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# HANDBOOK OF NUCLEAR DATA FOR SAFEGUARDS

Prepared by

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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/

January 2007

# CONTENTS

# 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: $10^{-24}$ $cm^2$

## 2.3 Symbols and notations

### 2.3.1 Decay data

$T_{1/2}$: half-life
BF: branching fraction
α: alpha particle
$\beta^-$: electron from $\beta^-$ decay
$\beta^+$: positron from $\beta^+$ 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
$P_\alpha$: α-particle emission probability
$P_\gamma$: γ-ray emission probability
$P_x$: X-ray emission probability

### 2.3.2 Cross-section and delayed-neutron data

$\sigma_0$: neutron cross section at 2200 m/s
σ: neutron cross section in a Maxwellian spectrum
$\sigma_r$: neutron cross section measured with reactor neutrons
$\sigma_c$: 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 $\sigma_0$ ($g = \sigma/\sigma_o$); 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
$\nu_t$: total neutron yield per fission
$\nu_d$: delayed-neutron yield per fission
$T_{1/2i}$: half-life of delayed-neutron group i
$\lambda_i$: mean life of delayed-neutron group i

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

$\beta_i$: 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.

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

Content of Table A-1:

1. Nuclide
2. Half-life with 1σ uncertainty, ($T_{1/2} \pm \Delta T_{1/2}$)
3. Units (s, m, h, d, y)
4. Decay mode (α, $\beta^+$, $\beta^-$, EC, IT, SF)
5. Branching fraction with 1σ uncertainty, (BF ± ΔBF)
6. Source of data

Data sources are listed below in order of preference:

BIPM-5: M.-M. Bé, V. Chisté, C. Dulieu, E. Browne, V. Chechev N. Kuzmenko, R. Helmer, A. Nichols, E. Schönfeld, R. Dersch, Monographie BIPM-5, Table of Radionuclides, Vol. 2 - A = 151 to 242, 2004.

LNHB: Laboratoire National Henri Becquerel, Decay Data Evaluation Project, http://www.nucleide.org/DDEP_WG/DDEPdata.htm, 3 October 2006.

IAEA-CRP-XG: M.-M. Bé, V.P. Chechev, R. Dersch, O.A.M. Helene, R.G. Helmer, M. Herman, S. Hlaváč, A. Marcinkowski, G.L. Molnár, A.L. Nichols, E. Schönfeld, V.R. Vanin, M.J. Woods, IAEA CRP "Update of X-ray and Gamma-ray Decay Data Standards for Detector Calibration and Other Applications", IAEA Nuclear Data Section, 2004.

ENSDF: Evaluated Nuclear Structure Data File, http://www-nds.iaea.org/ensdf/, 15 November 2006.

If the data in BIPM-5 and LNHB were the same for a given evaluation, BIPM-5 was quoted as the data source. Data from BIPM-5 and LNHB were adopted in preference to ENSDF data.

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

Content of Table A-2:

1. Nuclide
2. Half-life with 1σ uncertainty, ($T_{1/2} \pm \Delta T_{1/2}$)
3. Half-life units (s, m, h, d, y)
4. α-particle energy with 1σ uncertainty, ($E_\alpha \pm \Delta E_\alpha$ in keV)
5. Emission probability $P_\alpha$ per 100 decays with 1σ uncertainty, ($P_\alpha \pm \Delta P_\alpha$ in % decay)
6. Source of data
7. Notes

Data sources are listed below in order of preference:

BIPM-5: M.-M. Bé, V. Chisté, C. Dulieu, E. Browne, V. Chechev, N. Kuzmenko, R. Helmer, A. Nichols, E. Schönfeld, R. Dersch, Monographie BIPM-5, Table of Radionuclides, Vol. 2 - A = 151 to 242, 2004.

LNHB: Laboratoire National Henri Becquerel, Decay Data Evaluation Project, http://www.nucleide.org/DDEP_WG/DDEPdata.htm, 3 October 2006.

ENSDF: Evaluated Nuclear Structure Data File,
http://www-nds.iaea.org/ensdf/, 15 November 2006.

Same comments about preference are applicable as stated for Table A-1. Alpha particles with energies below 40 keV were normally omitted, as they are judged to be unsuitable for non-destructive assay.

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

Content of Table A-3:

1. Nuclide
2. Half-life with 1σ uncertainty, ($T_{1/2} \pm \Delta T_{1/2}$)
3. Half-life units (s, m, h, d, y).
4. γ-ray energy with 1σ uncertainty, ($E_\gamma \pm \Delta E_\gamma$ in keV)
5. Emission probability $P_\gamma$ per 100 decays with 1σ uncertainty, ($P_\gamma \pm \Delta P_\gamma$ in % decay)
6. Source of data
7. Notes

Data sources are listed below in order of preference:

ADS-98: I. Adsley, J.S. Backhouse, A.L. Nichols, J. Toole, U-238 Decay Chain: Resolution of Observed Anomalies in the Measured Secular Equilibrium Between Th-234 and Daughter Pa-234m, *Appl. Radiat. Isot.* **49** (1998) 1337.

BIPM-5: M.-M. Bé, V. Chisté, C. Dulieu, E. Browne, V. Chechev, N. Kuzmenko, R. Helmer, A. Nichols, E. Schönfeld, R. Dersch, Monographie BIPM-5, Table of Radionuclides, Vol. 2 - A = 151 to 242, 2004.

LNHB: Laboratoire National Henri Becquerel, Decay Data Evaluation Project,
http://www.nucleide.org/DDEP_WG/DDEPdata.htm, 3 October 2006.

IAEA-CRP-XG: M.-M. Bé, V.P. Chechev, R. Dersch, O.A.M. Helene, R.G. Helmer, M. Herman, S. Hlaváč, A. Marcinkowski, G.L. Molnár, A.L. Nichols, E. Schönfeld, V.R. Vanin, M.J. Woods, IAEA CRP "Update of X-ray and Gamma-ray Decay Data Standards for Detector Calibration and Other Applications", IAEA Nuclear Data Section, 2004.

ENSDF: Evaluated Nuclear Structure Data File,
http://www-nds.iaea.org/ensdf/, 15 November 2006.

Same comments about preference are applicable as stated for Table A-1. Gamma rays with energies below 40 keV were normally omitted, as they are judged to be unsuitable for non-destructve assay.

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

Content of Table A-4:

1. Nuclide
2. Half-life with 1σ uncertainty, ($T_{1/2} \pm \Delta T_{1/2}$)
3. Half-life units (s, m, h, d, y)
4. Decay mode (α, $\beta^+$, $\beta^-$, EC)

5. Origin of K X-rays - element of origin is specified, and the X-rays are defined on the basis of the Siegbahn notation. K X-rays associated with the following shell transitions are listed in the table:

| | | |
|---|---|---|
| $K\alpha_2$ | | K-L2 |
| $K\alpha_1$ | | K-L3 |
| $K'\beta_1$ | $K\beta_3$ | K-M2 |
| | $K\beta_1$ | K-M3 |
| | $K\beta_5$ | K-M5M4 |
| $K'\beta_2$ | $K\beta_2$ | K-N3N2 |
| | $K\beta_4$ | K-N5N4 |
| | KO | K-O23 |
| | KP | K-P23 |

6. X-ray energy ($E_x$) or energy group in keV
7. Emission probability $P_x$ per 100 decays with 1σ uncertainty, ($P_x \pm \Delta P_x$ in % decay)
8. Source of data

Data sources are listed below in order of preference:

PTB: E. Schönfeld, G. Rodloff, Energies and relative emission probabilities of K X-rays for elements with atomic number in the range from Z = 5 to Z = 100, Report PTB-6.11-1999-1, 1999.

BIPM-5: M.-M. Bé, V. Chisté, C. Dulieu, E. Browne, V. Chechev, N. Kuzmenko, R. Helmer, A. Nichols, E. Schönfeld, R. Dersch, Monographie BIPM-5, Table of Radionuclides, Vol. 2 - A = 151 to 242, 2004.

LNHB: Laboratoire National Henri Becquerel, Decay Data Evaluation Project, http://www.nucleide.org/DDEP_WG/DDEPdata.htm, 3 October 2006.

IAEA-CRP-XG: M.-M. Bé, V.P. Chechev, R. Dersch, O.A.M. Helene, R.G. Helmer, M. Herman, S. Hlaváč, A. Marcinkowski, G.L. Molnár, A.L. Nichols, E. Schönfeld, V.R. Vanin, M.J. Woods, IAEA CRP "Update of X-ray and Gamma-ray Decay Data Standards for Detector Calibration and Other Applications", IAEA Nuclear Data Section, 2004.

ENSDF: Evaluated Nuclear Structure Data File, http://www-nds.iaea.org/ensdf/, 15 November 2006.

K X-ray energies were always adopted from PTB. If the data in BIPM-5 and LNHB were the same for a given evaluation, BIPM-5 was quoted as the data source. Data from BIPM-5 and LNHB were adopted in preference to ENSDF data.

When ENSDF was selected as the source of data, only the emission probability for the $K\alpha_1$ transition was adopted from this evaluated nuclear database. The emission probabilities for $K\alpha_2$, $K'\beta_1$ and $K'\beta_2$ were calculated using the relatives emission probabilities listed in PTB.

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

Content of Table A-5:

1. Nuclide
2. Type of thermal cross section ($\sigma_0$, $\sigma$, $\sigma_r$, $\sigma_c$, $\sigma_{(m)}$, $\sigma_{(g)}$)
3. Thermal cross section with 1$\sigma$ uncertainty in barns, ($\sigma \pm \Delta\sigma$)
4. Westcott factor, ($g \pm \Delta g$)
5. Resonance integral with 1$\sigma$ uncertainty in barns, ($RI \pm \Delta RI$)
6. Source of data

Data sources are listed below:

TRK-05: A. Trkov, G.L. Molnár, Zs. Révay, S.F. Mughabghab, R.B. Firestone, V.G. Pronyaev, A.L. Nichols, M.C. Moxon, Revisiting the $^{238}$U Thermal Capture Cross Section and Gamma-ray Emission Probabilities from $^{239}$Np Decay, *Nucl. Sci. Eng.* **150** (2005) 336.

ANR: S.F. Mughabghab, Atlas of Neutron Resonances, Resonance Parameters and Thermal Cross Sections, Z = 1 - 100, 5th Edition, Elsevier, Amsterdam, 2006.

ENDF/B-VII: US Evaluated Nuclear Data Library ENDF/B-VII β3, Incident neutron data, http://www.nndc.bnl.gov/exfor4/endf00.htm, 2 October 2006; see also M.B. Chadwick *et al*., ENDF/B-VII.0: Next Generation Evaluated Nuclear Data Library for Nuclear Science and Technology, *Nucl. Data Sheets*, **107** (2006) 2931.

JEFF-3.1: Joint Evaluated Fission and Fusion File, Incident neutron data, http://www-nds.iaea.org/exfor/endf00.htm, 2 October 2006; see also A. Koning, R. Forrest, M. Kellett, R. Mills, H. Henriksson, Y. Rugama, The JEFF-3.1 Nuclear Data Library, JEFF Report 21, OECD/NEA, Paris, France, 2006, ISBN 92-64-02314-3.

Cross sections, Westcott factors and resonance integrals were adopted from ANR, whereas the U-238 thermal neutron capture cross section was taken from TRK-05. When ANR data were incomplete or judged to be inadequate, the ENDF/B-VII and the JEFF-3.1 evaluated nuclear data libraries were used as data sources. Additional remarks are included as footnotes to the table.

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

Content of Table A-6:

1. Nuclide (fissionable isotope)
2. Type of incident neutron spectrum (fast, thermal, spontaneous fission)
3. Total neutron yield per fission ($\nu_t$) and associated 1$\sigma$ uncertainty, ($\nu_t \pm \Delta\nu_t$)
4. Source of data for $\nu_t$
5. Total delayed-neutron yield per fission ($\nu_d$) and associated 1$\sigma$ uncertainty, ($\nu_d \pm \Delta\nu_d$)
6. Source of data for $\nu_d$

Data sources are listed below:

IAEA-CRP-STD: S.A. Badikov, A.D. Carlson, E.V. Gai, G.M. Hale, H.M. Hofmann, T. Kawano, N.M. Larson, Sy. Oh, V.G. Pronyaev, S. Tagesen, H.K. Vonach,

C. Zhenpeng, IAEA-CRP "Improvement of the standard cross sections for light elements", IAEA Nuclear Data Section, November 2004, http://www-nds.iaea.org/standards/lastresults.html.

NEA/WPEC-6: G. Rudstam, Ph. Finck, A. Filip, A. D'Angelo, R.D. McKnight, Delayed Neutron Data for the Major Actinides, NEA/WPEC-6, Volume 6, NEA/OECD, Paris, France, 2002.

JEFF-3.1: Joint Evaluated Fission and Fusion File, Incident neutron and radioactive decay data files, http://www.nea.fr/html/dbdata/JEFF/, 26 February 2006; see also A. Koning, R. Forrest, M. Kellett, R. Mills, H. Henriksson, Y. Rugama, The JEFF-3.1 Nuclear Data Library, JEFF Report 21, OECD/NEA, Paris, France, 2006, ISBN 92-64-02314-3.

ENDF/B-VII: US Evaluated Nuclear Data Library ENDF/B-VII β3, Incident neutron data, http://www.nndc.bnl.gov/exfor4/endf00.htm, 2 October 2006; see also M.B. Chadwick *et al.*, ENDF/B-VII.0: Next Generation Evaluated Nuclear Data Library for Nuclear Science and Technology, *Nucl. Data Sheets*, **107** (2006) 2931.

P&I(1998): V.M. Piksaikin, S.G. Isaev, Correlation properties of delayed neutrons from fast neutron induced fission, pp. 1-13 in INDC(CCP)-415, October 1998, IAEA, Vienna, Austria.

Mills(1995): R.W. Mills, Fission product yield evaluation, PhD thesis, University of Birmingham, UK, March 1995.

Tuttle(1979): R.J. Tuttle, Delayed-neutron yields in nuclear fission, pp. 29-67 in Proc. Consultants' Meeting on Delayed Neutron Properties, 26-30 March 1979, INDC(NDS)-107 (1979) 29, IAEA, Vienna, Austria.

EXFOR: Experimental Nuclear Reaction Data,
http://www-nds.iaea.org/exfor/exfor00.htm,
27 March 2006.

Total fission neutron yields reported in IAEA-CRP-STD were preferred. Otherwise, JEFF-3.1 data were recommended, with the exceptions of Th-232 and U-238 for which ENDF/B-VII data were chosen.

Delayed-neutron yields were usually adopted from the JEFF-3.1 library; exceptions were U-238 and the delayed-neutron yields from spontaneous fission. ENDF/B-VII data were selected for U-238, and values reported by Mills or Tuttle were adopted in the case of spontaneous fission.

Data adopted from the JEFF-3.1 or ENDF/B-VII evaluated nuclear data libraries were processed using the NJOY-99 code. A thermal or a fast reactor spectrum was used to average the corresponding thermal or fast neutron yield (GROUPR input option IWT= – 4 and – 8, respectively). If available, covariance file MF=31 was also processed to estimate uncertainties.

When the chosen data source did not include uncertainties, they were estimated from the experimental data to be found in the EXFOR library or reported by P&I (1998). The uncertainty was calculated on the basis of the following expression:

$$\sigma_\nu = [(\nu - \nu_{exp})^2 + \sigma_{\nu,exp}{}^2]^{½} \quad ,$$

where $\sigma_\nu$ is the standard deviation of $\nu$ (total or delayed-neutron yield),
$\nu$ is the recommended value of $\nu$ given in Table A-6,

$\nu_{exp}$ is the weighted average value of $\nu$ calculated from the selected experimental data - weights were the inverse of the squares of the individual measured uncertainties, and
$\sigma_{\nu,exp}$ is the standard deviation of $\nu_{exp}$.

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

Content of Table A-7:

1. Nuclide
2. Type of incident neutron spectrum (fast, thermal, spontaneous fission)
3. Delayed-neutron group
4. Half-life in seconds ($T_{1/2i}$)
5. Decay constant in $s^{-1}$ ($\lambda_i$)
6. Fraction $\alpha_i = \nu_{di}/\nu_d$ and associated $1\sigma$ uncertainty
7. Delayed neutron ratio $\beta_i = \nu_{di}/\nu_t$ [%] and associated $1\sigma$ uncertainty in percent
8. Notes

Sources of data:

NEA/WPEC-6: G. Rudstam, Ph. Finck, A. Filip, A. D'Angelo, R.D. McKnight, Delayed Neutron Data for the Major Actinides, NEA/WPEC-6, Volume 6, NEA/OECD, Paris, France, 2002.

JEFF-3.1: Joint Evaluated Fission and Fusion File, Incident neutron and radioactive decay data files, http://www.nea.fr/html/dbdata/JEFF/, 26 February 2006;
see also A. Koning, R. Forrest, M. Kellett, R. Mills, H. Henriksson, Y. Rugama, The JEFF-3.1 Nuclear Data Library, JEFF Report 21, OECD/NEA, Paris, France, 2006, ISBN 92-64-02314-3.

Recommended data were adopted from the JEFF-3.1 library and documentation. The eight-group delayed-neutron structure is discussed in NEA/WPEC-6.

4.2 Section B – Fission products

Table B-1: Half-lives and branching fractions for fission products

Table B-2: Gamma-ray energies and emission probabilities for fission products

Table B-3: Fission product data: Thermal neutron cross sections, resonance integrals and Westcott factors

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

4.2.1 Table B-1: Half-lives and branching fractions for fission products

Content of Table B-1:

1. Nuclide
2. Half-life with $1\sigma$ uncertainty, ($T_{1/2} \pm \Delta T_{1/2}$)
3. Units (s, m, h, d, y)

4. Decay mode ($\beta^-$, EC, IT)
5. Branching fraction with 1σ uncertainty, (BF ± ΔBF)
6. Source of data

Data sources are listed below in order of preference:

BIPM-5: M.-M. Bé, V. Chisté, C. Dulieu, E. Browne, V. Chechev, N. Kuzmenko, R. Helmer, A. Nichols, E. Schönfeld, R. Dersch, Monographie BIPM-5, Table of Radionuclides, Vol. 2 - A = 151 to 242, 2004.

LNHB: Laboratoire National Henri Becquerel, Decay Data Evaluation Project, http://www.nucleide.org/DDEP_WG/DDEPdata.htm, 3 October 2006.

IAEA-CRP-XG: M.-M. Bé, V.P. Chechev, R. Dersch, O.A.M. Helene, R.G. Helmer, M. Herman, S. Hlaváč, A. Marcinkowski, G.L. Molnár, A.L. Nichols, E. Schönfeld, V.R. Vanin, M.J. Woods, IAEA CRP "Update of X-ray and Gamma-ray Decay Data Standards for Detector Calibration and Other Applications", IAEA Nuclear Data Section, 2004.

ENSDF: Evaluated Nuclear Structure Data File, http://www-nds.iaea.org/ensdf/, 15 November 2006.

If the data in BIPM-5 and LNHB were the same for a given evaluation, BIPM-5 was quoted as the data source. Data from BIPM-5 and LNHB were adopted in preference to ENSDF data.

4.2.2 Table B-2: Gamma-ray energies and emission probabilities for fission products

Content of Table B-2:

1. Nuclide
2. Half-life with 1σ uncertainty, ($T_{1/2} \pm \Delta T_{1/2}$)
3. Half-life units (s, m, h, d, y)
4. γ-ray energy with 1σ uncertainty, ($E_\gamma \pm \Delta E_\gamma$ in keV)
5. Emission probability $P_\gamma$ per 100 decays with 1σ uncertainty, ($P_\gamma \pm \Delta P_\gamma$ in % decay)
6. Source of data
7. Notes

Data sources are listed below in order of preference:

BIPM-5: M.-M. Bé, V. Chisté, C. Dulieu, E. Browne, V. Chechev, N. Kuzmenko, R. Helmer, A. Nichols, E. Schönfeld, R. Dersch, Monographie BIPM-5, Table of Radionuclides, Vol. 2 - A = 151 to 242, 2004.

LNHB: Laboratoire National Henri Becquerel, Decay Data Evaluation Project, http://www.nucleide.org/DDEP_WG/DDEPdata.htm, 3 October 2006.

IAEA-CRP-XG: M.-M. Bé, V.P. Chechev, R. Dersch, O.A.M. Helene, R.G. Helmer, M. Herman, S. Hlaváč, A. Marcinkowski, G.L. Molnár, A.L. Nichols, E. Schönfeld, V.R. Vanin, M.J. Woods, IAEA CRP "Update of X-ray and Gamma-ray Decay Data Standards for Detector Calibration and Other Applications", IAEA Nuclear Data Section, 2004.

ENSDF: Evaluated Nuclear Structure Data File, http://www-nds.iaea.org/ensdf/, 15 November 2006.

Same comments about preference are applicable as noted for Table B-1. Gamma rays with energies below 40 keV were normally omitted, as they are judged to be unsuitable for non-destructive assay.

4.2.3 Table B-3: Fission product data: Thermal neutron cross sections, resonance integrals and Westcott factors

Content of Table B-3:

1. Nuclide
2. Type of thermal cross section ($\sigma_0$, $\sigma$, $\sigma_r$, $\sigma_c$, $\sigma_{(m)}$, $\sigma_{(g)}$)
3. Thermal cross section with 1$\sigma$ uncertainty in barns, ($\sigma \pm \Delta\sigma$)
4. Westcott factor, ($g \pm \Delta g$)
5. Resonance integral with 1$\sigma$ uncertainty in barns, ($RI \pm \Delta RI$)
6. Source of data

Data sources are listed below:

ANR: S.F. Mughabghab, Atlas of Neutron Resonances, Resonance Parameters and Thermal Cross Sections, Z = 1 - 100, 5th Edition, Elsevier, Amsterdam, 2006.

ENDF/B-VII: US Evaluated Nuclear Data Library ENDF/B-VII β3, Incident neutron data, http://www.nndc.bnl.gov/exfor4/endf00.htm, 2 October 2006; see also M.B. Chadwick *et al*., ENDF/B-VII.0: Next Generation Evaluated Nuclear Data Library for Nuclear Science and Technology, *Nucl. Data Sheets*, **107** (2006) 2931.

JENDL-3.3: Japanese Evaluated Nuclear Data Library, Incident neutron data, http://www-nds.iaea.org/exfor/endf00.htm, 2 October 2006.

HAR-91: H. Harada *et al*., Proceedings of 1990 Symposium on Nuclear Data, Japan Atomic Energy Research Institute Report JAERI-M 91-032 (1991) 199.

GRY-87: G. Gryntakis *et al*., Handbook on Nuclear Activation Data, IAEA Technical Reports Series No. 273 (1987) 199.

SEK-87: T. Sekine *et al*., Triple Neutron Capture of $^{153}$Eu in a Reactor: the Cross Sections of $^{154}$Eu and $^{155}$Eu, *Appl. Radiat. Isot*. **38** (1987) 513.

Cross sections, Westcott factors and resonance integrals were adopted from ANR. When ANR data were incomplete or judged to be inadequate, the ENDF/B-VII evaluated nuclear data library was used as the data source. Furthermore, specific resonance integrals and cross sections were compared with equivalent data in the JENDL-3.3 library or other well known publications – any notable observations are included as footnotes to the table.

4.3 Section C – Fission yields

Table C-1.1: Th-232 chain fission yields

Table C-1.2: U-233 chain fission yields

Table C-1.3: U-235 chain fission yields

Table C-1.4: U-238 chain fission yields

Table C-1.5: Pu-239 chain fission yields

Table C-1.6: Pu-241 chain fission yields

Table C-2.1: Th-232 fast fission yields for selected fission products

Table C-2.2: U-233 thermal fission yields for selected fission products

Table C-2.3: U-235 thermal fission yields for selected fission products

Table C-2.4: U-238 fast fission yields for selected fission products

Table C-2.5: Pu-239 thermal fission yields for selected fission products

Table C-2.6: Pu-241 thermal fission yields for selected fission products

Tables C-1.1 to C-1.6 list the chain yields and associated 1σ uncertainties for all mass chains at different energies. A maximum of three neutron energies are given: thermal, fast and 14 MeV. The units are percent per fission; only chain fission yields greater than $10^{-6}$% per fission are shown.

Tables C-2.1 to C-2.6 contain the independent and cumulative fission yields for 51 selected fission products. Fission yields are given for the thermal neutron fission of U-233, U-235, Pu-239 and Pu-241 and for the fast neutron fission of Th-232 and U-238. The units are percent per fission; independent fission yields below $10^{-9}$% were not included.

Data source for all tables in Section C:

JEFF-3.1: Joint Evaluated Fission and Fusion File, Neutron-induced fission yield library, http://www-nds.iaea.org/exfor/endf00.htm, 2 October 2006;
see also A. Koning, R. Forrest, M. Kellett, R. Mills, H. Henriksson, Y. Rugama, The JEFF-3.1 Nuclear Data Library, JEFF Report 21, OECD/NEA, Paris, France, 2006, ISBN 92-64-02314-3.

The contents of the tables are described below.

4.3.1 Table C-1.1: Th-232 chain fission yields

1. FPA: mass number of the chain.
2. Fast fission yields and uncertainties as % per fission.
3. 14-MeV fission yields and uncertainties as % per fission.

4.3.2 Table C-1.2: U-233 chain fission yields

1. FPA: mass number of the chain.
2. Thermal fission yields and uncertainties as % per fission.
3. Fast fission yields and uncertainties as % per fission.
4. 14-MeV fission yields and uncertainties as % per fission.

4.3.3 Table C-1.3: U-235 chain fission yields

1. FPA: mass number of the chain.
2. Thermal fission yields and uncertainties as % per fission.
3. Fast fission yields and uncertainties as % per fission.
4. 14-MeV fission yields and uncertainties as % per fission.

4.3.4 Table C-1.4: U-238 chain fission yields

1. FPA: mass number of the chain.
2. Fast fission yields and uncertainties as % per fission.
3. 14-MeV fission yields and uncertainties as % per fission.

4.3.5 Table C-1.5: Pu-239 chain fission yields

1. FPA: mass number of the chain.
2. Thermal fission yields and uncertainties as % per fission.
3. Fast fission yields and uncertainties as % per fission.

4.3.6 Table C-1.6: Pu-241 chain fission yields

1. FPA: mass number of the chain.
2. Thermal fission yields and uncertainties as % per fission.
3. Fast fission yields and uncertainties as % per fission.

4.3.7 Table C-2.1: Th-232 fast fission yields for selected fission products

1. Fission product.
2. Independent fast fission product yields and uncertainties as % per fission.
3. Cumulative fast fission product yields and uncertainties as % per fission.

4.3.8 Table C-2.2: U-233 thermal fission yields for selected fission products

1. Fission product.
2. Independent thermal fission product yields and uncertainties as % per fission.
3. Cumulative thermal fission product yields and uncertainties as % per fission.

4.3.9 Table C-2.3: U-235 thermal fission yields for selected fission products

1. Fission product.
2. Independent thermal fission product yields and uncertainties as % per fission.
3. Cumulative thermal fission product yields and uncertainties as % per fission.

4.3.10 Table C-2.4: U-238 fast fission yields for selected fission products

1. Fission product.
2. Independent fast fission product yields and uncertainties as % per fission.
3. Cumulative fast fission product yields and uncertainties as % per fission.

4.3.11 Table C-2.5: Pu-239 thermal fission yields for selected fission products

1. Fission product.
2. Independent thermal fission product yields and uncertainties as % per fission.
3. Cumulative thermal fission product yields and uncertainties as % per fission.

4.3.12 Table C-2.6: Pu-241 thermal fission yields for selected fission products

1. Fission product.
2. Independent thermal fission product yields and uncertainties as % per fission.
3. Cumulative thermal fission product yields and uncertainties as % per fission.

# 5 Concluding Remarks

The most respected nuclear databases have been assessed in detail during the course of an extensive exercise that took place in 2006 to review and improve the contents of a recommended set of data files maintained by the International Atomic Energy Agency and entitled “Nuclear Data for Safeguards”. An earlier version of these data files was used to specify the parameters to be included in the new tabulations, along with additional guidance

on their contents from analytical specialists associated with the non-destructive assay of nuclear materials.

The recommended data sets can be inspected in tabulated form, or through the adoption and use of appropriate software. Users are referred to the next section (Interactive Chart of Nuclides) for an introduction to software that can be downloaded from the Web and used to undertake rapid inspections of the assembled database. An appropriate Web site has been established for access to the recommended database, and is located at http://www-nds.iaea.org/sgnucdat/

Every effort has been made to ensure that the recommended data are credible and correct with respect to their original sources. Despite these best endeavours, absolute correctness can not be fully guaranteed – any errors detected by data users should be communicated to the International Atomic Energy Agency, Nuclear Data Section, to ensure their elimination and correction (e-mail: online@iaeand.iaea.org).

# INTERACTIVE CHART OF NUCLIDES

The interactive chart of nuclides represents a complementary means of browsing the information contained in the database of Nuclear Data for Safeguards. The following notes can be used as an aid in using this application.

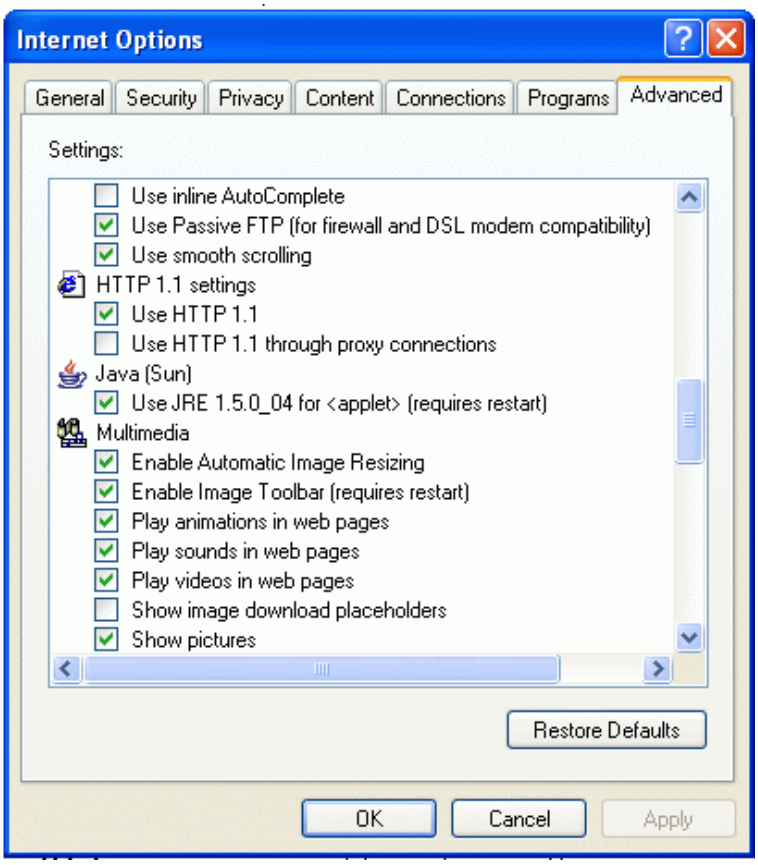
## BROWSER SETTINGS

Check that the correct Internet browser settings have been enabled:

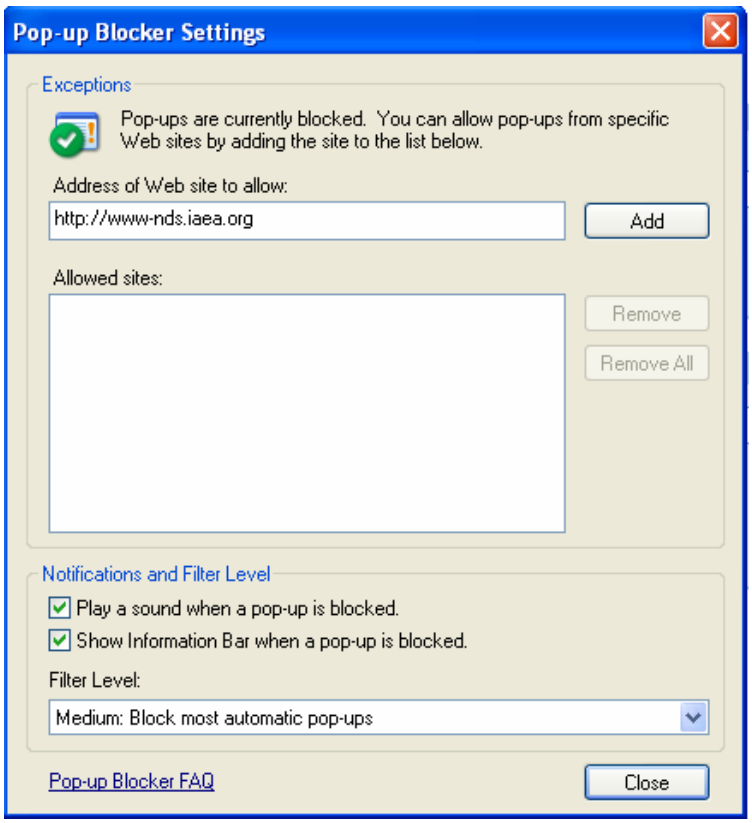
**Internet Explorer:**

1) go to menu

**Tools → Internet Options**. **Java (Sun)** checkbox should be defined as shown in the picture.



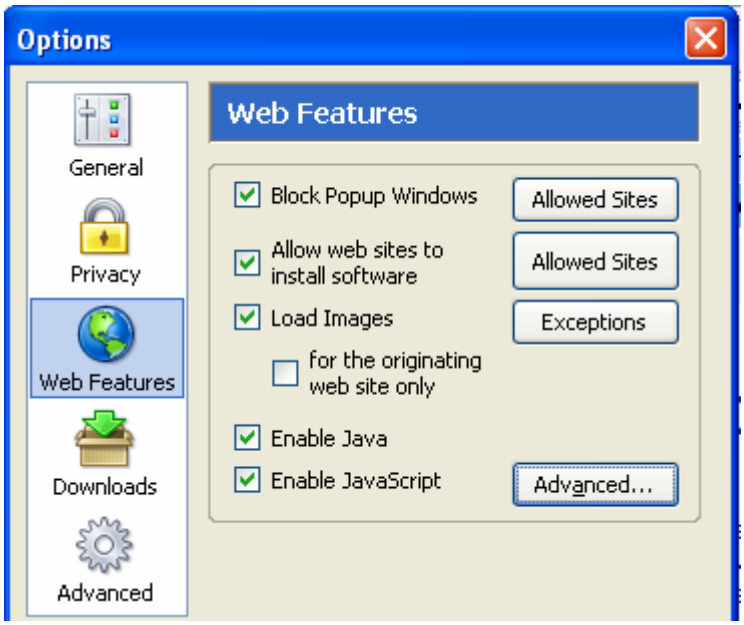
2) go to menu **Tools → Pop-up Blocker → Pop-up Blocker Settings** and then type in http://www-nds.iaea.org, before clicking the **add** button




**Firefox:**

go to menu **Tools → Options → Web Features**. **Enable Java**, and then **Block Popup Windows** checkboxes should be checked as shown in the picture.

