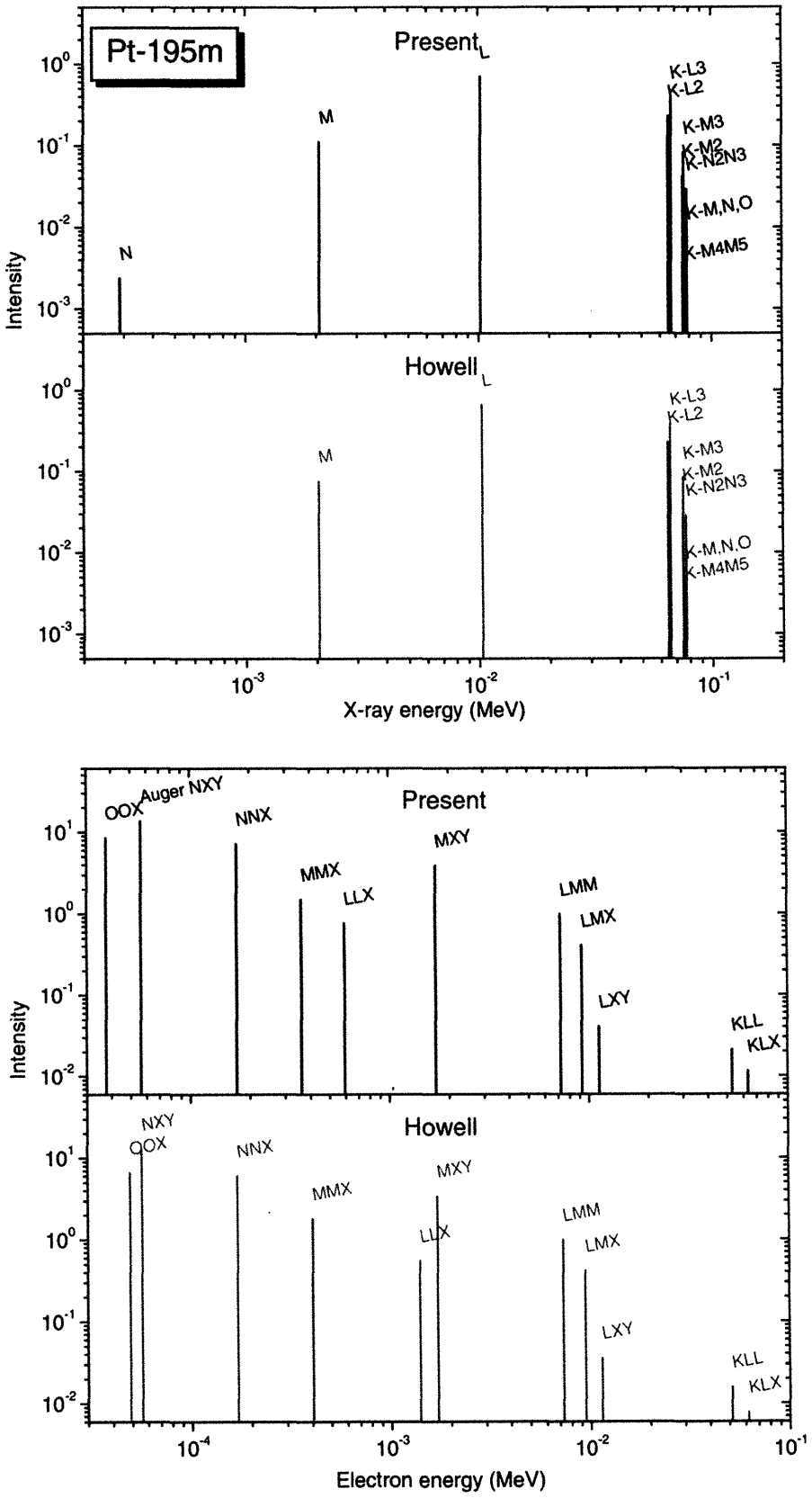


Fig. 4.7 continued: ^{195m}Pt

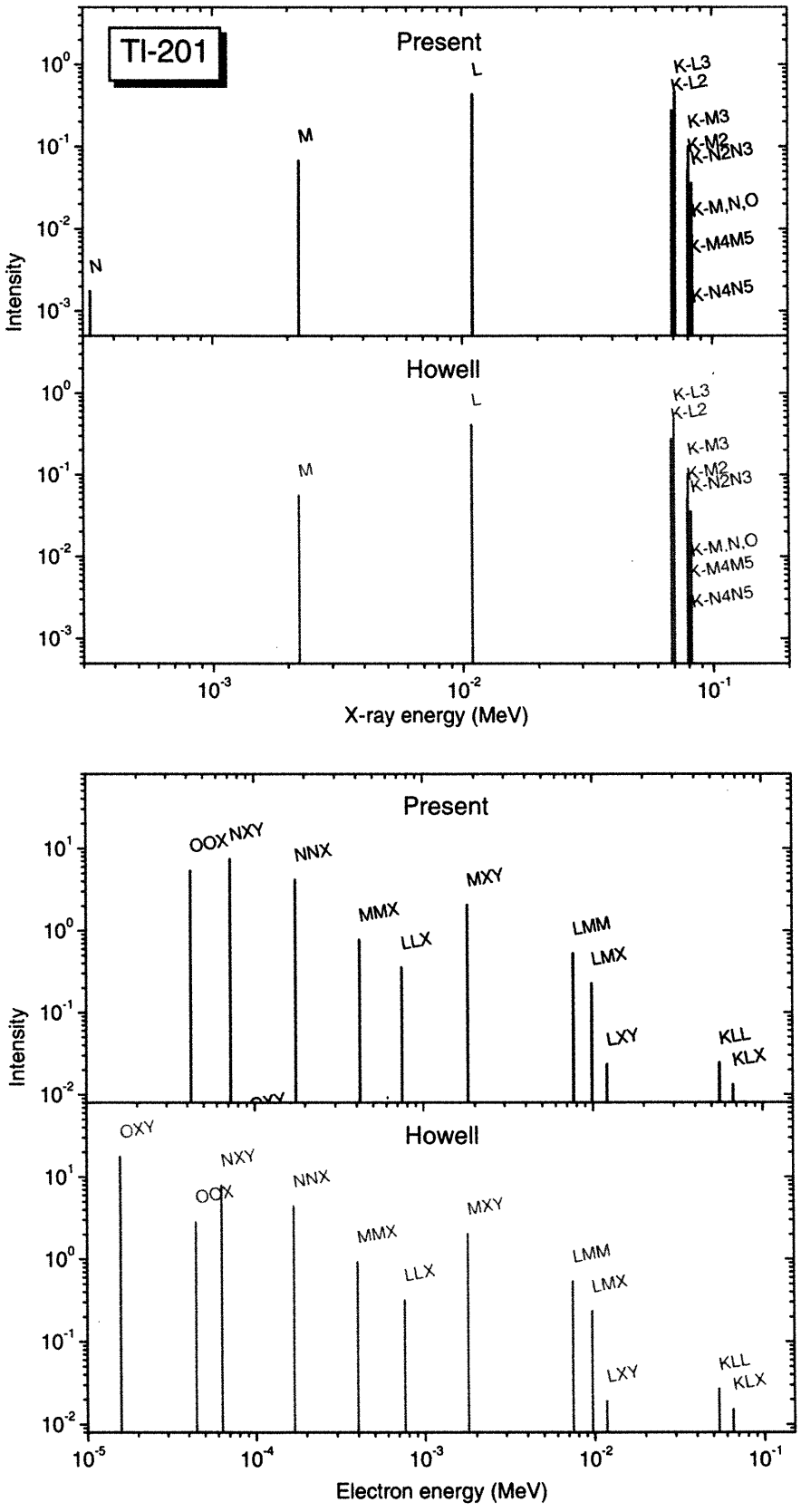


Fig. 4.7 continued: ^{201}Tl

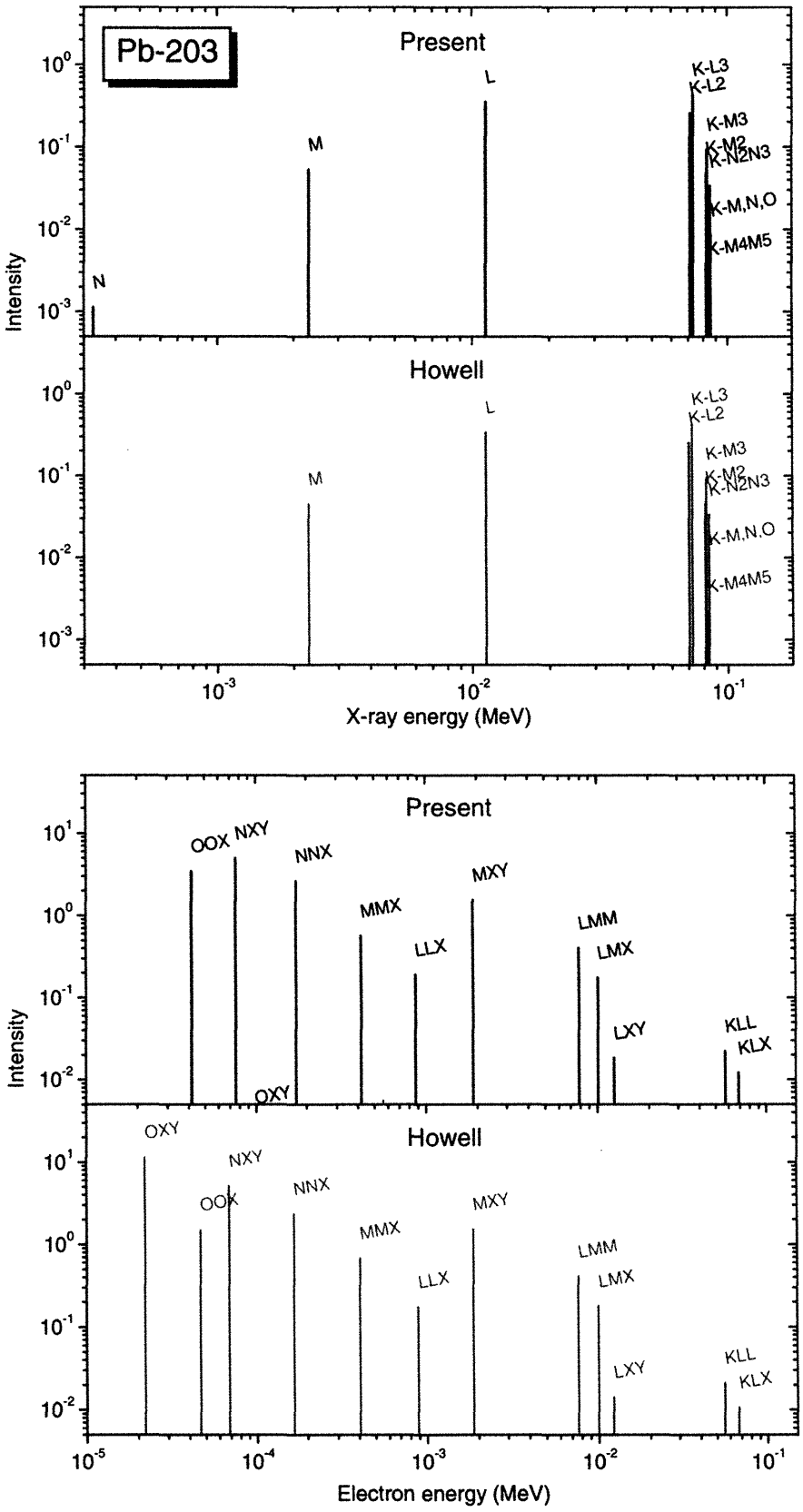


Fig. 4.7 continued: ^{203}Pb

4.2.5 Total Energy of Emitted Radiations

Decay heat calculation is one of the key issues in the design of power reactors. The calculation requires a set of reliable data for the energy emitted from the decay of fission products (FP). The radioactive decay databases, JEF-2.2[34] and JENDL FP 2000,[95] have been used as the latest libraries for predicting the decay heat during operation and after the shutdown of reactors. JEF-2.2,[34] Joint Evaluated File Version 2.2, is the database developed as a joint undertaking between NEA Data Bank and member countries and contains information for 2346 radionuclides. JENDL FP 2000, developed at JAERI, includes the decay data for 1229 FP for $A = 66 - 172$. The energies of emitted radiations were compared for selected radionuclides that are important for dosimetry, medical needs and environmental monitoring.

Table 4.9 shows the results of comparison for the energies of α particles, electrons and photons between DECDC2, JEF-2.2 and JENDL FP 2000. JENDL FP 2000 is the specialized data library for the nuclides with $A = 66 - 172$, and therefore the data for several light and heavy nuclides are not included. It is found that the emitted energies are in good agreement in the three compilations and that DECDC2 provides reliable data for cases in which the decay schemes are well established in the ENSDF.

