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Dose-rate conversion factors: update

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Abstract
In the field of luminescence and electron spin resonance dating, dose rate conversion factors are widely used to convert concentrations of radioactive isotopes to dose rate values. These factors are derived from data provided by the National Nuclear Data Center of the Brookhaven National Laboratory, which are compiled in Evaluated Nuclear Structure Data Files (ENSDF) and Nuclear Wallet Cards. The recalculated dose rate conversion factors are a few percent higher than those previously published, except for beta and gamma emissions of the isotopes of the U-series decay chains.

Introduction
In luminescence and electron spin resonance dating, an age is obtained by dividing the palaeodose with the dose-rate that an object to be dated has been exposed to. The latter is determined by measurements of concentrations of radioelements or activity using gamma spectrometry, ICP MS, neutron activation analysis, alpha counting, beta counting or flame photospectrometry. The elemental concentrations are then converted in dose rates using conversion factors. These depend on the properties of the nuclear decays involved. The conversion factors have been calculated from time to time, for example by Nambi and Aitken (1986) or Adamiec and Aitken (1998; see also references therein) based on the ENSDF data. However, a new data set is available and an update is timely. The data used here were downloaded on 5th November 2009 on the Chart of Nuclides (http://www.nndc.bnl.gov/chart/index.jsp) and are based on Evaluated Nuclear Structure Data Files (ENSDF) and Nuclear Wallet Cards. This paper presents updated conversion factors following the approach of Adamiec and Aitken (1998).

The data
Tables 1 and 2 show the energy emission values for the ^{232}Th, ^{238}U and ^{235}U and series for alpha, beta and gamma rays as derived from the data of the National Brookhaven Laboratory website. The most appreciable differences between the data in these tables and those of Adamiec and Aitken (1998) are in the ^{235}U series, since updated values for these radioelements have been published since 1998 (e.g. Browne, 2001) for ^{231}Th, ^{231}Pa, ^{227}Ac, ^{227}Th, ^{223}Fr, ^{223}Ra, ^{219}Rn.

The dose-rate values are given for infinite matrices (Aitken, 1985), for secular equilibrium of the radioactive decay chains as well as for total radon escape. Table 2 presents dose rate data for natural uranium, taking account of isotopic abundances (mass fractions: 99.29% for ^{238}U and 0.71% for ^{235}U). It should be noted here that the infinite matrix assumption implies homogeneity in absorption coefficients; taking account of different absorption characteristics between e.g. X-rays and gamma rays would require Monte Carlo modelling and is therefore beyond the scope of this paper.

Data for potassium and rubidium are given in Table 3. It should be noted that there is a significant difference for the potassium because the half-life of ^{40}K was recently reevaluated (Grau Malonda & Grau Carles, 2002; Kossert & Gunther, 2004) and is now 2.3% lower than previously published.

Concluding remarks
Even though uncertainty factors such as moisture content, heterogeneity of sedimentary media etc. have significant effects on the accuracy of dose rate , it is of paramount importance to minimize all sources of systematic errors. The overall effect of our update obviously depends on each case, but may reach a few percent on the final obtained age calculation. We therefore recommend that our newest conversion factors, which are derived from the up-to-date nuclear data, should be henceforth used for luminescence and ESR age calculations.

Table 1: *Energy release and dose rates in the ^{232}Th decay series.*

Isotope	Half-life (s)	Alpha		Beta		Gamma	
		Energy	Dose rate	Energy	Dose rate	Energy	Dose rate
^{232}Th	$4.43\ 10^{17}$	4.003	0.0821	0.0113	0.0002	0.0011	0.0000
^{228}Ra	$1.81\ 10^{8}$	-	-	0.0092	0.0002	0.0004	0.0000
^{228}Ac	$2.21\ 10^{4}$	-	-	0.4171	0.0086	0.8602	0.0176
^{228}Th	$6.03\ 10^{7}$	5.406	0.1109	0.0195	0.0004	0.0031	0.0001
^{224}Ra	$3.16\ 10^{5}$	5.673	0.1164	0.0023	0.0000	0.0104	0.0002
^{220}Rn	$5.56\ 10^{1}$	6.288	0.1290	-	-	0.0006	0.0000
^{216}Po	$1.45\ 10^{-1}$	6.778	0.1390	-	-	0.0000	0.0000
^{212}Pb	$3.83\ 10^{4}$	-	-	0.1721	0.0035	0.1437	0.0029
^{212}Bi	$3.63\ 10^{3}$	2.175	0.0446	0.5034	0.0103	0.1039	0.0021
^{212}Po (0.641)	$2.99\ 10^{-4}$	5.631	0.1155	-	-	-	-
^{208}Tl (0.359)	$1.83\ 10^{2}$	-	-	0.2140	0.0044	1.2136	0.0249
Total			**0.7375**		**0.0277**		**0.0479**
Pre-Rn total			**0.3093**		**0.0094**		**0.0180**
Adamiec & Aitken (1998)							
Total			0.7320		0.0273		0.0476
Pre-Rn total			0.3050		0.0091		0.0178
Rel. Difference (%)							
Total			0.75%		1.34%		0.70%
Pre-Rn total			1.42%		3.53%		0.84%

