Evaluation of Decay Data: Relevant IAEA Co-ordinated Research Projects

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IAEA Nuclear Data Section

- Provision of *nuclear data services* to scientists worldwide (data libraries, bibliographies and related materials) through Internet, CD-ROM and other media
- Production of new databases through *Co-ordinated Research Projects* (CRPs) and *Data Development* projects
- Assist developing countries through *technology transfer* activities

Applications of Nuclear Data

- Energy applications
  - fission power
  - fusion reactor technology
- Non-energy applications
  - nuclear medicine
  - materials analysis and process control
  - safeguards
  - radiation safety
  - waste management
  - environmental research
  - basic research (e.g. nuclear astrophysics) and education

Nuclear Data Files

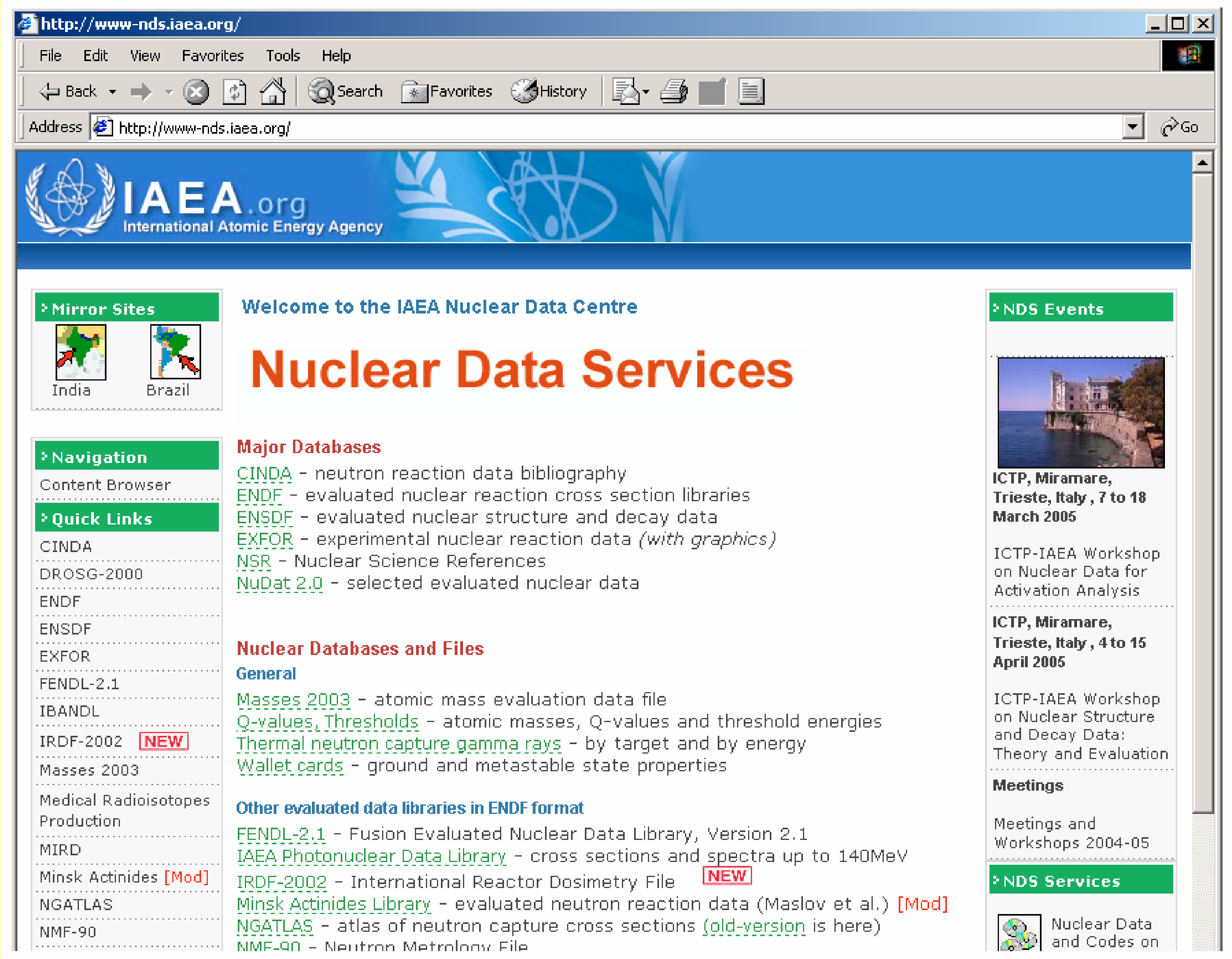
- **Bibliographic data** (e.g. CINDA, NSR)
- **Experimental data** (e.g. EXFOR)
- **Evaluated data** (e.g. ENDF, ENSDF)
- **Nuclear reaction data** (e.g. EXFOR, ENDF)
- **Nuclear structure and decay data** (e.g. ENSDF)

Data Centre Activities

- Compilation
  - new data (neutron-induced) in EXFOR
  - master files in cooperation with other centres
  - collect evaluated and specialized libraries
- On-line and Off-line data services with particular emphasis on the needs of developing countries
- Co-ordination of Data Centre Networks

IAEA Nuclear Data Section

http://www-nds.iaea.org/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CINDA
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ENSDF
EXFOR
FENDL-2.1
IBANDL
IRDF-2002 NEW
Masses 2003
Medical Radioisotopes Production
MIRD
Minsk Actinides [Mod]
NGATLAS
NMF-90
Welcome to the IAEA Nuclear Data Centre
Nuclear Data Services
Major Databases
CINDA - neutron reaction data bibliography
ENDF - evaluated nuclear reaction cross section libraries
ENSDF - evaluated nuclear structure and decay data
EXFOR - experimental nuclear reaction data (with graphics)
NSR - Nuclear Science References
NuDat 2.0 - selected evaluated nuclear data
Nuclear Databases and Files
General
Masses 2003 - atomic mass evaluation data file
Q-values, Thresholds - atomic masses, Q-values and threshold energies
Thermal neutron capture gamma rays - by target and by energy
Wallet cards - ground and metastable state properties
Other evaluated data libraries in ENDF format
FENDL-2.1 - Fusion Evaluated Nuclear Data Library, Version 2.1
IAEA Photonuclear Data Library - cross sections and spectra up to 140MeV
IRDF-2002 - International Reactor Dosimetry File NEW
Minsk Actinides Library - evaluated neutron reaction data (Maslov et al.) [Mod]
NGATLAS - atlas of neutron capture cross sections (old-version is here)
NMF-90 - Neutron Metrology File
NDS Events
ICTP, Miramare, Trieste, Italy, 7 to 18 March 2005
ICTP-IAEA Workshop on Nuclear Data for Activation Analysis
ICTP, Miramare, Trieste, Italy, 4 to 15 April 2005
ICTP-IAEA Workshop on Nuclear Structure and Decay Data: Theory and Evaluation
Meetings
Meetings and Workshops 2004-05
NDS Services
Nuclear Data and Codes on

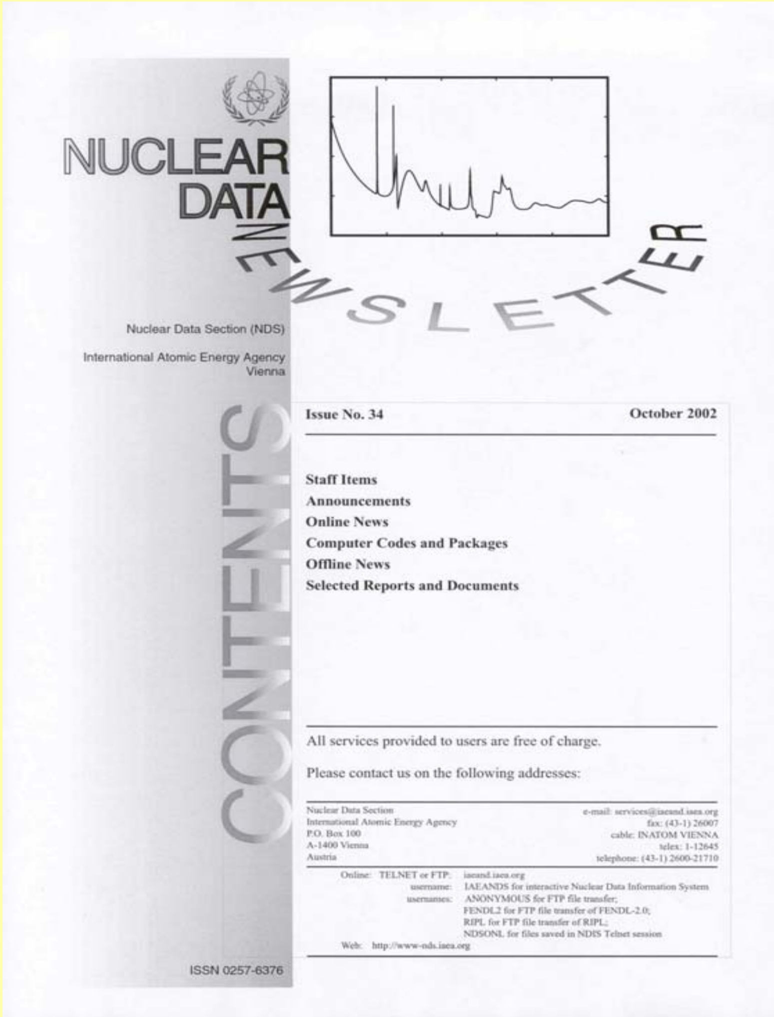
Nuclear Data Centre Networks

- **Network of 13 *<u>Nuclear Reaction Data Centres</u>***
  - **4 core centres:**
    - **IAEA Nuclear Data Section**, Vienna
    - **OECD NEA Data Bank**, Paris, France
    - **US National Nuclear Data Center**, Brookhaven, USA
    - **Russia Nuclear Data Centre**, Obninsk, Russian Federation
  - **Expanded network** includes additional co-operating specialized centres in Russian Federation, China, Japan, Hungary, Korea and Ukraine

- ***<u>Nuclear Structure and Decay Data Network</u>***
  - **IAEA Nuclear Data Section**, Vienna (Co-ordination)
  - **US National Nuclear Data Center**, Brookhaven, USA (Master database)
  - **13 data evaluation centres** in USA, Russian Federation, China, France, Japan, Kuwait, Belgium, Canada
  - **Data dissemination centres** IAEA, OECD-NEA, USA, France, Sweden

Want to be kept informed?

Available as hardcopy and from WWW in pdf format


NUCLEAR DATA NEWSLETTER

Nuclear Data Section (NDS)

International Atomic Energy Agency
Vienna

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Issue No. 34	October 2002

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Selected Reports and Documents

All services provided to users are free of charge.

