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Nuclear Decay Data for Dosimetric Calculations

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Nuclear Decay Data for Dosimetric Calculations

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Approved by ICRP Committee 2 in October 2007

Abstract–In this report, the Commission provides an electronic database of the physical data needed in calculations of radionuclide-specific protection and operational quantities. This database supersedes the data of *Publication 38* (ICRP, 1983), and will be used in future ICRP publications of dose coefficients for the intake of or exposure to radionuclides in the workplace and the environment.

The database contains information on the half-lives, decay chains, and yields and energies of radiations emitted in nuclear transformations of 1252 radionuclides of 97 elements. The CD accompanying the publication provides electronic access to complete tables of the emitted radiations, as well as the beta and neutron spectra. The database has been constructed such that user-developed software can extract the data needed for further calculations of a radionuclide of interest. A Windows-based application is provided to display summary information on a user-specified radionuclide, as well as the general characterisation of the nuclides contained in the database. In addition, the application provides a means by which the user can export the emissions of a specified radionuclide for use in subsequent calculations.
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Keywords: Radionuclide transformation; Half-life; Beta spectra; Fission neutron spectra; Auger-electron spectra

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Guest Editorial

IN THE BOOK OF LIFE, THE ANSWERS AREN'T IN THE BACK
– Charlie Brown, fictional character of
the *Peanuts* comic strip created by Charles Schulz

This publication tabulates the energies and intensities of radiations emitted in spontaneous nuclear transformation (decay) of 1252 radionuclides, and thus supersedes *Publication 38* (ICRP, 1983). The tabulations, collectively referred to as 'nuclear decay data', are provided electronically on a compact disk (CD) accompanying the publication rather than in printed tables as was the case for *Publication 38*. Unlike the oversize format of *Publication 38*, this issue of the *Annals of the ICRP* can reside on your bookshelf with the other issues of the journal.

For the past 30 years, all nuclide-specific dose quantities issued by ICRP have been based on the nuclear decay data of *Publication 38*. *Publication 38* was prepared by the Task Group on Dose Calculations (DOCAL), formed in June 1974 to assist Committee 2 with the preparation of *Publication 30* (ICRP, 1979, 1980, 1981). For that effort, DOCAL reviewed metabolic data, evaluated the radiations emitted in nuclear transformations of radionuclides, and implemented computational methods to derive the annual limit on intake (ALI) that appeared in *Publication 30*. *Publication 38* presented the nuclear decay data that DOCAL used in its computation of the ALIs.

Reliable information on physical characteristics of a radionuclide (half-life, modes of decay, energies and intensities of the emitted radiations, etc.) is the starting point in assessing the radiological significance of a radionuclide's presence in the workplace or in the environment. As the various radiations differ in their range in tissues, it is particularly important to account for the fraction of the available decay energy given to radiations of discrete energy (alpha particles, gamma rays, conversion electrons, Auger elections, and characteristic x rays) as well as the continuous energy spectra of beta particles. Accounting for such details requires very specific expertise and is a laborious task. Thus, as part of a schema for absorbed dose calculations of biologically distributed radionuclides, the Medical Internal Radiation Dose (MIRD) Committee of the Society of Nuclear Medicine began an effort to compile the physical data needed by dosimetrists. In the early 1970s, Dillman prepared a series of MIRD pamphlets (Dillman, 1969, 1970; Dillman and von der Lage, 1975) on the decay schemes and nuclear parameters of radionuclides of interest in nuclear medicine. As a member of DOCAL, Dillman developed the EDISTR software (Dillman, 1980) to translate the information contained in the evaluated nuclear structure data files

(ENSDF) into the required data. This computer-based file is maintained by the National Nuclear Data Center at Brookhaven National Laboratory (Tuli, 2001). An updated version of the EDISTR software was used to derive the data contained on the CD accompanying this publication. The nature of the updates is briefly discussed in this publication and is detailed in technical reports included on the CD.

The DOCAL Task Group, as formed in 1974, was centred at Oak Ridge National Laboratory (ORNL), and with the completion of *Publication 30* and issuance of *Publication 38*, the Task Group expected to be disbanded. However, Committee 2 was concerned about its reliance on a single organisation for computational support, ORNL had previously played a major role in the preparation of *Publication 2* (ICRP, 1959) and other publications, and thus requested that DOCAL become international in its membership, and established within several organisations the capability to serve the needs of Committee 2 in computational dosimetry of incorporated radionuclides. This capability was achieved by inclusion of members from the United Kingdom Health Protection Agency (formerly the National Radiation Protection Board), the German Federal Office for Radiation Protection (BfS), and the Ukraine Radiation Protection Institute. With this structure, DOCAL served the Committee's needs in development of age-specific dose coefficients for members of the public (ICRP, 1989, 1993, 1995a, 1995b, 1996, 2004) and dose coefficients for the workers (ICRP, 1994) following the issuance of the Commission's 1990 recommendations (ICRP, 1991). In the course of these efforts, DOCAL worked closely with the Task Group on Internal Dosimetry (INDOS), chaired by J. Stather (1994–2007) and J. Harrison (from 2007). In 2000, DOCAL was further restructured to be responsible for the computational dosimetry associated with external radiation fields. During its existence, DOCAL has been chaired by W.S. Snyder (1974–1977), M.R. Ford (1977–1984), K.F. Eckerman (1984–2004), and W.E. Bolch (from 2004).

With the issuance of the Commission's recommendations in *Publication 103* (ICRP, 2007), DOCAL now begins its efforts to derive dose coefficients for exposure to radionuclides in the workplace following the definition of the effective dose in the new recommendations. This publication sets forth the nuclear decay data for that effort by replacing DOCAL's first publication, *Publication 38*, issued in 1983. The publication provides comprehensive nuclear decay data for dose calculations in occupational, environmental, and medical exposures. The data are also useful for understanding the properties of radionuclides that are used in the calibration and testing of radiation protection instrumentation and spectrometers. While some readers may miss the graphic decay schemes and printed tables of emitted radiations given for 820 radionuclides in *Publication 38*, it must be realised that format is prohibitive when addressing the 1252 radionuclides of this publication. For these readers, it is noted that data for 333 radionuclides of interest in nuclear medicine have been tabulated with accompanying decay scheme graphics in a monograph entitled 'MIRD: Radionuclide Data and Decay Schemes' published by the Society of Nuclear Medicine (Eckerman and Endo, 2008). Furthermore, software distributed with the enclosed CD was developed to provide the user with insight into the decay characteristics of the radionuclides, and to tabulate summary and detailed information for a user-specified radionuclide.

This publication is an essential source of information for those working or studying in the field of nuclear medicine, radiation protection, medical physics, and health physics. Contrary to Charlie Brown's book of life, the answers are included on the enclosed CD.

Keith F. Eckerman
Hans-G. Menzel

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CONTENTS

ABSTRACT 1

GUEST EDITORIAL 3

CONTENTS 7

PREFACE 9

MAIN POINTS 11

GLOSSARY 13

1. INTRODUCTION 15

2. METHODS EMPLOYED IN COMPLILING THE NUCLEAR DECAY DATA ... 17
- 2.1. General 17
- 2.2. Alpha decay 17
- 2.3. Beta decay 18
- 2.4. Electron-capture decay 19
- 2.5. Isomeric transition and conversion of gamma rays 20
- 2.6. X-ray and Auger-electron yields and energies 21
- 2.7. Spontaneous fission 23

3. CONTENT OF ACCOMPANYING CD AND THE DATA FILES 25
- 3.1. Content of the CD 25
- 3.2. Nuclear data files 25

REFERENCES 33

ANNEX A. RADIONUCLIDES OF THE ICRP-07 COLLECTION 35

© USER GUIDE TO THE ICRP CD AND THE DECDATA SOFTWARE e1

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PREFACE

Committee 2 of the International Commission on Radiological Protection (ICRP) has the responsibility for providing dose coefficients for intakes of and exposure to radionuclides by workers who are occupationally exposed and by members of the public exposed to radionuclides in the environment. Over the past 30 years, the dosimetric coefficients calculated by the Task Group on Dose Calculations (formed in June 1974) were based on the yields and energies of radiations emitted in nuclear transformations as tabulated in *Publication 38* (ICRP, 1983). *Publication 38* provided data for the radionuclides addressed in *Publication 30* (ICRP, 1979) and for a few additional radionuclides of interest in nuclear medicine. Although *Publication 30* and subsequent publications of the Commission only considered the intake of radionuclides with half-lives of more than 10 min, the emissions of short-lived members of their decay chain had to be considered when deriving the parent's dose coefficient. Thus, *Publication 38* included data for 820 radionuclides, 764 with half-lives of more than 10 min and 56 with half-lives of less than 10 min, as either a member of the decay chain of a radionuclide with a half-life of more than 10 min or of potential interest in nuclear medicine.

This publication provides a comprehensive database of nuclear decay data for 1252 radionuclides. The database provides the physical data needed for calculation of absorbed doses in organs and tissues of the body, and the evaluation of localised depth dose distributions. The database includes all nuclides with a half-life of more than 1 min for which the nuclear structure information was judged sufficient for a meaningful assessment of the emissions. Data are provided for 922 radionuclides with a half-life of more than 10 min and 330 radionuclides with a half-life of less than 10 min. This publication departs from the format of *Publication 38*, and provides the data in electronic form on a CD in a pocket on the inside of the back cover. The electronic format enables inclusion of the continuous energy distribution of beta emissions that are needed in calculations of the depth dose distributions for walled organs and the skin. Similarly, the spectra of neutrons accompanying spontaneous fission are also included on the CD. The electronic format enables presentation of the emissions without invoking a limitation on the number of radiations considered, which would be necessary if the data were provided in printed tables.

The membership of the Working Party on Nuclear Decay Data that contributed to the development of the report was as follows:

K. Eckerman A. Endo

The work of the Working Party was greatly aided by significant technical contributions from T. Tamura and K. Umeda.

The membership of the Task Group on Dose Calculations during the period of preparation of the report was:

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MAIN POINTS

- **The yields and energies of radiations emitted in nuclear transformations of 1252 radionuclides have been assembled for use in calculating nuclide-specific protection and operational quantities.**
- **This publication supersedes *Publication 38* which was issued in 1983, and will be used in future calculations by the Task Group on Dose Calculations of Committee 2.**
- **Nuclides were selected for consideration if their half-life exceeded 1 min or if formed in nuclear transformation of a selected radionuclide. N-16 (half-life 7.13 s) was included largely for historical purposes. It is, of course, necessary that the basic nuclear physics information should be suitable for meaningful calculations of yields and energies of the emitted radiations.**
- **Data were compiled for 922 radionuclides with a half-life of more than 10 min, 330 radionuclides with a half-life of less than 10 min, and assembled in five data files.**
- **The data files contained on the CD accompanying this publication embody no restriction on the number of radiations, as was necessary in the tables of *Publication 38*. A Windows-based application is provided to enable tabular and graphical viewing of the emitted radiations of the radionuclides. Electronic access to the data is provided to assist those wanting to use the data in calculations.**

GLOSSARY

Alpha decay

In alpha decay, the nucleus of an atom of atomic number Z and mass number A emits an alpha particle (^{4}He nucleus) to form an atom of atomic number $Z - 2$ and mass number $A - 4$.

Air-kerma rate constant (Γ_δ)

This constant, a characteristic of a radionuclide, is defined in terms of an ideal point source as $\Gamma_\delta = l^2 \dot{K}_\delta / A$ where $\dot{K}_\delta$ is the air-kerma rate due to photons (gamma and x rays) of energy greater than δ at a distance l in a vacuum from a point source of the radionuclide of activity A.

Annihilation photons

The electromagnetic radiation (photon) emitted as a positron–electron pair undergoes annihilation. Annihilation generally occurs after the positron has lost its initial kinetic energy to the absorbing medium, and two photons, each equivalent in energy to the rest mass of an electron ($m_0c^2 = 0.511$ MeV), are created in opposite directions. The number of annihilation photons is taken to be twice the number of positrons emitted in beta-plus decay.

Auger transition

The filling of a vacancy in an inner electron shell of an atom, e.g. as created in electron capture, is accompanied by the emission of an electron from the outer shell, an Auger electron.

Beta-minus decay

In beta-minus decay, the nucleus of an atom of atomic number Z and mass number A emits a negative electron (β^-) and an antineutrino ($\bar{\nu}$) to form an atom of atomic number Z + 1 and mass number A.

Beta-plus decay

In beta-plus decay, the nucleus of an atom of atomic number Z and mass number A emits a positive electron (β^+, positron) and a neutrino (ν) to form an atom of atomic number $Z - 1$ and mass number A.

Branching fraction

Branching fraction is the fraction of the nuclear transformations of the radionuclide that forms a particular daughter nucleus.

Coster-Kronig (CK) transition

CK transition is an Auger transition in which the atomic shell vacancy is filled by an electron from a higher subshell of the same shell.

Inner bremsstrahlung

Inner bremsstrahlung is a continuous electromagnetic radiation produced by the sudden change of nuclear charge which occurs in beta-plus, beta-minus, or electron-capture decay. This radiation is not included here because of its low energy and low yield.

Electron-capture decay

In electron-capture decay, the nucleus of an atom of atomic number Z and mass number A captures an atomic electron and emits a neutrino (ν) to form an atom of atomic number $Z - 1$ and mass number A.

Forbiddenness

Beta transitions are classified as allowed transition or forbidden transition based on the spin and parity of the nuclear states involved in the transition. Forbiddenness indicates how 'fast' the transition occurs.

Half-life ($T_{1/2}$)

The half-life of a radionuclide is the interval required for its activity to decay to half of its initial value. The half-life is related to the decay constant λ as $T_{1/2} = \ln(2)/\lambda$ and to the mean life τ as $\tau = T_{1/2}/\ln(2)$.

Gamma ray

Gamma-rays are electromagnetic radiations (photons) emitted by the nucleus in transition from a high energy state to a lower energy state.

Isomeric transition decay

A nucleus in an excited energy state of an atom of atomic number Z and mass number A can transition to a lower energy state by emission of a gamma ray, or eject an orbital electron with the excess energy. No change in atomic and mass numbers occurs; the parent and daughter nuclei are isomers. Isomers of energy above the ground state are identified by appending 'm', 'n', 'p', or 'q' to the mass number.

Isomers

Nuclei of the same atomic number Z and mass number A but with a different energy state and different physical half-life. Isomers of energy above the ground state are identified by appending 'm', 'n', 'p', or 'q' to the mass number.

Internal conversion electron

An internal conversion electron is an orbital electron ejected from the atom as a result of the energy difference between states of the nucleus being transferred directly to a bound atomic electron. This process is a form of isomeric decay.

Nuclear transformation

Nuclear transformation is the occurrence of the decay process(es) that spontaneously transform(s) an atom from one state to another. It is often referred to as 'decay' and its SI unit is the becquerel.

Spontaneous fission

Spontaneous fission is a decay mechanism resulting in splitting of the nucleus into lighter nuclei, referred to as 'fission fragments', with the emission of neutrons.

Transition

The individual process by which a nucleus is spontaneously transformed to another energy state.

X ray

The filling of a vacancy in an inner electron shell of an atom, e.g. created in electron capture, may be accompanied by the emission of an x-ray photon.

1. INTRODUCTION

(1) This document provides information on the half-lives, decay chains, and energies and yields of radiations emitted by nuclear transformations and subsequent atomic processes that are needed in the computation of the radiation dose from internal or external exposure to radionuclides. These data were compiled as a replacement for the data of *Publication 38* (ICRP, 1983). Data are provided for 1252 radionuclides of 97 elements with an atomic number of less than 101 (see Fig. 1 and Table A.1). The data are presented here as an electronic database rather than the printed tables of *Publication 38*. Eckerman and Endo (2008) have published a monograph with printed tables and decay scheme drawings for 333 radionuclides of interest in nuclear medicine. The electronic database provided here is similar to the NUCDECAY database (Eckerman et al., 1994), and enables complete listings of the emissions including beta and neutron spectra. These data were assembled from the output of the EDISTR04 code (Endo et al., 2005); an updated version of EDISTR (Dillman, 1980) used in the production of *Publication 38*. EDISTR04 uses the basic nuclear structure data files [evaluated nuclear structure data files (ENSDF)] (Tuli, 2001) as input. The updating of EDISTR and the quality assurance efforts are discussed in detail by Endo et al. (2005). Below is a brief discussion of the methodology implemented in EDISTR04 and a detailed description of the electronic database. The electronic database, the software package DECDATA, and additional documentation, including the reports of Dillman (1980), Endo et al. (2005), and Endo and Eckerman (2007), are contained on the CD that accompanies this publication and as supplementary data to the online report at http://www.icrp.info.

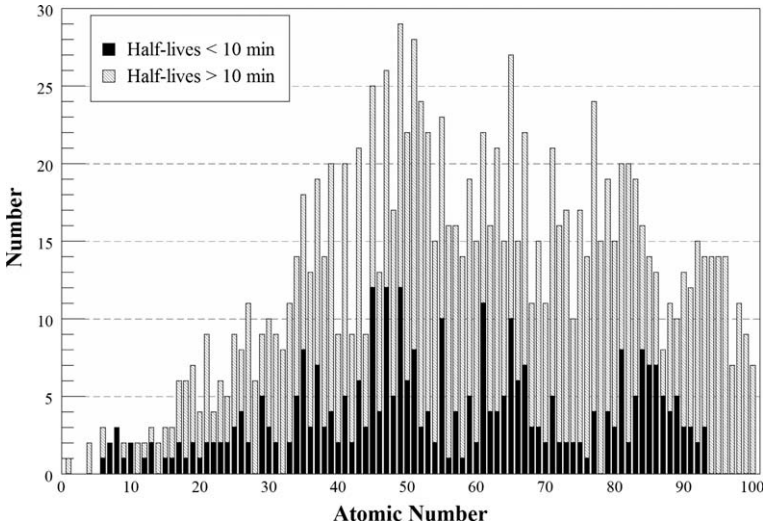


Fig. 1. Number of radioisotopes of the elements in this compilation.

2. METHODS EMPLOYED IN COMPILING THE NUCLEAR DECAY DATA

2.1. General

(2) The computer code EDISTR04 (Endo et al., 2005) was used to calculate the energies and yields of the radiations emitted by nuclear transformations and subsequent atomic processes. The code calculates the energy spectra of beta-minus and beta-plus emissions and, in the case of alpha transitions, the unique energies and yields of alpha particles and recoil nuclei. The energies and yields of various x ray and Auger-electron groups arising as a result of electron capture or internal conversion of gamma rays are also calculated. In the few cases in which spontaneous fission (SF) occurs (28 radionuclides in the collection), the yields of radiations concomitant with SF (fission fragments, neutron, prompt and delayed gamma, and delayed beta emissions) are computed.

(3) Information contained in the ENSDF is used as input data to EDISTR04. The ENSDF data are part of the computer database of the National Nuclear Data Center at Brookhaven National Laboratory, from which the radioactive decay data are published in the periodical 'Nuclear Data Sheets' (Academic Press, New York). The ENSDF were subject to review in terms of consistency with the latest nuclear parameters, by comparing the computed energies of emitted radiations with total decay energies. The fundamental decay properties in the ENSDF, such as total decay energy (Q values), branching fractions, excitation energies of isomers, physical half-life, and spin and parity of the initial and final states, were updated as necessary to those of NUBAS2003 (Audi et al., 2003) and AME2003 (Wapstra et al., 2003). The revised ENSDF were then processed by EDISTR04 in order to calculate the energies E (MeV) and yields Y (/Bq s) of alpha particles, beta particles, gamma rays including annihilation photons, internal conversion electrons, x rays, and Auger and Coster-Kronig (CK) electrons. For nuclides undergoing SF, the average energy and yields of fission fragments, prompt neutrons, prompt gamma rays, delayed gamma rays, and delayed beta particles were also computed.

(4) A comprehensive description of the theoretical and numerical techniques employed in the EDISTR and EDISTR04 codes has been published elsewhere (Dillman, 1980; Endo et al., 2005). These reports are included on the accompanying CD. A brief overview of these methods follows.

2.2. Alpha decay

(5) The emission of an alpha particle transforms the parent nucleus with an atomic number Z and mass number A to a daughter nucleus with atomic number $Z - 2$ and mass number $A - 4$. This is expressed symbolically as:

$$ {}^{A}_{Z}\mathrm{X} \rightarrow {}^{A-4}_{A-2}\mathrm{Y} + \alpha + \gamma \qquad (1) $$

where X and Y represent the parent and daughter elements, respectively, and γ represents the gamma ray accompanying a transformation ending in an excited state of the daughter nucleus. The alpha particle and the recoiling nucleus share the available

kinetic energy. The input data consist of the ground-state Q value (reaction energy for a ground-state-to-ground-state transition); the excitation energy of levels in the daughter nucleus at which the alpha transitions end, together with the corresponding yields; and the excitation energy of the parent (zero except for decay from an isomeric-level parent). From these data, the kinetic energies of the alpha particles and associated recoil nuclei are computed using conservation of energy and momentum. The corresponding absolute yields are computed from relative yields using the normalisation data directly available in the ENSDF.

2.3. Beta decay

(6) Beta decay is a three-body process that gives rise to a continuous energy spectrum of beta particles. For dosimetric purposes, the average energy of the spectrum is often sufficient; however, for calculation of the dose at a depth into tissue, e.g. the walls of the airways and the alimentary tract, the energy spectrum must be considered. The neutrino emitted in beta decay carries off a portion of the available energy; however, this energy does not contribute to dose because of the negligible interaction of neutrinos with matter. The average kinetic energy, $\overline{E}$, of the beta particles is determined from the spectrum as:

$$\overline{E} = \int_0^{E_0} P(E)E \, (\mathrm{d}E / \int_0^{E_0} P(E) \, \mathrm{d}E) \tag{2}$$

where $P(E)$ is proportional to the probability that the beta particle will be emitted with kinetic energy between E and $E + \mathrm{d}E$, and E_o *is* the maximum possible kinetic energy of the beta transition; the so-called end-point energy. The end-point kinetic energy, E_o, is determined from conservation of energy according to the equations:

$$\begin{aligned} &E_0(\beta^-) = Q + E_P - E_L \\ &\text{and} \\ &E_0(\beta^+) = Q + E_P - E_L - 2m_0c^2. \end{aligned} \tag{3}$$

(7) In these equations, $E_0(\beta^-)$ and $E_0(\beta^+)$ are the end-point kinetic energies for beta-minus and beta-plus particles, respectively, Q is the energy difference between the ground states of parent and daughter nuclei, E_p is the excitation energy of the parent ($E_\mathrm{P} = 0.0$ except for an isomeric-level parent nuclide), E_L is the excitation energy of the level in the daughter nucleus at which the transition ends, and m_0c^2 is the electron rest-mass energy (0.511 MeV). The values of Q, E_p, and E_L are all included in the ENSDF.

(8) The emission of a negatively charged beta particle (β^- or negatron) from the nucleus transforms the parent nucleus X with atomic number Z and mass number A to a daughter nucleus Y with atomic number Z + 1 and mass number A. The daughter nucleus has one more proton and one less neutron than the parent radionuclide. Symbolically, beta-minus decay is expressed as:

$$^{A}_{Z}X \;\rightarrow\; ^{A}_{Z+1}Y + \beta^- + \bar{\nu} + \gamma \tag{4}$$

Table 2.1. Classification of beta transitions.

Type of transition	Forbiddenness	Change in spin	Change in parity
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

where $\bar{\nu}$ is an antineutrino and γ represents the gamma-ray emissions accompanying a transition ending in an excited state of the daughter nucleus. The emission of a positively charged beta particle (β^+ or positron) from the nucleus transforms the parent nucleus X with atomic number Z and mass number A to a daughter nucleus Y with atomic number $Z - 1$ and mass number A. The daughter nucleus has one less proton and one more neutron than the parent nucleus. The beta-plus transition is expressed as:

$$ {}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + \beta^{+} + \nu + \gamma \tag{5} $$

where ν is the neutrino.

(9) Beta spectra are classified into various degrees of forbiddenness depending on the spin and parity changes that occur between the parent and daughter nuclear levels. The forbiddenness classifications are illustrated in Table 2.1.

(10) The mathematical form of $P(E)$ becomes lengthy for the case of forbidden unique spectra and, in the interest of brevity, is not presented here. Even for the case of allowed transitions, Coulomb screening and finite nuclear size corrections to the theory complicate otherwise simple expressions for $P(E)$. The interested reader is referred to Dillman (1980) for further details, and Endo et al. (2005) for a comparison of beta spectra calculated by EDISTR04 with other published works.

(11) Positrons are unstable in matter and will annihilate with an electron of the absorbing media to create two annihilation photons. If the annihilation occurs after the beta-plus particle has come to rest, which is the usual circumstance, the energy of each annihilation photon corresponds with the rest-mass energy of an electron or 0.511 MeV. In the database, the yield of annihilation photons is taken to be twice the beta-plus yield.

2.4. Electron-capture decay

(12) Electron capture is a form of beta decay that results in vacancies in the atomic subshells of the daughter atom. Vacancies are most likely to be created in the K shell if energetically possible. The distribution of primary vacancies among the atomic

shells and subshells must be calculated because this distribution affects the relative yields of the x rays and Auger electrons that result from the initial vacancies. Given a specific electron-capture transition, the basic computations required are the K/L/M... capture ratios. Electron capture is expressed as:

$$ {}^{A}_{Z}X + e^{-} \rightarrow {}^{A}_{z-1}Y + \nu + \gamma \qquad (6) $$

where all variables are as defined previously.

(13) EDISTR04 calculates the capture ratios from 24 subshells from K up to O_8 using the comprehensive tables of Firestone et al. (1996) and Bambynek et al. (1977). The electron-binding energies are taken from the evaluated atomic data library (EADL) of Perkins et al. (1991). EADL provides the atomic data for $Z = 1 - 100$* and includes theoretical binding energies of 29 subshells from K up to Q_1 subshells. When the transition energy between the parent and daughter nuclei is greater than twice the rest mass energy of an electron (1.022 MeV), the emission of a positron can compete with electron capture. This competition has dosimetric implications as, if positron emission is possible, the energy of the transition is shared between the positron and the neutrino. The neutrino leaves the nucleus with approximately two-thirds of the transitional energy. The probability of electron capture compared with positron emission generally increases with decreasing transition energy and increasing atomic number. Only electron capture can occur when the transition energy is less than the 1.022-MeV threshold required for positron emission.

2.5. Isomeric transition and conversion of gamma rays

(14) The de-excitation of a nuclear state of more than transitory existence (greater than a nanosecond) by the release of gamma rays or conversion electrons is referred to as 'isomeric transition'. Whereas the previous discussion of other decay modes showed gamma-ray emission from nuclei formed in an excited state by alpha- or beta-particle decay, the term 'isomeric transition' describes the decay of longer-lived metastable states where the loss of energy is the only change in the nucleus. Radionuclides that decay by isomeric transition are identified with an 'm' immediately after the mass number†, such as in ^{99m}Tc. Symbolically, this decay mode is expressed as:

$$ {}^{Am}_{Z}X \rightarrow {}^{A}_{Z}Y + \gamma. \qquad (7) $$

(15) An alternative means of de-excitation of the nucleus is internal conversion. This is a process by which energy, equal to the energy of the gamma ray, is transferred to an orbital electron and the orbital electron is ejected from the atom. The energy of the internal conversion electron emitted from one of the atomic shells

* EDISTR04 is not applicable to mendelevium (Md) and heavier elements; two isotopes of Md were addressed in *Publication 38*.

† Isomers are identified in order of increasing excitation energy by appending 'm', 'n', 'p', ... to mass number A.

(K, L,..) is equal to the energy of the corresponding gamma ray minus the binding energy of the ejected orbital electron. As with electron capture, vacancies can be created in various electron shells, and the distribution of these vacancies must be calculated in order to determine the yields of the resulting x rays and Auger electrons. The ratio of the number of conversion electrons to the number of gamma radiations emitted per transition is called the 'internal conversion coefficient'. The coefficient for each transition depends on transition energy, atomic number of the nucleus, and the multipolarity of the transition. The multipolarity depends on the total angular momentum and parity changes between the nuclear levels involved in the transition. Usually, the internal conversion coefficient for an atomic shell or subshell increases as the transition energy decreases, as the atomic number increases, and as the multipole order increases.

2.6. X-ray and Auger-electron yields and energies

(16) An atom excited by an atomic vacancy in one of its inner shells de-excites by x ray or Auger-electron emission or by CK transitions. The resulting cascade of atomic events leads to a myriad of x rays and Auger electrons being emitted, even in very simple nuclear decay schemes. In the x ray emission process, an electron in an outer shell, Y, makes a transition to the vacancy in an inner shell, X, and a photon is emitted. The energy of the emitted x ray is equal to E_x, the binding energy of an electron in shell X, minus E_y, the binding energy of an electron in shell Y. The original vacancy in shell X is transferred to shell Y, which will be subsequently filled.

(17) In Auger-electron emission, an electron in an outer shell, Y, makes a transition to the vacancy in an inner shell, X, and an electron in outer shell Y′ is ejected from the atom. Shell Y′ may or may not be the same as shell Y. The energy of the emitted electron (Auger electron) is approximately equal to $E_x - E_y - E_{y'}$. This process results in vacancies in both the Y and Y′ shells from a single vacancy in the X shell. If X is the K shell, Y the L_1 subshell, and Y′ the L_2 subshell, the electron is called a 'KL_1L_2 Auger electron'. A KLL Auger electron is one in which the Y and Y′ shells could be any of three L subshells.

(18) A CK transition is a non-radiative process involving an electron transition between two subshells of the same major shell. For example, if a vacancy is transferred from the L_1 subshell to the L_2 subshell, and the small energy difference between the subshells is transferred to one of the outermost electrons, ejecting it from the atom, the transition is said to be a 'CK transition'. The essential difference between CK and Auger transitions is that in the case of CK transitions, one of the final vacancies is in the same major shell as the initial vacancy. In Auger transitions, both of the final vacancies are in a different major shell from that of the initial vacancy.

(19) A method, based on the RELAX computer code of Cullen (1992), for calculating detailed atomic radiations has been introduced into EDISTR04 in order to treat transitions from outer shells. The energies and yields of x rays, Auger electrons,

and CK electrons are calculated for each transition; the Auger and CK emissions can exceed 3000 in number. These emissions are collected into 15 composite groups to

Table 2.2. Assignment for Auger and Coster-Kronig (CK) electrons in the tables.

Notation	Definition
Auger KLL	K-shell Auger transitions where the two new vacancies are in the L shell
Auger KLX	K-shell Auger transitions where one of the two new vacancies is in the L shell
Auger KXY	K-shell Auger transitions where neither of the two new vacancies is in the L shell
CK LLX	All L-shell CK transitions
Auger LMM	L-shell Auger transitions where the two new vacancies are in the M shell
Auger LMX	L-shell Auger transitions where one of the two new vacancies is in the M shell
Auger LXY	L-shell Auger transitions where neither of the two new vacancies is in the M shell
CK MMX	All M-shell CK transitions
Auger MNN	M-shell Auger transitions where the two new vacancies are in the N shell
Auger MNX	M-shell Auger transitions where one of the two new vacancies is in the N shell
Auger MXY	M-shell Auger transitions where neither of the two new vacancies is in the N shell
CK NNX	All N-shell CK transitions
Auger NXY	All N-shell Auger transitions
CK OOX	All O-shell CK transitions
Auger OXY	All O-shell Auger transitions

Table 2.3. International Union of Pure and Applied Chemistry (IUPAC) and Siegbahn notations for x rays (Jenkins et al., 1991).

K x-ray series			
Siegbahn	IUPAC	Siegbahn	IUPAC
K_{α_2}	$K - L_2$	$K^{I}_{\beta_5}$	$K - M_5$
K_{α_1}	$K - L_3$	$K^{II}_{\beta_2}$	$K - N_2$
K_{β_3}	$K - M_2$	$K^{I}_{\beta_2}$	$K - N_3$
K_{β_1}	$K - M_3$	$K^{II}_{\beta_4} K_{\beta_4 x}$	$K - N_4$
$K^{II}_{\beta_5}$	$K - M_4$	$K^{I}_{\beta_4}$	$K - N_5$

L x-ray series			
Siegbahn	IUPAC	Siegbahn	IUPAC
L_{β_4}	$L_1 - M_2$	L_{γ_6}	$L_2 - O_4$
L_{β_3}	$L_1 - M_3$	L_{ℓ}	$L_3 - M_1$
$L_{\beta_{10}}$	$L_1 - M_4$	L_{t}	$L_3 - M_2$
L_{β_9}	$L_1 - M_5$	L_{δ}	$L_3 - M_3$
L_{γ_2}	$L_1 - N_2$	L_{α_2}	$L_3 - M_4$
L_{γ_3}	$L_1 - N_3$	L_{α_1}	$L_3 - M_5$
L_{γ_4}	$L_1 - O_2$	L_{β_6}	$L_3 - N_1$
L_{γ_4}	$L_1 - O_3$	$L_{\beta_{15}}$	$L_3 - N_4$
L_{η}	$L_2 - M_1$	L_{β_2}	$L_3 - N_5$
$L_{\beta_{17}}$	$L_2 - M_3$	$L_{\beta'_7} L_u$	$L_3 - N_6$
L_{β_1}	$L_2 - M_4$	$L_{\beta'_7}, L_u$	$L_3 - N_7$
L_{γ_5}	$L_2 - N_1$	L_{β_7}	$L_3 - O_1$
L_{γ_1}	$L_2 - N_4$	L_{β_5}	$L_3 - O_4$
L_{γ_8}, L_v	$L_2 - N_6$	L_{β_5}	$L_3 - O_5$
L_{γ_8}	$L_2 - O_1$		

keep the tabulated data within an appropriate size. The grouping of the Auger and CK electrons is noted in Table 2.2. Ungrouped Auger and CK electron data (e.g. KL_1L_2, $M_1M_2M_5$) are contained on the accompanying CD for selected radionuclides. The x-ray notation of the International Union of Pure and Applied Chemistry (IUPAC) has been adopted for the data tables (Jenkins et al., 1991). The relationship of this notation with the conventional Siegbahn notation for the K and L series is given in Table 2.3. For example, the Siegbahn notation for the K_{α_2} x ray is denoted as 'K-L_2' under the IUPAC notation.