Notes for table 1.

1. Energies are given in MeV and represent the energy emitted per disintegration.
2. Branching ratios are shown in parenthesis against the radioelements in the branches; associated values given for energy release are after adjustment for branching. Note that the branching also affects the energy release of the radioelement at which the branching occurs; thus the value given for the alpha release by ^{212}Bi is 35.9% of the full energy - because ^{208}Tl is formed by alpha emission from ^{212}Bi.
3. Beta components include Auger electrons and internal conversion; gamma components include X-rays and annihilation radiation; alpha recoil and neutrinos are not included due to their insignificant contribution to dose-rates (cf. Adamiec and Aitken, 1998).
5. A dash indicates that no radiation of that type is mentioned by the National Nuclear Data Centre.
6. Dose rate values are given in Gy ka^{-1} per ppm of parent (i.e. mg of parent per kg of sample), assuming equilibrium in the decay chains. The activity of the parent is 4.057 Bq kg^{-1} of sample.
7. The rows labelled ‘pre-Rn’ give the values for 100% escape of radon.
8. Relative differences are calculated between this paper and values from Adamiec and Aitken (1998).
9. ^{216}At has been omitted since its contribution to the total energy is insignificant.

Table 2: *Energy release and dose rates in the uranium (^{238}U and ^{235}U) decay series.*

