THEORETICAL AND PRACTICAL SPECIFIC
ACTIVITIES AND OTHER PROPERTIES
OF COMMON RADIONUCLIDES

S. A. Reynolds

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ISOTOPES DEVELOPMENT CENTER

THEORETICAL AND PRACTICAL SPECIFIC ACTIVITIES
AND OTHER PROPERTIES OF COMMON RADIONUCLIDES

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THEORETICAL AND PRACTICAL SPECIFIC ACTIVITIES AND OTHER PROPERTIES OF COMMON RADIONUCLIDES

S. A. Reynolds

SUMMARY

Half-lives were carefully selected, and specific activities were calculated for 161 commonly used radioisotopes with half-lives greater than 12 hr. Practical specific activities of many bombardment products are listed, based where applicable upon critically evaluated neutron cross sections and fission yields, as well as analytical data. Up-to-date decay parameters for a number of additional nuclides are given. The information can be applied by manufacturers and users of radioisotope materials, radiochemical analysts, and others.

INTRODUCTION

The radioisotopes program at ORNL has resulted in the production of radionuclides by neutron irradiation, accelerator bombardment, and isolation from natural sources.¹ Yields, in terms of theoretical and practical specific activities, are listed for many of them. Half-life values and other data serve to improve some data given in the *Isotope User's Guide*.² This information was originally compiled for use at ORNL and is being published because it may be of use to others who produce or apply radionuclides.

SPECIFIC ACTIVITIES

The half-life values for the 161 nuclides in Table 1 were taken from the "Radioactive Atoms" table,³ issues of *Nuclear Data*, ORNL work,⁴ and other recent literature. They supersede the selections in the *Isotope User's Guide*. The isotopic specific activities were calculated as usual. Exponentials are represented in the tables in "E" format, i.e., kE_n means k times 10 to the power n . The present values replace those tabulated earlier.⁵ In many cases, only the theoretical specific activity is listed, since the product is of high abundance because of production by accelerator, (n,p) reaction, or decay of a parent, or because the material is isotopically enriched electromagnetically or by diffusion. Specific activities are useful for calculating curie contents of actinide preparations, for example, for which mass analyses are known.

Table 1. Theoretical and Practical Specific Activities

Nuclide	Half-Life	Theoretical Specific Activity (Ci/g)	σ_A of Target Nuclide (barns) ^a	σ_B of Radio- nuclide (barns)	Practical Specific Activity (Ci/g)	Remarks
²⁶ Al	7.4E5 y	1.9E-2				
²⁴¹ Am	433 y	3.43				
²⁴³ Am	7.4E3 y	0.20				
¹²² Sb	2.7 d	4.0E5	6.2 R		1.4E3	7 d at 2E15
¹²⁴ Sb	60.2 d	1.75E4	3.4 R	6.5	2.7E2	120 d at 8E14
¹²⁵ Sb	2.77 y	1.03E3				
³⁷ Ar	35 d	1.01E5				
³⁹ Ar	269 y	34			2.7	8% abundance
⁷³ As	80 d	2.2E4				
⁷⁴ As	17.8 d	9.9E4				
⁷⁶ As	26.3 h	1.6E6	4.3		1.5E3	2.5 d at 2E15
⁷⁷ As	38.7 h	1.05E6				
¹³¹ Ba	12 d	8.3E4	11 R		7.4E2	21 d at 8E14
^{133m} Ba	38.9 h	6.1E5				
¹³³ Ba	10.5 y	2.6E2	8.5		48	1 y at 8E14
^{135m} Ba	28.7 h	8.1E5			26	3 d at 2E15 (TM-3111)
¹⁴⁰ Ba	12.8 d	7.3E4			2.3E4	FP, 28-d irradiation
²⁴⁹ Bk	314 d	1.67E3				
²⁰⁶ Bi	6.24 d	1.02E5				
²⁰⁷ Bi	30 y	58				
²¹⁰ Bi	5.0 d	1.24E5	0.019 R		1.8	7 d at 2E15
⁸² Br	35.4 h	1.08E6	3 R		8.4E2	2.5 d at 2E15
¹⁰⁹ Cd	1.26 y	2.6E3	1.1	700	4	Max 130 d at 8E14
^{115m} Cd	44 d	2.6E4	0.036		3.2	90 d at 8E14
¹¹⁵ Cd	53.5 h	5.1E5	0.30 R		76	7 d at 2E15
⁴¹ Ca	1.3E5 y	6.7E-2				
⁴⁵ Ca	164 d	1.77E4	0.9		2.3E2	1 y at 8E14
⁴⁷ Ca	4.53 d	6.1E5	0.77		3.6E2	7 d at 2E15

