α β γ ISuS Institute for Spectrometry and Radiation Protection

Logistic, Consulting & Management for α·β·γ·n–Spectrometry and Radiation Protection.
Reference Systems and Software Products for *In Vivo*, *In Vitro* and *In Situ* Application.
Service for α-, β-, γ-, & n-Spectrometry Systems

Laboratory - Radionuclide Handbook

Version 6.7.0 - 1.Q 2021 (27 Years)

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Now with a separate large energy (~2800 photon-lines) and isotope list (~290 Radioisotopes)

Content – Quick-Info, Vorwort/Preface, Introduction, Notes, Descriptions, Symbols

Anthropogenic

- Activation & fission products
- NucMed: therapy, diagnostic, PET, …
  Dose: emitted energies per decay
- Iodine's & special nuclides
- Nuclide boxes with all decay details

Particle Induced Radiation

- Shielding, detector/mounting material
- Muon induced radiation
- Neutron scattering & capture
- Activation isotopes
- Fluorescence in shielding materials

Actinides

- U/Th (n,2n) & (n,γ) activation process
- Pu/Am/Np/U/Th/Pa - production
- All four Plutonium decay series
- Nuclide boxes with all decay details

Calibration Radioisotopes

- Standard & multiphoton sources
- Low & high energy isotopes
- Natural intrinsic check sources
- Neutron sources as Cf & Am

Naturals

- All decay series
- U-238/Th-232/U-235/Np-237/Pu-244
- Isotopics: Uranium ratios
- Cosmogenic, complementary nuclides
- Nuclide boxes with all decay details

Spectrometry Source-Detection Effects

- SE/DE/XE: single/double/x-ray escape
- CS/RS: coincidence/random summing
- Line broadening (Li-7)
- Asymmetric peaks: Ge lattice recoil
- Air filter samples: Pb-212 x-ray triplets

reference isotope Q_ε, Q_β MeV $t_{1/2}$	β-, ε-decay, IT E_β^{max}, $(\bar{E}_\beta)$ MeV	β-, ε-, IT-*branch* intensity %	daughter-nuclide & E_γ half-life $(t^m_{1/2})$ for IT levels γ-ray transitions to final state in keV, dose in MeV/Bq-s	E-list in I-order keV	γ- & X-intensity absol. equil./absolute %
NDS:108,2173,2007		β^- : 100%	γ-/β^--dose: $0.5631_{13}/0.1871_{12}$	in equilibrium	with ^{137}Ba
$^{137}_{55}$**Cs**	$\rightarrow$ β^-: 1.17563_{17}	5.30_{20}	$\rightarrow$ $^{137}_{56}$Ba (abundance: 11.23_2%)		
	$\rightarrow$ β^-: 0.89213_{20}	5.8_3E-4	$\rightarrow$ γ : 283.5	283.5_1	5.8_8E-4
	$\rightarrow$ β^-: 0.51397_{17}	94.70_{20}	$\rightarrow ^{137m}_{56}$Ba $\xrightarrow[2.55\ m]{IT}$ $^{137}_{56}$Ba	661.657_3	85.10_{20} (equilibr.)
	(0.1871_{10})				
$^{137m}_{56}$**Ba**	$\rightarrow$ IT:	100	$\rightarrow$ γ : $661.66^{M4,int} \rightarrow ^{137}_{56}$Ba	661.657_3	89.90_{14} (absolute)
2.552_1 m			$\rightarrow X$: ΣK_α	32.06	5.63/5.94
			$\rightarrow X$: K_{α_1}	32.194	$3.64_{10}/3.84_{10}$
	Note: data set		$\rightarrow X$: K_{α_2}	31.817	$1.99_5/2.10_6$
	completely		$\rightarrow X$: ΣK_β	36.40	$1.233_5/1.310$
			$\rightarrow X$: K_{β_1}	36.358	$0.672_{18}/0.709_{18}$
			$\rightarrow X$: K_{β_3}	36.304	$0.348_9/0.367_{10}$
$Q_{\beta^-}=1.17563_{17}$			$\rightarrow X$: K_{β_2}	37.255	$0.213_6/0.244_6$
30.08_9 y	$\alpha_t^{661} = 0.1102_{19}$		$\rightarrow X$: Σ L	4.47	$0.913_4/0.97_5$
int=^{60}Co(662.24, SE); ^{241}Am(662.40, 0.000364%); ^{239}U(662.24, 0.182%)				x-ray intensity	↕equil./absol.↕