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username: IAEANDS for interactive Nuclear Data Information System
usernames: ANONYMOUS for FTP file transfer;
FENDL2 for FTP file transfer of FENDL-2.0;
RIPL for FTP file transfer of RIPL;
NDSONL for files saved in NDIS Telnet session
Web: http://www-nds.iaea.org

ISSN 0257-6376

Data Access and Services

- **WWW**
  - IAEA Nuclear Data Services homepage: http://www-nds.iaea.org/
  - BARC, India mirror server:

    http://www-nds.indcentre.org.in/
  - IPEN, Brazil mirror server: http://www-nds.ipen.br/

- Secure **FTP** access to various libraries under IP address *ndsalpha.iaea.org*

- **Mail** services (request hardcopies, CD-ROMs etc.): e-mail to *services@iaeand.iaea.org*

Recent IAEA-NDS Co-ordinated Research Projects

Short Title	Duration	Participants
Update of X-ray and Gamma-ray Decay Data Standards for Detector Calibration and Other Applications	1998-2002	11
RIPL-II: Input Parameter Testing	1998-2002	8
Prompt Gamma Activation Analysis	1999-2003	10
Standard Cross Sections	2002-06	9
RIPL-III: Parameters for Nuclear Reaction Calculations – Non-energy Applications	2002-06	11
Nuclear Data for Th-U Fuel Cycle	2003-07	9
Cross Sections for Production of Therapeutic Radionuclides	2003-07	8
Updated Decay Data Library for Actinides	2005-09	approved
Reference Database for Ion Beam Analysis	2005-09	approved
Reference Database for Neutron Activation Analysis	2005-07 (?)	approved
Minor Actinide Neutron Reaction Data	2007-11 (?)	

Nuclear Structure and Decay Data: Relevant IAEA-NDS Co-ordinated Research Projects

Title	Duration	Participants
Decay Data of the Transactinium Nuclides (Technical Reports Series No. 261, IAEA Vienna, 1986)	1977-85	6
X-ray and Gamma-ray Standards for Detector Calibration (IAEA-TECDOC-619, IAEA Vienna, 1991)	1986-90	9

Decay Data of the Transactinium Nuclides

Technical Reports Series No. 261, May 1986

Objectives

- assess status of existing data
- identify data discrepancies and unfulfilled requirements
- encourage measurements to meet requirements
- evaluate the data
- assemble final set of recommended decay data (satisfy required accuracies)

Decay Data of the Transactinium Nuclides

Participants

- A.J. Fudge, UKAEA Atomic Energy Research Establishment (AERE), Harwell, UK
- R. Vaninbroukx, Central Bureau for Nuclear Measurements (CBNM), Geel, Belgium
- C.W. Reich, Idaho National Engineering Laboratory (INEL), Idaho Falls, Idaho, USA
- H. Okashita (and H. Umezawa), Japan Atomic Research Institute, Tokai-mura, Japan
- J. Legrand (and N. Coursol, F. Lagoutine and G. Malet), Laboratoire de Metrologie des Rayonnements Ionisants (LMRI), Gif-sur-Yvette, France
- A.L. Nichols, UKAEA Atomic Energy Establishment Winfrith (AEEW), UK

Nuclide	Data type	Accuracy (%) Required	Achieved	Needs	CRP activities Measurements	Evaluations
Th-228	$T_{1/2}$	1	0.1	Decay chain calculations (includes daughters)	–	CBNM
	P_γ	2	2–5		CBNM, INEL	CBNM, LMRI
Th-229	$T_{1/2}$	1	2	Mass determination in U-233 chain	–	–
	P_γ	2	1–3		INEL, +	INEL
Th-230	$T_{1/2}$	1	0.4	Marine dating	+	+

(continued)

Nuclide	Data type	Accuracy (%) Required	Accuracy (%) Achieved	Needs	CRP activities Measurements	CRP activities Evaluations
Th-232	$T_{1/2}$	not requested	0.4	Includes daughters	–	+
	P_γ	not requested			–	
Th-233	$T_{1/2}$	1	0.5	Thorium cycle-	–	–
	P_β	2	unknown	decay heat	–	–
	P_γ	2	unknown		AERE	–
Pa-231	$T_{1/2}$	1	0.3	Non-destructive assay	–	–
	P_α	2	2–7		–	AEEW
	P_γ	2	2–5		AERE	AEEW
Pa-233	$T_{1/2}$	1	0.4	Decay heat and mass	–	–
	P_β	2	unknown	determination	–	–
	P_γ	2	1		AERE, CBNM, INEL	INEL
U-232	$T_{1/2}$	1	0.7	Shielding calculations (includes daughters)	AERE, +	+
	P_α	2	1		–	–
	P_γ	2	1–2		AERE, CBNM, INEL, +	CBNM

(continued)

Nuclide	Data type	Accuracy (%) Required	Achieved	Needs	CRP activities Measurements	Evaluations
U-233	$T_{1/2}$	0.5	0.1	Thorium fuel cycle and environmental studies	+	+
	$T_{1/2}$ (SF)	not requested			+	–
	P_{α}	2	1–2		+	INEL
	P_{γ}	2	1–2		AERE, INEL	INEL
	P_{X}	5	unknown		–	–
U-234	$T_{1/2}$	0.3	0.1	Mass determination and non-destructive assay	+	AEEW
	$T_{1/2}$ (SF)	not requested			+	–
	P_{α}	1	0.03–1		CBNM, JAERI, +	AEEW
	P_{γ}	2	1–2		CBNM	AEEW
U-235	$T_{1/2}$	0.5	0.1	Mass determination and non-destructive assay	–	+
	$T_{1/2}$ (SF)	not requested			+	–
	P_{α}	3	5–12		–	–
	P_{γ}	1	1		AERE, CBNM, INEL, +	CBNM
U-236	$T_{1/2}$	1	0.1	Mass determination and non-destructive assay	–	+
	$T_{1/2}$ (SF)	not requested	3		+	–
	P_{α}	3	5–15		–	–
	P_{γ}	3	10		–	–
U-237	P_{γ}	1	2–3	Non-destructive assay of Pu	AERE, INEL	LMRI

(continued)

Nuclide	Data type	Accuracy (%) Required	Accuracy (%) Achieved	Needs	CRP activities Measurements	CRP activities Evaluations
U-238	$T_{1/2}$	1	0.1	Mass determination and non-destructive assay; $T_{1/2}$ (SF) for geochronology; P_X for environmental studies	–	+
	$T_{1/2}$ (SF)	2	1.2		+	+
	P_α	3	5–20		–	–
	P_γ	3	13		AERE, +	–
	P_X	3	unknown		–	–
U-239	$T_{1/2}$	1	0.2	Decay heat	–	AEEW
	P_β	2	2–20		+	AEEW
	P_γ	2	2		+	AEEW
Np-236	$T_{1/2}$	5	10	U-232 production	+	–
	Branching ratio	5	2		–	–
	P_β	2	unknown		–	–
	P_γ	2	2		–	–
Np-236m	$T_{1/2}$	5	2	U-232 production	–	–
	Branching ratio	5	2		–	–
Np-237	$T_{1/2}$	0.5	0.5	Environmental studies and mass determination	AERE/CBNM	–
	P_α	1	20		CBNM	–
	P_γ	1	1–2		AERE, CBNM, +	INEL
	P_X	2	unknown			

(continued)

Nuclide	Data type	Accuracy (%) Required	Achieved	Needs	CRP activities Measurements	Evaluations
Np-238	$T_{1/2}$	2	0.1	Activation analysis of	–	–
	P_{γ}	2	5	Np-237 and Am-242m	–	–
				determination		
Np-239	$T_{1/2}$	1	0.2	Decay heat and	–	–
	P_{β}	2	(c)	detector calibration	–	–
	P_{γ}	1	1–2	standard	CBNM, +	CBNM
Pu-236	$T_{1/2}$	1	3.0		–	+
	P_{α}	2	1–3	U-232 production	–	–
	P_{γ}	3	30		–	–
Pu-237	$T_{1/2}$	not requested	0.1		+	CBNM
	P_X	2	unknown	Environmental	–	–
				studies		
Pu-238	$T_{1/2}$	0.5	0.3		+	+
	$T_{1/2}$ (SF)	2	4	Mass determination	–	+
	P_{α}	1	<1	and non-destructive	CBNM, +	LMRI
	P_{γ}	1	1–2	assay; P_X for	CBNM, INEL,	LMRI
				detector calibration	LMRI	
	P_X	2	2–3		–	–

(continued)

Nuclide	Data type	Accuracy (%) Required	Accuracy (%) Achieved	Needs	CRP activities Measurements	CRP activities Evaluations
Pu-239	$T_{1/2}$	0.5	0.1	Mass determination, non-destructive assay and environmental studies	AERE, CBNM, +	CBNM
	P_α	1	1–2		+	JAERI
	P_γ	1	<1		INEL, LMRI, +	JAERI
	P_X	3	3		–	–
Pu-240	$T_{1/2}$	0.5	0.1	Mass determination, non-destructive assay and environmental studies; $T_{1/2}$ (SF) for waste management	+	CBNM/LMRI
	$T_{1/2}$ (SF)	2	3		CBNM	+
	P_α	1	1–2		+	LMRI
	P_γ	1	1–2		INEL, LMRI	LMRI
	P_X	3	3		–	–
Pu-241	$T_{1/2}$	0.5	0.7	Mass determination and non-destructive assay	AERE, CBNM, +	CBNM
	$T_{1/2}$ (α)	1	0.8		CBNM	–
	P_γ	1	1–2		INEL, +	LMRI
Pu-242	$T_{1/2}$	1	0.3	Mass determination, non-destructive assay and environmental studies	+	+
	$T_{1/2}$ (SF)	5	1.5		–	+
	P_α	5	<1		–	–
	P_γ	5	2–5		CBNM	–
	P_X	3	unknown		–	–
Am-241	$T_{1/2}$	0.2	0.1	Non-destructive assay and low energy gamma emission standard. 0.5% accuracy requested for 59.5 keV gamma emission probability	–	CBNM
	P_α	not requested	1–2		+	CBNM
	P_γ	0.5–1	1–10		CBNM, LMRI	CBNM
	P_X	2	3		–	–

(continued)