Isotope	Half-life (s)	Alpha			Beta			Gamma		
		Energy	Dose rate	Dose rate, nat. U	Energy	Dose rate	Dose rate, nat. U	Energy	Dose rate	Dose rate, nat. U
^{238}U	$1.41\ 10^{17}$	4.193	0.264	0.262	0.007	0.0005	0.0004	0.001	0.0001	0.0001
^{234}Th	$2.08\ 10^{6}$	-	-	-	0.059	0.0037	0.0037	0.008	0.0005	0.0005
^{234}Pa$_m$	$6.95\ 10^{1}$	-	-	-	0.810	0.0509	0.0506	0.016	0.0010	0.0010
^{234}Pa (0.0016)	$2.41\ 10^{4}$	-	-	-	0.001	0.0001	0.0001	0.001	0.0001	0.0001
^{234}U	$7.75\ 10^{12}$	4.759	0.299	0.297	0.012	0.0007	0.0007	0.001	0.0001	0.0001
^{230}Th	$2.38\ 10^{12}$	4.664	0.293	0.291	0.013	0.0008	0.0008	0.001	0.0001	0.0001
^{226}Ra	$5.05\ 10^{10}$	4.775	0.300	0.298	0.004	0.0002	0.0002	0.007	0.0005	0.0005
^{222}Rn	$3.30\ 10^{5}$	5.489	0.345	0.343	-	-	-	0.000	0.0000	0.0000
^{218}Po	$1.86\ 10^{2}$	6.001	0.377	0.375	-	-	-	-	-	-
^{214}Pb	$1.61\ 10^{3}$	-	-	-	0.291	0.0183	0.0182	0.239	0.0150	0.0149
^{214}Bi	$1.19\ 10^{3}$	0.001	0.000	0.000	0.654	0.0411	0.0408	1.475	0.0928	0.0921
^{214}Po	$1.64\ 10^{-4}$	7.687	0.483	0.480	-	-	-	0.000	0.0000	0.0000
^{210}Pb	$7.01\ 10^{8}$	-	-	-	0.033	0.0021	0.0021	0.005	0.0003	0.0003
^{210}Bi	$4.33\ 10^{5}$	-	-	-	0.389	0.0245	0.0243	-	-	-
^{210}Po	$1.20\ 10^{7}$	5.304	0.333	0.331	0.000	0.0000	0.0000	0.000	0.0000	0.0000
^{238}U total			2.695	2.676		0.1429	0.1419		0.1104	0.1096
^{238}U Pre-Rn total			1.156	1.148		0.0570	0.0566		0.0022	0.0022
^{235}U	$2.22\ 10^{16}$	4.114	1.663	0.012	0.029	0.0117	0.0001	0.164	0.0665	0.0005
^{231}Th	$2.20\ 10^{6}$	-	-	-	0.146	0.0591	0.0004	0.023	0.0094	0.0001
^{231}Pa	$1.03\ 10^{12}$	4.924	1.990	0.014	0.032	0.0130	0.0001	0.040	0.0160	0.0001
^{227}Ac	$6.87\ 10^{8}$	0.070	0.028	0.000	0.012	0.0049	0.0000	0.001	0.0002	0.0000
^{227}Th (0.986)	$1.61\ 10^{6}$	5.808	2.347	0.017	0.050	0.0202	0.0001	0.154	0.0621	0.0004
^{223}Fr (0.014)	$1.32\ 10^{3}$	0.005	0.002	0.000	0.000	0.0002	0.0000	0.001	0.0003	0.0000
^{223}Ra	$9.88\ 10^{5}$	5.664	2.289	0.016	0.068	0.0275	0.0002	0.135	0.0546	0.0004
^{219}Rn	$3.96\ 10^{0}$	6.753	2.729	0.019	0.007	0.0027	0.0000	0.058	0.0235	0.0002
^{215}Po	$1.78\ 10^{-3}$	7.392	2.987	0.021	-	-	-	-		
^{211}Pb	$2.17\ 10^{3}$	-	-	-	0.450	0.1817	0.0013	0.064	0.0258	0.0002
^{211}Bi	$1.28\ 10^{2}$	6.549	2.647	0.019	0.013	0.0053	0.0000	0.047	0.0191	0.0001
^{211}Po	$5.16\ 10^{-1}$	0.021	0.008	0.000	-	-	-	-	-	-
^{207}Tl	$2.86\ 10^{2}$	-	-	-	0.495	0.2002	0.0014	0.002	0.0009	0.0000
^{235}U total			16.690	0.1185		0.5265	0.0037		0.2807	0.0020
Total				**2.795**			**0.1457**			**0.1116**
Pre-Rn total				**1.267**			**0.0603**			**0.0042**
Adamiec & Aitken (1998)										
Total				2.78			0.146			0.113
Pre-Rn total				1.26			0.06			0.0044
Rel. Difference (%)										
Total				0.53%			-0.24%			-1.28%
Pre-Rn total				0.52%			0.54%			-4.43%

Notes for table 2.

1. See notes 1-8 of Table 1.
2. The mass abundances used in the natural uranium calculations for ^{238}U and ^{235}U (respectively 99.29% and 0.71%) correspond to the natural atomic abundances of 99.28% and 0.72% respectively.
3. The activity of the parent (per ppm of parent) is 12.44 Bq kg^{-1} of sample for ^{238}U, 79.94 for ^{235}U and 12.92 for natural uranium.
4. The rows labelled 'pre-Rn' give the values for 100% escape of radon in the case of ^{238}U series, but because of the short half-life of ^{219}Rn the values given for natural uranium include contributions of that gas and its daughters.
5. ^{218}At, ^{218}Rn, ^{210}Tl, ^{206}Tl and ^{215}At have been omitted since their contribution to the total is insignificant.

Table 3: *Dose-rate data for Potassium and Rubidium.*

		^{40}K	^{87}Rb
Natural abundance (mg.g^{-1})		0.119	283
Half-life (Ga)		1.248	48.1
Average energy per disintegration (MeV)	Beta	0.499	0.0817
	Gamma	0.1557	
Specific activity (Bq.kg^{-1}) for concentration of 1% nat. K and 50 ppm of nat. Rb	Total	316.4	44.8
	Beta	282.5	44.8
	Gamma	33.73	
Dose-rate (Gy.ka^{-1}) for concentrations as above	Beta	0.7982	0.0185
	Gamma	0.2491	
Dose-rate, Adamiec & Aitken (1998)	Beta	0.782	0.019
	Gamma	0.243	
Relative differences	Beta	2.07%	-2.67%
	Gamma	2.49%	

Notes for table 3.
1. The energy given for potassium is that released per disintegration, i.e. after allowance for branching between beta and gamma (89.28% and 10.72% respectively).
2. The contents given in row 1 correspond to natural atomic abundances of 116.7 ppm and 27.8%.

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Reviewer
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