2.7. Spontaneous fission

(20) SF is nuclear fission that occurs without the addition of particles or energy to the nucleus. From a dosimetric viewpoint, SF is very important because substantial energy is associated with fission. In addition, fission gives rise to a variety of radiations including fission fragments, neutrons, beta particles, prompt gamma rays, and delayed gamma rays. Dillman and Jones (1975) developed a set of empirical formulae to compute the energies and yields of these radiations, which were used in EDISTR. These formulae have been updated as discussed by Endo et al. (2005) in EDISTR04. The empirical formulations express the yields and energies of the radiations in terms of the fission decay fraction BF_{SF}, the mass number A and the atomic number Z of the parent nuclide, and the average number of neutrons emitted per fission, $\bar{\nu}$. The pertinent formulae are summarised in Table 2.4.

(21) The neutron spectral shape is well expressed by the Watt spectrum and the approximation has been incorporated into EDISTR04. The spectrum is expressed as:

$$N(E) = BF_{SF}\bar{\nu}e^{-\frac{E}{a}}\sinh(\sqrt{bE}) \tag{8}$$

where the *SF* branching fraction and the parameters a and b are given in Table 2.5.

Table 2.4. Energies and yields of radiations accompanying spontaneous fission.

Radiation type	Average energy (MeV)	Yield (/Bq s)
Neutrons	$0.25a^2b + 1.5a^*$	$BF_{SF}\bar{\nu}$
Fission fragments	$0.05945\frac{Z^2}{A^{1/3}} + 3.65$	$2\ BF_{SF}$
Prompt gamma rays	$-1.33 + 119.6\frac{Z^{1/3}}{A}$	$\frac{(2.51 - 1.13x10^{-5}Z^2A^{1/2})\bar{\nu} + 4}{\overline{E}_{p\gamma}}$
Delayed gamma rays	0.9578	$0.2102\left(5.98 + \frac{92}{236}A - Z\right)^2 BF_{SF}$
Delayed beta particles	$0.2058\left(5.98 + \frac{92}{236}A - Z\right)$	$\left(5.98 + \frac{92}{236}A - Z\right)BF_{SF}$

* a and b are parameters of the Watt approximation of the neutron spectrum.

Table 2.5. Parameters of the Watt spectrum for spontaneous fission.

Nuclide	BF_{SF}	$\bar{\nu}$	Watt parameters	
			a	*b*
U-238	5.450E-07	2.010	0.648318	6.81057
Pu-236	1.370E-09	2.130	0.988270	3.10386
Pu-238	1.850E-09	2.220	0.847833	4.16933
Pu-240	5.750E-08	2.160	0.794930	4.68927
Pu-242	5.540E-06	2.150	0.819150	4.36668
Pu-244	1.210E-03	2.300	0.694716	6.00370
Cm-240	3.900E-08	2.390	1.071680	2.69829
Cm-242	6.370E-08	2.520	0.887353	3.89176
Cm-244	1.371E-06	2.690	0.902523	3.72033
Cm-245	6.100E-09	2.870	0.911919	3.62393
Cm-246	2.630E-04	3.180	0.878224	3.88585
Cm-246	2.630E-04	3.180	0.878224	3.88585
Cm-248	8.390E-02	3.110	0.808387	4.53623
Cm-250	7.400E-01	3.310	0.734482	5.43559
Cf-246	2.500E-06	3.100	1.02600	2.93000
Cf-248	2.900E-05	3.340	1.02772	2.93228
Cf-249	5.020E-09	3.410	1.02600	2.93000
Cf-250	7.700E-04	3.530	1.02600	2.93000
Cf-252	3.092E-02	3.765	1.02500	2.92600
Cf-254	9.969E-01	3.890	1.02600	2.93000
Es-253	8.900E-08	3.930	0.82000	4.60000
Es-254	3.000E-08	3.950	0.82000	4.60000
Es-254m	4.500E-04	3.950	0.82000	4.60000
Es-255	4.500E-05	3.970	0.82000	4.60000
Fm-252	2.300E-05	3.900	0.82000	4.60000
Fm-255	2.300E-07	3.730	0.82000	4.60000
Fm-256	9.190E-01	4.010	0.82000	4.60000
Fm-257	2.100E-03	3.850	0.82000	4.60000

3. CONTENT OF ACCOMPANYING CD AND THE DATA FILES

3.1. Content of the CD

(22) The CD in the pocket on the inside back cover of this publication provides electronic files of the unabridged nuclear decay data for 1252 radionuclides of 97 elements in the ICRP collection. Table A.1 in Annex A lists the radionuclides addressed in the CD. The CD contains the following:

- README.TXT. A file containing information post preparation of the publication.
- CONTENT.PDF. A file detailing the content of the CD.
- LICENSE.TXT. A file containing the licence agreement and a liability statement.
- USERGUIDE.PDF. The user guide to the DECDATA software.
- Nuclear decay data files:
  - ICRP-07.NDX
  - ICRP-07.RAD
  - ICRP-07.BET
  - ICRP-07.NSF
  - ICRP-07.ACK
- SETUP.EXE. Executable file for installing the DECDATA software.
- Archive folders:
  - INPUT folder. EDISTR04 input files for nuclides of the ICRP-07 collection.
  - OUTPUT folder. EDISTR04 output files for nuclides of the ICRP-07 collection.
  - SOURCE folder. The source code for DECDATA.

(23) The software package DECDATA[‡] provides access to the nuclear decay data for a user-requested radionuclide, and extracts the energies and yields of the emitted radiations into ASCII files for use in further computations. DECDATA enables the user to view the decay data in tabular and graphical form on a personal computer with Windows operating system. However, the five data files have been constructed in a manner such that the data can be accessed directly by user-developed software. Further guidance on this issue is provided in the DECDATA user guide.

3.2. Nuclear data files

(24) The nuclear decay data are embodied in five formatted (hence can be viewed with an ASCII editor) direct-access files, each with the root name ICRP-07. The file ICRP-07.RAD contains the data on the absolute yields and mean[§] or discrete

[‡] Portions © 2002 Perfect Sync, Inc.

[§] Mean values are reported for beta transitions, Auger and CK electron groups, and the radiations emitted during SF – fission fragments, neutrons, and delayed beta emission.

energies of the radiations emitted by the nuclides of the ICRP-07 collection. This file contains data for all emitted radiations, i.e. no cut-off on the number of radiations has been used in creating the data files.

(25) The file ICRP-07.BET contains the beta spectra for all beta emitters in the collection. EDISTR04 computes the spectrum for each beta transition to determine the mean beta energy of the transition, and tabulates the composite spectrum for all beta transitions of the radionuclide. The composite spectrum is included in this file.

(26) The file ICRP-07.ACK contains detailed Auger–CK electron spectra for 136 selected radionuclides. In the RAD file, these discrete emissions were collected in no more than 15 groups (see Table 2.2) for each decay mode, with the average energy and yield reported for the group.

(27) The spectra of neutrons emitted during SF are contained in the file ICRP-07.NSF. In the ICRP-07 collection, 28 radionuclides decay by SF.

(28) To facilitate access to the data in these files, an additional file (ICRP-07.NDX) was constructed. A brief description of each of these five files is presented below. For convenience, the files are referred to by their extensions, i.e. NDX, RAD, BET, ACK, and NSF.

3.2.1. Index file: ICRP-07.NDX

(29) The NDX file serves as the entrance into the radiation file (RAD) and spectral (BET, ACK, and NSF) data files. The NDX file contains one record for each nuclide of the collection. The fields of the nuclide record specify the location (a pointer) of the nuclide's record in the RAD, BET, ACK, and NSF files. In addition to these pointers, the record includes fields giving the nuclide's physical half-life, decay mode (e.g. alpha or beta), identity of progeny (daughters), fraction of the nuclear transformations forming each daughter (so-called branching fraction), the total energies emitted by alpha, electron, and photon emissions (including electrons and photons accompanying SF), and other supportive data. A description of the NDX records is given in Table 3.1.

(30) The records of the index file have been sorted by the field containing the nuclide name, making it possible for user-developed software to locate the record for a radionuclide of interest by a binary search. While the purpose of the NDX file is to provide entry into the other data files, it is of considerable utility in its own right. For example, the decay chain headed by a radionuclide from information in the NDX file includes identification of the stable nucleus terminating the chain. Tantalum-180m, formed in the beta decay of Hf-180m, is assigned here as stable due to its very long half-life as in NUBASE2003 (Audi et al., 2003).

(31) The nuclide record in the NDX file has a field containing the air-kerma rate constant. This constant, a characteristic of a radionuclide, is defined in terms of an ideal point source. The International Commission on Radiation Units and Measurements (ICRU) defined the constant as $\Gamma_\delta = l^2\dot{K}_\delta/A$ where $\dot{K}_\delta$ is the air-kerma rate due to photons of energy greater than δ at a distance l in a vacuum from a point source of the radionuclide of activity A (ICRU, 1998). The photons referred to

Table 3.1 Structure of records in the ICRP-07.NDX file.

Field	Format*	Description
Record 1		
First	I4	Record number of first data record
Last	I4	Record number of last data record
Data records (first, . . ., last)		
Nuclide	A7	Name of nuclide (parent); e.g. Am-241, Tc-99m
Half-life	A8	Half-life of nuclide
Units	A2	Half-life units: μs, microsecond; ms, millisecond; s, second; m, minute; d, day; y, year
Decay mode	A8	A, alpha; B-, beta minus; B+, beta plus; EC, electron capture; IT, isomeric transition; SF, spontaneous fission
Pointer-1	I7	Location of nuclide in ICRP-07.RAD file
Pointer-2	I7	Location of nuclide in ICRP-07.BET file
Pointer-3	I7	Location of nuclide in ICRP-07.ACK file
Pointer-4	I6	Location of nuclide in ICRP-07.NSF file
The next block of three fields are repeated for radioactive daughter i, $i = 1 - 4$.		
Daughter-i	A7	Name of daughter nuclide i
Pointer-i	I6	Location of daughter i in ICRP-07.NDX file
Branch-i	E11.0	Branching fraction to daughter i
E-alpha	E7.0	Energy of alpha emissions (MeV/nuclear transformation)
E-electron	E8.0	Energy of electrons, including beta (MeV/nuclear transformation)
E-photon	E8.0	Energy of photon emission (MeV/nuclear transformation)
Number-1	I4	Number of photons of energy less than 10 keV
Number-2	I4	Number of photons of energy greater than 10 keV
Number-3	I4	Number of beta transitions
Number-4	I5	Number of mono-energetic electrons
Number-5	I4	Number of alpha transitions
AMU	E11.0	Atomic mass of radionuclide (Audi et al., 2003)
Γ_{10}	E10.0	Air-kerma rate constant (Gy-m^2/Bq s)
K_{air}	A9	Point source air-kerma coefficient (Gy-m^2/Bq s)

* The format is expressed in FORTRAN notation, e.g. A8 denotes an alphanumic field of length 8, I5 denotes an integer field of length 5, and E11.0 denotes a real numeric field of length 11.

include gamma rays, characteristic x rays, and inner bremsstrahlung; the latter are not addressed here. It should also be noted that annihilation photons, included in the RAD file, are not considered. In a source of finite size, attenuation and scattering occur, and external bremsstrahlung can be produced. In addition, any medium between the source and the point of measurement will give rise to absorption and scattering, external bremsstrahlung, and annihilation photons. In many cases, these processes can influence the observed kerma rate substantially. The constant, as defined, is given by:

$$\Gamma_\delta = \frac{1}{4\pi} \sum_i (\mu_k/\rho)_i Y_i E_i \tag{9}$$

where $(\mu_k/\rho)_i$ is the mass energy-transfer coefficient for air for photons of energy E_i emitted by the nuclide with yield Y_i. The value of δ used in the calculations here is 10 keV.

Point source air-kerma coefficient

(32) To address the annihilation photons associated with positron emission and the neutrons and photons that accompany SF, the air-kerma coefficient, $K_{\mathrm{air},\delta}$, for a hypothetical point source is defined as:

$$K_{air,\delta} = \frac{1}{4\pi}\left[\sum_i (\mu_k/\rho)_i Y_i E_i + \sum_i Y(E_i, E_{i+1})\overline{k}(E_i, E_{I+1})\right] \quad (10)$$

This has been included on the nuclide record in the NDX file. The summation in the first term of Eq. (10) extends over all photons of energy greater than δ, including annihilation photons arising from position emission, and the delay and prompt gamma radiations accompanying SF. The second term of Eq. (10) is the contribution to kerma of neutrons accompanying SF with yield $Y(E_i,E_{i+1})$ per nuclear transformation, and $\overline{k}(E_i, E_{i+1})$ denotes the average value of the neutron air-kerma coefficient (Chadwick et al., 1999) over energy E_i and $E_{\mathrm{i}+1}$. Only neutrons of energy greater than δ (10 keV) are considered. The constant and the coefficient are numerically equal except in cases of positron emission or SF decay. The cautionary statements above regarding the air-kerma rate constant and observed kerma rate for a real source in air are also applicable to the coefficient.

3.2.2. Radiation file: ICRP-07.RAD

(33) The records of the RAD file contain the data on the energy and yield of each radiation emitted in nuclear transformations of the radionuclide. The fields of the RAD records are described in Table 3.2. Briefly, the first record (header record) of a nuclide in the file contains the name of the nuclide, its half-life, and the number of data records for the emitted radiations that follow. The data record for each emitted radiation has the following fields: (1) an integer code (ICODE) that identifies the radiation type; (2) the absolute yield of the radiation (i.e. number per nuclear transformation); (3) the unique or average energy of the radiation (MeV); and (4) a two-character mnemonic denoting the radiation type. The ICODE code and the

Table 3.2 Structure of records in the ICRP-07.RAD file.

Field	Format	Description
Nuclide record		
Nuclide	A7	Nuclide name, e.g. Tc-99m
$T_{1/2}$	E11.0	Physical half-life of nuclide
Time unit	A2	Units of $T_{1/2}$
N	I9	Number of data records
Data record (1, …, N)		
ICODE	A2	Radiation type (see Table 2.3)
Yield	E12.0	Yield of the radiation (/nuclear transformation)
Energy	E12.0	Energy of the radiation (MeV)
JCODE	A3	Mnemonic (see Table 2.3)

Table 3.3. Description of integer code (ICODE) variable.

ICODE	Mnemonic	Description
1	G	Gamma rays
	PG	Prompt gamma rays*
	DG	Delayed gamma rays*
2	X	X rays
3	AQ	Annihilation photons
4	B+	Beta-plus particles
5	B-	Beta-minus particles
	BD	Delayed beta particles*
6	IE	Internal conversion electrons
7	AE	Auger electrons
8	A	Alpha particles
9	AR	Alpha recoil nuclei
10	FF	Fission fragments
11	N	Neutrons

* Prompt and delayed radiations of spontaneous fission.

mnemonic are defined in Table 3.3. The pointer on the nuclide's records in the NDX file is the record number of the nuclide's header record in the RAD file.

(34) The radiation records are ordered by radiation type, in ICODE order, and in increasing energy. The radiation groups are as follows:

- Photons, ICODE 1–3: x ray, gamma ray, annihilation photons, and prompt and delayed photons of SF
- Beta particles, ICODE 4–5: mean energies of each beta transition
- Mono-energetic electrons, ICODE 6–7: internal conversion and Auger–CK electrons
- Alpha particles, ICODE 8
- Alpha recoil nuclei, ICODE 9
- Fission fragments, ICODE 10
- Neutrons, ICODE 11

(35) The records of each group are sorted by increasing energy. This sorting facilitates interpolation of energy-dependent quantities, e.g. energy-dependent specific absorbed fraction data for the radiation type. Radiations of a particular type within its group can be identified using the mnemonic (e.g. annihilation photons, delayed gamma rays, etc.). The prompt and delayed gamma spectra following SF are represented by 48 and 28 discrete photons, respectively, following the suggestion of Dillman and Jones (1975). These emissions can be identified by their mnemonic.

3.2.3. Beta spectra file: ICRP-07.BET

(36) The BET file contains the beta spectra for each beta emitter in the ICRP-07 collection. The spectral data are tabulated on a fixed logarithmic-type energy grid. For each nuclide, the header record gives the name of the nuclide and the number of data records that follow. The fields of the data records contain the electron energy E (MeV) and the number of beta particles per MeV per nuclear transformation

Table 3.4 Structure of records in the ICRP-07.BET file.

Field	Format	Description
Nuclide record		
Nuclide	A7	Nuclide name, e.g. Tc-99m
N	I10	Number of data records
Data record (1, . . ., N)		
Energy	F7.0	Energy grid point (MeV)
Number	E10.0	Number of beta particles per MeV per nuclear transformation at this energy

emitted at this energy. A spectrum was synthesised for the delayed beta emissions following SF by first assuming forbidden unique transitions of atomic numbers 39 and 58 with the energy and yield indicated in Table 2.4. The structure of the records in the BET file is given in Table 3.4.

3.2.4. Auger–CK electron spectra file: ICRP-07.ACK

(37) For 136 selected nuclides, detailed Auger–CK electron spectra are contained in the ACK file. These emissions were collapsed into no more than 15 groups for each decay mode in the RAD file. The maximum number of discrete electrons in a spectrum is 3015 in the case of Hg-195m and Hg-197m. The fields of the header record contain the name of the nuclide and the number of data records that follow. The data records contain the electron energy E (eV), the yield (number of electrons of that energy per nuclear transformation), and identification of the atomic electron transition. The records of the ACK file are described in Table 3.5. The group data in the RAD file are sufficient to compute the average absorbed dose in organs and tissues; however, the data in the ACK file may be of interest in microdosimetric calculations of radionuclides within the cell nucleus.

Table 3.5 Structure of records in the ICRP-07.ACK file.

Field	Format	Description
Nuclide record		
Nuclide	A8	Nuclide name, e.g. I-123
N	I8	Number of discrete electron lines
Data record (1, . . ., N)		
Yield	E12.0	Number of electrons per nuclear transformation at this energy
Energy	E12.0	Electron energy (eV)
Transition	A9	Identification of atomic transition; e.g. L1 M2 M3

Table 3.6 Structure of records in the ICRP-07.NSF file.

Field	Format	Description
Nuclide record		
Nuclide	A8	Nuclide name, e.g. Cf-252
BF	E12.0	Spontaneous fission branching fraction
N	I3	Number of neutron energy bins
Data record (1, . . ., N)		
Energy-1	E9.0	Lower energy (MeV)
Energy-2	E9.0	Upper energy (MeV)
Yield	E12.0	Number of neutrons per nuclear transformation in bin

3.2.5. Neutron spectra file: ICRP-07.NSF

(38) The NSF file contains the spectra of neutrons emitted by the 28 radionuclides of the ICRP-07 collection that undergo SF. For each nuclide, the header record gives the name of the nuclide, the branching fraction for SF, and the number of data records that follow. The data records define a neutron energy bin (or energy group) and specify the number of neutrons per nuclear transformation in that energy bin. The records in the NSF file are described in Table 3.6.

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ANNEX A. RADIONUCLIDES OF THE ICRP-07 COLLECTION

(A1) The 1252 radionuclides of the ICRP-07 collection are listed in Table A.1 in order of atomic number. Indented on the line following the radionuclide is the identity of the daughter nuclide formed by the nuclear transformation (nt) of the parent, along with the fraction of the parent's transformation creating the daughter. If the daughter nucleus is stable then it is shown in italics. The half-life, decay mode, and energy emitted per nuclear transformation are also shown.

(A2) The units of the half-life are abbreviated as: μs - microsecond, ms - millisecond, s - second, m - minute, d - day, and y - year. The decay modes are abbreviated as: A - alpha, B− - beta minue, B+ - beta minus, EC - electron capture, IT - isomeric transition, SF-spontaneous fission. The contribution of fission fragments and neutrons associated with spontaneous fission are included in the total energy.

Table A.1 Properties of the radionuclides of the ICRP-07 collection.

					Emitted energy (MeV/nt)			
Z	Element	Nuclide	Half-life	Decay mode	Alpha	Electron	Photon	Total
1	Hydrogen	H-3	12.32 y	B-	–	0.005	–	0.0057
			He-3	1.00				
4	Beryllium	Be-7	53.22 d	EC	–	<E-04	0.0499	0.0499
			Li-7	1.00				
		Be-10	1.51E+6 y	B-	–	0.2525	–	0.2525
			B-10	1.00				
6	Carbon	C-10	19.255 s	ECB+	–	0.8087	1.7443	2.5531
			B-10	1.00				
		C-11	20.39 m	ECB+	–	0.3847	1.0196	1.4043
			B-11	1.00				
		C-14	5.70E+3 y	B-	–	0.0495	–	0.0495
			N-14	1.00				
7	Nitrogen	N-13	9.965 m	ECB+	–	0.4909	1.0200	1.5109
			C-13	1.00				
		N-16	7.13 s	B-	–	2.7646	4.4932	7.2579
			O-16	1.00				
8	Oxygen	O-14	70.606 s	ECB+	–	0.7763	3.3201	4.0965
			N-14	1.00				
		O-15	122.24 s	ECB+	–	0.7347	1.0210	1.7557
			N-15	1.00				
		O-19	26.464 s	B-	–	1.7608	0.9397	2.7006
			F-19	1.00				
9	Fluorine	F-17	64.49 s	ECB+	–	0.7385	1.0208	1.7593
			O-17	1.00				
		F-18	109.77 m	ECB+	–	0.2416	0.9886	1.2302
			O-18	1.00				
10	Neon	Ne-19	17.22 s	ECB+	–	0.9624	1.0210	1.9834
			F-19	1.00				
		Ne-24	3.38 m	B-	–	0.8035	0.5419	1.3455
			Na-24	1.00				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
11	Sodium	Na-22	2.6019 y	ECB+	–	0.1941	2.1926	2.3866
			Ne-22	1.00				
		Na-24	14.9590 h	B-	–	0.5538	4.1232	4.6770
			Mg-24	1.00				
12	Magnesium	Mg-27	9.458 m	B-	–	0.7021	0.8912	1.5933
			Al-27	1.00				
		Mg-28	20.915 h	B-	–	0.1610	1.3700	1.5310
			Al-28	1.00				
13	Aluminium	Al-26	7.17E+5 y	ECB+	–	0.4444	2.6751	3.1195
			Mg-26	1.00				
		Al-28	2.2414 m	B-	–	1.2417	1.7789	3.0205
			Si-28	1.00				
		Al-29	6.56 m	B-	–	0.9764	1.3794	2.3558
			Si-29	1.00				
14	Silicon	Si-31	157.3 m	B-	–	0.5949	0.0009	0.5957
			P-31	1.00				
		Si-32	132 y	B-	–	0.0686	–	0.0686
			P-32	1.00				
15	Phosphorus	P-30	2.498 m	ECB+	–	1.4389	1.0222	2.4610
			Si-30	1.00				
		P-32	14.263 d	B-	–	0.6948	–	0.6948
			S-32	1.00				
		P-33	25.34 d	B-	–	0.0764	–	0.0764
			S-33	1.00				
16	Sulphur	S-35	87.51 d	B-	–	0.0487	–	0.0487
			Cl-35	1.00				
		S-37	5.05 m	B-	–	0.7998	2.9311	3.7309
			Cl-37	1.00				
		S-38	170.3 m	B-	–	0.4898	1.6953	2.1851
			Cl-38	1.00				
17	Chlorine	Cl-34	1.5264 s	ECB+	–	2.0508	1.0212	3.0720
			S-34	1.00				
		Cl-34m	32.00 m	ECB+IT	–	0.4596	2.1127	2.5722
			Cl-34	4.4600E-01				
			S-34	5.5400E-01				
		Cl-36	3.01E+5 y	B-ECB+	–	0.2732	0.0001	0.2733
			Ar-36	9.8100E-01				
			S-36	1.9000E-02				
		Cl-38	37.24 m	B-	–	1.5504	1.4430	2.9934
			Ar-38	1.00				
		Cl-39	55.6 m	B-	–	0.8246	1.4509	2.2755
			Ar-39	1.00				
		Cl-40	1.35 m	B-	–	1.5265	4.0821	5.6085
			Ar-40	1.00				
18	Argon	Ar-37	35.04 d	EC	–	0.0023	0.0003	0.0025
			Cl-37	1.00				
		Ar-39	269 y	B-	–	0.2188	–	0.2188
			K-39	1.00				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Ar-41	109.61 m	B-	–	0.4637	1.2836	1.7474
			K-41	1.00				
		Ar-42	32.9 y	B-	–	0.2325	–	0.2325
			K-42	1.00				
		Ar-43	5.37 m	B-	–	1.3570	1.5352	2.8921
			K-43	1.00				
		Ar-44	11.87 m	B-	–	0.5245	1.9376	2.4621
			K-44	1.00				
19	Potassium	K-38	7.636 m	ECB+	–	1.2107	3.1867	4.3974
			Ar-38	1.00				
		K-40	1.251E+9 y	B-ECB+	–	0.5218	0.1567	0.6785
			Ca-40	8.9140E-01				
			Ar-40	1.0860E-01				
		K-42	12.360 h	B-	–	1.4303	0.2787	1.7090
			Ca-42	1.00				
		K-43	22.3 h	B-	–	0.3097	0.9641	1.2739
			Ca-43	1.00				
		K-44	22.13 m	B-	–	1.4567	2.3846	3.8413
			Ca-44	1.00				
		K-45	17.3 m	B-	–	0.9959	1.8360	2.8319
			Ca-45	1.00				
		K-46	105 s	B-	–	2.3161	2.8710	5.1871
			Ca-46	1.00				
20	Calcium	Ca-41	1.02E+5 y	EC	–	0.0027	0.0005	0.0032
			K-41	1.00				
		Ca-45	162.67 d	B-	–	0.0772	<E-04	0.0772
			Sc-45	1.00				
		Ca-47	4.536 d	B-	–	0.3521	1.0521	1.4042
			Sc-47	1.00				
		Ca-49	8.718 m	B-	–	0.8693	3.1675	4.0369
			Sc-49	1.00				
21	Scandium	Sc-42m	62.0 s	ECB+	–	1.2565	4.2042	5.4607
			Ca-42	1.00				
		Sc-43	3.891 h	ECB+	–	0.4195	0.9841	1.4035
			Ca-43	1.00				
		Sc-44	3.97 h	ECB+	–	0.5961	2.1369	2.7330
			Ca-44	1.00				
		Sc-44m	58.61 h	ITEC	–	0.0328	0.2743	0.3071
			Sc-44	9.8800E-01				
			Ca-44	1.2000E-02				
		Sc-46	83.79 d	B-	–	0.1121	2.0096	2.1217
			Ti-46	1.00				
		Sc-47	3.3492 d	B-	–	0.1624	0.1089	0.2713
			Ti-47	1.00				
		Sc-48	43.67 h	B-	–	0.2216	3.3529	3.5744
			Ti-48	1.00				

(*continued on next page*)

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Sc-49	57.2 m	B-	–	0.8177	0.0010	0.8188
			Ti-49	1.00				
		Sc-50	102.5 s	B-	–	1.6362	3.2022	4.8384
			Ti-50	1.00				
22	Titanium	Ti-44	60.0 y	EC	–	0.0108	0.1396	0.1504
			Sc-44	1.00				
		Ti-45	184.8 m	ECB+	–	0.3728	0.8703	1.2431
			Sc-45	1.00				
		Ti-51	5.76 m	B-	–	0.8692	0.3692	1.2383
			V-51	1.00				
		Ti-52	1.7 m	B-	–	0.7530	0.1282	0.8812
			V-52	1.00				
23	Vanadium	V-47	32.6 m	ECB+	–	0.8027	0.9951	1.7978
			Ti-47	1.00				
		V-48	15.9735 d	ECB+	–	0.1526	2.9140	3.0666
			Ti-48	1.00				
		V-49	330 d	EC	–	0.0035	0.0009	0.0045
			Ti-49	1.00				
		V-50	1.50E+17 y	ECB-	–	0.0158	1.4235	1.4393
			Ti-50	8.3000E-01				
			Cr-50	1.7000E-01				
		V-52	3.743 m	B-	–	1.0684	1.4449	2.5133
			Cr-52	1.00				
		V-53	1.61 m	B-	–	1.0048	1.0382	2.0430
			Cr-53	1.00				
24	Chromium	Cr-48	21.56 h	ECB+	–	0.0086	0.4363	0.4449
			V-48	1.00				
		Cr-49	42.3 m	ECB+	–	0.6047	1.0538	1.6584
			V-49	1.00				
		Cr-51	27.7025 d	EC	–	0.0038	0.0329	0.0367
			V-51	1.00				
		Cr-55	3.497 m	B-	–	1.1007	0.0007	1.1013
			Mn-55	1.00				
		Cr-56	5.94 m	B-	–	0.6083	0.0918	0.7000
			Mn-56	1.00				
25	Manganese	Mn-50m	1.75 m	ECB+	–	1.5243	4.6397	6.1640
			Cr-50	1.00				
		Mn-51	46.2 m	ECB+	–	0.9344	0.9977	1.9321
			Cr-51	1.00				
		Mn-52m	21.1 m	ECB+IT	–	1.1321	2.4086	3.5407
			Mn-52	1.7500E-02				
			Cr-52	9.8250E-01				
		Mn-52	5.591 d	ECB+	–	0.0750	3.4585	3.5335
			Cr-52	1.00				
		Mn-53	3.7E+6 y	EC	–	0.0040	0.0014	0.0053
			Cr-53	1.00				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Mn-54	312.12 d	ECB+B-	–	0.0042	0.8360	0.8402
			Cr-54	1.00				
			Fe-54	2.9000E-06				
		Mn-56	2.5789 h	B-	–	0.8299	1.6916	2.5215
			Fe-56	1.00				
		Mn-57	85.4 s	B-	–	1.1013	0.0996	1.2009
			Fe-57	1.00				
		Mn-58m	65.2 s	B-	–	1.7443	2.3854	4.1297
			Fe-58	1.00				
26	Iron	Fe-52	8.275 h	ECB+	–	0.1917	0.7405	0.9322
			Mn-52m	1.00				
		Fe-53	8.51 m	ECB+	–	1.1013	1.1782	2.2795
			Mn-53	1.00				
		Fe-53m	2.526 m	IT	–	0.0023	3.0547	3.0570
			Fe-53	1.00				
		Fe-55	2.737 y	EC	–	0.0042	0.0017	0.0058
			Mn-55	1.00				
		Fe-59	44.495 d	B-	–	0.1179	1.1883	1.3062
			Co-59	1.00				
		Fe-60	1.5E+6 y	B-	–	0.0647	–	0.0647
			Co-60m	1.00				
		Fe-61	5.98 m	B-	–	1.0934	1.3910	2.4844
			Co-61	1.00				
		Fe-62	68 s	B-	–	0.8258	0.5061	1.3319
			Co-62	1.00				
27	Cobalt	Co-54m	1.48 m	ECB+	–	2.0484	3.9306	5.9790
			Fe-54	1.00				
		Co-55	17.53 h	ECB+	–	0.4312	1.9960	2.4272
			Fe-55	1.00				
		Co-56	77.23 d	ECB+	–	0.1198	3.6404	3.7602
			Fe-56	1.00				
		Co-57	271.74 d	EC	–	0.0186	0.1252	0.1439
			Fe-57	1.00				
		Co-58	70.86 d	ECB+	–	0.0340	0.9749	1.0089
			Fe-58	1.00				
		Co-58m	9.04 h	IT	–	0.0229	0.0020	0.0249
			Co-58	1.00				
		Co-60	5.2713 y	B-	–	0.0969	2.5038	2.6007
			Ni-60	1.00				
		Co-60m	10.467 m	ITB-	–	0.0565	0.0067	0.0632
			Co-60	9.9760E-01				
			Ni-60	2.4000E-03				
		Co-61	1.650 h	B-	–	0.4664	0.0970	0.5634
			Ni-61	1.00				
		Co-62	1.50 m	B-	–	1.6336	1.6050	3.2386
			Ni-62	1.00				

(*continued on next page*)