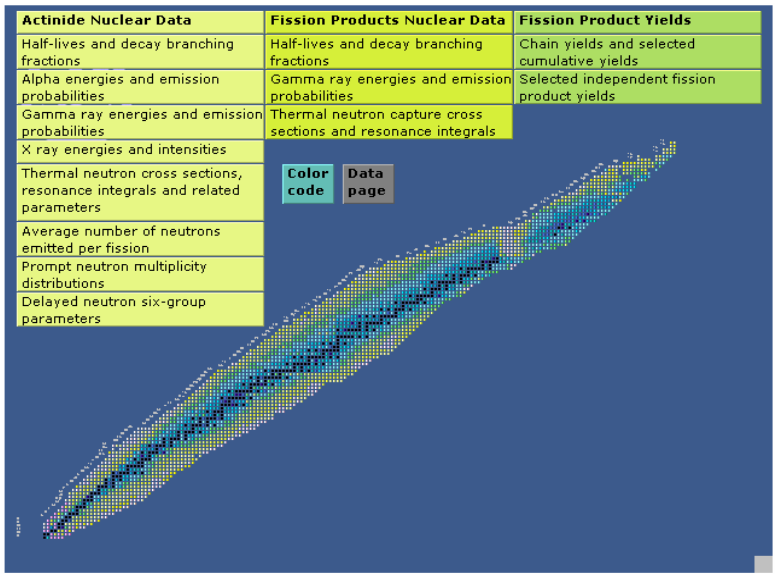
Click on the first **Allowed Sites** button and type http://www-nds.iaea.org in the text field.



## ACTIVATION

The loading panel will initially show the loading progression:

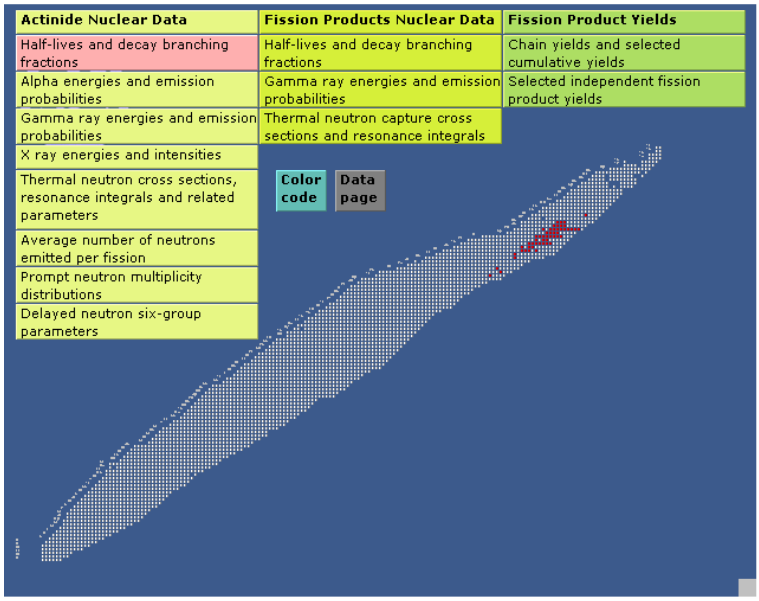

When the software is ready and the full image is shown, click on the blue area to activate the software.




## USE

If the image is bigger than the screen dimension, either the image resolution can be maintained using the browser scroll bar to move the image, or the image dimensions can be changed by dragging the lower-right grey corner to the desired dimension.

When the mouse is rolled on a menu-label, the relevant nuclides are shown in red.

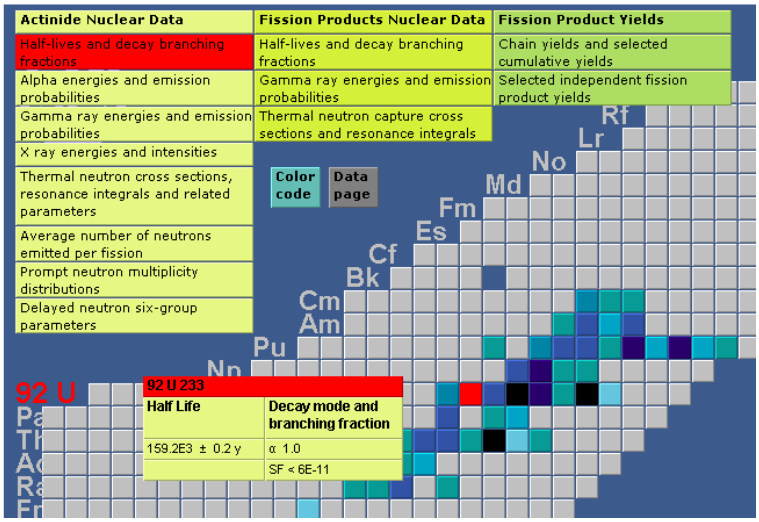


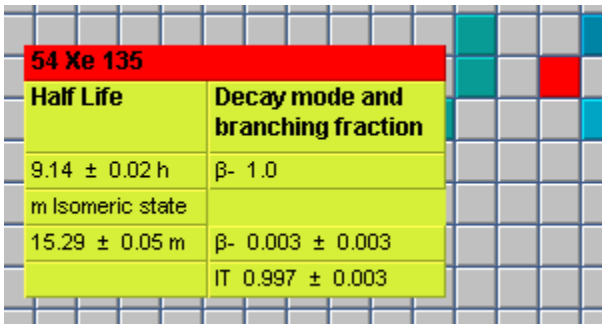
When a menu-label is clicked, the map zooms into the area of interest, and the data can be browsed by rolling the mouse over a nuclide.

Clicking on a nuclide will maintain selection and fix the data panel. Click a second time on the red-selected nuclide to restore the mouse-moving mode.

When a nuclide is selected the **Data page** button is activated; clicking on this button will open a new frame to reveal html-formatted data that can be saved.

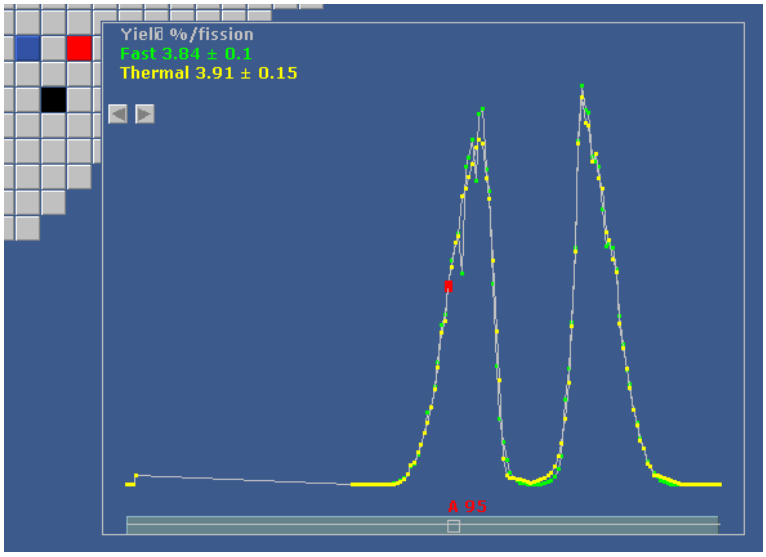
When a nuclide has isomeric states, the data panel shows the isomers.



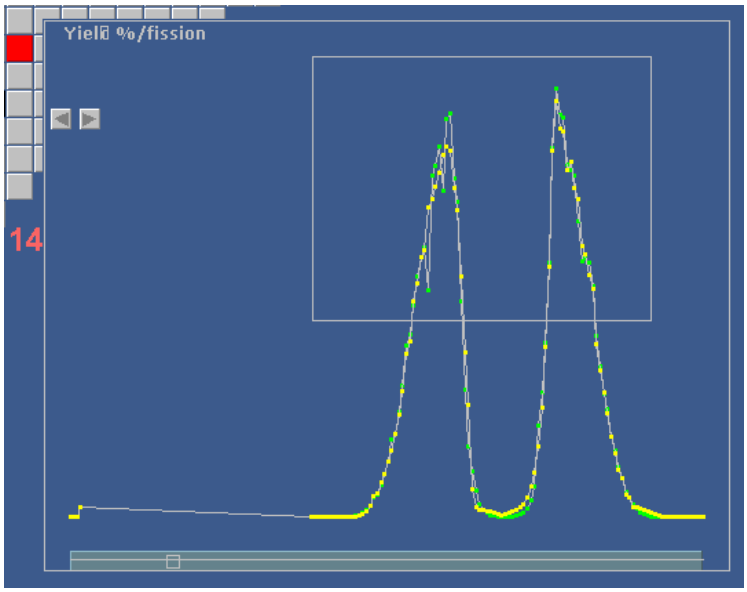

The **fission product yields** data are shown graphically.

Values can be browsed by means of the following methods:
- move the mouse on the bottom slide bar,
- click on a point,
- use the buttons above the graph panel.



Click with the mouse and drag a rectangle to produce a detailed view of a particular area.

When the mouse is released, the selected area expands by means of the zoom function. Just click the nuclide chart on the selected nuclide to restore to the original size.



# DATA TABLES

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

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

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

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

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

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

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

B-1: Half-lives and branching fractions for fission products.

B-2: Gamma-ray energies and emission probabilities for fission products.

B-3: Fission product data: Thermal neutron cross sections, resonance integrals and Westcott factors.

C-1: Chain fission yields for selected actinides.

C-2: Selected independent and cumulative fission product yields.

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

References


LNHB: Laboratoire National Henri Becquerel, Recommended Data, http://www.nucleide.org/DDEP_WG/DDEPdata.htm, 3 October 2006.

BIPM-5: M.-M. Bé, V. Chisté, C. Dulieu, E. Browne, V. Chechev, N. Kuzmenko, R. Helmer, A. Nichols, E. Schönfeld, R. Dersch, Monographie BIPM-5, Table of Radionuclides, Vol. 2 - A = 151 to 242, 2004.

ENSDF: Evaluated Nuclear Structure Data File, http://www-nds.iaea.org/ensdf/, 15 November 2006.

IAEA-CRP-XG: M.-M. Bé, V.P. Chechev, R. Dersch, O.A.M. Helene, R.G. Helmer, M. Herman, S. Hlaváč, A. Marcinkowski, G.L. Molnár, A.L. Nichols, E. Schönfeld, V.R. Vanin, M.J. Woods, IAEA CRP "Update of X-ray and Gamma-ray Decay Data Standards for Detector Calibration and Other Applications", IAEA Nuclear Data Section, 2004.


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

| Nuclide | Half-life $T_{1/2}$ | Units | Decay mode | Branching Fraction | Source |
|---|---|---|---|---|---|
| 81-Tl-206 | 4.202 ± 0.011 | m | β- | 1.0 | LNHB |
| 81-Tl-208 | 3.060 ± 0.008 | m | β- | 1.0 | BIPM-5 |
| 82-Pb-210 | 22.20 ± 0.22 | y | β-<br>α | 1.0<br>(1.9 ± 0.4) × $10^{-8}$ | ENSDF |
| 82-Pb-211 | 36.1 ± 0.2 | m | β- | 1.0 | ENSDF |
| 82-Pb-212 | 10.64 ± 0.01 | h | β- | 1.0 | BIPM-5 |
| 82-Pb-214 | 26.8 ± 0.9 | m | β- | 1.0 | ENSDF |
| 83-Bi-211 | 2.14 ± 0.02 | m | α<br>β- | 0.99724 ± 0.00004<br>0.00276 ± 0.00004 | ENSDF |
| 83-Bi-212 | 60.54 ± 0.06 | m | α<br>β- | 0.3593 ± 0.0007<br>0.6407 ± 0.0007 | BIPM-5 |
| 83-Bi-214 | 19.9 ± 0.4 | m | β-<br>α | 0.99979 ± 0.00001<br>0.00021 ± 0.00001 | ENSDF |
| 84-Po-210 | 138.376 ± 0.002 | d | α | 1.0 | ENSDF |
| 86-Rn-219 | 3.96 ± 0.01 | s | α | 1.0 | ENSDF |
| 86-Rn-220 | 55.8 ± 0.3 | s | α | 1.0 | BIPM-5 |
| 87-Fr-221 | 4.9 ± 0.2 | m | α<br>β- | 0.99995 ± 0.00003<br>0.00005 ± 0.00003 | ENSDF |

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

| Nuclide | Half-life $T_{1/2}$ | Units | Decay mode | Branching Fraction | Source |
|---|---|---|---|---|---|
| 88-Ra-223 | 11.43 ± 0.05 | d | α | 1.0 | ENSDF |
| | | | $^{14}C$ | (8.9 ± 0.4) × $10^{-10}$ | |
| 88-Ra-224 | 3.627 ± 0.007 | d | α | 1.0 | BIPM-5 |
| 88-Ra-225 | 14.9 ± 0.2 | d | β- | 1.0 | ENSDF |
| 88-Ra-226 | ( 1.600 ± 0.007 ) × $10^3$ | y | α | 1.0 | BIPM-5 |
| 88-Ra-228 | 5.75 ± 0.03 | y | β- | 1.0 | ENSDF |
| 89-Ac-224 | 2.78 ± 0.17 | h | EC | 0.909 $^{+0.014}_{-0.020}$ | ENSDF |
| | | | α | 0.091 $^{+0.020}_{-0.014}$ | |
| 89-Ac-225 | 10.0 ± 0.1 | d | α | 1.0 | ENSDF |
| 89-Ac-227 | 21.772 ± 0.003 | y | α | 0.01380 ± 0.00004 | ENSDF |
| | | | β- | 0.98620 ± 0.00004 | |
| 89-Ac-228 | 6.15 ± 0.02 | h | β- | 1.0 | ENSDF |
| 90-Th-227 | 18.718 ± 0.005 | d | α | 1.0 | BIPM-5 |
| 90-Th-228 | 698.60 ± 0.23 | d | α | 1.0 | BIPM-5 |
| 90-Th-229 | ( 7.34 ± 0.16 ) × $10^3$ | y | α | 1.0 | ENSDF |
| 90-Th-230 | ( 7.538 ± 0.030 ) × $10^4$ | y | α | 1.0 | ENSDF |
| | | | SF | ≤ 4. × $10^{-13}$ | |
| 90-Th-231 | 25.52 ± 0.01 | h | β- | 1.0 | ENSDF |
| | | | α | ~ 4. × $10^{-13}$ | |
| 90-Th-232 | ( 1.405 ± 0.006 ) × $10^{10}$ | y | α | 1.0 | ENSDF |
| | | | SF | ( 1.1 ± 0.4 ) × $10^{-11}$ | |
| 90-Th-233 | 22.15 ± 0.15 | m | β- | 1.0 | LNHB |
| 90-Th-234 | 24.10 ± 0.03 | d | β- | 1.0 | ENSDF |
| 91-Pa-231 | ( 3.276 ± 0.011 ) × $10^4$ | y | α | 1.0 | ENSDF |
| | | | SF | ≤ 3. × $10^{-12}$ | |
| 91-Pa-232 | 1.32 ± 0.02 | d | β- | 0.99997 ± 0.00001 | ENSDF |
| | | | EC | 0.00003 ± 0.00001 | |
| 91-Pa-233 | 26.98 ± 0.02 | d | β- | 1.0 | LNHB |

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

| Nuclide | Half-life $T_{1/2}$ | Units | Decay mode | Branching Fraction | Source |
|---|---|---|---|---|---|
| 91-Pa-234 | 6.70 ± 0.05 | h | β- | 1.0 | ENSDF |
| 91-Pa-234m | 1.159 ± 0.016 | m | β- | 0.9984 ± 0.0002 | IAEA-CRP-XG |
| | | | IT | 0.0016 ± 0.0002 | |
| 92-U-232 | 68.9 ± 0.4 | y | α | 1.0 | ENSDF |
| | | | SF | $< 1. \times 10^{-14}$ | |
| 92-U-233 | $( 1.592 \pm 0.002 ) \times 10^{5}$ | y | α | 1.0 | ENSDF |
| | | | SF | $< 6. \times 10^{-11}$ | |
| 92-U-234 | $( 2.455 \pm 0.006 ) \times 10^{5}$ | y | α | 1.0 | LNHB |
| | | | SF | $( 1.6 \pm 0.2 ) \times 10^{-11}$ | |
| 92-U-235 | $( 7.038 \pm 0.005 ) \times 10^{8}$ | y | α | 1.0 | ENSDF |
| | | | SF | $( 7. \pm 2. ) \times 10^{-11}$ | |
| 92-U-235m | 26. ± 1. | m | IT | 1.0 | ENSDF |
| 92-U-236 | $( 2.342 \pm 0.004 ) \times 10^{7}$ | y | α | 1.0 | ENSDF |
| | | | SF | $( 9.4 \pm 0.4 ) \times 10^{-10}$ | |
| 92-U-237 | 6.749 ± 0.016 | d | β- | 1.0 | LNHB |
| 92-U-238 | $( 4.468 \pm 0.005 ) \times 10^{9}$ | y | α | 1.0 | LNHB |
| | | | SF | $( 5.45 \pm 0.04 ) \times 10^{-7}$ | |
| 92-U-239 | 23.45 ± 0.02 | m | β- | 1.0 | ENSDF |
| 93-Np-236 | $( 1.55 \pm 0.08 ) \times 10^{5}$ | y | β- | 0.120 ± 0.006 | LNHB |
| | | | α | 0.0016 ± 0.0006 | |
| | | | EC | 0.878 ± 0.006 | |
| 93-Np-236m | 22.5 ± 0.4 | h | β- | 0.47 ± 0.01 | LNHB |
| | | | EC | 0.53 ± 0.01 | |
| 93-Np-237 | $( 2.144 \pm 0.007 ) \times 10^{6}$ | y | α | 1.0 | ENSDF |
| | | | SF | $< 2. \times 10^{-12}$ | |
| 93-Np-238 | 2.117 ± 0.002 | d | β- | 1.0 | ENSDF |
| 93-Np-239 | 2.356 ± 0.003 | d | β- | 1.0 | ENSDF |
| 94-Pu-236 | 2.858 ± 0.008 | y | α | 1.0 | ENSDF |
| | | | SF | $( 1.9 \pm 0.4 ) \times 10^{-9}$ | |
| 94-Pu-238 | 87.74 ± 0.03 | y | α | 1.0 | BIPM-5 |
| | | | SF | $( 1.85 \pm 0.05 ) \times 10^{-9}$ | |

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

| Nuclide | Half-life $T_{1/2}$ | Units | Decay mode | Branching Fraction | Source |
|---|---|---|---|---|---|
| 94-Pu-239 | $(2.411 \pm 0.003) \times 10^{4}$ | y | α | 1.0 | ENSDF |
| | | | SF | $(3.1 \pm 0.6) \times 10^{-12}$ | |
| 94-Pu-240 | $(6.561 \pm 0.007) \times 10^{3}$ | y | α | 1.0 | BIPM-5 |
| | | | SF | $(5.7 \pm 0.2) \times 10^{-8}$ | |
| 94-Pu-241 | 14.290 ± 0.006 | y | α | 0.0000245 ± 0.0000002 | ENSDF |
| | | | β- | 0.9999755 ± 0.0000002 | |
| 94-Pu-242 | $(3.73 \pm 0.03) \times 10^{5}$ | y | α | 1.0 | BIPM-5 |
| | | | SF | $(5.49 \pm 0.09) \times 10^{-6}$ | |
| 94-Pu-243 | 4.956 ± 0.003 | h | β- | 1.0 | ENSDF |
| 94-Pu-244 | $(8.00 \pm 0.09) \times 10^{7}$ | y | α | 0.99879 ± 0.00004 | ENSDF |
| | | | SF | 0.00121 ± 0.00004 | |
| 94-Pu-245 | 10.5 ± 0.1 | h | β- | 1.0 | ENSDF |
| 94-Pu-246 | 10.84 ± 0.02 | d | β- | 1.0 | ENSDF |
| 95-Am-240 | 50.8 ± 0.3 | h | EC | 0.9999981 ± 0.0000007 | ENSDF |
| | | | α | 0.0000019 ± 0.0000007 | |
| 95-Am-241 | 432.6 ± 0.6 | y | α | 1.0 | BIPM-5 |
| | | | SF | $(4.3 \pm 1.8) \times 10^{-12}$ | |
| 95-Am-242 | 16.02 ± 0.02 | h | β- | 0.827 ± 0.003 | ENSDF |
| | | | EC | 0.173 ± 0.003 | |
| 95-Am-242m | 141. ± 2. | y | IT | 0.9955 ± 0.0002 | ENSDF |
| | | | α | 0.0045 ± 0.0002 | |
| | | | SF | $< 4.7 \times 10^{-11}$ | |
| 95-Am-243 | $(7.370 \pm 0.017) \times 10^{3}$ | y | α | 1.0 | LNHB |
| | | | SF | $(3.8 \pm 0.7) \times 10^{-11}$ | |
| 96-Cm-242 | 162.86 ± 0.08 | d | α | 1.0 | LNHB |
| | | | SF | $(6.36 \pm 0.14) \times 10^{-8}$ | |
| 96-Cm-243 | 29.1 ± 0.1 | y | α | 0.9971 ± 0.0003 | ENSDF |
| | | | EC | 0.0029 ± 0.0003 | |
| | | | SF | $(5.3 \pm 0.9) \times 10^{-11}$ | |
| 96-Cm-244 | 18.11 ± 0.03 | y | α | 1.0 | LNHB |
| | | | SF | $(1.36 \pm 0.01) \times 10^{-6}$ | |
| 98-Cf-252 | 2.645 ± 0.008 | y | α | 0.96908 ± 0.00008 | ENSDF |
| | | | SF | 0.03092 ± 0.00008 | |

1 y = 1 year = 365.24219878 days

A-2. Alpha-particle energies and emission probabilities for actinides and natural decay products.

References


ENSDF: Evaluated Nuclear Structure Data File, http://www-nds.iaea.org/ensdf/, 15 November 2006.

LNHB: Laboratoire National Henri Becquerel, Recommended Data, http://www.nucleide.org/DDEP_WG/DDEPdata.htm, 3 October 2006.

BIPM-5: M.-M. Bé, V. Chisté, C. Dulieu, E. Browne, V. Chechev, N. Kuzmenko, R. Helmer, A. Nichols, E. Schönfeld, R. Dersch, Monographie BIPM-5, Table of Radionuclides, Vol. 2 - A = 151 to 242, 2004.


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

| Nuclide | Half-life $T_{1/2}$ | Units | α particles Energy [keV] | | Emission probability $P_\alpha$ [% decay] | | Source | Notes |
|---|---|---|---|---|---|---|---|---|
| 83-Bi-211 | 2.14 ± 0.02 | m | 6278.2 | ± 0.7 | 16.19 | ± 0.14 | ENSDF | |
| | | | 6622.9 | ± 0.6 | 83.54 | ± 0.14 | | |
| 83-Bi-212 | 60.54 ± 0.06 | m | 5606.63 | ± 0.14 | 0.43 | ± 0.04 | LNHB | |
| | | | 5768.27 | ± 0.10 | 0.63 | ± 0.03 | | |
| | | | 6050.92 | ± 0.04 | 25.1 | ± 0.1 | | |
| | | | 6090.02 | ± 0.04 | 9.7 | ± 0.1 | | |
| 84-Po-210 | 138.376 ± 0.002 | d | 5304.33 | ± 0.07 | 100. | | ENSDF | |
| 86-Rn-219 | 3.96 ± 0.01 | s | 6425. | ± 1. | 7.5 | ± 0.6 | ENSDF | |
| | | | 6552.6 | ± 1.0 | 12.9 | ± 0.6 | | |
| | | | 6819.1 | ± 0.3 | 79.4 | ± 1.0 | | |
| 86-Rn-220 | 55.8 ± 0.3 | s | 5748.46 | ± 0.14 | 0.118 | ± 0.015 | LNHB | |
| | | | 6288.22 | ± 0.10 | 99.882 | ± 0.015 | | |
| 88-Ra-223 | 11.43 ± 0.05 | d | 5433.6 | ± 0.5 | 2.22 | ± 0.20 | ENSDF | |
| | | | 5539.8 | ± 0.9 | 9.0 | ± 0.2 | | |
| | | | 5606.73 | ± 0.30 | 25.2 | ± 0.5 | | |
| | | | 5716.23 | ± 0.29 | 51.6 | ± 1.3 | | |
| | | | 5747.0 | ± 0.4 | 9.0 | ± 0.2 | | |
| | | | 5871.3 | ± 1.0 | 1.0 | ± 0.2 | | |
| 88-Ra-224 | 3.627 ± 0.007 | d | 5448.81 | ± 0.16 | 5.26 | ± 0.07 | LNHB | |
| | | | 5685.50 | ± 0.15 | 94.72 | ± 0.07 | | |
| 88-Ra-226 | ( 1.600 ± 0.007 ) × $10^3$ | y | 4601. | ± 1. | 5.96 | ± 0.08 | LNHB | |
| | | | 4784.34 | ± 0.25 | 94.03 | ± 0.08 | | |
| 90-Th-227 | 18.718 ± 0.005 | d | 5668.0 | ± 1.5 | 2.06 | ± 0.12 | LNHB | |
| | | | 5693.0 | ± 1.6 | 1.5 | ± 0.1 | | |
| | | | 5700.8 | ± 1.6 | 3.63 | ± 0.20 | | |
| | | | 5708.8 | ± 1.6 | 8.3 | ± 0.3 | | |
| | | | 5713.2 | ± 1.6 | 4.89 | ± 0.20 | | |
| | | | 5756.87 | ± 0.15 | 20.4 | ± 0.9 | | |
| | | | 5807.5 | ± 1.5 | 1.27 | ± 0.02 | | |
| | | | 5866.6 | ± 1.5 | 2.42 | ± 0.10 | | |
| | | | 5959.7 | ± 1.5 | 3.00 | ± 0.15 | | |
| | | | 5977.72 | ± 0.10 | 23.5 | ± 0.9 | | |
| | | | 6008.8 | ± 1.5 | 2.90 | ± 0.15 | | |
| | | | 6038.01 | ± 0.15 | 24.2 | ± 0.9 | | |

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

| Nuclide | Half-life $T_{1/2}$ | Units | α particles Energy [keV] | Emission probability $P_\alpha$ [% decay] | Source | Notes |
|---|---|---|---|---|---|---|
| 90-Th-228 | 698.60 ± 0.23 | d | 5340.38 ± 0.22 | 26.2 ± 0.2 | BIPM-5 | |
| | | | 5423.28 ± 0.22 | 73.2 ± 0.2 | | |
| 90-Th-229 | ( 7.34 ± 0.16 ) × $10^3$ | y | 4797.8 ± 1.2 | 1.5 ± 0.2 | ENSDF | |
| | | | 4814.6 ± 1.2 | 9.30 ± 0.08 | | |
| | | | 4838. ± 2. | 5.0 ± 0.2 | | |
| | | | 4845.3 ± 1.2 | 56.2 ± 0.2 | | |
| | | | 4901.0 ± 1.2 | 10.20 ± 0.08 | | |
| | | | 4967.5 ± 1.2 | 5.97 ± 0.06 | | |
| | | | 4978.5 ± 1.2 | 3.17 ± 0.04 | | |
| | | | 5053. ± 2. | 6.6 ± 0.1 | | |
| 90-Th-230 | ( 7.538 ± 0.030 ) × $10^4$ | y | 4620.5 ± 1.5 | 23.4 ± 0.1 | ENSDF | |
| | | | 4687.0 ± 1.5 | 76.3 ± 0.3 | | |
| 90-Th-232 | ( 1.405 ± 0.006 ) × $10^{10}$ | y | 3947.2 ± 2.0 | 21.7 ± 1.3 | ENSDF | |
| | | | 4012.3 ± 1.4 | 78.2 ± 1.3 | | |
| 91-Pa-231 | ( 3.276 ± 0.011 ) × $10^4$ | y | 4681. ± 2. | 1.5 ± 0.6 | ENSDF | [1] |
| | | | 4736.0 ± 0.8 | 8.4 ± 1.2 | | |
| | | | 4853. ± 2. | 1.4 ± 0.4 | | |
| | | | 4934. ± 2. | 3.0 ± 0.3 | | |
| | | | 4951.3 ± 1.4 | 22.8 ± 5.8 | | |
| | | | 4986. ± 2. | 1.4 ± 0.4 | | |
| | | | 5013.8 ± 1.4 | 25.4 ± 14.1 | | |
| | | | 5028.4 ± 1.0 | 20.0 ± 4.2 | | |
| | | | 5058.6 ± 1.5 | 11.0 ± 2.0 | | |
| 92-U -232 | 68.9 ± 0.4 | y | 5263.36 ± 0.09 | 31.55 ± 0.23 | ENSDF | |
| | | | 5320.12 ± 0.14 | 68.15 ± 0.23 | | |
| 92-U -233 | ( 1.592 ± 0.002 ) × $10^5$ | y | 4729. ± 1. | 1.61 ± 0.17 | ENSDF | [2] |
| | | | 4783.5 ± 1.2 | 13.2 ± 0.2 | | |
| | | | 4824.2 ± 1.2 | 84.4 ± 0.5 | | |
| 92-U -234 | ( 2.455 ± 0.006 ) × $10^5$ | y | 4722.4 ± 0.7 | 28.42 ± 0.02 | LNHB | |
| | | | 4774.6 ± 0.7 | 71.37 ± 0.02 | | |
| 92-U -235 | ( 7.038 ± 0.005 ) × $10^8$ | y | 4150. ± 5. | 0.9 ± 0.2 | ENSDF | |
| | | | 4214.7 ± 1.9 | 5.7 ± 0.6 | | |
| | | | 4366.1 ± 2.0 | 17. ± 2. | | |
| | | | 4397.8 ± 1.3 | 55. ± 3. | | |
| | | | 4414. ± 4. | 2.1 ± 0.2 | | |
| | | | 4502. ± 2. | 1.7 ± 0.2 | | |
| | | | 4556. ± 2. | 4.2 ± 0.3 | | |
| | | | 4596.4 ± 1.3 | 5.0 ± 0.5 | | |
| 92-U -236 | ( 2.342 ± 0.004 ) × $10^7$ | y | 4445. ± 5. | 25.9 ± 4.0 | ENSDF | |
| | | | 4494. ± 3. | 73.8 ± 4.0 | | |
| 92-U -238 | ( 4.468 ± 0.005 ) × $10^9$ | y | 4151. ± 5. | 22.33 ± 0.50 | LNHB | |
| | | | 4198. ± 3. | 77.54 ± 0.50 | | |

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

| Nuclide | Half-life $T_{1/2}$ | Units | α particles Energy [keV] | | Emission probability $P_\alpha$ [% decay] | | Source | Notes |
|---|---|---|---|---|---|---|---|---|
| 93-Np-237 | ( 2.144 ± 0.007 ) × $10^6$ | y | 4640.0 | ± 1.0 | 6.43 | ± 0.03 | ENSDF | |
| | | | 4665.0 | ± 0.9 | 3.478 | ± 0.024 | | |
| | | | 4766.5 | ± 0.8 | 9.3 | ± 0.3 | | |
| | | | 4771.4 | ± 0.8 | 23.2 | ± 0.3 | | |
| | | | 4788.0 | ± 0.9 | 47.64 | ± 0.06 | | |
| | | | 4803.5 | ± 1.0 | 2.014 | ± 0.017 | | |
| | | | 4816.8 | ± 1.0 | 2.430 | ± 0.017 | | |
| 94-Pu-236 | 2.858 ± 0.008 | y | 5721.00 | ± 0.10 | 30.6 | ± 0.5 | ENSDF | |
| | | | 5767.66 | ± 0.08 | 69.3 | ± 0.5 | | |
| 94-Pu-238 | 87.74 ± 0.03 | y | 5456.26 | ± 0.20 | 28.25 | ± 0.06 | BIPM-5 | |
| | | | 5499.03 | ± 0.20 | 71.04 | ± 0.06 | | |
| 94-Pu-239 | ( 2.411 ± 0.003 ) × $10^4$ | y | 5105.5 | ± 0.8 | 11.94 | ± 0.07 | ENSDF | |
| | | | 5144.3 | ± 0.8 | 17.11 | ± 0.14 | | |
| | | | 5156.59 | ± 0.14 | 70.77 | ± 0.14 | | |
| 94-Pu-240 | ( 6.561 ± 0.007 ) × $10^3$ | y | 5123.64 | ± 0.15 | 27.16 | ± 0.11 | BIPM-5 | |
| | | | 5168.13 | ± 0.15 | 72.74 | ± 0.11 | | |
| 94-Pu-241 | 14.290 ± 0.006 | y | 4853.0 | ± 1.1 | 0.000299 | ± 0.000006 | ENSDF | [3] |
| | | | 4896.3 | ± 1.1 | 0.00204 | ± 0.00003 | | |
| 94-Pu-242 | ( 3.73 ± 0.03 ) × $10^5$ | y | 4858.1 | ± 0.9 | 23.49 | ± 0.18 | BIPM-5 | |
| | | | 4902.2 | ± 0.9 | 76.48 | ± 0.18 | | |
| 95-Am-241 | 432.6 ± 0.6 | y | 5388.26 | ± 0.13 | 1.66 | ± 0.03 | BIPM-5 | |
| | | | 5442.86 | ± 0.12 | 13.23 | ± 0.10 | | |
| | | | 5485.56 | ± 0.12 | 84.45 | ± 0.10 | | |
| 95-Am-242m | 141. ± 2. | y | 5143.0 | ± 1.3 | 0.0257 | ± 0.0012 | ENSDF | [4] |
| | | | 5207.06 | ± 0.25 | 0.409 | ± 0.012 | | |
| 95-Am-243 | ( 7.370 ± 0.017 ) × $10^3$ | y | 5181. | ± 1. | 1.383 | ± 0.007 | LNHB | |
| | | | 5233.3 | ± 1.0 | 11.46 | ± 0.05 | | |
| | | | 5275.3 | ± 1.0 | 86.74 | ± 0.05 | | |
| | | | 5321. | ± 1. | 0.192 | ± 0.003 | | |
| | | | 5349.4 | ± 2.3 | 0.240 | ± 0.003 | | |
| 96-Cm-242 | 162.86 ± 0.08 | d | 6069.37 | ± 0.09 | 25.94 | ± 0.07 | LNHB | |
| | | | 6112.72 | ± 0.08 | 74.06 | ± 0.07 | | |
| 96-Cm-243 | 29.1 ± 0.1 | y | 5686. | ± 3. | 1.6 | ± 0.2 | ENSDF | [5] |
| | | | 5742.1 | ± 0.9 | 11.5 | ± 0.5 | | |
| | | | 5785.2 | ± 0.9 | 73.0 | ± 2.3 | | |
| | | | 5991.8 | ± 1.5 | 5.7 | ± 0.2 | | |
| | | | 6010. | ± 3. | 1.1 | ± 0.1 | | |
| | | | 6058. | ± 1. | 4.7 | ± 0.3 | | |
| | | | 6066.2 | ± 1.7 | 1.5 | ± 0.2 | | |
| 96-Cm-244 | 18.11 ± 0.03 | y | 5762.65 | ± 0.05 | 23.3 | ± 0.4 | LNHB | |
| | | | 5804.77 | ± 0.05 | 76.7 | ± 0.4 | | |
| 98-Cf -252 | 2.645 ± 0.008 | y | 6075.64 | ± 0.11 | 15.2 | ± 0.3 | ENSDF | |
| | | | 6118.10 | ± 0.04 | 81.6 | ± 0.3 | | |

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

[1] No uncertainties available for the experimental emission probabilities reported in ENSDF, but the evaluators deduced the following emission data from the γ-ray transition balance:

| Energy [keV] | | | $P_\alpha^{cal}$ [% decay] | | |
|---|---|---|---|---|---|
| 4681. | ± | 2. | 2.06 | ± | 0.18 |
| 4736.0 | ± | 0.8 | 9.3 | ± | 0.7 |
| 4853. | ± | 2. | 1.5 | ± | 0.3 |
| 4934. | ± | 2. | 3.0 | ± | 0.3 |
| 4951.3 | ± | 1.4 | 27. | ± | 4. |
| 4986. | ± | 2. | 1.2 | ± | 0.3 |
| 5013.8 | ± | 1.4 | 27. | ± | 14. |
| 5028.4 | ± | 1.0 | 19. | ± | 4. |
| 5058.6 | ± | 1.5 | ~ 9. | | |

the adopted 1σ uncertainties were estimated from $\Delta P_\alpha^{\,2} = ( P_\alpha - P_\alpha^{cal} )^2 + (\Delta P_\alpha^{cal})^2$.