Nuclide	Data type	Accuracy (%) Required	Accuracy (%) Achieved	Needs	CRP activities Measurements	CRP activities Evaluations
Am-242	$T_{1/2}$	1	0.1	Cm-244 production and	–	y ··
	Branching ratio	1	1	Am mass determination	–	–
Am-242m	$T_{1/2}$	1	1.4	Cm-244 production	+	AEEW
	Branching ratio	1	0.03	and Am mass determination	–	AEEW
	P_X	3	unknown		–	–
Am-243	$T_{1/2}$	1	0.2	Mass determination,	+	CBNM
	P_α	1	unknown	long term storage and	–	CBNM
	P_γ	1	2	environmental studies	CBNM, +	CBNM
	P_X	2	unknown		–	–
Cm-242	$T_{1/2}$	0.2	0.04		AERE, JAERI, +	JAERI
	$T_{1/2}$ (SF)	5	2	Non-destructive	JAERI, +	JAERI
	P_γ	5	4–20	assay	–	–
Cm-243	$T_{1/2}$	1	0.3		–	+
	P_α	5	1–3	Non-destructive	–	–
	P_γ	5	2–10	assay and environ-	–	–
	P_X	5	unknown	mental studies	–	–

(continued)

Nuclide	Data type	Accuracy (%) Required	Accuracy (%) Achieved	Needs	CRP activities Measurements	CRP activities Evaluations
Cm-244	$T_{1/2}$	1	0.3		–	+
	$T_{1/2}$ (SF)	3	0.4		–	+
	P_α	3	<1	Non-destructive assay	+	LMRI
	P_γ	3	2–10	and environmental	–	LMRI
	P_X	3	3	studies	–	–
Cm-245	$T_{1/2}$	1	1	Long term storage and	+	+
	P_α	5	0.5–2	environmental studies	–	–
	P_γ	5	10		–	–
	P_X	5	unknown		–	–
Cm-246	$T_{1/2}$	1	2	Long term storage and	–	+
	P_α	3	1–5	environmental studies	–	–
	P_γ	3	unknown		–	–
	P_X	3	unknown		–	–
Cm-248	$T_{1/2}$	2	1	Long term storage and	–	+
	P_α	3	<1	environmental studies	–	–
	P_γ	3	unknown		–	–
	P_X	3	unknown		–	–
Cf-250	$T_{1/2}$	0.2	0.7	Impurity in Cf-252	–	–
	$T_{1/2}$ (SF)	2	4	neutron standard	–	–
Cf-252	$T_{1/2}$	0.2	0.3	Neutron standard	LMRI	INEL
	$T_{1/2}$ (SF)	1	0.3		–	+

I. HALF-LIFE

Recommended value: $(2.14 \pm 0.01) \times 10^6$ a

This value is based on the results of only one precise measurement, namely that of Brauer et al. [1].

II. EMISSION PROBABILITIES OF SELECTED GAMMA RAYS

Evaluated by C.W. Reich (INEL, Idaho Falls, USA).

A. Recommended values

E_γ (keV)[a]	P_γ
29.37	0.153 ± 0.003
46.53	0.00106 ± 0.00006
57.15	0.00382 ± 0.00011
86.50	0.123 ± 0.002
88.04	0.00138 ± 0.00003
117.68	0.00173 ± 0.00003
131.04	0.00086 ± 0.00002
134.23	0.00071 ± 0.00002
143.21	0.00432 ± 0.00008
151.37	0.00234 ± 0.00004
155.22	0.00092 ± 0.00002
169.17	0.00071 ± 0.00001
195.09	0.00185 ± 0.00002
212.42	0.00151 ± 0.00002
238.0	0.00059 ± 0.00001

Note to Table A

[a] Nominal values only.

B. CRP measurements

^{237}Np

E_γ (keV)	Banham (1984) [2][a]	Vaninbroukx et al. (1984) [4]
29.37	0.154 *2*	0.1503 *40*
46.53	0.00104 *6*	0.0011 *1*
57.15	0.00373 *11*	0.0039 *1*
86.50	0.1220 *12*	0.1244 *33*
88.04	0.00138 *3*	0.0014 *1*
117.68	0.00175 *2*	0.00168 *5*
131.04	0.00086 *1*	–
134.23	0.00071 *1*	–
143.21	0.00430 *4*	0.00434 *10*
151.37	0.00236 *2*	0.00232 *6*
155.22	0.000917 *10*	–
169.17	0.000711 *7*	–
195.09	0.00184 *2*	0.00188 *5*
212.42	0.00150 *2*	0.00155 *5*
238.0	0.000586 *12*	–

Note to Table B

[a] The P_γ values previously reported by Banham and Fudge [3] have been modified somewhat owing to changes in their detector-efficiency curves resulting from the adoption of more recent values for the efficiency calibration standards. It is these modified P_γ values that are shown here.

C. Comparison with other measurements

E_γ(keV)[a]	CRP measurements		Other measurements				
	Banham (1984) [2]	Vaninbroukx et al. (1984) [4]	González et al. (1979) [5]	Skalsey and Connor (1976) [6]	Brown and Asaro (1969) [7]	Vara and Gaeta (1969) [8]	Recommended values[h]
29.37	0.154 *2*	0.1503 *40*	0.103 *10*	0.162 *9*	0.140 *20*	0.13	0.153 *3*
46.53	0.00104 *6*	0.0011 *1*	0.0010 *1*	0.0012 *2*	0.00140 *20*	0.001[e]	0.00106 *6*
57.15	0.00373 *11*	0.0039 *1*	0.0038 *4*	0.00433 *25*	0.00420 *38*	0.0006	0.00382 *11*
86.50	0.1220 *12*	0.1244 *33*	0.126[b]	0.123[c]	0.126[d]	0.13[f]	0.123 *2*
88.04	0.00138 *3*	0.0014 *1*	0.0012 *1*	0.0014 *4*	0.00160 *20*	–	0.00138 *3*
117.68	0.00175 *2*	0.00168 *5*	0.00151 *15*	0.00180 *12*	0.00170 *20*	–	0.00173 *3*
131.04	0.00086 *1*	–	0.00081 *8*	0.0010 *1*	0.00089 *9*	0.001	0.00086 *2*
134.23	0.00071 *1*	–	0.00063 *6*	0.00081 *16*	0.00071 *8*	0.001	0.00071 *2*
143.21	0.00430 *4*	0.00434 *10*	0.0041 *4*	0.00462 *28*	0.00420 *40*	0.004	0.00432 *8*
151.37	0.00236 *2*	0.00232 *6*	0.00227 *23*	0.00249 *16*	0.00249 *30*	0.001	0.00234 *4*
155.22	0.000917 *10*	–	0.00087 *9*	0.00097 *7*	0.00097 *9*	–	0.00092 *2*
169.17	0.000711 *7*	–	0.00074 *7*	0.00082 *9*	0.00076 *8*	–	0.00071 *1*
195.09	0.00184 *2*	0.00188 *5*	0.0016 *2*	0.00169 *21*	0.00210 *20*	0.001	0.00185 *2*
212.42	0.00150 *2*	0.00155 *5*	0.00160 *16*	0.00166 *11*	0.00159 *20*	0.001	0.00151 *2*
238.0	0.000586 *12*	–	0.00063 *7*	0.00075 *9*	0.00068 *6*	0.0005[g]	0.00059 *1*

International Nuclear Data Committee, May 2002 and May 2004:

recommended Update of Actinide Decay Data Library by means of a Co-ordinated Research Project

Planned for 2005 to 2009

X-ray and Gamma-ray Standards for Detector Calibration

IAEA-TECDOC-619, September 1991

<u>Primary Objective</u>

- produce a recommended set of decay parameters for selected radionuclides judged as the most important for the efficiency calibration of equipment used to detect and quantify x-ray and gamma-ray emissions

X-ray and Gamma-ray Standards for Detector Calibration

<u>Participants</u>

- W. Bambynek, CEC-JRC, Central Bureau for Nuclear Measurements (CBNM), Geel, Belgium
- Y. Yoshizawa, Hiroshima University, Hiroshima-shi, Japan
- R.G. Helmer, Idaho National Engineering Laboratory (INEL), Idaho Falls, Idaho, USA
- N. Coursol, Laboratoire de Metrologie des Rayonnements Ionisants (LMRI), Gif-sur-Yvette, France
- F.J. Schima, National Institute of Standards and Technology (NIST), Gaithersburg, Maryland, USA
- T. Barta and R. Jedlovszky, National Office of Measures (OMH), Budapest, Hungary
- P. Christmas, National Physical Laboratory (NPL), Teddington, Middlesex, UK
- K. Debertin, Physikalisch Technische Bundesanstalt (PTB), Braunschweig, Germany
- A.L. Nichols, AEA Technology, Winfrith Technology Centre, Dorchester, Dorset, UK

X-ray and Gamma-ray Standards for Detector Calibration

Ancillary Objectives

- selection of appropriate (efficiency) calibration nuclides
- assessment of the status of existing data
- identification of data discrepancies and limitations
- stimulation of measurements to meet data needs
- evaluation and recommendation of improved efficiency calibration data

X-ray and Gamma-ray Standards for Detector Efficiency Calibration

- cover as wide a range of photon energy as possible (5 keV to approximately 10 MeV)
- x-ray and low-energy gamma-ray emitting radionuclides from 5 to 100 keV
- commonly used and readily available nuclides
- nuclides used and offered as standards by national laboratories, multi-line nuclides for rapid calibrations
- definition of a set of single-line nuclides to avoid the need for coincidence summing corrections
- choice of nuclides with accurately known emission probabilities

X-ray and Gamma-ray Standards for Detector Calibration

Calibration Standards: Decay Parameters and CRP Activities

Radio-nuclide	Data Type	Uncertainty Achieved(%)+	CRP activities	
			Measurements	Evaluations
^{22}Na	$T_{1/2}$	0.1	NIST	NPL/PTB
	P_γ	0.015	-	NIST
^{24}Na	$T_{1/2}$	0.03	-	NPL/PTB
	P_γ	0.0015-0.005	-	NIST
^{46}Sc	$T_{1/2}$	0.05	-	NPL/PTB
	P_γ	0.0016	-	Hiroshima Univ.
^{51}Cr	$T_{1/2}$	0.03	-	NPL/PTB
	P_x	1.3	-	CBNM
	P_γ	0.5	OMH	AEA
^{54}Mn	$T_{1/2}$	0.13	NIST/NPL	NPL/PTB
	P_x	3.1	-	CBNM
	P_γ	0.0024	-	Hiroshima Univ.
^{55}Fe	$T_{1/2}$	0.8	PTB	NPL/PTB
	P_x	3.5	-	CBNM

(continued)

