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Translation from Nuclear Constants 5(44) 43 (1981)

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P.P. Dmitriev and G.A. Molin

Radionuclide yields during charged-particle bombardment of thick targets are nuclear constants, which are widely employed in various applied and research problems - production of radionuclides in accelerators, activation analysis using charged particles, study of mechanical wear by surface activation, use of nuclear physical methods in solid state physics, accelerator design, shielding physics and so on. The national centres for the recently established international charged-particle nuclear data compilation network collect data on radionuclide yields for thick targets in charged-particle reactions. Many of these data are written on the international exchange format EXFOR. The bibliography of integral charged particle nuclear data published recently by the Brookhaven National Laboratory (USA) [1] contains many references to studies which give radionuclide yields for thick targets.

The physical yield of a radionuclide in a given reaction is determined by the excitation function of the reaction, i.e. by the dependence of the effective reaction cross-section on the bombarding particle energy, by the particle path and by the content of the initial stable isotope in the target material. The relationship between the average effective reaction cross-section over the path length $\bar{\sigma}$, mb, and the radionuclide yield for a thick target B, MBq/μA·h, can be written in the form

$$\bar{\sigma} = 1{,}26 \frac{B \cdot T_{1/2} Z_a}{R} \frac{A}{P},$$

where $T_{\frac{1}{2}}$ is the half-life of the radionuclide in days, Z_a the relative charge of the bombarding particle, R the path of the bombarding particle in mg/cm^2, A the atomic weight of the element and P the content of the target isotope in %.

For a low target thickness (small particle path), when the change in the reaction cross-section through the target thickness can be neglected, this formula gives the relationship between the reaction cross-section and the radionuclide yield for a thin target. A similar method of determination of the reaction cross-section is widely used in measurements of the excitation functions of nuclear reactions by the "foil stacking" method.

The present study gives the measurements of radionuclide yields during 22-MeV-proton bombardment of thick targets made of different chemical elements. The work was carried out on the cyclotron of the Institute of Physics and Power Engineering (Obninsk). Altogether 188 yield values of 140 radionuclides were measured. The data obtained are shown in Table 1, where the following notations have been used: n - neutron, p - proton, t - triton, τ - helium-3, α - helium-4 (α particle). Deuteron, as a weakly bound system, has a low emission probability and is not shown in column 3.

Column 3 gives the reactions which have an energy threshold lower than 22 MeV. The comma separates the reactions which occur with the stable isotopes of the element indicated in column 2. Knowing the emitted particles, one can of course easily indicate the reactions of formation of the radionuclide. For example, during the production of ^{7}Be from Li, emission of particle n means the reaction (pn) with ^{7}Li: $^{7}Li(pn)^{7}Be$. During the production of ^{7}Be from boron, emission of particles α and αn means the formation of ^{7}Be in reactions (pα) and (pαn) with boron isotopes: $^{10}B(p\alpha)^{7}Be$ and $^{11}B(p\alpha n)$. Emission of particles 2p, τ, α, αn during the production of ^{46}Sc from titanium means the reactions: $^{47}Ti(p2p)^{46}Sc$, $^{48}Ti(p\tau)^{46}Sc$, $^{49}Ti(p\alpha)^{46}Sc$, $^{50}Ti(p\alpha n)^{46}Sc$.

The sign + in column 3 indicates that in some sums of reactions a shorter-lived isobaric nucleus is formed, which decays to the radioisotope obtained. For example, in the production of ^{18}F from fluorine, emission of particles pn + 2n means the reactions $^{19}F(ppn)^{18}F$ and $^{19}F(p2n)^{18}Ne(T_{\frac{1}{2}} = 1.67\ s) \rightarrow {}^{18}F$. Similarly, during the production of ^{57}Co from Ni, emission of particles 2p + pn + 2n,α,αn indicates the following channels of formation of ^{57}Co: $^{58}Ni(p2p)^{57}Co$, $^{58}Ni(ppn)^{57}Ni(T_{\frac{1}{2}} = 36.16\ years) \rightarrow {}^{57}Co$, $^{58}Ni(p2n)^{57}Cu(T_{\frac{1}{2}} = 0.18\ s) \rightarrow {}^{57}Ni \rightarrow {}^{57}Co$, $^{60}Ni(p\alpha)^{57}Co$, $^{61}Ni(p\alpha n)^{57}Co$. The form of writing used in column 3 is obviously very compact in comparison with writing out the reactions in full.

