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Isotopic compositions of the elements 2009 (IUPAC Technical Report)*

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Abstract: The Commission on Isotopic Abundances and Atomic Weights (CIAAW) of the International Union of Pure and Applied Chemistry (IUPAC) completed its last update of the isotopic compositions of the elements as determined by isotope-ratio mass spectrometry in 2009. That update involved a critical evaluation of the published literature and forms the basis of the table of the isotopic compositions of the elements (TICE) presented here. For each element, TICE includes evaluated data from the "best measurement" of the isotope abundances in a single sample, along with a set of representative isotope abundances and uncertainties that accommodate known variations in normal terrestrial materials. The representative isotope abundances and uncertainties generally are consistent with the standard atomic weight of the element $A_r(E)$ and its uncertainty $U[A_r(E)]$ recommended by CIAAW in 2007.

Keywords: atomic weights; critical evaluation; elements; isotopic composition; isotope abundance; IUPAC Inorganic Chemistry Division; uncertainty.

INTRODUCTION

The Commission on Isotopic Abundances and Atomic Weights (CIAAW) of the International Union of Pure and Applied Chemistry (IUPAC) has provided regular assessments of the standard atomic weights and isotopic compositions of the elements [1]. CIAAW has evaluated the isotopic composition of each element by examining carefully the most accurate and precise isotope-abundance measurements of the element in selected samples through its Subcommittee for Isotopic Abundance Measurements (SIAM), and by compiling evidence for known variations in the isotope abundances of the element in normal terrestrial materials, through its Subcommittee on Natural Isotopic Fractionation (SNIF). By "normal", CIAAW refers to terrestrial occurrences that satisfy the following criterion:

> The material is a reasonably possible source for this element or its compounds in commerce, for industry or science; the material is not itself studied for some extraordinary anomaly and its isotopic composition has not been modified significantly in a geologically brief period. [2]

The results of these investigations are important for a number of reasons, including the evaluated best measurements indicate the state of the metrology of isotope-abundance measurements, the best measurements provide benchmark data for isotopic reference materials, and the combination of best

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measurements and documented variations serve as the basis for the determination of the standard atomic weights of the elements. The table of the isotopic compositions of the elements was produced by CIAAW to accompany the 2007 table of standard atomic weights of the elements (TSAW) [3]. Entries in TSAW 2007 [3] are based on the atomic masses of the nuclides [4,5]. This report presents an updated table of the isotopic compositions of the elements as evaluated by SIAM and SNIF in the period July 2005 to July 2009. The previous table of the isotopic compositions of the elements was published in 2005 [6], following CIAAW deliberations in 2003.

The table of the isotopic compositions of the elements was produced by CIAAW to accompany the table of standard atomic weights of the elements [3], based on data evaluated by CIAAW published 2009. The table is intended to include data for normal terrestrial materials and does not include published values for meteoritic or other extraterrestrial materials. Additional supporting data and background information can be found in de Laeter et al. [1] and Coplen et al. [7,8]. The table consists of 9 columns, as follows:

Column l: The elements are tabulated in ascending order of atomic number (Z).

Column 2: The symbols for the elements (E) are listed using the abbreviations recommended by IUPAC.

Column 3: The mass number (A) for each isotope that can be found in normal terrestrial material.

Column 4: Range of natural variations
No data are given in this column unless a range has been reliably established (see, e.g., Coplen et al. [8]). The limits given may not include those of certain exceptional samples, which are indicated with a "g" in Column 5.

Column 5: Explanation of the annotations.
Note that the annotations apply to all isotopes of a given element.

- g geologically exceptional specimens are known in which the element has an isotopic composition outside the reported range.
- m modified isotopic compositions may be found in commercially available material that has been subjected to an undisclosed or inadvertent isotope fractionation. Substantial deviations from the listed isotopic compositions can occur (refers to column 9).
- r range in isotopic composition of normal terrestrial material prevents more precise values (for column 9) to be given. The tabulated values should be applicable to any normal material.