Radio-nuclide	Data Type	Uncertainty Achieved(%)+	CRP activities: Measurements	CRP activities: Evaluations
^{56}Co	$T_{1/2}$	0.3	PTB/NPL	NPL/PTB
	P_γ	0.007-0.4	-	Hiroshima Univ.
^{57}Co	$T_{1/2}$	0.03	NIST/NPL	NPL/PTB
	P_x	0.7	-	CBNM
	P_γ	0.2-1.5	PTB	OMH
^{58}Co	$T_{1/2}$	0.1	NPL	NPL/PTB
	P_x	3.8	-	CBNM
	P_γ	0.01	-	OMH
	α_t	3	-	LMRI
^{60}Co	$T_{1/2}$	0.03	NIST/NPL	NPL/PTB
	P_γ	0.006-0.02	-	NIST
^{65}Zn	$T_{1/2}$	0.11	NPL	NPL/PTB
	P_x	2.3	-	CBNM
	P_γ	0.5	NPL/PTB	AEA
^{75}Se	$T_{1/2}$	0.2	NIST/NPL	NPL/PTB
	P_x	7.1	-	CBNM
	P_γ *	0.3-1.2	LMRI/NIST/OMH/PTB	AEA
	α_t	1-7	-	LMRI
^{85}Sr	$T_{1/2}$	0.006	-	NPL/PTB
	P_x	1.4	-	CBNM
	P_γ	0.4	-	Hiroshima Univ.
	α_t	12	-	Hiroshima Univ.
^{88}Y	$T_{1/2}$	0.02	-	NPL/PTB
	P_x	1.3	-	CBNM
	P_γ	0.03-0.3	PTB	LMRI
	α_t	1	-	LMRI
^{93m}Nb	$T_{1/2}$	0.85	-	PTB/NPL
	P_x	3.2	-	CBNM
^{94}Nb	$T_{1/2}$	12	-	PTB/NPL
	P_γ	0.05	-	INEL
	α_t	1	-	LMRI

(continued)

Radio-nuclide	Data Type	Uncertainty Achieved(%)+	CRP activities	
			Measurements	Evaluations
^{95}Nb	$T_{1/2}$	0.02	-	PTB/NPL
	P_γ	0.03	-	INEL
	α_t	1-3	-	LMRI
^{109}Cd	$T_{1/2}$	0.15	NIST	PTB/NPL
	P_x	2.0	-	CBNM
	P_γ #	0.6	PTB	LMRI
	α_t	2	-	LMRI
^{111}In	$T_{1/2}$	0.02	-	PTB/NPL
	P_x	2.4	-	CBNM
	P_γ #	0.1	-	Hiroshima Univ.
	α_t	1.2	-	Hiroshima Univ.
^{113}Sn	$T_{1/2}$	0.03	-	PTB/NPL
	P_x	0.6	-	CBNM
	P_γ #	0.2	-	INEL
^{125}Sb	$T_{1/2}$	0.06	-	PTB/NPL
	P_γ	1	INEL	LMRI
^{125}I	$T_{1/2}$	0.02	NIST/NPL/PTB/CBNM	PTB/NPL
	P_x	2.2	-	CBNM
	P_γ #	1.2	PTB	LMRI
	α_t	1.5	-	LMRI
^{134}Cs	$T_{1/2}$	0.03	-	PTB/NPL
	P_γ	0.06-1.3	-	Hiroshima Univ.
^{137}Cs	$T_{1/2}$	0.4	NIST	PTB/NPL
	P_x	2.9	-	CBNM
	P_γ	0.24	-	LMRI
	α_t	0.7	-	LMRI
^{133}Ba	$T_{1/2}$	0.4	-	PTB/NPL
	P_x	1.3	-	CBNM
	P_γ *	0.3-0.8	OMH/PTB	OMH
	α_t	5.5-7	-	LMRI
^{139}Ce	$T_{1/2}$	0.02	-	PTB/NPL
	P_x	2.8	-	CBNM
	P_γ	0.08	-	LMRI
	α_t	0.4	-	LMRI

(continued)

Radio-nuclide	Data Type	Uncertainty Achieved(%)+	CRP activities	
			Measurements	Evaluations
^{152}Eu	$T_{1/2}$	0.2	NIST/NPL	PTB/NPL
	P_x	1.6	-	CBNM
	P_γ *	0.5	-	INEL
^{154}Eu	$T_{1/2}$	0.09	-	PTB/NPL
	P_x	2.3	-	CBNM
	P_γ	1.1-1.7	INEL/NIST/NPL	Hiroshima Univ.
^{155}Eu	$T_{1/2}$	2.8	PTB	PTB/NPL
^{198}Au	$T_{1/2}$	0.03	-	PTB/NPL
	P_x	7.1	-	CBNM
	P_γ	0.5	-	AEA
^{203}Hg	$T_{1/2}$	0.03	-	PTB/NPL
	P_x	3.1	-	CBNM
	P_γ	0.1	-	INEL
^{207}Bi	$T_{1/2}$	6	-	PTB/NPL
	P_x	5.2	-	CBNM
	P_γ	0.03-0.6	INEL/NIST/PTB	Hiroshima Univ.
	α_t	1.4	-	Hiroshima Univ.
^{228}Th (and daughters)	$T_{1/2}$	0.9	-	NPL/PTB
	P_γ	0.2-3.3	-	LMRI
^{239}Np	$T_{1/2}$	0.17	-	PTB/NPL
	P_γ	1.5	-	LMRI
^{241}Am	$T_{1/2}$	0.15	-	PTB/NPL
	P_x	2.0	-	CBNM
	P_γ	1-4	PTB	CBNM
^{243}Am	$T_{1/2}$	0.3	-	NPL/PTB
	P_γ	1.5-1.9	-	AEA/LMRI
	α_t	2	-	LMRI

X-ray and Gamma-ray Standards for Detector Efficiency Calibration

Half-life inconsistencies: further measurements recommended

Priority 1 – ^{55}Fe, ^{56}Co, ^{125}I and ^{155}Eu

Priority 2 – ^{54}Mn, ^{75}Se and ^{109}Cd

Priority 3 – ^{22}Na, ^{58}Co, ^{65}Zn and ^{133}Ba

X-ray and Gamma-ray Standards for Detector Efficiency Calibration

High-energy gamma rays, ^{66}Ga

Eγ (keV)	Pγ
833.6	0.0603(12)
1039.4	0.379
1333.2	0.01232(25)
1918.8	0.0214(4)
2189.9	0.0571(11)
2422.9	0.0196(4)
2752.3	0.232(8)
3229.2	0.0148(11)
3381.4	0.0140(11)
3791.6	0.0102(11)
4086.5	0.0114(19)
4295.7	0.035(7)
4807.0	0.015(4)

X-ray and Gamma-ray Standards for Detector Efficiency Calibration

Prompt gamma rays from the $^{14}N(n, \gamma)^{15}N$ reaction

Eγ (keV)	Pγ
1678.174(55)	0.0723(18)
1884.879(21)	0.1866(25)
2520.418(15)	0.0579(7)
3532.013(13)	0.0924(9)
3677.772(17)	0.1489(15)
4508.783(14)	0.1654(17)
5269.169(12)	0.3003(20)
5297.817(15)	0.2131(18)
5533.379(13)	0.1975(21)
5562.062(17)	0.1065(12)
6322.337(14)	0.1867(14)
7298.914(33)	0.0973(9)
8310.143(29)	0.0422(5)
9149.222(47)	0.0162(2)
10829.087(46)	0.1365(21)

X-ray and Gamma-ray Standards for Detector Efficiency Calibration

Other high-energy gamma rays?

$^{35}Cl(n, \gamma)^{36}Cl^*$

$^{48}Ti(n, \gamma)^{49}Ti^*$

$^{52}Cr(n, \gamma)^{53}Cr^*$

$^{53}Cr(n, \gamma)^{54}Cr^*$

$^{11}B(p, \gamma)^{12}C^*$

$^{14}N(p, \gamma)^{15}O^*$

$^{23}Na(p, \gamma)^{24}Mg^*$

$^{27}Al(p, \gamma)^{28}Si^*$

NEANDC - 311 "U"
INDC(SEC)-101

NUCLEAR DATA STANDARDS

FOR NUCLEAR MEASUREMENTS

1991 NEANDC/INDC NUCLEAR STANDARDS FILE

Editor

H. Condé
Uppsala University
Uppsala, Sweden

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

1992

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Status of Actinide Half Lives

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Geel Establishment, Central Bureau for Nuclear Measurements, B-2440 Geel, Belgium

H. Lemmel
International Atomic Energy Agency, A-1010 Vienna

ACTINIDE HALF-LIVES - Recommended Reference Data

Nuclide	Decay mode	Half-life and Uncertainty Years
U-233	Alpha	(1.592 ± 0.002) E05
	Spont. fission	> 2.7 E17
U-234	Alpha	(2.457 ± 0.003) E05
	Spont. fission	(1.42 ± 0.08) E16
U-235	Alpha	(7.037 ±0.007) E08
	Spont. fission	(1.0 ± 0.3) E19
U-238	Alpha	(4.47 ± 0.02) E09
	Spont. fission	(8.2 ± 0.1) E15
Np-237	Alpha	(2.14 ± 0.01) E06
	Spont. fission	> 1. E18
Pu-239	Alpha	(2.411 ± 0.003) E04
	Spont. fission	(8. ± 2.) E15
Pu-240	Alpha	(6.563 ± 0.007) E03
	Spont. fission	(1.16 ±0.02) E11
Pu-241	Alpha	(5.96 ± 0.04) E05
	Beta	(1.44 ± 0.01) E01
Pu-242	Alpha	(3.75 ± 0.02) E05
	Spont fission	(6.77 ± 0.07) E10
Pu-244	Alpha	(8.00 ± 0.09) E07
	Spont. fission	(6.6 ± 0.2) E10
Cf-252	Alpha	(2.73 ± 0.01) E00
	Spont. fission	(8.55 ± 0.03) E01
	Total	(2.645 ± 0.008) E00

X-ray and Gamma-ray Standards

J. Legrand, A. Lorenz
France/IAEA
June 1988

Updated by H.D. Lemmel, IAEA, Vienna, August 1992

Table 1: Half-Lives of Radionuclides Used for Detector Calibration

Nuclide	Decay Mode	Half-life (days) Value	Uncertainty	Exponent	Reference
11-Na-022	EC	950.8	± 0.9		(1)
11-Na-024	β-	0.62356	± 0.00017		(1)
21-Sc-046	β-	83.79	± 0.04		(1)
24-Cr-051	EC	27.706	± 0.007		(1)
25-Mn-054	EC	312.3	± 0.4		(1)
26-Fe-055	EC	999	± 8		(1)
27-Co-056	EC	77.31	± 0.19		(1)
27-Co-057	EC	271.79	± 0.09		(1)
27-Co-058	EC	70.86	± 0.07		(1)
27-Co-060	β-	1925.5	± 0.5		(1)
30-Zn-065	EC	244.26	± 0.26		(1)
34-Se-075	EC	119.64	± 0.24		(1)
38-Sr-085	EC	64.849	± 0.004		(1)
39-Y-088	EC	106.630	± 0.025		(1)
41-Nb-093m	IT	5890	± 50		(2)
41-Nb--094	β-	7.3	± 0.9	E+06	(2)
41-Nb-095	β-	34.975	± 0.007		(2)