Table 4.9 Comparison of radiation energy between DECDC2, JEF-2.2 and JENDL FP 2000

Nuclide	Data source	Energy per decay (MeV)		
		Alpha	Electron	Photon
^{3}H	DECDC2		5.680E−3	
	JEF-2.2		5.7E−3	
^{11}C	DECDC2		3.847E−1	1.020
	JEF-2.2		3.846E−1	1.020
^{13}N	DECDC2		4.909E−1	1.020
	JEF-2.2		4.911E−1	1.023
^{15}O	DECDC2		7.347E−1	1.021
	JEF-2.2		7.344E−1	1.021
^{22}Na	DECDC2		1.941E−1	2.193
	JEF-2.2		1.957E−1	2.199
^{24}Na	DECDC2		5.538E−1	4.123
	JEF-2.2		5.525E−1	4.124
^{32}P	DECDC2		6.948E−1	
	JEF-2.2		6.949E−1	
^{51}Cr	DECDC2		3.824E−3	3.290E−2
	JEF-2.2		3.7E−3	3.26E−2
^{60}Co	DECDC2		9.686E−2	2.504
	JEF-2.2		9.66E−2	2.504
^{65}Zn	DECDC2		6.877E−3	5.819E−1
	JEF-2.2		7.0E−3	5.843E−1
^{85}Sr	DECDC2		8.910E−3	5.001E−1
	JEF-2.2		8.7E−3	5.134E−1
	JENDL FP 2000		8.500E−3	5.000E−1
^{90}Sr	DECDC2		1.957E−1	
	JEF-2.2		1.956E−1	
	JENDL FP 2000		1.958E−1	
^{90}Y	DECDC2		9.331E−1	1.232E−6
	JEF-2.2		9.340E−1	
	JENDL FP 2000		9.338E−1	1.240E−6
^{93m}Nb	DECDC2		2.944E−2	2.004E−3
	JEF-2.2		2.80E−2	1.9E−3
	JENDL FP 2000		2.680E−2	1.960E−3

Table 4.9 continued from previous page

Nuclide	Data source	Energy per decay (MeV)		
		Alpha	Electron	Photon
^{106}Ru	DECDC2		1.003E−2	
	JEF-2.2		1.00E−2	
	JENDL FP 2000		1.003E−2	
^{106}Rh	DECDC2		1.411	2.061E−1
	JEF-2.2		1.413	2.087E−1
	JENDL FP 2000		1.411	2.060E−1
^{125}I	DECDC2		1.924E−2	4.284E−2
	JEF-2.2		1.65E−2	4.21E−2
	JENDL FP 2000		1.650E−2	4.220E−2
^{131}I	DECDC2		1.918E−1	3.828E−1
	JEF-2.2		1.914E−1	3.815E−1
	JENDL FP 2000		1.926E−1	3.830E−1
^{137}Cs	DECDC2		1.884E−1	1.653E−6
	JEF-2.2		1.860E−1	
	JENDL FP 2000		1.879E−1	1.640E−6
^{144}Ce	DECDC2		9.162E−2	1.937E−2
	JEF-2.2		9.16E−2	1.94E−2
	JENDL FP 2000		9.160E−2	1.940E−2
^{152}Eu	DECDC2		1.286E−1	1.176
	JEF-2.2		1.185E−1	1.177
	JENDL FP 2000		1.263E−1	1.159
^{154}Eu	DECDC2		2.730E−1	1.249
	JEF-2.2		2.788E−1	1.230
	JENDL FP 2000		2.730E−1	1.249
^{192}Ir	DECDC2		2.177E−1	8.165E−1
	JEF-2.2		2.162E−1	8.150E−1
^{226}Ra	DECDC2	4.774	3.911E−3	7.400E−3
	JEF-2.2	4.775	3.6E−3	6.8E−3
^{235}U	DECDC2	4.393	5.301E−2	1.669E−1
	JEF-2.2	4.387	4.75E−2	1.678E−1
^{239}Pu	DECDC2	5.148	7.455E−3	1.078E−3
	JEF-2.2	5.149	7.4E−3	7E−4
^{241}Am	DECDC2	5.479	3.730E−2	2.933E−2
	JEF-2.2	5.479	3.93E−2	2.82E−2

4.2.6 Radiations from Spontaneous Fission

Tables 4.10 – 4.12 compare the energies released by fission fragments, prompt neutrons, and prompt γ-rays from the selected SF nuclides between DECDC2 and JANIS,[109] a software of JEF radioactive decay data. The values are expressed as the emitted energy per decay of each nuclide.

For fission fragments, the present values were calculated using Eqs. (3.4) and (3.5) evaluated by Viola et al.[77] For prompt neutrons, the present values were computed on the basis of the Watt spectrum, while JANIS adopted the Maxwellian distribution. For prompt γ-rays, the present values were calculated using the nuclide-dependent equations (Eqs. (3.13) and (3.14)) developed by Valentine.[87] It is shown from **Tables 4.10 – 4.12** that the energies of the fission fragments, prompt neutrons, and prompt γ-rays are generally consistent between the two compilations.