Table 1. Continued

Nuclide	Half-Life	Theoretical Specific Activity (Ci/g)	σ_A of Target Nuclide (barns) ^a	σ_B of Radio- nuclide (barns)	Practical Specific Activity (Ci/g)	Remarks
²⁵² Cf	2.64 y	5.37E2				
¹⁴ C	5730 y	4.46				
¹⁴¹ Ce	32.5	2.9E4			4.6E3	FP, 60-d irradiation
¹⁴⁴ Ce	284 d	3.2E3			7.2E2	FP, 1 y
¹²⁹ Cs	32.6 h	7.4E5				
¹³¹ Cs	9.7 d	1.03E5				
¹³⁴ Cs	2.06 y	1.30E3	30 R	134	1.8E2	180 d at 8E14
¹³⁷ Cs	30 y	87			30	35% ¹³⁷ Cs
³⁶ Cl	3.0E5 y	3.3E-2			2.3E-2	69% ³⁶ Cl (TM-3677)
⁵¹ Cr	27.7 d	9.2E4	16		3.0E3	50 d at 8E14
⁵⁶ Co	77.3 d	3.0E4				
⁵⁷ Co	271 d	8.4E3				
⁵⁸ Co	71.3 d	3.16E4				
⁶⁰ Co	5.27 y	1.13E3			1E3	
⁶⁴ Cu	12.7 h	3.9E6	4.5		1.7E3	1 d at 2E15
⁶⁷ Cu	61.8 h	7.6E5				
²⁴² Cm	163 d	3.32E3				
²⁴⁴ Cm	18.1 y	80.9				
²⁴⁸ Cm	3.5E5 y	4.1E-2				
¹⁵² Eu	13 y	1.8E2	5.3E3	5.3E3	64	TM-3611
¹⁵⁴ Eu	8 y	2.9E2	480	1450	56	Max 7 d at 2E15 (TM-3611)
¹⁵⁶ Eu	15 d	5.6E4			4E4	Calc. from TM-3501
¹⁵³ Gd	241 d	3.5E3	1.2E2 R	1E4	78	TM-2632
⁶⁷ Ga	78 h	6.0E5				
⁷² Ga	14.1 h	3.1E6	5		1.7E3	1 d at 2E15
⁶⁸ Ge	280 d	6.8E3				
⁷¹ Ge	11 d	1.7E5	3.5		4.6E2	21 d at 8E14

Table 1. Continued

Nuclide	Half-Life	Theoretical Specific Activity (Ci/g)	σ_A of Target Nuclide (barns) ^a	σ_B of Radio- nuclide (barns)	Practical Specific Activity (Ci/g)	Remarks
¹⁹⁵ Au	184 d	3.6E3				
¹⁹⁸ Au	2.70 d	2.4E5	45 (Eff)		6.2E3	7 d at 2E15 Cd shield (Ref. 15)
¹⁹⁹ Au	3.14 d	2.08E5				
¹⁷⁵ Hf	70 d	1.07E4	390		8E3	Max 60 d at 8E14
¹⁸¹ Hf	42.5 d	1.69E4	12.6	40	6.4E2	90 d at 8E14
³ H	12.3 y	9.64E3				
¹¹¹ In	2.83 d	4.1E5				
^{114m} In	49.5 d	2.3E4	7.7 R		6.7E2	100 d at 8E14
¹²³ I	13.2 h	1.9E6				
¹²⁵ I	60 d	1.74E4				
¹²⁹ I	1.57E7 y (Ref. 4)	1.7E-4			1.5E-4	86% (ORNL-4343)
¹³⁰ I	12.3 h	2.0E6	28	18	5.2E3	1 d at 2E15
¹³¹ I	8.05 d	1.24E5			7.0E4	ORNL-4039
¹⁹² Ir	74 d	9.2E3	9.3E2	1.1E3	3.9E3	Max 13 d at 8E14
¹⁹⁴ Ir	19.4 h	8.3E5	110		1.6E4	2.5 d at 2E15
⁵⁵ Fe	2.7 y	2.4E3	2.2		1.1E2	1 y at 8E14
⁵⁹ Fe	44.6 d	5.0E4	1.1		1.9E2	90 d at 8E14
⁷⁹ Kr	35 h	1.13E6	4.9		1.8E4	7 d at 2E15
⁸⁵ Kr	10.7 y	3.9E2			1.7E2	44% abundance (TM-3558)
¹³⁷ La	6E4 y	4E-2				
¹⁴⁰ La	40.3 h	5.5E5	8.9	2.7	1.3E3	2.5 d at 2E15
²⁰³ Pb	52 h	3.0E5				
¹⁹⁷ Hg	64.1 h	2.5E5	3.1E3		1.7E5	Max 63 h at 2E15
²⁰³ Hg	46.7 d	1.4E4	4.9		2.3E2	90 d at 8E14
⁹⁹ Mo	66.2 h	4.8E5	0.15 R		42	7 d at 2E15

