

HANDBOOK OF NUCLEAR DATA FOR SAFEGUARDS

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Abstract

A set of recommended nuclear data have been assembled that are judged to be suitable for application with respect to nuclear materials accounting techniques. These revised data supersede the tabulations to be found within IAEA report INDC(NDS)-376, December 1997. The update is based on available evaluated nuclear databases and recently published files, books and technical reports. Every effort has been made to ensure that the recommended data are credible and correct with respect to their original sources. Section A contains decay data, thermal neutron capture cross section data, resonance integrals and neutron emission yields per fission for relevant actinides and their natural decay products; Section B includes decay and thermal neutron capture cross section data for some important fission products; Section C presents fission product yield data for selected actinides. The recommended data sets can be inspected as tables in this INDC(NDS) report, or through the adoption and use of appropriate software. Users are referred to "Interactive Chart of Nuclides" for an introduction to software that can be downloaded from the Web to undertake rapid inspections of the assembled database. The Web site is located at <http://www-nds.iaea.org/sgnucdat/>

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1 Introduction

The aim of the present handbook is to provide evaluated and carefully selected nuclear data suitable for application with respect to nuclear materials accounting techniques. These revised data supersede the tabulations to be found within IAEA report INDC(NDS)-376, December 1997. The update is based on available evaluated nuclear databases and recently published files, books and technical reports.

Adopted definitions, symbols and notations are listed in Section 2, below. The selection rules for recommended data from the various sources are given in Section 3, while Section 4 specifies the contents of the tables. The nuclear data for safeguards are given in three sections:

Section A contains decay data, thermal neutron cross-section data, resonance integrals and neutron emission yields per fission for relevant actinides and their natural decay products;

Section B includes decay and thermal neutron cross-section data for some important fission products;

Section C presents fission product yield data for some selected actinides.

Additional remarks are given as footnotes to the corresponding tables.

Notable additions in this release were the inclusion of decay data for a number of natural decay chain products of U-238, U-235 and Th-232. Furthermore, a re-evaluation of the Th-234 gamma-ray emission probabilities was performed and Pa-234m gamma-ray data were also included.

2 Definitions, Symbols and Notations

2.1 Definitions

Nuclide: atoms characterized by atomic number Z and mass number A .

Radionuclide: radioactive nuclide.

Disintegration: spontaneous transformation of the nucleus into another nucleus that gives rise to a change in the atomic number, into two or more nuclei (fission), or a transition to a lower energy state of the same nucleus.

Emission probability: particles or quanta emitted per disintegration.

Half-life ($T_{1/2}$): time required for the initial number of atomic nuclei to decrease by a factor of two via radioactive disintegration.

Independent fission yields: number of atoms of a specific nuclide produced directly by a fission event (not via radioactive decay of the precursors).

Cumulative fission yields: total number of atoms of a specific nuclide produced directly by a fission event and via decay of precursors.

Chain fission yields: sum of the cumulative yields of the last (stable or long-lived) chain members - obtained by means of mass spectrometric measurements of long-lived or stable products of mass chains.

Mass number yields: sum of all independent yields of a particular mass chain.

2.2 Units adopted

s: second
m: minute
h: hour
d: day
y: year (1 y = 365.24219878 d = 31 556 926 s)
J: joule
eV: electronvolt (1 eV = $1.602177 \cdot 10^{-19}$ J)
barn: 10^{-24} cm²

2.3 Symbols and notations

2.3.1 Decay data

$T_{1/2}$: half-life
BF: branching fraction
 α : alpha particle
 β^- : electron from β^- decay
 β^+ : positron from β^+ decay
e: electron
 γ : gamma quantum
X: X-ray quantum
 X_k : K X-ray quantum
n: neutron
SF: spontaneous fission
EC: electron capture
IT: isomeric transition
E: energy
 P_α : α -particle emission probability
 P_γ : γ -ray emission probability
 P_x : X-ray emission probability

2.3.2 Cross-section and delayed-neutron data

σ_0 : neutron cross section at 2200 m/s
 σ : neutron cross section in a Maxwellian spectrum
 σ_r : neutron cross section measured with reactor neutrons
 σ_c : neutron cross section calculated from resonance parameters or derived from equivalent data of the natural element
 $\sigma_{(m)}$: neutron cross section leading to a metastable state of the product
 $\sigma_{(g)}$: neutron cross section leading to the ground state of the product
g Westcott factor: ratio of the Maxwellian averaged cross section σ to 2200 m/s cross section σ_0 ($g = \sigma/\sigma_0$); if the cross section varies as a function of $1/v$, $g = 1.0$
RI: infinite dilution resonance integral (including $1/v$ contribution)
 γ : subscript for radiative capture cross section
f: subscript for fission cross section
 ν_t : total neutron yield per fission
 ν_d : delayed-neutron yield per fission
 $T_{1/2i}$: half-life of delayed-neutron group i
 λ_i : mean life of delayed-neutron group i

- α_i : ratio of the average number of delayed neutrons per fission emitted in group i to the average number of all delayed neutrons per fission ($\alpha_i = \nu_{di} / \nu_d$)
- β_i : ratio of the average number of delayed neutrons per fission emitted in group i to the average number of all neutrons per fission ($\beta_i = \nu_{di} / \nu_t = \alpha_i \cdot \nu_d / \nu_t$)

3 General rules for selection of data

The following criteria were applied in the course of selecting the data:

Preference was given to evaluated data recommended by international working groups and projects, reported in recent publications, or available on the web.

If the first criterion was not applicable, data were adopted from available evaluated nuclear data libraries: ENSDF for decay data and ENDF/B-VII or JEFF-3.1 for reaction data.

If uncertainties were not available in the evaluated nuclear data source, these parameters were adopted from the original documentation related to the selected source, or they were estimated from the experimental data available in the EXFOR library, or published in recent relevant papers or reports.

4 Contents of the tables

The data are presented in three sections:

Section A: Decay data, thermal neutron cross-section data, resonance integrals, average fission neutron yields and delayed-neutron eight-group parameters for actinides and natural decay products.

Section B: Decay data, thermal neutron cross-section data and resonance integrals for fission products.

Section C: Fission product yield data for the most important actinides.

4.1 Section A – Actinides and natural decay products

Table A-1: Half-lives and branching fractions for actinides and natural decay products

Table A-2: Alpha energies and emission probabilities for actinides and natural decay products

Table A-3: Gamma-ray energies and emission probabilities for actinides and natural decay products

Table A-4: X-ray energies and intensities for actinides and natural decay products

Table A-5: Actinide data: Thermal neutron cross sections, resonance integrals and Westcott factors

Table A-6: Average number of neutrons emitted per fission

Table A-7: Delayed-neutron eight-group parameters

A brief description of the data presented in each table is given below. Additional remarks are included as footnotes to the tables.