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Co-62m	13.91 m	B-	–	1.0974	2.6923	3.7897
			Ni-62	1.00				
28	Nickel	Ni-56	6.075 d	ECB+	–	0.0073	1.7207	1.7280
			Co-56	1.00				
		Ni-57	35.60 h	ECB+	–	0.1571	1.9382	2.0953
			Co-57	1.00				
		Ni-59	1.01E+5 y	ECB+	–	0.0045	0.0024	0.0069
			Co-59	1.00				
		Ni-63	100.1 y	B-	–	0.0174	–	0.0174
			Cu-63	1.00				
		Ni-65	2.51719 h	B-	–	0.6277	0.5583	1.1860
			Cu-65	1.00				
		Ni-66	54.6 h	B-	–	0.0734	–	0.0734
			Cu-66	1.00				
29	Copper	Cu-57	0.1963 s	ECB+	–	3.5987	1.1407	4.7394
			Ni-57	1.00				
		Cu-59	81.5 s	ECB+	–	1.4892	1.4451	2.9342
			Ni-59	1.00				
		Cu-60	23.7 m	ECB+	–	0.8975	3.9111	4.8087
			Ni-60	1.00				
		Cu-61	3.333 h	ECB+	–	0.3090	0.8237	1.1327
			Ni-61	1.00				
		Cu-62	9.673 m	ECB+	–	1.2843	1.0069	2.2912
			Ni-62	1.00				
		Cu-64	12.700 h	ECB+B-	–	0.1248	0.1855	0.3102
			Ni-64	6.1000E-01				
			Zn-64	3.9000E-01				
		Cu-66	5.120 m	B-	–	1.0664	0.0978	1.1642
			Zn-66	1.00				
		Cu-67	61.83 h	B-	–	0.1504	0.1154	0.2657
			Zn-67	1.00				
		Cu-69	2.85 m	B-	–	0.8863	0.5284	1.4147
			Zn-69	1.00				
30	Zinc	Zn-60	2.38 m	ECB+	–	1.1301	1.5282	2.6584
			Cu-60	1.00				
		Zn-61	89.1 s	ECB+	–	1.8571	1.5327	3.3898
			Cu-61	1.00				
		Zn-62	9.186 h	ECB+	–	0.0326	0.4431	0.4757
			Cu-62	1.00				
		Zn-63	38.47 m	ECB+	–	0.9204	1.0967	2.0171
			Cu-63	1.00				
		Zn-65	244.06 d	ECB+	–	0.0069	0.5819	0.5888
			Cu-65	1.00				
		Zn-69m	13.76 h	ITB-	–	0.0226	0.4162	0.4388
			Zn-69	9.9967E-01				
			Ga-69	3.3000E-04				
		Zn-69	56.4 m	B-	–	0.3216	<E-04	0.3216
			Ga-69	1.00				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Zn-71m	3.96 h	B-	–	0.5430	1.5606	2.1037
			Ga-71	1.00				
		Zn-71	2.45 m	B-	–	1.0474	0.3150	1.3624
			Ga-71	1.00				
		Zn-72	46.5 h	B-	–	0.1021	0.1519	0.2541
			Ga-72	1.00				
31	Gallium	Ga-64	2.627 m	ECB+	–	1.7031	3.3726	5.0756
			Zn-64	1.00				
		Ga-65	15.2 m	ECB+	–	0.8158	1.1650	1.9808
			Zn-65	1.00				
		Ga-66	9.49 h	ECB+	–	0.9634	2.4944	3.4577
			Zn-66	1.00				
		Ga-67	3.2612 d	EC	–	0.0363	0.1595	0.1959
			Zn-67	1.00				
		Ga-68	67.71 m	ECB+	–	0.7379	0.9487	1.6866
			Zn-68	1.00				
		Ga-70	21.14 m	B-EC	–	0.6441	0.0073	0.6514
			Ge-70	9.9590E-01				
			Zn-70	4.1000E-03				
		Ga-72	14.10 h	B-	–	0.5060	2.7071	3.2131
			Ge-72	1.00				
		Ga-73	4.86 h	B-	–	0.4999	0.3520	0.8519
			Ge-73	1.00				
		Ga-74	8.12 m	B-	–	0.9945	3.1540	4.1486
			Ge-74	1.00				
32	Germanium	Ge-66	2.26 h	ECB+	–	0.0984	0.6780	0.7764
			Ga-66	1.00				
		Ge-67	18.9 m	ECB+	–	1.1688	1.4254	2.5942
			Ga-67	1.00				
		Ge-68	270.95 d	EC	–	0.0050	0.0041	0.0091
			Ga-68	1.00				
		Ge-69	39.05 h	ECB+	–	0.1203	0.9505	1.0708
			Ga-69	1.00				
		Ge-71	11.43 d	EC	–	0.0050	0.0042	0.0092
			Ga-71	1.00				
		Ge-75	82.78 m	B-	–	0.4206	0.0352	0.4558
			As-75	1.00				
		Ge-77	11.30 h	B-	–	0.6493	1.0787	1.7280
			As-77	1.00				
		Ge-78	88 m	B-	–	0.2273	0.2781	0.5053
			As-78	1.00				
33	Arsenic	As-68	151.6 s	ECB+	–	1.9985	3.7113	5.7097
			Ge-68	1.00				
		As-69	15.23 m	ECB+	–	1.2182	1.1431	2.3613
			Ge-69	1.00				
		As-70	52.6 m	ECB+	–	0.8799	4.2528	5.1327
			Ge-70	1.00				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		As-71	65.28 h	ECB+	–	0.1167	0.5765	0.6932
			Ge-71	1.00				
		As-72	26.0 h	ECB+	–	1.0409	1.7832	2.8240
			Ge-72	1.00				
		As-73	80.30 d	EC	–	0.0606	0.0159	0.0765
			Ge-73	1.00				
		As-74	17.77 d	ECB+B-	–	0.2658	0.7582	1.0241
			Ge-74	6.6000E-01				
			Se-74	3.4000E-01				
		As-76	1.0778 d	B-	–	1.0670	0.4166	1.4836
			Se-76	1.00				
		As-77	38.83 h	B-	–	0.2258	0.0083	0.2342
			Se-77	1.00				
		As-78	90.7 m	B-	–	1.2460	1.3066	2.5525
			Se-78	1.00				
		As-79	9.01 m	B-	–	0.8771	0.0338	0.9109
			Se-79m	9.7188E-01				
			Se-79	2.8121E-02				
34	Selenium	Se-70	41.1 m	ECB+	–	0.2375	0.7211	0.9586
			As-70	1.00				
		Se-71	4.74 m	ECB+	–	1.3844	1.6056	2.9900
			As-71	1.00				
		Se-72	8.40 d	EC	–	0.0228	0.0343	0.0571
			As-72	1.00				
		Se-73	7.15 h	ECB+	–	0.3871	1.0924	1.4795
			As-73	1.00				
		Se-73m	39.8 m	ITECB+	–	0.1642	0.2633	0.4275
			Se-73	7.2600E-01				
			As-73	2.7400E-01				
		Se-75	119.779 d	EC	–	0.0144	0.3890	0.4034
			As-75	1.00				
		Se-77m	17.36 s	IT	–	0.0737	0.0888	0.1625
			Se-77	1.00				
		Se-79	2.95E+5 y	B-	–	0.0529	–	0.0529
			Br-79	1.00				
		Se-79m	3.92 m	ITB-	–	0.0820	0.0138	0.0957
			Se-79	9.9944E-01				
			Br-79	5.6000E-04				
		Se-81	18.45 m	B-	–	0.6108	0.0080	0.6188
			Br-81	1.00				
		Se-81m	57.28 m	ITB-	–	0.0871	0.0183	0.1054
			Se-81	9.9948E-01				
			Br-81	5.2000E-04				
		Se-83	22.3 m	B-	–	0.4528	2.6254	3.0782
			Br-83	1.00				
		Se-83m	70.1 s	B-	–	1.2570	0.9849	2.2419
			Br-83	1.00				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Se-84	3.1 m	B-	–	0.5499	0.4202	0.9701
			Br-84	1.00				
35	Bromine	Br-72	78.6 s	ECB+	–	2.7880	2.9624	5.7504
			Se-72	1.00				
		Br-73	3.4 m	ECB+	–	1.3434	1.4331	2.7765
			Se-73m	9.9881E-01				
			Se-73	1.1920E-03				
		Br-74	25.4 m	ECB+	–	1.0616	4.6130	5.6746
			Se-74	1.00				
		Br-74m	46 m	ECB+	–	1.2747	4.1467	5.4214
			Se-74	1.00				
		Br-75	96.7 m	ECB+	–	0.5283	1.1981	1.7263
			Se-75	1.00				
		Br-76	16.2 h	ECB+	–	0.6497	2.7933	3.4430
			Se-76	1.00				
		Br-76m	1.31 s	ITECB+	–	0.0690	0.0433	0.1123
			Br-76	9.9700E-01				
			Se-76	3.0000E-03				
		Br-77	57.036 h	ECB+	–	0.0094	0.3209	0.3303
			Se-77	1.00				
		Br-77m	4.28 m	IT	–	0.0876	0.0197	0.1073
			Br-77	1.00				
		Br-78	6.46 m	ECB+B-	–	1.0235	1.0336	2.0571
			Se-78	9.9990E-01				
			Kr-78	1.0000E-04				
		Br-80	17.68 m	B-ECB+	–	0.7247	0.0761	0.8007
			Kr-80	9.1700E-01				
			Se-80	8.3000E-02				
		Br-80m	4.4205 h	IT	–	0.0617	0.0242	0.0859
			Br-80	1.00				
		Br-82	35.30 h	B-	–	0.1454	2.6389	2.7844
			Kr-82	1.00				
		Br-82m	6.13 m	ITB-	–	0.0704	0.0081	0.0785
			Br-82	9.7600E-01				
			Kr-82	2.4000E-02				
		Br-83	2.40 h	B-	–	0.3258	0.0069	0.3326
			Kr-83m	9.9845E-01				
			Kr-83	1.5519E-03				
		Br-84	31.80 m	B-	–	1.2364	1.7595	2.9959
			Kr-84	1.00				
		Br-84m	6.0 m	B-	–	0.8983	2.7684	3.6667
			Kr-84	1.00				
		Br-85	2.90 m	B-	–	1.0384	0.0660	1.1045
			Kr-85m	9.9779E-01				
			Kr-85	2.2112E-03				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
36	Krypton	Kr-74	11.50 m	ECB+	–	0.6006	1.0579	1.6585
			Br-74	1.00				
		Kr-75	4.29 m	ECB+	–	1.5430	1.2800	2.8230
			Br-75	1.00				
		Kr-76	14.8 h	EC	–	0.0154	0.4276	0.4430
			Br-76	9.9189E-01				
			Br-76m	8.1144E-03				
		Kr-77	74.4 m	ECB+	–	0.6744	1.0384	1.7128
			Br-77	9.0386E-01				
			Br-77m	9.6135E-02				
		Kr-79	35.04 h	ECB+	–	0.0237	0.2549	0.2786
			Br-79	1.00				
		Kr-81	2.29E+5 y	EC	–	0.0052	0.0072	0.0124
			Br-81	1.00				
		Kr-81m	13.10 s	ITEC	–	0.0596	0.1309	0.1905
			Kr-81	9.9998E-01				
			Br-81	2.5000E-05				
		Kr-83m	1.83 h	IT	–	0.0388	0.0028	0.0416
			Kr-83	1.00				
		Kr-85	10.756 y	B-	–	0.2507	0.0022	0.2529
			Rb-85	1.00				
		Kr-85m	4.480 h	B-IT	–	0.2549	0.1574	0.4123
			Kr-85	2.1400E-01				
			Rb-85	7.8600E-01				
		Kr-87	76.3 m	B-	–	1.3281	0.7919	2.1201
			Rb-87	1.00				
		Kr-88	2.84 h	B-	–	0.3689	1.9538	2.3227
			Rb-88	1.00				
		Kr-89	3.15 m	B-	–	1.3705	1.9313	3.3018
			Rb-89	1.00				
37	Rubidium	Rb-77	3.77 m	ECB+	–	1.6865	1.5452	3.2318
			Kr-77	1.00				
		Rb-78	17.66 m	ECB+	–	1.2889	4.0918	5.3808
			Kr-78	1.00				
		Rb-78m	5.74 m	ECB+IT	–	1.4992	3.2149	4.7141
			Rb-78	1.0000E-01				
			Kr-78	9.0000E-01				
		Rb-79	22.9 m	ECB+	–	0.8099	1.4493	2.2592
			Kr-79	1.00				
		Rb-80	33.4 s	ECB+	–	2.0455	1.1900	3.2355
			Kr-80	1.00				
		Rb-81	4.576 h	ECB+	–	0.1222	0.5081	0.6304
			Kr-81m	9.5691E-01				
			Kr-81	4.3091E-02				
		Rb-81m	30.5 m	ITECB+	–	0.0817	0.0303	0.1120
			Rb-81	9.7600E-01				
			Kr-81	2.3786E-02				
			Kr-81m	2.1355E-04				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Rb-82	1.273 m	ECB+	–	1.4112	1.1083	2.5195
			Kr-82	1.00				
		Rb-82m	6.472 h	ECB+	–	0.0935	2.9212	3.0147
			Kr-82	1.00				
		Rb-83	86.2 d	EC	–	0.0083	0.4914	0.4997
			Kr-83m	7.4292E-01				
			Kr-83	2.5708E-01				
		Rb-84	32.77 d	ECB+B-	–	0.1633	0.9077	1.0710
			Kr-84	9.6200E-01				
			Sr-84	3.8000E-02				
		Rb-84m	20.26 m	IT	–	0.0813	0.3831	0.4644
			Rb-84	1.00				
		Rb-86	18.642 d	B-EC	–	0.6680	0.0930	0.7610
			Sr-86	9.9995E-01				
			Kr-86	5.2000E-05				
		Rb-86m	1.017 m	IT	–	0.0100	0.5461	0.5561
			Rb-86	1.00				
		Rb-87	4.923E10 y	B-	–	0.1154	–	0.1154
			Sr-87	1.00				
		Rb-88	17.78 m	B-	–	2.0720	0.6370	2.7089
			Sr-88	1.00				
		Rb-89	15.15 m	B-	–	0.9528	2.2430	3.1959
			Sr-89	1.00				
		Rb-90	158 s	B-	–	2.0443	2.0286	4.0729
			Sr-90	1.00				
		Rb-90m	258 s	B-IT	–	1.4104	3.2406	4.6510
			Sr-90	9.7400E-01				
			Rb-90	2.6000E-02				
38	Strontium	Sr-79	2.25 m	ECB+	–	1.8572	1.1801	3.0373
			Rb-79	1.00				
		Sr-80	106.3 m	ECB+	–	0.0418	0.4371	0.4789
			Rb-80	1.00				
		Sr-81	22.3 m	ECB+	–	0.9743	1.3866	2.3609
			Rb-81	9.9856E-01				
			Rb-81m	1.4422E-03				
		Sr-82	25.36 d	EC	–	0.0054	0.0079	0.0132
			Rb-82	1.00				
		Sr-83	32.41 h	ECB+	–	0.1604	0.8213	0.9817
			Rb-83	1.00				
		Sr-85	64.84 d	EC	–	0.0089	0.5001	0.5090
			Rb-85	1.00				
		Sr-85m	67.63 m	ITECB+	–	0.0130	0.2177	0.2307
			Sr-85	8.6600E-01				
			Rb-85	1.3400E-01				
		Sr-87m	2.815 h	ITEC	–	0.0672	0.3202	0.3874
			Rb-87	3.0000E-03				
			Sr-87	9.9700E-01				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Sr-89	50.53 d	B-	–	0.5845	<E-04	0.5846
			Y-89	1.00				
		Sr-90	28.79 y	B-	–	0.1957	–	0.1957
			Y-90	1.00				
		Sr-91	9.63 h	B-	–	0.6549	0.7072	1.3621
			Y-91m	5.8247E-01				
			Y-91	4.1753E-01				
		Sr-92	2.66 h	B-	–	0.2025	1.3368	1.5393
			Y-92	1.00				
		Sr-93	7.423 m	B-	–	0.8094	2.2637	3.0731
			Y-93	1.00				
		Sr-94	75.3 s	B-	–	0.8381	1.4270	2.2651
			Y-94	1.00				
39	Yttrium	Y-81	70.4 s	ECB+	–	1.9658	1.1702	3.1360
			Sr-81	1.00				
		Y-83	7.08 m	ECB+	–	1.3138	1.3458	2.6596
			Sr-83	1.00				
		Y-83m	2.85 m	ECB+IT	–	0.8177	0.8370	1.6546
			Sr-83	6.0000E-01				
			Y-83	4.0000E-01				
		Y-84m	39.5 m	ECB+	–	1.2253	3.9751	5.2003
			Sr-84	1.00				
		Y-85	2.68 h	ECB+	–	0.4881	1.0795	1.5676
			Sr-85m	1.00				
		Y-85m	4.86 h	ECB+	–	0.5765	1.3242	1.9007
			Sr-85	9.6000E-01				
			Sr-85m	3.9998E-02				
		Y-86	14.74 h	ECB+	–	0.2179	3.5777	3.7956
			Sr-86	1.00				
		Y-86m	48 m	ITECB+	–	0.0243	0.2203	0.2446
			Y-86	9.9310E-01				
			Sr-86	6.9000E-03				
		Y-87	79.8 h	ECB+	–	0.0072	0.4462	0.4534
			Sr-87m	1.00				
		Y-87m	13.37 h	ITECB+	–	0.0794	0.3072	0.3866
			Y-87	9.8430E-01				
			Sr-87	1.5700E-02				
		Y-88	106.65 d	ECB+	–	0.0067	2.6950	2.7017
			Sr-88	1.00				
		Y-89m	15.663 s	IT	–	0.0077	0.9014	0.9091
			Y-89	1.00				
		Y-90	64.10 h	B-	–	0.9331	<E-04	0.9331
			Zr-90	1.00				
		Y-90m	3.19 h	ITB-	–	0.0470	0.6354	0.6823
			Y-90	9.9998E-01				
			Zr-90	1.8000E-05				
		Y-91	58.51 d	B-	–	0.6032	0.0031	0.6063
			Zr-91	1.00				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Y-91m	49.71 m	IT	–	0.0279	0.5283	0.5562
			Y-91	1.00				
		Y-92	3.54 h	B-	–	1.4494	0.2517	1.7011
			Zr-92	1.00				
		Y-93	10.18 h	B-	–	1.1721	0.0961	1.2682
			Zr-93	1.00				
		Y-94	18.7 m	B-	–	1.8133	0.7725	2.5858
			Zr-94	1.00				
		Y-95	10.3 m	B-	–	1.4288	1.1080	2.5368
			Zr-95	1.00				
40	Zirconium	Zr-85	7.86 m	ECB+	–	1.3252	1.4718	2.7970
			Y-85m	9.6841E-01				
			Y-85	3.1588E-02				
		Zr-86	16.5 h	ECB+	–	0.0310	0.2952	0.3263
			Y-86	1.00				
		Zr-87	1.68 h	ECB+	–	0.8218	0.9271	1.7488
			Y-87m	9.9704E-01				
			Y-87	2.9636E-03				
		Zr-88	83.4 d	EC	–	0.0160	0.3918	0.4078
			Y-88	1.00				
		Zr-89	78.41 h	ECB+	–	0.1019	1.1581	1.2600
			Y-89	1.00				
		Zr-89m	4.161 m	ITECB+	–	0.0318	0.6344	0.6662
			Zr-89	9.3770E-01				
			Y-89	6.2300E-02				
		Zr-93	1.53E+6 y	B-	–	0.0194	–	0.0194
			Nb-93m	9.7500E-01				
			Nb-93	2.5000E-02				
		Zr-95	64.032 d	B-	–	0.1185	0.7321	0.8506
			Nb-95	9.8920E-01				
			Nb-95m	1.0802E-02				
		Zr-97	16.744 h	B-	–	0.7212	0.8792	1.6004
			Nb-97	1.00				
41	Niobium	Nb-87	3.75 m	ECB+	–	1.7709	1.2202	2.9911
			Zr-87	1.00				
		Nb-88	14.5 m	ECB+	–	1.4555	4.2188	5.6743
			Zr-88	1.00				
		Nb-88m	7.78 m	ECB+	–	1.4589	4.1063	5.5652
			Zr-88	1.00				
		Nb-89	2.03 h	ECB+	–	1.0859	1.3668	2.4527
			Zr-89	9.8772E-01				
			Zr-89m	1.2278E-02				
		Nb-89m	66 m	ECB+	–	0.7855	1.3058	2.0913
			Zr-89m	1.00				
		Nb-90	14.60 h	ECB+	–	0.4032	4.2135	4.6167
			Zr-90	1.00				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Nb-91	680 y	ECB+	–	0.0058	0.0118	0.0176
			Zr-91	1.00				
		Nb-91m	60.86 d	ITECB+	–	0.0963	0.0340	0.1303
			Nb-91	9.6600E-01				
			Zr-91	3.4000E-02				
		Nb-92	3.47E+7 y	EC	–	0.0079	1.5055	1.5133
			Zr-92	1.00				
		Nb-92m	10.15 d	ECB+	–	0.0065	0.9689	0.9753
			Zr-92	1.00				
		Nb-93m	16.13 y	IT	–	0.0294	0.0020	0.0314
			Nb-93	1.00				
		Nb-94	2.03E+4 y	B-	–	0.1684	1.5581	1.7265
			Mo-94	1.00				
		Nb-94m	6.263 m	ITB-	–	0.0356	0.0117	0.0473
			Nb-94	9.9500E-01				
			Mo-94	5.0000E-03				
		Nb-95	34.991 d	B-	–	0.0446	0.7645	0.8091
			Mo-95	1.00				
		Nb-95m	3.61 d	ITB-	–	0.1800	0.0697	0.2497
			Nb-95	9.4400E-01				
			Mo-95	5.6000E-02				
		Nb-96	23.35 h	B-	–	0.2534	2.4614	2.7149
			Mo-96	1.00				
		Nb-97	72.1 m	B-	–	0.4683	0.6650	1.1333
			Mo-97	1.00				
		Nb-98m	51.3 m	B-	–	0.7636	2.8177	3.5813
			Mo-98	1.00				
		Nb-99	15.0 s	B-	–	1.5132	0.1743	1.6875
			Mo-99	1.00				
		Nb-99m	2.6 m	B-IT	–	1.4148	0.7567	2.1714
			Mo-99	9.8000E-01				
			Nb-99	2.0000E-02				
42	Molybdenum	Mo-89	2.11 m	ECB+	–	1.9620	1.2173	3.1793
			Nb-89	1.00				
		Mo-90	5.56 h	ECB+	–	0.2107	0.8331	1.0438
			Nb-90	1.00				
		Mo-91	15.49 m	ECB+	–	1.4510	0.9773	2.4283
			Nb-91	9.9966E-01				
			Nb-91m	3.4232E-04				
		Mo-91m	64.6 s	ECB+IT	–	0.5559	1.3857	1.9416
			Nb-91m	5.0000E-01				
			Mo-91	5.0000E-01				
		Mo-93	4.0E+3 y	EC	–	0.0056	0.0107	0.0163
			Nb-93m	8.8000E-01				
			Nb-93	1.2000E-01				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Mo-93m	6.85 h	ITEC	–	0.1045	2.3183	2.4228
			Mo-93	9.9880E-01				
			Nb-93	1.2000E-03				
		Mo-99	65.94 h	B-	–	0.3929	0.1484	0.5413
			Tc-99m	8.7730E-01				
			Tc-99	1.2270E-01				
		Mo-101	14.61 m	B-	–	0.5524	1.4706	2.0230
			Tc-101	1.00				
		Mo-102	11.3 m	B-	–	0.3509	0.0185	0.3694
			Tc-102	1.00				
43	Technetium	Tc-91	3.14 m	ECB+	–	1.6985	2.4847	4.1832
			Mo-91	9.9302E-01				
			Mo-91m	6.9789E-03				
		Tc-91m	3.3 m	ECB+	–	1.8871	1.4231	3.3102
			Mo-91m	9.7976E-01				
			Mo-91	2.0245E-02				
		Tc-92	4.25 m	ECB+	–	1.7984	3.8278	5.6263
			Mo-92	1.00				
		Tc-93	2.75 h	ECB+	–	0.0436	1.5686	1.6122
			Mo-93	1.00				
		Tc-93m	43.5 m	ITECB+	–	0.1015	0.9522	1.0537
			Tc-93	7.6600E-01				
			Mo-93	2.3400E-01				
		Tc-94	293 m	ECB+	–	0.0475	2.6608	2.7083
			Mo-94	1.00				
		Tc-94m	52.0 m	ECB+	–	0.7543	1.9567	2.7110
			Mo-94	1.00				
		Tc-95	20.0 h	EC	–	0.0069	0.7965	0.8033
			Mo-95	1.00				
		Tc-95m	61 d	ECB+IT	–	0.0154	0.6887	0.7042
			Tc-95	3.8800E-02				
			Mo-95	9.6120E-01				
		Tc-96	4.28 d	EC	–	0.0089	2.5032	2.5121
			Mo-96	1.00				
		Tc-96m	51.5 m	ITECB+	–	0.0269	0.0480	0.0749
			Tc-96	9.8000E-01				
			Mo-96	2.0000E-02				
		Tc-97	2.6E+6 y	EC	–	0.0055	0.0114	0.0169
			Mo-97	1.00				
		Tc-97m	90.1 d	IT	–	0.0869	0.0096	0.0964
			Tc-97	1.00				
		Tc-98	4.2E+6 y	B-	–	0.1415	1.4127	1.5542
			Ru-98	1.00				
		Tc-99	2.111E+5 y	B-	–	0.1013	<E-04	0.1013
			Ru-99	1.00				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Tc-99m	6.015 h	ITB-	–	0.0162	0.1266	0.1428
			Tc-99	9.9996E-01				
			Ru-99	3.7000E-05				
		Tc-101	14.2 m	B-	–	0.4725	0.3367	0.8092
			Ru-101	1.00				
		Tc-102	5.28 s	B-	–	1.9441	0.0808	2.0249
			Ru-102	1.00				
		Tc-102m	4.35 m	B-IT	–	0.7902	2.4744	3.2646
			Tc-102	2.0000E-02				
			Ru-102	9.8000E-01				
		Tc-104	18.3 m	B-	–	1.6014	2.2453	3.8467
			Ru-104	1.00				
		Tc-105	7.6 m	B-	–	1.2708	0.7981	2.0690
			Ru-105	1.00				
44	Ruthenium	Ru-92	3.65 m	ECB+	–	0.7939	2.0844	2.8783
			Tc-92	1.00				
		Ru-94	51.8 m	ECB+	–	0.0085	0.5197	0.5282
			Tc-94m	1.00				
		Ru-95	1.643 h	ECB+	–	0.0831	1.2419	1.3249
			Tc-95	9.7387E-01				
			Tc-95m	2.6131E-02				
		Ru-97	2.9 d	EC	–	0.0132	0.2408	0.2540
			Tc-97	9.9958E-01				
			Tc-97m	4.2179E-04				
		Ru-103	39.26 d	B-	–	0.0660	0.4962	0.5622
			Rh-103m	9.8755E-01				
			Rh-103	1.2453E-02				
		Ru-105	4.44 h	B-	–	0.4406	0.7480	1.1886
			Rh-105	1.00				
		Ru-106	373.59 d	B-	–	0.0100	–	0.0100
			Rh-106	1.00				
		Ru-107	3.75 m	B-	–	1.0704	0.3453	1.4157
			Rh-107	1.00				
		Ru-108	4.55 m	B-	–	0.4803	0.0626	0.5429
			Rh-108	1.00				
45	Rhodium	Rh-94	70.6 s	ECB+	–	2.9012	3.7634	6.6645
			Ru-94	1.00				
		Rh-95	5.02 m	ECB+	–	0.8973	2.5603	3.4576
			Ru-95	1.00				
		Rh-95m	1.96 m	ITECB+	–	0.1822	0.8973	1.0794
			Rh-95	8.8000E-01				
			Ru-95	1.2000E-01				
		Rh-96	9.90 m	ECB+	–	0.7419	3.9266	4.6685
			Ru-96	1.00				
		Rh-96m	1.51 m	ITECB+	–	0.5673	1.2819	1.8492
			Rh-96	6.0000E-01				
			Ru-96	4.0000E-01				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Rh-97	30.7 m	ECB+	–	0.5211	1.4448	1.9660
			Ru-97	1.00				
		Rh-97m	46.2 m	ECB+IT	–	0.1992	2.2017	2.4009
			Ru-97	9.4400E-01				
			Rh-97	5.6000E-02				
		Rh-98	8.7 m	ECB+	–	1.3371	1.8115	3.1486
			Ru-98	1.00				
		Rh-99	16.1 d	ECB+	–	0.0611	0.5627	0.6238
			Ru-99	1.00				
		Rh-99m	4.7 h	ECB+	–	0.0367	0.6511	0.6878
			Ru-99	1.00				
		Rh-100	20.8 h	ECB+	–	0.0494	2.7425	2.7920
			Ru-100	1.00				
		Rh-100m	4.6 m	ITECB+	–	0.0802	0.0637	0.1439
			Rh-100	9.8300E-01				
			Ru-100	1.7000E-02				
		Rh-101	3.3 y	EC	–	0.0267	0.2878	0.3145
			Ru-101	1.00				
		Rh-101m	4.34 d	ECIT	–	0.0199	0.2877	0.3076
			Rh-101	6.4000E-02				
			Ru-101	9.3600E-01				
		Rh-102	207 d	ECB+B-	–	0.1717	0.5060	0.6777
			Ru-102	7.8000E-01				
			Pd-102	2.2000E-01				
		Rh-102m	3.742 y	ECB+IT	–	0.0125	2.1536	2.1661
			Rh-102	2.3300E-03				
			Ru-102	9.9767E-01				
		Rh-103m	56.114 m	IT	–	0.0377	0.0017	0.0394
			Rh-103	1.00				
		Rh-104	42.3 s	B-EC	–	0.9823	0.0124	0.9947
			Pd-104	9.9550E-01				
			Ru-104	4.5000E-03				
		Rh-104m	4.34 m	ITB-	–	0.0846	0.0441	0.1287
			Rh-104	9.9870E-01				
			Pd-104	1.3000E-03				
		Rh-105	35.36 h	B-	–	0.1533	0.0773	0.2306
			Pd-105	1.00				
		Rh-106	29.80 s	B-	–	1.4111	0.2061	1.6172
			Pd-106	1.00				
		Rh-106m	131 m	B-	–	0.3492	2.8526	3.2018
			Pd-106	1.00				
		Rh-107	21.7 m	B-	–	0.4407	0.3133	0.7539
			Pd-107	1.00				
		Rh-108	16.8 s	B-	–	1.8209	0.3172	2.1381
			Pd-108	1.00				
		Rh-109	80 s	B-	–	0.9320	0.2995	1.2315
			Pd-109	1.00				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
46	Palladium	Pd-96	122 s	ECB+	–	0.2257	1.4403	1.6660
			Rh-96m	1.00				
		Pd-97	3.10 m	ECB+	–	0.7524	2.3813	3.1337
			Rh-97	9.8838E-01				
			Rh-97m	1.1622E-02				
		Pd-98	17.7 m	ECB+	–	0.0455	0.4154	0.4609
			Rh-98	1.00				
		Pd-99	21.4 m	ECB+	–	0.4499	1.2833	1.7331
			Rh-99m	9.6647E-01				
			Rh-99	3.3529E-02				
		Pd-100	3.63 d	EC	–	0.0455	0.1231	0.1686
			Rh-100	1.00				
		Pd-101	8.47 h	ECB+	–	0.0328	0.3518	0.3846
			Rh-101m	9.9730E-01				
			Rh-101	2.7000E-03				
		Pd-103	16.991 d	EC	–	0.0058	0.0146	0.0204
			Rh-103m	9.9875E-01				
			Rh-103	1.2512E-03				
		Pd-107	6.5E+6 y	B-	–	0.0096	–	0.0096
			Ag-107	1.00				
		Pd-109	13.7012 h	B-	–	0.4380	0.0118	0.4497
			Ag-109	1.00				
		Pd-109m	4.69 m	IT	–	0.0777	0.1112	0.1889
			Pd-109	1.00				
		Pd-111	23.4 m	B-	–	0.8409	0.0478	0.8887
			Ag-111m	9.9756E-01				
			Ag-111	2.4368E-03				
		Pd-112	21.03 h	B-	–	0.0900	0.0051	0.0951
			Ag-112	1.00				
		Pd-114	2.42 m	B-	–	0.5317	0.0259	0.5576
			Ag-114	1.00				
47	Silver	Ag-99	124 s	ECB+	–	1.3076	2.3092	3.6168
			Pd-99	1.00				
		Ag-100m	2.24 m	ECB+	–	1.9068	2.8248	4.7316
			Pd-100	1.00				
		Ag-101	11.1 m	ECB+	–	0.8396	1.5703	2.4099
			Pd-101	1.00				
		Ag-102	12.9 m	ECB+	–	0.8430	3.4092	4.2522
			Pd-102	1.00				
		Ag-102m	7.7 m	ECB+IT	–	0.3964	1.9933	2.3897
			Ag-102	4.9000E-01				
			Pd-102	5.1000E-01				
		Ag-103	65.7 m	ECB+	–	0.1973	0.8440	1.0412
			Pd-103	1.00				
		Ag-104	69.2 m	ECB+	–	0.0917	2.7066	2.7982
			Pd-104	1.00				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Ag-104m	33.5 m	ECB+IT	–	0.7331	1.8047	2.5377
			Ag-104	7.0000E-04				
			Pd-104	9.9930E-01				
		Ag-105	41.29 d	EC	–	0.0192	0.5138	0.5330
			Pd-105	1.00				
		Ag-105m	7.23 m	ITECB+	–	0.0252	0.0013	0.0265
			Ag-105	9.9660E-01				
			Pd-105	3.4000E-03				
		Ag-106	23.96 m	ECB+B-	–	0.4967	0.6996	1.1963
			Pd-106	9.9000E-01				
			Cd-106	1.0000E-02				
		Ag-106m	8.28 d	EC	–	0.0131	2.8091	2.8222
			Pd-106	1.00				
		Ag-108	2.37 m	B-ECB+	–	0.6071	0.0186	0.6256
			Cd-108	9.7150E-01				
			Pd-108	2.8500E-02				
		Ag-108m	418 y	ECIT	–	0.0159	1.6209	1.6368
			Ag-108	8.7000E-02				
			Pd-108	9.1300E-01				
		Ag-109m	39.6 s	IT	–	0.0770	0.0111	0.0880
			Ag-109	1.00				
		Ag-110	24.6 s	B-EC	–	1.1812	0.0307	1.2119
			Cd-110	9.9700E-01				
			Pd-110	3.0000E-03				
		Ag-110m	249.76 d	B-IT	–	0.0758	2.7606	2.8363
			Ag-110	1.3600E-02				
			Cd-110	9.8640E-01				
		Ag-111	7.45 d	B-	–	0.3539	0.0265	0.3804
			Cd-111	1.00				
		Ag-111m	64.8 s	ITB-	–	0.0568	0.0079	0.0646
			Ag-111	9.9300E-01				
			Cd-111	7.0000E-03				
		Ag-112	3.130 h	B-	–	1.3540	0.6905	2.0445
			Cd-112	1.00				
		Ag-113	5.37 h	B-	–	0.7614	0.0719	0.8333
			Cd-113	9.8261E-01				
			Cd-113m	1.7388E-02				
		Ag-113m	68.7 s	ITB-	–	0.2278	0.2134	0.4412
			Ag-113	6.4000E-01				
			Cd-113	3.6000E-01				
		Ag-114	4.6 s	B-	–	2.1091	0.2589	2.3681
			Cd-114	1.00				
		Ag-115	20.0 m	B-	–	1.0928	0.4831	1.5760
			Cd-115	9.4210E-01				
			Cd-115m	5.7870E-02				
		Ag-116	2.68 m	B-	–	1.7540	2.1473	3.9014
			Cd-116	1.00				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Ag-117	73.6 s	B-	–	1.2813	1.3028	2.5841
			Cd-117	8.4703E-01				
			Cd-117m	1.5297E-01				
48	Cadmium	Cd-101	1.36 m	ECB+	–	1.0685	2.4853	3.5538
			Ag-101	1.00				
		Cd-102	5.5 m	ECB+	–	0.0756	0.8380	0.9136
			Ag-102m	9.4624E-01				
			Ag-102	5.3762E-02				
		Cd-103	7.3 m	ECB+	–	0.3636	2.0891	2.4527
			Ag-103	1.00				
		Cd-104	57.7 m	EC	–	0.0306	0.2513	0.2819
			Ag-104m	1.00				
		Cd-105	55.5 m	ECB+	–	0.2167	1.2995	1.5161
			Ag-105m	8.2963E-01				
			Ag-105	1.7037E-01				
		Cd-107	6.50 h	ECB+	–	0.0870	0.0337	0.1207
			Ag-107	1.00				
		Cd-109	461.4 d	EC	–	0.0827	0.0265	0.1092
			Ag-109	1.00				
		Cd-111m	48.50 m	IT	–	0.1066	0.2843	0.3908
			Cd-111	1.00				
		Cd-113	7.7E+15 y	B-	–	0.0926	–	0.0926
			In-113	1.00				
		Cd-113m	14.1 y	B-IT	–	0.1847	<E-04	0.1848
			Cd-113	1.4000E-03				
			In-113	9.9860E-01				
		Cd-115	53.46 h	B-	–	0.3182	0.1926	0.5107
			In-115m	1.00				
		Cd-115m	44.6 d	B-	–	0.6045	0.0329	0.6374
			In-115	9.9989E-01				
			In-115m	1.0578E-04				
		Cd-117	2.49 h	B-	–	0.4379	1.0796	1.5175
			In-117m	9.1507E-01				
			In-117	8.4933E-02				
		Cd-117m	3.36 h	B-	–	0.2279	2.0437	2.2716
			In-117	9.9002E-01				
			In-117m	9.9831E-03				
		Cd-118	50.3 m	B-	–	0.1614	–	0.1614
			In-118	1.00				
		Cd-119	2.69 m	B-	–	0.8186	1.6380	2.4566
			In-119m	9.0091E-01				
			In-119	9.9092E-02				
		Cd-119m	2.20 m	B-	–	0.6898	2.3021	2.9919
			In-119	9.9787E-01				
			In-119m	2.1328E-03				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
49	Indium	In-103	60 s	ECB+	–	1.5404	2.7528	4.2932
			Cd-103	1.00				
		In-105	5.07 m	ECB+	–	1.0358	1.9307	2.9666
			Cd-105	1.00				
		In-106m	5.2 m	ECB+	–	1.5889	2.8243	4.4132
			Cd-106	1.00				
		In-106	6.2 m	ECB+	–	1.0844	3.5541	4.6385
			Cd-106	1.00				
		In-107	32.4 m	ECB+	–	0.3263	1.5307	1.8570
			Cd-107	1.00				
		In-108m	39.6 m	ECB+	–	0.7021	2.7655	3.4675
			Cd-108	1.00				
		In-108	58.0 m	ECB+	–	0.1620	3.9164	4.0784
			Cd-108	1.00				
		In-109m	1.34 m	IT	–	0.0416	0.6085	0.6501
			In-109	1.00				
		In-109	4.2 h	ECB+	–	0.0334	0.6441	0.6775
			Cd-109	1.00				
		In-110m	69.1 m	ECB+	–	0.6282	1.5782	2.2065
			Cd-110	1.00				
		In-110	4.9 h	ECB+	–	0.0122	3.0972	3.1094
			Cd-110	1.00				
		In-111m	7.7 m	IT	–	0.0675	0.4706	0.5380
			In-111	1.00				
		In-111	2.8047 d	EC	–	0.0348	0.4061	0.4409
			Cd-111m	4.9998E-05				
			Cd-111	9.9995E-01				
		In-112m	20.56 m	IT	–	0.1217	0.0347	0.1564
			In-112	1.00				
		In-112	14.97 m	ECB+B-	–	0.2452	0.2675	0.5127
			Cd-112	5.6000E-01				
			Sn-112	4.4000E-01				
		In-113m	1.6579 h	IT	–	0.1361	0.2606	0.3967
			In-113	1.00				
		In-114m	49.51 d	ITEC	–	0.1450	0.0804	0.2254
			In-114	9.6750E-01				
			Cd-114	3.2500E-02				
		In-114	71.9 s	B-ECB+	–	0.7740	0.0023	0.7764
			Sn-114	9.9500E-01				
			Cd-114	5.0000E-03				
		In-115m	4.486 h	ITB-	–	0.1748	0.1627	0.3376
			In-115	9.5000E-01				
			Sn-115	5.0000E-02				
		In-115	4.41E+14 y	B-	–	0.1526	–	0.1526
			Sn-115	1.00				
		In-116m	54.41 m	B-	–	0.3128	2.4691	2.7819
			Sn-116	1.00				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		In-117m	116.2 m	B-IT	–	0.4344	0.0910	0.5254
			In-117	4.7100E-01				
			Sn-117	5.2900E-01				
		In-117	43.2 m	B-	–	0.2673	0.6939	0.9612
			Sn-117m	3.5321E-03				
			Sn-117	9.9647E-01				
		In-118m	4.364 m	B-	–	0.6708	2.7765	3.4473
			Sn-118	1.00				
		In-118	5.0 s	B-	–	1.8792	0.0778	1.9570
			Sn-118	1.00				
		In-119m	18.0 m	B-IT	–	1.0221	0.0660	1.0882
			In-119	5.6000E-02				
			Sn-119	9.4400E-01				
		In-119	2.4 m	B-	–	0.6148	0.7701	1.3849
			Sn-119m	9.4773E-03				
			Sn-119	9.9052E-01				
		In-121m	3.88 m	B-IT	–	1.5288	0.0635	1.5922
			Sn-121	9.8800E-01				
			In-121	1.2000E-02				
		In-121	23.1 s	B-	–	0.9869	0.9266	1.9135
			Sn-121	8.8650E-01				
			Sn-121m	1.1350E-01				
50	Tin	Sn-106	1.92 m	ECB+	–	0.1279	1.2091	1.3370
			In-106m	1.00				
		Sn-108	10.30 m	ECB+	–	0.0269	0.6847	0.7117
			In-108m	1.00				
		Sn-109	18.0 m	ECB+	–	0.0571	2.2063	2.2634
			In-109	7.1734E-01				
			In-109m	2.8266E-01				
		Sn-110	4.11 h	EC	–	0.0152	0.2918	0.3070
			In-110m	1.00				
		Sn-111	35.3 m	ECB+	–	0.1915	0.4903	0.6818
			In-111	9.9793E-01				
			In-111m	2.0745E-03				
		Sn-113m	21.4 m	ITEC	–	0.0588	0.0137	0.0725
			Sn-113	9.1100E-01				
			In-113	8.9000E-02				
		Sn-113	115.09 d	EC	–	0.0063	0.0237	0.0300
			In-113m	9.9998E-01				
			In-113	2.2352E-05				
		Sn-117m	13.76 d	IT	–	0.1616	0.1581	0.3197
			Sn-117	1.00				
		Sn-119m	293.1 d	IT	–	0.0781	0.0151	0.0932
			Sn-119	1.00				
		Sn-121m	43.9 y	ITB-	–	0.0354	0.0052	0.0405
			Sn-121	7.7600E-01				
			Sb-121	2.2400E-01				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Sn-121	27.03 h	B-	–	0.1156	–	0.1156
			Sb-121	1.00				
		Sn-123m	40.06 m	B-	–	0.4788	0.1407	0.6196
			Sb-123	1.00				
		Sn-123	129.2 d	B-	–	0.5227	0.0069	0.5296
			Sb-123	1.00				
		Sn-125m	9.52 m	B-	–	0.8070	0.3464	1.1534
			Sb-125	1.00				
		Sn-125	9.64 d	B-	–	0.8037	0.3346	1.1383
			Sb-125	1.00				
		Sn-126	2.30E+5 y	B-	–	0.1380	0.0569	0.1949
			Sb-126m	1.00				
		Sn-127m	4.13 m	B-	–	1.1140	0.5686	1.6826
			Sb-127	1.00				
		Sn-127	2.10 h	B-	–	0.5199	1.9075	2.4274
			Sb-127	1.00				
		Sn-128	59.07 m	B-	–	0.2457	0.6041	0.8498
			Sb-128m	1.00				
		Sn-129	2.23 m	B-	–	1.2576	1.0081	2.2657
			Sb-129	1.00				
		Sn-130m	1.7 m	B-	–	1.4040	0.8861	2.2901
			Sb-130	8.6005E-01				
			Sb-130m	1.3995E-01				
		Sn-130	3.72 m	B-	–	0.4612	0.9372	1.3984
			Sb-130m	1.00				
51	Antimony	Sb-111	75 s	ECB+	–	1.3640	1.4859	2.8499
			Sn-111	1.00				
		Sb-113	6.67 m	ECB+	–	0.7203	1.2683	1.9886
			Sn-113	7.7569E-01				
			Sn-113m	2.2431E-01				
		Sb-114	3.49 m	ECB+	–	1.2184	2.6893	3.9077
			Sn-114	1.00				
		Sb-115	32.1 m	ECB+	–	0.2342	0.8894	1.1236
			Sn-115	1.00				
		Sb-116	15.8 m	ECB+	–	0.5138	2.2788	2.7926
			Sn-116	1.00				
		Sb-116m	60.3 m	ECB+	–	0.1408	3.1029	3.2437
			Sn-116	1.00				
		Sb-117	2.80 h	ECB+	–	0.0298	0.1864	0.2162
			Sn-117	1.00				
		Sb-118	3.6 m	ECB+	–	0.8730	0.8039	1.6769
			Sn-118	1.00				
		Sb-118m	5.00 h	ECB+	–	0.0374	2.6130	2.6504
			Sn-118	1.00				
		Sb-119	38.19 h	EC	–	0.0258	0.0234	0.0492
			Sn-119	1.00				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Sb-120	15.89 m	ECB+	–	0.3077	0.4521	0.7599
			Sn-120	1.00				
		Sb-120m	5.76 d	EC	–	0.0449	2.4663	2.5112
			Sn-120	1.00				
		Sb-122	2.7238 d	B-ECB+	–	0.5618	0.4453	1.0072
			Te-122	9.7590E-01				
			Sn-122	2.4100E-02				
		Sb-122m	4.191 m	IT	–	0.0937	0.0707	0.1644
			Sb-122	1.00				
		Sb-124	60.20 d	B-	–	0.3831	1.8531	2.2362
			Te-124	1.00				
		Sb-124m	93 s	ITB-	–	0.1157	0.4401	0.5558
			Sb-124	7.5000E-01				
			Te-124	2.5000E-01				
		Sb-124n	20.2 m	IT	–	0.0256	0.0004	0.0260
			Sb-124m	1.00				
		Sb-125	2.75856 y	B-	–	0.1010	0.4373	0.5383
			Te-125m	2.3136E-01				
			Te-125	7.6864E-01				
		Sb-126	12.35 d	B-	–	0.3545	2.7552	3.1097
			Te-126	1.00				
		Sb-126m	19.15 m	B-IT	–	0.6322	1.5483	2.1805
			Sb-126	1.4000E-01				
			Te-126	8.6000E-01				
		Sb-127	3.85 d	B-	–	0.3160	0.6934	1.0094
			Te-127	8.2320E-01				
			Te-127m	1.7680E-01				
		Sb-128	9.01 h	B-	–	0.4999	3.0934	3.5934
			Te-128	1.00				
		Sb-128m	10.4 m	B-IT	–	0.9580	1.9063	2.8643
			Sb-128	3.6000E-02				
			Te-128	9.6400E-01				
		Sb-129	4.40 h	B-	–	0.3953	1.4601	1.8553
			Te-129	7.7381E-01				
			Te-129m	2.2619E-01				
		Sb-130	39.5 m	B-	–	0.7579	3.2724	4.0303
			Te-130	1.00				
		Sb-130m	6.3 m	B-	–	1.0290	2.7077	3.7367
			Te-130	1.00				
		Sb-131	23.03 m	B-	–	0.5867	2.0733	2.6601
			Te-131	9.1793E-01				
			Te-131m	8.2067E-02				
		Sb-133	2.5 m	B-	–	0.6785	2.7434	3.4219
			Te-133	8.2662E-01				
			Te-133m	1.7338E-01				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
52	Tellurium	Te-113	1.7 m	ECB+	–	1.7023	2.2208	3.9231
			Sb-113	1.00				
		Te-114	15.2 m	ECB+	–	0.1551	1.2817	1.4368
			Sb-114	1.00				
		Te-115	5.8 m	ECB+	–	0.8124	2.2449	3.0572
			Sb-115	1.00				
		Te-115m	6.7 m	ECB+	–	0.6939	2.6041	3.2980
			Sb-115	1.00				
		Te-116	2.49 h	ECB+	–	0.0618	0.1122	0.1740
			Sb-116	1.00				
		Te-117	62 m	ECB+	–	0.2139	1.5492	1.7631
			Sb-117	1.00				
		Te-118	6.00 d	EC	–	0.0061	0.0199	0.0260
			Sb-118	1.00				
		Te-119	16.05 h	ECB+	–	0.0143	0.7679	0.7822
			Sb-119	1.00				
		Te-119m	4.70 d	ECB+	–	0.0180	1.5059	1.5239
			Sb-119	1.00				
		Te-121	19.16 d	EC	–	0.0098	0.5775	0.5872
			Sb-121	1.00				
		Te-121m	154 d	ITEC	–	0.0817	0.2176	0.2993
			Te-121	8.8600E-01				
			Sb-121	1.1400E-01				
		Te-123	6.00E+14 y	EC	–	0.0028	0.0004	0.0031
			Sb-123	1.00				
		Te-123m	119.25 d	IT	–	0.0990	0.1477	0.2467
			Te-123	1.00				
		Te-125m	57.40 d	IT	–	0.1091	0.0360	0.1451
			Te-125	1.00				
		Te-127	9.35 h	B-	–	0.2246	0.0049	0.2294
			I-127	1.00				
		Te-127m	109 d	ITB-	–	0.0824	0.0113	0.0937
			Te-127	9.7600E-01				
			I-127	2.4000E-02				
		Te-129	69.6 m	B-	–	0.5436	0.0625	0.6061
			I-129	1.00				
		Te-129m	33.6 d	ITB-	–	0.2709	0.0376	0.3085
			Te-129	6.3000E-01				
			I-129	3.7000E-01				
		Te-131	25.0 m	B-	–	0.7122	0.4200	1.1322
			I-131	1.00				
		Te-131m	30 h	B-IT	–	0.1870	1.4545	1.6415
			I-131	7.7800E-01				
			Te-131	2.2200E-01				
		Te-132	3.204 d	B-	–	0.1108	0.2344	0.3453
			I-132	1.00				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Te-133	12.5 m	B-	–	0.6897	1.2007	1.8904
			I-133	1.00				
		Te-133m	55.4 m	B-IT	–	0.3880	1.8597	2.2477
			I-133	8.2500E-01				
			Te-133	1.7500E-01				
		Te-134	41.8 m	B-	–	0.2266	0.8714	1.0980
			I-134	1.00				
53	Iodine	I-118	13.7 m	ECB+	–	1.9645	2.0163	3.9809
			Te-118	1.00				
		I-118m	8.5 m	ECB+	–	1.1055	3.7513	4.8567
			Te-118	1.00				
		I-119	19.1 m	ECB+	–	0.5116	0.9110	1.4227
			Te-119	9.9046E-01				
			Te-119m	9.5421E-03				
		I-120	81.6 m	ECB+	–	1.1680	2.6611	3.8291
			Te-120	1.00				
		I-120m	53 m	ECB+	–	0.9070	3.5248	4.4318
			Te-120	1.00				
		I-121	2.12 h	ECB+	–	0.0665	0.3995	0.4660
			Te-121	9.9714E-01				
			Te-121m	2.8631E-03				
		I-122	3.63 m	ECB+	–	1.1055	0.9619	2.0674
			Te-122	1.00				
		I-123	13.27 h	EC	–	0.0282	0.1730	0.2012
			Te-123	9.9996E-01				
			Te-123m	4.4420E-05				
		I-124	4.1760 d	ECB+	–	0.1943	1.1132	1.3075
			Te-124	1.00				
		I-125	59.400 d	EC	–	0.0192	0.0428	0.0621
			Te-125	1.00				
		I-126	12.93 d	ECB+B-	–	0.1606	0.4354	0.5959
			Te-126	5.2700E-01				
			Xe-126	4.7300E-01				
		I-128	24.99 m	B-ECB+	–	0.7463	0.0676	0.8139
			Xe-128	9.3100E-01				
			Te-128	6.9000E-02				
		I-129	1.57E+7 y	B-	–	0.0651	0.0252	0.0902
			Xe-129	1.00				
		I-130	12.36 h	B-	–	0.2786	2.1372	2.4158
			Xe-130	1.00				
		I-130m	8.84 m	ITB-	–	0.1778	0.1097	0.2875
			I-130	8.4000E-01				
			Xe-130	1.6000E-01				
		I-131	8.02070 d	B-	–	0.1918	0.3828	0.5746
			Xe-131m	1.1759E-02				
			Xe-131	9.8824E-01				
		I-132	2.295 h	B-	–	0.4930	2.2645	2.7575
			Xe-132	1.00				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		I-132m	1.387 h	ITB-	–	0.1614	0.3403	0.5018
			I-132	8.6000E-01				
			Xe-132	1.4000E-01				
		I-133	20.8 h	B-	–	0.4142	0.6120	1.0262
			Xe-133	9.7115E-01				
			Xe-133m	2.8846E-02				
		I-134	52.5 m	B-	–	0.5776	2.5953	3.1729
			Xe-134	1.00				
		I-134m	3.60 m	ITB-	–	0.0913	0.2887	0.3800
			I-134	9.7700E-01				
			Xe-134	2.3000E-02				
		I-135	6.57 h	B-	–	0.3465	1.5815	1.9280
			Xe-135	8.3432E-01				
			Xe-135m	1.6568E-01				
54	Xenon	Xe-120	40 m	ECB+	–	0.0461	0.4015	0.4476
			I-120	1.00				
		Xe-121	40.1 m	ECB+	–	0.5819	1.4720	2.0539
			I-121	1.00				
		Xe-122	20.1 h	EC	–	0.0100	0.0684	0.0784
			I-122	1.00				
		Xe-123	2.08 h	ECB+	–	0.1875	0.6411	0.8286
			I-123	1.00				
		Xe-125	16.9 h	ECB+	–	0.0350	0.2723	0.3074
			I-125	1.00				
		Xe-127	36.4 d	EC	–	0.0325	0.2806	0.3131
			I-127	1.00				
		Xe-127m	69.2 s	IT	–	0.1293	0.1685	0.2978
			Xe-127	1.00				
		Xe-129m	8.88 d	IT	–	0.1844	0.0517	0.2362
			Xe-129	1.00				
		Xe-131m	11.84 d	IT	–	0.1470	0.0206	0.1676
			Xe-131	1.00				
		Xe-133	5.243 d	B-	–	0.1379	0.0474	0.1854
			Cs-133	1.00				
		Xe-133m	2.19 d	IT	–	0.1924	0.0410	0.2333
			Xe-133	1.00				
		Xe-135	9.14 h	B-	–	0.3208	0.2483	0.5691
			Cs-135	1.00				
		Xe-135m	15.29 m	ITB-	–	0.1008	0.4249	0.5257
			Xe-135	9.9400E-01				
			Cs-135	6.0000E-03				
		Xe-137	3.818 m	B-	–	1.6952	0.1908	1.8859
			Cs-137	1.00				
		Xe-138	14.08 m	B-	–	0.6596	1.1222	1.7818
			Cs-138	1.00				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
55	Caesium	Cs-121	155 s	ECB+	–	1.7391	1.1733	2.9123
			Xe-121	1.00				
		Cs-121m	122 s	ECB+IT	–	1.3475	1.1821	2.5296
			Xe-121	8.3000E-01				
			Cs-121	1.7000E-01				
		Cs-123	5.88 m	ECB+	–	0.9509	1.0860	2.0369
			Xe-123	1.00				
		Cs-124	30.8 s	ECB+	–	1.9908	1.1607	3.1515
			Xe-124	1.00				
		Cs-125	45 m	ECB+	–	0.3524	0.7550	1.1075
			Xe-125	1.00				
		Cs-126	1.64 m	ECB+	–	1.3193	1.1545	2.4738
			Xe-126	1.00				
		Cs-127	6.25 h	ECB+	–	0.0293	0.4334	0.4627
			Xe-127	1.00				
		Cs-128	3.640 m	ECB+	–	0.8735	0.8917	1.7651
			Xe-128	1.00				
		Cs-129	32.06 h	ECB+	–	0.0175	0.2802	0.2977
			Xe-129	1.00				
		Cs-130	29.21 m	ECB+B-	–	0.3869	0.5026	0.8894
			Xe-130	9.8400E-01				
			Ba-130	1.6000E-02				
		Cs-130m	3.46 m	ITEC	–	0.0937	0.0737	0.1674
			Cs-130	9.9840E-01				
			Xe-130	1.6000E-03				
		Cs-131	9.689 d	EC	–	0.0064	0.0232	0.0295
			Xe-131	1.00				
		Cs-132	6.479 d	ECB+B-	–	0.0143	0.7151	0.7294
			Xe-132	9.8130E-01				
			Ba-132	1.8700E-02				
		Cs-134	2.0648 y	B-EC	–	0.1639	1.5551	1.7190
			Ba-134	1.00				
			Xe-134	3.0000E-06				
		Cs-134m	2.903 h	IT	–	0.1122	0.0273	0.1394
			Cs-134	1.00				
		Cs-135	2.3E+6 y	B-	–	0.0894	–	0.0894
			Ba-135	1.00				
		Cs-135m	53 m	IT	–	0.0361	1.5972	1.6333
			Cs-135	1.00				
		Cs-136	13.16 d	B-	–	0.1449	2.1283	2.2732
			Ba-136	1.00				
		Cs-137	30.1671 y	B-	–	0.1884	<E-04	0.1884
			Ba-137m	9.4399E-01				
			Ba-137	5.6005E-02				
		Cs-138	33.41 m	B-	–	1.2462	2.3611	3.6073
			Ba-138	1.00				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Cs-138m	2.91 m	ITB-	–	0.3201	0.4149	0.7350
			Cs-138	8.1000E-01				
			Ba-138	1.9000E-01				
		Cs-139	9.27 m	B-	–	1.6598	0.3030	1.9629
			Ba-139	1.00				
		Cs-140	63.7 s	B-	–	1.9361	1.7692	3.7054
			Ba-140	1.00				
56	Barium	Ba-124	11.0 m	ECB+	–	0.1743	0.5728	0.7471
			Cs-124	1.00				
		Ba-126	100 m	ECB+	–	0.0178	0.5803	0.5981
			Cs-126	1.00				
		Ba-127	12.7 m	ECB+	–	0.5971	0.7282	1.3253
			Cs-127	1.00				
		Ba-128	2.43 d	EC	–	0.0086	0.0665	0.0751
			Cs-128	1.00				
		Ba-129	2.23 h	ECB+	–	0.1270	0.3331	0.4601
			Cs-129	1.00				
		Ba-129m	2.16 h	ECB+	–	0.0419	1.5833	1.6252
			Cs-129	1.00				
		Ba-131	11.50 d	EC	–	0.0455	0.4763	0.5219
			Cs-131	1.00				
		Ba-131m	14.6 m	IT	–	0.1102	0.0773	0.1875
			Ba-131	1.00				
		Ba-133	10.52 y	EC	–	0.0553	0.4030	0.4583
			Cs-133	1.00				
		Ba-133m	38.9 h	ITEC	–	0.2259	0.0686	0.2945
			Ba-133	9.9990E-01				
			Cs-133	9.6000E-05				
		Ba-135m	28.7 h	IT	–	0.2080	0.0602	0.2682
			Ba-135	1.00				
		Ba-137m	2.552 m	IT	–	0.0653	0.5963	0.6617
			Ba-137	1.00				
		Ba-139	83.06 m	B-	–	0.9012	0.0457	0.9470
			La-139	1.00				
		Ba-140	12.752 d	B-	–	0.3202	0.1826	0.5029
			La-140	1.00				
		Ba-141	18.27 m	B-	–	0.9624	0.9271	1.8895
			La-141	1.00				
		Ba-142	10.6 m	B-	–	0.4141	1.0469	1.4610
			La-142	1.00				
57	Lanthanum	La-128	5.18 m	ECB+	–	1.3340	2.8283	4.1623
			Ba-128	1.00				
		La-129	11.6 m	ECB+	–	0.6135	0.9212	1.5347
			Ba-129	9.2384E-01				
			Ba-129m	7.6164E-02				
		La-130	8.7 m	ECB+	–	1.1113	2.2324	3.3438
			Ba-130	1.00				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		La-131	59 m	ECB+	–	0.1963	0.6633	0.8596
			Ba-131	1.00				
		La-132	4.8 h	ECB+	–	0.5693	1.9952	2.5645
			Ba-132	1.00				
		La-132m	24.3 m	ITECB+	–	0.1126	0.6706	0.7832
			La-132	7.6000E-01				
			Ba-132	2.4000E-01				
		La-133	3.912 h	ECB+	–	0.0503	0.1605	0.2108
			Ba-133	1.00				
		La-134	6.45 m	ECB+	–	0.7647	0.7196	1.4844
			Ba-134	1.00				
		La-135	19.5 h	ECB+	–	0.0067	0.0361	0.0428
			Ba-135	1.00				
		La-136	9.87 m	ECB+	–	0.2941	0.4070	0.7011
			Ba-136	1.00				
		La-137	6.0E+4 y	EC	–	0.0065	0.0250	0.0315
			Ba-137	1.00				
		La-138	1.02E+11 y	ECB-	–	0.0377	1.2316	1.2693
			Ba-138	6.6400E-01				
			Ce-138	3.3600E-01				
		La-140	1.6781 d	B-	–	0.5346	2.3084	2.8429
			Ce-140	1.00				
		La-141	3.92 h	B-	–	0.9876	0.0268	1.0144
			Ce-141	1.00				
		La-142	91.1 m	B-	–	0.8697	2.3738	3.2435
			Ce-142	1.00				
		La-143	14.2 m	B-	–	1.2995	0.2631	1.5625
			Ce-143	1.00				
58	Cerium	Ce-130	22.9 m	ECB+	–	0.0738	0.5003	0.5741
			La-130	1.00				
		Ce-131	10.2 m	ECB+	–	0.6153	1.6267	2.2420
			La-131	1.00				
		Ce-132	3.51 h	EC	–	0.0180	0.2727	0.2908
			La-132	1.00				
		Ce-133	97 m	ECB+	–	0.3817	0.5430	0.9247
			La-133	1.00				
		Ce-133m	4.9 h	ECB+	–	0.0739	1.7373	1.8112
			La-133	1.00				
		Ce-134	3.16 d	EC	–	0.0072	0.0281	0.0353
			La-134	1.00				
		Ce-135	17.7 h	ECB+	–	0.0296	0.8237	0.8533
			La-135	1.00				
		Ce-137	9.0 h	ECB+	–	0.0165	0.0388	0.0553
			La-137	1.00				
		Ce-137m	34.4 h	ITEC	–	0.2067	0.0558	0.2625
			Ce-137	9.9220E-01				
			La-137	7.8000E-03				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Ce-139	137.641 d	EC	–	0.0355	0.1599	0.1954
			La-139	1.00				
		Ce-141	32.508 d	B-	–	0.1710	0.0768	0.2478
			Pr-141	1.00				
		Ce-143	33.039 h	B-	–	0.4364	0.2796	0.7159
			Pr-143	1.00				
		Ce-144	284.91 d	B-	–	0.0916	0.0194	0.1110
			Pr-144	9.9023E-01				
			Pr-144m	9.7699E-03				
		Ce-145	3.01 m	B-	–	0.6794	0.8142	1.4937
			Pr-145	1.00				
59	Praseodymium	Pr-134	11 m	ECB+	–	1.0801	3.1504	4.2305
			Ce-134	1.00				
		Pr-134m	17 m	ECB+	–	1.5274	2.3101	3.8375
			Ce-134	1.00				
		Pr-135	24 m	ECB+	–	0.5793	0.8741	1.4534
			Ce-135	1.00				
		Pr-136	13.1 m	ECB+	–	0.7545	2.1458	2.9003
			Ce-136	1.00				
		Pr-137	1.28 h	ECB+	–	0.1947	0.3693	0.5640
			Ce-137	1.00				
		Pr-138	1.45 m	ECB+	–	1.1617	0.8153	1.9770
			Ce-138	1.00				
		Pr-138m	2.12 h	ECB+	–	0.2208	2.4776	2.6984
			Ce-138	1.00				
		Pr-139	4.41 h	ECB+	–	0.0478	0.1298	0.1777
			Ce-139	1.00				
		Pr-140	3.39 m	ECB+	–	0.5516	0.5467	1.0983
			Ce-140	1.00				
		Pr-142	19.12 h	B-EC	–	0.8098	0.0581	0.8679
			Nd-142	9.9984E-01				
			Ce-142	1.6400E-04				
		Pr-142m	14.6 m	IT	–	0.0036	0.0001	0.0037
			Pr-142	1.00				
		Pr-143	13.57 d	B-	–	0.3150	<E-04	0.3150
			Nd-143	1.00				
		Pr-144	17.28 m	B-	–	1.2084	0.0289	1.2373
			Nd-144	1.00				
		Pr-144m	7.2 m	ITB-	–	0.0475	0.0134	0.0608
			Pr-144	9.9930E-01				
			Nd-144	7.0000E-04				
		Pr-145	5.984 h	B-	–	0.6757	0.0186	0.6943
			Nd-145	1.00				
		Pr-146	24.15 m	B-	–	1.3277	1.0105	2.3382
			Nd-146	1.00				
		Pr-147	13.4 m	B-	–	0.8896	0.4887	1.3784
			Nd-147	1.00				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Pr-148	2.29 m	B-	–	1.6637	0.9905	2.6542
			Nd-148	1.00				
		Pr-148m	2.01 m	B-	–	1.6807	0.9337	2.6144
			Nd-148	1.00				
60	Neodymium	Nd-134	8.5 m	ECB+	–	0.1728	0.5421	0.7149
			Pr-134m	1.00				
		Nd-135	12.4 m	ECB+	–	1.0551	1.2617	2.3168
			Pr-135	1.00				
		Nd-136	50.65 m	ECB+	–	0.0805	0.2793	0.3598
			Pr-136	1.00				
		Nd-137	38.5 m	ECB+	–	0.3247	1.1789	1.5036