Table 1. Continued

Nuclide	Half-Life	Theoretical Specific Activity (Ci/g)	σ_A of Target Nuclide (barns) ^a	σ_B of Radio- nuclide (barns)	Practical Specific Activity (Ci/g)	Remarks
⁹⁹ Mo	66.2 h	4.8E5			6.5E4	FP, 7-d irradiation
¹⁴⁷ Nd	11.0 d	8.1E4			6.4E3	FP, 28 d
²³⁷ Np	2.14E6 y	7.05E-4				
⁵⁹ Ni	8E4 y	8E-2	4.4	85	3.3E-3	Max 200 d at 2E15 (ORNL-4749)
⁶³ Ni	100 y (Ref. 16)	57	15	23 (Ref. 16)	20	1 y at 8E14
⁶⁶ Ni	55 h	8.6E5	1.5(64)	~65(65)	1.2	5 d at 2E15 Calc. from Ref. 17
^{92m} Nb	10.1 d	1.40E5				
⁹⁴ Nb	2.0E4 y	0.18	1.1	11	5E-3	1 y at 8E14
⁹⁵ Nb	35.1 d	3.9E4				
¹⁹¹ Os	15 d	4.6E4	13		8E2	28 d at 8E14
¹⁰⁹ Pd	13.5 h	2.1E6	12 R		2.6E3	1 d at 2E15
³² P	14.3 d	2.85E5			2.5E5	ORNL-4196
³³ P	25 d	1.6E5			3.2E4	20% (TM-3414)
²³⁶ Pu	2.85 y	5.32E2				
²³⁸ Pu	87.5 y	17.2				
²³⁹ Pu	2.44E4 y	6.14E-2				
²⁴⁰ Pu	6.54E3 y	0.229				
²⁴¹ Pu	14.8 y	100				
²⁴² Pu	3.87E5 y	3.82E-3				
⁴² K	12.4 h	6.0E6	1.3		8E2	1 d at 2E15
⁴³ K	22.3 h	3.3E6				
¹⁴² Pr	19.2 h	1.15E6	12	18	2.4E3	2.5d at 2E15
¹⁴³ Pr	13.6 d	6.7E4			4.5E4	FP, 28 d
¹⁴⁷ Pm	2.62 y	9.28E2				
^{148m} Pm	42 d	2.0E4	90	2.5E4	74	Max 1.3 d at 2E15