It should be borne in mind that in a number of cases, for example in the region of heavier nuclei, the thresholds of reactions with emissions of particles p2n and 2pn can be noticeably lower than 22 MeV, and these reactions, together with reactions (pt) and (pτ), will make a contribution to the radionuclide yield which may exceed that due to reactions with emission of t and τ. Column 3 contains no reaction of radiative proton capture (pγ) (emission of γ-rays only) because of the relatively low cross-section of these reactions.

Column 4 gives the yield and, in brackets, the error of this value. The third figure with a + or - sign means the power of 10: the yield value and the error have to be multiplied by 10 raised to this power. For example, 28(3) +3 means 28 000 ± 3000; 16.5(2.2)-4 corresponds to 0.00165 ± 0.00022 and so on.

In all cases, the yields were measured for elements of natural isotopic composition. During irradiation of a chemical compound the yield is converted in terms of the pure element. Most of the yield values given in Table 1 are being published for the first time, while some are taken from studies published earlier, where the radionuclide yields were measured as a function of the bombarding particle energy (the latest of these are Refs [2, 3]). The method of yield measurement is described in Ref. [3]; the error in the yield value in most cases is 11-15% and results mainly from the systematic errors during the measurement of the isotope activity and the integral sample-irradiation current. In some cases (radiochemical extraction, unfavourable conditions of activity measurement), the error in the yield value exceeds 15%.

Table 2 gives the half-lives and the energy and quantum yield of gamma rays used in the nuclide activity measurement. The data in Table 2 are taken from Refs [4, 5] and partly from the latest issues of the Nuclear Data Sheets.

The data presented on radionuclide yields during proton bombardment of thick targets are most complete. The yield values published by other authors [6] refer to a small number of nuclides and, in most cases, are "technological" yields. These values are usually lower than the physical yields, and this may be due to the following reasons: (a) loss of the radionuclide during bombardment (evaporation of the nuclide and the target material); (b) part of the recorded beam irradiates the structural parts of the target; (c) losses during radiochemical extraction of isotopes.

Publication of data on radionuclide yields for thick targets will continue. It is intended to publish the radionuclide yields for 22 MeV deuterons and 44 MeV α-particles.

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Table 1. Radionuclide yields for a thick target at 22 MeV proton energy

Radio-nuclide	Target	Emitted particles	Yield, MBq/μA·h	Radio-nuclide	Target	Emitted particles	Yield MBq/μA·h
I	2	3	4	I	2	3	4
^{17}Be	Li	n	I0,7(I,4)	^{46}Sc	Ti	2p, τ, α, αn	38(6)-3
	Be	t	46(6)-2	^{47}Sc	Ca	2n	45(7)-2
	B	α, αn	I9(2,5)-I		Ti	2p, τ, α	29(4)-2
^{11}C	B	n	28(3)+3		V	α, p	I6(2)-I
	C	pn, t	35(4)+2	^{44}Ti	Sc	2n	I5(2)-4
	N	α, αn	20(2)+2	^{48}V	Ti	n, 2n	I9(2)
^{13}N	C	n	48(5)+I	^{49}V	Ti	n, 2n	I2(2)-2
	N	pn, t	I7(2)+3		V	pn + 2n, t	37(6)-4
	O	α, αn	96(I0)+2	^{51}Cr	V	n	20,5(2,2)
^{18}F	O	n	I5,5(I,6)		Cr	pn + 2n, t	59(7)-I
	F	pn + 2n	33(3,5)+2		Mn	αn	59(7)-2
^{22}Na	Na	pn + 2n	23(3)-2	^{52}Mn	Cr	n, 2n	2I(2,4)
	Mg	τ, α, αn	I6,5(2,2)-3	^{54}Mn	Cr	n	I7(2)-3
^{24}Na	Mg	2p, τ	38(5,5)-I		Mn	pn	80(I0)-2
^{26}Al	Mg	n	48(7)-9	^{55}Fe	Mn	n	34(6)-2
	Al	pn	36(5,5)-8		Fe	pn + 2n, t	33(6)-2
^{42}K	Ca	2p, τ, αn	78(I2)-4	^{55}Co	Fe	2n	24(3)-I
^{43}K	Ca	2p, α	I8(2,6)-3		Ni	α	I6,6(2,I)
^{47}Ca	Ca	2p + pn	28(4)-3	^{56}Co	Fe	n, 2n	28(4)-I
$^{44}Sc^m$	Ca	n	65(I0)-2		Ni	τ + t, αn	I7,4(2,3)-3
	Sc	pn	36(6)	^{57}Co	Fe	n, 2n	2I(3)-3
^{44}Sc	Ca	n	32(5)		Co	t	92(I6)-4