Additional: α/β/γ-energies in E-order for nuclide each, U-isotopics, coincidence corrections, comments to data evaluation, list of isotopes & materials, references, nuclide & keyword index.

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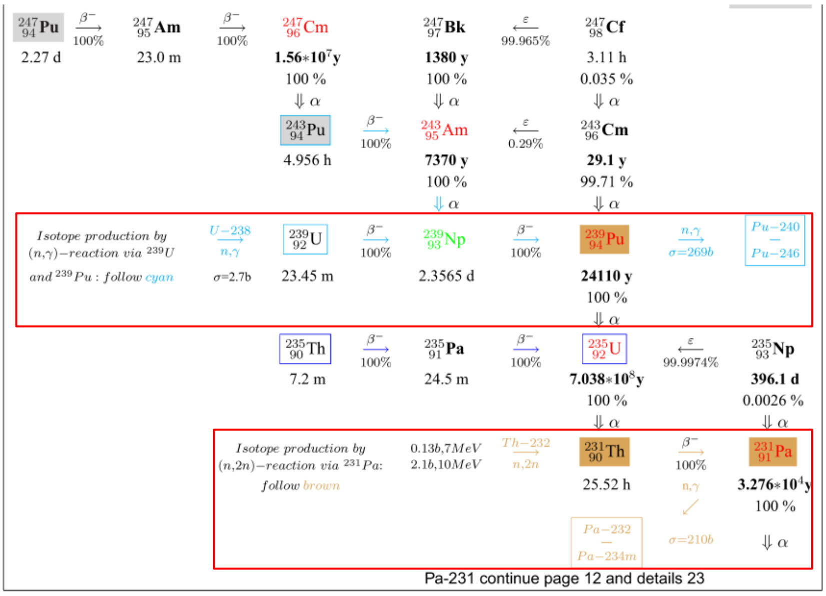
Section cut outs of the Radionuclide Handbook

Example for Isotope Production and Decay of Actinides

Production of Pu-isotopes via U- and Pu-239 in a nuclear reactor:

$$^{238}_{92}U + ^{1}_{0}n \longrightarrow ^{239}_{92}U \xrightarrow[23.5m]{\beta^-} ^{239}_{93}Np \xrightarrow[2.36d]{\beta^-} ^{239}_{94}Pu(24{,}110y) \xrightarrow[269b]{(n,\gamma)} \text{Pu-240 up to Pu-246}$$