Table 4.13 shows comparisons of the energies emitted from the delayed γ-rays and β particles between DECDC2 and the ENDF (Evaluated Nuclear Data File) library.[110] The values from the ENDF library are the data by neutron-induced fission of the listed nuclides. There are discrepancies in several nuclides between DECDC2 and ENDF; the maximum difference is found in ^{242}Cm reaching the level of 50 %. The reason of the difference might be originated by the simplified expressions for evaluating the properties of delayed γ-rays and β particles in EDISTR04. However, the energies released by the delayed emissions are about 10 % of the total energy of all emissions from SF. Therefore, the errors in the estimated energies for the delayed γ-rays and β particles are a few percent in the total energies from the SF radiations.

Table 4.10 Comparison of energy of fission fragments

	Energy per decay (MeV)	
Nuclide	DECDC2	JANIS
^{238}U	9.25E−5	8.79E−5
^{244}Cm	2.50E−4	2.42E−4
^{246}Cm	4.79E−2	4.64E−2
^{248}Cm	1.52E+1	1.45E+1
^{250}Cf	1.45E−1	1.39E−1
^{252}Cf	5.82	5.53
^{253}Es	1.70E−5	1.57E−5

Table 4.11 Comparison of energy of prompt neutrons

	Energy per decay (MeV)	
Nuclide	DECDC2	JANIS
^{238}U	1.85E−6	2.0E−6
^{244}Cm	7.79E−6	7.2E−6
^{246}Cm	1.73E−3	1.57E−3
^{248}Cm	5.10E−1	5.41E−1
^{250}Cf	6.28E−3	5.77E−3
^{252}Cf	2.68E−1	2.51E−1
^{253}Es	7.01E−7	9E−7

Table 4.12 Comparison of energy of prompt γ-rays

	Energy per decay (MeV)	
Nuclide	DECDC2	JANIS
^{238}U	3.31E−6	3.8E−6
^{244}Cm	8.74E−6	9.4E−6
^{246}Cm	1.79E−3	1.83E−3
^{248}Cm	5.63E−1	5.78E−1
^{250}Cf	5.24E−3	5.39E−3
^{252}Cf	2.15E−1	2.16E−4
^{253}Es	6.18E−7	6E−7

Table 4.13 Comparison of energy of delayed γ-rays and β particles

	Energy per fission (MeV)			
	Delayed γ-rays		Delayed β particles	
Nuclide	DECDC2	ENDF[1]	DECDC2	ENDF[1]
^{238}U	9.19	8.25	9.39	8.48
^{238}Pu	4.56	5.31	4.66	5.42
^{240}Pu	6.17	6.49	6.31	6.62
^{242}Pu	8.03	7.72	8.21	7.87
^{244}Pu	10.17	10.91	10.33	11.22
^{242}Cm	3.75	5.49	3.85	5.64
^{244}Cm	5.24	6.20	5.35	6.33
^{248}Cm	8.93	9.81	9.12	10.08

[1] The values from the ENDF library are the data by neutron-induced fission.

5 Summary

Nuclear decay data that will succeed Publication 38 of the International Commission on Radiological Protection have been assembled for 1034 radionuclides using the latest information on nuclear structure and decay properties. The resulting package of data files is called DECDC2. The data include a set of data on half-lives, decay chains, and energies and absolute intensities of radiations emitted by the nuclear transformation, subsequent atomic process, and spontaneous fission. Significant enhancement has been made to X-ray and Auger electron spectra for evaluating localized dose distribution in the cellular dimension. The reliability of the compiled data has been examined by consistency checking with the decay energies and by comparison with several measurements and evaluated data libraries. The information can be used for any evaluation of radiation dose and health risk from exposures to radionuclides. The developed nuclear decay data will be used extensively for internal and external dose calculation in medical, environmental and occupational exposures.