			Pr-137	1.00				
		Nd-138	5.04 h	EC	–	0.0082	0.0438	0.0520
			Pr-138	1.00				
		Nd-139	29.7 m	ECB+	–	0.2084	0.4431	0.6515
			Pr-139	1.00				
		Nd-139m	5.50 h	ECB+IT	–	0.0795	1.5852	1.6647
			Pr-139	8.8200E-01				
			Nd-139	1.1800E-01				
		Nd-140	3.37 d	EC	–	0.0069	0.0287	0.0357
			Pr-140	1.00				
		Nd-141	2.49 h	ECB+	–	0.0165	0.0765	0.0930
			Pr-141	1.00				
		Nd-141m	62.0 s	ITECB+	–	0.0622	0.6947	0.7569
			Nd-141	9.9968E-01				
			Pr-141	3.2000E-04				
		Nd-144	2.29E+15 y	A	1.9052	–	–	1.9052
			Ce-140	1.00				
		Nd-147	10.98 d	B-	–	0.2702	0.1408	0.4109
			Pm-147	1.00				
		Nd-149	1.728 h	B-	–	0.5042	0.3713	0.8756
			Pm-149	1.00				
		Nd-151	12.44 m	B-	–	0.6195	0.8518	1.4712
			Pm-151	1.00				
		Nd-152	11.4 m	B-	–	0.3314	0.1644	0.4957
			Pm-152	1.00				
61	Promethium	Pm-136	107 s	ECB+	–	2.1436	2.7178	4.8614
			Nd-136	1.00				
		Pm-137m	2.4 m	ECB+	–	1.1120	1.7835	2.8955
			Nd-137	1.00				
		Pm-139	4.15 m	ECB+	–	1.0416	0.9390	1.9807
			Nd-139	1.00				
		Pm-140	9.2 s	ECB+	–	2.0432	1.0506	3.0937
			Nd-140	1.00				
		Pm-140m	5.95 m	ECB+	–	0.9932	3.0324	4.0256
			Nd-140	1.00				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Pm-141	20.90 m	ECB+	–	0.6054	0.7349	1.3403
			Nd-141	9.9833E-01				
			Nd-141m	1.6651E-03				
		Pm-142	40.5 s	ECB+	–	1.3122	0.8561	2.1683
			Nd-142	1.00				
		Pm-143	265 d	EC	–	0.0083	0.3157	0.3240
			Nd-143	1.00				
		Pm-144	363 d	EC	–	0.0171	1.5631	1.5802
			Nd-144	1.00				
		Pm-145	17.7 y	ECA	<E-04	0.0126	0.0315	0.0441
			Nd-145	1.00				
			Pr-141	2.8000E-09				
		Pm-146	5.53 y	ECB-	–	0.0941	0.7512	0.8453
			Sm-146	3.4000E-01				
			Nd-146	6.6000E-01				
		Pm-147	2.6234 y	B-	–	0.0619	<E-04	0.0619
			Sm-147	1.00				
		Pm-148	5.368 d	B-	–	0.7284	0.5743	1.3028
			Sm-148	1.00				
		Pm-148m	41.29 d	B-IT	–	0.1699	1.9916	2.1615
			Sm-148	9.5800E-01				
			Pm-148	4.2000E-02				
		Pm-149	53.08 h	B-	–	0.3650	0.0119	0.3769
			Sm-149	1.00				
		Pm-150	2.68 h	B-	–	0.8101	1.4705	2.2806
			Sm-150	1.00				
		Pm-151	28.40 h	B-	–	0.3048	0.3289	0.6337
			Sm-151	1.00				
		Pm-152	4.12 m	B-	–	1.3283	0.2866	1.6149
			Sm-152	1.00				
		Pm-152m	7.52 m	B-	–	0.9055	1.5189	2.4244
			Sm-152	1.00				
		Pm-153	5.25 m	B-	–	0.6881	0.0764	0.7645
			Sm-153	1.00				
		Pm-154	1.73 m	B-	–	0.8706	1.7933	2.6638
			Sm-154	1.00				
		Pm-154m	2.68 m	B-	–	0.9492	1.7996	2.7488
			Sm-154	1.00				
62	Samarium	Sm-139	2.57 m	ECB+	–	1.0871	1.4540	2.5410
			Pm-139	1.00				
		Sm-140	14.82 m	ECB+	–	0.1710	0.5677	0.7387
			Pm-140	1.00				
		Sm-141	10.2 m	ECB+	–	0.7126	1.4089	2.1215
			Pm-141	1.00				
		Sm-141m	22.6 m	ECB+IT	–	0.3995	1.9494	2.3489
			Pm-141	9.9690E-01				
			Sm-141	3.1000E-03				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Sm-142	72.49 m	ECB+	–	0.0446	0.1105	0.1551
			Pm-142	1.00				
		Sm-143	8.75 m	ECB+	–	0.4978	0.5289	1.0267
			Pm-143	1.00				
		Sm-143m	66 s	ITECB+	–	0.0720	0.6844	0.7564
			Sm-143	9.9760E-01				
			Pm-143	2.4000E-03				
		Sm-145	340 d	EC	–	0.0307	0.0642	0.0950
			Pm-145	1.00				
		Sm-146	1.03E+8 y	A	2.5290	–	–	2.5290
			Nd-142	1.00				
		Sm-147	1.060E11 y	A	2.3105	–	–	2.3105
			Nd-143	1.00				
		Sm-148	7E+15 y	A	1.9860	–	–	1.9860
			Nd-144	1.00				
		Sm-151	90 y	B-	–	0.0200	<E-04	0.0200
			Eu-151	1.00				
		Sm-153	46.50 h	B-	–	0.2699	0.0643	0.3341
			Eu-153	1.00				
		Sm-155	22.3 m	B-	–	0.5674	0.1029	0.6703
			Eu-155	1.00				
		Sm-156	9.4 h	B-	–	0.2093	0.1150	0.3242
			Eu-156	1.00				
		Sm-157	8.03 m	B-	–	0.8750	0.4142	1.2892
			Eu-157	1.00				
63	Europium	Eu-142	2.34 s	ECB+	–	2.7670	1.1970	3.9641
			Sm-142	1.00				
		Eu-142m	1.223 m	ECB+	–	1.7683	3.4305	5.1987
			Sm-142	1.00				
		Eu-143	2.59 m	ECB+	–	1.3676	1.1227	2.4903
			Sm-143	9.9879E-01				
			Sm-143m	1.2069E-03				
		Eu-144	10.2 s	ECB+	–	2.0761	1.0917	3.1678
			Sm-144	1.00				
		Eu-145	5.93 d	ECB+	–	0.0254	1.2798	1.3052
			Sm-145	1.00				
		Eu-146	4.61 d	ECB+	–	0.0455	2.4007	2.4462
			Sm-146	1.00				
		Eu-147	24.1 d	ECB+A	<E-04	0.0431	0.4721	0.5152
			Sm-147	9.9998E-01				
			Pm-143	2.2000E-05				
		Eu-148	54.5 d	ECB+A	<E-04	0.0224	2.2287	2.2511
			Sm-148	1.00				
			Pm-144	9.4000E-09				
		Eu-149	93.1 d	EC	–	0.0241	0.0661	0.0902
			Sm-149	1.00				
		Eu-150	36.9 y	ECB+	–	0.0285	1.5554	1.5839
			Sm-150	1.00				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Eu-150m	12.8 h	B-ECB+	–	0.3122	0.0494	0.3615
			Gd-150	8.9000E-01				
			Sm-150	1.1000E-01				
		Eu-152	13.537 y	ECB+B-	–	0.1286	1.1759	1.3045
			Gd-152	2.7900E-01				
			Sm-152	7.2100E-01				
		Eu-152m	9.3116 h	B-ECB+	–	0.5060	0.2963	0.8023
			Gd-152	7.2000E-01				
			Sm-152	2.8000E-01				
		Eu-152n	96 m	IT	–	0.0666	0.0753	0.1419
			Eu-152	1.00				
		Eu-154	8.593 y	B-EC	–	0.2730	1.2493	1.5223
			Gd-154	9.9980E-01				
			Sm-154	2.0000E-04				
		Eu-154m	46.0 m	IT	–	0.0745	0.0706	0.1451
			Eu-154	1.00				
		Eu-155	4.7611 y	B-	–	0.0647	0.0612	0.1259
			Gd-155	1.00				
		Eu-156	15.19 d	B-	–	0.4579	1.2342	1.6920
			Gd-156	1.00				
		Eu-157	15.18 h	B-	–	0.3961	0.2930	0.6891
			Gd-157	1.00				
		Eu-158	45.9 m	B-	–	0.8920	1.2978	2.1898
			Gd-158	1.00				
		Eu-159	18.1 m	B-	–	0.8923	0.3032	1.1954
			Gd-159	1.00				
64	Gadolinium	Gd-142	70.2 s	ECB+	–	0.7390	1.0432	1.7822
			Eu-142	1.00				
		Gd-143m	110.0 s	ECB+	–	1.2854	2.1211	3.4065
			Eu-143	1.00				
		Gd-144	4.47 m	ECB+	–	0.5858	0.9086	1.4944
			Eu-144	1.00				
		Gd-145	23.0 m	ECB+	–	0.3456	2.4236	2.7692
			Eu-145	1.00				
		Gd-145m	85 s	ITECB+	–	0.1927	0.6814	0.8741
			Gd-145	9.4300E-01				
			Eu-145	5.7000E-02				
		Gd-146	48.27 d	EC	–	0.1274	0.2526	0.3800
			Eu-146	1.00				
		Gd-147	38.1 h	ECB+	–	0.0617	1.4030	1.4647
			Eu-147	1.00				
		Gd-148	74.6 y	A	3.2712	–	–	3.2712
			Sm-144	1.00				
		Gd-149	9.28 d	ECB+	–	0.0686	0.5292	0.5978
			Eu-149	1.00				
		Gd-150	1.79E+6 y	A	2.8090	–	–	2.8090
			Sm-146	1.00				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Gd-151	124 d	ECA	<E-04	0.0394	0.0708	0.1102
			Sm-147	1.0000E-08				
			Eu-151	1.0000E+00				
		Gd-152	1.08E+14 y	A	2.2046	–	–	2.2046
			Sm-148	1.00				
		Gd-153	240.4 d	EC	–	0.0438	0.1057	0.1494
			Eu-153	1.00				
		Gd-159	18.479 h	B-	–	0.3096	0.0539	0.3635
			Tb-159	1.00				
		Gd-162	8.4 m	B-	–	0.3387	0.4170	0.7557
			Tb-162	1.00				
65	Terbium	Tb-146	23 s	ECB+	–	1.4644	3.6256	5.0900
			Gd-146	1.00				
		Tb-147	1.64 h	ECB+	–	0.2810	2.1845	2.4655
			Gd-147	1.00				
		Tb-147m	1.87 m	ECB+	–	0.3196	1.9116	2.2312
			Gd-147	1.00				
		Tb-148	60 m	ECB+	–	0.8411	2.3590	3.2001
			Gd-148	1.00				
		Tb-148m	2.20 m	ECB+	–	0.3106	3.1390	3.4495
			Gd-148	1.00				
		Tb-149	4.118 h	ECB+A	0.6810	0.0871	1.3612	2.1292
			Gd-149	8.3300E-01				
			Eu-145	1.6700E-01				
		Tb-149m	4.16 m	ECB+A	0.0009	0.2091	1.3748	1.5847
			Gd-149	9.9978E-01				
			Eu-145	2.2000E-04				
		Tb-150	3.48 h	ECB+A	<E-04	0.2890	2.4403	2.7293
			Gd-150	1.00				
			Eu-146	7.0000E-06				
		Tb-150m	5.8 m	ECB+	–	0.1267	2.5202	2.6470
			Gd-150	1.00				
		Tb-151	17.609 h	ECB+A	0.0003	0.0800	0.9941	1.0744
			Gd-151	1.00				
			Eu-147	9.5000E-05				
		Tb-151m	25 s	ITECB+	–	0.0793	0.0808	0.1601
			Tb-151	9.3400E-01				
			Gd-151	6.6000E-02				
		Tb-152	17.5 h	ECB+	–	0.2503	1.4932	1.7436
			Gd-152	1.00				
		Tb-152m	4.2 m	ITECB+	–	0.1520	0.7619	0.9139
			Tb-152	7.8800E-01				
			Gd-152	2.1200E-01				
		Tb-153	2.34 d	ECB+	–	0.0481	0.3318	0.3800
			Gd-153	1.00				
		Tb-154	21.5 h	ECB+	–	0.0681	2.2831	2.3512
			Gd-154	1.00				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Tb-155	5.32 d	EC	–	0.0434	0.1777	0.2211
			Gd-155	1.00				
		Tb-156	5.35 d	EC	–	0.0835	1.9371	2.0206
			Gd-156	1.00				
		Tb-156m	24.4 h	IT	–	0.0171	0.0370	0.0540
			Tb-156	1.00				
		Tb-156n	5.3 h	IT	–	0.0874	0.0048	0.0922
			Tb-156	1.00				
		Tb-157	71 y	EC	–	0.0057	0.0057	0.0114
			Gd-157	1.00				
		Tb-158	180 y	ECB-	–	0.1117	0.8048	0.9165
			Gd-158	8.3400E-01				
			Dy-158	1.6600E-01				
		Tb-160	72.3 d	B-	–	0.2593	1.1264	1.3856
			Dy-160	1.00				
		Tb-161	6.906 d	B-	–	0.2025	0.0365	0.2390
			Dy-161	1.00				
		Tb-162	7.60 m	B-	–	0.5327	1.1066	1.6393
			Dy-162	1.00				
		Tb-163	19.5 m	B-	–	0.3597	0.7887	1.1484
			Dy-163	1.00				
		Tb-164	3.0 m	B-	–	0.8249	2.4455	3.2704
			Dy-164	1.00				
		Tb-165	2.11 m	B-	–	0.8966	0.8363	1.7330
			Dy-165m	8.9028E-01				
			Dy-165	1.0972E-01				
66	Dysprosium	Dy-148	3.3 m	ECB+	–	0.0278	0.7170	0.7448
			Tb-148	1.00				
		Dy-149	4.20 m	ECB+	–	0.1120	1.6222	1.7342
			Tb-149	5.6682E-01				
			Tb-149m	4.3318E-01				
		Dy-150	7.17 m	ECB+A	1.5664	0.0070	0.2785	1.8519
			Tb-150	6.4000E-01				
			Gd-146	3.6000E-01				
		Dy-151	17.9 m	ECB+A	0.2341	0.0653	1.3723	1.6717
			Tb-151	5.3377E-01				
			Tb-151m	4.1023E-01				
			Gd-147	5.6000E-02				
		Dy-152	2.38 h	ECA	0.0037	0.0130	0.2867	0.3034
			Tb-152	9.9900E-01				
			Gd-148	1.0000E-03				
		Dy-153	6.4 h	ECB+A	0.0003	0.0901	0.8746	0.9651
			Tb-153	1.00				
			Gd-149	9.4000E-05				
		Dy-154	3.0E+6 y	A	2.9470	–	–	2.9470
			Gd-150	1.00				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Dy-155	9.9 h	ECB+	–	0.0272	0.6687	0.6959
			Tb-155	1.00				
		Dy-157	8.14 h	EC	–	0.0138	0.3472	0.3610
			Tb-157	1.00				
		Dy-159	144.4 d	EC	–	0.0131	0.0456	0.0587
			Tb-159	1.00				
		Dy-165	2.334 h	B-	–	0.4473	0.0267	0.4740
			Ho-165	1.00				
		Dy-165m	1.257 m	ITB-	–	0.1049	0.0192	0.1240
			Dy-165	9.7760E-01				
			Ho-165	2.2400E-02				
		Dy-166	81.6 h	B-	–	0.1667	0.0433	0.2100
			Ho-166	1.00				
		Dy-167	6.20 m	B-	–	0.7262	0.5326	1.2589
			Ho-167	1.00				
		Dy-168	8.7 m	B-	–	0.4332	0.3948	0.8280
			Ho-168	1.00				
67	Holmium	Ho-150	76.8 s	ECB+	–	1.9857	1.8843	3.8701
			Dy-150	1.00				
		Ho-153	2.01 m	ECB+A	0.0020	0.5387	1.0281	1.5689
			Dy-153	9.9949E-01				
			Tb-149m	5.1000E-04				
		Ho-153m	9.3 m	ECB+A	0.0074	0.6952	1.0618	1.7644
			Dy-153	9.9820E-01				
			Tb-149	1.8000E-03				
		Ho-154	11.76 m	ECB+A	0.0008	1.0927	1.8817	2.9752
			Dy-154	9.9981E-01				
			Tb-150	1.9000E-04				
		Ho-154m	3.10 m	ECB+A	<E-04	0.5434	2.4367	2.9801
			Dy-154	1.00				
			Tb-150m	1.0000E-05				
		Ho-155	48 m	ECB+	–	0.2176	0.6142	0.8318
			Dy-155	1.00				
		Ho-156	56 m	ECB+	–	0.6655	2.1064	2.7719
			Dy-156	1.00				
		Ho-157	12.6 m	ECB+	–	0.0929	0.5835	0.6764
			Dy-157	1.00				
		Ho-159	33.05 m	ECB+	–	0.0576	0.3857	0.4433
			Dy-159	1.00				
		Ho-160	25.6 m	ECB+	–	0.0703	1.6950	1.7653
			Dy-160	1.00				
		Ho-161	2.48 h	EC	–	0.0336	0.0582	0.0918
			Dy-161	1.00				
		Ho-162	15.0 m	ECB+	–	0.0598	0.1640	0.2239
			Dy-162	1.00				
		Ho-162m	67.0 m	ITECB+	–	0.0739	0.5614	0.6353
			Ho-162	6.2000E-01				
			Dy-162	3.8000E-01				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Ho-163	4570 y	EC	–	0.0005	<E-04	0.0006
			Dy-163	1.00				
		Ho-164	29 m	ECB-	–	0.1470	0.0297	0.1768
			Dy-164	6.0000E-01				
			Er-164	4.0000E-01				
		Ho-164m	38.0 m	IT	–	0.0926	0.0472	0.1399
			Ho-164	1.00				
		Ho-166	26.80 h	B-	–	0.6963	0.0301	0.7264
			Er-166	1.00				
		Ho-166m	1.20E+3 y	B-	–	0.1497	1.6249	1.7746
			Er-166	1.00				
		Ho-167	3.1 h	B-	–	0.2329	0.3661	0.5990
			Er-167	1.00				
		Ho-168	2.99 m	B-	–	0.8138	0.8762	1.6901
			Er-168	1.00				
		Ho-168m	132 s	IT	–	0.0518	0.0073	0.0590
			Ho-168	1.00				
		Ho-170	2.76 m	B-	–	0.8366	1.7041	2.5407
			Er-170	1.00				
68	Erbium	Er-154	3.73 m	ECB+A	0.0201	0.0376	0.0759	0.1336
			Ho-154	9.9530E-01				
			Dy-150	4.7000E-03				
		Er-156	19.5 m	EC	–	0.0943	0.0678	0.1621
			Ho-156	1.00				
		Er-159	36 m	ECB+	–	0.0738	0.9635	1.0373
			Ho-159	1.00				
		Er-161	3.21 h	ECB+	–	0.0522	0.9905	1.0427
			Ho-161	1.00				
		Er-163	75.0 m	ECB+	–	0.0081	0.0403	0.0484
			Ho-163	1.00				
		Er-165	10.36 h	EC	–	0.0080	0.0379	0.0459
			Ho-165	1.00				
		Er-167m	2.269 s	IT	–	0.1111	0.0967	0.2078
			Er-167	1.00				
		Er-169	9.40 d	B-	–	0.1035	<E-04	0.1035
			Tm-169	1.00				
		Er-171	7.516 h	B-	–	0.4205	0.3731	0.7936
			Tm-171	1.00				
		Er-172	49.3 h	B-	–	0.1387	0.5166	0.6552
			Tm-172	1.00				
		Er-173	1.434 m	B-	–	0.7213	0.8313	1.5526
			Tm-173	1.00				
69	Thulium	Tm-161	30.2 m	ECB+	–	0.2308	1.2992	1.5300
			Er-161	1.00				
		Tm-162	21.70 m	ECB+	–	0.5648	1.9155	2.4803
			Er-162	1.00				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Tm-163	1.810 h	ECB+	–	0.0716	1.3200	1.3916
			Er-163	1.00				
		Tm-164	2.0 m	ECB+	–	0.5994	0.7760	1.3754
			Er-164	1.00				
		Tm-165	30.06 h	ECB+	–	0.0637	0.5625	0.6262
			Er-165	1.00				
		Tm-166	7.70 h	ECB+	–	0.0892	1.9768	2.0660
			Er-166	1.00				
		Tm-167	9.25 d	EC	–	0.1332	0.1482	0.2814
			Er-167	1.00				
		Tm-168	93.1 d	ECB+B-	–	0.0847	1.2432	1.3279
			Er-168	9.9990E-01				
			Yb-168	1.0000E-04				
		Tm-170	128.6 d	B-EC	–	0.3280	0.0041	0.3321
			Yb-170	9.9869E-01				
			Er-170	1.3100E-03				
		Tm-171	1.92 y	B-	–	0.0255	0.0006	0.0261
			Yb-171	1.00				
		Tm-172	63.6 h	B-	–	0.5327	0.4744	1.0072
			Yb-172	1.00				
		Tm-173	8.24 h	B-	–	0.3103	0.3885	0.6988
			Yb-173	1.00				
		Tm-174	5.4 m	B-	–	0.5129	1.7787	2.2915
			Yb-174	1.00				
		Tm-175	15.2 m	B-	–	0.5196	1.0848	1.6044
			Yb-175	1.00				
		Tm-176	1.85 m	B-	–	0.9972	1.9682	2.9654
			Yb-176	1.00				
70	Ytterbium	Yb-162	18.87 m	ECB+	–	0.0374	0.2519	0.2893
			Tm-162	1.00				
		Yb-163	11.05 m	ECB+	–	0.2718	0.7277	0.9996
			Tm-163	1.00				
		Yb-164	75.8 m	EC	–	0.0095	0.0542	0.0637
			Tm-164	1.00				
		Yb-165	9.9 m	ECB+	–	0.1518	0.3390	0.4908
			Tm-165	1.00				
		Yb-166	56.7 h	EC	–	0.0417	0.0868	0.1285
			Tm-166	1.00				
		Yb-167	17.5 m	ECB+	–	0.0952	0.2696	0.3648
			Tm-167	1.00				
		Yb-169	32.026 d	EC	–	0.1471	0.3302	0.4773
			Tm-169	1.00				
		Yb-175	4.185 d	B-	–	0.1308	0.0391	0.1699
			Lu-175	1.00				
		Yb-177	1.911 h	B-	–	0.4358	0.1952	0.6309
			Lu-177	1.00				
		Yb-178	74 m	B-	–	0.1925	0.0381	0.2306
			Lu-178	1.00				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Yb-179	8.0 m	B-	–	0.7093	0.9743	1.6836
			Lu-179	1.00				
71	Lutetium	Lu-165	10.74 m	ECB+	–	0.3751	1.1102	1.4853
			Yb-165	1.00				
		Lu-167	51.5 m	ECB+	–	0.1109	1.6920	1.8030
			Yb-167	1.00				
		Lu-169	34.06 h	ECB+	–	0.0477	1.3166	1.3643
			Yb-169	1.00				
		Lu-169m	160 s	IT	–	0.0274	0.0017	0.0290
			Lu-169	1.00				
		Lu-170	2.012 d	ECB+	–	0.0585	2.5636	2.6220
			Yb-170	1.00				
		Lu-171	8.24 d	ECB+	–	0.0928	0.6503	0.7431
			Yb-171	1.00				
		Lu-171m	79 s	IT	–	0.0691	0.0021	0.0711
			Lu-171	1.00				
		Lu-172	6.70 d	ECB+	–	0.1154	1.9565	2.0718
			Yb-172	1.00				
		Lu-172m	3.7 m	IT	–	0.0404	0.0015	0.0419
			Lu-172	1.00				
		Lu-173	1.37 y	EC	–	0.0526	0.1834	0.2360
			Yb-173	1.00				
		Lu-174	3.31 y	ECB+	–	0.0458	0.1163	0.1621
			Yb-174	1.00				
		Lu-174m	142 d	ITEC	–	0.1188	0.0626	0.1814
			Lu-174	9.9380E-01				
			Yb-174	6.2000E-03				
		Lu-176	3.85E+10 y	B-	–	0.3026	0.4799	0.7825
			Hf-176	1.00				
		Lu-176m	3.635 h	B-EC	–	0.4783	0.0146	0.4929
			Hf-176	9.9905E-01				
			Yb-176	9.5000E-04				
		Lu-177	6.647 d	B-	–	0.1479	0.0351	0.1830
			Hf-177	1.00				
		Lu-177m	160.4 d	B-IT	–	0.2687	1.0005	1.2692
			Lu-177	2.1700E-01				
			Hf-177	7.8300E-01				
		Lu-178	28.4 m	B-	–	0.7561	0.1256	0.8817
			Hf-178	1.00				
		Lu-178m	23.1 m	B-	–	0.4907	1.0481	1.5389
			Hf-178	1.00				
		Lu-179	4.59 h	B-	–	0.4869	0.0298	0.5167
			Hf-179	1.00				
		Lu-180	5.7 m	B-	–	0.6352	1.5148	2.1499
			Hf-180	1.00				
		Lu-181	3.5 m	B-	–	0.8512	0.5740	1.4252
			Hf-181	1.00				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
72	Hafnium	Hf-167	2.05 m	ECB+	–	0.4952	0.6171	1.1123
			Lu-167	1.00				
		Hf-169	3.24 m	ECB+	–	0.1309	0.6416	0.7725
			Lu-169	9.6904E-01				
			Lu-169m	3.0960E-02				
		Hf-170	16.01 h	EC	–	0.0687	0.4403	0.5090
			Lu-170	1.00				
		Hf-172	1.87 y	EC	–	0.0828	0.1062	0.1890
			Lu-172m	1.00				
		Hf-173	23.6 h	ECB+	–	0.0524	0.3970	0.4494
			Lu-173	1.00				
		Hf-174	2.0E+15 y	A	2.4948	–	–	2.4948
			Yb-170	1.00				
		Hf-175	70 d	EC	–	0.0450	0.3534	0.3984
			Lu-175	1.00				
		Hf-177m	51.4 m	IT	–	0.5078	2.2864	2.7941
			Hf-177	1.00				
		Hf-178m	31 y	IT	–	0.2113	2.2383	2.4496
			Hf-178	1.00				
		Hf-179m	25.05 d	IT	–	0.1897	0.9207	1.1104
			Hf-179	1.00				
		Hf-180m	5.5 h	ITB-	–	0.1437	0.9884	1.1321
			Hf-180	9.9700E-01				
			Ta-180m	3.0000E-03				
		Hf-181	42.39 d	B-	–	0.2052	0.5324	0.7377
			Ta-181	1.00				
		Hf-182	9E+6 y	B-	–	0.0632	0.2397	0.3030
			Ta-182	1.00				
		Hf-182m	61.5 m	B-IT	–	0.2441	0.9135	1.1575
			Ta-182	4.9070E-01				
			Hf-182	4.2000E-01				
			Ta-182m	8.9280E-02				
		Hf-183	1.067 h	B-	–	0.4478	0.7749	1.2227
			Ta-183	1.00				
		Hf-184	4.12 h	B-	–	0.4787	0.2387	0.7174
			Ta-184	1.00				
73	Tantalum	Ta-170	6.76 m	ECB+	–	1.6049	1.0602	2.6652
			Hf-170	1.00				
		Ta-172	36.8 m	ECB+	–	0.5513	1.6967	2.2480
			Hf-172	1.00				
		Ta-173	3.14 h	ECB+	–	0.1686	0.5824	0.7510
			Hf-173	1.00				
		Ta-174	1.14 h	ECB+	–	0.4670	0.9767	1.4438
			Hf-174	1.00				
		Ta-175	10.5 h	ECB+	–	0.0663	1.1126	1.1790
			Hf-175	1.00				
		Ta-176	8.09 h	ECB+	–	0.0849	2.2322	2.3171
			Hf-176	1.00				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Ta-177	56.56 h	EC	–	0.0240	0.0678	0.0917
			Hf-177	1.00				
		Ta-178	9.31 m	ECB+	–	0.0391	0.1218	0.1609
			Hf-178	1.00				
		Ta-178m	2.36 h	EC	–	0.1616	1.1558	1.3174
			Hf-178	1.00				
		Ta-179	1.82 y	EC	–	0.0078	0.0256	0.0334
			Hf-179	1.00				
		Ta-180	8.152 h	ECB-	–	0.0565	0.0482	0.1048
			Hf-180	8.6000E-01				
			W-180	1.4000E-01				
		Ta-182	114.43 d	B-	–	0.2105	1.2918	1.5023
			W-182	1.00				
		Ta-182m	15.84 m	IT	–	0.2665	0.2659	0.5324
			Ta-182	1.00				
		Ta-183	5.1 d	B-	–	0.3537	0.2963	0.6499
			W-183	1.00				
		Ta-184	8.7 h	B-	–	0.5426	1.5727	2.1152
			W-184	1.00				
		Ta-185	49.4 m	B-	–	0.7416	0.1547	0.8963
			W-185	1.00				
		Ta-186	10.5 m	B-	–	1.0710	1.4202	2.4912
			W-186	1.00				
74	Tungsten	W-177	132 m	ECB+	–	0.0970	0.9185	1.0155
			Ta-177	1.00				
		W-178	21.6 d	EC	–	0.0075	0.0164	0.0239
			Ta-178	1.00				
		W-179	37.05 m	EC	–	0.0326	0.0554	0.0880
			Ta-179	1.00				
		W-179m	6.40 m	ITEC	–	0.1661	0.0561	0.2221
			W-179	9.9720E-01				
			Ta-179	2.8000E-03				
		W-181	121.2 d	EC	–	0.0129	0.0404	0.0533
			Ta-181	1.00				
		W-185	75.1 d	B-	–	0.1270	<E-04	0.1270
			Re-185	1.00				
		W-185m	1.597 m	IT	–	0.1738	0.0287	0.2025
			W-185	1.00				
		W-187	23.72 h	B-	–	0.2995	0.4483	0.7478
			Re-187	1.00				
		W-188	69.78 d	B-	–	0.0997	0.0019	0.1016
			Re-188	1.00				
		W-190	30.0 m	B-	–	0.4771	0.1511	0.6282
			Re-190	1.00				
75	Rhenium	Re-178	13.2 m	ECB+	–	0.6192	1.7085	2.3277
			W-178	1.00				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Re-179	19.5 m	ECB+	–	0.0668	1.0841	1.1509
			W-179	7.6079E-01				
			W-179m	2.3921E-01				
		Re-180	2.44 m	ECB+	–	0.1720	1.2028	1.3748
			W-180	1.00				
		Re-181	19.9 h	ECB+	–	0.1360	0.8044	0.9404
			W-181	1.00				
		Re-182	64.0 h	EC	–	0.2045	1.7982	2.0027
			W-182	1.00				
		Re-182m	12.7 h	ECB+	–	0.0922	1.2214	1.3136
			W-182	1.00				
		Re-183	70.0 d	EC	–	0.1093	0.1575	0.2667
			W-183	1.00				
		Re-184	38.0 d	ECB+	–	0.0562	0.8919	0.9481
			W-184	1.00				
		Re-184m	169 d	ITEC	–	0.1413	0.3836	0.5249
			Re-184	7.5400E-01				
			W-184	2.4600E-01				
		Re-186	3.7183 d	B-EC	–	0.3362	0.0208	0.3570
			Os-186	9.2530E-01				
			W-186	7.4700E-02				
		Re-186m	2.00E+5 y	IT	–	0.1267	0.0207	0.1474
			Re-186	1.00				
		Re-187	4.12E+10 y	B-	–	0.0006	–	0.0006
			Os-187	1.00				
		Re-188	17.0040 h	B-	–	0.7793	0.0613	0.8406
			Os-188	1.00				
		Re-188m	18.59 m	IT	–	0.0976	0.0715	0.1692
			Re-188	1.00				
		Re-189	24.3 h	B-	–	0.3260	0.0556	0.3816
			Os-189m	1.2211E-01				
			Os-189	8.7789E-01				
		Re-190	3.1 m	B-	–	0.6863	1.3376	2.0239
			Os-190	1.00				
		Re-190m	3.2 h	B-IT	–	0.4456	0.9257	1.3714
			Re-190	4.5600E-01				
			Os-190	5.4400E-01				
76	Osmium	Os-180	21.5 m	ECB+	–	0.0298	0.1265	0.1564
			Re-180	1.00				
		Os-181	105 m	ECB+	–	0.0918	1.3835	1.4753
			Re-181	1.00				
		Os-182	22.10 h	EC	–	0.0565	0.4317	0.4882
			Re-182m	1.00				
		Os-183	13.0 h	ECB+	–	0.0792	0.6288	0.7081
			Re-183	1.00				
		Os-183m	9.9 h	ECB+IT	–	0.0416	1.0062	1.0478
			Re-183	8.5000E-01				
			Os-183	1.5000E-01				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Os-185	93.6 d	EC	–	0.0184	0.6917	0.7101
			Re-185	1.00				
		Os-186	2.0E+15 y	A	2.8220	–	–	2.8220
			W-182	1.00				
		Os-189m	5.8 h	IT	–	0.0286	0.0023	0.0309
			Os-189	1.00				
		Os-190m	9.9 m	IT	–	0.1166	1.5894	1.7059
			Os-190	1.00				
		Os-191	15.4 d	B-	–	0.1372	0.0843	0.2215
			Ir-191	1.00				
		Os-191m	13.10 h	IT	–	0.0664	0.0080	0.0744
			Os-191	1.00				
		Os-193	30.11 h	B-	–	0.3797	0.0674	0.4471
			Ir-193m	3.4757E-03				
			Ir-193	9.9652E-01				
		Os-194	6.0 y	B-	–	0.0453	0.0045	0.0498
			Ir-194	1.00				
		Os-196	34.9 m	B-	–	0.3807	0.0805	0.4612
			Ir-196	1.00				
77	Iridium	Ir-180	1.5 m	ECB+	–	1.2439	1.5955	2.8394
			Os-180	1.00				
		Ir-182	15 m	ECB+	–	1.0474	1.4121	2.4595
			Os-182	1.00				
		Ir-183	58 m	ECB+	–	0.1516	1.1889	1.3404
			Os-183m	7.0972E-01				
			Os-183	2.9028E-01				
		Ir-184	3.09 h	ECB+	–	0.3194	1.9644	2.2838
			Os-184	1.00				
		Ir-185	14.4 h	ECB+	–	0.1228	0.8581	0.9809
			Os-185	1.00				
		Ir-186	16.64 h	ECB+	–	0.1453	1.6651	1.8104
			Os-186	1.00				
		Ir-186m	1.92 h	ECB+IT	–	0.1103	1.2523	1.3626
			Os-186	7.5000E-01				
			Ir-186	2.5000E-01				
		Ir-187	10.5 h	ECB+	–	0.0568	0.3325	0.3892
			Os-187	1.00				
		Ir-188	41.5 h	ECB+	–	0.0508	2.0974	2.1483
			Os-188	1.00				
		Ir-189	13.2 d	EC	–	0.0458	0.0793	0.1251
			Os-189m	7.4264E-02				
			Os-189	9.2574E-01				
		Ir-190	11.78 d	EC	–	0.0746	1.4768	1.5514
			Os-190	1.00				
		Ir-190m	1.120 h	IT	–	0.0240	0.0024	0.0264
			Ir-190	1.00				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Ir-190n	3.087 h	ECIT	–	0.0289	0.0577	0.0867
			Os-190m	9.1400E-01				
			Ir-190	8.6000E-02				
		Ir-191m	4.94 s	IT	–	0.0971	0.0764	0.1735
			Ir-191	1.00				
		Ir-192	73.827 d	B-EC	–	0.2177	0.8165	1.0342
			Pt-192	9.5130E-01				
			Os-192	4.8700E-02				
		Ir-192m	1.45 m	ITB-	–	0.0540	0.0029	0.0569
			Ir-192	9.9983E-01				
			Pt-192	1.7500E-04				
		Ir-192n	241 y	IT	–	0.1617	0.0066	0.1682
			Ir-192	1.00				
		Ir-193m	10.53 d	IT	–	0.0776	0.0027	0.0803
			Ir-193	1.00				
		Ir-194	19.28 h	B-	–	0.8105	0.0911	0.9015
			Pt-194	1.00				
		Ir-194m	171 d	B-	–	0.1422	2.3339	2.4761
			Pt-194	1.00				
		Ir-195	2.5 h	B-	–	0.3803	0.0593	0.4397
			Pt-195	1.00				
		Ir-195m	3.8 h	B-IT	–	0.2606	0.3766	0.6372
			Pt-195m	4.3692E-01				
			Ir-195	5.0000E-02				
			Pt-195	5.1308E-01				
		Ir-196	52 s	B-	–	1.1738	0.2322	1.4060
			Pt-196	1.00				
		Ir-196m	1.40 h	B-	–	0.3844	2.4677	2.8522
			Pt-196	1.00				
78	Platinum	Pt-184	17.3 m	ECB+A	<E-04	0.2004	0.7266	0.9271
			Ir-184	1.00				
			Os-180	1.7000E-05				
		Pt-186	2.08 h	ECA	<E-04	0.0451	0.6844	0.7296
			Ir-186m	8.1942E-01				
			Ir-186	1.8058E-01				
			Os-182	1.0000E-06				
		Pt-187	2.35 h	ECB+	–	0.1549	0.6183	0.7732
			Ir-187	1.00				
		Pt-188	10.2 d	ECA	<E-04	0.0823	0.2055	0.2878
			Ir-188	1.00				
			Os-184	2.9000E-07				
		Pt-189	10.87 h	ECB+	–	0.0996	0.4870	0.5867
			Ir-189	1.00				
		Pt-190	6.50E+11 y	A	3.2490	–	–	3.2490
			Os-186	1.00				
		Pt-191	2.802 d	EC	–	0.0749	0.2960	0.3709
			Ir-191	1.00				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Pt-193	50 y	EC	–	0.0071	0.0026	0.0097
			Ir-193	1.00				
		Pt-193m	4.33 d	IT	–	0.1377	0.0132	0.1510
			Pt-193	1.00				
		Pt-195m	4.02 d	IT	–	0.1845	0.0772	0.2617
			Pt-195	1.00				
		Pt-197	19.8915 h	B-	–	0.2552	0.0256	0.2809
			Au-197	1.00				
		Pt-197m	95.41 m	ITB-	–	0.3250	0.0839	0.4089
			Pt-197	9.6700E-01				
			Au-197	3.3000E-02				
		Pt-199	30.80 m	B-	–	0.5455	0.1995	0.7450
			Au-199	1.00				
		Pt-200	12.5 h	B-	–	0.2321	0.0605	0.2926
			Au-200	1.00				
		Pt-202	44 h	B-	–	0.6537	–	0.6537
			Au-202	1.00				
79	Gold	Au-186	10.7 m	ECB+	–	1.0751	1.4983	2.5735
			Pt-186	1.00				
		Au-187	8.4 m	ECB+A	0.0001	0.1360	1.0652	1.2014
			Pt-187	1.00				
			Ir-183	3.0000E-05				
		Au-190	42.8 m	ECB+	–	0.2129	2.3807	2.5936
			Pt-190	1.00				
		Au-191	3.18 h	ECB+	–	0.0865	0.5946	0.6811
			Pt-191	1.00				
		Au-192	4.94 h	ECB+	–	0.0904	1.9392	2.0296
			Pt-192	1.00				
		Au-193	17.65 h	EC	–	0.0575	0.1673	0.2249
			Pt-193	1.00				
		Au-193m	3.9 s	ITEC	–	0.0904	0.1979	0.2883
			Au-193	9.9970E-01				
			Pt-193m	3.0000E-04				
		Au-194	38.02 h	ECB+	–	0.0421	1.0386	1.0806
			Pt-194	1.00				
		Au-195	186.098 d	EC	–	0.0520	0.0839	0.1359
			Pt-195	1.00				
		Au-195m	30.5 s	IT	–	0.1172	0.2014	0.3186
			Au-195	1.00				
		Au-196	6.183 d	ECB-	–	0.0372	0.4734	0.5105
			Pt-196	9.2800E-01				
			Hg-196	7.2000E-02				
		Au-196m	9.6 h	IT	–	0.3760	0.2473	0.6233
			Au-196	1.00				
		Au-198	2.69517 d	B-	–	0.3277	0.4029	0.7306
			Hg-198	1.00				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Au-198m	2.27 d	IT	–	0.2748	0.5332	0.8080
			Au-198	1.00				
		Au-199	3.139 d	B-	–	0.1451	0.0961	0.2412
			Hg-199	1.00				
		Au-200	48.4 m	B-	–	0.7303	0.2737	1.0041
			Hg-200	1.00				
		Au-200m	18.7 h	B-IT	–	0.2433	1.9843	2.2276
			Au-200	1.8000E-01				
			Hg-200	8.2000E-01				
		Au-201	26 m	B-	–	0.4259	0.0346	0.4605
			Hg-201	1.00				
		Au-202	28.8 s	B-	–	1.0749	0.1720	1.2469
			Hg-202	1.00				
80	Mercury	Hg-190	20.0 m	ECB+	–	0.0539	0.2018	0.2557
			Au-190	1.00				
		Hg-191m	50.8 m	ECB+	–	0.1378	1.4895	1.6273
			Au-191	1.00				
		Hg-192	4.85 h	EC	–	0.0636	0.2749	0.3385
			Au-192	1.00				
		Hg-193	3.80 h	ECB+	–	0.0740	0.8377	0.9117
			Au-193	9.6459E-01				
			Au-193m	3.5408E-02				
		Hg-193m	11.8 h	ECB+IT	–	0.0470	1.0239	1.0709
			Au-193m	8.9197E-01				
			Hg-193	7.1000E-02				
			Au-193	3.7027E-02				
		Hg-194	440 y	EC	–	0.0078	0.0027	0.0106
			Au-194	1.00				
		Hg-195	10.53 h	ECB+	–	0.0650	0.2008	0.2658
			Au-195	1.00				
		Hg-195m	41.6 h	ITECB+	–	0.1480	0.2047	0.3527
			Hg-195	5.4200E-01				
			Au-195	4.5800E-01				
		Hg-197	64.94 h	EC	–	0.0702	0.0740	0.1442
			Au-197	1.00				
		Hg-197m	23.8 h	ITEC	–	0.2170	0.0977	0.3148
			Hg-197	9.1400E-01				
			Au-197	8.6000E-02				
		Hg-199m	42.66 m	IT	–	0.3487	0.1836	0.5323
			Hg-199	1.00				
		Hg-203	46.612 d	B-	–	0.0990	0.2380	0.3370
			Tl-203	1.00				
		Hg-205	5.2 m	B-	–	0.5390	0.0053	0.5444
			Tl-205	1.00				
		Hg-206	8.15 m	B-	–	0.4211	0.1215	0.5426
			Tl-206	1.00				
		Hg-207	2.9 m	B-	–	0.8262	2.6614	3.4876
			Tl-207	1.00				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
81	Thallium	Tl-190	2.6 m	ECB+	–	1.5288	1.2914	2.8202
			Hg-190	1.00				
		Tl-190m	3.7 m	ECB+	–	0.7985	2.4550	3.2535
			Hg-190	1.00				
		Tl-194	33.0 m	ECB+	–	0.5972	0.9143	1.5115
			Hg-194	1.00				
		Tl-194m	32.8 m	ECB+	–	0.3037	2.5218	2.8255
			Hg-194	1.00				
		Tl-195	1.16 h	ECB+	–	0.0740	1.2250	1.2991
			Hg-195	9.9656E-01				
			Hg-195m	3.4358E-03				
		Tl-196	1.84 h	ECB+	–	0.1782	1.8734	2.0516
			Hg-196	1.00				
		Tl-197	2.84 h	ECB+	–	0.0544	0.4587	0.5130
			Hg-197	1.00				
		Tl-198	5.3 h	ECB+	–	0.0414	2.0108	2.0522
			Hg-198	1.00				
		Tl-198m	1.87 h	ECB+IT	–	0.2006	1.2168	1.4175
			Tl-198	4.6000E-01				
			Hg-198	5.4000E-01				
		Tl-199	7.42 h	ECB+	–	0.0600	0.2520	0.3120
			Hg-199	1.00				
		Tl-200	26.1 h	ECB+	–	0.0408	1.3106	1.3514
			Hg-200	1.00				
		Tl-201	72.912 h	EC	–	0.0447	0.0938	0.1385
			Hg-201	1.00				
		Tl-202	12.23 d	EC	–	0.0233	0.4658	0.4891
			Hg-202	1.00				
		Tl-204	3.78 y	B-EC	–	0.2372	0.0013	0.2385
			Pb-204	9.7100E-01				
			Hg-204	2.9000E-02				
		Tl-206	4.200 m	B-	–	0.5398	0.0001	0.5399
			Pb-206	1.00				
		Tl-206m	3.74 m	IT	–	0.2003	2.4192	2.6195
			Tl-206	1.00				
		Tl-207	4.77 m	B-	–	0.4952	0.0024	0.4975
			Pb-207	1.00				
		Tl-208	3.053 m	B-	–	0.6113	3.3603	3.9716
			Pb-208	1.00				
		Tl-209	2.161 m	B-	–	0.6875	2.1426	2.8302
			Pb-209	1.00				
		Tl-210	1.30 m	B-	–	1.2699	2.7632	4.0331
			Pb-210	1.00				
82	Lead	Pb-194	12.0 m	ECB+A	<E-04	0.0844	1.0832	1.1677
			Tl-194	1.00				
			Hg-190	7.3000E-08				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Pb-195m	15 m	ECB+	–	0.3167	1.6547	1.9714
			Tl-195	1.00				
		Pb-196	37 m	ECB+	–	0.0969	0.4940	0.5909
			Tl-196	1.00				
		Pb-197	8 m	ECB+	–	0.0818	1.5319	1.6137
			Tl-197	1.00				
		Pb-197m	43 m	ECB+IT	–	0.2477	1.1732	1.4209
			Tl-197	8.1000E-01				
			Pb-197	1.9000E-01				
		Pb-198	2.4 h	EC	–	0.0781	0.4385	0.5166
			Tl-198	1.00				
		Pb-199	90 m	ECB+	–	0.0584	1.0394	1.0978
			Tl-199	1.00				
		Pb-200	21.5 h	EC	–	0.0997	0.2086	0.3083
			Tl-200	1.00				
		Pb-201	9.33 h	ECB+	–	0.0594	0.7562	0.8156
			Tl-201	1.00				
		Pb-201m	61 s	IT	–	0.2633	0.3658	0.6291
			Pb-201	1.00				
		Pb-202	5.25E+4 y	ECA	0.0260	0.0061	0.0025	0.0346
			Tl-202	9.9000E-01				
			Hg-198	1.0000E-02				
		Pb-202m	3.53 h	ITEC	–	0.1321	1.9925	2.1246
			Pb-202	9.0500E-01				
			Tl-202	9.5000E-02				
		Pb-203	51.873 h	EC	–	0.0530	0.3143	0.3672
			Tl-203	1.00				
		Pb-204m	67.2 m	IT	–	0.1030	2.0634	2.1664
			Pb-204	1.00				
		Pb-205	1.53E+7 y	EC	–	0.0062	0.0025	0.0087
			Tl-205	1.00				
		Pb-209	3.253 h	B-	–	0.1974	–	0.1974
			Bi-209	1.00				
		Pb-210	22.20 y	B-A	<E-04	0.0404	0.0053	0.0457
			Bi-210	1.00				
			Hg-206	1.9000E-08				
		Pb-211	36.1 m	B-	–	0.4543	0.0644	0.5187
			Bi-211	1.00				
		Pb-212	10.64 h	B-	–	0.1766	0.1450	0.3217
			Bi-212	1.00				
		Pb-214	26.8 m	B-	–	0.2948	0.2533	0.5481
			Bi-214	1.00				
83	Bismuth	Bi-197	9.3 m	ECB+	–	0.2887	1.6992	1.9879
			Pb-197	5.6103E-01				
			Pb-197m	4.3897E-01				
		Bi-200	36.4 m	ECB+	–	0.2469	2.4355	2.6825
			Pb-200	1.00				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Bi-201	108 m	ECB+	–	0.0612	1.7304	1.7916
			Pb-201	5.4833E-01				
			Pb-201m	4.5167E-01				
		Bi-202	1.72 h	ECB+	–	0.1515	2.7561	2.9076
			Pb-202	1.00				
		Bi-203	11.76 h	ECB+	–	0.0809	2.3850	2.4659
			Pb-203	1.00				
		Bi-204	11.22 h	ECB+	–	0.0807	2.9162	2.9968
			Pb-204m	9.8525E-02				
			Pb-204	9.0148E-01				
		Bi-205	15.31 d	ECB+	–	0.0346	1.6913	1.7259
			Pb-205	1.00				
		Bi-206	6.243 d	ECB+	–	0.1379	3.2796	3.4175
			Pb-206	1.00				
		Bi-207	32.9 y	ECB+	–	0.1193	1.5370	1.6563
			Pb-207	1.00				
		Bi-208	3.68E+5 y	EC	–	0.0144	2.6460	2.6604
			Pb-208	1.00				
		Bi-210	5.013 d	B-A	<E-04	0.3889	<E-04	0.3889
			Po-210	1.00				
			Tl-206	1.3200E-06				
		Bi-210m	3.04E+6 y	A	5.0064	0.0475	0.2607	5.3146
			Tl-206	1.00				
		Bi-211	2.14 m	A B-	6.6757	0.0100	0.0473	6.7330
			Tl-207	9.9724E-01				
			Po-211	2.7600E-03				
		Bi-212	60.55 m	B-A	2.2164	0.5046	0.1038	2.8247
			Po-212	6.4060E-01				
			Tl-208	3.5940E-01				
		Bi-212n	7.0 m	B-	–	0.5351	–	0.5351
			Po-212m	1.00				
		Bi-213	45.59 m	B-A	0.1245	0.4440	0.1277	0.6963
			Po-213	9.7910E-01				
			Tl-209	2.0900E-02				
		Bi-214	19.9 m	B-A	0.0012	0.6631	1.4793	2.1436
			Po-214	9.9979E-01				
			Tl-210	2.1000E-04				
		Bi-215	7.6 m	B-	–	0.6694	0.2534	0.9228
			Po-215	1.00				
		Bi-216	2.17 m	B-	–	1.3295	0.7385	2.0680
			Po-216	1.00				
84	Polonium	Po-203	36.7 m	ECB+A	0.0060	0.1672	1.6348	1.8080
			Bi-203	9.9890E-01				
			Pb-199	1.1000E-03				
		Po-204	3.53 h	ECA	0.0362	0.1839	1.1650	1.3850
			Bi-204	9.9340E-01				
			Pb-200	6.6000E-03				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Po-205	1.66 h	ECB+A	0.0021	0.0660	1.5846	1.6527
			Bi-205	9.9900E-01				
			Pb-201	4.0000E-04				
		Po-206	8.8 d	ECA	0.2903	0.1655	1.1928	1.6486
			Bi-206	9.4550E-01				
			Pb-202	5.4500E-02				
		Po-207	5.80 h	ECB+A	0.0011	0.0490	1.2847	1.3347
			Bi-207	9.9979E-01				
			Pb-203	2.1000E-04				
		Po-208	2.898 y	AEC	5.2154	<E-04	<E-04	5.2154
			Bi-208	2.2300E-05				
			Pb-204	9.9998E-01				
		Po-209	102 y	AEC	4.9529	0.0030	0.0063	4.9622
			Pb-205	9.9520E-01				
			Bi-209	4.8000E-03				
		Po-210	138.376 d	A	5.4075	<E-04	<E-04	5.4075
			Pb-206	1.00				
		Po-211	0.516 s	A	7.5860	0.0002	0.0082	7.5944
			Pb-207	1.00				
		Po-212	2.99E-7 s	A	8.9541	–	–	8.9541
			Pb-208	1.00				
		Po-212m	45.1 s	A	11.7755	0.0004	0.0792	11.8551
			Pb-208	9.9930E-01				
		Po-213	4.2E-6 s	A	8.5370	<E-04	<E-04	8.5370
			Pb-209	1.00				
		Po-214	1.643E-4 s	A	7.8334	<E-04	<E-04	7.8335
			Pb-210	1.00				
		Po-215	1.781E-3 s	A	7.5261	<E-04	0.0002	7.5263
			Pb-211	1.00				
		Po-216	0.145 s	A	6.9064	<E-04	<E-04	6.9064
			Pb-212	1.00				
		Po-218	3.10 m	A B-	6.1134	<E-04	–	6.1135
			Pb-214	9.9980E-01				
			At-218	2.0000E-04				
85	Astatine	At-204	9.2 m	ECB+A	0.2307	0.4485	2.3234	3.0025
			Po-204	9.6200E-01				
			Bi-200	3.8000E-02				
		At-205	26.2 m	ECB+A	0.6021	0.2575	1.1444	2.0039
			Po-205	9.0000E-01				
			Bi-201	1.0000E-01				
		At-206	30.6 m	ECB+A	0.0517	0.3324	2.4807	2.8647
			Po-206	9.9110E-01				
			Bi-202	8.9000E-03				
		At-207	1.80 h	ECB+A	0.5049	0.1298	2.0136	2.6483
			Po-207	9.1400E-01				
			Bi-203	8.6000E-02				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		At-208	1.63 h	ECB+A	0.0316	0.1598	3.0408	3.2322
			Po-208	9.9450E-01				
			Bi-204	5.5000E-03				
		At-209	5.41 h	ECB+A	0.2360	0.1172	2.2846	2.6378
			Po-209	9.5900E-01				
			Bi-205	4.1000E-02				
		At-210	8.1 h	ECB+A	0.0097	0.0796	2.9622	3.0515
			Po-210	9.9825E-01				
			Bi-206	1.7500E-03				
		At-211	7.214 h	ECA	2.4998	0.0059	0.0367	2.5424
			Po-211	5.8200E-01				
			Bi-207	4.1800E-01				
		At-215	1.00E-4 s	A	8.1778	<E-04	0.0002	8.1780
			Bi-211	1.00				
		At-216	3.00E-4 s	A	7.9407	0.0013	0.0025	7.9446
			Bi-212	1.00				
		At-217	3.23E-2 s	A	7.2008	<E-04	0.0002	7.2011
			Bi-213	9.9988E-01				
		At-218	1.5 s	A B-	6.8042	0.0011	–	6.8053
			Bi-214	9.9900E-01				
			Rn-218	1.0000E-03				
		At-219	56 s	A	6.1343	–	–	6.1343
			Bi-215	9.7000E-01				
		At-220	3.71 m	B-A	0.4842	1.2130	0.4497	2.1469
			Rn-220	9.2000E-01				
			Bi-216	8.0000E-02				
86	Radon	Rn-207	9.25 m	ECB+A	1.3126	0.2197	0.9854	2.5177
			At-207	7.9000E-01				
			Po-203	2.1000E-01				
		Rn-209	28.5 m	ECB+A	1.0466	0.1167	1.1953	2.3586
			At-209	8.3000E-01				
			Po-205	1.7000E-01				
		Rn-210	2.4 h	AEC	5.9121	0.0091	0.0610	5.9821
			Po-206	9.6000E-01				
			At-210	4.0000E-02				
		Rn-211	14.6 h	ECB+A	1.6205	0.0663	1.8727	3.5595
			At-211	7.2600E-01				
			Po-207	2.7400E-01				
		Rn-212	23.9 m	A	6.3847	<E-04	0.0003	6.3850
			Po-208	1.00				
		Rn-215	2.30 us	A	8.8390	–	–	8.8390
			Po-211	1.00				
		Rn-216	4.5E-5 s	A	8.2000	–	–	8.2000
			Po-212	1.00				
		Rn-217	5.40E-4 s	A	7.8856	–	–	7.8856
			Po-213	1.00				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Rn-218	3.5E-2 s	A	7.2618	<E-04	0.0008	7.2626
			Po-214	1.00				
		Rn-219	3.96 s	A	6.8801	0.0068	0.0586	6.9456
			Po-215	1.00				
		Rn-220	55.6 s	A	6.4040	<E-04	0.0006	6.4047
			Po-216	1.00				
		Rn-222	3.8235 d	A	5.5899	<E-04	0.0004	5.5903
			Po-218	1.00				
		Rn-223	24.3 m	B-	–	0.6282	0.3444	0.9726
			Fr-223	1.00				
87	Francium	Fr-212	20.0 m	ECB+A	2.7731	0.1294	1.1415	4.0440
			Rn-212	5.7000E-01				
			At-208	4.3000E-01				
		Fr-219	2.0E-2 s	A	7.4437	0.0004	0.0036	7.4477
			At-215	1.00				
		Fr-220	27.4 s	A B-	6.7413	0.0163	0.0105	6.7680
			At-216	9.9650E-01				
			Ra-220	3.5000E-03				
		Fr-221	4.9 m	A	6.4199	0.0089	0.0294	6.4582
			At-217	1.00				
		Fr-222	14.2 m	B-	–	0.7145	0.1806	0.8951
			Ra-222	1.00				
		Fr-223	22.00 m	B-A	0.0003	0.3829	0.0583	0.4415
			Ra-223	1.00				
			At-219	6.0000E-05				
		Fr-224	3.33 m	B-	–	0.8751	0.5523	1.4274
			Ra-224	1.00				
		Fr-227	2.47 m	B-	–	0.7967	0.4499	1.2466
			Ra-227	1.00				
88	Radium	Ra-219	10 ms	A	7.9071	0.0600	0.1702	8.1372
			Rn-215	1.00				
		Ra-220	1.79E-2 s	A	7.5904	0.0002	0.0047	7.5952
			Rn-216	1.00				
		Ra-221	28 s	A	6.7915	0.0690	0.0390	6.8995
			Rn-217	1.00				
		Ra-222	38.0 s	A	6.6710	0.0009	0.0092	6.6811
			Rn-218	1.00				
		Ra-223	11.43 d	A	5.7702	0.0781	0.1413	5.9895
			Rn-219	1.00				
		Ra-224	3.66 d	A	5.7766	0.0023	0.0104	5.7893
			Rn-220	1.00				
		Ra-225	14.9 d	B-	–	0.1050	0.0145	0.1194
			Ac-225	1.00				
		Ra-226	1600 y	A	4.8603	0.0039	0.0074	4.8716
			Rn-222	1.00				
		Ra-227	42.2 m	B-	–	0.4511	0.1508	0.6019
			Ac-227	1.00				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Ra-228	5.75 y	B-	–	0.0132	0.0031	0.0163
			Ac-228	1.00				
		Ra-230	93 m	B-	–	0.2201	0.0794	0.2995
			Ac-230	1.00				
89	Actinium	Ac-223	2.10 m	A	6.6721	0.0254	0.0190	6.7165
			Fr-219	9.9000E-01				
		Ac-224	2.78 h	ECA	0.5662	0.0490	0.2325	0.8477
			Ra-224	9.0900E-01				
			Fr-220	9.1000E-02				
		Ac-225	10.0 d	A	5.8920	0.0248	0.0171	5.9338
			Fr-221	1.00				
		Ac-226	29.37 h	B-ECA	0.0003	0.2914	0.1327	0.4245
			Th-226	8.3000E-01				
			Ra-226	1.7000E-01				
			Fr-222	6.0000E-05				
		Ac-227	21.772 y	B-A	0.0693	0.0150	0.0011	0.0853
			Th-227	9.8620E-01				
			Fr-223	1.3800E-02				
		Ac-228	6.15 h	B-	–	0.4495	0.8671	1.3166
			Th-228	1.00				
		Ac-230	122 s	B-	–	0.9229	0.5440	1.4668
			Th-230	1.00				
		Ac-231	7.5 m	B-	–	0.6361	0.4190	1.0550
			Th-231	1.00				
		Ac-232	119 s	B-	–	0.9707	1.1528	2.1235
			Th-232	1.00				
		Ac-233	145 s	B-	–	0.8355	0.4993	1.3348
			Th-233	1.00				
90	Thorium	Th-223	0.60 s	A	7.4134	0.0575	0.0754	7.5463
			Ra-219	1.00				
		Th-224	1.05 s	A	7.2635	0.0129	0.0232	7.2996
			Ra-220	1.00				
		Th-226	30.57 m	A	6.4219	0.0211	0.0089	6.4519
			Ra-222	1.00				
		Th-227	18.68 d	A	5.9883	0.0755	0.1317	6.1955
			Ra-223	1.00				
		Th-228	1.9116 y	A	5.4956	0.0210	0.0036	5.5202
			Ra-224	1.00				
		Th-229	7.34E+3 y	A	4.9584	0.1217	0.0971	5.1772
			Ra-225	1.00				
		Th-230	7.538E+4 y	A	4.7538	0.0146	0.0018	4.7702
			Ra-226	1.00				
		Th-231	25.52 h	B-	–	0.1622	0.0269	0.1891
			Pa-231	1.00				
		Th-232	1.405E10 y	A	4.0688	0.0126	0.0015	4.0829
			Ra-228	1.00				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Th-233	22.3 m	B-	–	0.4140	0.0375	0.4515
			Pa-233	1.00				
		Th-234	24.10 d	B-	–	0.0622	0.0105	0.0728
			Pa-234m	1.00				
		Th-235	7.1 m	B-	–	0.6713	0.0537	0.7251
			Pa-235	1.00				
		Th-236	37.5 m	B-	–	0.3671	0.0346	0.4017
			Pa-236	1.00				
91	Protactinium	Pa-227	38.3 m	AEC	5.5650	0.0226	0.0234	5.6110
			Ac-223	8.5000E-01				
			Th-227	1.5000E-01				
		Pa-228	22 h	ECB+A	0.1217	0.1320	1.3694	1.6230
			Th-228	9.8000E-01				
			Ac-224	2.0000E-02				
		Pa-229	1.50 d	ECA	0.0274	0.0131	0.0666	0.1071
			Th-229	9.9520E-01				
			Ac-225	4.8000E-03				
		Pa-230	17.4 d	ECB-A	0.0002	0.0668	0.6708	0.7377
			Th-230	9.1600E-01				
			U-230	8.4000E-02				
			Ac-226	3.2000E-05				
		Pa-231	3.276E+4 y	A	5.0592	0.0538	0.0450	5.1580
			Ac-227	1.00				
		Pa-232	1.31 d	B-EC	–	0.1738	0.9393	1.1131
			U-232	1.00				
			Th-232	3.0000E-05				
		Pa-233	26.967 d	B-	–	0.2151	0.2229	0.4380
			U-233	1.00				
		Pa-234	6.70 h	B-	–	0.4037	1.4718	1.8755
			U-234	1.00				
		Pa-234m	1.17 m	B-IT	–	0.8171	0.0162	0.8334
			U-234	9.9840E-01				
			Pa-234	1.6000E-03				
		Pa-235	24.5 m	B-	–	0.4886	0.0008	0.4894
			U-235m	9.9990E-01				
			U-235	1.0109E-04				
		Pa-236	9.1 m	B-	–	0.8049	0.9148	1.7197
			U-236	1.00				
		Pa-237	8.7 m	B-	–	0.5780	0.6095	1.1875
			U-237	1.00				
92	Uranium	U-227	1.1 m	A	6.9984	0.0960	0.1199	7.2143
			Th-223	1.00				
		U-228	9.1 m	A	6.6046	0.0231	0.0056	6.6333
			Th-224	9.7500E-01				
		U-230	20.8 d	A	5.9681	0.0216	0.0032	5.9929
			Th-226	1.00				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		U-231	4.2 d	ECA	0.0002	0.0847	0.0896	0.1745
			Pa-231	1.00				
			Th-227	4.0000E-05				
		U-232	68.9 y	A	5.3948	0.0164	0.0023	5.4135
			Th-228	1.00				
		U-233	1.592E+5 y	A	4.9013	0.0059	0.0013	4.9085
			Th-229	1.00				
		U-234	2.455E+5 y	A	4.8430	0.0137	0.0020	4.8587
			Th-230	1.00				
		U-235	7.04E+8 y	A	4.4693	0.0530	0.1669	4.6891
			Th-231	1.00				
		U-235m	26 m	IT	–	<E-04	<E-04	<E-04
			U-235	1.00				
		U-236	2.342E+7 y	A	4.5592	0.0114	0.0018	4.5723
			Th-232	1.00				
		U-237	6.75 d	B-	–	0.1991	0.1442	0.3433
			Np-237	1.00				
		U-238	4.468E+9 y	ASF	4.2584	0.0092	0.0014	4.2691
			Th-234	1.00				
			SF	5.4500E-07				
		U-239	23.45 m	B-	–	0.4108	0.0519	0.4626
			Np-239	1.00				
		U-240	14.1 h	B-	–	0.1276	0.0099	0.1374
			Np-240m	1.00				
		U-242	16.8 m	B-	–	0.3859	0.0413	0.4272
			Np-242	1.00				
93	Neptunium	Np-232	14.7 m	ECB+	–	0.1073	1.1969	1.3042
			U-232	1.00				
		Np-233	36.2 m	ECA	<E-04	0.0144	0.0911	0.1055
			U-233	1.00				
			Pa-229	1.0000E-05				
		Np-234	4.4 d	ECB+	–	0.0574	1.1086	1.1660
			U-234	1.00				
		Np-235	396.1 d	ECA	0.0001	0.0105	0.0071	0.0178
			U-235	9.9598E-01				
			U-235m	3.9933E-03				
			Pa-231	2.6000E-05				
		Np-236	1.54E+5 y	ECB-A	0.0074	0.2372	0.1594	0.4039
			U-236	8.7300E-01				
			Pu-236	1.2500E-01				
			Pa-232	1.6000E-03				
		Np-236m	22.5 h	ECB-	–	0.0880	0.0507	0.1387
			U-236	5.2000E-01				
			Pu-236	4.8000E-01				
		Np-237	2.144E+6 y	A	4.8499	0.0681	0.0350	4.9529
			Pa-233	1.00				