[2] No uncertainties reported for the 4729-keV alpha-particle emission in ENSDF; an uncertainty of 1 keV was adopted for the energy, and approximately 10% relative uncertainty was recommended for the corresponding emission probability.

[3] Only low intensity emissions.

[4] Low intensity emissions included.

[5] No uncertainties reported for the 5686- and 6010-keV alpha-particle emissions; a value of 3 keV was adopted from R.B. Firestone and V.S. Shirley (editor), Table of Isotopes, 8 th ed., Volume II: A = 151 - 272, John Wiley & Sons, New York, 1996; approximately 10% relative uncertainty is recommended for the corresponding emission probabilities.

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

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

| Nuclide | Half-life $T_{1/2}$ | Units | $\gamma$ rays Energy [keV] | Emission probability [% decay] | Source | Notes |
|---|---|---|---|---|---|---|
| 81-Tl-208 | 3.060 ± 0.008 | m | 277.37 ± 0.03 | 6.6 ± 0.3 | BIPM-5 | [1] |
| | | | 583.187 ± 0.002 | 85.0 ± 0.3 | | |
| | | | 860.56 ± 0.03 | 12.5 ± 0.1 | | |
| | | | 2614.511 ± 0.010 | 99.79 ± 0.01 | | |
| 82-Pb-210 | 22.20 ± 0.22 | y | 46.539 ± 0.001 | 4.25 ± 0.04 | ENSDF | |
| 82-Pb-211 | 36.1 ± 0.2 | m | 404.853 ± 0.010 | 3.78 ± 0.06 | ENSDF | |
| | | | 427.088 ± 0.010 | 1.76 ± 0.04 | | |
| | | | 704.64 ± 0.03 | 0.46 ± 0.01 | | |
| | | | 766.51 ± 0.03 | 0.62 ± 0.02 | | |
| | | | 832.01 ± 0.03 | 3.52 ± 0.06 | | |
| 82-Pb-212 | 10.64 ± 0.01 | h | 115.183 ± 0.005 | 0.623 ± 0.022 | BIPM-5 | |
| | | | 238.632 ± 0.002 | 43.6 ± 0.3 | | |
| | | | 300.09 ± 0.01 | 3.18 ± 0.13 | | |
| 82-Pb-214 | 26.8 ± 0.9 | m | 53.2275 ± 0.0021 | 1.066 ± 0.014 | IAEA-CRP-XG | |
| | | | 241.997 ± 0.003 | 7.19 ± 0.06 | | |
| | | | 295.224 ± 0.002 | 18.28 ± 0.14 | | |
| | | | 351.932 ± 0.002 | 35.34 ± 0.27 | | |
| 83-Bi-211 | 2.14 ± 0.02 | m | 351.06 ± 0.04 | 12.91 ± 0.11 | ENSDF | |
| 83-Bi-212 | 60.54 ± 0.06 | m | 727.33 ± 0.01 | 6.74 ± 0.12 | BIPM-5 | |
| | | | 785.37 ± 0.09 | 1.11 ± 0.01 | | |
| | | | 1078.63 ± 0.11 | 0.55 ± 0.02 | | |
| | | | 1620.74 ± 0.01 | 1.51 ± 0.03 | | |

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

| Nuclide | Half-life $T_{1/2}$ | Units | γ rays Energy [keV] | Emission probability [% decay] | Source | Notes |
|---|---|---|---|---|---|---|
| 83-Bi-214 | 19.9 ± 0.4 | m | 609.316 ± 0.003 | 45.16 ± 0.33 | IAEA-CRP-XG | |
| | | | 665.453 ± 0.022 | 1.521 ± 0.011 | | |
| | | | 768.367 ± 0.011 | 4.850 ± 0.038 | | |
| | | | 806.185 ± 0.011 | 1.255 ± 0.011 | | |
| | | | 934.061 ± 0.012 | 3.074 ± 0.025 | | |
| | | | 1120.287 ± 0.010 | 14.78 ± 0.11 | | |
| | | | 1155.19 ± 0.02 | 1.624 ± 0.014 | | |
| | | | 1238.110 ± 0.012 | 5.785 ± 0.045 | | |
| | | | 1280.96 ± 0.02 | 1.425 ± 0.012 | | |
| | | | 1377.669 ± 0.012 | 3.954 ± 0.033 | | |
| | | | 1401.516 ± 0.014 | 1.324 ± 0.011 | | |
| | | | 1407.993 ± 0.007 | 2.369 ± 0.019 | | |
| | | | 1509.217 ± 0.008 | 2.108 ± 0.021 | | |
| | | | 1661.316 ± 0.013 | 1.037 ± 0.010 | | |
| | | | 1729.640 ± 0.012 | 2.817 ± 0.023 | | |
| | | | 1764.539 ± 0.015 | 15.17 ± 0.12 | | |
| | | | 1847.420 ± 0.025 | 2.000 ± 0.018 | | |
| | | | 2118.536 ± 0.008 | 1.148 ± 0.011 | | |
| | | | 2204.071 ± 0.021 | 4.89 ± 0.10 | | |
| | | | 2447.673 ± 0.010 | 1.536 ± 0.015 | | |
| 86-Rn-219 | 3.96 ± 0.01 | s | 271.23 ± 0.01 | 10.8 ± 0.6 | ENSDF | |
| | | | 401.81 ± 0.01 | 6.6 ± 0.4 | | |
| 86-Rn-220 | 55.8 ± 0.3 | s | 549.76 ± 0.04 | 0.115 ± 0.015 | BIPM-5 | |
| 88-Ra-223 | 11.43 ± 0.05 | d | 122.319 ± 0.010 | 1.21 ± 0.02 | ENSDF | |
| | | | 144.235 ± 0.010 | 3.27 ± 0.08 | | |
| | | | 154.208 ± 0.010 | 5.70 ± 0.16 | | |
| | | | 269.463 ± 0.010 | 13.9 ± 0.3 | | |
| | | | 323.871 ± 0.010 | 3.99 ± 0.09 | | |
| | | | 338.282 ± 0.010 | 2.84 ± 0.07 | | |
| | | | 445.033 ± 0.012 | 1.29 ± 0.05 | | |
| 88-Ra-224 | 3.627 ± 0.007 | d | 240.986 ± 0.006 | 4.12 ± 0.04 | BIPM-5 | |
| 88-Ra-226 | ( 1.600 ± 0.007 ) × $10^3$ | y | 186.211 ± 0.013 | 3.533 ± 0.028 | IAEA-CRP-XG | |
| 90-Th-227 | 18.718 ± 0.005 | d | 50.13 ± 0.01 | 8.2 ± 0.5* | LNHB | [2] |
| | | | 79.69 ± 0.02 | 1.90 ± 0.11 | | |
| | | | 93.88 ± 0.05 | 1.48 ± 0.08 | | |
| | | | 210.62 ± 0.05 | 1.22 ± 0.11 | | |
| | | | 235.96 ± 0.02 | 12.6 ± 0.6 | | |
| | | | 256.23 ± 0.02 | 6.8 ± 0.4 | | |
| | | | 286.09 ± 0.02 | 1.70 ± 0.17* | | |
| | | | 289.59 ± 0.10 | 1.9 ± 0.4* | | |
| | | | 299.98 ± 0.03 | 2.16 ± 0.12* | | |
| | | | 304.50 ± 0.02 | 1.12 ± 0.14 | | |
| | | | 329.85 ± 0.02 | 2.9 ± 0.2 | | |
| | | | 334.37 ± 0.02 | 1.11 ± 0.09 | | |
| 90-Th-228 | 698.60 ± 0.23 | d | 84.373 ± 0.003 | 1.17 ± 0.05 | BIPM-5 | |
| | | | 131.612 ± 0.004 | 0.124 ± 0.006 | | |
| | | | 166.410 ± 0.004 | 0.094 ± 0.007 | | |
| | | | 215.985 ± 0.004 | 0.226 ± 0.020 | | |
| 90-Th-229 | ( 7.34 ± 0.16 ) × $10^3$ | y | 107.108 ± 0.008 | 0.81 ± 0.05 | ENSDF | |
| | | | 136.99 ± 0.04 | 1.18 ± 0.04 | | |
| | | | 148.15 ± 0.04 | 0.88 ± 0.07 | | |
| | | | 156.409 ± 0.009 | 1.19 ± 0.04 | | |
| | | | 193.509 ± 0.004 | 4.41 ± 0.07 | | |
| | | | 210.853 ± 0.003 | 2.8 ± 0.4 | | |

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

| Nuclide | Half-life $T_{1/2}$ | Units | γ rays Energy [keV] | Emission probability [% decay] | Source | Notes |
|---|---|---|---|---|---|---|
| 90-Th-230 | ( 7.538 ± 0.030 ) × $10^4$ | y | 67.672 ± 0.002 | 0.38 ± 0.04 | ENSDF | |
| | | | 143.872 ± 0.004 | 0.049 ± 0.004 | | |
| | | | 253.729 ± 0.010 | 0.0111 ± 0.0009 | | |
| 90-Th-231 | 25.52 ± 0.01 | h | 58.5700 ± 0.0024 | 0.46 ± 0.03 | ENSDF | |
| | | | 81.2280 ± 0.0014 | 0.90 ± 0.06 | | |
| | | | 82.0870 ± 0.0014 | 0.42 ± 0.03 | | |
| | | | 84.2140 ± 0.0013 | 6.6 ± 0.4 | | |
| | | | 89.95 ± 0.02 | 1.00 ± 0.06 | | |
| | | | 102.2700 ± 0.0013 | 0.44 ± 0.03 | | |
| 90-Th-232 | ( 1.405 ± 0.006 ) × $10^{10}$ | y | 63.81 ± 0.01 | 0.263 ± 0.013 | ENSDF | |
| | | | 140.88 ± 0.01 | 0.021 ± 0.004 | | |
| 90-Th-233 | 22.15 ± 0.15 | m | 29.373 ± 0.010 | 2.5 ± 0.4 | LNHB | [3] |
| | | | 86.477 ± 0.010 | 2.7 ± 0.4 | | |
| | | | 94.65 ± 0.05 | 0.8 ± 0.1 | | |
| | | | 169.159 ± 0.010 | 0.34 ± 0.05 | | |
| | | | 459.222 ± 0.007 | 1.4 ± 0.3 | | |
| | | | 669.902 ± 0.016 | 0.68 ± 0.14 | | |
| 90-Th-234 | 24.10 ± 0.03 | d | 63.29 ± 0.02 | 3.70 ± 0.06 | ADS-98 | [4] |
| | | | 92.38 ± 0.01 | 2.62 ± 0.06 | | |
| | | | 92.80 ± 0.02 | 2.59 ± 0.06 | | |
| | | | 112.81 ± 0.05 | 0.244 ± 0.015 | | |
| 91-Pa-231 | ( 3.276 ± 0.011 ) × $10^4$ | y | 260.19 ± 0.06 | 0.188 ± 0.012 | ENSDF | |
| | | | 283.69 ± 0.01 | 1.7 ± 0.1 | | |
| | | | 300.07 ± 0.01 | 2.5 ± 0.2 | | |
| | | | 302.65 ± 0.05 | 2.2 ± 0.4 | | |
| | | | 330.06 ± 0.01 | 1.40 ± 0.09 | | |
| | | | 340.74 ± 0.05 | 0.181 ± 0.011 | | |
| | | | 357.12 ± 0.09 | 0.175 ± 0.013 | | |
| 91-Pa-233 | 26.98 ± 0.02 | d | 75.269 ± 0.010 | 1.30 ± 0.03 | LNHB | |
| | | | 86.595 ± 0.010 | 1.99 ± 0.11 | | |
| | | | 103.86 ± 0.01 | 0.853 ± 0.006 | | |
| | | | 271.555 ± 0.010 | 0.323 ± 0.003 | | |
| | | | 300.129 ± 0.005 | 6.60 ± 0.21 | | |
| | | | 311.904 ± 0.005 | 38.25 ± 0.23 | | |
| | | | 340.476 ± 0.005 | 4.47 ± 0.03 | | |
| | | | 375.404 ± 0.005 | 0.684 ± 0.007 | | |
| | | | 398.492 ± 0.005 | 1.408 ± 0.014 | | |
| | | | 415.764 ± 0.005 | 1.747 ± 0.007 | | |
| 91-Pa-234m | 1.159 ± 0.016 | m | 258.24 ± 0.07 | 0.0726 ± 0.0009 | IAEA-CRP-XG | |
| | | | 742.814 ± 0.022 | 0.096 ± 0.003 | | |
| | | | 766.358 ± 0.020 | 0.318 ± 0.005 | | |
| | | | 786.272 ± 0.022 | 0.054 ± 0.001 | | |
| | | | 1001.025 ± 0.022 | 0.832 ± 0.010 | | |
| 92-U-232 | 68.9 ± 0.4 | y | 57.78 ± 0.05 | 0.200 ± 0.002 | ENSDF | [5] |
| | | | 129.08 ± 0.05 | 0.0682 ± 0.0004 | | |
| | | | 270.2 ± 0.2 | 0.00316 ± 0.00005 | | |
| | | | 327.9 ± 0.2 | 0.00283 ± 0.00006 | | |

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

| Nuclide | Half-life $T_{1/2}$ | Units | γ rays Energy [keV] | Emission probability [% decay] | Source | Notes |
|---|---|---|---|---|---|---|
| 92-U-233 | ( 1.592 ± 0.002 ) × $10^5$ | y | 54.699 ± 0.001 | 0.0182 ± 0.0003 | ENSDF | [5] |
| | | | 118.968 ± 0.002 | 0.00406 ± 0.00004 | | |
| | | | 120.816 ± 0.001 | 0.00332 ± 0.00003 | | |
| | | | 135.36 ± 0.03 | 0.00232 ± 0.00002 | | |
| | | | 146.345 ± 0.002 | 0.00657 ± 0.00006 | | |
| | | | 164.522 ± 0.002 | 0.00623 ± 0.00005 | | |
| | | | 208.171 ± 0.002 | 0.00229 ± 0.00003 | | |
| | | | 245.345 ± 0.002 | 0.00362 ± 0.00003 | | |
| | | | 291.354 ± 0.004 | 0.00537 ± 0.00005 | | |
| | | | 317.16 ± 0.01 | 0.00776 ± 0.00007 | | |
| | | | 320.541 ± 0.005 | 0.00290 ± 0.00003 | | |
| 92-U-234 | ( 2.455 ± 0.006 ) × $10^5$ | y | 53.20 ± 0.02 | 0.1253 ± 0.0040 | LNHB | [5] |
| | | | 120.90 ± 0.04 | 0.0386 ± 0.0032 | | |
| 92-U-235 | ( 7.038 ± 0.005 ) × $10^8$ | y | 109.16 ± 0.02 | 1.54 ± 0.06 | ENSDF | |
| | | | 140.76 ± 0.04 | 0.22 ± 0.03 | | |
| | | | 143.76 ± 0.02 | 10.96 ± 0.14 | | |
| | | | 163.33 ± 0.02 | 5.08 ± 0.07 | | |
| | | | 182.61 ± 0.05 | 0.34 ± 0.03 | | |
| | | | 185.715 ± 0.005 | 57.2 ± 0.8 | | |
| | | | 194.94 ± 0.01 | 0.63 ± 0.02 | | |
| | | | 202.11 ± 0.02 | 1.08 ± 0.03 | | |
| | | | 205.311 ± 0.010 | 5.01 ± 0.06 | | |
| | | | 221.38 ± 0.02 | 0.12 ± 0.02 | | |
| 92-U-236 | ( 2.342 ± 0.004 ) × $10^7$ | y | 49.369 ± 0.009 | 0.078 ± 0.012 | ENSDF | |
| | | | 112.750 ± 0.015 | 0.019 ± 0.003 | | |
| 92-U-237 | 6.749 ± 0.016 | d | 59.5409 ± 0.0001 | 34.1 ± 0.8 | LNHB | |
| | | | 64.83 ± 0.02 | 1.286 ± 0.017 | | |
| | | | 164.61 ± 0.02 | 1.86 ± 0.03 | | |
| | | | 208.00 ± 0.01 | 21.3 ± 0.3 | | |
| | | | 332.36 ± 0.04 | 1.199 ± 0.016 | | |
| 92-U-238 | ( 4.468 ± 0.005 ) × $10^9$ | y | 49.55 ± 0.06 | 0.0697 ± 0.0026 | LNHB | |
| | | | 113.5 ± 0.1 | 0.0174 ± 0.0047 | | |
| 92-U-239 | 23.45 ± 0.02 | m | 43.533 ± 0.001 | 4.07 ± 0.13 | ENSDF | |
| | | | 74.664 ± 0.001 | 49.2 ± 1.2 | | |
| | | | 662.24 ± 0.03 | 0.182 ± 0.005 | | |
| | | | 819.22 ± 0.04 | 0.148 ± 0.004 | | |
| | | | 844.10 ± 0.04 | 0.162 ± 0.004 | | |
| 93-Np-236m | 22.5 ± 0.4 | h | 538.11 ± 0.10 | 0.0125 ± 0.0015 | LNHB | |
| | | | 642.35 ± 0.09 | 1.08 ± 0.06 | | |
| | | | 687.60 ± 0.05 | 0.292 ± 0.021 | | |
| 93-Np-237 | ( 2.144 ± 0.007 ) × $10^6$ | y | 57.104 ± 0.020 | 0.354 ± 0.008 | ENSDF | |
| | | | 86.477 ± 0.010 | 12.4 ± 0.3 | | |
| | | | 87.99 ± 0.03 | 0.167 ± 0.004 | | |
| | | | 117.702 ± 0.020 | 0.169 ± 0.004 | | |
| | | | 143.249 ± 0.020 | 0.443 ± 0.008 | | |
| | | | 151.414 ± 0.020 | 0.23 ± 0.02 | | |
| | | | 194.95 ± 0.03 | 0.177 ± 0.005 | | |
| | | | 212.29 ± 0.05 | 0.151 ± 0.003 | | |

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

| Nuclide | Half-life $T_{1/2}$ | Units | γ rays Energy [keV] | Emission probability [% decay] | Source | Notes |
|---|---|---|---|---|---|---|
| 93-Np-238 | 2.117 ± 0.002 | d | 101.90 ± 0.03 | 0.251 ± 0.007 | ENSDF | |
| | | | 882.63 ± 0.03 | 0.811 ± 0.011 | | |
| | | | 918.69 ± 0.04 | 0.532 ± 0.007 | | |
| | | | 923.98 ± 0.02 | 2.62 ± 0.04 | | |
| | | | 936.61 ± 0.06 | 0.368 ± 0.006 | | |
| | | | 941.38 ± 0.05 | 0.514 ± 0.007 | | |
| | | | 962.77 ± 0.03 | 0.645 ± 0.008 | | |
| | | | 984.45 ± 0.02 | 25.19 ± 0.21 | | |
| | | | 1025.87 ± 0.02 | 8.72 ± 0.15 | | |
| | | | 1028.54 ± 0.02 | 18.3 ± 0.3 | | |
| 93-Np-239 | 2.356 ± 0.003 | d | 61.460 ± 0.002 | 1.30 ± 0.02 | ENSDF | |
| | | | 106.123 ± 0.002 | 26.3 ± 1.0 | | |
| | | | 209.753 ± 0.002 | 3.42 ± 0.03 | | |
| | | | 226.38 ± 0.02 | 0.259 ± 0.016 | | |
| | | | 228.183 ± 0.001 | 11.14 ± 0.11 | | |
| | | | 277.599 ± 0.001 | 14.44 ± 0.10 | | |
| | | | 315.880 ± 0.003 | 1.60 ± 0.02 | | |
| | | | 334.310 ± 0.002 | 2.06 ± 0.02 | | |
| 94-Pu-236 | 2.858 ± 0.008 | y | 47.57 ± 0.01 | 0.066 ± 0.020 | ENSDF | [6] |
| | | | 109.00 ± 0.01 | 0.012 ± 0.004 | | |
| | | | 165.0 ± 0.5 | 0.00066 ± 0.00020 | | |
| | | | 645. ± 2. | 0.00024 ± 0.00008 | | |
| 94-Pu-238 | 87.74 ± 0.03 | y | 43.498 ± 0.001 | 0.0397 ± 0.0008 | BIPM-5 | [7] |
| | | | 99.852 ± 0.003 | 0.00735 ± 0.00008 | | |
| | | | 152.719 ± 0.002 | 0.000930 ± 0.000007 | | |
| 94-Pu-239 | ( 2.411 ± 0.003 ) × $10^4$ | y | 51.624 ± 0.001 | 0.02722 ± 0.00003 | ENSDF | [7] |
| | | | 56.828 ± 0.003 | 0.001152 ± 0.000013 | | |
| | | | 129.296 ± 0.001 | 0.00631 ± 0.00004 | | |
| | | | 144.201 ± 0.003 | 0.000283 ± 0.000006 | | |
| | | | 146.094 ± 0.006 | 0.000119 ± 0.000003 | | |
| | | | 161.450 ± 0.015 | 0.000123 ± 0.000002 | | |
| | | | 171.393 ± 0.006 | 0.000110 ± 0.000002 | | |
| | | | 195.679 ± 0.008 | 0.000107 ± 0.000001 | | |
| | | | 203.550 ± 0.005 | 0.000569 ± 0.000003 | | |
| | | | 332.845 ± 0.005 | 0.000494 ± 0.000003 | | |
| | | | 345.013 ± 0.004 | 0.000556 ± 0.000005 | | |
| | | | 375.054 ± 0.003 | 0.001554 ± 0.000009 | | |
| | | | 380.191 ± 0.006 | 0.000305 ± 0.000006 | | |
| | | | 382.75 ± 0.05 | 0.000259 ± 0.000005 | | |
| | | | 392.53 ± 0.03 | 0.000205 ± 0.000020 | | |
| | | | 413.713 ± 0.005 | 0.001466 ± 0.000011 | | |
| | | | 422.598 ± 0.019 | 0.000122 ± 0.000002 | | |
| | | | 451.481 ± 0.010 | 0.0001894 ± 0.0000016 | | |
| | | | 645.94 ± 0.04 | 0.0000152 ± 0.0000003 | | |
| | | | 652.05 ± 0.02 | 0.0000066 ± 0.0000002 | | |
| | | | 658.86 ± 0.06 | 0.0000097 ± 0.0000002 | | |
| 94-Pu-240 | ( 6.561 ± 0.007 ) × $10^3$ | y | 45.242 ± 0.003 | 0.0450 ± 0.0009 | BIPM-5 | [7] |
| | | | 104.234 ± 0.006 | 0.00714 ± 0.00007 | | |
| | | | 160.307 ± 0.003 | 0.0004045 ± 0.0000022 | | |
| 94-Pu-241 | 14.290 ± 0.006 | y | 77.10 ± 0.10 | 0.0000211 ± 0.0000008 | ENSDF | [7] |
| | | | 103.680 ± 0.005 | 0.000102 ± 0.000002 | | |
| | | | 148.567 ± 0.010 | 0.000185 ± 0.000003 | | |

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

| Nuclide | Half-life $T_{1/2}$ | Units | γ rays Energy [keV] | Emission probability [% decay] | Source | Notes |
|---|---|---|---|---|---|---|
| 94-Pu-242 | ( 3.73 ± 0.03 ) × $10^5$ | y | 44.915 ± 0.013 | 0.0376 ± 0.0008 | BIPM-5 | [7] |
| | | | 103.50 ± 0.04 | 0.00251 ± 0.00011 | | |
| | | | 158.80 ± 0.08 | 0.000298 ± 0.000020 | | |
| 95-Am-241 | 432.6 ± 0.6 | y | 26.3446 ± 0.0002 | 2.40 ± 0.03 | BIPM-5 | [8] |
| | | | 33.1963 ± 0.0003 | 0.121 ± 0.003 | | |
| | | | 59.5409 ± 0.0001 | 35.78 ± 0.09 | | |
| | | | 98.95 ± 0.01 | 0.0203 ± 0.0004 | | |
| | | | 102.97 ± 0.01 | 0.0195 ± 0.0004 | | |
| | | | 123.02 ± 0.02 | 0.00100 ± 0.00004 | | |
| | | | 125.29 ± 0.01 | 0.0041 ± 0.0002 | | |
| | | | 146.57 ± 0.01 | 0.00046 ± 0.00001 | | |
| | | | 169.55 ± 0.02 | 0.00017 ± 0.00001 | | |
| | | | 208.00 ± 0.02 | 0.000786 ± 0.000005 | | |
| | | | 322.53 ± 0.03 | 0.000151 ± 0.000003 | | |
| | | | 335.40 ± 0.03 | 0.000496 ± 0.000005 | | |
| | | | 368.63 ± 0.03 | 0.000214 ± 0.000004 | | |
| | | | 662.41 ± 0.02 | 0.000367 ± 0.000005 | | |
| 95-Am-242m | 141. ± 2. | y | 49.35 ± 0.02 | 0.13 ± 0.01 | ENSDF | [9] |
| | | | 60.13 ± 0.06 | 0.005 ± 0.001 | | |
| | | | 66.89 ± 0.02 | 0.015 ± 0.001 | | |
| | | | 73.66 ± 0.02 | 0.008 ± 0.001 | | |
| | | | 86.65 ± 0.02 | 0.023 ± 0.001 | | |
| | | | 135.19 ± 0.02 | 0.007 ± 0.001 | | |
| | | | 136.03 ± 0.02 | 0.009 ± 0.001 | | |
| 95-Am-243 | ( 7.370 ± 0.017 ) × $10^3$ | y | 43.53 ± 0.02 | 5.89 ± 0.10 | LNHB | |
| | | | 74.66 ± 0.02 | 67.2 ± 1.2 | | |
| | | | 86.71 ± 0.02 | 0.346 ± 0.009 | | |
| | | | 141.90 ± 0.06 | 0.115 ± 0.008 | | |
| 96-Cm-242 | 162.86 ± 0.08 | d | 44.08 ± 0.03 | 0.0330 ± 0.0007 | LNHB | [7] |
| | | | 101.92 ± 0.04 | 0.00251 ± 0.00014 | | |
| | | | 157.42 ± 0.09 | 0.00145 ± 0.00016 | | |
| 96-Cm-243 | 29.1 ± 0.1 | y | 209.753 ± 0.002 | 3.29 ± 0.1 | ENSDF | |
| | | | 228.183 ± 0.002 | 10.6 ± 0.3 | | |
| | | | 277.599 ± 0.002 | 14.0 ± 0.4 | | |
| | | | 285.460 ± 0.002 | 0.73 ± 0.02 | | |
| 96-Cm-244 | 18.11 ± 0.03 | y | 42.824 ± 0.008 | 0.0258 ± 0.0007 | LNHB | [7] |
| | | | 98.860 ± 0.013 | 0.00136 ± 0.00009 | | |
| | | | 152.63 ± 0.02 | 0.00102 ± 0.00005 | | |
| 98-Cf-252 | 2.645 ± 0.008 | y | 43.399 ± 0.025 | 0.0148 ± 0.0009 | ENSDF | [7] |
| | | | 100.2 ± 0.4 | 0.013 ± 0.006 | | |

[1] 510.7-keV emission probability of 22.6 ± 0.2% has been set aside as too close in energy to any annihilation radiation.

[2] Possible minor interference from other gamma-ray emissions of comparable energy (*).

[3] Doubly-placed transitions were not considered. Uncertainties of the emission probabilities are adopted from E. Browne, R.B. Firestone and V.S. Shirley, Table of Radioactive Isotopes, John Wiley & Sons, New York, 1986.

[4] Measurement of the emission probability of the 63.29-keV gamma ray by Abousahl et al., Nucl. Instrum. Meth. Phys. Res. A517 (2004) 211, has been incorporated into an earlier evaluation (Adsley et al., Appl. Radiat. Isot. 49 (1998) 1337) to give a recommended value of (3.70 ± 0.06)%; all other emissions probabilities and uncertainties were adjusted accordingly.

[5] Low intensity emissions.

[6] Energy uncertainties are adopted from E. Browne, R.B. Firestone and V.S. Shirley, Table of Radioactive Isotopes, John Wiley & Sons, New York, 1986.

[7] Low intensity emissions (no alternative).

[8] Low intensity emissions included.

[9] Low intensity emissions included; doubly-placed transitions were not considered.

A-4. K X-ray energies and intensities for actinides and natural decay products.

References


PTB: E. Schönfeld, G. Rodloff, Energies and relative emission probabilities of K X-rays for elements with atomic number in the range from Z = 5 to Z = 100, Report PTB-6.11-1999-1, 1999.

LNHB: Laboratoire National Henri Becquerel, Recommended Data, http://www.nucleide.org/DDEP_WG/DDEPdata.htm, 3 October 2006.

BIPM-5: M.-M. Bé, V. Chisté, C. Dulieu, E. Browne, V. Chechev, N. Kuzmenko, R. Helmer, A. Nichols, E. Schönfeld, R. Dersch, Monographie BIPM-5, Table of Radionuclides, Vol. 2 - A = 151 to 242, 2004.

ENSDF: Evaluated Nuclear Structure Data File, http://www-nds.iaea.org/ensdf/, 25 October 2006; see also NuDat2, http://www.nndc.bnl.gov/nudat2, 25 October 2006.

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

| Nuclide | Half-life $T_{1/2}$ | Units | Decay mode | Origin | Energy [keV] | Emission probability $P_x$ [% decay] | Source |
|---|---|---|---|---|---|---|---|
| 81-Tl-206 | 4.202 ± 0.011 | m | β- | Pb $K\alpha_2$ | 72.8049 | 0.026 ± 0.003 | [1] |
| | | | | Pb $K\alpha_1$ | 74.9700 | 0.044 ± 0.005 | |
| | | | | Pb $K'\beta_1$ | 84.451 – 85.470 | 0.0150 ± 0.0017 | |
| | | | | Pb $K'\beta_2$ | 87.238 – 88.003 | 0.0045 ± 0.0006 | |
| 81-Tl-208 | 3.060 ± 0.008 | m | β- | Pb $K\alpha_2$ | 72.8049 | 2.15 ± 0.06 | [1] |
| | | | | Pb $K\alpha_1$ | 74.9700 | 3.61 ± 0.09 | |
| | | | | Pb $K'\beta_1$ | 84.451 - 85.470 | 1.23 ± 0.04 | |
| | | | | Pb $K'\beta_2$ | 87.238 - 88.003 | 0.373 ± 0.013 | |
| 82-Pb-212 | 10.64 ± 0.01 | h | β- | Bi $K\alpha_2$ | 74.8157 | 10.7 ± 0.3 | [2] |
| | | | | Bi $K\alpha_1$ | 77.1088 | 17.9 ± 0.5 | |
| | | | | Bi $K'\beta_1$ | 86.835 - 87.862 | 6.12 ± 0.20 | |
| | | | | Bi $K'\beta_2$ | 89.732 - 90.522 | 1.87 ± 0.07 | |
| 83-Bi -212 | 60.54 ± 0.06 | m | α | Tl $K\alpha_2$ | 70.8325 | 0.0563 ± 0.0027 | [2] |
| | | | | Tl $K\alpha_1$ | 72.8725 | 0.095 ± 0.005 | |
| | | | | Tl $K'\beta_1$ | 82.118 - 83.115 | 0.0323 ± 0.0016 | |
| | | | | Tl $K'\beta_2$ | 84.838 - 85.530 | 0.0096 ± 0.0005 | |
| 83-Bi -212 | 60.54 ± 0.06 | m | β- | Po $K\alpha_2$ | 76.864 | 0.0404 ± 0.0010 | [2] |
| | | | | Po $K\alpha_1$ | 79.293 | 0.0672 ± 0.0017 | |
| | | | | Po $K'\beta_1$ | 89.256 - 90.363 | 0.0231 ± 0.0007 | |
| | | | | Po $K'\beta_2$ | 92.263 - 93.095 | 0.00720 ± 0.00024 | |
| 88-Ra-224 | 3.627 ± 0.007 | d | α | Rn $K\alpha_2$ | 81.07 | 0.130 ± 0.004 | [2] |
| | | | | Rn $K\alpha_1$ | 83.78 | 0.215 ± 0.007 | |
| | | | | Rn $K'\beta_1$ | 94.247 - 95.449 | 0.0744 ± 0.0024 | |
| | | | | Rn $K'\beta_2$ | 97.48 - 98.389 | 0.0238 ± 0.0009 | |
| 88-Ra-226 | ( 1.600 ± 0.007 ) × $10^3$ | y | α | Rn $K\alpha_2$ | 81.07 | 0.191 ± 0.007 | [2] |
| | | | | Rn $K\alpha_1$ | 83.78 | 0.315 ± 0.011 | |
| | | | | Rn $K'\beta_1$ | 94.247 – 95.449 | 0.109 ± 0.004 | |
| | | | | Rn $K'\beta_2$ | 97.48 – 98.389 | 0.0349 ± 0.0014 | |
| 89-Ac-224 | 2.78 ± 0.17 | h | EC | Ra $K\alpha_2$ | 85.43 | 22.2 ± 0.8 | [3] |
| | | | | Ra $K\alpha_1$ | 88.47 | 36.2 ± 1.2 | |
| | | | | Ra $K'\beta_1$ | 99.432 - 100.738 | 12.8 ± 0.5 | |
| | | | | Ra $K'\beta_2$ | 102.89 - 103.899 | 4.22 ± 0.16 | |
| 89-Ac-224 | 2.78 ± 0.17 | h | α | Fr $K\alpha_2$ | 83.231 | 0.150 ± 0.015 | [3] |
| | | | | Fr $K\alpha_1$ | 86.105 | 0.247 ± 0.023 | |
| | | | | Fr $K'\beta_1$ | 96.815 -98.069 | 0.087 ± 0.009 | |
| | | | | Fr $K'\beta_2$ | 100.16 - 101.118 | 0.028 ± 0.003 | |