Decay of Am-243/Pu-239 down to natural U-235



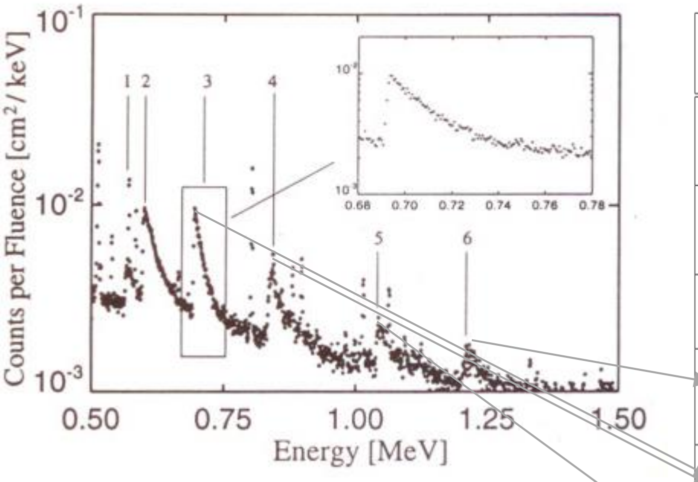
half life $t_{1/2}$	isotope decay branch, %	α-decay energy, MeV (intensity, %)**	β-decay energy, MeV (intensity, %)**	γ-emission energy, keV; (intensity, %)*
4.956 h	$^{243}_{94}$Pu** 100 β↘		β: 0.579 (60) β: 0.495 (21.0) β: 0.537 (8.9)	γ: 84.0 (23.1) γ: 25.2 (8.0) γ: 41.8 (0.76)
23.45 m 7370 y	$^{239}_{92}$U** 100 β↘ $^{243}_{95}$Am 100 ⇓α	α: 5.275 (87.1)$_{Am}$ α: 5.233 (11.2)$_{Am}$	β: 1.189 (69.0)$_U$ β: 1.264 (18.7)$_U$ β: 1.232 (9.4)$_U$	γ: 74.66 (49.2)$_U$ γ: 43.53 (4.07)$_U$ γ: 74.66 (67.2)$_{Am}$ γ: 43.53 (5.90)$_{Am}$
7.2 m 2.3565 d	$^{235}_{90}$Th** 100 β↓ $^{239}_{93}$Np 100 ↓β	Th: no more data available	β: 0.436 (45) β: 0.336 (42.0) β: 0.392 (7.0)	γ: 106.12 (26.3)$_{Np}$ γ: 277.60 (14.44)$_{Np}$ γ: 228.18 (11.14)$_{Np}$ Th-γ: no data available
24.44 m 24110 y	$^{235}_{91}$Pa 100 β↘ $^{239}_{94}$Pu** 100 ↙α	α: 5.157 (70.77) α: 5.144 (17.11) α: 5.106 (11.94)	β: 1.41 (100) β: 1.03 (0.005) β: 0.72 (0.005)	γ: 51.62 (0.0272)$_{Pu}$ γ: 38.66 (0.0104)$_{Pu}$ Pa-γ: no reliable data available
7.038∗10^{8}y	$^{235}_{92}$U** 100 ⇓α	α: 4.395 (57.73) α: 4.364 (18.92)		γ: 185.72 (57.0) γ: 143.76 (10.96) γ: 163.36 (5.08)
25.52 h	$^{231}_{90}$Th** 100 ↓β		β: 0.290 (40) β: 0.307 (32) β: 0.208 (12.1) β: 0.289 (12)	γ: 25.64 (14.1) γ: 84.21 (6.6) γ: 89.95 (1.00)
3.276∗10^{4}y	$^{231}_{91}$Pa 100 ⇓α	α: 5.014 (25.4) α: 4.951 (22.8) α: 5.028 (20)		γ: 27.36 (10.3) γ: 302.65 (2.88) γ: 300.07 (2.47)

*γ-emission: intensity per 100 decays; **α-, β-decay: absolute intensity Σ ≈100%

**& **: Isotopes with double asterix are activated by (n,2n) and/or (n,γ) as well as (d,2n) interacting processes.

Example for Partical Induced Radiation

Neutron scattering with asymmetric photon peak-shape: the n-spectrum and the isotope list are showing the Ge-isotopes



Section cut out of the pulse-height distribution from the most important inelastic scattering peaks with the different Ge-isotopes, measured with an HPGe detector irradiated by neutrons from an ^{241}AmBe source.