Update of X-ray and Gamma-ray Decay Data Standards for Detector Calibration and Other Applications (1998 – 2002)

M. Herman
IAEA Nuclear Data Section

Update of X-ray and Gamma-ray Decay Data Standards

International Nuclear Data Committee, 1997: strongly recommended IAEA to re-visit and place further emphasis on the development of improved decay data for “standards” applications

- detector efficiency calibration
- other applications (e.g. nuclear medicine, dosimetry, safeguards and environmental monitoring)

Update of X-ray and Gamma-ray Decay Data Standards

Participants

- M.-M. Bé, BNM-CEA/LNHB, Centre d'Etudes Nucleaires de Saclay, Gif-sur-Yvette, France
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- M.J. Woods, Centre for Ionising Radiation Metrology, National Physical Laboratory, Teddington, UK

Update of X-ray and Gamma-ray Decay Data Standards

Main issues

1. **Update of the current database**
   IAEA-TECDOC-619 data for 36 radionuclides were revisited and revised -
   experimental data measured and published after 1990,
   - average x-ray energies and emission probabilities are given in IAEA-TECDOC-619 – require systematic analysis of the energies and emission probabilities of the individual $K_{\alpha 1}$, $K_{\alpha 2}$, $K_{\beta 1'}$ and $K_{\beta 2'}$ components.
2. **Additional radionuclides**
   68 radionuclides formulated at Consultants' Meeting, and adopted as a suitable starting point.
3. **Extension of energy range**
   - new nuclear techniques (for example radiotherapy) suffer from a lack of high-energy calibration standards,
   - data required for the calibration of γ-ray detectors up to 25 MeV,
   - appropriate radionuclides (^{56}Co, ^{66}Ga) and nuclear reactions identified, and γ-ray emission probabilities were compiled and evaluated.

Update of X-ray and Gamma-ray Decay Data Standards

Main issues (cont.)

4. **γ - γ coincidence:** absolute γ-ray detection efficiency without absolutely calibrated γ-ray source
   - angular correlation coefficients of specific nuclei, 80 keV to 2.75 MeV,
   - ^{24}Na, ^{45}Sc, ^{60}Co, ^{66}Ga, ^{67}Ga, ^{75}Se, ^{88}Y, ^{94}Nb, ^{111}In, ^{123m}Te, ^{133}Ba, ^{134}Cs, ^{152}Eu, ^{154}Eu and ^{207}Bi,
   - ^{11}B(p, γ)^{12}C* (4.43 and 11.67 MeV γ rays)

5. **Covariances**
   - lack of necessary data (and detail) in published measurements,
   - instructions proposed for communication to authors concerning data requirements for covariance analysis.

Update of X-ray and Gamma-ray Decay Data Standards

Evaluations undertaken in conjunction with Decay Data Evaluation Project (DDEP) – member laboratories of the International Committee for Radionuclide Metrology (ICRM)

- co-ordinator: E. Browne (Lawrence Berkeley National Laboratory),
- CRP evaluations carried out under agreed DDEP methodology/procedures for consistency,
- recommendations reviewed and approved by DDEP prior to acceptance for CRP,
- adopted by DDEP

  http://www.nucleide.org/DDEP_WG/DDEPdata.htm

Update of X-ray and Gamma-ray Decay Data Standards

Selected Radionuclides and Applications.

Nuclide	X/γ-Ray Standard	Dosimetry Standard	Medical Applications	Environmental Monitoring	Waste Management	Safeguards
^{22}Na	P	-	x	-	-	-
^{24}Na	P	-	-	-	-	-
^{40}K	S	-	-	x	-	-
^{46}Sc	P	-	-	-	-	-
^{51}Cr	S	-	x	-	-	-
^{54}Mn	P	-	-	x	x	-
^{56}Mn	P	-	x	-	-	-
^{55}Fe	S	-	x	-	x	-
^{59}Fe	S	-	x	-	-	-
^{56}Co	S	-	-	-	-	-
^{57}Co	P (122 keV)	-	x	-	-	x
^{58}Co	P	-	-	x	-	-
^{60}Co	P	-	x	x	x	x
^{64}Cu	-	-	x	-	-	-
^{65}Zn	S	-	-	x	x	-
^{66}Ga	S	-	x	-	-	-
^{67}Ga	S	-	x	-	-	-

Update of X-ray and Gamma-ray Decay Data Standards

(continued)

Nuclide	X/γ-Ray Standard	Dosimetry Standard	Medical Applications	Environmental Monitoring	Waste Management	Safeguards
^{68}Ga	-	-	x	-	-	-
^{75}Se	S	-	x	-	-	-
^{85}Kr	-	-	-	x	-	-
^{85}Sr	P	-	x	x	-	-
^{88}Y	P (1836 keV) S (898 keV)	-	-	-	-	-
^{93m}Nb	-	x	-	-	-	-
^{94}Nb	P	-	-	-	-	-
^{95}Nb	P	-	-	x	-	-
^{99}Mo	P (140.5 keV)	-	x	-	-	-
^{99m}Tc	P (140.5 keV)	-	x	-	-	-
^{103}Ru	-	-	x	x	-	-
^{106}Ru-^{106}Rh	S	-	x	x	-	-
^{110m}Ag	S	-	-	x	x	-
^{109}Cd	S	-	-	x	-	-
^{111}In	P	-	x	-	-	-
^{113}Sn	P	-	-	-	-	-
^{125}Sb	-	-	-	x	-	-

Update of X-ray and Gamma-ray Decay Data Standards

(continued)

Nuclide	X/γ-Ray Standard	Dosimetry Standard	Medical Applications	Environmental Monitoring	Waste Management	Safeguards
^{123m}Te	-	-	-	-	-	-
^{123}I	P	-	x	-	-	-
^{125}I	S	x	x	-	-	-
^{129}I	S	-	-	x	x	-
^{131}I	S	x	x	x	-	-
^{134}Cs	S	-	-	x	-	-
^{137}Cs	P	x	-	x	x	-
^{133}Ba	S	-	x	-	-	-
^{139}Ce	P	-	-	x	-	-
^{141}Ce	S	-	-	x	-	-
^{144}Ce	S	-	x	x	-	-
^{153}Sm	-	-	x	-	-	-
^{152}Eu	S	-	-	x	x	x
^{154}Eu	S	-	-	x	x	x
^{155}Eu	S	-	-	x	x	-
$^{166m}Ho-^{166}Ho$	S	-	x	-	-	x

Update of X-ray and Gamma-ray Decay Data Standards

(continued)

Nuclide	X/γ-Ray Standard	Dosimetry Standard	Medical Applications	Environmental Monitoring	Waste Management	Safeguards
^{170}Tm	S	-	-	-	-	-
^{169}Yb	S	-	x	-	-	-
^{192}Ir	S	x	x	-	-	-
^{198}Au	P	-	-	-	-	-
^{203}Hg	P	-	-	-	-	-
^{201}Tl	-	-	x	-	-	-
^{207}Bi	P (569.7 keV)	-	x	-	-	-
^{226}Ra decay chain	S	x	-	x	x	-
^{228}Th decay chain	P	-	-	x	-	-
^{234m}Pa	-	-	-	x	x	-
^{241}Am	P	-	-	x	x	x
^{243}Am	-	-	-	-	x	-

P primary efficiency calibration standard.
S secondary efficiency calibration standard

Update of X-ray and Gamma-ray Decay Data Standards

High-energy Gamma-ray Standards

^{226}Ra up to 2.45 MeV

^{56}Co up to 3.55 MeV

^{66}Ga up to 4.8 MeV

$^{14}N(n, \gamma)^{15}N^*$ up to 10.8 MeV

$^{35}Cl(n, \gamma)^{36}Cl^*$ up to 8.6 MeV

$^{48}Ti(n, \gamma)^{49}Ti^*$ up to 6.8 MeV

$^{50,52,53}Cr(n, \gamma)^{51,53,54}Cr^*$ up to 9.7 MeV

$^{11}B(p, \gamma)^{12}C^*$ up to 13.9 MeV

$^{23}Na(p, \gamma)^{24}Mg^*$ up to 11.6 MeV

$^{27}Al(p, \gamma)^{28}Si^*$ up to 10.8 MeV

Update of X-ray and Gamma-ray Decay Data Standards

CRP

IAEA technical document in preparation – will only include selected data from evaluated decay scheme for detector efficiency calibration and other applications: half-lives, P_X and P_γ (listed with E_X and E_γ)

DDEP

Recommended complete decay schemes available through *http://www.nucleide.org/DDEP_WG/DDEPdata.htm*

LNHB, Centre d’Etudes Nucleaires de Saclay,

F-91191 Gif-sur-Yvette Cedex, France

Update of X-ray and Gamma-ray Decay Data Standards

^{51}Cr

Half-life evaluated by M. J. Woods (NPL, UK), September 2003.

Decay scheme evaluated by E. Schönfeld (PTB, Germany) and R. G. Helmer (INEEL. USA), February 2000.

Recommended data:

Half-life

$T_{1/2}$ = 27.7009 (20) d

Selected gamma ray

E_γ (keV)	P_γ per decay
320.0835 (4) [a]	0.0987 (5) [b]

[a] from Ref. [1].

[b] from direct emission probability measurements.

Update of X-ray and Gamma-ray Decay Data Standards

^{51}Cr

Selected X-rays

Origin	**E_X (keV)**	**P_X per decay**
V Kα	4.94 - 4.95	0.202 (3)
V Kβ	5.43 - 5.46	0.0269 (7)

Update of X-ray and Gamma-ray Decay Data Standards

^{51}Cr

Input data:

Half-life (d)	**Reference**
27.7010 (12) [a]	Unterweger *et al* [H1]
27.71 (3)	Walz *et al* [H2]
27.704 (3)	Rutledge *et al* [H3]
27.690 (5)	Houtermans *et al* [H4]
27.72 (3)	Lagoutine *et al* [H5]
27.703 (8)	Tse *et al* [H6]
27.75 (1) [b]	Visser et al [H7]
28.1 (17) [b]	Araminowicz and Dresler [H8]
27.76 (15) [b]	Emery et al [H9]
27.80 (51) [b]	Bormann et al [H10]
27.7009 (20)	**Recommended**

[a] uncertainty increased to (25) to ensure weighting factor not greater than 0.50.