Column 6: The best measurement from a single terrestrial source.
The values are reproduced or calculated by CIAAW from the original literature. The uncertainties on the last digits are given in parentheses. As they are not reported in any uniform manner in the literature, "ls", "2s", or "3s" indicates l, 2, or 3 standard deviations, "P" indicates some other "uncertainty" as defined by the author, and "se" indicates standard error (standard deviation of the mean).

"C" is appended when calibrated mixtures have been used to correct the mass spectrometer for bias, giving an "absolute" result within the "uncertainty" stated in the original publication.

"F" is appended when calibrated mixtures have been used to correct for isotope fractionation but the measurement fails to fulfill all of the requirements of a "C" measurement.

"L" is appended when the linearity of the mass spectrometer has been established for the relevant abundance ratios by using synthetic mixtures of isotopes or certified reference materials.

"N" is appended when none of the above requirements are met.

Users should be aware of the following:

a) A "best measurement" is not necessarily free of systematic errors, nor is it necessarily calibrated; it is just the best measurement available.

b) If a range of isotope-abundance ratios has been established for an element, the sample used for the "best measurement" may represent any part of the range.

c) Because the data are reproduced from the literature, the sum of the isotope mole fractions may not equal 1.

Column 7: Reference for the best measurement in column 6.

Column 8: In this column are listed the isotopic reference materials that were used for the best measurements given in column 6 (with asterisk) and agencies that distribute additional isotopic reference materials (see Section "Sources of isotopic reference materials"). If no asterisk is given, the best measurement was made on a substance that was not a recognized reference material.

Column 9: Representative isotopic composition.
In this column are listed the values that, in the opinion of CIAAW, represent the isotopic composition of chemicals and/or natural materials that are likely to be encountered in the laboratory. These values generally are consistent with the standard atomic weights [3]; however, for elements with known isotope-abundance variations, they may not necessarily correspond to the best measurements. The expanded uncertainties listed in parentheses include the range of probable isotope-abundance variations among different materials as well as measurement uncertainties.

Users should be aware of the following:

a) Values in column 9 can be used to determine the average properties of the element in materials of unspecified natural terrestrial origin, but those values may not represent the most abundant materials and it is possible that no real sample exists having the exact values listed.

b) When precise work is to be undertaken, such as assessment of isotope-dependent properties, samples with precisely known isotopic compositions (such as those listed in column 8) should be used or suitable isotopic analyses should be made.

Table 1 Isotopic compositions of the elements 2009.

Z	E	Mass number	Observed range of natural variations (mole fraction)	Annotations	Best measurement from a single terrestrial source (mole fraction)	Ref.	Available reference materials[a]	Representative isotopic composition (mole fraction)
1	2	3	4	5	6	7	8	9
1	H	1	0.999 816–0.999 974	g,m,r	0.999 844 26(5) 2s C	[9]	VSMOW*	0.999 885(70)
		2	0.000 026–0.000 184		0.000 155 74(5)		IAEA	0.000 115(70)[b]
							NIST	
2	He	3	4.6×10^{-10}–0.000 041	g,r	0.000 001 343(13) 1s C	[10]	Air*	0.000 001 34(3)
		4	0.999 959–1		0.999 998 657(13)			0.999 998 66(3) (in air)
3	Li	6	0.072 25–0.077 14	g,m,r	0.075 89(24) 2s C	[11]	IRMM-016*	[0.0759(4)][c]
		7	0.922 75–0.927 86		0.924 11(24)		IAEA	[0.9241(4)]
							NIST	
							IRMM	
4	Be	9			1	[12]		1

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Table 1 (*Continued*).