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Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Np-238	2.117 d	B-	–	0.2519	0.5879	0.8398
			Pu-238	1.00				
		Np-239	2.3565 d	B-	–	0.2623	0.1846	0.4469
			Pu-239	1.00				
		Np-240	61.9 m	B-	–	0.5095	1.0538	1.5632
			Pu-240	1.00				
		Np-240m	7.22 m	B-IT	–	0.6779	0.3225	1.0004
			Pu-240	9.9890E-01				
			Np-240	1.1000E-03				
		Np-241	13.9 m	B-	–	0.4341	0.0395	0.4736
			Pu-241	1.00				
		Np-242	2.2 m	B-	–	0.9027	0.2654	1.1681
			Pu-242	1.00				
		Np-242m	5.5 m	B-	–	0.7551	0.9194	1.6744
			Pu-242	1.00				
94	Plutonium	Pu-232	33.7 m	ECA	1.5402	0.0087	0.0633	1.6122
			Np-232	7.7000E-01				
			U-228	2.3000E-01				
		Pu-234	8.8 h	ECA	0.3776	0.0114	0.0693	0.4583
			Np-234	9.4000E-01				
			U-230	6.0000E-02				
		Pu-235	25.3 m	ECA	0.0002	0.0228	0.0957	0.1187
			Np-235	9.9997E-01				
			U-231	2.7000E-05				
		Pu-236	2.858 y	ASF	5.8524	0.0128	0.0022	5.8674
			U-232	1.00				
			SF	1.3700E-09				
		Pu-237	45.2 d	ECA	0.0002	0.0171	0.0537	0.0710
			Np-237	1.00				
			U-233	4.2000E-05				
		Pu-238	87.7 y	ASF	5.5803	0.0107	0.0021	5.5930
			U-234	1.00				
			SF	1.8500E-09				
		Pu-239	2.411E+4 y	A	5.2357	0.0075	0.0011	5.2442
			U-235m	9.9940E-01				
			U-235	6.0000E-04				
		Pu-240	6564 y	ASF	5.2434	0.0105	0.0019	5.2559
			U-236	1.00				
			SF	5.7500E-08				
		Pu-241	14.35 y	B-A	0.0001	0.0052	<E-04	0.0054
			Am-241	9.9998E-01				
			U-237	2.4500E-05				
		Pu-242	3.75E+5 y	ASF	4.9738	0.0090	0.0017	4.9855
			U-238	1.00				
			SF	5.5400E-06				
		Pu-243	4.956 h	B-	–	0.1729	0.0259	0.1988
			Am-243	1.00				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Pu-244	8.00E+7 y	ASF	4.6513	0.0197	0.0211	4.9094
			U-240	9.9879E-01				
			SF	1.2100E-03				
		Pu-245	10.5 h	B-	–	0.3190	0.4027	0.7217
			Am-245	1.00				
		Pu-246	10.84 d	B-	–	0.1159	0.1431	0.2590
			Am-246m	1.00				
95	Americium	Am-237	73.0 m	ECA	0.0015	0.0802	0.3714	0.4531
			Pu-237	9.9975E-01				
			Np-233	2.5000E-04				
		Am-238	98 m	ECB+A	<E-04	0.0485	0.9023	0.9509
			Pu-238	1.00				
			Np-234	1.0000E-06				
		Am-239	11.9 h	ECA	0.0006	0.1709	0.2436	0.4150
			Pu-239	9.9990E-01				
			Np-235	1.0000E-04				
		Am-240	50.8 h	ECA	<E-04	0.0758	1.0355	1.1112
			Pu-240	1.00				
			Np-236	1.9000E-06				
		Am-241	432.2 y	A	5.5712	0.0373	0.0293	5.6379
			Np-237	1.00				
		Am-242	16.02 h	B-EC	–	0.1806	0.0188	0.1994
			Cm-242	8.2700E-01				
			Pu-242	1.7300E-01				
		Am-242m	141 y	ITA	0.0238	0.0439	0.0056	0.0734
			Am-242	9.9550E-01				
			Np-238	4.5000E-03				
		Am-243	7.37E+3 y	A	5.3583	0.0234	0.0585	5.4402
			Np-239	1.00				
		Am-244	10.1 h	B-	–	0.3330	0.8052	1.1382
			Cm-244	1.00				
		Am-244m	26 m	B-	–	0.5187	0.0172	0.5359
			Cm-244	9.9960E-01				
		Am-245	2.05 h	B-	–	0.2874	0.0324	0.3198
			Cm-245	1.00				
		Am-246	39 m	B-	–	0.7241	0.7498	1.4739
			Cm-246	1.00				
		Am-246m	25.0 m	B-	–	0.5033	0.9799	1.4832
			Cm-246	1.00				
		Am-247	23.0 m	B-	–	0.5683	0.1348	0.7031
			Cm-247	1.00				
96	Curium	Cm-238	2.4 h	ECA	0.2537	0.0117	0.0829	0.3482
			Am-238	9.6160E-01				
			Pu-234	3.8400E-02				
		Cm-239	2.9 h	ECB+	–	0.0291	0.2593	0.2883
			Am-239	1.00				

