REVISS SERVICES

REVISS Services
Quality And Operations Group

Technical Memorandum

Nuclide Heating

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1. PURPOSE AND SCOPE

The purpose of this document is to define the decay heat output of a variety of nuclides for use in thermal calculations and analysis.

2. INTRODUCTION

When radiation is emitted by a decaying nucleus, energy is carried away by a combination of particles and electromagnetic radiation. When that radiation is absorbed, e.g. by shielding, its' energy is dissipated in the form of heat. The maximum amount of heating will occur when all of the energy of the radiation is absorbed. Any emitted neutrinos can be discounted, as they interact only weakly with matter and are not considered to contribute to heating effects.

3. CALCULATION OF NUCLIDE HEATING

In order to determine the total energy emitted by a decaying radioactive isotope, we must consider all possible decay routes that emit particles, except neutrinos, or photons. Browne *et al*[1] have published a table of experimental values for the average energy released, per disintegration, for a range of radioactive isotopes; they consider electromagnetic radiation, α-particles, electrons and positrons. Summing the average energies per disintegration, for all of these radiation types, gives the total average energy per disintegration that is available for conversion to heat.

Average energies emitted for a range of isotopes are listed in the Table of Radioactive Isotopes in units of keV. The total energy has been converted to power using the following relationships:

1 keV	=	1.60×10^{-16} J
1 W	=	1 Js^{-1}
1 Bq	=	1 disintegration per second
1Ci	=	3.7×10^{10} Bq

$\therefore$ Power	=	1.60×10^{-16} WBq^{-1}
	$\equiv$	0.160 $mWTBq^{-1}$
	$\equiv$	5.92×10^{-3} $mWCi^{-1}$

4. REFERENCES

Table of Radioactive Isotopes, E Browne & R B Firestone (ed Virginia S Shirley), John Wiley & Sons, 1986.

Average Energies and Power Dissipation

Nuclide	Symbol	Half-Life	Average Energy Per Disintegration / keV					Power Dissipation	
			alpha	electron	positron	e.m	Total	mW / Ci	mW / TBq
Actinium-227	^{227}Ac	21.77 yr	67.3	12.5		0.168	80	0.47	13
Americium-241	^{241}Am	432.7 yr	5480	30.4		28.7	5539	32.79	886
Americium-243	^{243}Am	7380 yr	5270			48.1	5318	31.48	851
Antimony-122	^{122}Sb	2.70 dy		566		434	1000	5.92	160
Antimony-124	^{124}Sb	60.20 dy		390		1850	2240	13.26	358
Bismuth-210	^{210}Bi	5.013 dy		389		0.45	389	2.31	62
Bismuth-214	^{214}Bi	19.9 min	1.43	662		1510	2173	12.87	348
Cadmium-109	^{109}Cd	1.267 yr		81.3		26	107	0.64	17
Caesium-134	^{134}Cs	2.062 yr		164		1550	1714	10.15	274
Caesium-137	^{137}Cs	30.0 yr		250		566	816	4.83	131
Californium-252	^{252}Cf	2.64 yr	5930	5.14		1.14	5936	35.14	950
Cobalt-56	^{56}Co	77.7 dy		3.6	120	3580	3704	21.93	593
Cobalt-57	^{57}Co	271.77 dy		17.6		125	143	0.84	23
Cobalt-58	^{58}Co	70.92 dy		3.6	30	977	1011	5.98	162
Cobalt-60	^{60}Co	5.271 yr		96		2500	2596	15.37	415
Curium-242	^{242}Cm	162.9 dy	6040	8.95		1.75	6051	35.82	968
Curium-244	^{244}Cm	18.11 yr	5800			1.6	5802	34.35	928
Europium-152	^{152}Eu	13.33 yr		127	8.70E-02	1160	1287	7.62	206
Europium-154	^{154}Eu	8.8 yr		279		1250	1529	9.05	245
Europium-155	^{155}Eu	4.96 yr		65		63	128	0.76	20
Europium-156	^{156}Eu	15.2 dy		425		1330	1755	10.39	281
Gadolinium-153	^{153}Gd	241.6 dy		39.9		102	142	0.84	23
Gold-198	^{198}Au	2.6935 dy		421		403	824	4.88	132
Hydrogen-3	^{3}H	12.3 yr		5.7		1.12E-04	6	0.03	1
Iodine-125	^{125}I	60.1 dy		17.9		42.4	60	0.36	10
Iodine-131	^{131}I	8.04 dy		192		382	574	3.40	92
Iridium-192	^{192}Ir	73.83 dy		216		813	1029	6.09	165
Iridium-194	^{194}Ir	19.15 hr		811		92	903	5.35	144
Iron-59	^{59}Fe	44.5 dy		118		1190	1308	7.74	209
Krypton-85	^{85}Kr	10.72 yr		251		2.4	253	1.50	41
Lead-201	^{201}Pb	9.33 hr		60.9	9.70E-02	760	821	4.86	131
Lead-210	^{210}Pb	22.3 yr		34.2		4.67	39	0.23	6
Lead-214	^{214}Pb	27 min		294		250	544	3.22	87
Molybdenum-99	^{99}Mo	2.7477 dy		408		273	681	4.03	109
Neptunium-237	^{237}Np	2.14E06 yr	4760	64		32.7	4857	28.75	777
Phosphorus-32	^{32}P	14.282 dy		695		1.18	696	4.12	111