Z	E	Mass number	Observed range of natural variations (mole fraction)	Annotations	Best measurement from a single terrestrial source (mole fraction)	Ref.	Available reference materials[a]	Representative isotopic composition (mole fraction)
1	2	3	4	5	6	7	8	9
5	B	10	0.189 29–0.203 86	g,m,r	0.1982(2) 2s C	[13]	IRMM-011*	0.199(7)
		11	0.796 14–0.810 71		0.8018(2)		NIST	0.801(7)
							IRMM	
							BAM	
6	C	12	0.988 53–0.990 37	g,r	0.988 922(28) P C	[14]	NBS 19*	0.9893(8)
		13	0.009 63–0.011 47		0.011 078(28)		IAEA	0.0107(8)
							NIST	
7	N	14	0.995 79–0.996 54	g,r	0.996 337(4)[d] P C	[15]	Air*	0.996 36(20)
		15	0.003 46–0.004 21		0.003 663(4)[d]		IAEA	0.003 64(20)
							NIST	
8	O	16	0.997 38–0.997 76	g,r	0.997 6206(5)[e] 1s N	[16,17]	VSMOW*	0.997 57(16)
		17	0.000 37–0.000 40		0.000 3790(9)[e]		IAEA	0.000 38(1)
		18	0.001 88–0.002 22		0.002 0004(5)[e]		NIST	0.002 05(14)
9	F	19			1	[18]		1
10	Ne	20	0.8847–0.9051	g,m	0.904 838(90) 1s C	[19]	Air*	0.9048(3)
		21	0.0027–0.0171		0.002 696(5)			0.0027(1)
		22	0.0920–0.0996		0.092 465(90)			0.0925(3)
								(in air)
11	Na	23			1	[20]		1
12	Mg	24	0.789 58–0.790 17		0.789 92(25) 2s C	[21]	NIST-	0.7899(4)
		25	0.099 96–0.100 12		0.100 03(9)		SRM980*	0.1000(1)
		26	0.109 87–0.110 30		0.110 05(19)		IRMM	0.1101(3)
13	Al	27			1	[20]		1
14	Si	28	0.922 05–0.922 41	r	0.922 2968(44) 2s C	[22]	IAEA	0.922 23(19)
		29	0.046 78–0.046 92		0.046 8316(32)		IRMM	0.046 85(8)
		30	0.030 82–0.031 02		0.030 8716(32)		NIST	0.030 92(11)
15	P	31			1	[12]		1
16	S	32	0.944 54–0.952 81	g,r	0.950 4074(88) 2s C	[23]	IAEA-S1*	0.9499(26)
		33	0.007 30–0.007 93		0.007 4869(60)		IAEA	0.0075(2)
		34	0.039 76–0.047 34		0.041 9599(66)		NIST	0.0425(24)
		36	0.000 13–0.000 19		0.000 145 79(89)		IRMM	0.0001(1)
17	Cl	35	0.756 44–0.759 23	g,m,r	0.757 71(45) 2s C	[24]	NIST-	0.7576(10)
		37	0.240 77–0.243 56		0.242 29(45)		SRM975*	0.2424(10)
							IRMM	
18	Ar	36		g,r	0.003 3361(35) 1s F	[25]	Air*	0.003 336(21)
		38			0.000 6289(12)			0.000 629(7)
		40			0.996 0350(42)			0.996 035(25)[h]
								(in air)
19	K	39			0.932 5811(292) 2s C	[26]	NIST-	0.932 581(44)
		40			0.000 116 72(41)		SRM985*	0.000 117(1)
		41			0.067 3022(292)			0.067 302(44)

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Table 1 (*Continued*).