Radio- nuclide	Tar- get	Emitted particles	Yield MBq/μA·h	Radio- nuclide	Target	Emitted particles	Yield MBq/μA·h
1	2	3	4	1	2	3	4
	Ni	2p+pn+2n, α, αn	II(I,4)-I		Zr	τ, α, αn	96(I4)-4
^{58}Co	Co	pn	4I(5)-I	^{88}Zr	Y	2n	I9(2,7)-I
	Ni	τ, α, αn	37(5)-3	^{89}Zr	Y	n	89(5,5)
^{60}Co	Ni	2p, τ, αn	I3(2)-5		Nb	αn	20,4(3)-I
^{56}Ni	Ni	t	35(5)-3	^{95}Zr	Zr	2p + pn	44(6,5)-3
^{57}Ni	Ni	pn + 2n	32(4)	$^{92}Nb^{m}$	Zr	n, 3n	89(I2)-2
^{64}Cu	Cu	pn	I3(I,8)+I	^{95}Nb	Nb	pn	22(3)-I
^{67}Cu	Zn	2p, α	44(8)-3		Zr	2n	25(3,5)-2
^{62}Zn	Cu	2n	I0,4(I,4)+I	$^{93}Mo^{m}$	Nb	n	30(4,5)
^{65}Zn	Cu	n	59(7)-2	^{93}Mo	Nb	n	I4,4(2,2)-5
	Zn	pn + 2n, t	39(5)-2	$^{95}Tc^{m}$	Mo	n, 2n, 3n	54(6,5)-2
	Ga	αn	89(II)-3	^{96}Tc	Mo	n, 2n, 3n	I9,4(2,3)
^{66}Ga	Zn	n, 2n	26(3)+I	$^{97}Tc^{m}$	Mo	n, 2n	39(5)-2
^{67}Ga	Zn	n, 2n	32(3,8)	$^{101}Rh^{m}$	Ru	n, 2n	3I(4,6)
	Ge	α, α2n	23(3,2)-I		Rh	t + 3n	70(II)-2
^{68}Ge	Ga	2n	67(9)-2	$^{102}Rh^{m}$	Rh	pn	24(3,6)-3
^{69}Ge	Ga	n, 3n	93(II)	^{102}Rh	Rh	pn	27(4)-2
	Ge	pn + 2n	6I(8)	^{103}Pd	Rh	n	94(I3)-I
^{71}As	Ge	n, 3n	32(5)	^{105}Ag	Cd	2p, α, αn	74(II)-3
^{72}As	Ge	n, 2n	I3,5(2)+I	$^{106}Ag^{m}$	Ag	pn	I0,4(I,5)-I
^{73}As	Ge	n, 2n	I9(2,5)-I	$^{108}Ag^{m}$	Ag	pn	I3,7(2)-6
^{74}As	Ge	n, 3n	70(9)-I	$^{110}Ag^{m}$	Cd	2p, τ, α, αn	52(8)-5
	As	pn	35(4,5)-I	^{107}Cd	Ag	n, 3n	35(5)+I
	Se	τ, α, αn	56(8)-3	^{109}Cd	Ag	n	I9(2,5)-2
^{76}As	Ge	n	96(I4)-I		Cd	pn+2n, t+3n	27(4)-3
^{75}Se	As	n	20(3)-I	^{115}Cd	Cd	pn	74(II)-2
	Se	pn + 2n, t	23(3,5)-2	^{111}In	Cd	n, 2n, 3n	54(6,5)
^{76}Br	Se	n, 2n	93(I2)	$^{114}In^{m}$	Cd	n, 3n	4I(5)-2
^{77}Br	Se	n, 2n	34(4,5)		In	pn	42(5,5)-2
	Br	t	4I(6)-2	^{113}Sn	In	n, 3n	I0,3(I,3)-2
^{82}Br	Se	n	I0,7(I,4)		Sn	pn+2n, t+3n	II(I,5)-3
^{79}Kr	Br	n, 2n	67(I0)	$^{120}Sb^{m}$	Sn	n, 3n	78(II)-2
^{84}Rb	Rb	pn	52(8)-2	^{122}Sb	Sn	n, 3n	33(5)-I
	Sr	τ, α, αn	52(8)-2	^{124}Sb	Sn	n	92(I4)-3
^{85}Sr	Rb	n, 3n	26(3,I)-I	$^{121}Te^{m}$	Sb	n, 3n	2I,4(3)-2
	Sr	pn + 2n, t	2I(2,5)-2	^{121}Te	Sb	n, 3n	30(4)-I
^{86}Y	Sr	n, 2n	6I(9)	$^{123}Te^{m}$	Sb	n	I5,5(2)-2
^{87}Y	Sr	n, 2n	85(II)	^{123}I	Te	n, 2n, 3n	4I(5)
^{88}Y	Sr	n	83(4,3)-I	^{124}I	Te	n, 2n, 3n	96(I2)-I
	Y	pn	42(5,5)-2				