(*continued on next page*)

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Cm-240	27 d	ASF	6.3650	0.0108	0.0022	6.3781
			Pu-236	9.9700E-01				
			SF	3.9000E-08				
		Cm-241	32.8 d	ECA	0.0603	0.1342	0.5034	0.6979
			Am-241	9.9000E-01				
			Pu-237	1.0000E-02				
		Cm-242	162.8 d	ASF	6.2041	0.0096	0.0020	6.2156
			Pu-238	1.00				
			SF	6.3700E-08				
		Cm-243	29.1 y	AEC	5.8929	0.1342	0.1353	6.1624
			Pu-239	9.9760E-01				
			Am-243	2.4000E-03				
		Cm-244	18.10 y	ASF	5.8915	0.0079	0.0017	5.9014
			Pu-240	1.00				
			SF	1.3710E-06				
		Cm-245	8.5E+3 y	ASF	5.4474	0.0824	0.1084	5.6382
			Pu-241	1.00				
			SF	6.1000E-09				
		Cm-246	4.76E+3 y	ASF	5.4654	0.0085	0.0050	5.5285
			Pu-242	9.9974E-01				
			SF	2.6300E-04				
		Cm-247	1.56E+7 y	A	5.0292	0.0114	0.3138	5.3544
			Pu-243	1.00				
		Cm-248	3.48E+5 y	ASF	4.7212	0.7716	1.3127	22.5608
			Pu-244	9.1610E-01				
			SF	8.3900E-02				
		Cm-249	64.15 m	B-	–	0.2835	0.0200	0.3035
			Bk-249	1.00				
		Cm-250	8300 y	AB-SF	0.9283	8.4270	13.3167	161.287
			Pu-246	1.8000E-01				
			Bk-250	8.0000E-02				
			SF	7.4000E-01				
		Cm-251	16.8 m	B-	–	0.4545	0.1112	0.5657
			Bk-251	1.00				
97	Berkelium	Bk-245	4.94 d	ECA	0.0075	0.1326	0.2352	0.3752
			Cm-245	9.9880E-01				
			Am-241	1.2000E-03				
		Bk-246	1.80 d	EC	–	0.0554	0.8546	0.9101
			Cm-246	1.00				
		Bk-247	1.38E+3 y	A	5.7031	0.0691	0.1468	5.9190
			Am-243	1.00				
		Bk-248m	23.7 h	B-EC	–	0.1910	0.0559	0.2470
			Cf-248	7.0000E-01				
			Cm-248	3.0000E-01				
		Bk-249	330 d	B-A	<E-04	0.0324	<E-04	0.0325
			Cf-249	1.00				
			Am-245	1.4500E-05				