Nuclide	Symbol	Half-Life	Average Energy Per Disintegration / keV					Power Dissipation	
			alpha	electron	positron	e.m	Total	mW / Ci	mW / TBq
Plutonium-238	^{238}Pu	87.7 yr	5490	9.92		1.76	5502	32.57	880
Plutonium-239	^{239}Pu	2.411E+04 yr	5100			6.60E-02	5100	30.19	816
Plutonium-240	^{240}Pu	6.54E+03 yr	5160			2.86E-02	5160	30.55	826
Plutonium-241	^{241}Pu	14.4 yr	0.118	5.2		1.46E-03	5	0.03	1
Polonium-210	^{210}Po	138.376 dy	5300				5300	31.38	848
Polonium-214	^{214}Po	163.7 ms	7690			8.30E-02	7690	45.53	1230
Polonium-218	^{218}Po	3.11 min	6000				6000	35.52	960
Promethium-147	^{147}Pm	2.6234 yr		62		1.86E-02	62	0.37	10
Protactinium-231	^{231}Pa	3.28E+04 yr	4920	48		39.9	5008	29.65	801
Radium-226	^{226}Ra	1.60E+03 yr	4770	3.53		6.74	4780	28.30	765
Radon-222	^{222}Rn	3.825 dy	5490				5490	32.50	878
Samarium-151	^{151}Sm	90 yr		125		6.71E-02	125	0.74	20
Selenium-75	^{75}Se	119.77 dy		14.2		392	406	2.40	65
Silver-110m	^{110}Ag	249.76 dy		75.5		2740	2816	16.67	450
Sodium-24	^{24}Na	14.659 hr		554		4120	4674	27.67	748
Strontium-90	^{90}Sr	28.5 yr		196		0.124	196	1.16	31
Sulphur-35	^{35}S	87.5 dy		48.6		8.60E-03	49	0.29	8
Technetium-99m	^{99}Tc	6.006 hr		14.2		124	138	0.82	22
Tellurium-131m	^{131}Te	1.2 dy		52.3		1420	1472	8.72	236
Thorium-228	^{228}Th	1.913 yr	5400	20.1		3.4	5424	32.11	868
Thorium-230	^{230}Th	7.54E+04 yr	4660			0.371	4660	27.59	746
Thulium-170	^{170}Tm	128.6 dy		330		5.73	336	1.99	54
Tin-119m	^{119}Sn	293 dy		78.3		11.4	90	0.53	14
Tritium	See Hydrogen-3						0	0.00	0
Uranium-233	^{233}U	1.59E+05 yr	4810	5.5		1.29	4817	28.52	771
Uranium-235	^{235}U	7.04E+08 yr	4380	42		156	4578	27.10	732
Uranium-238	^{238}U	4.468E+09 yr	4190	9.5		1.3	4201	24.87	672
Ytterbium-169	^{169}Yb	32.022 dy		112		312	424	2.51	68