Z	E	Mass number	Observed range of natural variations (mole fraction)	Annotations	Best measurement from a single terrestrial source (mole fraction)	Ref.	Available reference materials[a]	Representative isotopic composition (mole fraction)
1	2	3	4	5	6	7	8	9
20	Ca	40	0.969 33–0.969 47	g	0.969 41(6) 2s N	[27]	NIST-	0.969 41(156)[h]
		42	0.006 46–0.006 48		0.006 47(3)		SRM915*	0.006 47(23)
		43	0.001 35–0.001 35		0.001 35(2)			0.001 35(10)
		44	0.020 82–0.020 92		0.020 86(4)			0.020 86(110)
		46	0.000 04–0.000 04		0.000 04(1)			0.000 04(3)
		48	0.001 86–0.001 88		0.001 87(1)			0.001 87(21)
21	Sc	45			1	[28]		1
22	Ti	46			0.082 49(21) 2s C	[29]		0.0825(3)
		47			0.074 37(14)			0.0744(2)
		48			0.737 20(22)			0.7372(3)
		49			0.054 09(10)			0.0541(2)
		50			0.051 85(13)			0.0518(2)
23	V	50	0.002 487–0.002 502		0.002 497(6) 1s F	[30]		0.002 50(4)
		51	0.997 498–0.997 513		0.997 503(6)			0.997 50(4)
24	Cr	50	0.042 94–0.043 45		0.043 452(85) 2s C	[31]	NIST-	0.043 45(13)
		52	0.837 62–0.837 90		0.837 895(117)		SRM979*	0.837 89(18)
		53	0.095 01–0.095 53		0.095 006(110)		IRMM	0.095 01(17)
		54	0.023 65–0.023 91		0.023 647(48)			0.023 65(7)
25	Mn	55			1	[12]		1
26	Fe	54	0.058 37–0.058 61		0.058 45(23) 2s C	[32]	IRMM-014*	0.058 45(35)
		56	0.917 42–0.917 60		0.917 54(24)		IRMM	0.917 54(36)
		57	0.021 16–0.021 21		0.021 191(65)			0.021 19(10)
		58	0.002 81–0.002 82		0.002 819(27)			0.002 82(4)
27	Co	59			1	[12]		1
28	Ni	58		r	0.680 769(59) 2s C	[33]	NIST-	0.680 77(19)
		60			0.262 231(51)		SRM986*	0.262 23(15)
		61			0.011 399(4)			0.011 399(13)
		62			0.036 345(11)			0.036 346(40)
		64			0.009 256(6)			0.009 255(19)
29	Cu	63	0.689 83–0.693 38	r	0.691 74(20) 2s C	[34]	NIST-	0.6915(15)
		65	0.306 62–0.310 17		0.308 26(20)		SRM976*	0.3085(15)
							IRMM	
30	Zn	64		r	0.491 704(83) 2s C	[35]	IRMM-	0.4917(75)
		66			0.277 31(11)		3702*	0.2773(98)
		67			0.040 401(18)		IRMM	0.0404(16)
		68			0.184 483(69)			0.1845(63)
		70			0.006 106(11)			0.0061(10)
31	Ga	69			0.601 079(62) 2s C	[36]	NIST-	0.601 08(9)
		71			0.398 921(62)		SRM994*	0.398 92(9)

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Table 1 (*Continued*).

Z	E	Mass number	Observed range of natural variations (mole fraction)	Annotations	Best measurement from a single terrestrial source (mole fraction)	Ref.	Available reference materials[a]	Representative isotopic composition (mole fraction)
1	2	3	4	5	6	7	8	9
32	Ge	70			0.205 69(90) 1s C	[37]		0.2057(27)
		72			0.2745(11)			0.2745(32)
		73			0.077 50(40)			0.0775(12)
		74			0.365 03(67)			0.3650(20)
		76			0.077 31(40)			0.0773(12)
33	As	75			1	[12]		1
34	Se	74		r	0.008 89(3) 1s N	[38]		0.0089(4)
		76			0.093 66(18)			0.0937(29)
		77			0.076 35(10)			0.0763(16)
		78			0.237 72(20)			0.2377(28)
		80			0.496 07(17)			0.4961(41)
		82			0.087 31(10)			0.0873(22)
35	Br	79			0.506 86(26) 2s C	[39]	NIST-	0.5069(7)
		81			0.493 14(26)		SRM977*	0.4931(7)
36	Kr	78		g,m	0.003 5518(32) 2s C	[40]		0.003 55(3)
		80			0.022 8560(96)			0.022 86(10)
		82			0.115 930(62)			0.115 93(31)
		83			0.114 996(58)			0.115 00(19)
		84			0.569 877(58)			0.569 87(15)
		86			0.172 790(32)			0.172 79(41) (in air)
37	Rb	85		g	0.721 654(132) 2s C	[41]	NIST-	0.7217(2)
		87			0.278 346(132)		SRM984* IRMM	0.2783(2)
38	Sr	84	0.0055–0.0058	g,r	0.005 574(16) 2s C	[42]	NIST-	0.0056(1)
		86	0.0975–0.0999		0.098 566(34)		SRM987*	0.0986(1)
		87	0.0694–0.0714		0.070 015(26)		NIST	0.0700(1)[h]
		88	0.8229–0.8275		0.825 845(66)		IRMM	0.8258(1)
39	Y	89			1	[43]		1
40	Zr	90		g	0.514 52(9) 2s N	[44]		0.5145(40)
		91			0.112 23(12)			0.1122(5)
		92			0.171 46(7)			0.1715(8)
		94			0.1738(12)			0.1738(28)
		96			0.027 99(5)			0.0280(9)
41	Nb	93			1	[20]		1
42	Mo	92		g	0.145 25(15)[o] 1s F	[45]		0.1453(30)
		94			0.091 514(74)			0.0915(9)
		95			0.158 375(98)			0.1584(11)
		96			0.166 72(19)			0.1667(15)
		97			0.095 991(73)			0.0960(14)
		98			0.243 91(18)			0.2439(37)
		100			0.098 24(50)			0.0982(31)
43	Tc				–			–