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Bk-250	3.212 h	B-	–	0.2949	0.8983	1.1932
			Cf-250	1.00				
		Bk-251	55.6 m	B-	–	0.3693	0.0915	0.4608
			Cf-251	1.00				
98	Californium	Cf-244	19.4 m	A	7.3196	0.0075	0.0020	7.3291
			Cm-240	1.00				
		Cf-246	35.7 h	ASF	6.8527	0.0060	0.0014	6.8606
			Cm-242	1.00				
			SF	2.5000E-06				
		Cf-247	3.11 h	ECA	0.0022	0.0463	0.1050	0.1536
			Bk-247	9.9965E-01				
			Cm-243	3.5000E-04				
		Cf-248	334 d	ASF	6.3518	0.0075	0.0020	6.3670
			Cm-244	9.9997E-01				
			SF	2.9000E-05				
		Cf-249	351 y	ASF	5.9262	0.0399	0.3282	6.2944
			Cm-245	1.00				
			SF	5.0200E-09				
		Cf-250	13.08 y	ASF	6.1168	0.0103	0.0111	6.2897
			Cm-246	9.9923E-01				
			SF	7.7000E-04				
		Cf-251	900 y	A	5.8803	0.1705	0.1245	6.1754
			Cm-247	1.00				
		Cf-252	2.645 y	ASF	6.0177	0.2516	0.4572	12.8107
			Cm-248	9.6908E-01				
			SF	3.0920E-02				
		Cf-253	17.81 d	B-A	0.0188	0.0908	0.0048	0.1144
			Es-253	9.9690E-01				
			Cm-249	3.1000E-03				
		Cf-254	60.5 d	ASF	0.0183	10.0442	16.8399	222.890
			Cm-250	3.1000E-03				
			SF	9.9690E-01				
		Cf-255	85 m	B-	–	0.2178	–	0.2178
			Es-255	1.00				
99	Einsteinium	Es-249	102.2 m	ECB+A	0.0392	0.0437	0.4129	0.4958
			Cf-249	9.9430E-01				
			Bk-245	5.7000E-03				
		Es-250	8.6 h	EC	–	0.3281	1.2235	1.5516
			Cf-250	9.8500E-01				
		Es-250m	2.22 h	ECB+	–	0.0343	0.5549	0.5892
			Cf-250	1.00				
		Es-251	33 h	ECA	0.0329	0.0522	0.1016	0.1868
			Cf-251	9.9500E-01				
			Bk-247	5.0000E-03				
		Es-253	20.47 d	ASF	6.7335	0.0022	0.0008	6.7366
			Bk-249	1.00				
			SF	8.9000E-08				

(*continued on next page*)

Table A.1 continued

Z	Element	Nuclide	Half-life	Decay mode	Emitted energy (MeV/nt)			
					Alpha	Electron	Photon	Total
		Es-254	275.7 d	A B-SF	6.5244	0.0727	0.0208	6.6179
			Bk-250	1.00				
			Fm-254	1.7400E-06				
			SF	3.0000E-08				
		Es-254m	39.3 h	B-AECSF	0.0208	0.2408	0.4757	0.8269
			Fm-254	9.8000E-01				
			Bk-250	3.2000E-03				
			Cf-254	7.6000E-04				
			SF	4.5000E-04				
		Es-255	39.8 d	B-ASF	0.5117	0.0737	0.0007	0.5950
			Fm-255	9.2000E-01				
			Bk-251	8.0000E-02				
			SF	4.5000E-05				
		Es-256	25.4 m	B-	–	0.5822	0.0032	0.5854
			Fm-256	1.00				
100	Fermium	Fm-251	5.30 h	ECB+A	0.1252	0.0337	0.1588	0.3176
			Es-251	9.8200E-01				
			Cf-247	1.8000E-02				
		Fm-252	25.39 h	ASF	7.1449	0.0064	0.0018	7.1578
			Cf-248	9.9998E-01				
			SF	2.3000E-05				
		Fm-253	3.00 d	ECA	0.8352	0.1084	0.0713	1.0150
			Es-253	8.8000E-01				
			Cf-249	1.2000E-01				
		Fm-254	3.240 h	ASF	7.2956	0.0095	0.0086	7.4339
			Cf-250	9.9941E-01				
			SF	5.9200E-04				
		Fm-255	20.07 h	ASF	7.1292	0.0954	0.0170	7.2417
			Cf-251	1.00				
			SF	2.3000E-07				
		Fm-256	157.6 m	ASF	0.5686	6.3116	12.4371	205.496
			Cf-252	8.1000E-02				
			SF	9.1900E-01				
		Fm-257	100.5 d	ASF	6.6154	0.1471	0.1521	7.3388
			Cf-253	9.9790E-01				
			SF	2.1000E-03				

USER GUIDE TO THE ICRP CD AND THE DECDATA SOFTWARE

K. F. Eckerman, A. Endo

1. Basic Information About the CD and Software Package

The ICRP publication entitled "Decay Data for Dosimetric Calculations" includes a CD that provides electronic files of the unabridged nuclear decay data for 1252 radionuclides of 97 elements. The CD contains the following:

- README.TXT: A file containing information post preparation of the publication
- CONTENT.PDF: A file detailing the content of the CD
- LICENSE.TXT: A file containing the license agreement and a liability statement
- USERGUIDE.PDF: The user guide to the DECDATA software; this document
- ICRP-07 nuclear decay data files:
  - ICRP-07.NDX
  - ICRP-07.RAD
  - ICRP-07.BET
  - ICRP-07.NSF
  - ICRP-07.ACK
- SETUP.EXE: Executable file for installing DECDATA software
- ARCHIVE folder:
  - INPUT folder: EDISTR04 input files for nuclides of the ICRP collection
  - OUTPUT folder: EDISTR04 output files for nuclides of the ICRP collection
  - SOURCE folder: Source code for DECDATA

The software package DECDATA enables viewing the radiological properties of radionuclides of the ICRP collection in a tabular and graphical manner as no detailed tabulations are included in the publication. Data on the yields and energies of the radiations of a user-specified radionuclide can be extracted into ASCII files for subsequent use. DECDATA is intended for use on a personal computer (PC) with Windows operating system.

The CD contains a file, AUTORUN.INF, which invokes SETUP.EXE to install DECDATA when the CD is placed in the CD drive. If this function has been disabled on the computer then, from Explorer, click on SETUP.EXE to install DECDATA. AUTORUN can be bypassed by holding down the shift key when the CD is placed in the drive.

SETUP.EXE is a Windows installation procedure[1] that installs DECDATA and its data files. After the user agrees to the license statement the procedure creates a folder with the default name ICRP07 on the hard drive, installs the software in the folder, and places the DECDATA icon on the desktop. Three additional folders,

[1] The install package was created using Inno Setup compiler available from http://www.innosetup.com.

below the main folder, are created. The decay data files reside in the subfolder DATA, decay scheme drawings for selected files are in the FIGS subfolder, and all output files generated by DECDATA are written to the subfolder OUTPUT. The subfolder REPORT contains documents of potential interest to the user, including this document.

DECDATA is a console application developed using PowerBASIC™ Console Compiler[2] with Perfect Sync, Inc[3] modules Console Tools™ and Graphics Tools™ providing additional functionality. Graphical support is provided by the DPlot Jr[4] module. Documents in the REPORT subfolder can be selected for viewing within DECDATA, as can some of DECDATA output files. This capability depends on the user having associated files with file extensions *pdf* and *txt* with Acrobat Reader[5] and an ASCII editor (such as Microsoft's Notepad), respectively.

[2] PowerBASIC, Inc.; 1978 Tamiami Trail S. #200; Venice, FL 34293. See http://www.powerbasic.com/.

[3] Perfect Sync, Inc. 6511 Franklin Woods Dr., Traverse City, MI. See http://perfectsync.com/.

[4] HydeSoft Computing, Inc., 110 Roseland Drive, Vicksburg, MS 39180. See http://www.dplot.com/index.htm.

[5] Adobe Acrobat Reader of Adobe Inc. is available from http://www.pdf-2007.com/index.asp.

2. Information on the Nuclear Decay Data Files

The nuclear decay data are embodied in five formatted (hence readable with an ASCII editor) direct-access files, each with the root name ICRP-07. The file ICRP-07.RAD contains the data on the absolute yields (or intensities) and mean[6] or discrete energies of the radiations emitted by the 1252 nuclides of the ICRP-07 collection. This file contains data for all emitted radiations; i.e., no cutoff on the number of radiations has been applied to the data of the electronic files as would be required in printed tabulations.

The file ICRP-07.BET contains the beta spectra for all beta emitters in the collection. EDISTR04 (Dillman, 1980; Endo *et al.* 2005), the software used to compute the energies and yields of the emitted radiations, computes the spectrum for each beta transition to determine the mean beta energy of the transitions and tabulates the composite spectra for all beta transitions of the radionuclide. Only the composite spectra are included in this file.

The file ICRP-07.ACK contains the Auger and Coster-Kronig (CK) electron spectra for selected radionuclides. These discrete emissions were collected into no more than 15 groups for each decay mode in the ICRP-07.RAD file. Hereafter Auger and Coster-Kronig (CK) is denoted as Auger-CK.

The spectra of neutrons emitted during spontaneous fission are contained in the file ICRP-07.NSF. In the ICRP-07 collection, 28 radionuclides decay by spontaneous fission.

To facilitate access to the data in these files, an additional file ICRP-07.NDX was constructed. A brief description of each of these five files is presented below. For convenience, the files are referred to by their file extension, i.e., NDX, RAD, BET, ACK, and NSF.

Index File: ICRP-07.NDX

The NDX file serves as the entrance into the larger radiation (RAD) and spectral (BET, ACK, and NSF) files. The NDX file contains one record for each nuclide of the collection. Fields of the nuclide record specify the location of the nuclide's records in the RAD, BET, ACK, and NSF files. In addition to these so-called pointers, the record contains fields giving the nuclide's physical half-life, decay mode (e.g., alpha or beta), identity of progeny (daughters), fraction of the nuclear transformations forming each daughter (so-called branching fraction), the total energies emitted by alpha, electron, and photon emissions (including electrons and photons accompanying spontaneous fission), and other supportive data. A full description of the NDX records is given in Table 1.

The records of the index file have been sorted by the nuclide field, making it possible for user-developed software to locate the record for a radionuclide of interest using a binary search algorithm. While the purpose of the NDX file is to provide entrance into the other data files, it is of considerable utility in its own right. For

[6] Mean values are reported for beta particles, Auger and Coster-Kronig electron groups, and the radiations emitted during spontaneous fission – fission fragments, neutrons, and delayed beta emission.

Table 1. Structure of Records in ICRP-07.NDX File.

Field	Format[a]	Description
Record 1[b]		
First	I4	Record number of first data record
Last	I4	Record number of last data record
Data Records (First,. . ., Last)[c]		
Nuclide	A7	Name of nuclide (parent); e.g., Am-241, Tc-99m
Half-life	A8	Half-life of nuclide
Units	A2	Half-life units: μs - microsecond, ms - millisecond, s - second, m - minute, d - day, and y - year
Decay Mode	A8	A denotes alpha, B- beta minus, B+ beta plus, EC electron capture, IT internal transition, and SF spontaneous fission
Pointer-1	I7	Location of nuclide in ICRP-07.RAD file
Pointer-2	I7	Location of nuclide in ICRP-07.BET file
Pointer-3	I7	Location of nuclide in ICRP-07.ACK file
Pointer-4	I6	Location of nuclide in ICRP-07.NSF file
The next block of three fields is repeated for radioactive daughter *i*,*i* = 1 to 4.		
Daughter-*i*	A7	Name of daughter nuclide *i*
Record-i	I6	Location of daughter *i* in ICRP-07.NDX file
Branch-i	E11.0	Branching fraction to daughter *i*
E-alpha	E7.0	Energy of alpha emissions (MeV/nt)
E-electron	E8.0	Energy of electrons, including beta (MeV/nt)
E-photon	E8.0	Energy of photon emission (MeV/nt)
Number-1	I4	Number of photon of energy less than 10 keV per nt
Number-2	I4	Number of photons of energy greater than 10 keV per nt
Number-3	I4	Number of beta transitions per nt
Number-4	I5	Number of monoenergetic electrons per nt
Number-5	I4	Number of alpha transitions per nt
AMU	E11.0	Atomic mass of radionuclide (Audi *et al.* 2003)
Γ_{10}	E10.0	Air kerma-rate constant (Gy-m^2 (Bq s)$^{-1}$)
K_{air}	E9.0	Air kerma coefficient (Gy-m^2 (Bq s)$^{-1}$)

[a] The format is expressed in FORTRAN notation, e.g., A8 denotes an alphanumic field of length 8, I5 an integer field of length 5, and E11.0 a real numeric field of length 11.

[b] FORTRAN Format(2I4)

[c] FORTRAN Format (A7,A8,A2,A8,3I7,I6,1X,3(A7,I6,E11.0,1X),A7,I6,E11.0,F7.0,2F8.0,3I4,I5,I4, E11.0,E10.0,E9.0)

example, DECDATA constructs the decay chain headed by a radionuclide from information in the NDX file - this is discussed further below.

Both the radioactive and stable daughter nuclei and their branching fractions are included in the file. The Tantulum-180 m daughter, formed in 0.3% of the decays of Hf-180 m is indicated here as stable as in NUBASE2003 (Audi *et al.* 2003). In the NDX file, daughter nuclei with a zero record pointer (Record-i of Table 1) are stable. A list of the radionuclides of the ICRP-07 collection is contained in the REPORT folder (ICRP_Nuclides.TXT).

Radiation File: ICRP-07.RAD

The records of the RAD file contain the data on the energy and yield of each radiation emitted in nuclear transformations of the radionuclide. No cutoff is applied to the number of radiations in this file. The fields of the RAD records are described in

Table 2. Structure of Records in ICRP-07.RAD File.

Field	Format	Description
Nuclide Record		
Nuclide	A7	Nuclide name; e.g., Tc-99m
$T_{1/2}$	E11.0	Physical half-life of nuclide
Time unit	A2	Units of $T_{1/2}$, see Table 1
N	I9	Number of data records
Data Record (1, . . ., N)		
ICODE	A2	Radiation type (see Table 3)
Yield	E12.0	Yield of the radiation (/nt)
Energy	E12.0	Energy of the radiation (MeV)
JCODE	A3	Mnemonic (see Table 3)

Table 2. The first record (header record) of a nuclide in the file contains the name of the nuclide, its half-life, and the number of data records for each radiation that follow. The fields of the data record are: (1) an integer code (ICODE) that identifies the radiation type; (2) the absolute yield of the radiation (i.e., number per nuclear transformation); (3) the unique or average energy of the radiation; and (4) a two-character mnemonic denoting the radiation type. The ICODE and the mnemonic are defined in Table 3. The nuclide record in the NDX file includes a field, Pointer-1 of Table 1, which contains the record number of header record of the nuclide in the RAD file, a so-called pointer.

The data records for the nuclides are ordered by radiation type, the order of ICODE, and by increasing energy. The radiations group are:

- Photons- ICODE 1-3: x ray, γ ray, annihilation photons, and prompt and delayed photons of spontaneous fission
- Beta particles- ICODE 4-5: mean energy of each beta transition

Table 3. Description of ICODE Variable.

ICODE	Mnemonic For ICODE	Description
1	G	Gamma rays
	PG	Prompt gamma rays*
	DG	Delayed gamma rays*
2	X	X rays
3	AQ	Annihilation photons
4	B+	Beta + particles
5	B –	Beta – particles
	BD	Delayed beta particles*
6	IE	IC electrons
7	AE	Auger electrons
8	A	Alpha particles
9	AR	Alpha recoil nuclei
10	FF	Fission fragments
11	N	Neutrons

* Prompt and delayed radiations of spontaneous fission.

- Monoenergetic electrons- ICODE 6-7: internal conversion and Auger-CK electrons
- Alpha particles- ICODE 8
- Alpha recoil nuclei- ICODE 9
- Fission fragments- ICODE 10
- Neutrons- ICODE 11

The records of each group are sorted by increasing energy. This sorting facilitates interpolation in an energy-dependent function, e.g., the energy-dependent specific absorbed fraction data for the radiation type. The mnemonic can be used to identify a particular radiation type within its group (for example, annihilation photons, delayed gamma rays, etc.).

Beta Spectra File: ICRP-07.BET

The BET file contains the beta spectrum for each beta emitter of the ICRP-07 collection. The spectral data are tabulated on a fixed logarithmic-type energy grid. For each nuclide, the header record gives the name of the nuclide and the number of data records that follow. The fields of the data records contain the electron energy E (MeV) and the number of electrons emitted per nuclear transformation with energy between E and $E + dE$. The structure of the records of the BET file is given in Table 4. A field of the nuclide record in the NDX file, Pointer-2 of Table 1, contains the record number of the nuclide's header record in the BET file.

Auger-CK Electron Spectra File: ICRP-07.ACK

For 136 selected nuclides, detailed Auger-CK electron spectra are contained in the ACK file. These emissions were collapsed into no more than 15 groups for each decay mode in the RAD file. The maximum number of discrete electrons in the spectrum of a radionuclide is 3015 in the case of Hg-195 m and Hg-197 m. The fields of the header record contain the name of the nuclide and the number of data records that follow. The fields of the data records contain the electron energy E (eV), the yield (number of electrons of that energy per nuclear transformation), and an identification of the orbital transition. The data records have been sorted by increasing electron energy. The format of the records is given in Table 5. A list of the nuclides, for which detailed spectra are included in the ACK file, is contained in the REPORT folder (AugerList.TXT). A field of the nuclide record in the NDX file, Pointer-3 of Table 1, contains the record number of the nuclide's header record in the ACK file.

Table 4. Structure of Records in ICRP-07.BET File.

Field	Format	Description
Nuclide Record		
Nuclide	A7	Nuclide name; e.g., Tc-99m
N	I10	Number of data records
Data Record (1, …, N)		
Energy	F7.0	Energy grid point (MeV)
Number	E10.0	Number of beta particles per MeV per nuclear transformation at this energy

Table 5. Structure of Records in ICRP-07.ACK File.

Field	Format	Description
Nuclide Record		
Nuclide	A7	Nuclide name; e.g., I-123
$T_{1/2}$	A17	Half-life with its units
N	18	Number of discrete electron lines
Data Record (1, . . ., N)		
Yield	E11.0	Number of electrons per nt at this energy
Energy	E12.0	Electron energy (eV)
Transition	A9	Identification of atomic transition; e.g., L1 M2 M3

Table 6. Structure of Records in ICRP-07.NSF File.

Field	Format	Description
Nuclide Record		
Nuclide	A7	Nuclide name; e.g., Cf-252
BF	E13.0	SF branching fraction
N	I9	Number of neutron energy bins
Data Record (1, . . ., N)		
Energy-1	E8.0	Lower energy (MeV)
Energy-2	E9.0	Upper energy (MeV)
Yield	E12.0	Number of neutrons per nt in bin

Neutron Spectra File: ICRP-07.NSF

The NSF file contains the spectra of neutrons emitted by radionuclides undergoing spontaneous fission. In the ICRP-07 collection, 28 radionuclies decay by spontaneous fission. For each nuclide, the header record gives the name of the nuclide, the branching fraction for spontaneous fission, and the number of data records that follow. The fields of data records define a neutron energy bin (a lower and upper energy are given) and the number of neutrons per nuclear transformation in that energy bin. The format of the records of the NSF file is given in Table 6. A field of the nuclide record in the NDX file, Pointer-4 of Table 1, contains the record number of the nuclide's header record in the NSF file.

3. Air Kerma for Ideal Point Source

A field of the nuclide record in the NDX file contains the quantity air kerma as a measure of the radiation field in the vicinity of a point source of the radionuclides. Kerma, an acronym for the kinetic energy released per unit mass, is the kinetic energy of charged particles liberated by photon and neutron interactions per unit mass.

3.1. Air Kerma-Rate Constant

The nuclide record in the NDX file has a field containing the air-kerma rate constant. This constant, a characteristic of a radionuclide, is defined in terms of an ideal point source. The International Commission on Radiation Units and Measurements (ICRU 1998) defined the constant as $\Gamma_\delta = l^2\dot{K}_\delta/A$ where $\dot{K}_\delta$ is the air kerma rate due to photons of energy greater than δ at a distance l in vacuum from a point source of the radionuclide of activity A. The photons referred to include gamma rays, characteristic x rays, and inner bremsstrahlung; the latter is not addressed in the ICRP-07 collection because of its low yield and energy. Annihilation photons, included in the tabulated emissions, are not included in the definition of the constant as they would not be present for an ideal point source in a vacuum. In a source of finite size, attenuation and scattering occur, and external bremsstrahlung can be produced. In addition, any medium between the source and the point of measurement will give rise to absorption and scattering, external bremsstrahlung, and annihilation photons. In many cases, these processes can substantially influence the observed kerma rate. The constant, as defined, is given by

$$\Gamma_\delta = \frac{1}{4\pi}\sum_i (\mu_k/\rho)_i Y_i E_i \tag{1}$$

where $(\mu_k/\rho)_i$ is the mass energy-transfer coefficient in air for photons of energy E_i emitted by the nuclide with yield Y_i. The mass energy-transfer coefficients used to derive the tabulated values are from Shultis and Faw (1999). The value of δ was 10 keV. The air kerma-rate constant is the SI equivalent of the quantity referred to as the specific gamma constant.

3.2. Point Source Air-Kerma Coefficient

As noted above, the air kerma-rate constant does not consider annihilation photons associated with positron emission and the neutrons and photons accompanying spontaneous fission. To address these radiations, the air-kerma coefficient $K_{\mathrm{air},\delta}$ for a hypothetical point source is defined as

$$K_{air,\delta} = \frac{1}{4\pi}\left[\sum_i (\mu_k/\rho)_i Y_i E_i + \sum_i Y(E_i, E_{i+1})\bar{k}(E_i, E_{I+1})\right] \tag{2}$$

and is included on the nuclide record in the NDX file. The first summation in the right hand side Eq. (2) extends over all photons of energy greater than δ, including annihilation photons arising from position emission and the delayed and prompt

gamma-rays accompanying spontaneous fission. The second summation in Eq. (2) is the contribution to air kerma of neutrons accompanying spontaneous fission with yield $Y(E_i,E_{i+1})$ per nuclear transformation and $\bar{k}(E_i, E_{i+1})$ denotes the value of the neutron air kerma coefficient (Chadwick *et al.* 1999) averaged over the energies E_i to E_{i+1}. Only neutrons of energy greater than δ (10 keV) are considered. The constant and the coefficient are numerically equal except in the cases of positron emission or spontaneous fission decay. The cautionary statements above regarding the air kerma-rate constant and the observed kerma rate for a real source in air are applicable to the coefficient.

4. Basic Operation and Features of the DECDATA Software

DECDATA can be invoked by clicking on its desktop icon. To access the records for a radionuclide of interest the user clicks on the chemical symbol of the element in the periodic table. Displayed in the lower right corner of the screen is the name of the element corresponding to the chemical symbol over which the mouse cursor is currently located (the cursor is not shown in Fig. 1). If the ICRP-07 collection contains no radioisotopes of the element (as for He, Li, B, Md, No, and Lr) then the phrase "No Data" appears in the lower right corner of the display. If the mouse is clicked (left click) while over an element then a list box of the radioisotopes of the element in the collection (see Fig. 2) is displayed. If only a single radioisotope of the element is included in the collection, then clicking on that element results in the display of the summary information for the radioisotope – hydrogen is the only such case. After a radioisotope of the element is selected from the list box of multiple isotopes, e.g., Cf-252, the software displays the physical half-life, decay mode, specific activity, and radioactive progeny of the radionuclide followed by a summary tabulation of its emissions as shown in Fig. 3. Graphical display of the decay scheme of 333 radionuclides were published earlier (Eckerman and Endo 2008) and these graphics are included here in the FIGS folder. A message is displayed as seen in Fig. 3 when the graphic exists for the selected radionuclide.

The summary reports the number of records of each radiation type in the RAD file, the yield or number per nuclear transformation (nt), the total emitted energy (MeV per nt), the mean (average) emitted energy (MeV), and the equilibrium

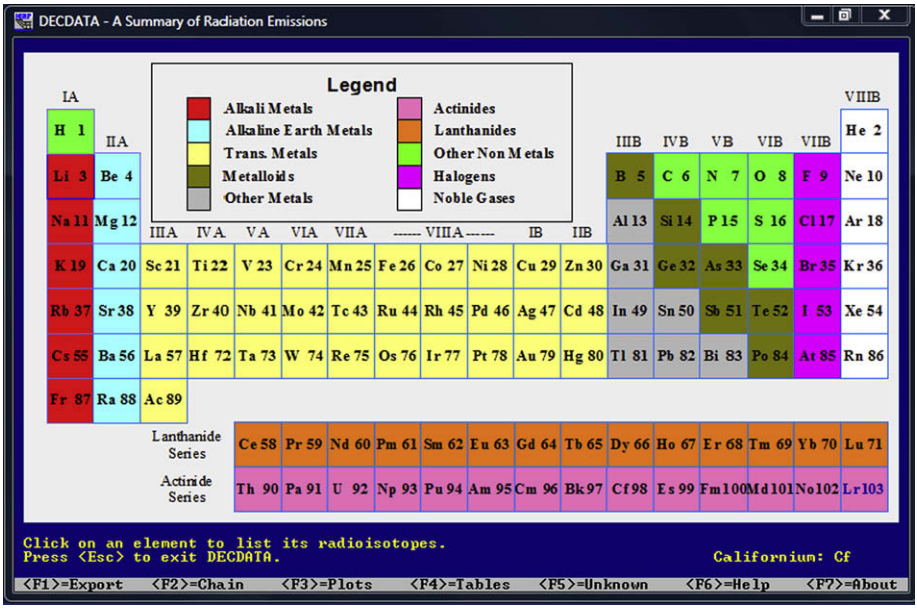


Fig. 1. DECDATA's interface for selecting radioisotopes of the elements in ICRP-07.

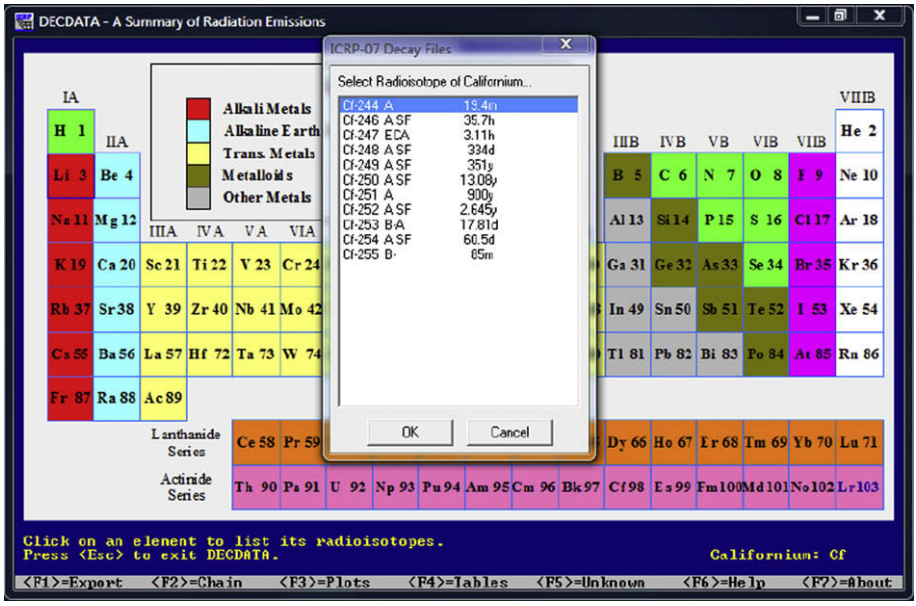


Fig. 2. Menu to select a radioisotope of the selected element.

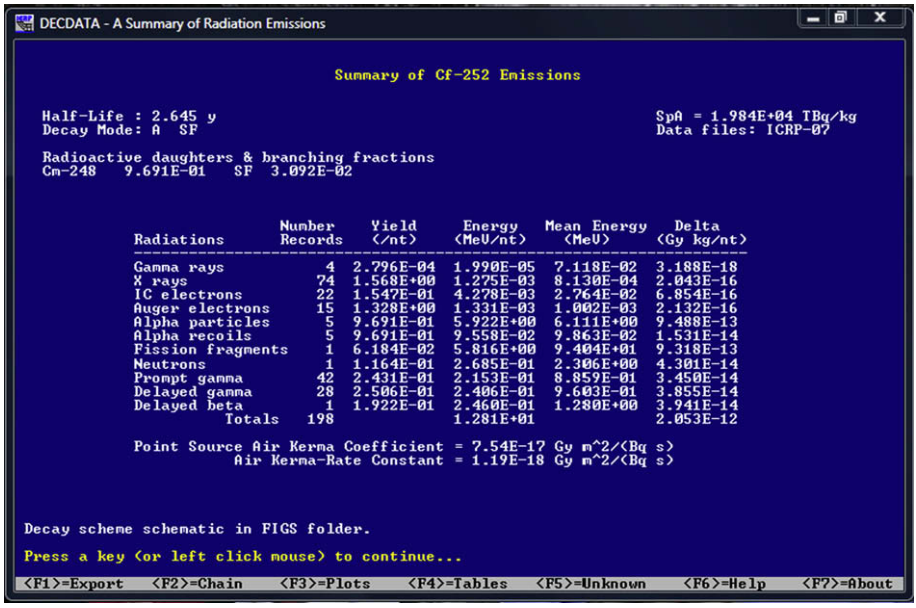


Fig. 3. Summary display of the Cf-252 emissions.

absorbed dose quantity Δ (Gy kg nt^{-1}). For brevity, nuclear transformation (Bq s) is abbreviated as nt in the display. The 14 radiation groups of the summary table are

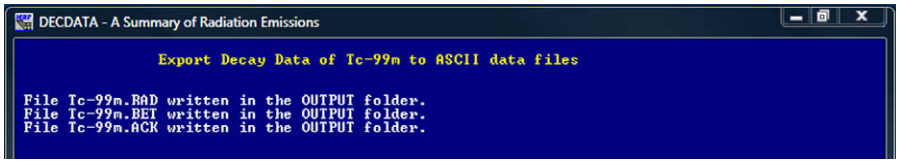
listed as: Gamma rays, X rays, Annh photons, Beta+, Beta-, IC electrons, Auger electrons, Alpha particles, Alpha recoil, Fission fragments, Neutrons, Prompt gamma, Delayed gamma, and Delayed beta. In the event photons of energy greater than 10 keV are emitted, the air kerma-rate constant and air kerma coefficient for a point source are displayed. The latter quantity includes for positron emitters the contributions from annihilation photons and for spontaneous fission the contributions from the neutron and the prompt and delayed gamma radiations.