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

| Nuclide | Half-life $T_{1/2}$ | Units | Decay mode | Origin | Energy [keV] | Emission probability $P_x$ [% decay] | Source |
|---|---|---|---|---|---|---|---|
| 89-Ac-228 | 6.15 ± 0.02 | h | β- | Th $K\alpha_2$ | 89.954 | 1.92 ± 0.19 | [3] |
| | | | | Th $K\alpha_1$ | 93.351 | 3.1 ± 0.3 | |
| | | | | Th $K'\beta_1$ | 104.819 - 106.239 | 1.11 ± 0.11 | |
| | | | | Th $K'\beta_2$ | 108.509 - 109.630 | 0.37 ± 0.04 | |
| 90-Th-227 | 18.718 ± 0.005 | d | α | Ra $K\alpha_2$ | 85.43 | 1.81 ± 0.06 | [2] |
| | | | | Ra $K\alpha_1$ | 88.47 | 2.96 ± 0.10 | |
| | | | | Ra $K'\beta_1$ | 99.432 – 100.738 | 1.04 ± 0.04 | |
| | | | | Ra $K'\beta_2$ | 102.89 – 103.899 | 0.340 ± 0.013 | |
| 90-Th-228 | 698.60 ± 0.23 | d | α | Ra $K\alpha_2$ | 85.43 | 0.0172 ± 0.0008 | [2] |
| | | | | Ra $K\alpha_1$ | 88.47 | 0.0281 ± 0.0012 | |
| | | | | Ra $K'\beta_1$ | 99.432 - 100.738 | 0.0098 ± 0.0005 | |
| | | | | Ra $K'\beta_2$ | 102.89 - 103.899 | 0.00323 ± 0.00016 | |
| 90-Th-231 | 25.52 ± 0.01 | h | β- | Pa $K\alpha_2$ | 92.288 | 0.37 ± 0.05 | [3] |
| | | | | Pa $K\alpha_1$ | 95.869 | 0.60 ± 0.07 | |
| | | | | Pa $K'\beta_1$ | 107.595 - 109.072 | 0.216 ± 0.026 | |
| | | | | Pa $K'\beta_2$ | 111.405 - 112.575 | 0.073 ± 0.009 | |
| 90-Th-233 | 22.15 ± 0.15 | m | β- | Pa $K\alpha_2$ | 92.288 | 0.48 ± 0.05 | [4] |
| | | | | Pa $K\alpha_1$ | 95.869 | 0.78 ± 0.08 | |
| | | | | Pa $K'\beta_1$ | 107.595 - 109.072 | 0.28 ± 0.03 | |
| | | | | Pa $K'\beta_2$ | 111.405 - 112.575 | 0.095 ± 0.010 | |
| 91-Pa-231 | ( 3.276 ± 0.011 ) × $10^4$ | y | α | Ac $K\alpha_2$ | 87.768 | 0.75 ± 0.04 | [3] |
| | | | | Ac $K\alpha_1$ | 90.885 | 1.22 ± 0.06 | |
| | | | | Ac $K'\beta_1$ | 102.101 - 103.462 | 0.435 ± 0.022 | |
| | | | | Ac $K'\beta_2$ | 105.679 - 106.738 | 0.145 ± 0.008 | |
| 91-Pa-232 | 1.32 ± 0.02 | d | β- | U $K\alpha_2$ | 94.666 | 1.06 ± 0.04 | [3] |
| | | | | U $K\alpha_1$ | 98.440 | 1.70 ± 0.06 | |
| | | | | U $K'\beta_1$ | 110.421 - 111.964 | 0.613 ± 0.023 | |
| | | | | U $K'\beta_2$ | 114.407 - 115.580 | 0.210 ± 0.009 | |
| 91-Pa-233 | 26.98 ± 0.02 | d | β- | U $K\alpha_2$ | 94.666 | 9.09 ± 0.25 | [1] |
| | | | | U $K\alpha_1$ | 98.440 | 14.6 ± 0.4 | |
| | | | | U $K'\beta_1$ | 110.421 - 111.964 | 5.25 ± 0.21 | |
| | | | | U $K'\beta_2$ | 114.407 - 115.580 | 1.80 ± 0.08 | |

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

| Nuclide | Half-life $T_{1/2}$ | Units | Decay mode | Origin | Energy [keV] | Emission probability $P_x$ [% decay] | Source |
|---|---|---|---|---|---|---|---|
| 91-Pa-234 | 6.75 ± 0.05 | h | β- | U $K\alpha_2$ | 94.666 | 12.3 ± 0.8 | [3] |
| | | | | U $K\alpha_1$ | 98.440 | 19.7 ± 1.2 | |
| | | | | U $K'\beta_1$ | 110.421 - 111.964 | 7.1 ± 0.5 | |
| | | | | U $K'\beta_2$ | 114.407 - 115.580 | 2.43 ± 0.16 | |
| 92-U -233 | ( 1.592 ± 0.002 ) × $10^5$ | y | α | Th $K\alpha_2$ | 89.954 | 0.00810 ± 0.00022 | [3] |
| | | | | Th $K\alpha_1$ | 93.351 | 0.0131 ± 0.0003 | |
| | | | | Th $K'\beta_1$ | 104.819 - 106.239 | 0.00469 ± 0.00012 | |
| | | | | Th $K'\beta_2$ | 108.509 - 109.630 | 0.00158 ± 0.00005 | |
| 92-U -235 | ( 7.038 ± 0.005 ) × $10^8$ | y | α | Th $K\alpha_2$ | 89.954 | 3.46 ± 0.09 | [3] |
| | | | | Th $K\alpha_1$ | 93.351 | 5.60 ± 0.12 | |
| | | | | Th $K'\beta_1$ | 104.819 - 106.239 | 2.00 ± 0.05 | |
| | | | | Th $K'\beta_2$ | 108.509 - 109.630 | 0.675 ± 0.018 | |
| 92-U -237 | 6.749 ± 0.016 | d | β- | Np $K\alpha_2$ | 97.069 | 14.7 ± 0.4 | [1] |
| | | | | Np $K\alpha_1$ | 101.059 | 23.4 ± 0.6 | |
| | | | | Np $K'\beta_1$ | 113.303 - 114.912 | 8.50 ± 0.27 | |
| | | | | Np $K'\beta_2$ | 117.463 - 118.646 | 2.92 ± 0.10 | |
| 93-Np-236 | ( 1.55 ± 0.08 ) × $10^5$ | y | EC | U $K\alpha_2$ | 94.666 | 20.2 ± 0.3 | [1] |
| | | | | U $K\alpha_1$ | 98.440 | 32.4 ± 0.5 | |
| | | | | U $K'\beta_1$ | 110.421 - 111.964 | 11.68 ± 0.25 | |
| | | | | U $K'\beta_2$ | 114.407 - 115.580 | 3.99 ± 0.11 | |
| 93-Np-237 | ( 2.144 ± 0.007 ) × $10^6$ | y | α | Pa $K\alpha_2$ | 92.288 | 1.67 ± 0.10 | [3] |
| | | | | Pa $K\alpha_1$ | 95.869 | 2.68 ± 0.14 | |
| | | | | Pa $K'\beta_1$ | 107.595 - 109.072 | 0.96 ± 0.06 | |
| | | | | Pa $K'\beta_2$ | 111.405 - 112.575 | 0.327 ± 0.018 | |
| 93-Np-238 | 2.117 ± 0.002 | d | β- | Pu $K\alpha_2$ | 99.525 | 0.172 ± 0.009 | [5] |
| | | | | Pu $K\alpha_1$ | 103.734 | 0.272 ± 0.013 | |
| | | | | Pu $K'\beta_1$ | 116.244 - 117.918 | 0.099 ± 0.005 | |
| | | | | Pu $K'\beta_2$ | 120.540 - 121.768 | 0.034 ± 0.002 | |
| 93-Np-239 | 2.356 ± 0.003 | d | β- | Pu $K\alpha_2$ | 99.525 | 14.0 ± 0.6 | [3] |
| | | | | Pu $K\alpha_1$ | 103.734 | 22.2 ± 0.8 | |
| | | | | Pu $K'\beta_1$ | 116.244 - 117.918 | 8.1 ± 0.4 | |
| | | | | Pu $K'\beta_2$ | 120.540 - 121.768 | 2.80 ± 0.11 | |

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

| Nuclide | Half-life $T_{1/2}$ | Units | Decay mode | Origin | Energy [keV] | Emission probability $P_x$ [% decay] | Source |
|---|---|---|---|---|---|---|---|
| 94-Pu-239 | ( 2.411 ± 0.003 ) × $10^4$ | y | α | U $K\alpha_2$ | 94.666 | 0.0036 ± 0.0004 | [3] |
| | | | | U $K\alpha_1$ | 98.440 | 0.0058 ± 0.0005 | |
| | | | | U $K'\beta_1$ | 110.421 - 111.964 | 0.00209 ± 0.00019 | |
| | | | | U $K'\beta_2$ | 114.407 - 115.580 | 0.00072 ± 0.00007 | |
| 94-Pu-241 | 14.290 ± 0.006 | y | α | U $K\alpha_2$ | 94.666 | 0.000312 ± 0.000011 | [3] |
| | | | | U $K\alpha_1$ | 98.440 | 0.000499 ± 0.000017 | |
| | | | | U $K'\beta_1$ | 110.421 - 111.964 | 0.000180 ± 0.000007 | |
| | | | | U $K'\beta_2$ | 114.407 - 115.580 | 0.0000615 ± 0.0000023 | |
| 95-Am-241 | 432.6 ± 0.6 | y | β- | Np $K\alpha_2$ | 97.069 | 0.00116 ± 0.00002 | [2] |
| | | | | Np $K\alpha_1$ | 101.059 | 0.00185 ± 0.00004 | |
| | | | | Np $K'\beta_1$ | 113.303 - 114.912 | 0.000670 ± 0.000014 | |
| | | | | Np $K'\beta_2$ | 117.463 - 118.646 | 0.000231 ± 0.000005 | |
| 95-Am-242 | 16.02 ± 0.02 | h | EC | Pu $K\alpha_2$ | 99.525 | 3.6 ± 0.3 | [3] |
| | | | | Pu $K\alpha_1$ | 103.734 | 5.7 ± 0.4 | |
| | | | | Pu $K'\beta_1$ | 116.244 - 117.918 | 2.07 ± 0.15 | |
| | | | | Pu $K'\beta_2$ | 120.540 - 121.768 | 0.72 ± 0.06 | |
| 96-Cm-243 | 29.1 ± 0.1 | y | α | Pu $K\alpha_2$ | 99.525 | 13.2 ± 0.6 | [3] |
| | | | | Pu $K\alpha_1$ | 103.734 | 20.9 ± 0.8 | |
| | | | | Pu $K'\beta_1$ | 116.244 - 117.918 | 7.6 ± 0.4 | |
| | | | | Pu $K'\beta_2$ | 120.540 - 121.768 | 2.64 ± 0.11 | |

[1] X-ray energies adopted from PTB. Emission probabilities adopted from LNHB; the values listed in LNHB are consistent with the relative X-ray emission probabilities reported in PTB.

[2] X-ray energies adopted from PTB. Emission probabilities adopted from BIPM-5 - the values listed in BIPM-5 are consistent with the relative X-ray emission probabilities reported in PTB.

[3] X-ray energies adopted from PTB. Emission probabilities are calculated from the relative X-ray emission probabilities listed in PTB and the absolute $K\alpha_1$-emission probability given in the ENSDF database.

[4] X-ray energies adopted from PTB. Emission probabilities reported without uncertainties were adopted from LNHB. There are no precise measurements of $P_x$ available in the literature for Th-233 and known experimental data without uncertainties are based on unpublished work; under these circumstances an uncertainty of ~10% was adopted for $P_x$ values.

[5] X-ray energies adopted from PTB. Emission probabilities are not listed by NuDat2; therefore, the $K\alpha_1$-emission probability was directly taken from the ENSDF file. The remaining X-ray emission probabilities were calculated from the relative X-ray emission probabilities listed in PTB and the absolute $K\alpha_1$-emission probability extracted from the ENSDF database.

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

References


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| | |
|---|---|
| $\sigma_0$ | Neutron cross section at 2200 m/s. |
| $\sigma$ | Neutron cross section measured in a Maxwellian spectrum. |
| $\sigma_r$ | Neutron cross section measured with reactor neutrons. |
| $\sigma_c$ | 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 $\sigma_0$ ($g = \sigma/\sigma_o$). If the cross section varies as a function of 1/v, g = 1.0. |
| RI | Infinite dilution resonance integral (including the 1/v contribution). |
| γ | Subscript for radiative capture cross section. |
| f | Subscript for fission cross section. |

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

| Nuclide | Thermal Cross Section Type | $\sigma_x$ [barn] | Westcott Factor g | Resonance Integral RI [barn] | Source |
|---|---|---|---|---|---|
| 90-Th-232 | $\sigma_{0\gamma}$ | 7.35 ± 0.03 | 0.9982 | 83.3 ± 1.5 | [1] |
| 92-U -233 | $\sigma_{0\gamma}$ | 45.5 ± 0.7 | 1.0495 ± 0.0223 | 138. ± 6. | [2] |
| | $\sigma_{0f}$ | 529.1 ± 1.2 | 0.9955 ± 0.0015 | 775. ± 17. | |
| 92-U -234 | $\sigma_{0\gamma}$ | 99.8 ± 1.3 | 0.9903 | 640. ± 20. | [1] |
| 92-U -235 | $\sigma_{0\gamma}$ | 98.8 ± 0.8 | 0.9956 ± 0.0016 | 146. ± 6. | [3] |
| | $\sigma_{0f}$ | 582.6 ± 1.1 | 0.9771 ± 0.0008 | 275. ± 5. | |
| 92-U -236 | $\sigma_{0\gamma}$ | 5.09 ± 0.10 | 1.0027 | 345. ± 15. | [4] |
| 92-U -237 | $\sigma_{\gamma}$ | 443. ± 167. | 0.9767 | 1200. ± 200. | [5] |
| 92-U -238 | $\sigma_{0\gamma}$ | 2.683 ± 0.012 | 1.0009 | 277. ± 3. | [6] |
| 93-Np-237 | $\sigma_{0\gamma}$ | 175.9 ± 2.9 | 0.982 | 652. ± 24. | [1] |
| 93-Np-239 | $\sigma_{r\gamma}$ | 68. ± 10. | 1.0005 | 455. | [7] |
| 94-Pu-238 | $\sigma_{0\gamma}$ | 540. ± 7. | 0.9563 | 162. ± 15. | [1] |
| | $\sigma_{0f}$ | 17.9 ± 0.4 | 0.9562 | 33. ± 5. | |
| 94-Pu-239 | $\sigma_{0\gamma}$ | 269.3 ± 2.9 | 1.1369 ± 0.0119 | 180. ± 20. | [2] |
| | $\sigma_{0f}$ | 748.1 ± 2.0 | 1.0553 ± 0.0013 | 303. ± 10. | |
| 94-Pu-240 | $\sigma_{0\gamma}$ | 289.5 ± 1.4 | 1.0264 | 8452. ± 200. | [1] |
| 94-Pu-241 | $\sigma_{0\gamma}$ | 362.1 ± 5.1 | 1.038 | 162. ± 8. | [8] |
| | $\sigma_{0f}$ | 1011.1 ± 6.2 | 1.046 ± 0.006 | 570. ± 15. | |
| 94-Pu-242 | $\sigma_{0\gamma}$ | 18.5 ± 0.5 | 1.0096 | 1115. ± 40. | [1] |
| 95-Am-241 | $\sigma_{0\gamma}$ | 587. ± 12. | 1.051 | 1425. ± 100. | [1] |
| | $\sigma_{0f}$ | 3.20 ± 0.09 | 0.996 | 14.4 ± 1.0 | |
| | $\sigma_{0\gamma(g)}$ | 533. ± 13. | | 1230. ± 100. | |
| | $\sigma_{0\gamma(m)}$ | 54. ± 5. | | 195. ± 20. | |
| 95-Am-242 | $\sigma_{\gamma}$ | 330. ± 50. | 1.0471 | 186. | [7] |
| | $\sigma_{f}$ | 2100. ± 200. | 1.0502 | 986. | |
| 95-Am-242m | $\sigma_{\gamma}$ | 1290. ± 300. | 1.100 | 211. | [9] |
| | $\sigma_{0f}$ | 6200. ± 200. | 1.104 | 1570. ± 80. | |

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

| Nuclide | Thermal Cross Section | | Westcott Factor | Resonance Integral | Source |
|---|---|---|---|---|---|
| | Type | $\sigma_x$ [barn] | g | RI [barn] | |
| 95-Am-243 | $\sigma_{0\gamma}$ | 75.1 ± 1.8 | 1.014 | 1820. ± 70. | [10] |
| | $\sigma_f$ | 0.1983 ± 0.0043 | 1.012 | 8.5 ± 0.5 | |
| 96-Cm-242 | $\sigma_\gamma$ | 16. ± 5. | 0.9939 | 110. ± 20. | [11] |
| | $\sigma_f$ | < 5. | 0.9964 | 12.9 ± 0.7 | |
| 96-Cm-243 | $\sigma_{0\gamma}$ | 130. ± 10. | 1.005 | 215. ± 20. | [1] |
| | $\sigma_{0f}$ | 617. ± 20. | 1.0054 | 1570. ± 100. | |
| 96-Cm-244 | $\sigma_{0\gamma}$ | 15.2 ± 1.2 | 0.999 | 655. ± 30. | [1] |
| | $\sigma_{0f}$ | 1.04 ± 0.20 | 0.989 | 12.5 ± 2.5 | |

[1] Data adopted from ANR; no uncertainty available for Westcott factors.

[2] Data adopted from ANR; $g_\gamma$ factor was calculated from fission and absorption cross-section data.

[3] All data adopted from ANR.

[4] Cross-section data and resonance integral adopted from ANR; Westcott factors without uncertainties calculated from the ENDF/B-VII library.

[5] Cross-section data and resonance integral adopted from ANR; Westcott factor without uncertainty calculated from the JEFF-3.1 library; RI = 296 barns in the ENDF/B-VII library.

[6] Thermal cross-section data adopted from TRK-05 (value of 2.680 ± 0.019 barns reported in ANR), and $g_\gamma$ and resonance integral take from ANR; no uncertainty available for Westcott factor.

[7] Cross-section data adopted from ANR; Westcott factors without uncertainties and resonance integrals calculated from the ENDF/B-VII library; a relative uncertainty of 20% is recommended.

[8] Data adopted from ANR; no uncertainty available for the $g_\gamma$ factor.

[9] Data adopted from ANR; $g_\gamma$ factor without uncertainty was calculated from the ENDF/B-VII library; resonance integral for radiative capture reported in ANR without uncertainty; a relative uncertainty of 20% is recommended.

[10] Data adopted from ANR; $g_f$ factor without uncertainty was calculated from the ENDF/B-VII library.

[11] $\sigma_\gamma$ and resonance integrals adopted from ANR; $\sigma_f$ < 5 barns is reported in ANR; values of 3 and 5 barns are given in the ENDF/B-VII and the JEFF-3.1 libraries, respectively; Westcott factors without uncertainties were calculated from the JEFF-3.1 library.

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

References


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

| Nuclide | Type | Total neutron yield $\nu_t$ | Source | Delayed-neutron yield $\nu_d$ | Source |
|---|---|---|---|---|---|
| 90-Th-232 | fast | 2.456 ± 0.018 | ENDF/B-VII | 0.0499 ± 0.0019 | ENDF/B-VII[1] |
| 92-U -233 | thermal | 2.4968 ± 0.0036 | IAEA-CRP-STD | 0.0067 ± 0.0003 | JEFF-3.1[2] |
| 92-U -235 | thermal | 2.4355 ± 0.0023 | IAEA-CRP-STD | 0.0162 ± 0.0005 | JEFF-3.1[3] |
| 92-U -238 | fast | 2.819 ± 0.020 | ENDF/B-VII[4] | 0.0465 ± 0.0024 | JEFF-3.1[3] |
| 92-Pu-238 | fast | 3.00 ± 0.14 | JEFF-3.1[2] | 0.0047 ± 0.0005 | JEFF-3.1[1] |
| 94-Pu-239 | thermal | 2.8836 ± 0.0047 | IAEA-CRP-STD | 0.0065 ± 0.0003 | JEFF-3.1[3] |
| 94-Pu-240 | fast | 3.086 ± 0.025 | JEFF-3.1[2] | 0.0090 ± 0.0004 | JEFF-3.1[1] |
| 94-Pu-241 | thermal | 2.9479 ± 0.0055 | IAEA-CRP-STD | 0.0160 ± 0.0008 | JEFF-3.1[2] |
| 94-Pu-242 | fast | 3.189 ± 0.035 | JEFF-3.1[2] | 0.0183 ± 0.0010 | JEFF-3.1[1] |
| 95-Am-241 | thermal | 3.239 ± 0.024 | JEFF-3.1[2] | 0.0043 ± 0.0006 | JEFF-3.1[2] |
| 96-Cm-242 | sf | 2.529 ± 0.017 | JEFF-3.1[5] | 0.0013 ± 0.0003 | Mills(1995) |
| 96-Cm-243 | thermal | 3.433 ± 0.047 | JEFF-3.1[2] | 0.0030 ± 0.0003 | JEFF-3.1[2] |
| 96-Cm-244 | sf | 2.691 ± 0.012 | JEFF-3.1[5] | 0.0033 ± 0.0010 | Mills(1995) |
| 96-Cm-245 | thermal | 3.60 ± 0.13 | JEFF-3.1[2] | 0.0064 ± 0.0014 | JEFF-3.1[2] |
| 98-Cf -252 | sf | 3.7692 ± 0.0047 | IAEA-CRP-STD | 0.0086 ± 0.0010 | Tuttle(1979) |

fast = fast spectrum, thermal = thermal spectrum, sf = spontaneous fission.

(1) Uncertainties estimated from selected experimental data reported by P&I (1998).

(2) Uncertainties estimated from selected experimental data available in EXFOR.

(3) Delayed-neutron data adopted from NEA/WPEC-6.

(4) Prompt-neutron yield adopted from ENDF/B-VII β3; uncertainty in prompt-neutron yield estimated from the U-238 covariance files included in the ENDF/B-VII β1 library (modification flag 5E for material 9237); total neutron yield calculated as the sum of prompt- and delayed-neutron yields.

(5) Prompt-neutron yield adopted from the JEFF-3.1 radioactive decay data library; uncertainty in prompt-neutron yield estimated from selected experimental data available in EXFOR; total spontaneous neutron yield calculated as the sum of prompt- and delayed-neutron yields.

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

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


| Nuclide | Type | Group | $T_{1/2}$ [s] | $\lambda_i$ [$s^{-1}$] | $\alpha_i = \nu_i/\nu_d$ | $\beta_i = \nu_i/\nu_t$ [%] | Notes |
|---|---|---|---|---|---|---|---|
| 90-Th-232 | fast | 1 | 55.6 | 0.012467 | 0.0334 ± 0.0025 | 0.0680 ± 0.0058 | [1] |
| | | 2 | 24.5 | 0.028292 | 0.0733 ± 0.0053 | 0.149 ± 0.013 | |
| | | 3 | 16.3 | 0.042524 | 0.0931 ± 0.0019 | 0.1892 ± 0.0084 | |
| | | 4 | 5.21 | 0.133042 | 0.136 ± 0.024 | 0.276 ± 0.050 | |
| | | 5 | 2.37 | 0.292467 | 0.3815 ± 0.0076 | 0.775 ± 0.034 | |
| | | 6 | 1.04 | 0.666488 | 0.1402 ± 0.0082 | 0.285 ± 0.021 | |
| | | 7 | 0.424 | 1.634781 | 0.114 ± 0.013 | 0.232 ± 0.028 | |
| | | 8 | 0.195 | 3.554600 | 0.0281 ± 0.0006 | 0.0572 ± 0.0026 | |
| | | Total | 6.985 | 0.099229 | 1.000 ± 0.030 | 2.032 ± 0.079 | |
| 92-U-233 | thermal | 1 | 55.6 | 0.012467 | 0.0797 ± 0.0036 | 0.0214 ± 0.0015 | [1] |
| | | 2 | 24.5 | 0.028292 | 0.1670 ± 0.0035 | 0.0448 ± 0.0024 | |
| | | 3 | 16.3 | 0.042524 | 0.1500 ± 0.0030 | 0.0402 ± 0.0022 | |
| | | 4 | 5.21 | 0.133042 | 0.200 ± 0.040 | 0.054 ± 0.012 | |
| | | 5 | 2.37 | 0.292467 | 0.298 ± 0.022 | 0.0799 ± 0.0071 | |
| | | 6 | 1.04 | 0.666488 | 0.0388 ± 0.0008 | 0.01040 ± 0.00055 | |
| | | 7 | 0.424 | 1.634781 | 0.056 ± 0.025 | 0.015 ± 0.0068 | |
| | | 8 | 0.195 | 3.554600 | 0.0105 ± 0.0002 | 0.00281 ± 0.00015 | |
| | | Total | 12.782 | 0.054228 | 1.000 ± 0.053 | 0.268 ± 0.013 | |
| 92-U-235 | thermal | 1 | 55.6 | 0.012467 | 0.0328 ± 0.0042 | 0.0218 ± 0.0029 | [1] |
| | | 2 | 24.5 | 0.028292 | 0.1539 ± 0.0068 | 0.1023 ± 0.0056 | |
| | | 3 | 16.3 | 0.042524 | 0.091 ± 0.009 | 0.0605 ± 0.0063 | |
| | | 4 | 5.21 | 0.133042 | 0.197 ± 0.023 | 0.131 ± 0.016 | |
| | | 5 | 2.37 | 0.292467 | 0.3308 ± 0.0066 | 0.2200 ± 0.0083 | |
| | | 6 | 1.04 | 0.666488 | 0.0902 ± 0.0045 | 0.0600 ± 0.0036 | |
| | | 7 | 0.424 | 1.634781 | 0.0812 ± 0.0016 | 0.0540 ± 0.0021 | |
| | | 8 | 0.195 | 3.554600 | 0.0229 ± 0.0095 | 0.0152 ± 0.0064 | |
| | | Total | 9.020 | 0.076849 | 1.000 ± 0.029 | 0.665 ± 0.021 | |

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

| Nuclide | Type | Group | $T_{1/2}$ [s] | $\lambda_i$ [$s^{-1}$] | $\alpha_i = \nu_i/\nu_d$ | $\beta_i = \nu_i/\nu_t$ [%] | Notes |
|---|---|---|---|---|---|---|---|
| 92-U-238 | fast | 1 | 55.6 | 0.012467 | 0.0084 ± 0.0013 | 0.0139 ± 0.0023 | [1] |
| | | 2 | 24.5 | 0.028292 | 0.1040 ± 0.0022 | 0.1716 ± 0.0097 | |
| | | 3 | 16.3 | 0.042524 | 0.0375 ± 0.0008 | 0.0619 ± 0.0035 | |
| | | 4 | 5.21 | 0.133042 | 0.137 ± 0.020 | 0.226 ± 0.036 | |
| | | 5 | 2.37 | 0.292467 | 0.294 ± 0.012 | 0.485 ± 0.033 | |
| | | 6 | 1.04 | 0.666488 | 0.1980 ± 0.0023 | 0.327 ± 0.018 | |
| | | 7 | 0.424 | 1.634781 | 0.128 ± 0.013 | 0.211 ± 0.025 | |
| | | 8 | 0.195 | 3.554600 | 0.0931 ± 0.0034 | 0.1536 ± 0.0098 | |
| | | Total | 5.315 | 0.130409 | 1.000 ± 0.027 | 1.650 ± 0.086 | |
| 94-Pu-238 | fast | 1 | 55.6 | 0.012467 | 0.045 ± 0.009 | 0.0071 ± 0.0017 | [2] |
| | | 2 | 24.5 | 0.028292 | 0.250 ± 0.018 | 0.0393 ± 0.0056 | |
| | | 3 | 16.3 | 0.042524 | 0.052 ± 0.001 | 0.0082 ± 0.0011 | |
| | | 4 | 5.21 | 0.133042 | 0.256 ± 0.014 | 0.0402 ± 0.0054 | |
| | | 5 | 2.37 | 0.292467 | 0.251 ± 0.035 | 0.0394 ± 0.0073 | |
| | | 6 | 1.04 | 0.666488 | 0.119 ± 0.012 | 0.0187 ± 0.0030 | |
| | | 7 | 0.424 | 1.634781 | 0.027 ± 0.016 | 0.0042 ± 0.0026 | |
| | | 8 | 0.195 | 3.554600 | | | |
| | | Total | 11.538 | 0.060073 | 1.000 ± 0.048 | 0.157 ± 0.019 | |
| 94-Pu-239 | thermal | 1 | 55.6 | 0.012467 | 0.032 ± 0.012 | 0.0072 ± 0.0028 | [1] |
| | | 2 | 24.5 | 0.028292 | 0.237 ± 0.034 | 0.0533 ± 0.0081 | |
| | | 3 | 16.3 | 0.042524 | 0.0826 ± 0.0016 | 0.01859 ± 0.00098 | |
| | | 4 | 5.21 | 0.133042 | 0.182 ± 0.052 | 0.041 ± 0.012 | |
| | | 5 | 2.37 | 0.292467 | 0.294 ± 0.029 | 0.0662 ± 0.0073 | |
| | | 6 | 1.04 | 0.666488 | 0.0816 ± 0.0016 | 0.01836 ± 0.00097 | |
| | | 7 | 0.424 | 1.634781 | 0.072 ± 0.031 | 0.0162 ± 0.0071 | |
| | | 8 | 0.195 | 3.554600 | 0.0185 ± 0.0004 | 0.00416 ± 0.00023 | |
| | | Total | 10.698 | 0.064794 | 1.000 ± 0.077 | 0.225 ± 0.011 | |
| 94-Pu-240 | fast | 1 | 55.6 | 0.012467 | 0.0220 ± 0.0033 | 0.0064 ± 0.0011 | [1] |
| | | 2 | 24.5 | 0.028292 | 0.2069 ± 0.0048 | 0.0604 ± 0.0033 | |
| | | 3 | 16.3 | 0.042524 | 0.0795 ± 0.0016 | 0.0232 ± 0.0013 | |
| | | 4 | 5.21 | 0.133042 | 0.161 ± 0.055 | 0.047 ± 0.017 | |
| | | 5 | 2.37 | 0.292467 | 0.3139 ± 0.0088 | 0.0917 ± 0.0051 | |
| | | 6 | 1.04 | 0.666488 | 0.1050 ± 0.0098 | 0.0307 ± 0.0033 | |
| | | 7 | 0.424 | 1.634781 | 0.079 ± 0.017 | 0.0231 ± 0.0051 | |
| | | 8 | 0.195 | 3.554600 | 0.0325 ± 0.0030 | 0.00949 ± 0.00099 | |
| | | Total | 9.320 | 0.074374 | 1.000 ± 0.060 | 0.292 ± 0.014 | |
| 94-Pu-241 | thermal | 1 | 55.6 | 0.012467 | 0.016 ± 0.003 | 0.0087 ± 0.0017 | [1] |
| | | 2 | 24.5 | 0.028292 | 0.175 ± 0.019 | 0.095 ± 0.012 | |
| | | 3 | 16.3 | 0.042524 | 0.055 ± 0.012 | 0.0299 ± 0.0067 | |
| | | 4 | 5.21 | 0.133042 | 0.170 ± 0.018 | 0.092 ± 0.011 | |
| | | 5 | 2.37 | 0.292467 | 0.280 ± 0.035 | 0.152 ± 0.021 | |
| | | 6 | 1.04 | 0.666488 | 0.166 ± 0.033 | 0.090 ± 0.019 | |
| | | 7 | 0.424 | 1.634781 | 0.113 ± 0.035 | 0.061 ± 0.020 | |
| | | 8 | 0.195 | 3.554600 | 0.0245 ± 0.0063 | 0.0133 ± 0.0035 | |
| | | Total | 7.848 | 0.088319 | 1.000 ± 0.067 | 0.543 ± 0.028 | |

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

| Nuclide | Type | Group | $T_{1/2}$ [s] | $\lambda_i$ [$s^{-1}$] | $\alpha_i = \nu_i/\nu_d$ | $\beta_i = \nu_i/\nu_t$ [%] | Notes |
|---|---|---|---|---|---|---|---|
| 94-Pu-242 | fast | 1 | 55.6 | 0.012467 | 0.0138 ± 0.0003 | 0.00792 ± 0.00048 | [1] |
| | | 2 | 24.5 | 0.028292 | 0.095 ± 0.051 | 0.055 ± 0.030 | |
| | | 3 | 16.3 | 0.042524 | 0.134 ± 0.015 | 0.0769 ± 0.0097 | |
| | | 4 | 5.21 | 0.133042 | 0.033 ± 0.020 | 0.019 ± 0.012 | |
| | | 5 | 2.37 | 0.292467 | 0.4038 ± 0.0081 | 0.232 ± 0.014 | |
| | | 6 | 1.04 | 0.666488 | 0.001 ± 0.060 | 0.001 ± 0.035 | |
| | | 7 | 0.424 | 1.634781 | 0.258 ± 0.046 | 0.148 ± 0.028 | |
| | | 8 | 0.195 | 3.554600 | 0.062 ± 0.052 | 0.036 ± 0.030 | |
| | | Total | 6.530 | 0.106145 | 1.00 ± 0.11 | 0.574 ± 0.032 | |
| 95-Am-241 | thermal | 1 | 55.6 | 0.012467 | 0.0340 ± 0.0031 | 0.00448 ± 0.00073 | [1] |
| | | 2 | 24.5 | 0.028292 | 0.238 ± 0.033 | 0.03137 ± 0.00603 | |
| | | 3 | 16.3 | 0.042524 | 0.061 ± 0.012 | 0.00804 ± 0.00191 | |
| | | 4 | 5.21 | 0.133042 | 0.182 ± 0.033 | 0.02399 ± 0.00540 | |
| | | 5 | 2.37 | 0.292467 | 0.305 ± 0.035 | 0.04021 ± 0.00707 | |
| | | 6 | 1.04 | 0.666488 | 0.1060 ± 0.0021 | 0.01397 ± 0.00188 | |
| | | 7 | 0.424 | 1.634781 | 0.038 ± 0.066 | 0.00501 ± 0.00873 | |
| | | 8 | 0.195 | 3.554600 | 0.036 ± 0.072 | 0.00475 ± 0.00952 | |
| | | Total | 10.518 | 0.065899 | 1.00 ± 0.12 | 0.13183 ± 0.01752 | |
| 96-Cm-245 | thermal | 1 | 55.6 | 0.012467 | 0.016 ± 0.005 | 0.0028 ± 0.0011 | [2] |
| | | 2 | 24.5 | 0.028292 | 0.269 ± 0.020 | 0.048 ± 0.012 | |
| | | 3 | 16.3 | 0.042524 | 0.045 ± 0.001 | 0.0080 ± 0.0018 | |
| | | 4 | 5.21 | 0.133042 | 0.204 ± 0.046 | 0.036 ± 0.012 | |
| | | 5 | 2.37 | 0.292467 | 0.255 ± 0.040 | 0.045 ± 0.013 | |
| | | 6 | 1.04 | 0.666488 | 0.178 ± 0.050 | 0.032 ± 0.012 | |
| | | 7 | 0.424 | 1.634781 | 0.033 ± 0.084 | 0.006 ± 0.016 | |
| | | 8 | 0.195 | 3.554600 | | | |
| | | Total | 10.080 | 0.068765 | 1.00 ± 0.12 | 0.178 ± 0.039 | |
| 98-Cf- 252 | sf | 1 | 55.6 | 0.012467 | 0.014 ± 0.007 | 0.0032 ± 0.0017 | [2] |
| | | 2 | 24.5 | 0.028292 | 0.318 ± 0.007 | 0.0725 ± 0.0088 | |
| | | 3 | 16.3 | 0.042524 | 0.001 ± 0.024 | 0.0002 ± 0.0055 | |
| | | 4 | 5.21 | 0.133042 | 0.209 ± 0.018 | 0.0477 ± 0.0070 | |
| | | 5 | 2.37 | 0.292467 | 0.200 ± 0.004 | 0.0456 ± 0.0055 | |
| | | 6 | 1.04 | 0.666488 | 0.144 ± 0.031 | 0.0328 ± 0.0081 | |
| | | 7 | 0.424 | 1.634781 | 0.114 ± 0.044 | 0.026 ± 0.011 | |
| | | 8 | 0.195 | 3.554600 | | | |
| | | Total | 10.347 | 0.066992 | 1.000 ± 0.063 | 0.228 ± 0.027 | |

fast = fast spectrum, thermal = thermal spectrum, sf = spontaneous fission.