[b] rejected as an outlier.

Update of X-ray and Gamma-ray Decay Data Standards

^{51}Cr

References - half-life

[H1] M. P. Unterweger, D. D. Hoppes, F. J. Schima, Nucl. Instrum. Meth. Phys. Res. **A312** (1992) 349

[H2] K. F. Walz, K. Debertin, H. Schrader, Int. J. Appl. Radiat. Isot. **34** (1983) 1191.

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Update of X-ray and Gamma-ray Decay Data Standards

^{51}Cr

Gamma ray: measured and evaluated emission probability

Eγ (keV) [1]	[2]	[3]	[4]	[5]	[6]	[7]
320.0835	9.8 (6)	9 (1)	9.72 (15)	10.2 (6)	9.75 (20)	10.2 (10)

Eγ (keV) [1]	[8]	[9]	[10]	**Evaluated**
320.0835	9.85 (9)	10.30 (19)	9.86 (8)	9.87 (5)

Evaluated emission probabilities are the weighted averages calculated according to the Limitation of Relative Statistical Weights Method; no value has a relative weighting factor greater than 0.50.

Update of X-ray and Gamma-ray Decay Data Standards

^{51}Cr

References – radiations

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Detailed tables and comments can be found on http://www.nucleide.org/DDEP_WG/DDEPdata.htm

Decay Data Evaluation Project (DDEP)

^{56}Mn – Comments on evaluation of decay data

Evaluated: November 1999
Re-evaluated: January 2004

Evaluation Procedures:

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Data Evaluation Project (DDEP)

Reference	**Half-life (days)**
1968Sh07	0.10771(4)
1971GoYM	0.10742(33)
1972Em01	0.10779(25)
1973La12	0.107438(8)
1980RuZY	0.107350(33)
1992An13	0.107454(4)[§]
1994Ya02	0.1040(20)[*]
Evaluated value	0.107449(18)

[§] Uncertainty increased to ± 0.000008 to ensure weighting factor not greater than 0.50.

[*] Method development study: removed from data set due to uncharacteristically large uncertainty.

Decay Data Evaluation Project (DDEP)

Gamma-ray Emission Probabilities: Relative to P_γ(846.7638 keV) of 100%

	P_γ^{rel}						
E_γ(keV)	1967Au01	1968Sh07	1973Ar15	1974Ho25	1974Ti01	2004MiXX	Recommended Values*
846.7638(19)†	100(3)	100(3)	100(3)	100(3)	100(3)	100.000(103)	100(3)
1037.8333(24)†	-	-	0.06(1)	0.03(1)	0.040(5)	-	0.040(4)§
1238.2736(22)†	-	-	0.14(3)	0.13(1)	0.10(1)	0.097(2)	0.098(2)§
1810.726(4)†	30(3)	29.4(16)	28.6(15)	26.9(13)	27.5(8)	26.610(72)	27.2(4)
2113.092(6)†	17.4(17)	16.0(9)	16.0(8)	14.3(7)	14.5(4)	13.956(53)	14.4(3)§
2523.06(5)‡	1.10(15)	1.6(5)	1.14(5)	1.01(5)	1.00(3)	1.025(9)	1.03(2)
2598.438(4)†	-	-	0.026(5)	0.02(1)	0.019(2)	-	0.020(2)
2657.56(1)‡	0.60(10)	0.66(6)	0.71(4)	0.66(7)	0.66(2)	0.648(8)	0.652(7)§
2959.92(1)‡	0.31(6)	0.26(3)	0.30(2)	0.32(3)	0.31(1)	0.314(6)	0.311(5)§
3119.3(5)#	-	0.08(4)	-	-	-	-	-
3369.84(4)‡	0.22(5)	0.20(4)	0.15(2)	0.16(2)	0.17(1)	-	0.17(1)

† Energy adopted from 2000He14.
‡ Energy calculated from the nuclear level energies specified by 1999Hu04.
# Energy from 1968Sh07, but transition not included in proposed decay scheme.
* Weighted mean values adopted using LWEIGHT, unless stated.
§ Recommended values adopted from a combination of the normalised residuals and Rajeval methods (see 2004MaYY).

Decay Data Evaluation Project (DDEP)

$^{56}_{25}\mathrm{Mn}_{31}$

1 Decay Scheme

Mn-56 decays by beta minus emission to excited levels of Fe-56.

Le manganèse 56 se désintègre par émission bêta moins vers les niveaux excités du fer 56.

2 Nuclear Data

$T_{1/2}(^{56}\mathrm{Mn})$: 2,57878 (46) h
$Q^{-}(^{56}\mathrm{Mn})$: 3695,5 (3) keV

2.1 β^- Transitions

	Energy keV	Probability × 100	Nature	lg ft
$\beta^-_{0,7}$	250,2 (3)	0,020 (2)	Allowed	6,57
$\beta^-_{0,6}$	325,7 (3)	1,20 (3)	Allowed	5,17
$\beta^-_{0,5}$	572,6 (3)	0,040 (4)	Allowed	7,5
$\beta^-_{0,4}$	735,6 (3)	14,5 (3)	Allowed	5,34
$\beta^-_{0,3}$	1037,9 (3)	27,5 (4)	Allowed	5,621
$\beta^-_{0,2}$	1610,4 (3)	0,057 (6)	Allowed	9,06
$\beta^-_{0,1}$	2848,7 (3)	56,6 (7)	Allowed	7,101

Decay Data Evaluation Project (DDEP)

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K	α_L	α_M+	α_T
$\gamma_{1,0}$(Fe)	846,776 (5)	98,88 (3)	E2	0,000270 (8)	0,0000250 (8)	0,0000037 (1)	0,000300 (9)
$\gamma_{5,2}$(Fe)	1037,85 (2)	0,040 (4)	M1+0.04%E2	0,000130 (4)	0,0000120 (4)	0,0000060 (2)	0,0001500 (45)
$\gamma_{2,1}$(Fe)	1238,300 (12)	0,097 (2)	E2	0,000110 (3)	0,0000100 (3)	0,00000200 (6)	0,000120 (4)
$\gamma_{3,1}$(Fe)	1810,786 (15)	26,9 (4)	M1+3%E2	0,0000460 (14)	0,00000430 (13)	0,00000063 (2)	0,0000510 (15)
$\gamma_{4,1}$(Fe)	2113,15 (1)	14,2 (3)	M1+4%E2				
$\gamma_{6,1}$(Fe)	2523,06 (5)	1,02 (2)	M1+E2				
$\gamma_{7,1}$(Fe)	2598,53 (2)	0,020 (2)	M1+E2				
$\gamma_{3,0}$(Fe)	2657,56 (1)	0,645 (7)	E2				
$\gamma_{4,0}$(Fe)	2959,92 (1)	0,307 (5)	E2				
$\gamma_{6,0}$(Fe)	3369,84 (4)	0,17 (1)	E2				

Decay Data Evaluation Project (DDEP)

3 Atomic Data

3.1 Fe

ω_K	:	0,355	(4)
$\bar{\omega}_L$	:	0,0060	(6)
n_{KL}	:	1,447	(4)

3.1.1 X Radiations

		Energy keV		Relative probability
X_K				
	$K\alpha_2$	6,39091		51
	$K\alpha_1$	6,40391		100
	$K\beta_1$	7,05804	}	
	$K\beta_5''$	7,1083	}	20,6

3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	5,370 – 5,645	100
KLX	6,158 – 6,400	27,4
KXY	6,926 – 7,105	1,87
Auger L	0,510 – 0,594	307

Decay Data Evaluation Project (DDEP)

4 Electron Emissions

		Energy keV		Electrons per 100 disint.
e_{AL}	(Fe)	0,510 - 0,594		0,0428 (3)
e_{AK}	(Fe)			0,0180 (1)
	KLL	5,370 - 5,645	}	
	KLX	6,158 - 6,400	}	
	KXY	6,926 - 7,105	}	
$\beta^-_{0,7}$	max:	250,2	(3)	0,020 (2)
$\beta^-_{0,7}$	avg:	73,5	(1)	
$\beta^-_{0,6}$	max:	325,7	(3)	1,20 (3)
$\beta^-_{0,6}$	avg:	99,1	(1)	
$\beta^-_{0,5}$	max:	572,6	(3)	0,040 (4)
$\beta^-_{0,5}$	avg:	190,4	(2)	
$\beta^-_{0,4}$	max:	735,6	(3)	14,5 (3)
$\beta^-_{0,4}$	avg:	255,2	(2)	
$\beta^-_{0,3}$	max:	1037,9	(3)	27,5 (4)
$\beta^-_{0,3}$	avg:	381,9	(2)	
$\beta^-_{0,2}$	max:	1610,4	(3)	0,057 (6)
$\beta^-_{0,2}$	avg:	636,3	(2)	
$\beta^-_{0,1}$	max:	2848,7	(3)	56,6 (7)
$\beta^-_{0,1}$	avg:	1216,8	(2)	

Decay Data Evaluation Project (DDEP)

5 Photon Emissions

5.1 X-Ray Emissions

		Energy keV		Photons per 100 disint.	
$XK\alpha_2$	(Fe)	6,39091		0,00295 (4)	} $K\alpha$
$XK\alpha_1$	(Fe)	6,40391		0,00578 (7)	}
$XK\beta_1$	(Fe)	7,05804	}	0,00119 (2)	$K'\beta_1$
$XK\beta''_5$	(Fe)	7,1083	}		

Decay Data Evaluation Project (DDEP)

5.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{1,0}$(Fe)	846,7638 (19)	98,85 (3)
$\gamma_{5,2}$(Fe)	1037,8333 (24)	0,040 (4)
$\gamma_{2,1}$(Fe)	1238,2736 (22)	0,097 (2)
$\gamma_{3,1}$(Fe)	1810,726 (4)	26,9 (4)
$\gamma_{4,1}$(Fe)	2113,092 (6)	14,2 (3)
$\gamma_{6,1}$(Fe)	2523,06 (5)	1,02 (2)
$\gamma_{7,1}$(Fe)	2598,438 (4)	0,020 (2)
$\gamma_{3,0}$(Fe)	2657,56 (1)	0,645 (7)
$\gamma_{4,0}$(Fe)	2959,92 (1)	0,307 (5)
$\gamma_{6,0}$(Fe)	3369,84 (4)	0,17 (1)