Radio-nuclide	Target	Emitted particles	Yield MBq/μA·h
I	2	3	4
^{125}I	Te	n, 2n	II,4(I,9)-I
^{126}I	Te	n, 3n	36(4,5)-I
	I	pn	I8(2,2)-I
^{130}I	Te	n	39(5)
^{127}Xe	I	n	I9(3)-I
^{132}Cs	Cs	pn	I7,4(2,4)-I
$^{133}Ba^m$	Cs	n	I8,5(2,8)
^{133}Ba	Cs	n	2I(3)-3
$^{135}Ba^m$	Ba	pn, t	85(I0)-2
	La	αn	85(I0)-I
^{135}La	Ba	n, 2n, 3n	2I,5(3)
^{139}Ce	La	n	44(5,3)-2
	Ce	pn + 2n	I3(I,8)-I
^{139}Pr	Ce	2n	92(I3)+I
^{140}Nd	Pr	2n	92(I3)
^{143}Pm	Nd	n, 2n, 3n	59(8)-2
^{144}Pm	Nd	n, 2n, 3n	2I(3)-2
^{148}Pm	Nd	n, 3n	I5(2,I)-I
^{147}Eu	Sm	n, 2n, 3n	24(3,5)-I
^{148}Eu	Sm	n, 2n, 3n	56(8)-2
$^{150}Eu^m$	Sm	n, 3n	I0,7(I,6)-4
	Eu	pn	I0,4(I,5)-4
^{152}Eu	Sm	n, 3n	37(5,5)-4
	Eu	pn	44(6,5)-4
^{154}Eu	Sm	n	I7(2,6)-4
^{151}Gd	Eu	n, 3n	63(I0)-3
^{153}Gd	Eu	n	4I(6)-3
^{155}Tb	Gd	n, 2n, 3n	55(8)
^{156}Tb	Gd	n, 2n, 3n	I4,3(2)
^{158}Tb	Gd	n, 3n	59(9)-5
^{165}Tu	Er	2n, 3n	73(8,5)
^{166}Tu	Er	n, 2n, 3n	29(3,3)+I
^{167}Tu	Er	n, 2n	93(II)-I
^{168}Tu	Er	n, 3n	24(2,8)-2
^{170}Tu	Er	n	I6,6(3,I)-3
^{173}Lu	Yb	n, 2n	30(4,4)-2
^{174}Lu	Yb	n, 3n	28(4)-3
^{175}Hf	Hf	pn+2n, t+3n	40(6)-2
^{176}Ta	Hf	n, 2n, 3n	I2,8(2)+I
^{177}Ta	Hf	n, 2n, 3n	38(5,5)
^{181}W	Ta	n	I2(I,8)-2
^{181}Re	W	2n, 3n	I0,4(I,4)+I
$^{182}Re^m$	W	n, 2n, 3n	87(II)-I
^{182}Re	W	n, 2n, 3n	68(9)
^{183}Re	W	n, 2n	I2,2(I,6)-I
$^{184}Re^m$	W	n, 3n	30(4)-3
^{184}Re	W	n, 3n	I2,6(I,6)-I
^{185}Os	Re	n, 3n	I2,2(I,7)-I
^{194}Au	Pt	n, 2n, 3n	78(II)
^{195}Au	Pt	n, 2n	I5(2,2)-2
^{196}Au	Pt	n, 3n	26(3,7)-I
	Au	pn	I8(2,7)-I
^{197}Hg	Au	n	92(I4)-I
^{203}Hg	Hg	2p+pn	I6,6(2,5)-3
^{200}Tl	Hg	n, 2n, 3n	43(6,4)
^{201}Tl	Hg	n, 2n	3I(4,6)
^{202}Tl	Hg	n, 3n	80(I2)-2
	Tl	pn	96(I4)-3
^{201}Pb	Tl	3n	28(4,2)
$^{202}Pb^m$	Tl	2n	63(9,5)
^{203}Pb	Tl	n, 3n	32(3,9)
^{205}Bi	Pb	2n, 3n	72(II)-I
^{206}Bi	Pb	n, 2n, 3n	II,3(I,7)
^{207}Bi	Pb	n, 2n	I5(2,2)-3
	Bi	t + 3n	I3(I,9)-4