The last line of the display delineates actions assigned to the function keys F1 through F7. These keys can be pressed at any time. The first three keys act on the displayed nuclide while the other keys are not specific to a nuclide. The key assignments are summarized below and described in more detail in the paragraphs that follow.

Function Key	Action
F1	Export to ASCII files the nuclear decay data for the displayed nuclide
F2	Show the decay chain headed by the displayed nuclide and tabulate the cumulative energy associated with the chain members
F3	Graphically display the beta and neutron spectra (continuous) and line spectra for the discrete energies of alpha particles, IC electrons, Auger-CK electrons, and photon radiations
F4	List the radionuclides in the collection sorted by: a) atomic number, b) half-life, c) total emitted energy, d) alpha emitters, e) beta emitters, f) internal transition (IT), g) spontaneous fission, h) principal alpha emission, i) principal beta transition, j) principal photon emission, k) nuclides with detailed Auger-CK spectra
F5	Given an alpha or photon emission of known energy, a search of the RAD file is carried out in an attempt to identify a radionuclide in the ICRP-07 which emits such a radiation
F6	Display documents in the REPORT folder
F7	Display the usual software credit screen

F1 key: Export nuclide data

If the F1 key is pressed while the summary information for a radionuclide is displayed, then the nuclear decay data for the nuclide is extracted from the data files and written to ASCII files in the OUTPUT folder. In the case where the data from Tc-99m is to be extracted the following files are created:



The names of the output files are constructed from the nuclide name with the file extension being the extension of the ICRP-07 file from which the data were extracted. In each output file, the second line of the file is the header record of the nuclide in the file from which the data are extracted. A partial listing of the Tc-99m.RAD file follows.

```
File: Tc-99m.RAD for Tc-99m
Tc-99m     6.015h     143
Tl/2 = 6.015h Decay Mode: ITB-
Radiations of each type listed in increasing energy
Number of photon radiations: 86
Number of beta radiations: 3
Number of monoenergetic electron radiations: 54
ICODE Y (/nt) E(MeV) Mnemonic
START RADIATION RECORDS
2 5.49690E+00 7.87678E-06 X
  / / / / / / / / / / / / / / /
  : : : : : : : : : : : : : : : : :
  / / / / / / / / / / / / / / /
  1 6.65489E-11 2.17260E-03 G
  2 1.69925E-06 2.23236E-03 X
  / / / / / / / / / / / / / / /
  : : : : : : : : : : : : : : : : :
  / / / / / / / / / / / / / / /
  1 9.69400E-07 3.22400E-01 G
  5 1.07767E-06 3.01202E-02 B-
  5 2.59439E-05 1.02026E-01 B-
  / / / / / / / / / / / / / / /
  : : : : : : : : : : : : : : : : :
  / / / / / / / / / / / / / / /
  6 5.99387E-11 3.22400E-01 IE
END RADIATION RECORDS
```

As seen in above listing, the file begins with a few brief comments and then lists, for each radiation type, the number of records in the file. The decay data are bracketed between a start and end delimiter (“START RADIATION RECORDS” and “END RADIATION RECORDS”, respectively). The radiation records are in the format of the RAD file. See Table 2 for the definition of ICODE and the mnemonic.

The records of the Tc-99m.BET file have the same structure as the record in the BET file but are bracketed by start and end delimiters. A few lines from the Tc-99m.bet file are listed below.

```
File: Tc-99m.BET for Tc-99m
Tc-99m        100
Beta Spectrum for Tc-99m
Spectrum is normalized to 1 nt (Bq s)
To normalize to 1 beta, divide by 3.7000E-05
Number of energy points: 100
E(MeV)     P(E)
START RADIATION RECORDS
0.00000 2.319E-04
0.00010 2.318E-04
```

```
    ::      ::
0.36000 7.143E-06
0.40000 1.990E-06
0.43618 0.000E+00
END RADIATION RECORDS
```

For selected radionuclides, Tc-99m being one, detailed spectra of the Auger-CK electron emissions are contained in the ACK file. While this level of detail is not necessary in calculations of mean absorbed dose, it is of interest in microdosimetric calculations, e.g., the dose to the cell nucleus from such an emitter incorporated in the cell nucleus. Below is an excerpt from the Tc-99m. ACK file.

```
File: Tc-99m.ACK for Tc-99m
Tc-99m        968
Auger/Coster-Kronig Spectrum for Tc-99m
Number of electrons: 968
Y(/nt)     E(eV)     transition
START RADIATION RECORDS
6.57103E-05 3.34000E+00 M1 M4 M5
1.66012E-04 7.28000E+00 M1 M5 M5
7.71672E-08 9.83000E+00 M1 M2 N1
3.19642E-03 1.22200E+01 M2 M3 N4
6.44567E-04 1.23300E+01 M1 M2 N1
7.26819E-03 1.25100E+01 M2 M3 N5
    ::   ::       ::   ::       ::
1.90107E-11 2.20272E+04 K N3 N4
1.90107E-11 2.20275E+04 K N3 N5
1.26734E-11 2.20300E+04 K N3 O1
END RADIATION RECORDS
```

In the case of Tc-99m, the emissions of 968 discrete electrons are tabulated. The unit of the electron energy in this file is eV. In this case the electron energy ranges over four decades.

If decay data for a radionuclide which decays by spontaneous fission, e.g., Cf-252, is requested, a file of the neutron spectra associated with the spontaneous fission process is created. Below is an excerpt from the Cf-252.NSF file.

```
Output File Cf-252.NSF for Cf-252
Cf-252     3.092E-02         52
Neutron Spectra for Cf-252
Number of neutrons per fission — 3.767
Spectrum is normalized to 1 nt (Bq-s)
To normalize to 1 fission, divide by 3.09E-02
To normalize to 1 neutron, divide by 1.1641E-01
Number of energy bins: 52
E1 (MeV) E2 (MeV) Yield (/nt)
START RADIATION RECORDS
```

```
4.14E-07 1.00E-06 1.85105E-11
1.00E-06 1.00E-05 1.15581E-09
1.00E-05 5.00E-05 1.27176E-08
5.00E-05 1.00E-04 2.56849E-08
    ::   ::   ::   ::   ::   ::
1.20E+01 1.30E+01 3.82221E-05
1.30E+01 1.40E+01 1.82774E-05
1.40E+01 1.50E+01 8.66434E-06
END RADIATION RECORDS
```

F2 key: Show the decay chain

The decay of some radionuclides results in formation of radioactive nuclei (daughters) and hence a serial decay chain. The F2 key displays the decay chain and is illustrated below for the case of the parent radionuclide Es-254m, the longest chain in the ICRP-07 collection. After selecting Es-254m, its summary display is shown and then pressing F2 results in the display of Fig. 4.a. The values under the columns headed by *f1*, *f2*, *f3*, and *f4* denote the fractions of the nuclear transformations of the nuclide in the second column which form the daughter nuclei shown immediately to the right of those fractions. Spontaneous fission, which is a decay mode of several chain members, is denoted as SF in the table. Note that stable nuclei are shown in yellow.

The decay chain information is presented in two screens when the length of the chain is greater than 7 members, as in this case. Upon continuing the display, the additional information provides an evaluation of the potential dosimetric impor-

DECDATA - A Summary of Radiation Emissions

Es-254m Decay Chain: Half-lives and Branching Fractions

	Nuclide	Halflife	f1	Daughter Products: Nuclide	f2	Nuclide	f3	Nuclide	f4	Nuclide
1	Es-254m	39.3h	9.800E-01	Fm-254	7.600E-04	Cf-254	3.200E-03	Bk-250	4.500E-04	SF
2	Fm-254	3.240h	9.994E-01	Cf-250	5.920E-04	SF				
3	Cf-254	60.5d	3.100E-03	Cm-250	9.969E-01	SF				
4	Cm-250	8300y	8.000E-02	Bk-250	1.800E-01	Pu-246	7.400E-01	SF		
5	Bk-250	3.212h	1.000E+00	Cf-250						
6	Cf-250	13.08y	9.992E-01	Cm-246	7.700E-04	SF				
7	Pu-246	10.84d	1.000E+00	Am-246m						
8	Am-246m	25.0m	1.000E+00	Cm-246						
9	Cm-246	4.76E+3y	9.997E-01	Pu-242	2.630E-04	SF				
10	Pu-242	3.75E+5y	1.000E+00	U-238	5.540E-06	SF				
11	U-238	4.468E+9y	1.000E+00	Th-234	5.450E-07	SF				
12	Th-234	24.10d	1.000E+00	Pa-234m						
13	Pa-234m	1.17m	1.600E-03	Pa-234	9.984E-01	U-234				
14	Pa-234	6.70h	1.000E+00	U-234						
15	U-234	2.455E+5y	1.000E+00	Th-230						
16	Th-230	7.538E+4y	1.000E+00	Ra-226						
17	Ra-226	1600y	1.000E+00	Rn-222						
18	Rn-222	3.8235d	1.000E+00	Po-218						
19	Po-218	3.10m	9.998E-01	Pb-214	2.000E-04	At-218				
20	Pb-214	26.8m	1.000E+00	Bi-214						
21	At-218	1.5s	9.990E-01	Bi-214	1.000E-03	Rn-218				
22	Bi-214	19.9m	9.998E-01	Po-214	2.100E-04	Tl-210				
23	Rn-218	3.5E-2s	1.000E+00	Po-214						
24	Po-214	1.643E-4s	1.000E+00	Pb-210						
25	Tl-210	1.30m	1.000E+00	Pb-210						
26	Pb-210	22.20y	1.000E+00	Bi-210	1.900E-08	Hg-206				
27	Bi-210	5.013d	1.000E+00	Po-210	1.320E-06	Tl-206				
28	Hg-206	8.15m	1.000E+00	Tl-206						
29	Po-210	138.376d	1.000E+00	Pb-206						
30	Tl-206	4.200m	1.000E+00	Pb-206						

Stable isotope(s) shown in yellow.
Press a key (or left click mouse) to continue...

Fig. 4.a. Display of the Es-254m decay chain.

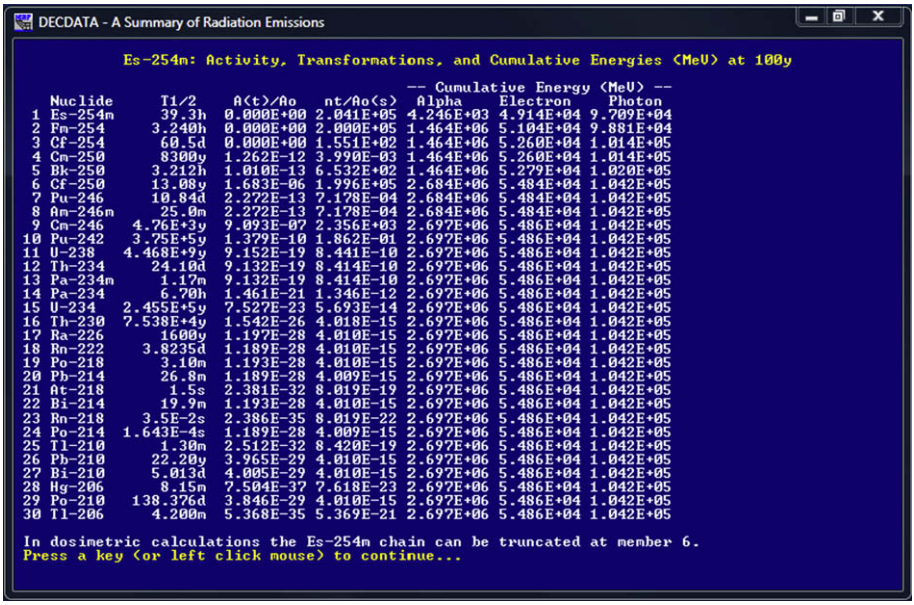


Fig. 4.b. Summary of emitted energies of the Es-254m chain.

tance of the chain members. Fig. 4.b. shows the additional information for the Es-254m chain.

Briefly, DECDATA constructs and displays a table of activities, nuclear transformations, and cumulative energies of emitted alpha, electron, and photon emissions of the chain members over a period of 100 y, assuming a unit activity of the pure parent (e.g., 1 Bq of Es-254m) at time zero. The cumulative energy of alpha, electron (including beta) and photon emissions for the decay series is shown in the right three columns. The length of the chain that accounts for 99% of the total emitted energy over the 100 y time period is calculated for each energy type. For Es-254m the suggestion is made that for dosimetric purposes the chain could be truncated after the sixth member (Cm-250) because the contribution of the rest of the members to the cumulative energy of each radiation type is not significant. Some loss in numerical significance may be evident in these calculations for some decay chains and the guidance concerning truncation is somewhat arbitrary. However, this guidance has proven to be useful when considering the truncation of chains headed by or including long-lived radionuclides. In any event, the user must make the decision regarding truncation of the chain in his application.

F3 key: Plots of radiation emissions

This function key generates, for the displayed radionuclide, a series of plots of the yield vs. energy of the emitted radiations. In the case of beta emission (negatron and positron) and neutrons the plots are continuous function of energy. For radiations of discrete energy a line plots are generated. Fig. 5 show the generated plots displayed in a cascade manner of the emissions of Cf-252. To expand the plot of interest, click

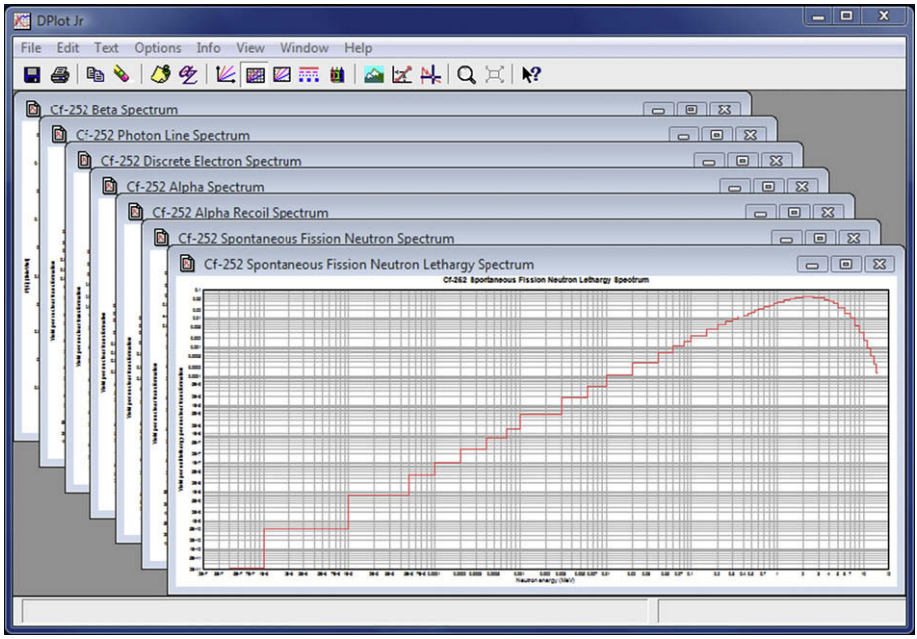


Fig. 5. Cascade plots of Cf-252 emissions.

the "maximize" icon in the upper right corner of the plot. The plots of the other radiations can then be selected for viewing by clicking on the "Window" item on DPlotJr's tool bar. You can force DECDATA to display the plots in the maximized manner by creating a file named "DPlotJr. INI" in the ICRP07 folder. The type of axis and their numerical extent can be modified by selecting the options item on DPlot Jr menu. Additional information is available under the help menu.

The neutron spectral data in the NSF file are binned and displayed in two plots evident in Fig. 5, the first being simply the binned spectra (y-axis is the number of neutron per nt with energy within the bin) and the second a lethargy plot (y-axis is the number of neutrons in the bin per nt in lethargy units, i.e., number per nt/ln(E_{i+1}/E_i) where E_{i+1} and E_i are the upper and lower energy bounds of the i^{th} energy bin).

Upon its very first use, DPlotJr may start with its plot window maximized. After resizing the window in the usual Windows manner (dragging the edge and centering) click on Options on the toolbar, select that last item (General) and remove the check mark on "Always start maximized." DplotJr will then start as sized in future applications.

If the ICRP-07.ACK file contains the Auger-CK electron spectrum for the selected radionuclide then the spectrum is also plotted in the cascade. The Auger-CK spectrum of Hg-195m is shown in Fig. 6.

F4 key: Nuclide lists

The function key F4 displays a menu providing a number of options for sorting and listing the radionuclides in the ICRP-07 collection. In addition, the last two

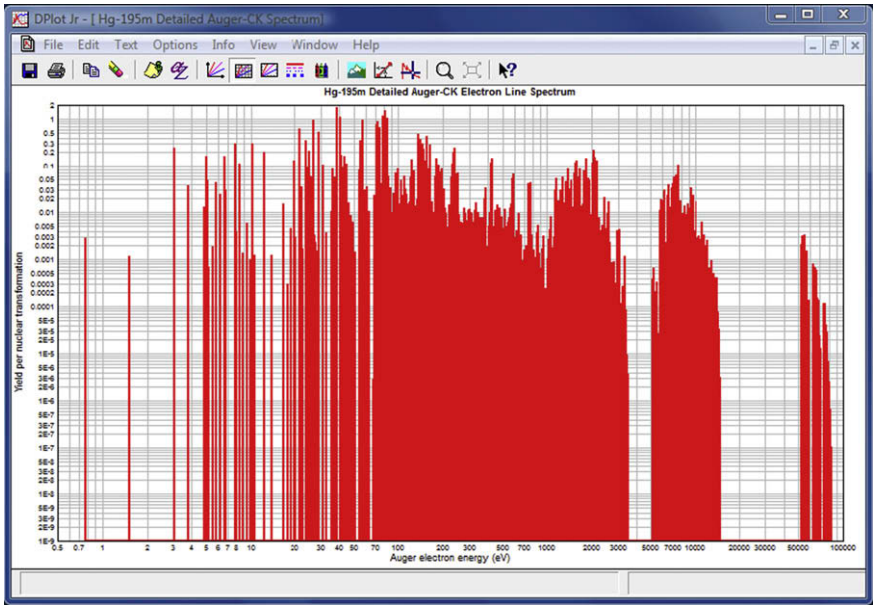


Fig. 6. Detailed Auger and Coster-Kronig electron emissions of Hg-195m.

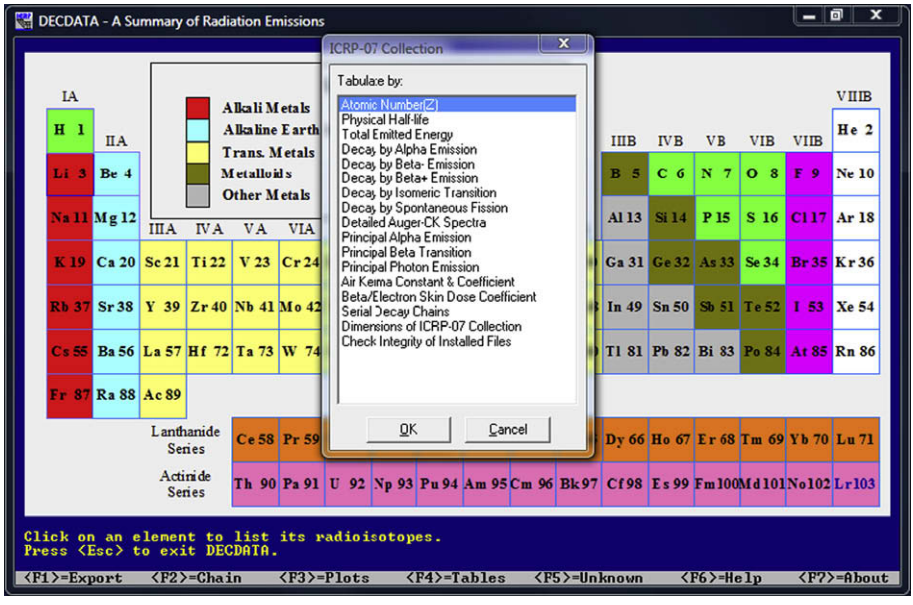


Fig. 7. Menu to characterize the ICRP-07 collection.

menu items characterize the data files. The actions under this menu are displayed and written to the file NucList-X.TXT, where X corresponds to the index of the user-

specified criteria selected from a menu. After the file(s) are constructed DECDATA will open the file using an application registered to open files with the extension TXT. The user is cautioned to be patient while DECDATA constructs the desired information and Windows loads an application to view the file. The menu items are presented below and shown in Fig. 7.

Menu items for sorting and characterizing the radionuclides in ICRP-07

Menu Item	Description
1. Atomic Number(Z)	List nuclides in order of atomic number
2. Physical Half-life	List nuclides by increasing physical half-life
3. Total Emitted Energy	List nuclides by increasing emitted energy
4. Decay by Alpha Emission	List nuclides that undergo alpha decay
5. Decay by Beta- Emission	List nuclides that undergo β^- (negatron) decay
6. Decay by Beta+ Emission	List nuclides that undergo β^+ (positron) decay
7. Decay by Internal Transition	List nuclides that undergo internal transition decay
8. Decay by Spontaneous Fission	List nuclides that undergo spontaneous fission
9. Detailed Auger-CK Spectra	List nuclides in the ACK file
10. Principal Alpha Emission	List nuclides by increasing energy of principal alpha emission
11. Principal Beta Transition	List nuclides by increasing energy of principal beta emission
12. Principal Photon Emission	List nuclides by increasing energy of principal photon emission
13. Air Kerma Constant & Coefficient	Tabulate air kerma-rate constant and coefficient
14. Beta/Electron Skin Dose Coefficient	Compute beta/electron skin dose coefficient
15. Serial Decay Chains	Tabulate serial decay chains
16. Dimensions of ICRP-07 Collection	List dimensions of collection
17. Check Integrity of Installed Files	Verify checksum of ICRP-07 data files.

As the files created by menu items 1 and 9 can be of frequent interest they are included in the REPORT folder as ICRP_Nuclide.TXT and AugerList.TXT, respectively. They can be accessed under the help provisions of the F6 key.

Menu item 14 invokes a calculation of absorbed dose rate to skin (Gy s^{-1} cm^2 Bq^{-1}) resulting from contamination of the skin by radionuclides that undergo beta decay or emit energetic conversion electrons. The absorbed dose calculations is based on the paper by Faw (1992) and is calculated as

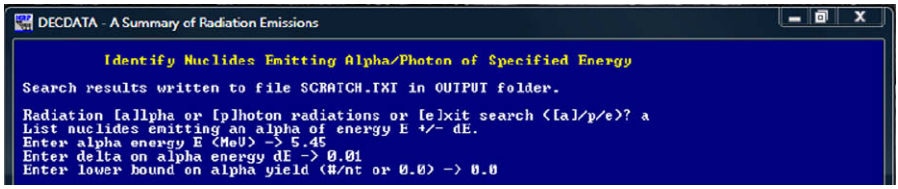
$$D_{skin} = 1.60210^{-10} \int_0^{\infty} P(E)R(E)dE + \sum_i Y(E_i)R(E_i) \tag{3}$$

where $P(E)$ is the number of electrons of energy between $E$and $E + dE$ emitted per nt as tabulated in the BET file, $Y(Ei)$ is the number of monoenergetic electrons of energy E_i emitted per nt, and $R(E)$ (MeV cm^2 g^{-1}) is the absorbed dose to the skin (averaged over a depth of 5 to 10 mg cm^{-2}) as a function of electron energy expressed in functional form by the parameters of Table 3 of Faw (1992). The integral over the beta spectrum is evaluated by fitting a piecewise cubic hermite interpolation polynomial to the integrand using the PCHIP routines of Fritsch and Carlson (1980).

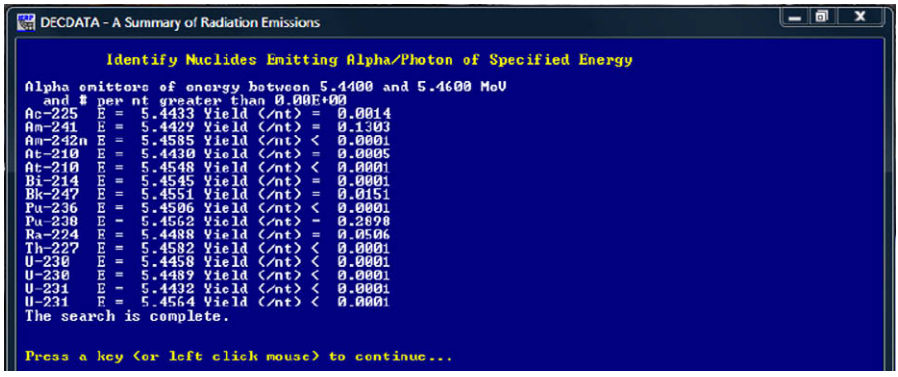
F5 key: Identify unknown radionuclide

This function key provides a means to associate an observed alpha particle or photon with a radionuclide in the ICRP-07 collection. For example, assume the emission

of an alpha particle of energy 5.45 MeV has been observed. Pressing the F5 key opens a screen within which the user first defines whether the observed radiation is an alpha particle or a photon and then enters the observed energy. In addition to the point-value for the energy, a tolerance (or delta) in energy value and a lower bound on its yield (range from zero to 1.0) is requested as shown below.



A search of the RAD file is performed, as guided by information in the NDX file. The results appear on the screen and are written to the file SCRATCH.TXT in the OUTPUT folder. In this case the screen display is



The search can lead to a substantial number of candidates, particularly for photons, and thus the file SCRATCH.TXT will need to be reviewed. The information on the yield of the radiations within the indicated energy range may be of help in eliminating some candidates. DECDATA will attempt to open the file using the application that has been associated with files with extension TXT, e.g., Microsoft Notepad or an ASCII editor.

F6 key: View files in the REPORT folder

The REPORT folder contains this User Guide, reports produced by the authors (Endo *et al.* 2005, Endo, 2005, Endo and Eckerman 2007) during the course of the work creating the decay database, the original EDISTR report of Dillman (1980), and two files created via the F4 key as discussed above. The user can develop and maintain notes on the operation of DECDATA by creating in the REPORT folder a file with an extension registered by the operating system, e.g., using Microsoft NotePad. The file MyNotes.TXT is provided as a template.

F7 key: About

Provides the usual *About* screen associated with current software. The software license, agree to during the installation of DECDATA, can be viewed at this time by pressing the F8 key.

5. Programmer's Notes

The ICRP-07 data files are formatted direct-access files. Each record in these files is of fixed length and includes a carriage return and line feed so that the files are readable when opened with an ASCII editor. The length of the records, less the carriage return and line feed, for each of the ICRP-07 files is listed below.

Length of Records in the Direct-Access Files

File	Record Length*	Number of records
ICRP-07.NDX	226	1,253
ICRP-07.RAD	29	455,625
ICRP-07.BET	17	111,325
ICRP-07.ACK	32	131,571
ICRP-07.NSF	29	1,484

* Value does not include the carriage return and line feed.

The number of data records N in the RAD file for a given nuclide is given in the header record for that nuclide in the file but it can also be computed from the nuclide's record in the NDX file as

$$N = \begin{cases} \sum_{1}^{5} \text{Number} - \text{i} + \text{Number} - 5, & SF \notin \text{DecayMode} \\ \sum_{1}^{5} \text{Number} - \text{i} + \text{Number} - 5 + 2, & SF \in \text{DecayMode} \end{cases}$$

where Number-i refers to the fields of the nuclide record so designated in Table 1. Whether a nuclide decays by spontaneous fission can be determined by parsing its decay mode for the characters "SF" or by noting if the pointer into the NSF file (Pointer-4 of Table 1) is nonzero. The number of alpha transitions, Number-5, enters into the above equation twice since records are included in the RAD file for the kinetic energy of the recoiling nuclei formed in alpha decay as well as the alpha particles themselves. The two additional records for those nuclides undergoing spontaneous fission are those of the mean energies of the fission fragments and neutrons accompanying spontaneous fission.

Records in the RAD file for a particular radiation type emitted by a specific radionuclide can be read as tabulated below. In the table below the fields Pointer-i and Number-i defined in Table 1 of the nuclide's record in the NDX file are denoted by P_i and N_i, respectively. The data records for the radiation type in the RAD file lie between the lower and upper record numbers specified in the last two columns below.

Radiation Type	Record Number of Radiations in RAD File		
	Number	Location of Data Records for Radiation Type	
	Records	From	To
Photons, E < 10 keV	N_1	$P_1 + 1$	$P_1 + N_1$
Photons, E ⩾ 10 keV	N_2	$P_1 + N_1 + 1$	$P_1 + N_1 + N_2$
Photons, all	$N_1 + N_2$	$P_1 + 1$	$P_1 + N_1 + N_2$
Beta particles	N_3	$P_1 + N_1 + N_2 + 1$	$P_1 + N_1 + N_2 + N_3$
Monoenegetic electrons	N_4	$P_1 + N_1 + N_2 + N_3 + 1$	$P_1 + N_1 + N_2 + N_3 + N_4$
Alpha particles	N_5	$P_1 + N_1 + N_2 + N_3 + N_4 + 1$	$P_1 + N_1 + N_2 + N_3 + N_4 + N_5$
Alpha recoil	N_5	$P_1 + N_1 + N_2 + N_3 + N_4 + N_5 + 1$	$P_1 + N_1 + N_2 + N_3 + N_4 + 2N_5$
Fission fragments[a]	*1*	$P_1 + N_1 + N_2 + N_3 + N_4 + 2N_5 + 1$	$P_1 + N_1 + N_2 + N_3 + N_4 + 2N_5 + 1$
Neutrons[a]	*1*	$P_1 + N_1 + N_2 + N_3 + N_4 + 2N_5 + 1$	$P_1 + N_1 + N_2 + N_3 + N_4 + 2N_5 + 2$

[a] Records present only if nuclide undergo spontaneous fission, i.e., $P_4 > 0$.

The dimensions of the ICRP-07 collection can be tabulated by selecting the penultimate item on the menu displayed via the F4 key. The listing created gives the maximum number of radiations of the various types in the RAD file and the number of discrete energy points in the continuous beta and neutron spectra. For example, the maximum number of records in the RAD file for radiations emitted by a single radionuclide is 4121 in the case of Lu-170. The resultant list is shown below.

```
Dimensions of the ICRP-07 Collection
Radionuclides                -        1252
Radiation records            -        4121 (Lu-170)
Beta transitions             -        79 (Gd-145)
Alpha transitions            -        52 (Pu-239)
Photons: E < 10 keV          -        83 (Sm-141m)
Photons: E > 10 keV          -        664 (Lu-170)
  Total                      -        699 (Lu-170)
Discrete electrons           -        3409 (Lu-170)

Energy Range: Discrete Radiations
  Betas*                     -        6.2E-04 to 4.9806 MeV (Re-187, N-16)
  Photons                    -        3.1E-07 to 9.9100 MeV (Na-24, Cf-246)
  Electrons                  -        8.8E-06 to 8.8693 MeV (In-114m, N-16)
  Alphas                     -        1.85224 to 11.6512 MeV (Nd-144, Po-212m)
  Alpha recoils              -        0.05148 to 0.2242 MeV (Pb-202, Po-212m)
  Fission fragments$         -        84.84610 to 97.7707 MeV (U-238, Fm-252)
  Fission neutrons$          -        1.68813 to 2.3823 MeV (U-238, Cm-240)
----------                   -

*Average energy of beta transitions
$Average energy in spontaneous fission

Spectral Dimensions
  Beta spectrum              -        138 (N-16)
  Auger-CK spectrum          -        3015 (Hg-195m)
  Neutron spectrum           -        52 (Cf-246)
```

Energy Range: Spectra		
Beta	-	0.00 to 10.4207 MeV (N-16)
Neutron (bins)	-	0.41 eV to 15.0000 MeV (U-238, Cm-240)
Auger-CK electrons	-	0.15 eV to 88.1763 keV (Tb-157, Bi-204)
Decay Chains		
Chain length	-	30 (Es-254m)
Elements Number	-	97
Radioisotopes	-	29 (Indium)

Data File		Record length	# records
ICRP-07.NDX	-	226	1253
ICRP-07.RAD	-	29	455625
ICRP-07.BET	-	17	111325
ICRP-07.ACK	-	32	131571
ICRP-07.NSF	-	29	1484

The DECDATA source code is included in the folder SOURCE of the ARCHIVE folder on the CD. The functions and subroutines of the code can be readily translated to other programming languages.

SUPPLEMENTARY DATA

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.icrp.2008.10.001.

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