[1] Values of $T_{1/2}$, $\lambda_i$ and $\alpha_i$ adopted from the JEFF-3.1 library; uncertainties in $\alpha_i$ adopted from NEA/WPEC-6.

[2] Data adopted from NEA/WPEC-6.

B-1. Half-lives and branching fractions for fission products.

References


BIPM-5: M.-M. Bé, V. Chisté, C. Dulieu, E. Browne, V. Chechev, N. Kuzmenko, R. Helmer, A. Nichols, E. Schönfeld, R. Dersch, Monographie BIPM-5, Table of Radionuclides, Vol. 1 - A = 1 to 150 and Vol. 2 - A = 151 to 242, 2004.

LNHB: Laboratoire National Henri Becquerel, Recommended Data, http://www.nucleide.org/DDEP_WG/DDEPdata.htm, 16 January 2006.

IAEA-CRP-XG: M.-M. Bé, V.P. Chechev, R. Dersch, O.A.M. Helene, R.G. Helmer, M. Herman, S. Hlaváč, A. Marcinkowski, G.L. Molnár, A.L. Nichols, E. Schönfeld, V.R. Vanin, M.J. Woods, IAEA CRP "Update of X-ray and Gamma-ray Decay Data Standards for Detector Calibration and Other Applications", IAEA Nuclear Data Section, 2004.

ENSDF: Evaluated Nuclear Structure Data File, http://www-nds.iaea.org/ensdf/, 26 January 2006.


Table B-1. Half-lives and branching fractions for fission products.

| Nuclide | Half-life $T_{1/2}$ | | Units | Decay mode | Branching Fraction | | Source | Notes |
|---|---|---|---|---|---|---|---|---|
| 36-Kr- 85 | 10.752 | ± 0.023 | y | β- | 1.0 | | BIPM-5 | |
| 40-Zr- 95 | 64.032 | ± 0.006 | d | β- | 1.0 | | LNHB | |
| 41-Nb- 95 | 34.991 | ± 0.006 | d | β- | 1.0 | | LNHB | |
| 41-Nb- 95m | 3.61 | ± 0.03 | d | IT<br>β- | 0.975<br>0.025 | ± 0.001<br>± 0.001 | LNHB | [1] |
| 44-Ru-103 | 39.247 | ± 0.013 | d | β- | 1.0 | | IAEA-CRP-XG | |
| 44-Ru-106 | 1.018 | ± 0.005 | y | β- | 1.0 | | IAEA-CRP-XG | |
| 45-Rh-106 | 30.1 | ± 0.3 | s | β- | 1.0 | | IAEA-CRP-XG | |
| 51-Sb-125 | 2.7584 | ± 0.0006 | y | β- | 1.0 | | IAEA-CRP-XG | |
| 53- I -131 | 8.0233 | ± 0.0019 | d | β- | 1.0 | | BIPM-5 | |
| 53- I -135 | 6.57 | ± 0.02 | h | β- | 1.0 | | ENSDF | |
| 54-Xe-131m | 11.930 | ± 0.016 | d | IT | 1.0 | | BIPM-5 | |
| 54-Xe-133 | 5.243 | ± 0.001 | d | β- | 1.0 | | ENSDF | |
| 54-Xe-133m | 2.19 | ± 0.01 | d | IT | 1.0 | | ENSDF | |
| 54-Xe-135 | 9.14 | ± 0.02 | h | β- | 1.0 | | ENSDF | |
| 54-Xe-135m | 15.29 | ± 0.05 | m | IT<br>β- | 0.997<br>0.003 | ± 0.003<br>± 0.003 | ENSDF | [2] |

Table B-1. Half-lives and branching fractions for fission products.

| Nuclide | Half-life $T_{1/2}$ | | Units | Decay mode | Branching Fraction | | Source | Notes |
|---|---|---|---|---|---|---|---|---|
| 55-Cs-134 | 2.063 | ± 0.003 | y | β-<br>EC | 0.999997<br>0.000003 | ± 0.000001<br>± 0.000001 | IAEA-CRP-XG | [3] |
| 55-Cs-137 | 30.05 | ± 0.08 | y | β- | 1.0 | | LNHB | |
| 56-Ba-140 | 12.753 | ± 0.004 | d | β- | 1.0 | | BIPM-5 | |
| 57-La-140 | 1.67850 | ± 0.00017 | d | β- | 1.0 | | BIPM-5 | |
| 58-Ce-141 | 32.508 | ± 0.010 | d | β- | 1.0 | | LNHB | |
| 58-Ce-144 | 285.1 | ± 0.6 | d | β- | 1.0 | | IAEA-CRP-XG | |
| 59-Pr-144 | 17.28 | ± 0.05 | m | β- | 1.0 | | ENSDF | |
| 60-Nd-147 | 10.98 | ± 0.01 | d | β- | 1.0 | | ENSDF | |
| 61-Pm-147 | 2.6234 | ± 0.0002 | y | β- | 1.0 | | ENSDF | |
| 61-Pm-148 | 5.368 | ± 0.002 | d | β- | 1.0 | | ENSDF | |
| 61-Pm-148m | 41.29 | ± 0.11 | d | β-<br>IT | 0.958<br>0.042 | ± 0.007<br>± 0.007 | ENSDF | |
| 61-Pm-149 | 2.2117 | ± 0.0021 | d | β- | 1.0 | | ENSDF | |
| 61-Pm-151 | 1.1833 | ± 0.0017 | d | β- | 1.0 | | ENSDF | |
| 62-Sm-151 | 90. | ± 8. | y | β- | 1.0 | | ENSDF | |
| 62-Sm-153 | 1.92855 | ± 0.00005 | d | β- | 1.0 | | LNHB | |
| 63-Eu-154 | 8.592 | ± 0.004 | y | β-<br>EC | 0.99980<br>0.00020 | ± 0.00010<br>± 0.00010 | IAEA-CRP-XG | [3] |
| 63-Eu-155 | 4.753 | ± 0.016 | y | β- | 1.0 | | IAEA-CRP-XG | |

1 y = 1 year = 365.24219878 days

[1] ENSDF branching fractions: 0.944 ± 0.007 for IT and 0.056 ± 0.007 for β-.

[2] Branching fractions were averaged from ENSDF database.

[3] Branching fractions were adopted from ENSDF database.

B-2. Gamma-ray energies and emission probabilities for fission products.

References


BIPM-5: M.-M. Bé, V. Chisté, C. Dulieu, E. Browne, V. Chechev, N. Kuzmenko, R. Helmer, A. Nichols, E. Schönfeld, R. Dersch, Monographie BIPM-5, Table of Radionuclides, Vol. 1 - A = 1 to 150 and Vol. 2 - A = 151 to 242,

LNHB: Laboratoire National Henri Becquerel, Recommended Data, http://www.nucleide.org/DDEP_WG/DDEPdata.htm, 3 October 2006.

AEA-CRP-XG: M.-M. Bé, V.P. Chechev, R. Dersch, O.A.M. Helene, R.G. Helmer, M. Herman, S. Hlaváč, A. Marcinkowski, G.L. Molnár, A.L. Nichols, E. Schönfeld, V.R. Vanin, M.J. Woods, IAEA CRP "Update of X-ray and Gamma-ray Decay Data Standards for Detector Calibration and Other Applications", IAEA Nuclear Data Section, 2004 .

ENSDF: Evaluated Nuclear Structure Data File,http://www-nds.iaea.org/ensdf/, 15 November 2006.


Table B-2. Gamma-ray energies and emission probabilities for fission products.

| Nuclide | Half-life $T_{1/2}$ | | Units | γ rays Energy [keV] | | Emission probability [% decay] | | Source | Notes |
|---|---|---|---|---|---|---|---|---|---|
| 36-Kr- 85 | 10.752 | ± 0.023 | y | 513.997 | ± 0.005 | 0.435 | ± 0.010 | BIPM-5 | |
| 40-Zr- 95 | 64.032 | ± 0.006 | d | 235.69 | ± 0.02 | 0.27 | ± 0.02 | LNHB | |
| | | | | 724.193 | ± 0.003 | 44.27 | ± 0.22 | | |
| | | | | 756.729 | ± 0.012 | 54.38 | ± 0.22 | | |
| 41-Nb- 95 | 34.991 | ± 0.006 | d | 765.803 | ± 0.006 | 99.808 | ± 0.007 | LNHB | |
| 41-Nb- 95m | 3.61 | ± 0.03 | d | 235.69 | ± 0.02 | 25.1 | ± 0.3 | LNHB | |
| 44-Ru-103 | 39.247 | ± 0.013 | d | 39.760 | ± 0.010 | 0.071 | ± 0.003 | IAEA-CRP-XG | |
| | | | | 53.275 | ± 0.010 | 0.384 | ± 0.006 | | |
| | | | | 294.98 | ± 0.02 | 0.289 | ± 0.006 | | |
| | | | | 443.80 | ± 0.02 | 0.344 | ± 0.003 | | |
| | | | | 497.08 | ± 0.02 | 91.31 | ± 0.07 | | |
| | | | | 557.04 | ± 0.02 | 0.855 | ± 0.005 | | |
| | | | | 610.33 | ± 0.02 | 5.78 | ± 0.03 | | |
| 45-Rh-106 | 30.1 | ± 0.3 | s | 511.8534 | ± 0.0023 | 20.50 | ± 0.21 | IAEA-CRP-XG | [1] |
| | | | | 616.22 | ± 0.09 | 0.724 | ± 0.013 | | |
| | | | | 621.93 | ± 0.06 | 9.86 | ± 0.11 | | |
| | | | | 873.49 | ± 0.05 | 0.435 | ± 0.008 | | |
| | | | | 1050.41 | ± 0.06 | 1.488 | ± 0.022 | | |
| | | | | 1128.07 | ± 0.05 | 0.399 | ± 0.006 | | |
| 51-Sb-125 | 2.7584 | ± 0.0006 | y | 176.314 | ± 0.002 | 6.82 | ± 0.07 | IAEA-CRP-XG | |
| | | | | 380.452 | ± 0.008 | 1.520 | ± 0.015 | | |
| | | | | 427.874 | ± 0.004 | 29.55 | ± 0.24 | | |
| | | | | 463.365 | ± 0.004 | 10.48 | ± 0.09 | | |
| | | | | 600.597 | ± 0.002 | 17.76 | ± 0.18 | | |
| | | | | 606.713 | ± 0.003 | 5.02 | ± 0.05 | | |
| | | | | 635.950 | ± 0.003 | 11.32 | ± 0.10 | | |
| | | | | 671.441 | ± 0.006 | 1.783 | ± 0.016 | | |

Table B-2. Gamma-ray energies and emission probabilities for fission products.

| Nuclide | Half-life $T_{1/2}$ | | Units | γ rays Energy [keV] | | Emission probability [% decay] | | Source | Notes |
|---|---|---|---|---|---|---|---|---|---|
| 53- I -131 | 8.0233 | ± 0.0019 | d | 80.1850 | ± 0.0019 | 2.607 | ± 0.027 | BIPM-5 | |
| | | | | 284.305 | ± 0.005 | 6.06 | ± 0.06 | | |
| | | | | 364.489 | ± 0.005 | 81.2 | ± 0.8 | | |
| | | | | 636.989 | ± 0.004 | 7.26 | ± 0.08 | | |
| | | | | 722.911 | ± 0.005 | 1.796 | ± 0.020 | | |
| 54-Xe-131m | 11.930 | ± 0.016 | d | 163.930 | ± 0.008 | 1.98 | ± 0.06 | BIPM-5 | |
| 54-Xe-133 | 5.243 | ± 0.001 | d | 80.997 | ± 0.003 | 38.0 | ± 0.7 | ENSDF | |
| 55-Cs-134 | 2.063 | ± 0.003 | y | 563.243 | ± 0.003 | 8.37 | ± 0.03 | IAEA-CRP-XG | |
| | | | | 569.327 | ± 0.003 | 15.38 | ± 0.04 | | |
| | | | | 604.720 | ± 0.003 | 97.650 | ± 0.018 | | |
| | | | | 795.83 | ± 0.03 | 85.5 | ± 0.3 | | |
| | | | | 801.945 | ± 0.004 | 8.70 | ± 0.03 | | |
| | | | | 1365.186 | ± 0.004 | 3.017 | ± 0.012 | | |
| 55-Cs-137 | 30.05 | ± 0.08 | y | 661.657 | ± 0.003 | 84.99 | ± 0.20 | LNHB | |
| 56-Ba-140 | 12.753 | ± 0.004 | d | 29.9656 | ± 0.0015 | 14.32 | ± 0.25 | BIPM-5 | |
| | | | | 132.6972 | ± 0.0025 | 0.201 | ± 0.004 | | |
| | | | | 162.6628 | ± 0.0024 | 6.26 | ± 0.09 | | |
| | | | | 304.872 | ± 0.004 | 4.30 | ± 0.04 | | |
| | | | | 423.721 | ± 0.004 | 3.11 | ± 0.03 | | |
| | | | | 437.569 | ± 0.003 | 1.927 | ± 0.019 | | |
| | | | | 537.303 | ± 0.006 | 24.39 | ± 0.22 | | |
| 57-La-140 | 1.67850 | ± 0.00017 | d | 328.761 | ± 0.004 | 20.8 | ± 0.3 | BIPM-5 | |
| | | | | 432.513 | ± 0.008 | 2.995 | ± 0.016 | | |
| | | | | 487.022 | ± 0.006 | 46.1 | ± 0.4 | | |
| | | | | 751.653 | ± 0.007 | 4.392 | ± 0.024 | | |
| | | | | 815.781 | ± 0.006 | 23.72 | ± 0.12 | | |
| | | | | 867.839 | ± 0.016 | 5.58 | ± 0.03 | | |
| | | | | 919.533 | ± 0.010 | 2.730 | ± 0.023 | | |
| | | | | 925.198 | ± 0.007 | 7.04 | ± 0.04 | | |
| | | | | 950.988 | ± 0.020 | 0.531 | ± 0.005 | | |
| | | | | 1596.203 | ± 0.013 | 95.40 | ± 0.08 | | |
| | | | | 2347.847 | ± 0.014 | 0.845 | ± 0.007 | | |
| | | | | 2521.390 | ± 0.014 | 3.412 | ± 0.024 | | |
| 58-Ce-141 | 32.508 | ± 0.010 | d | 145.4433 | ± 0.0014 | 48.29 | ± 0.20 | LNHB | |
| 58-Ce-144 | 285.1 | ± 0.6 | d | 33.568 | ± 0.010 | 0.235 | ± 0.012 | IAEA-CRP-XG | |
| | | | | 40.98 | ± 0.10 | 0.41 | ± 0.25 | | |
| | | | | 80.12 | ± 0.05 | 1.52 | ± 0.10 | | |
| | | | | 133.515 | ± 0.004 | 11.09 | ± 0.16 | | |
| 59-Pr-144 | 17.28 | ± 0.05 | m | 696.505 | ± 0.004 | 1.342 | ± 0.014 | IAEA-CRP-XG | [2] |
| | | | | 1489.148 | ± 0.003 | 0.296 | ± 0.005 | | |
| | | | | 2185.645 | ± 0.005 | 0.680 | ± 0.018 | | |

Table B-2. Gamma-ray energies and emission probabilities for fission products.

| Nuclide | Half-life $T_{1/2}$ | | Units | γ rays Energy [keV] | | Emission probability [% decay] | | Source | Notes |
|---|---|---|---|---|---|---|---|---|---|
| 60-Nd-147 | 10.98 | ± 0.01 | d | 91.105 | ± 0.002 | 27.9 | ± 1.1 | ENSDF | |
| | | | | 275.374 | ± 0.015 | 0.80 | ± 0.06 | | |
| | | | | 319.411 | ± 0.018 | 1.95 | ± 0.14 | | |
| | | | | 398.155 | ± 0.020 | 0.87 | ± 0.07 | | |
| | | | | 439.895 | ± 0.022 | 1.20 | ± 0.10 | | |
| | | | | 531.016 | ± 0.022 | 13.1 | ± 0.9 | | |
| | | | | 685.90 | ± 0.04 | 0.81 | ± 0.06 | | |
| 61-Pm-147 | 2.6234 | ± 0.0002 | y | 121.220 | ± 0.017 | 0.00285 | ± 0.00011 | ENSDF | [3] |
| 61-Pm-148 | 5.368 | ± 0.002 | d | 550.27 | ± 0.03 | 22.0 | ± 0.5 | ENSDF | |
| | | | | 611.26 | ± 0.03 | 1.02 | ± 0.03 | | |
| | | | | 896.42 | ± 0.03 | 0.98 | ± 0.02 | | |
| | | | | 914.85 | ± 0.03 | 11.5 | ± 0.3 | | |
| | | | | 1465.12 | ± 0.03 | 22.2 | ± 0.5 | | |
| 61-Pm-148m | 41.29 | ± 0.11 | d | 98.48 | ± 0.03 | 2.47 | ± 0.05 | ENSDF | |
| | | | | 189.63 | ± 0.03 | 1.10 | ± 0.03 | | |
| | | | | 288.11 | ± 0.03 | 12.56 | ± 0.16 | | |
| | | | | 311.63 | ± 0.03 | 3.92 | ± 0.06 | | |
| | | | | 414.07 | ± 0.03 | 18.66 | ± 0.24 | | |
| | | | | 432.78 | ± 0.03 | 5.35 | ± 0.08 | | |
| | | | | 501.26 | ± 0.03 | 6.75 | ± 0.10 | | |
| | | | | 550.27 | ± 0.03 | 94.9 | ± 1.2 | | |
| | | | | 599.74 | ± 0.03 | 12.54 | ± 0.17 | | |
| | | | | 611.26 | ± 0.03 | 5.48 | ± 0.10 | | |
| | | | | 629.97 | ± 0.03 | 89.0 | ± 0.9 | | |
| | | | | 725.70 | ± 0.03 | 32.8 | ± 0.5 | | |
| | | | | 915.33 | ± 0.03 | 17.17 | ± 0.25 | | |
| | | | | 1013.81 | ± 0.03 | 20.3 | ± 0.3 | | |
| 63-Eu-154 | 8.592 | ± 0.004 | y | 123.0706 | ± 0.0009 | 40.4 | ± 0.5 | IAEA-CRP-XG | |
| | | | | 247.9288 | ± 0.0007 | 6.89 | ± 0.07 | | |
| | | | | 591.755 | ± 0.003 | 4.95 | ± 0.05 | | |
| | | | | 692.4205 | ± 0.0018 | 1.79 | ± 0.03 | | |
| | | | | 723.3014 | ± 0.0022 | 20.05 | ± 0.21 | | |
| | | | | 756.8020 | ± 0.0023 | 4.53 | ± 0.05 | | |
| | | | | 873.1834 | ± 0.0023 | 12.17 | ± 0.12 | | |
| | | | | 996.262 | ± 0.006 | 10.50 | ± 0.10 | | |
| | | | | 1004.725 | ± 0.007 | 17.85 | ± 0.17 | | |
| | | | | 1246.121 | ± 0.004 | 0.862 | ± 0.008 | | |
| | | | | 1274.429 | ± 0.004 | 34.9 | ± 0.3 | | |
| | | | | 1596.4804 | ± 0.0028 | 1.783 | ± 0.017 | | |
| 63-Eu-155 | 4.753 | ± 0.016 | y | 45.2990 | ± 0.0010 | 1.31 | ± 0.05 | IAEA-CRP-XG | |
| | | | | 60.0086 | ± 0.0010 | 1.22 | ± 0.05 | | |
| | | | | 86.0591 | ± 0.0010 | 0.154 | ± 0.017 | | |
| | | | | 86.5479 | ± 0.0010 | 30.7 | ± 0.3 | | |
| | | | | 105.3083 | ± 0.0010 | 21.1 | ± 0.6 | | |

[1] 511.8534-keV emission is extremely close in energy to any annihilation radiation.

[2] Half-life adopted from ENSDF; gamma-ray data taken from IAEA-CRP-XG.

[3] Only low intensity emission (no alternative).

B-3 Fission product data: Thermal neutron cross sections, resonance integrals and Westcott factors.

References


ANR: S.F. Mughabghab, Atlas of Neutron Resonances, Resonance Parameters and Thermal Cross Sections, Z = 1 - 100, 5th Edition, Elsevier, Amsterdam, 2006.

ENDF/B-VII: US Evaluated Nuclear Data Library ENDF/B-VII β3, Incident neutron data, http://www.nndc.bnl.gov/exfor4/endf00.htm, 2 October 2006; see also M.B. Chadwick et al., ENDF/B-VII.0 : Next Generation Evaluated Nuclear Data Library for Nuclear Science and Technology, Nucl. Data Sheets, 107 (2006) 2931.

JENDL-3.3: Japanese Evaluated Nuclear Data Library, Incident neutron data, http://www-nds.iaea.org/exfor/endf00.htm, 2 October 2006.

HAR-91: H. Harada et al., Proceedings of 1990 Symposium on Nuclear Data, Japan Atomic Energy Research Institute Report JAERI-M 91-032 (1991) 199.

GRY-87: G. Gryntakis et al., Handbook on Nuclear Activation Data, IAEA Technical Reports Series No. 273 (1987) 199.

SEK-87: T. Sekine et al., Triple Neutron Capture of $^{153}$Eu in a Reactor: the Cross Sections of $^{154}$Eu and $^{155}$Eu, Appl. Radiat. Isot. 38 (1987) 513.


| | |
|---|---|
| $\sigma_0$ | Neutron cross section at 2200 m/s. |
| $\sigma$ | Neutron cross section measured in a Maxwellian spectrum. |
| $\sigma_r$ | Neutron cross section measured with reactor neutrons. |
| $\sigma_c$ | 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 $\sigma_0$ ($g = \sigma/\sigma_o$). If the cross section varies as a function of 1/v, g = 1.0. |
| RI | Infinite dilution resonance integral (including the 1/v contribution). |
| γ | Subscript for radiative capture cross section. |
| f | Subscript for fission cross section. |

Table B-3: Fission product data: Thermal neutron cross sections, resonance integrals and Westcott factors.

| Nuclide | Type | Thermal Cross Section $\sigma_x$ [barn] | Westcott Factor g | Resonance Integral RI [barn] | Source |
|---|---|---|---|---|---|
| 36-Kr- 82 | $\sigma_\gamma$ | 19. ± 4. | 1.0004 | 156. ± 20. | [1] |
| 36-Kr- 83 | $\sigma_\gamma$ | 197. ± 10. | 0.9979 | 157. ± 25. | [1] |
| 36-Kr- 84 | $\sigma_\gamma$ | 0.110 ± 0.015 | 1.0004 | 2.43 ± 0.20 | [1] |
| | $\sigma_{\gamma(g)}$ | 0.042 ± 0.004 | | | |
| | $\sigma_{\gamma(m)}$ | 0.090 ± 0.013 | | | |
| 36-Kr- 85 | $\sigma_\gamma$ | 1.66 ± 0.20 | 0.9996 | 1.8 ± 1.0 | [1] |
| 40-Zr- 90 | $\sigma_\gamma$ | 0.077 ± 0.016 | 1.0003 | 0.17 ± 0.02 | [1] |
| 40-Zr- 91 | $\sigma_\gamma$ | 0.83 ± 0.08 | 1.0003 | 5.76 ± 0.40 | [1] |
| 40-Zr- 92 | $\sigma_\gamma$ | 0.26 ± 0.08 | 1.0004 | 0.64 ± 0.11 | [2] |
| 40-Zr- 93 | $\sigma_\gamma$ | 0.696 | 1.0007 | 17.8 | [3] |

Table B-3: Fission product data: Thermal neutron cross sections, resonance integrals and Westcott factors.

| Nuclide | Type | Thermal Cross Section $\sigma_x$ [barn] | | | Westcott Factor g | Resonance Integral RI [barn] | | | Source |
|---|---|---|---|---|---|---|---|---|---|
| 40-Zr- 94 | $\sigma_\gamma$ | 0.0494 | ± | 0.0017 | 1.0004 | 0.280 | ± | 0.010 | [1] |
| 40-Zr- 95 | $\sigma_{0\gamma}$ | 1.2 | | | 1.0004 | 7.79 | | | [4] |
| 40-Zr- 96 | $\sigma_\gamma$ | 0.0229 | ± | 0.0010 | 1.0006 | 5.28 | ± | 0.11 | [1] |
| 42-Mo- 95 | $\sigma_\gamma$ | 13.4 | ± | 0.3 | 1.0000 | 118. | ± | 7. | [1] |
| 42-Mo- 96 | $\sigma_\gamma$ | 0.5 | ± | 0.2 | 1.0006 | 17. | ± | 3. | [1] |
| 42-Mo- 97 | $\sigma_\gamma$ | 2.2 | ± | 0.2 | 1.0001 | 14.4 | ± | 3.0 | [1] |
| 42-Mo- 98 | $\sigma_{0\gamma}$ | 0.130 | ± | 0.006 | 1.0008 | 6.7 | ± | 0.3 | [1] |
| 42-Mo-100 | $\sigma_\gamma$ | 0.199 | ± | 0.003 | 1.0003 | 3.76 | ± | 0.15 | [1] |
| 44-Ru-100 | $\sigma_{0\gamma}$ | 5.8 | ± | 0.4 | 1.0003 | 11.2 | ± | 1.1 | [1] |
| 44-Ru-101 | $\sigma_{0\gamma}$ | 5.2 | ± | 0.3 | 1.0011 | 102. | ± | 10. | [1] |
| 44-Ru-102 | $\sigma_{0\gamma}$ | 1.27 | ± | 0.04 | 1.0003 | 4.9 | ± | 0.3 | [1] |
| 44-Ru-103 | $\sigma_\gamma$ | 1.2 | | | 1.0017 | 47. | | | [5] |
| 44-Ru-104 | $\sigma_{0\gamma}$ | 0.491 | ± | 0.010 | 1.0004 | 6.3 | ± | 0.2 | [1] |
| 44-Ru-106 | $\sigma_{0\gamma}$ | 0.146 | ± | 0.045 | 1.0004 | 2.0 | ± | 0.6 | [1] |
| 54-Xe-130 | $\sigma_{0\gamma}$ | 4.8 | ± | 1.2 | 0.9984 | 4.8 | | | [6] |
| | $\sigma_{0\gamma(m)}$ | 0.45 | ± | 0.10 | | | | | |
| 54-Xe-131 | $\sigma_{0\gamma}$ | 87. | ± | 10. | 1.0015 | 890. | ± | 50. | [1] |
| 54-Xe-132 | $\sigma_{0\gamma}$ | 0.45 | ± | 0.06 | 1.0004 | 5.0 | ± | 0.6 | [1] |
| | $\sigma_{0\gamma(m)}$ | 0.05 | ± | 0.01 | | 0.9 | ± | 0.2 | |
| 54-Xe-133 | $\sigma_{r\gamma}$ | 190. | ± | 90. | 1.0004 | 90. | | | [7] |
| 54-Xe-135 | $\sigma_{0\gamma}$ | 2650000. | ± | 110000. | 1.1594 | 7600. | ± | 500. | [1] |
| 54-Xe-136 | $\sigma_{0\gamma}$ | 0.26 | ± | 0.02 | 1.0007 | 0.74 | ± | 0.21 | [8] |
| 55-Cs-133 | $\sigma_{0\gamma}$ | 30.3 | ± | 1.1 | 1.0029 | 437. | ± | 26. | [1] |
| | $\sigma_{0\gamma(m)}$ | 2.6 | ± | 0.1 | | 29.0 | ± | 1.1 | |
| 55-Cs-134 | $\sigma_{r\gamma}$ | 140. | ± | 12. | 0.9985 | 105. | | | [9] |
| 55-Cs-135 | $\sigma_\gamma$ | 8.3 | ± | 0.3 | 0.9977 | 37.9 | ± | 2.7 | [10] |
| 55-Cs-137 | $\sigma_{r\gamma}$ | 0.27 | ± | 0.03 | 1.0005 | 0.35 | | | [11] |

Table B-3: Fission product data: Thermal neutron cross sections, resonance integrals and Westcott factors.

| Nuclide | Type | Thermal Cross Section $\sigma_x$ [barn] | | | Westcott Factor g | Resonance Integral RI [barn] | | | Source |
|---|---|---|---|---|---|---|---|---|---|
| 58-Ce-144 | $\sigma_\gamma$ | 1.0 | ± | 0.1 | 1.0005 | 2.6 | ± | 0.3 | [1] |
| 59-Pr-141 | $\sigma_{0\gamma}$ | 11.5 | ± | 0.3 | 0.9996 | 17.4 | ± | 2.0 | [1] |
| | $\sigma_{0\gamma(m)}$ | 3.9 | ± | 0.3 | | | | | |
| 59-Pr-143 | $\sigma_{0\gamma}$ | 90. | ± | 10. | 0.9998 | 190. | ± | 25. | [1] |
| 60-Nd-142 | $\sigma_\gamma$ | 18.7 | ± | 0.7 | 0.9990 | 6.2 | | | [12] |
| 60-Nd-143 | $\sigma_{0\gamma}$ | 325. | ± | 10. | 0.9967 | 129. | ± | 30. | [1] |
| 60-Nd-144 | $\sigma_\gamma$ | 3.6 | ± | 0.3 | 1.0004 | 4.2 | ± | 0.5 | [1] |
| 60-Nd-145 | $\sigma_{0\gamma}$ | 50.0 | ± | 1.0 | 1.0001 | 230. | ± | 35. | [1] |
| 60-Nd-146 | $\sigma_{0\gamma}$ | 1.49 | ± | 0.06 | 1.0004 | 2.57 | ± | 0.14 | [1] |
| 60-Nd-147 | $\sigma_\gamma$ | 440. | ± | 150. | 0.9957 | 539.8 | | | [13] |
| 60-Nd-148 | $\sigma_{0\gamma}$ | 2.58 | ± | 0.07 | 1.0005 | 15.5 | ± | 1.5 | [1] |
| 60-Nd-150 | $\sigma_{0\gamma}$ | 1.04 | ± | 0.04 | 1.0003 | 15.2 | ± | 0.8 | [1] |
| 61-Pm-147 | $\sigma_{0\gamma}$ | 168.4 | ± | 3.5 | 0.9971 | 2064. | ± | 100. | [1] |
| | $\sigma_{0\gamma(g)}$ | 96.0 | ± | 1.8 | | 1274. | ± | 66. | |
| | $\sigma_{0\gamma(m)}$ | 72.4 | ± | 3.0 | | 790. | ± | 100. | |
| 61-Pm-148 | $\sigma_{r\gamma}$ | 2000. | ± | 1000. | 1.0005 | 2515. | | | [14] |
| 61-Pm-148m | $\sigma_{0\gamma}$ | 10600. | ± | 1000. | 1.4863 | 3600. | ± | 2400. | [1] |
| 61-Pm-149 | $\sigma_\gamma$ | 1400. | ± | 300. | 1.0005 | 1577. | | | [14] |
| 61-Pm-151 | $\sigma_{0\gamma}$ | 150. | | | 1.0068 | 2977. | | | [15] |
| 62-Sm-147 | $\sigma_{0\gamma}$ | 57. | ± | 3. | 0.9965 | 777. | ± | 30. | [1] |
| 62-Sm-148 | $\sigma_\gamma$ | 2.4 | ± | 0.6 | 0.9995 | 27. | ± | 14. | [1] |
| 62-Sm-149 | $\sigma_{0\gamma}$ | 40140. | ± | 600. | 1.7102 | 3390. | | | [16] |
| 62-Sm-150 | $\sigma_{0\gamma}$ | 100. | ± | 4. | 0.9985 | 358. | ± | 50. | [17] |
| 62-Sm-151 | $\sigma_{0\gamma}$ | 15170. | ± | 300. | 0.9274 | 3765. | ± | 160. | [17] |
| 62-Sm-152 | $\sigma_{0\gamma}$ | 206. | ± | 6. | 1.0036 | 2970. | ± | 100. | [1] |
| 62-Sm-153 | $\sigma_{0\gamma}$ | 420. | ± | 180. | 0.9999 | 4872. | | | [18] |
| 62-Sm-154 | $\sigma_\gamma$ | 8.3 | ± | 0.5 | 0.9994 | 36. | ± | 4. | [1] |

Table B-3: Fission product data: Thermal neutron cross sections, resonance integrals and Westcott factors.

| Nuclide | Type | Thermal Cross Section $\sigma_x$ [barn] | Westcott Factor g | Resonance Integral RI [barn] | Source |
|---|---|---|---|---|---|
| 63-Eu-151 | $\sigma_{0\gamma}$ | 9200. ± 100. | 0.8940 | 3300. ± 300. | [19] |
| | $\sigma_{0\gamma(g)}$ | 5900. ± 200. | | 1510. ± 330. | |
| | $\sigma_{0\gamma(m1)}$ | 3300. ± 200. | | 1790. ± 140. | |
| | $\sigma_{r\,\gamma(m2)}$ | 4.0 ± 2.0 | | | |
| 63-Eu-152 | $\sigma_{0\gamma}$ | 12800. ± 600. | 0.967 ± 0.058 | 2310. | [20] |
| 63-Eu-153 | $\sigma_{0\gamma}$ | 312. ± 7. | 0.9860 | 1420. ± 100. | [17] |
| 63-Eu-154 | $\sigma_{0\gamma}$ | 1340. ± 130. | 1.2290 | 1300. | [21] |
| 63-Eu-155 | $\sigma_{\gamma}$ | 3950. ± 125. | 1.0219 | 15528. | [22] |

[1] Cross-section data and resonance integral adopted from ANR; Westcott factor calculated from the ENDF/B-VII library.

[2] Cross-section data adopted from ANR; value of the resonance integral adopted from ANR; RI uncertainty adopted from GRY-87; Westcott factor calculated from the ENDF/B-VII library.

[3] Data adopted from ENDF/B-VII; $\sigma_{\gamma}$ < 4 barns and RI = 17.5 barns are reported in ANR; $\sigma_{\gamma}$ = 2.24 barns and RI = 18.2 barns are reported in JENDL-3.3.

[4] Data adopted from the ENDF/B-VII library; ENDF/B-VII data were adopted from JENDL-3.3; no data available in ANR.

[5] Data adopted from the ENDF/B-VII library; values in ANR are 1.2 and 5 barns for the thermal cross section and resonance integral, respectively; no uncertainty was reported.

[6] Cross-section data and resonance integral adopted from ANR; RI uncertainty not available; Westcott factor calculated from the ENDF/B-VII library.

[7] Cross-section data adopted from ANR; resonance integral and Westcott factor calculated from the ENDF/B-VII library; resonance integral not reported in ANR.

[8] Cross-section data and resonance integral adopted from ANR; Westcott factor calculated from the ENDF/B-VII library; RI = 0.14 ± 0.01 barns from resolved resonance parameters.