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Appendix A
Index of X-rays and Auger and Coster-Kronig Electrons in EDISTR04

Tables A.1 – A.3 show the IUPAC notation[71] and INDEX assigned in EDISTR04 to identify for X-rays, Auger and Coster-Kronig electrons. Conventional Siegbahn notation is also listed. Further details on INDEX are found in pp.65–66 in the manual of EDISTR.[22]

Table A.1 INDEX for X-rays in EDISTR04

• INDEX for K series X-rays

IUPAC notation	INDEX in EDISTR04	Siegbahn notation[71]
$K-L_2$	1	K_{α_2}
$K-L_3$	2	K_{α_1}
$K-M_2$	3	K_{β_3}
$K-M_3$	4	K_{β_1}
$K-M_4$	5	$K^{II}_{\beta_5}$
$K-M_5$	6	$K^{I}_{\beta_5}$
$K-N_2$	7	$K^{II}_{\beta_2}$
$K-N_3$	8	$K^{I}_{\beta_2}$
$K-N_4$	9	$K^{II}_{\beta_4}$, $K_{\beta_{4x}}$
$K-N_5$	10	$K^{I}_{\beta_4}$
$K-O_2$	11	
$K-O_3$	12	
$K-O_4$	13	
$K-O_5$	14	
$K-P_2$	15	
$K-P_3$	16	

• INDEX for L series X-rays

IUPAC notation	INDEX in EDISTR04	Siegbahn notation
L_1-L_2	21	
L_1-L_3	22	
L_1-M_2	23	L_{β_4}
L_1-M_3	24	L_{β_3}
L_1-M_4	25	$L_{\beta_{10}}$
L_1-M_5	26	L_{β_9}
L_1-N_2	27	L_{γ_2}
L_1-N_3	28	L_{γ_3}
L_1-N_4	29	
L_1-N_5	30	
L_1-O_2	31	$L_{\gamma'_4}$
L_1-O_3	32	L_{γ_4}
L_1-O_4	33	
L_1-O_5	34	
L_1-P_2	35	
L_1-P_3	36	

(INDEX for L series X-rays – continued)

IUPAC notation	INDEX in EDISTR04	Siegbahn notation
L_2-L_3	41	
L_2-M_1	42	L_η
L_2-M_3	43	$L_{\beta_{17}}$
L_2-M_4	44	L_{β_1}
L_2-N_1	45	L_{γ_5}
L_2-N_3	46	
L_2-N_4	47	L_{γ_1}
L_2-N_6	48	$L_{\gamma'_8}$, L_v
L_2-O_1	49	L_{γ_8}
L_2-O_3	50	
L_2-O_4	51	L_{γ_6}
L_2-O_6	52	
L_2-P_1	53	
L_2-P_3	54	
L_2-Q_1	55	
L_3-M_1	61	L_ℓ
L_3-M_2	62	L_t
L_3-M_3	63	L_s
L_3-M_4	64	L_{α_2}
L_3-M_5	65	L_{α_1}
L_3-N_1	66	L_{β_6}
L_3-N_2	67	
L_3-N_3	68	
L_3-N_4	69	$L_{\beta_{15}}$
L_3-N_5	70	L_{β_2}
L_3-N_6	71	$L_{\beta'_7}$, L_u
L_3-N_7	72	$L_{\beta'_7}$, L_u
L_3-O_1	73	L_{β_7}
L_3-O_2	74	
L_3-O_3	75	
L_3-O_4	76	L_{β_5}
L_3-O_5	77	L_{β_5}
L_3-O_6	78	
L_3-O_7	79	
L_3-P_1	80	
L_3-P_2	81	
L_3-P_3	82	
L_3-Q_1	83	

Table A.1 continued

• INDEX for M series X-rays

IUPAC notation	INDEX in EDISTR04	Siegbahn notation
$M_1 - M_2$	91	
$M_1 - M_3$		
$M_1 - N_2$		
$M_1 - N_3$		
$M_1 - O_2$		
$M_1 - O_3$		
$M_1 - P_2$		
$M_1 - P_3$		
$M_2 - M_4$		
$M_2 - N_1$		
$M_2 - N_4$		
$M_2 - O_1$		
$M_2 - O_4$		
$M_2 - P_1$		
$M_2 - Q_1$		
$M_3 - M_4$		
$M_3 - M_5$		
$M_3 - N_1$		
$M_3 - N_4$		
$M_3 - N_5$		M_γ
$M_3 - O_1$		
$M_3 - O_4$		
$M_3 - O_5$		
$M_3 - P_1$		
$M_3 - Q_1$		
$M_4 - N_2$		M_ζ
$M_4 - N_3$		M_ζ
$M_4 - N_6$		M_β
$M_4 - O_2$		
$M_4 - O_3$		
$M_4 - O_6$		
$M_4 - P_2$		
$M_4 - P_3$		
$M_5 - N_3$		M_ζ
$M_5 - N_6$		M_{α_2}
$M_5 - N_7$		M_{α_1}
$M_5 - O_3$		
$M_5 - O_6$		
$M_5 - O_7$		
$M_5 - P_3$	↓	