Decay Data Evaluation Project (DDEP)

6 Main Production Modes

Cr – 56(β^-)Mn – 56
Mn – 55(n,γ)Mn – 56
Mn – 55(d,p)Mn – 56
Fe – 58(d,α)Mn – 56

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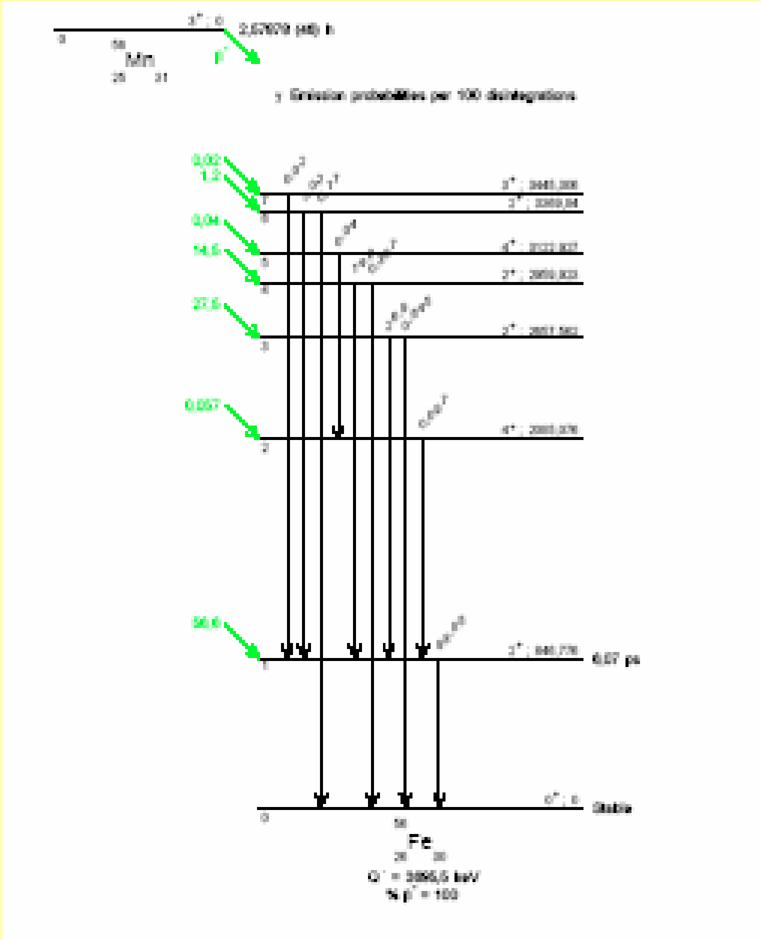
Decay Data Evaluation Project (DDEP)



Decay Data Evaluation Project (DDEP)

8 Remarks

8.1 Nuclear Data

Half-life adopted from the evaluation of Woods for the IAEA-CRP: Update of X- and Gamma-ray Decay Data Standards for Detector Calibration. The measurements of 1968Sh07, 1971GoYM, 1972Em01, 1973La12, 1980RuZY, 1992An13 and 1994Ya02 were considered.

8.2 β^- Transitions

All beta-particle energies were calculated from the structural details of the proposed decay scheme. The nuclear level energies of 1999Hu04 and the Q-value were used to determine the energies and uncertainties of the beta-particle transitions to the various levels. The beta-particle emission probabilities were calculated from recommended gamma-ray emission probabilities and the theoretical internal conversion coefficients of 1976Ba63 (latter estimated by interpolation of data). Log ft systematics can be applied to the beta-particle transition to the ground state of Fe-56, with a lower limit for log ft of 13.9 (1998Si17), to give a beta-particle emission probability of ¡ 0.0005 (set to zero).

Decay Data Evaluation Project (DDEP)

8.3 Gamma Transitions and Conversion Electron Coefficients

Energies

A number of well-defined gamma-ray energies were adopted from the recommended standards of 2000He14. All other gamma-ray energies were calculated from the structural details of the proposed decay scheme and the nuclear level energies of 1999Hu04 (as derived from the energy measurements of 1973Ar15, 1974Ho25 and 1974Ti01). An additional gamma ray with an energy of 3119.3(5) keV was only detected by 1968Sh01, and has been discarded due to a lack of evidence in all of the other studies.

Emission Probabilities

Weighted mean relative emission probabilities were determined for all of the gamma rays assigned to the decay scheme, using the relevant data from the measurements of 1967Au01, 1968Sh07, 1973Ar15, 1974Ho25, 1974Ti01 and 2004MiXX. All gamma-ray emissions were expressed relative to the 846.7638 keV transition, which was arbitrarily assigned an uncertainty of 3% (100(3)%).

The normalisation factor for the gamma-ray emission probabilities was calculated from the proposed decay scheme via two routes:

(a) beta population of all Fe-56 nuclear levels derived from gamma-ray depopulation/population and summed, assuming beta decay to Fe-56 ground state is zero (spin and parity considerations).

for all nuclear levels populated by beta decay sum P(beta) = 101.163(1479) NF = 100

NF = 0.9885(145)

etc.

Decay Data Evaluation Project (DDEP)

^{228}Th – Comments on evaluation of decay data

Evaluated: July/August 2001
Re-evaluated: January 2004

Evaluation Procedures:

Limitation of Relative Statistical Weight Method (LWM) was applied to average numbers throughout the evaluation. The uncertainty assigned to the average value was always greater than or equal to the smallest uncertainty of the values used to calculate the average.

Decay Data Evaluation Project (DDEP)

Published Gamma-ray Emission Probabilities

E_γ (keV)	P_γ			
	1969Pe17	1977Ku15†	1982Sa36‡	1984Ge07
74.4(1)	-	4.0(14)	-	-
84.373(3)	1.21(6)	12100(600)	1.9(1)	100.0(16)
131.612(4)	-	1240(60)	0.17(2)	10.70(15)
142.7(1)	-	0.013(4)	-	-
166.410(4)	-	960(50)	0.13(1)	8.49(12)
182.3(1)	-	0.052(18)	-	-
205.99(4)	-	184(9)	-	-
215.985(4)	-	2390(130)	0.30(2)	1.61(5)
228.4(2)	-	0.18(3)	-	20.78(25)
700.4(1)	-	~ 0.03	-	-
741.87(1)	-	0.014(4)	-	-
832.0(1)	-	0.14(2)	-	-
908.28(1)	-	-	-	-
992.65(6)	-	~ 0.015	-	-

† Emission probabilities expressed in terms of photons per 10^6 disintegrations.
‡ Emission probabilities published relative to Pγ(238.63 keV) for ^{212}Pb of 43.0%.

Decay Data Evaluation Project (DDEP)

Gamma-ray Emission Probabilities: Relative to Pγ(84.373 keV) of 100

E_{γ} (keV)	P_{γ}^{rel}			
	1977Ku15	1982Sa36	1984Ge07	Recommended Values*
74.4(1)	0.033(12)	-	-	0.033(12)
84.373(3)	100(5)	100(5)	100.0(16)	100.0(16)
131.612(4)	10.25(50)	8.9(10)	10.70(15)	10.6(2)
142.7(1)	0.00011(3)	-	-	0.00011(3)
166.410(4)	7.9(4)	6.8(5)	8.49(12)	8.0(5)
182.3(1)	0.00043(15)	-	-	0.00043(15)
205.99(4)	1.52(7)	-	1.61(5)	1.58(5)
215.985(4)	19.8(11)	15.8(11)	20.78(25)	19.3(15)
228.4(2)	0.0015(3)	-	-	0.0015(3)
700.4(1)	~ 0.00025	-	-	0.00025(8)
741.87(1)	0.00012(3)	-	-	0.00012(3)
832.0(1)	0.0012(2)	-	-	0.0012(2)
908.28(1)	-	-	-	0.00014(4)
992.65(6)	~ 0.00012	-	-	0.00012(3)

* Weighted mean values adopted when judged appropriate; remainder derived from proposed decay scheme.

Decay Data Evaluation Project (DDEP)

Adjusted Alpha-particle Emission Probabilities per 100 Disintegrations of ^{228}Th

E_α(keV)	P_α					
	1953As31	1969Pe17	1970Ba20	1976BaZZ	1993Ba72	Recommended Values*
4448.0(3)	-	-	-	-	-	4.4(12) x 10^{-6}
4523.0(3)	-	-	-	-	-	1.7(3) x 10^{-5}
4952.5(4)	-	-	-	-	-	2.5(5) x 10^{-5}
4997.8(3)	-	-	-	-	-	1.0(3) x 10^{-5}
5138.01(26)	-	-	~ 0.05	-	-	0.036(7)
5176.89(23)	20	-	0.18	-	-	0.20(2)
5211.08(22)	40	-	0.36	-	-	0.38(3)
5340.38(22)	28	26.7(2)	26.7	27.3(5)	26.5(6)	26.2(2)
5423.28(22)	71	[73.3(2)]	72.7	72.7(5)	73.5(6)	73.2(2)

*P_α(5423.28 keV) of 73.2(2) is effectively the weighted mean of the normalised studies, which is subsequently matched against Pα(5340.38 keV) of 26.2(2); recommended emission probabilities of the low-intensity α transitions were derived from the evaluated gamma-ray emission probabilities and theoretical internal conversion coefficients.

Decay Data Evaluation Project (DDEP)

$^{228}_{90}\mathrm{Th}_{138}$

1 Decay Scheme

Th-228 decays 100% by alpha-particle emission to various excited levels and the ground state of Ra-224.
Le thorium 228 se désintègre par émission alpha principalement vers le niveau fondamental et le niveau excité de 84,4 keV de radium 224.