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Table 1 (*Continued*).

Z	E	Mass number	Observed range of natural variations (mole fraction)	Annotations	Best measurement from a single terrestrial source (mole fraction)	Ref.	Available reference materials[a]	Representative isotopic composition (mole fraction)
1	2	3	4	5	6	7	8	9
44	Ru	96		g	0.055 420(1) 1s N	[46]		0.0554(14)
		98			0.018 688(2)			0.0187(3)
		99			0.127 579(6)			0.1276(14)
		100			0.125 985(4)			0.1260(7)
		101			0.170 600(10)			0.1706(2)
		102			0.315 519(11)			0.3155(14)
		104			0.186 210(11)			0.1862(27)
45	Rh	103			1	[12]		1
46	Pd	102		g	0.01020(8) 2s C	[47]		0.0102(1)
		104			0.1114(5)			0.1114(8)
		105			0.2233(5)			0.2233(8)
		106			0.2733(2)			0.2733(3)
		108			0.2646(6)			0.2646(9)
		110			0.1172(6)			0.1172(9)
47	Ag	107		g	0.518 392(51) 2s C	[48]	NIST-	0.518 39(8)
		109			0.481 608(51)		SRM978*	0.481 61(8)
48	Cd	106		g	0.0125(2) 2s F	[49]	IRMM	0.0125(6)
		108			0.0089(1)		BAM	0.0089(3)
		110			0.1249(6)			0.1249(18)
		111			0.1280(4)			0.1280(12)
		112			0.2413(7)			0.2413(21)
		113			0.1222(4)			0.1222(12)
		114			0.2873(14)			0.2873(42)
		116			0.0749(6)			0.0749(18)
49	In	113			0.042 88(5) 2s N	[50]		0.0429(5)
		115			0.957 12(5)			0.9571(5)
50	Sn	112		g	0.009 73(3) 1s C	[51,52]		0.0097(1)
		114			0.006 59(3)[f]			0.0066(1)
		115			0.003 39(3)[f]			0.0034(1)
		116			0.145 36(31)			0.1454(9)
		117			0.076 76(22)			0.0768(7)
		118			0.242 23(30)			0.2422(9)
		119			0.085 85(13)			0.0859(4)
		120			0.325 93(20)			0.3258(9)
		122			0.046 29(9)			0.0463(3)
		124			0.057 89(17)			0.0579(5)
51	Sb	121		g	0.572 13(32) 2s C	[53]		0.5721(5)
		123			0.427 87(32)			0.4279(5)
52	Te	120		g	0.000 96(1)[i] 2se N	[54]		0.0009(1)
		122			0.026 03(1)[i]			0.0255(12)
		123			0.009 08(1)[i]			0.0089(3)
		124			0.048 16(2)[i]			0.0474(14)
		125			0.071 39(2)[i]			0.0707(15)
		126			0.189 52(4)[i]			0.1884(25)
		128			0.316 87(4)[i]			0.3174(8)
		130			0.337 99(3)[i]			0.3408(62)

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Table 1 (*Continued*).