[9] Cross-section data adopted from ANR; resonance integral and Westcott factor calculated from the ENDF/B-VII library; RI = 76 barns is reported in ANR from the resolved resonance parameters.

[10] Cross-section data and resonance integral adopted from ANR; Westcott factor calculated from the ENDF/B-VII library; RI = 50.9 barns in the ENDF/B-VII library.

[11] Cross-section data adopted from ANR; resonance integral and Westcott factor calculated from the ENDF/B-VII library; measured RI = 0.35 ± 0.07 barns reported by HAR-91.

[12] Cross-section data adopted from ANR; resonance integral and Westcott factor calculated from the ENDF/B-VII library; values of 34 ± 11 and 8.8 ± 0.5 barns are also reported in ANR - the first is an experimental value and the second was calculated from the resolved resonance parameters; the ENDF/B-VII evaluation is in good agreement with recent measurements of the capture cross section in the energy range between 3 and 225 keV.

[13] Cross-section data adopted from ANR; resonance integral and Westcott factor calculated from the ENDF/B-VII library; a resonace integral of 430 barns was calculated from the resolved resonance parameters, and is reported in ANR.

[14] Cross-section data adopted from ANR; resonance integral and Westcott factor calculated from the ENDF/B-VII library; resonance integrals are not reported in ANR.

[15] Data adopted from the ENDF/B-VII library; an upper limit of 700 barns is reported for $\sigma_{\gamma}$ in ANR.

[16] Data adopted from ANR; resonance integral calculated from resolved resonance parameters; a resonance integral of 3700 ± 400 barns is reported by GRY-87.

[17] All data adopted from ANR.

[18] Cross-section data adopted from ANR; Westcott factor and resonance integral calculated from the ENDF/B-VII library; a resonance integral of 3700 ± 2000 barns is reported by GRY-87.

[19] All data adopted from ANR; resonance integral is not available for the Eu-151(n,γ)Eu-152$m_2$ reaction.

[20] Cross-section data and Westcott factor taken from ANR; resonance integral calculated from the ENDF/B-VII library; a value of 2170 barns is reported in JENDL-3.3 for the resonance integral.

[21] Cross-section data taken from ANR; Westcott factor calculated from the ENDF/B-VII library, a value of g = 0.8979 is reported in ANR; resonance integral adopted from the ENDF/B-VII library, while a value of 1500 ± 450 barns is reported by GRY-87.

[22] Cross-section data taken from ANR; resonance integral and Westcott factor calculated from the ENDF/B-VII library; resonance integral in the ENDF/B-VII library is in good agreement with the value of 15300 ± 2700 barns reported by SEK-91; a resonance integral of 23200 ± 300 barns is reported in ANR.

C-1.1: Th-232 chain fission yields.

Reference

JEFF-3.1: Joint Evaluated Fission and Fusion File, Incident neutron data, http://www-nds.iaea.org/exfor/endf00.htm, 2 October 2006; see also A. Koning, R. Forrest, M. Kellett, R. Mills, H. Henriksson, Y. Rugama, The JEFF-3.1 Nuclear Data Library, JEFF Report 21, OECD/NEA, Paris, France, 2006, ISBN 92-64-02314-3.

Table C-1.1: Th-232 chain fission yields.

| FPA | Fast Fission Yield [% per fission] | | | 14-MeV Fission Yield [% per fission] | | |
|---|---|---|---|---|---|---|
| 1 | 0.00161 | ± | 0.00027 | 0.00232 | ± | 0.00039 |
| 2 | 0.000491 | ± | 0.000076 | 0.00071 | ± | 0.00011 |
| 3 | 0.00701 | ± | 0.00069 | 0.0101 | ± | 0.0010 |
| 4 | 0.1016 | ± | 0.0059 | 0.1467 | ± | 0.0085 |
| 69 | 0.0000025 | ± | 0.0000004 | 0.00083 | ± | 0.00013 |
| 70 | 0.0000111 | ± | 0.0000017 | 0.00167 | ± | 0.00025 |
| 71 | 0.0000454 | ± | 0.0000068 | 0.00309 | ± | 0.00046 |
| 72 | 0.000172 | ± | 0.000034 | 0.00530 | ± | 0.00080 |
| 73 | 0.000507 | ± | 0.000076 | 0.0108 | ± | 0.0016 |
| 74 | 0.00138 | ± | 0.00020 | 0.0216 | ± | 0.0032 |
| 75 | 0.00317 | ± | 0.00048 | 0.0393 | ± | 0.0061 |
| 76 | 0.00656 | ± | 0.00100 | 0.071 | ± | 0.011 |
| 77 | 0.0109 | ± | 0.0012 | 0.123 | ± | 0.016 |
| 78 | 0.0330 | ± | 0.0052 | 0.287 | ± | 0.059 |
| 79 | 0.089 | ± | 0.015 | 0.81 | ± | 0.22 |
| 80 | 0.233 | ± | 0.045 | 1.15 | ± | 0.36 |
| 81 | 0.52 | ± | 0.12 | 1.45 | ± | 0.58 |
| 82 | 1.13 | ± | 0.32 | 1.86 | ± | 0.83 |
| 83 | 2.08 | ± | 0.44 | 2.52 | ± | 0.91 |
| 84 | 4.64 | ± | 0.74 | 3.43 | ± | 0.84 |
| 85 | 4.29 | ± | 0.24 | 4.01 | ± | 0.69 |
| 86 | 6.9 | ± | 1.5 | 4.78 | ± | 0.81 |
| 87 | 6.77 | ± | 0.63 | 5.4 | ± | 1.1 |
| 88 | 7.06 | ± | 0.40 | 5.07 | ± | 0.25 |
| 89 | 7.21 | ± | 0.70 | 5.96 | ± | 0.73 |
| 90 | 7.32 | ± | 0.36 | 6.2 | ± | 1.5 |
| 91 | 7.1 | ± | 1.3 | 5.85 | ± | 0.28 |
| 92 | 7.07 | ± | 0.28 | 5.39 | ± | 0.20 |
| 93 | 6.46 | ± | 0.48 | 5.75 | ± | 0.23 |
| 94 | 5.33 | ± | 0.24 | 5.6 | ± | 1.1 |
| 95 | 5.52 | ± | 0.17 | 4.82 | ± | 0.49 |
| 96 | 5.16 | ± | 0.62 | 4.10 | ± | 0.66 |
| 97 | 4.46 | ± | 0.12 | 3.11 | ± | 0.24 |
| 98 | 3.74 | ± | 0.62 | 2.52 | ± | 0.44 |
| 99 | 2.919 | ± | 0.076 | 1.953 | ± | 0.098 |
| 100 | 1.73 | ± | 0.26 | 1.79 | ± | 0.37 |
| 101 | 0.86 | ± | 0.13 | 1.61 | ± | 0.25 |
| 102 | 0.371 | ± | 0.056 | 1.20 | ± | 0.21 |
| 103 | 0.1538 | ± | 0.0095 | 0.884 | ± | 0.064 |
| 104 | 0.090 | ± | 0.013 | 0.95 | ± | 0.14 |
| 105 | 0.0711 | ± | 0.0032 | 1.017 | ± | 0.060 |

Table C-1.1: Th-232 chain fission yields.

| FPA | Fast Fission Yield [% per fission] | | 14-MeV Fission Yield [% per fission] | |
|---|---|---|---|---|
| 106 | 0.0541 | ± 0.0031 | 1.101 | ± 0.083 |
| 107 | 0.0525 | ± 0.0079 | 1.07 | ± 0.17 |
| 108 | 0.0535 | ± 0.0080 | 1.06 | ± 0.16 |
| 109 | 0.0532 | ± 0.0043 | 1.03 | ± 0.11 |
| 110 | 0.0591 | ± 0.0089 | 1.14 | ± 0.19 |
| 111 | 0.0650 | ± 0.0060 | 1.187 | ± 0.065 |
| 112 | 0.0693 | ± 0.0078 | 1.219 | ± 0.067 |
| 113 | 0.068 | ± 0.010 | 1.199 | ± 0.056 |
| 114 | 0.068 | ± 0.010 | 1.25 | ± 0.24 |
| 115 | 0.0662 | ± 0.0079 | 1.20 | ± 0.21 |
| 116 | 0.067 | ± 0.010 | 1.17 | ± 0.21 |
| 117 | 0.068 | ± 0.010 | 1.14 | ± 0.22 |
| 118 | 0.067 | ± 0.010 | 1.10 | ± 0.21 |
| 119 | 0.066 | ± 0.010 | 1.06 | ± 0.20 |
| 120 | 0.0652 | ± 0.0098 | 1.01 | ± 0.19 |
| 121 | 0.0636 | ± 0.0096 | 0.929 | ± 0.078 |
| 122 | 0.0617 | ± 0.0093 | 0.98 | ± 0.18 |
| 123 | 0.0595 | ± 0.0089 | 1.00 | ± 0.18 |
| 124 | 0.0573 | ± 0.0086 | 1.02 | ± 0.18 |
| 125 | 0.0560 | ± 0.0084 | 1.04 | ± 0.18 |
| 126 | 0.0593 | ± 0.0087 | 1.08 | ± 0.17 |
| 127 | 0.0800 | ± 0.0070 | 1.138 | ± 0.065 |
| 128 | 0.170 | ± 0.026 | 1.36 | ± 0.23 |
| 129 | 0.431 | ± 0.089 | 1.68 | ± 0.33 |
| 130 | 0.85 | ± 0.14 | 1.82 | ± 0.44 |
| 131 | 1.513 | ± 0.083 | 2.31 | ± 0.14 |
| 132 | 2.60 | ± 0.10 | 2.99 | ± 0.15 |
| 133 | 4.53 | ± 0.19 | 4.12 | ± 0.21 |
| 134 | 5.84 | ± 0.31 | 5.88 | ± 0.42 |
| 135 | 5.47 | ± 0.26 | 5.20 | ± 0.36 |
| 136 | 5.99 | ± 0.23 | 6.69 | ± 0.35 |
| 137 | 6.30 | ± 0.30 | 6.29 | ± 0.99 |
| 138 | 6.37 | ± 0.20 | 6.14 | ± 0.96 |
| 139 | 7.12 | ± 0.41 | 5.64 | ± 0.42 |
| 140 | 7.71 | ± 0.25 | 5.69 | ± 0.20 |
| 141 | 7.11 | ± 0.28 | 5.72 | ± 0.38 |
| 142 | 6.54 | ± 0.21 | 5.14 | ± 0.40 |
| 143 | 6.49 | ± 0.30 | 4.96 | ± 0.24 |
| 144 | 7.66 | ± 0.55 | 3.90 | ± 0.78 |
| 145 | 5.06 | ± 0.70 | 3.1 | ± 1.2 |
| 146 | 3.6 | ± 1.1 | 2.42 | ± 0.59 |
| 147 | 3.03 | ± 0.18 | 1.79 | ± 0.11 |
| 148 | 1.95 | ± 0.18 | 1.39 | ± 0.36 |
| 149 | 1.11 | ± 0.16 | 0.93 | ± 0.30 |
| 150 | 0.77 | ± 0.41 | 0.406 | ± 0.077 |
| 151 | 0.399 | ± 0.065 | 0.165 | ± 0.035 |
| 152 | 0.300 | ± 0.083 | 0.123 | ± 0.020 |
| 153 | 0.202 | ± 0.027 | 0.0858 | ± 0.0070 |
| 154 | 0.062 | ± 0.011 | 0.075 | ± 0.012 |
| 155 | 0.0158 | ± 0.0025 | 0.0552 | ± 0.0086 |
| 156 | 0.00252 | ± 0.00032 | 0.0363 | ± 0.0073 |
| 157 | 0.00086 | ± 0.00013 | 0.0187 | ± 0.0028 |

Table C-1.1: Th-232 chain fission yields.

| FPA | Fast Fission Yield [% per fission] | | | 14-MeV Fission Yield [% per fission] | | |
|---|---|---|---|---|---|---|
| 158 | 0.000275 | ± | 0.000041 | 0.0093 | ± | 0.0014 |
| 159 | 0.000082 | ± | 0.000012 | 0.00440 | ± | 0.00044 |
| 160 | 0.0000224 | ± | 0.0000034 | 0.00222 | ± | 0.00033 |
| 161 | 0.0000058 | ± | 0.0000009 | 0.001060 | ± | 0.000053 |
| 162 | 0.0000014 | ± | 0.0000002 | 0.000419 | ± | 0.000063 |

C-1.2: U-233 chain fission yields.

Reference

JEFF-3.1: Joint Evaluated Fission and Fusion File, Incident neutron data,
http://www-nds.iaea.org/exfor/endf00.htm, 2 October 2006;
see also A. Koning, R. Forrest, M. Kellett, R. Mills, H. Henriksson, Y. Rugama, The JEFF-3.1 Nuclear Data Library, JEFF Report 21, OECD/NEA, Paris, France, 2006,
ISBN 92-64-02314-3.

Table C-1.2: U-233 chain fission yields.

| FPA | Thermal Fission Yield [% per fission] | Fast Fission Yield [% per fission] | 14-MeV Fission Yield [% per fission] |
|---|---|---|---|
| 1 | 0.00334 ± 0.00055 | 0.00334 ± 0.00055 | 0.00310 ± 0.00059 |
| 2 | 0.00085 ± 0.00013 | 0.00102 ± 0.00015 | 0.00095 ± 0.00017 |
| 3 | 0.01140 ± 0.00050 | 0.01140 ± 0.00050 | 0.0248 ± 0.0056 |
| 4 | 0.2111 ± 0.0080 | 0.2110 ± 0.0080 | 0.196 ± 0.021 |
| 68 | 0.0000019 ± 0.0000003 | 0.0000017 ± 0.0000002 | 0.00277 ± 0.00041 |
| 69 | 0.0000072 ± 0.0000011 | 0.0000061 ± 0.0000009 | 0.00442 ± 0.00067 |
| 70 | 0.0000259 ± 0.0000039 | 0.0000211 ± 0.0000032 | 0.0068 ± 0.0010 |
| 71 | 0.000088 ± 0.000013 | 0.000069 ± 0.000010 | 0.0099 ± 0.0015 |
| 72 | 0.000281 ± 0.000043 | 0.000212 ± 0.000032 | 0.01365 ± 0.00097 |
| 73 | 0.00085 ± 0.00013 | 0.000614 ± 0.000092 | 0.0234 ± 0.0036 |
| 74 | 0.00244 ± 0.00040 | 0.00169 ± 0.00025 | 0.0393 ± 0.0060 |
| 75 | 0.0066 ± 0.0012 | 0.00431 ± 0.00065 | 0.0637 ± 0.0099 |
| 76 | 0.0173 ± 0.0037 | 0.0105 ± 0.0016 | 0.102 ± 0.016 |
| 77 | 0.0395 ± 0.0045 | 0.0240 ± 0.0036 | 0.158 ± 0.026 |
| 78 | 0.0634 ± 0.0054 | 0.0518 ± 0.0078 | 0.241 ± 0.041 |
| 79 | 0.1267 ± 0.0076 | 0.106 ± 0.016 | 0.359 ± 0.062 |
| 80 | 0.2496 ± 0.0092 | 0.204 ± 0.032 | 0.526 ± 0.095 |
| 81 | 0.371 ± 0.014 | 0.370 ± 0.060 | 0.75 ± 0.14 |
| 82 | 0.590 ± 0.030 | 0.64 ± 0.10 | 1.05 ± 0.21 |
| 83 | 1.070 ± 0.055 | 1.000 ± 0.053 | 1.36 ± 0.12 |
| 84 | 1.697 ± 0.040 | 1.681 ± 0.085 | 1.94 ± 0.42 |
| 85 | 2.166 ± 0.028 | 2.10 ± 0.10 | 2.39 ± 0.52 |
| 86 | 3.093 ± 0.030 | 2.85 ± 0.14 | 3.02 ± 0.61 |
| 87 | 4.008 ± 0.055 | 4.30 ± 0.43 | 3.72 ± 0.93 |
| 88 | 5.435 ± 0.060 | 5.18 ± 0.26 | 4.31 ± 0.34 |
| 89 | 6.02 ± 0.17 | 6.19 ± 0.40 | 4.88 ± 0.62 |
| 90 | 6.648 ± 0.073 | 6.39 ± 0.33 | 5.07 ± 0.80 |
| 91 | 6.569 ± 0.072 | 6.26 ± 0.32 | 5.02 ± 0.35 |
| 92 | 6.568 ± 0.072 | 6.51 ± 0.43 | 4.99 ± 0.59 |
| 93 | 6.950 ± 0.076 | 7.04 ± 0.38 | 5.66 ± 0.64 |
| 94 | 6.800 ± 0.068 | 6.70 ± 0.36 | 4.8 ± 1.4 |
| 95 | 6.386 ± 0.058 | 6.28 ± 0.18 | 5.05 ± 0.28 |
| 96 | 5.742 ± 0.057 | 5.74 ± 0.32 | 4.0 ± 1.7 |
| 97 | 5.574 ± 0.050 | 5.51 ± 0.16 | 4.76 ± 0.36 |
| 98 | 5.17 ± 0.16 | 5.14 ± 0.29 | 3.6 ± 1.4 |
| 99 | 5.03 ± 0.14 | 4.85 ± 0.17 | 3.87 ± 0.22 |
| 100 | 4.41 ± 0.15 | 4.42 ± 0.26 | 3.27 ± 0.91 |
| 101 | 3.219 ± 0.084 | 3.68 ± 0.74 | 3.18 ± 0.64 |
| 102 | 2.429 ± 0.027 | 2.61 ± 0.56 | 2.98 ± 0.47 |
| 103 | 1.458 ± 0.058 | 1.58 ± 0.16 | 2.72 ± 0.13 |
| 104 | 0.976 ± 0.014 | 1.01 ± 0.22 | 2.26 ± 0.35 |
| 105 | 0.501 ± 0.013 | 0.55 ± 0.11 | 1.84 ± 0.14 |

Table C-1.2: U-233 chain fission yields.

| FPA | Thermal Fission Yield [% per fission] | | Fast Fission Yield [% per fission] | | 14-MeV Fission Yield [% per fission] | |
|---|---|---|---|---|---|---|
| 106 | 0.2505 | ± 0.0078 | 0.291 | ± 0.029 | 1.46 | ± 0.26 |
| 107 | 0.1149 | ± 0.0034 | 0.160 | ± 0.027 | 1.36 | ± 0.32 |
| 108 | 0.0797 | ± 0.0026 | 0.101 | ± 0.017 | 1.31 | ± 0.35 |
| 109 | 0.0420 | ± 0.0045 | 0.076 | ± 0.013 | 1.31 | ± 0.39 |
| 110 | 0.0395 | ± 0.0043 | 0.068 | ± 0.011 | 1.26 | ± 0.34 |
| 111 | 0.0247 | ± 0.0021 | 0.065 | ± 0.011 | 1.31 | ± 0.16 |
| 112 | 0.0143 | ± 0.0010 | 0.063 | ± 0.010 | 1.61 | ± 0.12 |
| 113 | 0.0158 | ± 0.0027 | 0.062 | ± 0.010 | 1.19 | ± 0.29 |
| 114 | 0.0173 | ± 0.0031 | 0.061 | ± 0.010 | 1.12 | ± 0.32 |
| 115 | 0.0192 | ± 0.0016 | 0.0586 | ± 0.0043 | 1.27 | ± 0.17 |
| 116 | 0.0177 | ± 0.0030 | 0.0584 | ± 0.0098 | 1.36 | ± 0.34 |
| 117 | 0.0151 | ± 0.0011 | 0.0596 | ± 0.0064 | 1.33 | ± 0.32 |
| 118 | 0.0156 | ± 0.0011 | 0.0596 | ± 0.0064 | 1.30 | ± 0.32 |
| 119 | 0.0159 | ± 0.0013 | 0.0733 | ± 0.0088 | 1.26 | ± 0.30 |
| 120 | 0.0175 | ± 0.0013 | 0.0823 | ± 0.0090 | 1.22 | ± 0.28 |
| 121 | 0.0185 | ± 0.0012 | 0.080 | ± 0.013 | 1.19 | ± 0.25 |
| 122 | 0.0195 | ± 0.0012 | 0.0824 | ± 0.0089 | 1.22 | ± 0.26 |
| 123 | 0.0223 | ± 0.0034 | 0.090 | ± 0.015 | 1.28 | ± 0.26 |
| 124 | 0.0322 | ± 0.0022 | 0.119 | ± 0.012 | 1.39 | ± 0.23 |
| 125 | 0.116 | ± 0.014 | 0.149 | ± 0.011 | 1.516 | ± 0.095 |
| 126 | 0.233 | ± 0.032 | 0.325 | ± 0.075 | 1.79 | ± 0.24 |
| 127 | 0.47 | ± 0.11 | 0.50 | ± 0.19 | 2.14 | ± 0.11 |
| 128 | 0.93 | ± 0.15 | 1.17 | ± 0.51 | 2.50 | ± 0.41 |
| 129 | 1.63 | ± 0.26 | 1.73 | ± 0.24 | 3.01 | ± 0.43 |
| 130 | 2.65 | ± 0.43 | 2.40 | ± 0.60 | 3.69 | ± 0.64 |
| 131 | 3.565 | ± 0.100 | 3.86 | ± 0.13 | 4.47 | ± 0.94 |
| 132 | 4.80 | ± 0.14 | 4.71 | ± 0.12 | 4.01 | ± 0.39 |
| 133 | 5.98 | ± 0.17 | 5.70 | ± 0.17 | 4.56 | ± 0.49 |
| 134 | 6.29 | ± 0.25 | 6.37 | ± 0.36 | 4.81 | ± 0.43 |
| 135 | 5.50 | ± 0.37 | 6.28 | ± 0.27 | 5.24 | ± 0.67 |
| 136 | 8.7 | ± 2.0 | 6.92 | ± 0.33 | 5.8 | ± 1.3 |
| 137 | 6.21 | ± 0.22 | 6.51 | ± 0.31 | 5.06 | ± 0.43 |
| 138 | 6.02 | ± 0.38 | 6.62 | ± 0.42 | 5.9 | ± 1.1 |
| 139 | 5.625 | ± 0.096 | 6.47 | ± 0.41 | 5.81 | ± 0.31 |
| 140 | 6.45 | ± 0.26 | 6.20 | ± 0.20 | 4.71 | ± 0.33 |
| 141 | 6.218 | ± 0.081 | 6.49 | ± 0.23 | 4.49 | ± 0.17 |
| 142 | 6.83 | ± 0.33 | 6.47 | ± 0.41 | 3.75 | ± 0.60 |
| 143 | 5.91 | ± 0.12 | 5.38 | ± 0.28 | 3.18 | ± 0.12 |
| 144 | 4.655 | ± 0.093 | 4.49 | ± 0.18 | 2.46 | ± 0.52 |
| 145 | 3.399 | ± 0.068 | 3.24 | ± 0.19 | 1.93 | ± 0.46 |
| 146 | 2.529 | ± 0.048 | 2.41 | ± 0.14 | 1.51 | ± 0.37 |
| 147 | 1.827 | ± 0.086 | 1.737 | ± 0.050 | 1.251 | ± 0.073 |
| 148 | 1.294 | ± 0.025 | 1.204 | ± 0.060 | 0.98 | ± 0.22 |
| 149 | 0.769 | ± 0.031 | 0.717 | ± 0.034 | 0.81 | ± 0.18 |
| 150 | 0.4884 | ± 0.0073 | 0.466 | ± 0.023 | 0.64 | ± 0.12 |
| 151 | 0.333 | ± 0.017 | 0.312 | ± 0.014 | 0.49 | ± 0.11 |
| 152 | 0.1962 | ± 0.0084 | 0.1936 | ± 0.0095 | 0.281 | ± 0.050 |
| 153 | 0.106 | ± 0.042 | 0.118 | ± 0.022 | 0.144 | ± 0.017 |
| 154 | 0.0458 | ± 0.0022 | 0.067 | ± 0.010 | 0.099 | ± 0.016 |
| 155 | 0.0214 | ± 0.0060 | 0.0351 | ± 0.0053 | 0.067 | ± 0.011 |
| 156 | 0.0109 | ± 0.0018 | 0.0169 | ± 0.0027 | 0.0444 | ± 0.0035 |
| 157 | 0.0069 | ± 0.0011 | 0.0116 | ± 0.0019 | 0.0284 | ± 0.0044 |

Table C-1.2: U-233 chain fission yields.

| FPA | Thermal Fission Yield [% per fission] | Fast Fission Yield [% per fission] | 14-MeV Fission Yield [% per fission] |
|---|---|---|---|
| 158 | 0.00264 ± 0.00045 | 0.00485 ± 0.00073 | 0.0177 ± 0.0027 |
| 159 | 0.00096 ± 0.00012 | 0.00189 ± 0.00031 | 0.0108 ± 0.0014 |
| 160 | 0.000350 ± 0.000053 | 0.00110 ± 0.00016 | 0.0073 ± 0.0010 |
| 161 | 0.000119 ± 0.000016 | 0.000494 ± 0.000086 | 0.00475 ± 0.00041 |
| 162 | 0.0000338 ± 0.0000051 | 0.000140 ± 0.000021 | 0.00277 ± 0.00042 |
| 163 | 0.0000090 ± 0.0000013 | 0.0000375 ± 0.0000056 | 0.00157 ± 0.00024 |
| 164 | 0.0000022 ± 0.0000003 | 0.0000094 ± 0.0000014 | 0.00087 ± 0.00013 |

C-1.3: U-235 chain fission yields.

Reference

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Table C-1.3: U-235 chain fission yields.

| FPA | Thermal Fission Yield [% per fission] | Fast Fission Yield [% per fission] | 14-MeV Fission Yield [% per fission] |
|---|---|---|---|
| 1 | 0.00171 ± 0.00018 | 0.00269 ± 0.00044 | 0.00264 ± 0.00045 |
| 2 | 0.00084 ± 0.00015 | 0.00082 ± 0.00012 | 0.00081 ± 0.00012 |
| 3 | 0.01080 ± 0.00040 | 0.01080 ± 0.00040 | 0.0174 ± 0.0036 |
| 4 | 0.1702 ± 0.0049 | 0.1700 ± 0.0049 | 0.1667 ± 0.0088 |
| 70 | 0.0000033 ± 0.0000005 | 0.0000052 ± 0.0000008 | 0.00317 ± 0.00046 |
| 71 | 0.0000109 ± 0.0000016 | 0.0000175 ± 0.0000026 | 0.00456 ± 0.00068 |
| 72 | 0.0000340 ± 0.0000051 | 0.0000561 ± 0.0000084 | 0.00566 ± 0.00043 |
| 73 | 0.000100 ± 0.000019 | 0.000170 ± 0.000026 | 0.0115 ± 0.0012 |
| 74 | 0.000343 ± 0.000052 | 0.000492 ± 0.000074 | 0.0189 ± 0.0029 |
| 75 | 0.000828 ± 0.000084 | 0.00133 ± 0.00020 | 0.0301 ± 0.0046 |
| 76 | 0.00478 ± 0.00081 | 0.00346 ± 0.00054 | 0.0462 ± 0.0069 |
| 77 | 0.00849 ± 0.00070 | 0.0085 ± 0.0014 | 0.0682 ± 0.0070 |
| 78 | 0.0205 ± 0.0011 | 0.0201 ± 0.0035 | 0.121 ± 0.019 |
| 79 | 0.0487 ± 0.0053 | 0.0454 ± 0.0091 | 0.206 ± 0.033 |
| 80 | 0.1285 ± 0.0068 | 0.099 ± 0.023 | 0.338 ± 0.055 |
| 81 | 0.1975 ± 0.0097 | 0.200 ± 0.051 | 0.530 ± 0.085 |
| 82 | 0.328 ± 0.012 | 0.380 ± 0.099 | 0.78 ± 0.11 |
| 83 | 0.558 ± 0.016 | 0.587 ± 0.034 | 1.15 ± 0.13 |
| 84 | 1.028 ± 0.019 | 1.087 ± 0.063 | 1.42 ± 0.29 |
| 85 | 1.310 ± 0.012 | 1.313 ± 0.043 | 1.77 ± 0.34 |
| 86 | 2.003 ± 0.020 | 2.04 ± 0.13 | 2.20 ± 0.41 |
| 87 | 2.604 ± 0.028 | 2.69 ± 0.12 | 2.68 ± 0.28 |
| 88 | 3.569 ± 0.063 | 3.75 ± 0.26 | 3.79 ± 0.36 |
| 89 | 4.690 ± 0.057 | 4.38 ± 0.12 | 4.029 ± 0.085 |
| 90 | 5.73 ± 0.13 | 5.22 ± 0.18 | 4.41 ± 0.18 |
| 91 | 5.849 ± 0.053 | 5.37 ± 0.12 | 4.59 ± 0.14 |
| 92 | 6.041 ± 0.066 | 5.86 ± 0.16 | 5.00 ± 0.75 |
| 93 | 6.435 ± 0.089 | 6.06 ± 0.13 | 5.40 ± 0.58 |
| 94 | 6.403 ± 0.090 | 6.15 ± 0.33 | 5.04 ± 0.94 |
| 95 | 6.502 ± 0.072 | 6.349 ± 0.083 | 5.07 ± 0.19 |
| 96 | 6.302 ± 0.095 | 6.32 ± 0.48 | 4.8 ± 1.1 |
| 97 | 6.000 ± 0.083 | 6.033 ± 0.065 | 5.21 ± 0.25 |
| 98 | 5.734 ± 0.092 | 6.20 ± 0.63 | 4.6 ± 1.3 |
| 99 | 6.132 ± 0.092 | 5.80 ± 0.13 | 5.02 ± 0.13 |
| 100 | 6.25 ± 0.11 | 6.48 ± 0.36 | 4.1 ± 1.1 |
| 101 | 5.168 ± 0.088 | 5.24 ± 0.20 | 3.78 ± 0.92 |
| 102 | 4.286 ± 0.069 | 4.48 ± 0.22 | 3.42 ± 0.71 |
| 103 | 3.103 ± 0.084 | 3.248 ± 0.042 | 3.14 ± 0.11 |
| 104 | 1.876 ± 0.024 | 2.29 ± 0.27 | 2.46 ± 0.47 |
| 105 | 0.946 ± 0.010 | 1.282 ± 0.060 | 1.73 ± 0.22 |
| 106 | 0.410 ± 0.011 | 0.469 ± 0.036 | 2.15 ± 0.59 |
| 107 | 0.1393 ± 0.0060 | 0.184 ± 0.030 | 1.82 ± 0.47 |

Table C-1.3: U-235 chain fission yields.

| FPA | Thermal Fission Yield [% per fission] | | Fast Fission Yield [% per fission] | | 14-MeV Fission Yield [% per fission] | |
|---|---|---|---|---|---|---|
| 108 | 0.0571 | ± 0.0030 | 0.079 | ± 0.013 | 1.58 | ± 0.37 |
| 109 | 0.0288 | ± 0.0019 | 0.0457 | ± 0.0079 | 1.301 | ± 0.091 |
| 110 | 0.0254 | ± 0.0020 | 0.0363 | ± 0.0063 | 1.18 | ± 0.22 |
| 111 | 0.01970 | ± 0.00061 | 0.0329 | ± 0.0013 | 1.195 | ± 0.030 |
| 112 | 0.01183 | ± 0.00071 | 0.0265 | ± 0.0033 | 0.708 | ± 0.098 |
| 113 | 0.01596 | ± 0.00082 | 0.0346 | ± 0.0038 | 1.09 | ± 0.15 |
| 114 | 0.01288 | ± 0.00066 | 0.0315 | ± 0.0053 | 0.97 | ± 0.24 |
| 115 | 0.01136 | ± 0.00066 | 0.0270 | ± 0.0030 | 0.972 | ± 0.044 |
| 116 | 0.01604 | ± 0.00087 | 0.0363 | ± 0.0040 | 1.11 | ± 0.25 |
| 117 | 0.0123 | ± 0.0013 | 0.0381 | ± 0.0068 | 1.13 | ± 0.25 |
| 118 | 0.0136 | ± 0.0024 | 0.0407 | ± 0.0074 | 1.15 | ± 0.25 |
| 119 | 0.0150 | ± 0.0016 | 0.0427 | ± 0.0079 | 1.15 | ± 0.23 |
| 120 | 0.0146 | ± 0.0017 | 0.0442 | ± 0.0083 | 1.15 | ± 0.21 |
| 121 | 0.01260 | ± 0.00052 | 0.0451 | ± 0.0086 | 1.14 | ± 0.11 |
| 122 | 0.0180 | ± 0.0012 | 0.0456 | ± 0.0088 | 1.15 | ± 0.22 |
| 123 | 0.01506 | ± 0.00063 | 0.0465 | ± 0.0089 | 1.18 | ± 0.28 |
| 124 | 0.0316 | ± 0.0027 | 0.0505 | ± 0.0095 | 1.26 | ± 0.35 |
| 125 | 0.0260 | ± 0.0014 | 0.067 | ± 0.011 | 1.42 | ± 0.42 |
| 126 | 0.0594 | ± 0.0052 | 0.098 | ± 0.020 | 1.62 | ± 0.49 |
| 127 | 0.1202 | ± 0.0048 | 0.301 | ± 0.027 | 1.96 | ± 0.32 |
| 128 | 0.3306 | ± 0.0073 | 0.48 | ± 0.11 | 1.80 | ± 0.36 |
| 129 | 0.706 | ± 0.032 | 1.03 | ± 0.26 | 1.59 | ± 0.18 |
| 130 | 1.779 | ± 0.093 | 2.19 | ± 0.49 | 2.89 | ± 0.56 |
| 131 | 2.878 | ± 0.032 | 3.365 | ± 0.054 | 4.11 | ± 0.14 |
| 132 | 4.296 | ± 0.043 | 4.699 | ± 0.066 | 4.47 | ± 0.18 |
| 133 | 6.60 | ± 0.11 | 6.61 | ± 0.13 | 5.58 | ± 0.41 |
| 134 | 7.79 | ± 0.11 | 7.77 | ± 0.34 | 5.73 | ± 0.42 |
| 135 | 6.62 | ± 0.23 | 6.33 | ± 0.18 | 6.6 | ± 1.9 |
| 136 | 6.57 | ± 0.16 | 6.42 | ± 0.34 | 5.28 | ± 0.34 |
| 137 | 6.221 | ± 0.069 | 5.889 | ± 0.096 | 5.6 | ± 1.3 |
| 138 | 6.72 | ± 0.11 | 6.52 | ± 0.23 | 5.6 | ± 1.4 |
| 139 | 6.345 | ± 0.089 | 6.365 | ± 0.089 | 4.97 | ± 0.75 |
| 140 | 6.315 | ± 0.095 | 5.960 | ± 0.048 | 4.508 | ± 0.081 |
| 141 | 5.86 | ± 0.15 | 5.795 | ± 0.081 | 4.44 | ± 0.20 |
| 142 | 5.860 | ± 0.099 | 5.72 | ± 0.11 | 4.58 | ± 0.93 |
| 143 | 5.954 | ± 0.083 | 5.533 | ± 0.055 | 4.02 | ± 0.54 |
| 144 | 5.475 | ± 0.055 | 5.094 | ± 0.076 | 3.155 | ± 0.038 |
| 145 | 3.944 | ± 0.043 | 3.796 | ± 0.068 | 2.81 | ± 0.57 |
| 146 | 2.987 | ± 0.030 | 2.927 | ± 0.053 | 2.30 | ± 0.50 |
| 147 | 2.232 | ± 0.040 | 2.148 | ± 0.028 | 1.657 | ± 0.045 |
| 148 | 1.681 | ± 0.012 | 1.697 | ± 0.020 | 0.595 | ± 0.034 |
| 149 | 1.053 | ± 0.021 | 1.064 | ± 0.030 | 0.557 | ± 0.090 |
| 150 | 0.6508 | ± 0.0065 | 0.702 | ± 0.017 | 0.480 | ± 0.074 |
| 151 | 0.4204 | ± 0.0071 | 0.431 | ± 0.015 | 0.388 | ± 0.061 |
| 152 | 0.2526 | ± 0.0028 | 0.305 | ± 0.014 | 0.304 | ± 0.049 |
| 153 | 0.1477 | ± 0.0071 | 0.1512 | ± 0.0097 | 0.230 | ± 0.015 |
| 154 | 0.0726 | ± 0.0023 | 0.1111 | ± 0.0076 | 0.144 | ± 0.023 |
| 155 | 0.0308 | ± 0.0013 | 0.044 | ± 0.010 | 0.088 | ± 0.014 |
| 156 | 0.01334 | ± 0.00023 | 0.01783 | ± 0.00068 | 0.0520 | ± 0.0018 |
| 157 | 0.00657 | ± 0.00047 | 0.0116 | ± 0.0020 | 0.0336 | ± 0.0051 |
| 158 | 0.00194 | ± 0.00027 | 0.0065 | ± 0.0010 | 0.0210 | ± 0.0032 |
| 159 | 0.001061 | ± 0.000066 | 0.00317 | ± 0.00054 | 0.0127 | ± 0.0013 |

Table C-1.3: U-235 chain fission yields.

| FPA | Thermal Fission Yield [% per fission] | Fast Fission Yield [% per fission] | 14-MeV Fission Yield [% per fission] |
|---|---|---|---|
| 160 | 0.000310 ± 0.000047 | 0.00102 ± 0.00015 | 0.0082 ± 0.0012 |
| 161 | 0.0000810 ± 0.0000066 | 0.000302 ± 0.000026 | 0.00505 ± 0.00039 |
| 162 | 0.0000272 ± 0.0000041 | 0.000097 ± 0.000014 | 0.00317 ± 0.00047 |
| 163 | 0.0000086 ± 0.0000013 | 0.0000293 ± 0.0000044 | 0.00186 ± 0.00028 |
| 164 | 0.0000026 ± 0.0000004 | 0.0000084 ± 0.0000013 | 0.00104 ± 0.00016 |

C-1.4: U-238 chain fission yields.