2 Nuclear Data

$T_{1/2}(^{228}\mathrm{Th})$	:	698,60	(23)	d
$T_{1/2}(^{224}\mathrm{Ra})$	:	3,66	(4)	d
$Q^{\alpha}(^{228}\mathrm{Th})$	:	5520,12	(22)	keV

2.1 α Transitions

	Energy keV	Probability × 100	F
$\alpha_{0,8}$	4527,5 (3)	0,0000044 (12)	7,37
$\alpha_{0,7}$	4603,8 (3)	0,000017 (3)	6,96
$\alpha_{0,6}$	5040,9 (4)	0,000025 (5)	4370
$\alpha_{0,5}$	5087,1 (3)	0,000010 (3)	21300
$\alpha_{0,4}$	5229,76 (26)	0,036 (7)	44,1
$\alpha_{0,3}$	5269,34 (23)	0,20 (2)	13,6
$\alpha_{0,2}$	5304,14 (22)	0,38 (3)	11,5
$\alpha_{0,1}$	5435,75 (22)	26,2 (2)	0,948
$\alpha_{0,0}$	5520,12 (22)	73,2 (2)	1

Decay Data Evaluation Project (DDEP)

2.2 Gamma Transitions and Internal Conversion Coefficients

	Energy keV	$P_{\gamma+ce}$ × 100	Multipolarity	α_K	α_L	α_M+	α_T
$\gamma_{4,2}$(Ra)	74,4 (1)	0,016 (6)	[E2]		28,9 (8)	7,89 (16)	39,5 (8)
$\gamma_{1,0}$(Ra)	84,373 (3)	26,6 (14)	E2		15,9 (3)	5,8 (1)	21,7 (4)
$\gamma_{2,1}$(Ra)	131,612 (4)	0,155 (8)	E1	0,195 (4)	0,041 (1)	0,013 (1)	0,249 (6)
$\gamma_{5,4}$(Ra)	142,7 (1)	0,0000041 (13)	[E2]	0,280 (6)	1,396 (28)	0,50 (1)	2,18 (4)
$\gamma_{3,1}$(Ra)	166,410 (4)	0,205 (16)	E2	0,225 (5)	0,704 (14)	0,256 (5)	1,185 (24)
$\gamma_{5,3}$(Ra)	182,3 (1)	0,0000056 (20)	[E1]	0,090 (2)	0,0178 (3)	0,0060 (1)	0,114 (2)
$\gamma_{4,1}$(Ra)	205,99 (4)	0,0201 (11)	[E1]	0,0676 (14)	0,0131 (3)	0,0042 (1)	0,0849 (17)
$\gamma_{2,0}$(Ra)	215,985 (4)	0,243 (22)	E1	0,0605 (12)	0,01160 (25)	0,0038 (1)	0,0759 (15)
$\gamma_{6,3}$(Ra)	228,4 (2)	0,000025 (5)	[E2]	0,125 (2)	0,182 (4)	0,065 (1)	0,372 (7)
$\gamma_{7,2}$(Ra)	700,4 (1)	0,0000029 (9)	E1	0,00508 (10)	0,00084 (2)	0,000270 (5)	0,00619 (12)
$\gamma_{8,3}$(Ra)	741,87 (1)	0,0000014 (4)	[E2]	0,0121 (2)	0,00330 (6)	0,00110 (2)	0,0165 (3)
$\gamma_{7,1}$(Ra)	832,0 (1)	0,000014 (2)	E2+M3	0,0098 (2)	0,00240 (5)	0,00090 (2)	0,0131 (3)
$\gamma_{8,1}$(Ra)	908,28 (1)	0,0000016 (5)	[M1+50%E2]	0,0203 (20)	0,0038 (4)	0,0012 (1)	0,0253 (25)
$\gamma_{8,0}$(Ra)	992,65 (6)	0,0000014 (4)	[E2]	0,00720 (15)	0,00160 (3)	0,00050 (1)	0,0093 (2)

Decay Data Evaluation Project (DDEP)

3 Atomic Data

3.1 Ra

ω_K : 0,968 (4)
$\bar{\omega}_L$: 0,452 (18)
n_{KL} : 0,801 (5)

3.1.1 X Radiations

		Energy keV		Relative probability
X_K				
	$K\alpha_2$	85,43		61,22
	$K\alpha_1$	88,47		100
	$K\beta_3$	99,432	}	
	$K\beta_1$	100,13	}	
	$K\beta_5''$	100,738	}	34,9
	$K\beta_2$	102,89	}	
	$K\beta_4$	103,295	}	11,51
	$KO_{2,3}$	103,74	}	
X_L				
	$L\ell$	10,622		
	$L\alpha$	12,196 – 12,339		
	$L\eta$	13,662		
	$L\beta$	14,236 – 15,447		
	$L\gamma$	17,848 – 18,412		

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3.1.2 Auger Electrons

	Energy keV	Relative probability
Auger K		
KLL	65,15 – 72,73	100
KLX	79,72 – 88,47	58
KXY	94,27 – 103,91	8,4
Auger L	5,71 – 12,04	9050

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4 α Emissions

	Energy keV	Probability × 100
$\alpha_{0,8}$	4448,0 (3)	0,0000044 (12)
$\alpha_{0,7}$	4523,0 (3)	0,000017 (3)
$\alpha_{0,6}$	4952,5 (4)	0,000025 (5)
$\alpha_{0,5}$	4997,8 (3)	0,000010 (3)
$\alpha_{0,4}$	5138,01 (26)	0,036 (7)
$\alpha_{0,3}$	5176,89 (23)	0,20 (2)
$\alpha_{0,2}$	5211,08 (22)	0,38 (3)
$\alpha_{0,1}$	5340,38 (22)	26,2 (2)
$\alpha_{0,0}$	5423,28 (22)	73,2 (2)

5 Electron Emissions

		Energy keV	Electrons per 100 disint.
e_{AL}	(Ra)	5,71 - 12,04	10,5 (4)
e_{AK}	(Ra)		0,00193 (26)
	KLL	65,15 - 72,73	}
	KLX	79,72 - 88,47	}
	KXY	94,27 - 103,91	}
$ec_{1,0\ T}$	(Ra)	65,14 - 84,09	25,4 (8)
$ec_{1,0\ L}$	(Ra)	65,14 - 68,93	18,6 (6)
$ec_{1,0\ M}$	(Ra)	79,55 - 84,09	6,8 (2)
$ec_{2,0\ K}$	(Ra)	112,067 (5)	0,180 (6)
$ec_{3,1\ L}$	(Ra)	147,17 - 150,97	0,066 (2)

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6 Photon Emissions

6.1 X-Ray Emissions

		Energy keV		Photons per 100 disint.	
XL	(Ra)	10,622 — 18,412		8,8 (4)	
XKα_2	(Ra)	85,43		0,0172 (8)	} Kα
XKα_1	(Ra)	88,47		0,0281 (12)	}
XKβ_3	(Ra)	99,432	}		
XKβ_1	(Ra)	100,13	}	0,0098 (5)	K$'\beta_1$
XKβ_5''	(Ra)	100,738	}		
XKβ_2	(Ra)	102,89	}		
XKβ_4	(Ra)	103,295	}	0,00323 (16)	K$'\beta_2$
XKO$_{2,3}$	(Ra)	103,74	}		

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6.2 Gamma Emissions

	Energy keV	Photons per 100 disint.
$\gamma_{4,2}$(Ra)	74,4 (1)	0,00039 (14)
$\gamma_{1,0}$(Ra)	84,373 (3)	1,17 (5)
$\gamma_{2,1}$(Ra)	131,612 (4)	0,124 (6)
$\gamma_{5,4}$(Ra)	142,7 (1)	0,0000013 (4)
$\gamma_{3,1}$(Ra)	166,410 (4)	0,094 (7)
$\gamma_{5,3}$(Ra)	182,3 (1)	0,0000050 (18)
$\gamma_{4,1}$(Ra)	205,99 (4)	0,0185 (10)
$\gamma_{2,0}$(Ra)	215,985 (4)	0,226 (20)
$\gamma_{6,3}$(Ra)	228,4 (2)	0,000018 (4)
$\gamma_{7,2}$(Ra)	700,4 (1)	0,0000029 (9)
$\gamma_{8,3}$(Ra)	741,87 (1)	0,0000014 (4)
$\gamma_{7,1}$(Ra)	832,0 (1)	0,000014 (2)
$\gamma_{8,1}$(Ra)	908,28 (1)	0,0000016 (5)
$\gamma_{8,0}$(Ra)	992,65 (6)	0,0000014 (4)

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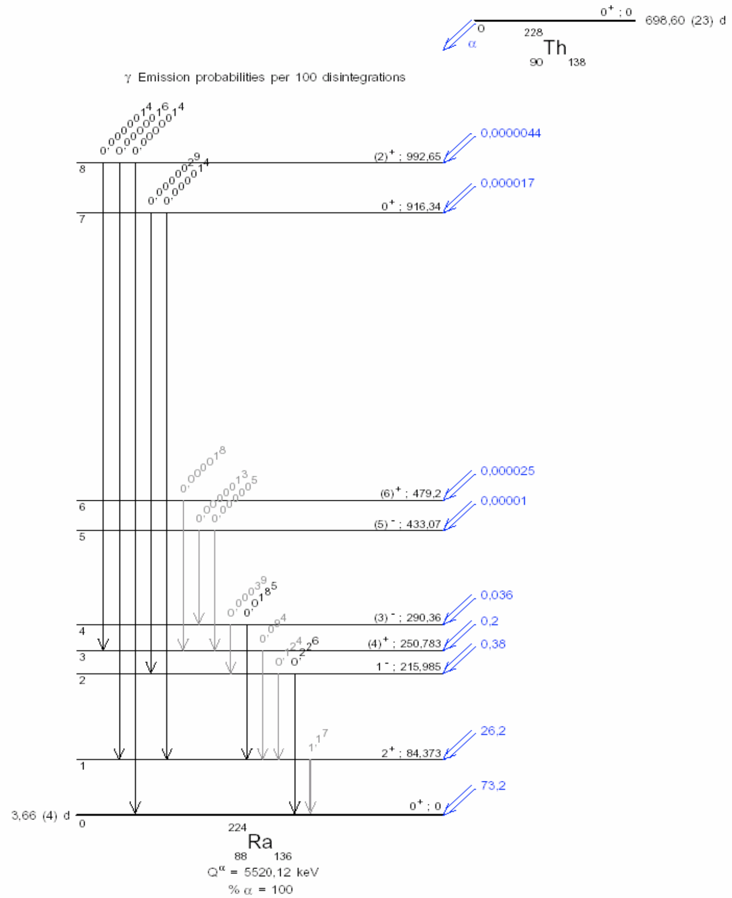

Decay Data Evaluation Project (DDEP)

LNHB web site:
http://www.nucleide.org/

DDEP pages:
http://www.nucleide.org/DDEP_WG/DDEPdata.htm

IAEA Co-ordinated Research Project (CRP)

Financial Support

1. Lump-sum cost-sharing contract
   - average IAEA contribution of $5,000,
   - provision to attend RCMs.

2. Cost-free agreement (Developed Countries)
   - only provision to attend RCMs.

IAEA Co-ordinated Research Project (CRP)

1. Must assist Agency programmes (particularly CRPs).

2. Proposed project must be compatible with the Agency's approved programmes and functions.

IAEA Co-ordinated Research Project (CRP)

Research contracts: one year – renewable up to total period of project (normally for 3 years)

Reports: yearly progress report and final report

Publications: acknowledge IAEA support of the work

Other provisions: equipment