Z	E	Mass number	Observed range of natural variations (mole fraction)	Annotations	Best measurement from a single terrestrial source (mole fraction)	Ref.	Available reference materials[a]	Representative isotopic composition (mole fraction)
1	2	3	4	5	6	7	8	9
53	I	127			1	[55]		1
54	Xe	124		g,m	0.000 952(3) 3s C	[56]		0.000 952(3)
		126			0.000 890(2)			0.000 890(2)
		128			0.019 102(8)			0.019 102(8)
		129			0.264 006(82)			0.264 006(82)
		130			0.040 710(13)			0.040 710(13)
		131			0.212 324(30)			0.212 324(30)
		132			0.269 086(33)			0.269 086(33)
		134			0.104 357(21)			0.104 357(21)
		136			0.088 573(44)			0.088 573(44) (in air)
55	Cs	133			1	[20]		1
56	Ba	130			0.001 058(2) 3se F	[57]		0.001 06(1)
		132			0.001 012(2)			0.001 01(1)
		134			0.024 17(3)			0.024 17(18)
		135			0.065 92(2)			0.065 92(12)
		136			0.078 53(4)			0.078 54(24)
		137			0.112 32(4)			0.112 32(24)
		138			0.716 99(7)			0.716 98(42)
57	La	138		g	0.000 8881(24) 2s N	[58]		0.000 8881(71)
		139			0.999 1119(24)			0.999 1119(71)
58	Ce	136	0.001 85–0.001 86	g	0.001 86(1) 2s C	[59]		0.001 85(2)
		138	0.002 51–0.002 54		0.002 51(1)			0.002 51(2)[h]
		140	0.884 46–0.884 49		0.884 49(34)			0.884 50(51)
		142	0.111 14–0.111 14		0.111 14(34)			0.111 14(51)
59	Pr	141			1	[43]		1
60	Nd	142		g	0.271 53(19) 2s C	[60]		0.271 52(40)
		143			0.121 73(18)			0.121 74(26)[h]
		144			0.237 98(12)			0.237 98(19)
		145			0.082 93(7)			0.082 93(12)
		146			0.171 89(17)			0.171 89(32)
		148			0.057 56(8)			0.057 56(21)
		150			0.056 38(9)			0.056 38(28)
61	Pm				–			–
62	Sm	144		g	0.030 734(9) 2s F	[61]		0.0307(7)
		147			0.149 934(18)			0.1499(18)
		148			0.112 406(15)			0.1124(10)
		149			0.138 189(18)			0.1382(7)
		150			0.073 796(14)			0.0738(1)
		152			0.267 421(66)			0.2675(16)
		154			0.227 520(68)			0.2275(29)
63	Eu	151		g	0.478 10(42) 2se C	[62]		0.4781(6)
		153			0.521 90(42)			0.5219(6)

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Table 1 (*Continued*).