Reference

JEFF-3.1: Joint Evaluated Fission and Fusion File, Incident neutron data, http://www-nds.iaea.org/exfor/endf00.htm, 2 October 2006; see also A. Koning, R. Forrest, M. Kellett, R. Mills, H. Henriksson, Y. Rugama, The JEFF-3.1 Nuclear Data Library, JEFF Report 21, OECD/NEA, Paris, France, 2006, ISBN 92-64-02314-3.

Table C-1.4: U-238 chain fission yields.

| FPA | Fast Fission Yield [% per fission] | | | 14-MeV Fission Yield [% per fission] | | |
|---|---|---|---|---|---|---|
| 1 | 0.00235 | ± | 0.00040 | 0.00130 | ± | 0.00024 |
| 2 | 0.00072 | ± | 0.00011 | 0.000398 | ± | 0.000068 |
| 3 | 0.0103 | ± | 0.0010 | 0.0065 | ± | 0.0014 |
| 4 | 0.1488 | ± | 0.0086 | 0.0823 | ± | 0.0078 |
| 68 | 0.0000013 | ± | 0.0000002 | 0.000282 | ± | 0.000042 |
| 69 | 0.0000035 | ± | 0.0000005 | 0.000528 | ± | 0.000079 |
| 70 | 0.0000094 | ± | 0.0000014 | 0.00099 | ± | 0.00015 |
| 71 | 0.0000242 | ± | 0.0000036 | 0.00175 | ± | 0.00026 |
| 72 | 0.0000601 | ± | 0.0000090 | 0.00300 | ± | 0.00042 |
| 73 | 0.000143 | ± | 0.000021 | 0.0054 | ± | 0.0010 |
| 74 | 0.000336 | ± | 0.000049 | 0.0091 | ± | 0.0014 |
| 75 | 0.00071 | ± | 0.00011 | 0.0141 | ± | 0.0022 |
| 76 | 0.00151 | ± | 0.00023 | 0.0219 | ± | 0.0034 |
| 77 | 0.00306 | ± | 0.00050 | 0.0321 | ± | 0.0031 |
| 78 | 0.0077 | ± | 0.0012 | 0.0416 | ± | 0.0050 |
| 79 | 0.0178 | ± | 0.0027 | 0.095 | ± | 0.016 |
| 80 | 0.0405 | ± | 0.0061 | 0.200 | ± | 0.035 |
| 81 | 0.080 | ± | 0.013 | 0.362 | ± | 0.075 |
| 82 | 0.158 | ± | 0.027 | 0.55 | ± | 0.13 |
| 83 | 0.304 | ± | 0.054 | 0.738 | ± | 0.037 |
| 84 | 0.617 | ± | 0.098 | 1.362 | ± | 0.086 |
| 85 | 0.85 | ± | 0.11 | 1.052 | ± | 0.066 |
| 86 | 1.157 | ± | 0.065 | 1.83 | ± | 0.19 |
| 87 | 1.699 | ± | 0.069 | 1.923 | ± | 0.091 |
| 88 | 2.324 | ± | 0.092 | 2.23 | ± | 0.16 |
| 89 | 3.035 | ± | 0.079 | 2.78 | ± | 0.12 |
| 90 | 3.11 | ± | 0.14 | 3.07 | ± | 0.16 |
| 91 | 4.16 | ± | 0.14 | 3.635 | ± | 0.084 |
| 92 | 4.37 | ± | 0.16 | 3.820 | ± | 0.057 |
| 93 | 5.38 | ± | 0.26 | 4.59 | ± | 0.12 |
| 94 | 4.93 | ± | 0.25 | 4.67 | ± | 0.61 |
| 95 | 5.188 | ± | 0.089 | 4.594 | ± | 0.056 |
| 96 | 5.95 | ± | 0.38 | 4.55 | ± | 0.97 |
| 97 | 5.720 | ± | 0.080 | 5.206 | ± | 0.046 |
| 98 | 5.71 | ± | 0.37 | 4.9 | ± | 1.3 |
| 99 | 6.181 | ± | 0.099 | 5.737 | ± | 0.040 |
| 100 | 6.52 | ± | 0.42 | 5.4 | ± | 1.1 |
| 101 | 6.43 | ± | 0.29 | 5.80 | ± | 0.10 |
| 102 | 5.9 | ± | 1.4 | 4.38 | ± | 0.39 |
| 103 | 6.029 | ± | 0.096 | 4.495 | ± | 0.085 |
| 104 | 4.94 | ± | 0.81 | 3.63 | ± | 0.13 |

Table C-1.4: U-238 chain fission yields.

| FPA | Fast Fission Yield [% per fission] | | 14-MeV Fission Yield [% per fission] | |
|---|---|---|---|---|
| 105 | 3.74 | ± 0.12 | 3.109 | ± 0.047 |
| 106 | 2.52 | ± 0.11 | 2.56 | ± 0.13 |
| 107 | 1.78 | ± 0.12 | 1.83 | ± 0.22 |
| 108 | 0.602 | ± 0.096 | 1.67 | ± 0.41 |
| 109 | 0.159 | ± 0.011 | 1.35 | ± 0.12 |
| 110 | 0.098 | ± 0.016 | 1.18 | ± 0.23 |
| 111 | 0.0644 | ± 0.0023 | 0.971 | ± 0.049 |
| 112 | 0.0455 | ± 0.0048 | 1.022 | ± 0.032 |
| 113 | 0.0315 | ± 0.0059 | 0.912 | ± 0.042 |
| 114 | 0.0347 | ± 0.0054 | 0.92 | ± 0.14 |
| 115 | 0.0381 | ± 0.0019 | 0.900 | ± 0.025 |
| 116 | 0.0316 | ± 0.0050 | 0.91 | ± 0.14 |
| 117 | 0.0279 | ± 0.0043 | 0.90 | ± 0.14 |
| 118 | 0.0249 | ± 0.0039 | 0.92 | ± 0.18 |
| 119 | 0.0230 | ± 0.0036 | 0.99 | ± 0.18 |
| 120 | 0.0212 | ± 0.0033 | 1.05 | ± 0.19 |
| 121 | 0.0200 | ± 0.0030 | 1.10 | ± 0.18 |
| 122 | 0.0191 | ± 0.0029 | 1.13 | ± 0.21 |
| 123 | 0.0194 | ± 0.0030 | 1.22 | ± 0.31 |
| 124 | 0.0205 | ± 0.0032 | 1.23 | ± 0.23 |
| 125 | 0.0210 | ± 0.0038 | 1.277 | ± 0.063 |
| 126 | 0.093 | ± 0.020 | 1.38 | ± 0.25 |
| 127 | 0.1455 | ± 0.0080 | 1.436 | ± 0.020 |
| 128 | 0.294 | ± 0.070 | 1.56 | ± 0.26 |
| 129 | 0.622 | ± 0.034 | 1.66 | ± 0.19 |
| 130 | 1.65 | ± 0.53 | 2.97 | ± 0.83 |
| 131 | 3.321 | ± 0.083 | 3.62 | ± 0.17 |
| 132 | 4.76 | ± 0.17 | 4.690 | ± 0.066 |
| 133 | 6.71 | ± 0.23 | 5.74 | ± 0.17 |
| 134 | 6.83 | ± 0.61 | 6.37 | ± 0.33 |
| 135 | 6.44 | ± 0.27 | 5.46 | ± 0.12 |
| 136 | 7.31 | ± 0.66 | 6.33 | ± 0.56 |
| 137 | 6.02 | ± 0.15 | 5.62 | ± 0.68 |
| 138 | 6.03 | ± 0.22 | 4.65 | ± 0.20 |
| 139 | 5.85 | ± 0.34 | 4.99 | ± 0.21 |
| 140 | 5.972 | ± 0.084 | 4.620 | ± 0.037 |
| 141 | 5.93 | ± 0.45 | 4.418 | ± 0.080 |
| 142 | 4.90 | ± 0.26 | 4.20 | ± 0.11 |
| 143 | 4.68 | ± 0.11 | 3.855 | ± 0.058 |
| 144 | 4.67 | ± 0.11 | 3.58 | ± 0.14 |
| 145 | 3.88 | ± 0.21 | 2.99 | ± 0.15 |
| 146 | 3.57 | ± 0.18 | 2.63 | ± 0.38 |
| 147 | 2.677 | ± 0.046 | 2.134 | ± 0.041 |
| 148 | 2.296 | ± 0.037 | 1.37 | ± 0.15 |
| 149 | 1.683 | ± 0.067 | 1.358 | ± 0.080 |
| 150 | 1.311 | ± 0.049 | 0.98 | ± 0.24 |
| 151 | 0.810 | ± 0.012 | 0.800 | ± 0.057 |
| 152 | 0.557 | ± 0.032 | 0.54 | ± 0.12 |
| 153 | 0.367 | ± 0.014 | 0.395 | ± 0.021 |
| 154 | 0.239 | ± 0.018 | 0.262 | ± 0.048 |
| 155 | 0.127 | ± 0.021 | 0.174 | ± 0.030 |
| 156 | 0.0655 | ± 0.0017 | 0.1138 | ± 0.0082 |

Table C-1.4: U-238 chain fission yields.

| FPA | Fast Fission Yield [% per fission] | | | 14-MeV Fission Yield [% per fission] | | |
|---|---|---|---|---|---|---|
| 157 | 0.0342 | ± | 0.0053 | 0.071 | ± | 0.011 |
| 158 | 0.0173 | ± | 0.0026 | 0.0435 | ± | 0.0068 |
| 159 | 0.00836 | ± | 0.00093 | 0.0259 | ± | 0.0032 |
| 160 | 0.00330 | ± | 0.00050 | 0.0147 | ± | 0.0022 |
| 161 | 0.001192 | ± | 0.000093 | 0.00813 | ± | 0.00081 |
| 162 | 0.000548 | ± | 0.000082 | 0.00543 | ± | 0.00082 |
| 163 | 0.000242 | ± | 0.000036 | 0.00341 | ± | 0.00052 |
| 164 | 0.000102 | ± | 0.000015 | 0.00203 | ± | 0.00030 |
| 165 | 0.0000418 | ± | 0.0000063 | 0.00116 | ± | 0.00017 |
| 166 | 0.0000163 | ± | 0.0000024 | 0.000630 | ± | 0.000063 |
| 167 | 0.0000062 | ± | 0.0000009 | 0.000408 | ± | 0.000061 |
| 168 | 0.0000022 | ± | 0.0000003 | 0.000238 | ± | 0.000036 |

C-1.5: Pu-239 chain fission yields.

Reference

JEFF-3.1: Joint Evaluated Fission and Fusion File, Incident neutron data,http://www-nds.iaea.org/exfor/endf00.htm, 2 October 2006; see also A. Koning, R. Forrest, M. Kellett, R. Mills, H. Henriksson, Y. Rugama, The JEFF-3.1 Nuclear Data Library, JEFF Report 21, OECD/NEA, Paris, France, 2006, ISBN 92-64-02314-3.

Table C-1.5: Pu-239 chain fission yields.

| FPA | Thermal Fission Yield [% per fission] | | | Fast Fission Yield [% per fission] | | |
|---|---|---|---|---|---|---|
| 1 | 0.00408 | ± | 0.00041 | 0.00346 | ± | 0.00057 |
| 2 | 0.00135 | ± | 0.00019 | 0.00106 | ± | 0.00016 |
| 3 | 0.01420 | ± | 0.00070 | 0.01420 | ± | 0.00070 |
| 4 | 0.2192 | ± | 0.0090 | 0.2190 | ± | 0.0090 |
| 67 | 0.0000014 | ± | 0.0000002 | 0.0000043 | ± | 0.0000006 |
| 68 | 0.0000035 | ± | 0.0000005 | 0.0000111 | ± | 0.0000017 |
| 69 | 0.0000088 | ± | 0.0000013 | 0.0000272 | ± | 0.0000041 |
| 70 | 0.0000214 | ± | 0.0000032 | 0.0000656 | ± | 0.0000098 |
| 71 | 0.0000503 | ± | 0.0000075 | 0.000153 | ± | 0.000023 |
| 72 | 0.000114 | ± | 0.000017 | 0.000344 | ± | 0.000052 |
| 73 | 0.000289 | ± | 0.000043 | 0.00075 | ± | 0.00011 |
| 74 | 0.00070 | ± | 0.00011 | 0.00160 | ± | 0.00024 |
| 75 | 0.00162 | ± | 0.00024 | 0.00325 | ± | 0.00050 |
| 76 | 0.00360 | ± | 0.00054 | 0.0065 | ± | 0.0010 |
| 77 | 0.00768 | ± | 0.00087 | 0.0125 | ± | 0.0020 |
| 78 | 0.0291 | ± | 0.0028 | 0.0235 | ± | 0.0039 |
| 79 | 0.0550 | ± | 0.0091 | 0.0429 | ± | 0.0076 |
| 80 | 0.101 | ± | 0.018 | 0.077 | ± | 0.015 |
| 81 | 0.177 | ± | 0.031 | 0.133 | ± | 0.029 |
| 82 | 0.232 | ± | 0.041 | 0.226 | ± | 0.054 |
| 83 | 0.2820 | ± | 0.0099 | 0.328 | ± | 0.030 |
| 84 | 0.478 | ± | 0.020 | 0.525 | ± | 0.036 |
| 85 | 0.588 | ± | 0.026 | 0.622 | ± | 0.049 |
| 86 | 0.784 | ± | 0.018 | 0.825 | ± | 0.053 |
| 87 | 0.973 | ± | 0.042 | 1.051 | ± | 0.042 |
| 88 | 1.306 | ± | 0.036 | 1.447 | ± | 0.097 |
| 89 | 1.689 | ± | 0.032 | 1.712 | ± | 0.072 |
| 90 | 2.013 | ± | 0.054 | 2.031 | ± | 0.057 |
| 91 | 2.443 | ± | 0.029 | 2.58 | ± | 0.10 |
| 92 | 3.026 | ± | 0.066 | 3.08 | ± | 0.15 |
| 93 | 3.91 | ± | 0.13 | 3.92 | ± | 0.19 |
| 94 | 4.32 | ± | 0.12 | 4.25 | ± | 0.20 |
| 95 | 4.949 | ± | 0.099 | 4.683 | ± | 0.098 |
| 96 | 4.94 | ± | 0.15 | 4.89 | ± | 0.22 |
| 97 | 5.294 | ± | 0.073 | 5.021 | ± | 0.074 |
| 98 | 5.86 | ± | 0.65 | 5.61 | ± | 0.27 |
| 99 | 6.185 | ± | 0.056 | 5.82 | ± | 0.13 |
| 100 | 6.84 | ± | 1.00 | 6.61 | ± | 0.34 |
| 101 | 6.18 | ± | 0.30 | 6.63 | ± | 0.84 |
| 102 | 6.08 | ± | 0.51 | 6.76 | ± | 0.82 |
| 103 | 6.948 | ± | 0.083 | 6.59 | ± | 0.16 |

Table C-1.5: Pu-239 chain fission yields.

| FPA | Thermal Fission Yield [% per fission] | | Fast Fission Yield [% per fission] | |
|---|---|---|---|---|
| 104 | 6.08 | ± 0.32 | 6.69 | ± 0.67 |
| 105 | 5.76 | ± 0.21 | 5.28 | ± 0.10 |
| 106 | 4.190 | ± 0.092 | 4.13 | ± 0.24 |
| 107 | 3.18 | ± 0.18 | 3.14 | ± 0.59 |
| 108 | 2.06 | ± 0.12 | 2.06 | ± 0.64 |
| 109 | 1.67 | ± 0.27 | 1.43 | ± 0.29 |
| 110 | 0.625 | ± 0.037 | 0.73 | ± 0.20 |
| 111 | 0.3079 | ± 0.0074 | 0.409 | ± 0.020 |
| 112 | 0.1282 | ± 0.0077 | 0.143 | ± 0.017 |
| 113 | 0.0810 | ± 0.0041 | 0.129 | ± 0.018 |
| 114 | 0.0539 | ± 0.0028 | 0.096 | ± 0.013 |
| 115 | 0.0364 | ± 0.0019 | 0.0767 | ± 0.0059 |
| 116 | 0.0457 | ± 0.0023 | 0.0621 | ± 0.0078 |
| 117 | 0.0458 | ± 0.0023 | 0.055 | ± 0.011 |
| 118 | 0.0457 | ± 0.0033 | 0.051 | ± 0.011 |
| 119 | 0.0487 | ± 0.0035 | 0.054 | ± 0.010 |
| 120 | 0.0433 | ± 0.0064 | 0.0530 | ± 0.0097 |
| 121 | 0.0551 | ± 0.0088 | 0.0540 | ± 0.0098 |
| 122 | 0.0697 | ± 0.0036 | 0.058 | ± 0.011 |
| 123 | 0.089 | ± 0.015 | 0.069 | ± 0.013 |
| 124 | 0.1283 | ± 0.0066 | 0.092 | ± 0.016 |
| 125 | 0.117 | ± 0.015 | 0.138 | ± 0.022 |
| 126 | 0.314 | ± 0.049 | 0.209 | ± 0.044 |
| 127 | 0.461 | ± 0.027 | 0.53 | ± 0.14 |
| 128 | 0.833 | ± 0.062 | 1.00 | ± 0.34 |
| 129 | 1.407 | ± 0.086 | 1.31 | ± 0.13 |
| 130 | 2.79 | ± 0.67 | 2.87 | ± 0.76 |
| 131 | 3.724 | ± 0.078 | 4.09 | ± 0.12 |
| 132 | 5.274 | ± 0.095 | 5.18 | ± 0.33 |
| 133 | 6.99 | ± 0.13 | 7.03 | ± 0.33 |
| 134 | 6.87 | ± 0.36 | 7.52 | ± 0.26 |
| 135 | 7.38 | ± 0.24 | 7.54 | ± 0.23 |
| 136 | 6.99 | ± 0.25 | 7.31 | ± 0.74 |
| 137 | 6.594 | ± 0.080 | 6.36 | ± 0.12 |
| 138 | 6.11 | ± 0.16 | 5.82 | ± 0.30 |
| 139 | 5.968 | ± 0.090 | 5.53 | ± 0.28 |
| 140 | 5.333 | ± 0.059 | 5.324 | ± 0.075 |
| 141 | 5.205 | ± 0.073 | 5.01 | ± 0.16 |
| 142 | 4.976 | ± 0.055 | 4.99 | ± 0.13 |
| 143 | 4.476 | ± 0.049 | 4.296 | ± 0.056 |
| 144 | 3.756 | ± 0.030 | 3.505 | ± 0.053 |
| 145 | 3.036 | ± 0.033 | 3.037 | ± 0.067 |
| 146 | 2.496 | ± 0.025 | 2.527 | ± 0.053 |
| 147 | 2.044 | ± 0.039 | 1.929 | ± 0.046 |
| 148 | 1.658 | ± 0.017 | 1.697 | ± 0.029 |
| 149 | 1.263 | ± 0.032 | 1.275 | ± 0.056 |
| 150 | 0.977 | ± 0.013 | 1.011 | ± 0.019 |
| 151 | 0.776 | ± 0.018 | 0.797 | ± 0.037 |
| 152 | 0.608 | ± 0.018 | 0.615 | ± 0.047 |
| 153 | 0.380 | ± 0.030 | 0.40 | ± 0.18 |
| 154 | 0.281 | ± 0.012 | 0.267 | ± 0.049 |
| 155 | 0.174 | ± 0.030 | 0.171 | ± 0.054 |

Table C-1.5: Pu-239 chain fission yields.

| FPA | Thermal Fission Yield [% per fission] | | | Fast Fission Yield [% per fission] | | |
|---|---|---|---|---|---|---|
| 156 | 0.1097 | ± | 0.0071 | 0.1270 | ± | 0.0089 |
| 157 | 0.0767 | ± | 0.0082 | 0.1048 | ± | 0.0051 |
| 158 | 0.0415 | ± | 0.0066 | 0.054 | ± | 0.011 |
| 159 | 0.0214 | ± | 0.0020 | 0.0286 | ± | 0.0052 |
| 160 | 0.0105 | ± | 0.0016 | 0.0144 | ± | 0.0024 |
| 161 | 0.00490 | ± | 0.00046 | 0.00696 | ± | 0.00067 |
| 162 | 0.00240 | ± | 0.00036 | 0.00352 | ± | 0.00054 |
| 163 | 0.00114 | ± | 0.00017 | 0.00173 | ± | 0.00026 |
| 164 | 0.000523 | ± | 0.000078 | 0.00082 | ± | 0.00012 |
| 165 | 0.000232 | ± | 0.000035 | 0.000377 | ± | 0.000057 |
| 166 | 0.000099 | ± | 0.000015 | 0.000166 | ± | 0.000025 |
| 167 | 0.0000412 | ± | 0.0000062 | 0.000072 | ± | 0.000011 |
| 168 | 0.0000165 | ± | 0.0000025 | 0.0000302 | ± | 0.0000045 |
| 169 | 0.0000064 | ± | 0.0000010 | 0.0000122 | ± | 0.0000018 |
| 170 | 0.0000024 | ± | 0.0000004 | 0.0000048 | ± | 0.0000007 |

C-1.6: Pu-241 chain fission yields.

Reference

JEFF-3.1: Joint Evaluated Fission and Fusion File, Incident neutron data, http://www-nds.iaea.org/exfor/endf00.htm, 2 October 2006; see also A. Koning, R. Forrest, M. Kellett, R. Mills, H. Henriksson, Y. Rugama, The JEFF-3.1 Nuclear Data Library, JEFF Report 21, OECD/NEA, Paris, France, 2006, ISBN 92-64-02314-3.

Table C-1.6: Pu-241 chain fission yields.

| FPA | Thermal Fission Yield [% per fission] | | | Fast Fission Yield [% per fission] | | |
|---|---|---|---|---|---|---|
| 1 | 0.00294 | ± | 0.00048 | 0.00294 | ± | 0.00048 |
| 2 | 0.00090 | ± | 0.00013 | 0.00090 | ± | 0.00013 |
| 3 | 0.01410 | ± | 0.00061 | 0.01410 | ± | 0.00061 |
| 4 | 0.1860 | ± | 0.0071 | 0.1860 | ± | 0.0071 |
| 67 | 0.0000014 | ± | 0.0000004 | 0.0000034 | ± | 0.0000010 |
| 68 | 0.0000031 | ± | 0.0000009 | 0.0000083 | ± | 0.0000025 |
| 69 | 0.0000066 | ± | 0.0000020 | 0.0000197 | ± | 0.0000059 |
| 70 | 0.0000138 | ± | 0.0000041 | 0.000046 | ± | 0.000014 |
| 71 | 0.0000277 | ± | 0.0000083 | 0.000104 | ± | 0.000031 |
| 72 | 0.000053 | ± | 0.000016 | 0.000228 | ± | 0.000068 |
| 73 | 0.000096 | ± | 0.000029 | 0.00049 | ± | 0.00015 |
| 74 | 0.000167 | ± | 0.000050 | 0.00102 | ± | 0.00030 |
| 75 | 0.000265 | ± | 0.000080 | 0.00203 | ± | 0.00061 |
| 76 | 0.00039 | ± | 0.00012 | 0.0040 | ± | 0.0012 |
| 77 | 0.000496 | ± | 0.000067 | 0.0076 | ± | 0.0023 |
| 78 | 0.0033 | ± | 0.0010 | 0.0142 | ± | 0.0043 |
| 79 | 0.0102 | ± | 0.0031 | 0.0256 | ± | 0.0078 |
| 80 | 0.0256 | ± | 0.0081 | 0.046 | ± | 0.014 |
| 81 | 0.057 | ± | 0.019 | 0.077 | ± | 0.024 |
| 82 | 0.118 | ± | 0.042 | 0.128 | ± | 0.039 |
| 83 | 0.205 | ± | 0.010 | 0.2002 | ± | 0.0060 |
| 84 | 0.379 | ± | 0.020 | 0.366 | ± | 0.011 |
| 85 | 0.431 | ± | 0.069 | 0.401 | ± | 0.021 |
| 86 | 0.644 | ± | 0.040 | 0.596 | ± | 0.018 |
| 87 | 0.792 | ± | 0.078 | 0.795 | ± | 0.022 |
| 88 | 1.018 | ± | 0.063 | 1.017 | ± | 0.030 |
| 89 | 1.22 | ± | 0.13 | 1.41 | ± | 0.44 |
| 90 | 1.510 | ± | 0.074 | 1.502 | ± | 0.041 |
| 91 | 1.86 | ± | 0.10 | 1.896 | ± | 0.051 |
| 92 | 2.29 | ± | 0.12 | 2.392 | ± | 0.064 |
| 93 | 2.95 | ± | 0.15 | 3.101 | ± | 0.078 |
| 94 | 3.18 | ± | 0.39 | 3.306 | ± | 0.086 |
| 95 | 3.91 | ± | 0.15 | 3.84 | ± | 0.10 |
| 96 | 4.23 | ± | 0.21 | 4.36 | ± | 0.12 |
| 97 | 4.70 | ± | 0.22 | 4.69 | ± | 0.12 |
| 98 | 4.82 | ± | 0.29 | 4.88 | ± | 0.14 |
| 99 | 5.61 | ± | 0.25 | 4.1 | ± | 2.3 |
| 100 | 5.75 | ± | 0.49 | 6.18 | ± | 0.17 |
| 101 | 5.98 | ± | 0.35 | 6.34 | ± | 0.21 |
| 102 | 6.23 | ± | 0.33 | 6.70 | ± | 0.21 |
| 103 | 6.54 | ± | 0.32 | 5.9 | ± | 2.7 |

Table C-1.6: Pu-241 chain fission yields.

| FPA | Thermal Fission Yield [% per fission] | | Fast Fission Yield [% per fission] | |
|---|---|---|---|---|
| 104 | 6.69 | ± 0.33 | 7.19 | ± 0.22 |
| 105 | 6.63 | ± 0.42 | 7.3 | ± 2.0 |
| 106 | 5.95 | ± 0.70 | 6.12 | ± 0.19 |
| 107 | 5.54 | ± 0.33 | 5.7 | ± 2.0 |
| 108 | 4.36 | ± 0.38 | 3.9 | ± 1.3 |
| 109 | 2.97 | ± 0.43 | 2.30 | ± 0.67 |
| 110 | 2.03 | ± 0.25 | 1.29 | ± 0.55 |
| 111 | 0.511 | ± 0.051 | 0.83 | ± 0.26 |
| 112 | 0.190 | ± 0.025 | 0.48 | ± 0.15 |
| 113 | 0.13 | ± 0.20 | 0.24 | ± 0.11 |
| 114 | 0.13 | ± 0.16 | 0.133 | ± 0.063 |
| 115 | 0.12 | ± 0.11 | 0.079 | ± 0.032 |
| 116 | 0.101 | ± 0.073 | 0.048 | ± 0.018 |
| 117 | 0.077 | ± 0.045 | 0.029 | ± 0.010 |
| 118 | 0.057 | ± 0.029 | 0.0191 | ± 0.0063 |
| 119 | 0.047 | ± 0.022 | 0.0143 | ± 0.0046 |
| 120 | 0.058 | ± 0.018 | 0.0141 | ± 0.0044 |
| 121 | 0.091 | ± 0.019 | 0.0173 | ± 0.0054 |
| 122 | 0.104 | ± 0.023 | 0.0248 | ± 0.0079 |
| 123 | 0.134 | ± 0.031 | 0.038 | ± 0.012 |
| 124 | 0.178 | ± 0.044 | 0.060 | ± 0.020 |
| 125 | 0.249 | ± 0.065 | 0.092 | ± 0.020 |
| 126 | 0.362 | ± 0.089 | 0.157 | ± 0.031 |
| 127 | 0.55 | ± 0.14 | 0.303 | ± 0.063 |
| 128 | 0.81 | ± 0.22 | 0.57 | ± 0.11 |
| 129 | 1.28 | ± 0.36 | 1.67 | ± 0.36 |
| 130 | 1.97 | ± 0.55 | 2.26 | ± 0.41 |
| 131 | 3.076 | ± 0.074 | 3.164 | ± 0.085 |
| 132 | 4.529 | ± 0.095 | 4.59 | ± 0.13 |
| 133 | 6.61 | ± 0.18 | 6.67 | ± 0.19 |
| 134 | 7.53 | ± 0.52 | 7.73 | ± 0.21 |
| 135 | 7.02 | ± 0.24 | 7.27 | ± 0.20 |
| 136 | 6.97 | ± 0.60 | 7.21 | ± 0.18 |
| 137 | 6.28 | ± 0.14 | 6.37 | ± 0.18 |
| 138 | 6.42 | ± 0.23 | 6.27 | ± 0.16 |
| 139 | 5.95 | ± 0.30 | 6.16 | ± 0.18 |
| 140 | 5.76 | ± 0.11 | 5.36 | ± 0.14 |
| 141 | 4.90 | ± 0.12 | 4.63 | ± 0.62 |
| 142 | 4.74 | ± 0.14 | 4.68 | ± 0.13 |
| 143 | 4.380 | ± 0.092 | 4.59 | ± 0.12 |
| 144 | 4.123 | ± 0.095 | 4.18 | ± 0.11 |
| 145 | 3.141 | ± 0.091 | 3.272 | ± 0.085 |
| 146 | 2.657 | ± 0.069 | 2.740 | ± 0.071 |
| 147 | 2.252 | ± 0.095 | 2.228 | ± 0.062 |
| 148 | 1.881 | ± 0.064 | 1.945 | ± 0.049 |
| 149 | 1.454 | ± 0.071 | 1.452 | ± 0.041 |
| 150 | 1.155 | ± 0.032 | 1.200 | ± 0.032 |
| 151 | 0.86 | ± 0.24 | 0.910 | ± 0.025 |
| 152 | 0.718 | ± 0.052 | 0.711 | ± 0.019 |
| 153 | 0.40 | ± 0.23 | 0.45 | ± 0.19 |
| 154 | 0.368 | ± 0.087 | 0.372 | ± 0.010 |
| 155 | 0.19 | ± 0.35 | 0.231 | ± 0.084 |

Table C-1.6: Pu-241 chain fission yields.

| FPA | Thermal Fission Yield [% per fission] | | Fast Fission Yield [% per fission] | |
|---|---|---|---|---|
| 156 | 0.18 | ± 0.24 | 0.153 | ± 0.052 |
| 157 | 0.17 | ± 0.16 | 0.098 | ± 0.032 |
| 158 | 0.14 | ± 0.10 | 0.060 | ± 0.020 |
| 159 | 0.112 | ± 0.058 | 0.036 | ± 0.011 |
| 160 | 0.091 | ± 0.039 | 0.0209 | ± 0.0065 |
| 161 | 0.067 | ± 0.024 | 0.0118 | ± 0.0036 |
| 162 | 0.048 | ± 0.015 | 0.0064 | ± 0.0020 |
| 163 | 0.024 | ± 0.011 | 0.0034 | ± 0.0010 |
| 164 | 0.0125 | ± 0.0046 | 0.00176 | ± 0.00053 |
| 165 | 0.0062 | ± 0.0021 | 0.00088 | ± 0.00026 |
| 166 | 0.00293 | ± 0.00092 | 0.00043 | ± 0.00013 |
| 167 | 0.00134 | ± 0.00041 | 0.000202 | ± 0.000061 |
| 168 | 0.00059 | ± 0.00018 | 0.000093 | ± 0.000028 |
| 169 | 0.000252 | ± 0.000076 | 0.000041 | ± 0.000012 |
| 170 | 0.000104 | ± 0.000031 | 0.0000179 | ± 0.0000054 |
| 171 | 0.000042 | ± 0.000013 | 0.0000075 | ± 0.0000023 |
| 172 | 0.0000163 | ± 0.0000049 | 0.0000031 | ± 0.0000009 |
| 173 | 0.0000062 | ± 0.0000019 | 0.0000012 | ± 0.0000004 |
| 174 | 0.0000022 | ± 0.0000007 | 0.0 | ± 0.0 |

C-2.1: Th-232 fast fission yields for selected fission products.

Reference

JEFF-3.1: Joint Evaluated Fission and Fusion File, Incident neutron data, http://www-nds.iaea.org/exfor/endf00.htm, 2 October 2006;
see also A. Koning, R. Forrest, M. Kellett, R. Mills, H. Henriksson, Y. Rugama, The JEFF-3.1 Nuclear Data Library, JEFF Report 21, OECD/NEA, Paris, France, 2006, ISBN 92-64-02314-3.