Table 2: Characteristics of the radionuclides used in activity measurement

Nuclide	Half-life	Gamma ray energy, keV	Quantum yield per decay, %	Nuclide	Half-life	Gamma ray energy, keV	Quantum yield per decay, %
I	2	3	4	I	2	3	4
^{7}Be	53,3 d	477,6	IO,3	^{46}Sc	83,9 d	II2O	IOO
^{11}C	20,5 min	5II±	200	^{47}Sc	3,4 d	I59,4	70
^{13}N	9,97 min	5II±	200	^{44}Ti	47,3 a	II57	IO3
^{18}F	IO9,7 min	5II±	I93	^{48}V	I6 d	I3II	98
^{22}Na	2,60 d	I274	IOO	^{49}V	330 d	KX4,55	I9,3
^{24}Na	I5,0 h	I368	IOO	^{51}Cr	27,7 d	320,0	9,8
^{26}Al	$7{,}38 \cdot IO^{5}$ a	I809	99,7	^{52}Mn	5,67 d	744,0	85
^{42}K	I2,4 h	I5,25	I8	^{54}Mn	3I2 d	835,0	IOO
^{43}K	22,6 h	593,0	8,9	^{55}Fe	2,6 a	KX5,93	25,7
^{47}Ca	4,55 d	I297	75	^{55}Co	I7,5 h	932,0	75
^{44}Sc^{m}	2,44 d	270,9	87	^{56}Co	78,5 d	I238	67,6
^{44}Sc	3,92 h	II57	IO3	^{57}Co	27I d	I22,1	85,2

Nuclide	Half-life	Gamma ray energy, keV	Quantum yield per decay, %	Nuclide	Half-life	Gamma ray energy, keV	Quantum yield per decay, %
^{58}Co	70,8 d	8I0,8	99,4	$^{97}Tc^{m}$	87 d	KXI8,66	49
^{60}Co	5,27 a	I3,32	I00	$^{101}Rh^{m}$	4,34 d	306,8	84,3
^{56}Ni	6,I d	750,6	48	$^{102}Rh^{m}$	2,89 a	697,I	46
^{57}Ni	36,2 h	I378	82,3	^{102}Rh	207 d	5II±	28
^{64}Cu	I2,7 h	I347	0,55	^{103}Pd	I7,0 d	357,6	0,029
^{67}Cu	6I,9 h	I84,6	47	^{105}Ag	4I,3 d	644,6	II,8
^{62}Zn	9,26 h	596,6	22,7	$^{106}Ag^{m}$	8,4I d	I045	25,7
^{65}Zn	244 d	III5	50,6	$^{108}Ag^{m}$	I27 a	6I4,4	92,5
^{66}Ga	9,4 h	I039	35,5	$^{110}Ag^{m}$	250 d	937,5	32,4
^{67}Ga	78,3 h	I84,6	22,7	^{107}Cd	6,49 h	93,I	4,7
^{68}Ge	288 d	I078	3,2	^{109}Cd	453 d	88,0	3,79
^{69}Ge	39,0 h	II06	3I	^{115}Cd	53,5 h	527,9	26,4
^{71}As	64,8 h	I74,9	87,5	^{111}In	2,8 d	245,4	94
^{72}As	26,0 h	834,0	77,4	^{114}In	49,5 d	I9I,6	I7
^{73}As	80,3 d	53,3	I0,6	^{113}Sn	II5 d	39I,7	64,2
^{74}As	I7,8 d	595,7	60	$^{120}Sb^{m}$	5,76 d	I97,3	88
^{76}As	26,6 h	559,5	43	^{122}Sb	2,7I d	564,0	7I
^{75}Se	II8 d	264,6	59,5	^{124}Sb	60,2 d	I69I	49
^{76}Br	I6,2 h	559,2	73,4	$^{121}Te^{m}$	I54 d	2I2,2	8I
^{77}Br	57 h	238,9	26,I	^{121}Te	I7 d	507,5	I9,3
^{82}Br	35,3 h	698,3	28,6	$^{123}Te^{m}$	I20 d	I59,0	84
^{79}Kr	35 h	398,0	9,5	^{123}I	I3,3 h	I59,0	82,9
^{84}Rb	32,8 d	88I,5	75,3	^{124}I	4,I8 d	602,7	62,8
^{85}Sr	64,7 d	5I4,0	99,3	^{125}I	59,9 d	KX28,03	I39
^{86}Y	I4,7 h	627,7	33,3	^{126}I	I2,9 d	666,4	33
^{87}Y	80,3 h	484,8	92,I	^{130}I	I2,4 h	II57	II,4
^{88}Y	I07 d	I836	99,6	^{127}Xe	36,4 d	375,0	20
^{88}Zr	83,4 d	394,0	97	^{132}Cs	6,48 d	667,5	98
^{89}Zr	78,4 h	909,I	99,9	$^{133}Ba^{m}$	38,9 h	275,6	I7,5
^{95}Zr	64 d	724,2	43,7	^{133}Ba	I0,5 a	356,0	6I,6
$^{92}Nb^{m}$	I0I,I d	934,0	99,I	$^{135}Ba^{m}$	28,7 h	268,2	I4,9
^{95}Nb	35 d	765,8	998	^{135}La	I9,5 h	480,5	I,87
$^{93}Mo^{m}$	6,85 h	684,6	92	^{139}Ce	I38 d	I65,8	80,I
^{93}Mo	3000 a	KXI6,86	48	^{139}Pr	4,42 h	5II±	I5,8
$^{95}Tc^{m}$	6I d	204,I	66,2	^{140}Nd	3,37 d	KX36,75	67
^{96}Tc	4,28 d	II27	I5,2	^{143}Pm	265 d	74I,9	47