Z 1	E 2	Mass number 3	Observed range of natural variations (mole fraction) 4	Annotations 5	Best measurement from a single terrestrial source (mole fraction) 6	Ref. 7	Available reference materials[a] 8	Representative isotopic composition (mole fraction) 9
64	Gd	152		g	0.002 029(4) 2se N	[63]		0.0020(1)
		154			0.021 809(4)			0.0218(3)
		155			0.147 998(17)			0.1480(12)
		156			0.204 664(6)			0.2047(9)
		157			0.156 518(9)			0.1565(2)
		158			0.248 347(16)			0.2484(7)
		160			0.218 635(7)			0.2186(19)
65	Tb	159			1	[43]		1
66	Dy	156		g	0.000 56(2) 2s C	[64]		0.000 56(3)
		158			0.000 95(2)			0.000 95(3)
		160			0.023 29(12)			0.023 29(18)
		161			0.188 89(28)			0.188 89(42)
		162			0.254 75(24)			0.254 75(36)
		163			0.248 96(28)			0.248 96(42)
		164			0.2826(36)			0.282 60(54)
67	Ho	165			1	[43]		1
68	Er	162		g	0.001 391(30) 2s C	[65]		0.001 39(5)
		164			0.016 006(20)			0.016 01(3)
		166			0.335 014(240)			0.335 03(36)
		167			0.228 724(60)			0.228 69(9)
		168			0.269 852(120)			0.269 78(18)
		170			0.149 013(240)			0.149 10(36)
69	Tm	169			1	[43]		1
70	Yb	168		g	0.001 232(4) 2s F	[66]		0.001 23(3)
		170			0.029 82(6)			0.029 82(39)
		171			0.140 86(20)			0.140 9(14)
		172			0.216 86(19)			0.216 8(13)
		173			0.161 03(9)			0.161 03(63)
		174			0.320 25(12)			0.320 26(80)
		176			0.129 95(13)			0.129 96(83)
71	Lu	175		g	0.974 013(12) 2s N	[67]		0.974 01(13)
		176			0.025 987(12)			0.025 99(13)
72	Hf	174	0.001 619–0.001 621		0.001 620(9) 2se N	[68]		0.0016(1)
		176	0.052 06–0.052 71		0.052 604(56)			0.0526(7)[h]
		177	0.185 93–0.186 06		0.185 953(12)			0.1860(9)
		178	0.272 78–0.272 97		0.272 811(22)			0.2728(7)
		179	0.136 19–0.1363		0.136 210(9)			0.1362(2)
		180	0.350 76–0.351		0.350 802(26)			0.3508(16)
73	Ta	180			0.000 1201(8) 2s L	[69]		0.000 1201(32)
		181			0.999 8799(8)			0.999 8799(32)
74	W	180			0.001 198(2) 1s N	[70]		0.0012(1)
		182			0.264 985(49)			0.2650(16)
		183			0.143 136(6)			0.1431(4)
		184			0.306 422(13)			0.3064(2)
		186			0.284 259(62)			0.2843(19)

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Table 1 (*Continued*).

Z	E	Mass number	Observed range of natural variations (mole fraction)	Annotations	Best measurement from a single terrestrial source (mole fraction)	Ref.	Available reference materials[a]	Representative isotopic composition (mole fraction)
1	2	3	4	5	6	7	8	9
75	Re	185			0.373 98(16) 2s C	[71]	NIST-SRM989*	0.3740(2)
		187			0.626 02(16)			0.6260(2)
76	Os	184		g	0.000 197(5) 1s N	[72]		0.0002(1)
		186			0.015 859(44)			0.0159(3)
		187			0.019 644(12)			0.0196(2)[h]
		188			0.132 434(19)			0.1324(8)
		189			0.161 466(16)			0.1615(5)
		190			0.262 584(14)			0.2626(2)
		192			0.407 815(22)			0.4078(19)
77	Ir	191			0.372 72(15) 1s N	[73]		0.373(2)
		193			0.627 28(15)			0.627(2)
78	Pt	190			0.000 1172(58) 1s F	[74]	IRMM-010*	0.000 12(2)
		192			0.007 818(80)			0.007 82(24)
		194			0.328 6(14)			0.328 6(40)
		195			0.337 75(79)			0.337 8(24)
		196			0.252 10(11)			0.252 1(34)
		198			0.073 56(43)			0.073 56(130)
79	Au	197			1	[12]		1
80	Hg	196			0.001 5344(19) 1s N	[75]	IRMM NRC-CNRC	0.0015(1)
		198			0.099 68(13)			0.0997(20)
		199			0.168 73(17)			0.1687(22)
		200			0.230 96(26)			0.2310(19)
		201			0.131 81(13)			0.1318(9)
		202			0.298 63(33)			0.2986(26)
		204			0.068 65(7)			0.0687(15)
81	Tl	203	0.294 94–0.295 28		0.295 24(9) 2s C	[76]	NIST-SRM997* IRMM	0.2952(1)
		205	0.704 72–0.705 06		0.704 76(9)			0.7048(1)
82	Pb	204	0.0104–0.0165	g,r	0.014 245(12) 2s C	[77]	NIST-SRM981* NIST	0.014(1)
		206	0.2084–0.2748		0.241 447(57)			0.241(1)[h]
		207	0.1762–0.2365		0.220 827(27)			0.221(1)[h]
		208	0.5128–0.5621		0.523 481(86)			0.524(1)[h]
83	Bi	209			1	[12]		1
84	Po							
85	At							
86	Rn							
87	Fr							
88	Ra							
89	Ac							
90	Th	232		g	1	[78]	IRMM	1
91	Pa	231			1	[79]		1

(*continues on next page*)

Table 1 (*Continued*).