Table C-2.1: Th-232 fast fission yields for selected fission products.

| Fission Product | Independent yield [% per fission] | | | Cumulative yield [% per fission] | | |
|---|---|---|---|---|---|---|
| 1-H-1 | 0.00161 | ± | 0.00055 | 0.00161 | ± | 0.00027 |
| 1-H-2 | 0.00049 | ± | 0.00017 | 0.000491 | ± | 0.000076 |
| 1-H-3 | 0.0070 | ± | 0.0022 | 0.00701 | ± | 0.00069 |
| 2-He-3 | 0.0 | ± | 0.0 | 0.00701 | ± | 0.00069 |
| 2-He-4 | 0.102 | ± | 0.031 | 0.1016 | ± | 0.0059 |
| 36-Kr-82 | 0.000000013 | ± | 0.000000004 | 0.000088 | ± | 0.000034 |
| 36-Kr-85 | 0.00115 | ± | 0.00040 | 0.924 | ± | 0.096 |
| 40-Zr-95 | 0.00099 | ± | 0.00036 | 5.52 | ± | 0.17 |
| 41-Nb-95 | 0.000000136 | ± | 0.000000049 | 5.52 | ± | 0.17 |
| 41-Nb-95m | 0.000000027 | ± | 0.000000010 | 0.0597 | ± | 0.0076 |
| 42-Mo-92 | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 42-Mo-94 | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 42-Mo-96 | 0.0 | ± | 0.0 | 0.0000060 | ± | 0.0000024 |
| 42-Mo-99 | 0.0000125 | ± | 0.0000044 | 2.919 | ± | 0.076 |
| 44-Ru-103 | 0.0 | ± | 0.0 | 0.1538 | ± | 0.0095 |
| 44-Ru-106 | 0.000000043 | ± | 0.000000016 | 0.0541 | ± | 0.0031 |
| 45-Rh-106 | 0.0 | ± | 0.0 | 0.0541 | ± | 0.0031 |
| 51-Sb-125 | 0.000129 | ± | 0.000051 | 0.0560 | ± | 0.0084 |
| 52-Te-132 | 0.238 | ± | 0.077 | 2.60 | ± | 0.10 |
| 53-I-131 | 0.000042 | ± | 0.000015 | 1.513 | ± | 0.083 |
| 53-I-135 | 1.13 | ± | 0.30 | 5.45 | ± | 0.26 |
| 54-Xe-128 | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 54-Xe-130 | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 54-Xe-131m | 0.000000002 | ± | 0.000000001 | 0.0164 | ± | 0.0020 |
| 54-Xe-133 | 0.0000074 | ± | 0.0000027 | 4.53 | ± | 0.19 |
| 54-Xe-133m | 0.0000207 | ± | 0.0000077 | 0.129 | ± | 0.013 |
| 54-Xe-135 | 0.0039 | ± | 0.0014 | 5.46 | ± | 0.26 |
| 54-Xe-135m | 0.0110 | ± | 0.0040 | 0.911 | ± | 0.095 |
| 55-Cs-134 | 0.000000080 | ± | 0.000000030 | 0.000000150 | ± | 0.000000041 |
| 55-Cs-137 | 0.0051 | ± | 0.0019 | 6.30 | ± | 0.30 |
| 56-Ba-140 | 0.0194 | ± | 0.0072 | 7.71 | ± | 0.25 |
| 57-La-140 | 0.0000095 | ± | 0.0000036 | 7.71 | ± | 0.25 |
| 58-Ce-141 | 0.000000021 | ± | 0.000000008 | 7.11 | ± | 0.28 |
| 58-Ce-144 | 0.00106 | ± | 0.00041 | 7.66 | ± | 0.55 |
| 59-Pr-144 | 0.000000011 | ± | 0.000000004 | 7.66 | ± | 0.55 |
| 60-Nd-142 | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 60-Nd-144 | 0.0 | ± | 0.0 | 7.66 | ± | 0.55 |
| 60-Nd-147 | 0.00000031 | ± | 0.00000012 | 3.03 | ± | 0.18 |
| 61-Pm-147 | 0.0 | ± | 0.0 | 3.03 | ± | 0.18 |
| 61-Pm-148 | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 61-Pm-148m | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 61-Pm-149 | 0.000000014 | ± | 0.000000005 | 1.11 | ± | 0.16 |
| 61-Pm-151 | 0.0000076 | ± | 0.0000030 | 0.399 | ± | 0.065 |

Table C-2.1: Th-232 fast fission yields for selected fission products.

| Fission Product | Independent yield [% per fission] | | | Cumulative yield [% per fission] | | |
|---|---|---|---|---|---|---|
| 62-Sm-148 | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 62-Sm-150 | 0.0 | ± | 0.0 | 0.00000044 | ± | 0.00000032 |
| 62-Sm-151 | 0.0 | ± | 0.0 | 0.399 | ± | 0.065 |
| 62-Sm-153 | 0.000000141 | ± | 0.000000055 | 0.202 | ± | 0.027 |
| 63-Eu-151 | 0.0 | ± | 0.0 | 0.399 | ± | 0.065 |
| 63-Eu-152 | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 63-Eu-154 | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 63-Eu-155 | 0.000000005 | ± | 0.000000002 | 0.0158 | ± | 0.0025 |

C-2.2: U-233 thermal fission yields for selected fission products.

Reference

JEFF-3.1: Joint Evaluated Fission and Fusion File, Incident neutron data, http://www-nds.iaea.org/exfor/endf00.htm, 2 October 2006; see also A. Koning, R. Forrest, M. Kellett, R. Mills, H. Henriksson, Y. Rugama, The JEFF-3.1 Nuclear Data Library, JEFF Report 21, OECD/NEA, Paris, France, 2006, ISBN 92-64-02314-3.

Table C-2.2: U-233 thermal fission yields for selected fission products.

| Fission Product | Independent yield [% per fission] | | | Cumulative yield [% per fission] | | |
|---|---|---|---|---|---|---|
| 1-H-1 | 0.0033 | ± | 0.0011 | 0.00334 | ± | 0.00055 |
| 1-H-2 | 0.00085 | ± | 0.00023 | 0.00085 | ± | 0.00013 |
| 1-H-3 | 0.0114 | ± | 0.0023 | 0.01140 | ± | 0.00050 |
| 2-He-3 | 0.0 | ± | 0.0 | 0.01140 | ± | 0.00050 |
| 2-He-4 | 0.211 | ± | 0.012 | 0.2111 | ± | 0.0080 |
| 36-Kr-82 | 0.000037 | ± | 0.000013 | 0.0070 | ± | 0.0018 |
| 36-Kr-85 | 0.073 | ± | 0.025 | 0.523 | ± | 0.048 |
| 40-Zr-95 | 0.261 | ± | 0.087 | 6.385 | ± | 0.058 |
| 41-Nb-95 | 0.00075 | ± | 0.00026 | 6.382 | ± | 0.057 |
| 41-Nb-95m | 0.000173 | ± | 0.000061 | 0.0692 | ± | 0.0082 |
| 42-Mo-92 | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 42-Mo-94 | 0.000000005 | ± | 0.000000002 | 0.000000101 | ± | 0.000000035 |
| 42-Mo-96 | 0.0000097 | ± | 0.0000034 | 0.0083 | ± | 0.0029 |
| 42-Mo-99 | 0.0197 | ± | 0.0071 | 5.03 | ± | 0.14 |
| 44-Ru-103 | 0.000120 | ± | 0.000044 | 1.458 | ± | 0.058 |
| 44-Ru-106 | 0.000188 | ± | 0.000072 | 0.2505 | ± | 0.0078 |
| 45-Rh-106 | 0.000000004 | ± | 0.000000002 | 0.2505 | ± | 0.0078 |
| 51-Sb-125 | 0.0146 | ± | 0.0053 | 0.116 | ± | 0.014 |
| 52-Te-132 | 3.29 | ± | 0.38 | 4.59 | ± | 0.14 |
| 53-I-131 | 0.036 | ± | 0.013 | 3.565 | ± | 0.100 |
| 53-I-135 | 2.96 | ± | 0.48 | 4.31 | ± | 0.32 |
| 54-Xe-128 | 0.0000000010 | ± | 0.0000000004 | 0.0000064 | ± | 0.0000025 |
| 54-Xe-130 | 0.0000044 | ± | 0.0000016 | 0.00325 | ± | 0.00100 |
| 54-Xe-131m | 0.000092 | ± | 0.000033 | 0.0388 | ± | 0.0040 |
| 54-Xe-133 | 0.0113 | ± | 0.0041 | 5.98 | ± | 0.17 |
| 54-Xe-133m | 0.0273 | ± | 0.0100 | 0.197 | ± | 0.016 |
| 54-Xe-135 | 0.343 | ± | 0.091 | 5.47 | ± | 0.37 |
| 54-Xe-135m | 0.83 | ± | 0.22 | 1.54 | ± | 0.20 |
| 55-Cs-134 | 0.00066 | ± | 0.00023 | 0.00114 | ± | 0.00029 |
| 55-Cs-137 | 0.49 | ± | 0.17 | 6.20 | ± | 0.22 |
| 56-Ba-140 | 1.50 | ± | 0.40 | 6.43 | ± | 0.26 |
| 57-La-140 | 0.0178 | ± | 0.0062 | 6.45 | ± | 0.26 |
| 58-Ce-141 | 0.00063 | ± | 0.00022 | 6.218 | ± | 0.081 |
| 58-Ce-144 | 0.283 | ± | 0.094 | 4.654 | ± | 0.093 |
| 59-Pr-144 | 0.000107 | ± | 0.000038 | 4.655 | ± | 0.093 |
| 60-Nd-142 | 0.0 | ± | 0.0 | 0.00000331 | ± | 0.00000092 |
| 60-Nd-144 | 0.00000069 | ± | 0.00000025 | 4.655 | ± | 0.093 |
| 60-Nd-147 | 0.00212 | ± | 0.00078 | 1.827 | ± | 0.086 |
| 61-Pm-147 | 0.00000098 | ± | 0.00000036 | 1.827 | ± | 0.086 |
| 61-Pm-148 | 0.0000048 | ± | 0.0000018 | 0.0000053 | ± | 0.0000018 |
| 61-Pm-148m | 0.0000112 | ± | 0.0000043 | 0.0000112 | ± | 0.0000043 |
| 61-Pm-149 | 0.000188 | ± | 0.000070 | 0.769 | ± | 0.031 |

Table C-2.2: U-233 thermal fission yields for selected fission products.

| Fission Product | Independent yield [% per fission] | | | Cumulative yield [% per fission] | | |
|---|---|---|---|---|---|---|
| 61-Pm-151 | 0.0048 | ± | 0.0021 | 0.333 | ± | 0.017 |
| 62-Sm-148 | 0.000000003 | ± | 0.000000001 | 0.0000159 | ± | 0.0000045 |
| 62-Sm-150 | 0.00000242 | ± | 0.00000088 | 0.00113 | ± | 0.00042 |
| 62-Sm-151 | 0.000030 | ± | 0.000011 | 0.333 | ± | 0.017 |
| 62-Sm-153 | 0.00021 | ± | 0.00013 | 0.106 | ± | 0.042 |
| 63-Eu-151 | 0.000000004 | ± | 0.000000002 | 0.333 | ± | 0.017 |
| 63-Eu-152 | 0.000000032 | ± | 0.000000013 | 0.000000068 | ± | 0.000000020 |
| 63-Eu-154 | 0.0000041 | ± | 0.0000016 | 0.0000078 | ± | 0.0000022 |
| 63-Eu-155 | 0.000048 | ± | 0.000020 | 0.0214 | ± | 0.0060 |

C-2.3: U-235 thermal fission yields for selected fission products.

Reference

JEFF-3.1: Joint Evaluated Fission and Fusion File, Incident neutron data, http://www-nds.iaea.org/exfor/endf00.htm, 2 October 2006; see also A. Koning, R. Forrest, M. Kellett, R. Mills, H. Henriksson, Y. Rugama, The JEFF-3.1 Nuclear Data Library, JEFF Report 21, OECD/NEA, Paris, France, 2006, ISBN 92-64-02314-3.

Table C-2.3: U-235 thermal fission yields for selected fission products.

| Fission Product | Independent yield [% per fission] | | Cumulative yield [% per fission] | |
|---|---|---|---|---|
| 1-H-1 | 0.00171 | ± 0.00029 | 0.00171 | ± 0.00018 |
| 1-H-2 | 0.00084 | ± 0.00024 | 0.00084 | ± 0.00015 |
| 1-H-3 | 0.01080 | ± 0.00059 | 0.01080 | ± 0.00040 |
| 2-He-3 | 0.0 | ± 0.0 | 0.01080 | ± 0.00040 |
| 2-He-4 | 0.1700 | ± 0.0081 | 0.1702 | ± 0.0049 |
| 36-Kr-82 | 0.000000217 | ± 0.000000075 | 0.000285 | ± 0.000076 |
| 36-Kr-85 | 0.0049 | ± 0.0018 | 0.286 | ± 0.021 |
| 40-Zr-95 | 0.035 | ± 0.013 | 6.502 | ± 0.072 |
| 41-Nb-95 | 0.0000175 | ± 0.0000065 | 6.498 | ± 0.072 |
| 41-Nb-95m | 0.0000041 | ± 0.0000015 | 0.0702 | ± 0.0067 |
| 42-Mo-92 | 0.0 | ± 0.0 | 0.0 | ± 0.0 |
| 42-Mo-94 | 0.0 | ± 0.0 | 0.0 | ± 0.0 |
| 42-Mo-96 | 0.000000069 | ± 0.000000025 | 0.00042 | ± 0.00015 |
| 42-Mo-99 | 0.00180 | ± 0.00066 | 6.132 | ± 0.092 |
| 44-Ru-103 | 0.0000099 | ± 0.0000036 | 3.103 | ± 0.084 |
| 44-Ru-106 | 0.0000028 | ± 0.0000011 | 0.410 | ± 0.011 |
| 45-Rh-106 | 0.0 | ± 0.0 | 0.410 | ± 0.011 |
| 51-Sb-125 | 0.00072 | ± 0.00026 | 0.0260 | ± 0.0014 |
| 52-Te-132 | 1.61 | ± 0.37 | 4.276 | ± 0.043 |
| 53-I-131 | 0.00136 | ± 0.00047 | 2.878 | ± 0.032 |
| 53-I-135 | 2.55 | ± 0.54 | 6.39 | ± 0.22 |
| 54-Xe-128 | 0.0 | ± 0.0 | 0.0 | ± 0.0 |
| 54-Xe-130 | 0.000000005 | ± 0.000000002 | 0.0000380 | ± 0.0000098 |
| 54-Xe-131m | 0.00000036 | ± 0.00000012 | 0.0313 | ± 0.0030 |
| 54-Xe-133 | 0.00044 | ± 0.00016 | 6.60 | ± 0.11 |
| 54-Xe-133m | 0.00106 | ± 0.00038 | 0.189 | ± 0.015 |
| 54-Xe-135 | 0.069 | ± 0.024 | 6.61 | ± 0.22 |
| 54-Xe-135m | 0.167 | ± 0.057 | 1.22 | ± 0.12 |
| 55-Cs-134 | 0.0000070 | ± 0.0000026 | 0.0000121 | ± 0.0000032 |
| 55-Cs-137 | 0.072 | ± 0.026 | 6.221 | ± 0.069 |
| 56-Ba-140 | 0.29 | ± 0.10 | 6.314 | ± 0.095 |
| 57-La-140 | 0.00052 | ± 0.00019 | 6.315 | ± 0.095 |
| 58-Ce-141 | 0.0000056 | ± 0.0000020 | 5.86 | ± 0.15 |
| 58-Ce-144 | 0.035 | ± 0.013 | 5.474 | ± 0.055 |
| 59-Pr-144 | 0.00000168 | ± 0.00000063 | 5.474 | ± 0.055 |
| 60-Nd-142 | 0.0 | ± 0.0 | 0.000000006 | ± 0.000000002 |
| 60-Nd-144 | 0.0000000011 | ± 0.0000000004 | 5.475 | ± 0.055 |
| 60-Nd-147 | 0.000074 | ± 0.000026 | 2.232 | ± 0.040 |
| 61-Pm-147 | 0.000000003 | ± 0.000000001 | 2.232 | ± 0.040 |
| 61-Pm-148 | 0.000000044 | ± 0.000000017 | 0.000000050 | ± 0.000000017 |
| 61-Pm-148m | 0.000000104 | ± 0.000000039 | 0.000000104 | ± 0.000000039 |
| 61-Pm-149 | 0.0000047 | ± 0.0000017 | 1.053 | ± 0.021 |

Table C-2.3: U-235 thermal fission yields for selected fission products.

| Fission Product | Independent yield [% per fission] | | | Cumulative yield [% per fission] | | |
|---|---|---|---|---|---|---|
| 61-Pm-151 | 0.00067 | ± | 0.00025 | 0.4204 | ± | 0.0071 |
| 62-Sm-148 | 0.0 | ± | 0.0 | 0.000000149 | ± | 0.000000041 |
| 62-Sm-150 | 0.000000016 | ± | 0.000000006 | 0.000061 | ± | 0.000022 |
| 62-Sm-151 | 0.00000052 | ± | 0.00000019 | 0.4204 | ± | 0.0071 |
| 62-Sm-153 | 0.0000221 | ± | 0.0000095 | 0.1477 | ± | 0.0071 |
| 63-Eu-151 | 0.0 | ± | 0.0 | 0.4204 | ± | 0.0071 |
| 63-Eu-152 | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 63-Eu-154 | 0.000000103 | ± | 0.000000047 | 0.000000195 | ± | 0.000000064 |
| 63-Eu-155 | 0.0000029 | ± | 0.0000011 | 0.0308 | ± | 0.0013 |

C-2.4: U-238 fast fission yields for selected fission products.

Reference

JEFF-3.1: Joint Evaluated Fission and Fusion File, Incident neutron data, http://www-nds.iaea.org/exfor/endf00.htm, 2 October 2006; see also A. Koning, R. Forrest, M. Kellett, R. Mills, H. Henriksson, Y. Rugama, The JEFF-3.1 Nuclear Data Library, JEFF Report 21, OECD/NEA, Paris, France, 2006, ISBN 92-64-02314-3.

Table C-2.4: U-238 fast fission yields for selected fission products.

| Fission Product | Independent yield [% per fission] | | | Cumulative yield [% per fission] | | |
|---|---|---|---|---|---|---|
| 1-H-1 | 0.00235 | ± | 0.00081 | 0.00235 | ± | 0.00040 |
| 1-H-2 | 0.00072 | ± | 0.00024 | 0.00072 | ± | 0.00011 |
| 1-H-3 | 0.0103 | ± | 0.0032 | 0.0103 | ± | 0.0010 |
| 2-He-3 | 0.0 | ± | 0.0 | 0.0103 | ± | 0.0010 |
| 2-He-4 | 0.149 | ± | 0.045 | 0.1488 | ± | 0.0086 |
| 36-Kr-82 | 0.0000000011 | ± | 0.0000000004 | 0.0000089 | ± | 0.0000030 |
| 36-Kr-85 | 0.000185 | ± | 0.000066 | 0.182 | ± | 0.030 |
| 40-Zr-95 | 0.00094 | ± | 0.00034 | 5.188 | ± | 0.089 |
| 41-Nb-95 | 0.000000132 | ± | 0.000000048 | 5.185 | ± | 0.089 |
| 41-Nb-95m | 0.000000027 | ± | 0.000000010 | 0.0561 | ± | 0.0069 |
| 42-Mo-92 | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 42-Mo-94 | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 42-Mo-96 | 0.0 | ± | 0.0 | 0.0000063 | ± | 0.0000024 |
| 42-Mo-99 | 0.0000260 | ± | 0.0000094 | 6.181 | ± | 0.099 |
| 44-Ru-103 | 0.000000070 | ± | 0.000000025 | 6.029 | ± | 0.096 |
| 44-Ru-106 | 0.00197 | ± | 0.00076 | 2.52 | ± | 0.11 |
| 45-Rh-106 | 0.000000182 | ± | 0.000000070 | 2.52 | ± | 0.11 |
| 51-Sb-125 | 0.0000161 | ± | 0.0000065 | 0.0210 | ± | 0.0038 |
| 52-Te-132 | 0.34 | ± | 0.11 | 4.76 | ± | 0.17 |
| 53-I-131 | 0.000051 | ± | 0.000017 | 3.321 | ± | 0.083 |
| 53-I-135 | 1.12 | ± | 0.32 | 6.42 | ± | 0.27 |
| 54-Xe-128 | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 54-Xe-130 | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 54-Xe-131m | 0.000000002 | ± | 0.000000001 | 0.0361 | ± | 0.0036 |
| 54-Xe-133 | 0.0000067 | ± | 0.0000024 | 6.71 | ± | 0.23 |
| 54-Xe-133m | 0.0000188 | ± | 0.0000067 | 0.191 | ± | 0.017 |
| 54-Xe-135 | 0.0038 | ± | 0.0014 | 6.43 | ± | 0.27 |
| 54-Xe-135m | 0.0106 | ± | 0.0038 | 1.07 | ± | 0.11 |
| 55-Cs-134 | 0.000000060 | ± | 0.000000021 | 0.000000113 | ± | 0.000000030 |
| 55-Cs-137 | 0.0044 | ± | 0.0016 | 6.02 | ± | 0.15 |
| 56-Ba-140 | 0.0142 | ± | 0.0052 | 5.972 | ± | 0.084 |
| 57-La-140 | 0.0000068 | ± | 0.0000025 | 5.972 | ± | 0.084 |
| 58-Ce-141 | 0.000000016 | ± | 0.000000005 | 5.93 | ± | 0.45 |
| 58-Ce-144 | 0.00066 | ± | 0.00024 | 4.67 | ± | 0.11 |
| 59-Pr-144 | 0.000000007 | ± | 0.000000002 | 4.67 | ± | 0.11 |
| 60-Nd-142 | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 60-Nd-144 | 0.0 | ± | 0.0 | 4.67 | ± | 0.11 |
| 60-Nd-147 | 0.00000032 | ± | 0.00000012 | 2.677 | ± | 0.046 |
| 61-Pm-147 | 0.0 | ± | 0.0 | 2.677 | ± | 0.046 |
| 61-Pm-148 | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 61-Pm-148m | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 61-Pm-149 | 0.000000025 | ± | 0.000000009 | 1.683 | ± | 0.067 |

Table C-2.4: U-238 fast fission yields for selected fission products.

| Fission Product | Independent yield [% per fission] | | | Cumulative yield [% per fission] | | |
|---|---|---|---|---|---|---|
| 61-Pm-151 | 0.0000182 | ± | 0.0000067 | 0.810 | ± | 0.012 |
| 62-Sm-148 | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 62-Sm-150 | 0.0 | ± | 0.0 | 0.00000084 | ± | 0.00000032 |
| 62-Sm-151 | 0.0000000012 | ± | 0.0000000004 | 0.810 | ± | 0.012 |
| 62-Sm-153 | 0.00000033 | ± | 0.00000012 | 0.367 | ± | 0.014 |
| 63-Eu-151 | 0.0 | ± | 0.0 | 0.810 | ± | 0.012 |
| 63-Eu-152 | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 63-Eu-154 | 0.0 | ± | 0.0 | 0.000000002 | ± | 0.000000001 |
| 63-Eu-155 | 0.000000056 | ± | 0.000000022 | 0.127 | ± | 0.021 |

C-2.5: Pu-239 thermal fission yields for selected fission products.

Reference

JEFF-3.1: Joint Evaluated Fission and Fusion File, Incident neutron data, http://www-nds.iaea.org/exfor/endf00.htm, 2 October 2006; see also A. Koning, R. Forrest, M. Kellett, R. Mills, H. Henriksson, Y. Rugama, The JEFF-3.1 Nuclear Data Library, JEFF Report 21, OECD/NEA, Paris, France, 2006, ISBN 92-64-02314-3.

Table C-2.5: Pu-239 thermal fission yields for selected fission products.

| Fission Product | Independent yield [% per fission] | | | Cumulative yield [% per fission] | | |
|---|---|---|---|---|---|---|
| 1-H-1 | 0.00408 | ± | 0.00071 | 0.00408 | ± | 0.00041 |
| 1-H-2 | 0.00135 | ± | 0.00029 | 0.00135 | ± | 0.00019 |
| 1-H-3 | 0.0142 | ± | 0.0011 | 0.01420 | ± | 0.00070 |
| 2-He-3 | 0.0 | ± | 0.0 | 0.01420 | ± | 0.00070 |
| 2-He-4 | 0.219 | ± | 0.012 | 0.2192 | ± | 0.0090 |
| 36-Kr-82 | 0.0000050 | ± | 0.0000019 | 0.00175 | ± | 0.00060 |
| 36-Kr-85 | 0.0117 | ± | 0.0042 | 0.136 | ± | 0.014 |
| 40-Zr-95 | 0.133 | ± | 0.048 | 4.949 | ± | 0.099 |
| 41-Nb-95 | 0.00036 | ± | 0.00013 | 4.946 | ± | 0.099 |
| 41-Nb-95m | 0.000084 | ± | 0.000031 | 0.0535 | ± | 0.0066 |
| 42-Mo-92 | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 42-Mo-94 | 0.000000002 | ± | 0.000000001 | 0.000000036 | ± | 0.000000013 |
| 42-Mo-96 | 0.0000048 | ± | 0.0000017 | 0.0051 | ± | 0.0018 |
| 42-Mo-99 | 0.0191 | ± | 0.0069 | 6.185 | ± | 0.056 |
| 44-Ru-103 | 0.00035 | ± | 0.00013 | 6.948 | ± | 0.083 |
| 44-Ru-106 | 0.30 | ± | 0.10 | 4.188 | ± | 0.092 |
| 45-Rh-106 | 0.00082 | ± | 0.00030 | 4.188 | ± | 0.092 |
| 51-Sb-125 | 0.0125 | ± | 0.0044 | 0.117 | ± | 0.015 |
| 52-Te-132 | 2.94 | ± | 0.45 | 5.095 | ± | 0.094 |
| 53-I-131 | 0.0234 | ± | 0.0081 | 3.724 | ± | 0.078 |
| 53-I-135 | 4.19 | ± | 0.62 | 6.33 | ± | 0.23 |
| 54-Xe-128 | 0.0 | ± | 0.0 | 0.00000234 | ± | 0.00000085 |
| 54-Xe-130 | 0.00000116 | ± | 0.00000036 | 0.00166 | ± | 0.00056 |
| 54-Xe-131m | 0.000032 | ± | 0.000011 | 0.0405 | ± | 0.0040 |
| 54-Xe-133 | 0.0071 | ± | 0.0026 | 6.99 | ± | 0.13 |
| 54-Xe-133m | 0.0172 | ± | 0.0063 | 0.216 | ± | 0.016 |
| 54-Xe-135 | 0.306 | ± | 0.097 | 7.36 | ± | 0.24 |
| 54-Xe-135m | 0.74 | ± | 0.24 | 1.78 | ± | 0.21 |
| 55-Cs-134 | 0.00039 | ± | 0.00014 | 0.00067 | ± | 0.00018 |
| 55-Cs-137 | 0.46 | ± | 0.16 | 6.588 | ± | 0.080 |
| 56-Ba-140 | 0.88 | ± | 0.28 | 5.322 | ± | 0.059 |
| 57-La-140 | 0.0113 | ± | 0.0040 | 5.333 | ± | 0.059 |
| 58-Ce-141 | 0.00029 | ± | 0.00011 | 5.205 | ± | 0.073 |
| 58-Ce-144 | 0.163 | ± | 0.060 | 3.755 | ± | 0.030 |
| 59-Pr-144 | 0.000064 | ± | 0.000024 | 3.756 | ± | 0.030 |
| 60-Nd-142 | 0.0 | ± | 0.0 | 0.00000145 | ± | 0.00000040 |
| 60-Nd-144 | 0.000000261 | ± | 0.000000096 | 3.756 | ± | 0.030 |
| 60-Nd-147 | 0.00174 | ± | 0.00063 | 2.044 | ± | 0.039 |
| 61-Pm-147 | 0.00000077 | ± | 0.00000028 | 2.044 | ± | 0.039 |
| 61-Pm-148 | 0.0000050 | ± | 0.0000019 | 0.0000056 | ± | 0.0000019 |
| 61-Pm-148m | 0.0000118 | ± | 0.0000044 | 0.0000118 | ± | 0.0000044 |
| 61-Pm-149 | 0.000272 | ± | 0.000098 | 1.263 | ± | 0.032 |

Table C-2.5: Pu-239 thermal fission yields for selected fission products.

| Fission Product | Independent yield [% per fission] | | | Cumulative yield [% per fission] | | |
|---|---|---|---|---|---|---|
| 61-Pm-151 | 0.0140 | ± | 0.0048 | 0.776 | ± | 0.018 |
| 62-Sm-148 | 0.000000002 | ± | 0.000000001 | 0.0000168 | ± | 0.0000046 |
| 62-Sm-150 | 0.0000032 | ± | 0.0000011 | 0.00227 | ± | 0.00078 |
| 62-Sm-151 | 0.000053 | ± | 0.000019 | 0.776 | ± | 0.018 |
| 62-Sm-153 | 0.00087 | ± | 0.00031 | 0.380 | ± | 0.030 |
| 63-Eu-151 | 0.000000007 | ± | 0.000000003 | 0.776 | ± | 0.018 |
| 63-Eu-152 | 0.000000092 | ± | 0.000000033 | 0.000000195 | ± | 0.000000050 |
| 63-Eu-154 | 0.0000258 | ± | 0.0000092 | 0.000049 | ± | 0.000012 |
| 63-Eu-155 | 0.00037 | ± | 0.00014 | 0.174 | ± | 0.030 |

C-2.6: Pu-241 thermal fission yields for selected fission products.

Reference

JEFF-3.1: Joint Evaluated Fission and Fusion File, Incident neutron data, http://www-nds.iaea.org/exfor/endf00.htm, 2 October 2006; see also A. Koning, R. Forrest, M. Kellett, R. Mills, H. Henriksson, Y. Rugama, The JEFF-3.1 Nuclear Data Library, JEFF Report 21, OECD/NEA, Paris, France, 2006, ISBN 92-64-02314-3.

Table C-2.6: Pu-241 thermal fission yields for selected fission products.

| Fission Product | Independent yield [% per fission] | | | Cumulative yield [% per fission] | | |
|---|---|---|---|---|---|---|
| 1-H-1 | 0.0029 | ± | 0.0010 | 0.00294 | ± | 0.00048 |
| 1-H-2 | 0.00090 | ± | 0.00030 | 0.00090 | ± | 0.00013 |
| 1-H-3 | 0.0141 | ± | 0.0021 | 0.01410 | ± | 0.00061 |
| 2-He-3 | 0.0 | ± | 0.0 | 0.01410 | ± | 0.00061 |
| 2-He-4 | 0.186 | ± | 0.020 | 0.1860 | ± | 0.0071 |
| 36-Kr-82 | 0.000000080 | ± | 0.000000034 | 0.000124 | ± | 0.000059 |
| 36-Kr-85 | 0.00152 | ± | 0.00062 | 0.094 | ± | 0.018 |
| 40-Zr-95 | 0.0200 | ± | 0.0075 | 3.91 | ± | 0.15 |
| 41-Nb-95 | 0.0000130 | ± | 0.0000049 | 3.91 | ± | 0.15 |
| 41-Nb-95m | 0.0000030 | ± | 0.0000011 | 0.0423 | ± | 0.0048 |
| 42-Mo-92 | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 42-Mo-94 | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 42-Mo-96 | 0.000000061 | ± | 0.000000024 | 0.00033 | ± | 0.00013 |
| 42-Mo-99 | 0.00177 | ± | 0.00064 | 5.61 | ± | 0.25 |
| 44-Ru-103 | 0.0000165 | ± | 0.0000061 | 6.54 | ± | 0.32 |
| 44-Ru-106 | 0.105 | ± | 0.043 | 5.95 | ± | 0.70 |
| 45-Rh-106 | 0.000073 | ± | 0.000030 | 5.95 | ± | 0.70 |
| 51-Sb-125 | 0.0032 | ± | 0.0014 | 0.249 | ± | 0.065 |
| 52-Te-132 | 1.16 | ± | 0.34 | 4.512 | ± | 0.095 |
| 53-I-131 | 0.00092 | ± | 0.00033 | 3.076 | ± | 0.074 |
| 53-I-135 | 2.41 | ± | 0.60 | 6.84 | ± | 0.23 |
| 54-Xe-128 | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 54-Xe-130 | 0.000000002 | ± | 0.000000001 | 0.000023 | ± | 0.000010 |
| 54-Xe-131m | 0.000000166 | ± | 0.000000060 | 0.0334 | ± | 0.0036 |
| 54-Xe-133 | 0.000262 | ± | 0.000094 | 6.61 | ± | 0.18 |
| 54-Xe-133m | 0.00063 | ± | 0.00023 | 0.189 | ± | 0.017 |
| 54-Xe-135 | 0.051 | ± | 0.019 | 7.01 | ± | 0.24 |
| 54-Xe-135m | 0.124 | ± | 0.046 | 1.25 | ± | 0.13 |
| 55-Cs-134 | 0.0000053 | ± | 0.0000020 | 0.0000092 | ± | 0.0000026 |
| 55-Cs-137 | 0.065 | ± | 0.024 | 6.28 | ± | 0.14 |
| 56-Ba-140 | 0.178 | ± | 0.068 | 5.76 | ± | 0.11 |
| 57-La-140 | 0.00038 | ± | 0.00014 | 5.76 | ± | 0.11 |
| 58-Ce-141 | 0.00000275 | ± | 0.00000099 | 4.90 | ± | 0.12 |
| 58-Ce-144 | 0.0174 | ± | 0.0067 | 4.123 | ± | 0.095 |
| 59-Pr-144 | 0.00000098 | ± | 0.00000038 | 4.123 | ± | 0.095 |
| 60-Nd-142 | 0.0 | ± | 0.0 | 0.000000004 | ± | 0.000000001 |
| 60-Nd-144 | 0.0 | ± | 0.0 | 4.123 | ± | 0.095 |
| 60-Nd-147 | 0.000043 | ± | 0.000016 | 2.252 | ± | 0.095 |
| 61-Pm-147 | 0.000000002 | ± | 0.000000001 | 2.252 | ± | 0.095 |
| 61-Pm-148 | 0.000000038 | ± | 0.000000014 | 0.000000042 | ± | 0.000000014 |
| 61-Pm-148m | 0.000000089 | ± | 0.000000032 | 0.000000089 | ± | 0.000000032 |
| 61-Pm-149 | 0.0000045 | ± | 0.0000018 | 1.454 | ± | 0.071 |

Table C-2.6: Pu-241 thermal fission yields for selected fission products.

| Fission Product | Independent yield [% per fission] | | | Cumulative yield [% per fission] | | |
|---|---|---|---|---|---|---|
| 61-Pm-151 | 0.00102 | ± | 0.00048 | 0.86 | ± | 0.24 |
| 62-Sm-148 | 0.0 | ± | 0.0 | 0.000000127 | ± | 0.000000034 |
| 62-Sm-150 | 0.000000014 | ± | 0.000000006 | 0.000079 | ± | 0.000031 |
| 62-Sm-151 | 0.00000055 | ± | 0.00000026 | 0.86 | ± | 0.24 |
| 62-Sm-153 | 0.000045 | ± | 0.000023 | 0.40 | ± | 0.23 |
| 63-Eu-151 | 0.0 | ± | 0.0 | 0.86 | ± | 0.24 |
| 63-Eu-152 | 0.0 | ± | 0.0 | 0.0 | ± | 0.0 |
| 63-Eu-154 | 0.00000047 | ± | 0.00000020 | 0.00000089 | ± | 0.00000034 |
| 63-Eu-155 | 0.000013 | ± | 0.000012 | 0.19 | ± | 0.35 |

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