• INDEX for N and O series X-rays

IUPAC notation	INDEX in EDISTR04	Siegbahn notation
$N_1 - N_2$	92	
$N_1 - N_3$		
$N_1 - O_2$		
$N_1 - O_3$		
$N_1 - P_2$		
$N_1 - P_3$		
$N_2 - N_4$		
$N_2 - O_1$		
$N_2 - O_4$		
$N_2 - P_1$		
$N_2 - Q_1$		
$N_3 - N_4$		
$N_3 - N_5$		
$N_3 - O_1$		
$N_3 - O_4$		
$N_3 - O_5$		
$N_3 - P_1$		
$N_3 - Q_1$		
$N_4 - N_6$		
$N_4 - O_2$		
$N_4 - O_3$		
$N_4 - O_6$		
$N_4 - P_2$		
$N_4 - P_3$		
$N_5 - N_6$		
$N_5 - N_7$		
$N_5 - O_3$		
$N_5 - O_6$		
$N_5 - O_7$		
$N_5 - P_3$		
$N_6 - O_4$		
$N_6 - O_5$		
$N_7 - O_5$	↓	
$O_1 - O_2$	93	
$O_1 - O_3$		
$O_1 - P_2$		
$O_1 - P_3$		
$O_2 - O_4$		
$O_2 - P_1$		
$O_2 - Q_1$		
$O_3 - O_4$		
$O_3 - O_5$		
$O_3 - P_1$		
$O_3 - Q_1$	↓	
Free-Bound	94	

Table A.2 INDEX assignment for Auger and Coster-Kronig electrons in EDISTR04

Notation	INDEX	Definition
Auger KLL	1	K-shell Auger transition where the two new vacancies are in the L-shell.
Auger KLX	2	K-shell Auger transition where one of the two new vacancies is in the L-shell.
Auger KXY	3	K-shell Auger transition where neither of the two new vacancies is in the L-shell.
CK LLX	4	All L-shell Coster-Kronig transitions.
Auger LMM	5	L-shell Auger transition where the two new vacancies are in the M-shell.
Auger LMX	6	L-shell Auger transition where one of the two new vacancies is in the M-shell.
Auger LXY	7	L-shell Auger transition where neither of the two new vacancies is in the M-shell.
CK MMX	8	All M-shell Coster-Kronig transitions.
Auger MNN	9	M-shell Auger transition where the two new vacancies are in the N-shell.
Auger MNX	10	M-shell Auger transition where one of the two new vacancies is in the N-shell.
Auger MXY	11	M-shell Auger transition where neither of the two new vacancies is in the N-shell.
CK NNX	12	All N-shell Coster-Kronig transitions.
Auger NXY	13	All N-shell Auger transitions.
CK OOX	14	All O-shell Coster-Kronig transitions.
Auger OXY	15	All O-shell Auger transitions.

Table A.3 INDEX for spontaneous fission radiations in EDISTR04

INDEX	Type of radiation
1	Prompt neutrons
2	Fission fragments
3	Prompt γ-rays
4	Delayed γ-rays
5	Delayed β particles

国際単位系（SI）と換算表

表1　SI基本単位および補助単位

量	名称	記号
長さ	メートル	m
質量	キログラム	kg
時間	秒	s
電流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光度	カンデラ	cd
平面角	ラジアン	rad
立体角	ステラジアン	sr

表2　SIと併用される単位

名称	記号
分，時，日	min，h，d
度，分，秒	°，′，″
リットル	l，L
トン	t
電子ボルト	eV
原子質量単位	u

1 eV=1.60218×10^{-19}J

1 u=1.66054×10^{-27}kg

表5　SI接頭語

倍数	接頭語	記号
10^{18}	エクサ	E
10^{15}	ペタ	P
10^{12}	テラ	T
10^{9}	ギガ	G
10^{6}	メガ	M
10^{3}	キロ	k
10^{2}	ヘクト	h
10^{1}	デカ	da
10^{-1}	デシ	d
10^{-2}	センチ	c
10^{-3}	ミリ	m
10^{-6}	マイクロ	μ
10^{-9}	ナノ	n
10^{-12}	ピコ	p
10^{-15}	フェムト	f
10^{-18}	アト	a