Z	E	Mass number	Observed range of natural variations (mole fraction)	Annotations	Best measurement from a single terrestrial source (mole fraction)	Ref.	Available reference materials[a]	Representative isotopic composition (mole fraction)
1	2	3	4	5	6	7	8	9
92	U	234	0.000 050–0.000 059	g,m	0.000 054 20(42) 2s C	[80]	IRMM-184*	[0.000 054(5)]
		235	0.007 198–0.007 207		0.007 200(1)		IRMM	[0.007 204(6)][c]
		238	0.992 739–0.992 752		0.992 745(10)		NBL	[0.992 742(10)]

[a]NIST materials previously were labeled NBS. IRMM materials previously were labeled CBNM. An asterisk (*) indicates the reference material used for the best measurement (column 6).
[b]Tank hydrogen has reported ^{2}H mole fractions as low as 0.000 032.
[c]Materials depleted in ^{6}Li and ^{235}U are commercial sources of laboratory shelf reagents. In the case of Li, such samples are known to have ^{6}Li mole fractions in the range of 0.020 07 to 0.076 72, with natural materials at the higher end of this range. In the case of U, the ^{235}U mole fractions are reported to range from 0.0021 to 0.007 207, far removed from the natural value.
[d]CIAAW recommends that a value of 272 be employed for $N(^{14}\mathrm{N})/N(^{15}\mathrm{N})$ of N_2 in air where N is the number fraction, for the calculation of the mole fraction of ^{15}N from measured (^{15}N) values.
[e]The best measurement was derived by combining independent analyses of the $N(^{18}\mathrm{O}/^{16}\mathrm{O})$ and $N(^{17}\mathrm{O}/^{16}\mathrm{O})$ ratios in VSMOW.
[f]The original data for Sn were adjusted to account for possible errors due to ^{115}In contamination, and an error in the ^{114}Sn abundance.
[h]The abundance of this radiogenic isotope may vary substantially.
[i]An electron multiplier was used for the Te measurements and the measured abundances were adjusted by using a "square root of the masses" correction factor.
[o]During its biennial evaluation in 2007, SIAM found that the best measurement of the isotope-amount abundance of ^{92}Mo published in [44] is incorrect. It appears as 0.145 246(15), but based on data that appears in the paper, it should be 0.145 25(15).

SOURCES OF ISOTOPIC REFERENCE MATERIALS

IAEA
Isotope Hydrology Laboratory
International Atomic Energy Agency
Room No. G-162
P.O. Box 100
A-1400, Vienna, Austria
<http://www.iaea.org/programmes/aqcs/>

NIST
Standard Reference Materials® Program NIST
100 Bureau Drive, Stop 2300
Gaithersburg, MD 20899-2300, USA
<http://ts.nist.gov/measurementservices/referencematerials>

IRMM
European Commission
Joint Research Centre
Institute for Reference Materials and Measurements
Reference Materials Unit
ATTN: Reference Materials Sales
Retieseweg 111
B-2440 Geel, Belgium
<http://irmm.jrc.ec.europa.eu/html/reference_materials_catalogue>

NBL
U.S. Department of Energy
New Brunswick Laboratory, Bldg. 350
ATTN: Reference Materials Sales
9800 South Cass Avenue
Argonne, IL 60439, USA
<http://www.nbl.doe.gov/htm/certified_reference_materials.htm>

NRC-CNRC	Institute for National Measurement Standards National Research Council Canada, Government of Canada 1200 Montreal Road, Ottawa ON K1A 0R6, Canada <http://www.nrc-cnrc.gc.ca/inms-ienm/index.html>
BAM	BAM and European Reference Materials Programme Richard-Wilistaetter-Str. 11 12489 Berlin, Germany <http://www.webshop.bam.de/>

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