Table 1. Continued

Nuclide	Half-Life	Theoretical Specific Activity (Ci/g)	σ_A of Target Nuclide (barns) ^a	σ_B of Radio- nuclide (barns)	Practical Specific Activity (Ci/g)	Remarks
¹⁸⁶ Re	91 h	1.9E5	110		1.3E4	7 d at 2E15
¹⁸⁸ Re	16.9 h	9.9E5	75		1.2E4	2.5 d at 2E15
¹⁰² Rh	206 d	6.2E3				
⁸³ Rb	86 d	1.8E4				
⁸⁴ Rb	34 d	4.6E4				
⁸⁶ Rb	18.7 d	8.1E4	0.5 R		49	28 d at 8E14
⁹⁷ Ru	2.9 d	4.6E5	0.2 R		60	9 d at 2E15 (TM-2910)
¹⁰³ Ru	39.5 d	3.2E4			4.3E3	FP, 60 d
¹⁰⁶ Ru	1.01 y	3.3E3			85	FP, 1 y
¹⁵¹ Sm	90 y	26				
¹⁵³ Sm	46.7 h	4.4E5	210		3.5E4	7 d at 2E15
⁴⁶ Sc	83.8 d	3.4E4	25	8	5.5E3	180 d at 8E14
⁴⁷ Sc	3.4 d	8.2E5				
⁷⁵ Se	120 d	1.4E4	55		5.8E3	Max 210 d at 8E14
³² Si	~5E2 y	~22				
^{110m} Ag	250 d	4.7E3	4.1 (93 tot.)	82	1.6E2	Max 135 d at 8E14
¹¹¹ Ag	7.45 d	1.6E5				
²⁴ Na	15.0 h	8.7E6	0.53		5E2	1 d at 2E15
⁸⁵ Sr	64.5 d	2.4E4	0.8		73	90 d at 8E14
⁸⁹ Sr	50.5 d	2.9E4			6.4E3	FP, 90 d
⁹⁰ Sr	28.5 y	140			77	55% (ORNL-IIC-36)
³⁵ S	88 d	4.2E4				
¹⁸² Ta	115 d	6.2E3	21 R	8E3	16	Max 14 d at 8E14
^{95m} Tc	61 d	2.3E4				
⁹⁹ Tc	2.13E5 y	1.70E-2				
^{121m} Te	154 d	7.0E3	0.34		30	1 y at 8E14
^{123m} Te	120 d	8.8E3	0.3	5E3	~1	3 d at 1E15 (TM-3708)

Table 1. Continued

Nuclide	Half-Life	Theoretical Specific Activity (Ci/g)	σ_A of Target Nuclide ^a (barns)	σ_B of Radio- nuclide (barns)	Practical Specific Activity (Ci/g)	Remarks
^{125m} Te	58 d	1.8E4				
¹³² Te	78 h	3.0E5			1.3E5	FP, 7 d
¹⁵⁶ Tb	5.4 d	1.6E5				
²⁰⁴ Tl	3.78 y	4.6E2	11	22	85	1 y at 8E14 (ORNL-4306)
²²⁹ Th	7.34E3 y	0.213				
²³⁰ Th	7.7E4 y	2.02E-2				
¹⁷⁰ Tm	128 d	6.0E3	115 R	92	2.1E3	Max 100 d at 8E14
¹⁷¹ Tm	7E2 d	1.1E3				
¹¹³ Sn	115 d	1.00E4	0.7 R		51	180 d at 8E14
¹⁸¹ W	121.5 d	5.9E3	10		5E2	180 d at 8E14
¹⁸⁵ W	75 d	9.4E3	1.8		1.0E2	180 d at 8E14
¹⁸⁷ W	24 h	7.0E5	33	64	4.7E3	2.5 d at 2E15 (CF-65-12-30)
¹⁸⁸ W	69 d	1.01E4	33(186)	64(187)	12	140 d at 8E14
²³³ U	1.58E5 y	9.68E-3				
²³⁴ U	2.48E5 y	6.16E-3				
²³⁵ U	7.04E8 y	2.16E-6				
²³⁶ U	2.40E7 y	6.31E-5				
²³⁸ U	4.47E9 y	3.36E-7				
⁴⁸ V	16.0 d	1.7E5				
^{129m} Xe	8 d	1.26E5	6.2(¹²⁷ I)	0.43(¹²⁸ Xe)	40	120 d at 8E14
^{131m} Xe	12.0 d	8.3E4	28(¹²⁹ I)	0.34(¹³⁰ Xe)	30	120 d at 8E14
¹³³ Xe	5.29 d	1.85E5			1.5E4	FP, 8% abundance
⁸⁶ Y	14.7 h	2.5E6				
⁸⁷ Y	80 h	4.5E5				
⁸⁸ Y	107 d	1.4E4				
⁹⁰ Y	64.0 h	5.4E5				
⁹¹ Y	59 d	2.4E4			2.3E4	FP, ~95% abundance (ORNL-4343)

Table 1. Continued

Nuclide	Half-Life	Theoretical Specific Activity (Ci/g)	σ_A of Target Nuclide (barns) ^a	σ_B of Radio- nuclide (barns)	Practical Specific Activity (Ci/g)	Remarks
⁶⁵ Zn	244 d	8.2E3	0.7		90	1 y at 8E14
^{69m} Zn	13.8 h	3.3E6				
⁹⁵ Zr	65 d	2.1E4			3E3	FP, 90 d

^a"R" following the cross-section value indicates that resonance activation is significant.