reference isotopes	excited levels: 0., 1., 2., 3., .. IT ($t_{1/2}$)	γ-ray transitions to final level level half-life ($t_{1/2}$) E_γ in keV; (Intensity in %) keV	**inelastic fast n-scattering** remarks (Ge recoil)	isotopic abundance %
NDS:112,707,2011 for Bi-207 $\xrightarrow[32\,y]{\epsilon}$ Pb-207		^{207}Bi see page 70		
$^{207}_{82}$**Pb**	1.-exc. to 0. 2.-exc. to 1.	→ γ : 569.698$_2^{E2}$ → γ : 897.77$_{12}^{E2}$, ...	$(n,n'\gamma)$ $(n,n'\gamma)$	22.1
$^{207m}_{82}$**Pb**	IT (100 %), (806$_5$ ms)	→ γ : 1063.656$_3^{M4}$(88.8$_{13}$), 569.70(97.7$_{14}$)	$(n,n'\gamma)$	
NDS:109,1527,2008 for Bi-206 $\xrightarrow[6.2\,d]{\epsilon}$ Pb-206				
$^{206}_{82}$**Pb**	1.-exc. to 0. 2.-exc. to 0. 3.-exc. to 1.	→ γ : 803.10$_5^{E2}$ → γ : 1163^{E0} (no γ-transition, 0.77 ns) → γ : 537.45$_5^{M1,E2}$, ...	$(n,n'\gamma)$ $(n,n'\gamma)$ $(n,n'\gamma)$	24.1
NDS:74,63,1995 for Ga-76 $\xrightarrow[33\,s]{\beta^-}$ Ge-76			asym. peak	
$^{76}_{32}$**Ge**	1.-exc. to 0. 2.-exc. to 1.	→ γ : 562.93$_3^{E2}$ → γ : 545.51$_3^{E2,M1}$, ...	$(n,n'\gamma)$ $(n,n'\gamma)$	7.44
NDS:107,1923,2006 for As-74 $\xrightarrow[18\,d]{\epsilon/\beta^-}$ Ge-74			asym. peak	
$^{74}_{32}$**Ge**	1.-exc. to 0. 2.-exc. to 1. 2.-exc. to 0.	→ γ : 595.83$_8^{E2}$ → γ : 608.43$_8^{E2,M1}$, ... → γ : 1204.35$_8^{pcd,E2,M1}$	$(n,n'\gamma)$ $(n,n'\gamma)$ $(n,n'\gamma)$	35.94
NDS:111,1,2010 for As-72 $\xrightarrow[26\,h]{\epsilon}$ Ge-72			asym. peak	
$^{72}_{32}$**Ge**	1.-exc. to 0. 2.-exc. to 0.	→ γ : 689.6$_5^{E0}$ (444 ns);conversion electron → γ : 834.01$_2^{int,E2}$ int = ^{54}Mn(834.85)	$(n,n'e^-)$ $(n,n'\gamma)$	27.66
NDS:136,1,2016 for Ga-70 $\xrightarrow[21\,m]{\beta^-}$ Ge-70			asym. peak	
$^{70}_{32}$**Ge**	1.-exc. to 0.	→ γ : 1039.513$_{10}^{int,E2}$ int = ^{134}Cs(1038.61)	$(n,n'\gamma)$	21.23
NDS:111,2425,2010 for Ni-65 $\xrightarrow[2.5\,h]{\beta^-}$ Cu-65				
$^{65}_{29}$**Cu**	1.-exc. to 0. 2.-exc. to 0. 3.-exc. to 2. 3.-exc. to 0.	→ γ : 770.6$_2^{M1,E2}$ → γ : 1115.539$_2^{M1,E2}$ → γ : 366.27$_3^{M1,E2}$, ... → γ : 1481.84$_5^{M1,E2}$	$(n,n'\gamma)$ $(n,n'\gamma)$ $(n,n'\gamma)$ $(n,n'\gamma)$	30.83

Detector response: The contribution to the full energy deposition of the photon or conversion electron emitted in the reaction leads to narrow gauss peaks whereas the fraction of kinetic energy transferred to the recoil nucleus or to secondary elastic scattering leads to exponential decreasing peak responses caused by superposed spectra of mono-energetic neutrons.

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