表3　固有の名称をもつSI組立単位

量	名称	記号	他のSI単位による表現
周波数	ヘルツ	Hz	s^{-1}
力	ニュートン	N	m·kg/s^2
圧力，応力	パスカル	Pa	N/m^2
エネルギー,仕事,熱量	ジュール	J	N·m
工率，放射束	ワット	W	J/s
電気量，電荷	クーロン	C	A·s
電位，電圧，起電力	ボルト	V	W/A
静電容量	ファラド	F	C/V
電気抵抗	オーム	Ω	V/A
コンダクタンス	ジーメンス	S	A/V
磁束	ウェーバ	Wb	V·s
磁束密度	テスラ	T	Wb/m^2
インダクタンス	ヘンリー	H	Wb/A
セルシウス温度	セルシウス度	℃	
光束	ルーメン	lm	cd·sr
照度	ルクス	lx	lm/m^2
放射能	ベクレル	Bq	s^{-1}
吸収線量	グレイ	Gy	J/kg
線量等量	シーベルト	Sv	J/kg

表4　SIと共に暫定的に維持される単位

名称	記号
オングストローム	Å
バーン	b
バール	bar
ガル	Gal
キュリー	Ci
レントゲン	R
ラド	rad
レム	rem

1 Å=0.1nm=10^{-10}m

1 b=100fm^2=10^{-28}m^2

1 bar=0.1MPa=10^5Pa

1 Gal=1cm/s^2=10^{-2}m/s^2

1 Ci=3.7×10^{10}Bq

1 R=2.58×10^{-4}C/kg

1 rad=1cGy=10^{-2}Gy

1 rem=1cSv=10^{-2}Sv

（注）

1．表1－5は「国際単位系」第5版，国際度量衡局1985年刊行による。ただし，1 eVおよび1 uの値はCODATAの1986年推奨値によった。

2．表4には海里，ノット，アール，ヘクタールも含まれているが日常の単位なのでここでは省略した。

3．barは，JISでは流体の圧力を表わす場合に限り表2のカテゴリーに分類されている。

4．EC閣僚理事会指令ではbar，barnおよび「血圧の単位」mmHgを表2のカテゴリーに入れている。

換算表

力

N(=10^5dyn)	kgf	lbf
1	0.101972	0.224809
9.80665	1	2.20462
4.44822	0.453592	1

粘度　1 Pa·s(N·s/m^2)=10 P(ポアズ)(g/(cm·s))

動粘度　1m^2/s=10^4St(ストークス)(cm^2/s)

圧力

MPa(=10bar)	kgf/cm^2	atm	mmHg(Torr)	lbf/in^2(psi)
1	10.1972	9.86923	7.50062×10^3	145.038
0.0980665	1	0.967841	735.559	14.2233
0.101325	1.03323	1	760	14.6959
1.33322×10^{-4}	1.35951×10^{-3}	1.31579×10^{-3}	1	1.93368×10^{-2}
6.89476×10^{-3}	7.03070×10^{-2}	6.80460×10^{-2}	51.7149	1

エネルギー・仕事・熱量

J(=10^7 erg)	kgf·m	kW·h	cal(計量法)	Btu	ft·lbf	eV
1	0.101972	2.77778×10^{-7}	0.238889	9.47813×10^{-4}	0.737562	6.24150×10^{18}
9.80665	1	2.72407×10^{-6}	2.34270	9.29487×10^{-3}	7.23301	6.12082×10^{19}
3.6×10^6	3.67098×10^5	1	8.59999×10^5	3412.13	2.65522×10^6	2.24694×10^{25}
4.18605	0.426858	1.16279×10^{-6}	1	3.96759×10^{-3}	3.08747	2.61272×10^{19}
1055.06	107.586	2.93072×10^{-4}	252.042	1	778.172	6.58515×10^{21}
1.35582	0.138255	3.76616×10^{-7}	0.323890	1.28506×10^{-3}	1	8.46233×10^{18}
1.60218×10^{-19}	1.63377×10^{-20}	4.45050×10^{-26}	3.82743×10^{-20}	1.51857×10^{-22}	1.18171×10^{-19}	1

1 cal= 4.18605J（計量法）

= 4.184J（熱化学）

= 4.1855J（15℃）

= 4.1868J（国際蒸気表）

仕事率　1 PS(仏馬力)

= 75 kgf·m/s

= 735.499W

放射能

Bq	Ci
1	2.70270×10^{-11}
3.7×10^{10}	1

吸収線量

Gy	rad
1	100
0.01	1

照射線量

C/kg	R
1	3876
2.58×10^{-4}	1

線量当量

Sv	rem
1	100
0.01	1

（86年12月26日現在）