Practical specific activities are those actually realized at ORNL, or calculated for readily obtainable conditions. For neutron-capture products, listed cross sections are σ_A , the thermal cross section for formation of a particular nuclide, and σ_B for its destruction, unless otherwise noted. The values are compatible with those compiled⁶ for the 1972 *Chart of the Nuclides*, except for a few determined locally, or found in recent literature. The yields were calculated as usual,⁷ and the specific activities are actual, taking into account any transmutations during irradiation. Isotopically pure targets were assumed, and flux values were those typical of the ORNL High Flux Isotope Reactor (HFIR), 2E15 for a week or less, and 8E14 for longer irradiations. "Max" indicates time of maximum yield of the product at the given flux. Unless dictated otherwise, desirable bombardments of 1-2 half-lives (50-75% "saturation") were chosen. References to Oak Ridge National Laboratory documents (ORNL, TM, IIC, and CF) are given under "remarks," and call-outs are listed for outside publications. Values were compared with an earlier table,⁸ which gave curies per gram of target for a variety of fluxes.

Because of the uncertainties in most cross sections, corrections for effects causing errors of 10% or less were ignored if they made calculations more tedious. Resonance activation was not included, but its occurrence is indicated by "R" in cases where it would be comparable to thermal activation of a thin sample in a typical reactor spectrum. Self-shadowing was also not considered, although its effect can be quite large. These two effects are qualitatively compensating.

For fission products (FP), allowance was made for isotopic composition, as calculated from fission yields.⁹ Secondary neutron capture by fission products was ignored. In some cases, actual compositions found for ORNL products are noted.

RADIOISOTOPE CHARACTERISTICS

Up-to-date values for decay parameters of 17 radionuclides, now known to be significantly different from those given in the *Isotope User's Guide*, are listed in Table 2. It must be noted that most of the nuclides have other properties listed in the *Guide* which remain unchanged. *Nuclear Data* is the source of most of the adoptions and should be consulted for details. Intensities of K x rays are included here for several nuclides for which those are the most significant radiations. Important recent developments in other areas discussed in the *Guide* include a survey¹⁰ of the radioactivity standards situation by a National Research Council panel, continuing contributions by the National Bureau of Standards,^{11,12} revisions (now in progress) of an NCRP handbook¹³ and the *Users' Guides for Radioactivity Standards*, and a review of ORNL assay methods.¹⁴ It should be noted that many radionuclides decay to active daughters, whose disintegration rates can be less than, equal to, or greater than those of the parents, depending on the relative values of the half-lives, and the time of production or separation.⁷

Table 2. Changes in Radionuclide Properties

Nuclide	Half-Life	Photons ^a
¹³³ Ba		Cs K x rays (118)
¹⁴⁰ Ba		0.030 (14) 0.537 (24)
¹⁰ Be	1.6E6 y (Ref. 18)	
¹⁰⁹ Ag		Ag K x rays (100) 0.088 (3.8)
⁶⁷ Cu		0.185 (47)
¹⁵⁵ Eu	4.8 y	
⁶⁷ Ga		Zn K x rays (25) 0.093 (42) 0.185 (24) 0.300 (17) 0.394 (4.6)
¹²⁴ I		Te K x rays (57) $\gamma^{\pm}$ (46) 0.603 (62) 0.723 (10) 1.69 (11) Others
¹²⁵ I		Te K x rays (136)
¹²⁹ I		Xe K x rays (68)
⁵⁵ Fe		Mn K x rays (26)
⁷⁹ Kr		Cr K x rays (51)
^{191m} Os		Os x rays
^{193m} Pt	~4.0 d	
^{195m} Pt	4.0 d	0.099 (12) 0.129 (3) Pt x rays
^{108m} Ag	~127 y	0.434 (90) 0.614 (91) 0.223 (91) Pd, Ag x rays
¹⁸¹ W		Ta K x rays (60)

^aEnergies in MeV; percentages in parentheses.

CONCLUSION

The values for half-lives, cross sections, and other characteristics have been selected to assure reasonable accuracy in applications in such fields as biomedicine, analysis, and source technology. Questions about the values selected and about ORNL work should be directed to the author, and additional information would be gratefully accepted.

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