Nuclide	Half-life	Gamma ray energy, keV	Quantum yield per decay, %	Nuclide	Half-life	Gamma ray energy, keV	Quantum yield per decay, %
1	2	3	4	1	2	3	4
^{144}Pm	363 d	696,5	100	^{181}W	121 d	KX58,8	64,8
^{148}Pm	5,37 d	1465	24	^{181}Re	20 h	365,5	56,4
^{147}Eu	24,3 d	197,3	22	$^{182}Re^m$	64 h	1121	24,5
^{148}Eu	54 d	413,9	9,7	^{182}Re	12,7 h	1121	31,5
$^{150}Eu^m$	35,8 a	439,0	66	^{183}Re	70 d	291,7	3,3
^{152}Eu	13,2 a	964,0	14,2	$^{184}Re^m$	165 d	920,9	8,3
^{154}Eu	8,5 a	123,1	40,5	^{184}Re	38 d	792,1	34
^{151}Gd	120 d	243,6	7,1	^{185}Os	94 d	646,1	81
^{153}Gd	242 d	97,43	22,6	^{194}Au	39,5 h	328,5	61
^{155}Tb	5,32 d	105,3	19,2	^{195}Au	192 d	98,86	12
^{156}Tb	5,34 d	534,3	66	^{196}Au	6,18 d	355,7	90
^{158}Tb	150 a	962,2	20,1	^{197}Hg	64,1 h	191,5	0,96
^{165}Tu	29,6 h	242,9	36	^{203}Hg	46,8 d	279,2	81,4
^{166}Tu	7,7 h	1275	14,6	^{200}Tl	26,1 h	368,0	89,3
^{167}Tu	9,24 d	207,8	41	^{201}Tl	73,5 h	167,4	8,8
^{168}Tu	93,1 d	198,2	52	^{202}Tl	12,2 d	439,4	92
^{170}Tu	129 d	84,26	3,1	^{201}Pb	9,4 h	331,2	81
^{173}Lu	1,37 a	272,0	17,6	$^{202}Pb^m$	3,62 h	787,0	50
^{174}Lu	3,31 a	1241	6	^{203}Pb	52,1 h	279,2	81
^{175}Hf	70 d	343,4	88	^{205}Bi	15,3 d	1764	21
^{176}Ta	3,08 h	1159	24,1	^{206}Bi	6,24 d	1719	32
^{177}Ta	56,6 h	1130	6	^{207}Bi	38 a	1064	74

Remarks: 1. KX-rays were used to measure the activities of ^{49}V, ^{55}Fe, ^{93}Mo, $^{97}Tc^m$, ^{125}I, ^{140}Nd and ^{181}W. 2. The activities of some nuclides, for example ^{44}Ti, ^{68}Ge, ^{113}Sn were measured from the gamma-rays of the daughter. 3. In column 3: 511$\pm$ means annihilation radiation.