

## 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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\*Sponsoring body: IUPAC Inorganic Chemistry Division, Commission on Isotopic Abundances and Atomic Weights: see more details on page 408.

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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 1: 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, “1s”, “2s”, or “3s” indicates 1, 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 “best measurement” is not necessarily free of systematic errors, nor is it necessarily calibrated; it is just the best measurement available.
- 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.
- 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:

- 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.
- 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 <sup>a</sup>	Representative isotopic composition (mole fraction)
1	2	3	4	5	6	7	8	9
1	H	1 2	0.999 816–0.999 974 0.000 026–0.000 184	g,m,r	0.999 844 26(5) 2s C 0.000 155 74(5)	[9]	VSMOW* IAEA NIST	0.999 885(70) 0.000 115(70) <sup>b</sup>
2	He	3 4	$4.6 \times 10^{-10}$ –0.000 041 0.999 959–1	g,r	0.000 001 343(13) 1s C 0.999 998 657(13)	[10]	Air*	0.000 001 34(3) 0.999 998 66(3) (in air)
3	Li	6 7	0.072 25–0.077 14 0.922 75–0.927 86	g,m,r	0.075 89(24) 2s C 0.924 11(24)	[11]	IRMM-016* IAEA NIST IRMM	[0.0759(4)] <sup>c</sup> [0.9241(4)]
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 <sup>a</sup>	Representative isotopic composition (mole fraction)
1	2	3	4	5	6	7	8	9
5	B	10 11	0.18929–0.20386 0.79614–0.81071	g,m,r	0.1982(2) 2s C 0.8018(2)	[13]	IRMM-011* NIST IRMM BAM	0.199(7) 0.801(7)
6	C	12 13	0.98853–0.99037 0.00963–0.01147	g,r	0.988922(28) P C 0.011078(28)	[14]	NBS 19* IAEA NIST	0.9893(8) 0.0107(8)
7	N	14 15	0.99579–0.99654 0.00346–0.00421	g,r	0.996337(4) <sup>d</sup> P C 0.003663(4) <sup>d</sup>	[15]	Air* IAEA NIST	0.99636(20) 0.00364(20)
8	O	16 17 18	0.99738–0.99776 0.00037–0.00040 0.00188–0.00222	g,r	0.9976206(5) <sup>e</sup> 1s N 0.0003790(9) <sup>e</sup> 0.0020004(5) <sup>e</sup>	[16,17]	VSMOW* IAEA NIST	0.99757(16) 0.00038(1) 0.00205(14)
9	F	19			1	[18]		1
10	Ne	20 21 22	0.8847–0.9051 0.0027–0.0171 0.0920–0.0996	g,m	0.904838(90) 1s C 0.002696(5) 0.092465(90)	[19]	Air*	0.9048(3) 0.0027(1) 0.0925(3) (in air)
11	Na	23			1	[20]		1
12	Mg	24 25 26	0.78958–0.79017 0.09996–0.10012 0.10987–0.11030		0.78992(25) 2s C 0.10003(9) 0.11005(19)	[21]	NIST- SRM980* IRMM	0.7899(4) 0.1000(1) 0.1101(3)
13	Al	27			1	[20]		1
14	Si	28 29 30	0.92205–0.92241 0.04678–0.04692 0.03082–0.03102	r	0.9222968(44) 2s C 0.0468316(32) 0.0308716(32)	[22]	IAEA IRMM NIST	0.92223(19) 0.04685(8) 0.03092(11)
15	P	31			1	[12]		1
16	S	32 33 34 36	0.94454–0.95281 0.00730–0.00793 0.03976–0.04734 0.00013–0.00019	g,r	0.9504074(88) 2s C 0.0074869(60) 0.0419599(66) 0.00014579(89)	[23]	IAEA-S1* IAEA NIST IRMM	0.9499(26) 0.0075(2) 0.0425(24) 0.0001(1)
17	Cl	35 37	0.75644–0.75923 0.24077–0.24356	g,m,r	0.75771(45) 2s C 0.24229(45)	[24]	NIST- SRM975* IRMM	0.7576(10) 0.2424(10)
18	Ar	36 38 40		g,r	0.0033361(35) 1s F 0.0006289(12) 0.9960350(42)	[25]	Air*	0.003336(21) 0.000629(7) 0.996035(25) <sup>h</sup> (in air)
19	K	39 40 41			0.9325811(292) 2s C 0.00011672(41) 0.0673022(292)	[26]	NIST- SRM985*	0.932581(44) 0.000117(1) 0.067302(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 <sup>a</sup>	Representative isotopic composition (mole fraction)
1	2	3	4	5	6	7	8	9
20	Ca	40	0.96933–0.96947	g	0.96941(6)	[27]	NIST-SRM915*	0.96941(156) <sup>h</sup>
		42	0.00646–0.00648		0.00647(3)			0.00647(23)
		43	0.00135–0.00135		0.00135(2)			0.00135(10)
		44	0.02082–0.02092		0.02086(4)			0.02086(110)
		46	0.00004–0.00004		0.00004(1)			0.00004(3)
		48	0.00186–0.00188		0.00187(1)			0.00187(21)
21	Sc	45		1		[28]		1
22	Ti	46			0.08249(21)	[29]		0.0825(3)
		47			0.07437(14)		0.0744(2)	
		48			0.73720(22)		0.7372(3)	
		49			0.05409(10)		0.0541(2)	
		50			0.05185(13)		0.0518(2)	
23	V	50	0.002487–0.002502		0.002497(6)	[30]		0.00250(4)
		51	0.997498–0.997513		0.997503(6)		0.99750(4)	
24	Cr	50	0.04294–0.04345		0.043452(85)	[31]	NIST-SRM979* IRMM	0.04345(13)
		52	0.83762–0.83790		0.837895(117)			0.83789(18)
		53	0.09501–0.09553		0.095006(110)			0.09501(17)
		54	0.02365–0.02391		0.023647(48)			0.02365(7)
25	Mn	55		1		[12]		1
26	Fe	54	0.05837–0.05861		0.05845(23)	[32]	IRMM-014* IRMM	0.05845(35)
		56	0.91742–0.91760		0.91754(24)			0.91754(36)
		57	0.02116–0.02121		0.021191(65)			0.02119(10)
		58	0.00281–0.00282		0.002819(27)			0.00282(4)
27	Co	59		1		[12]		1
28	Ni	58		r	0.680769(59)	[33]	NIST-SRM986*	0.68077(19)
		60			0.262231(51)			0.26223(15)
		61			0.011399(4)			0.011399(13)
		62			0.036345(11)			0.036346(40)
		64			0.009256(6)			0.009255(19)
29	Cu	63	0.68983–0.69338	r	0.69174(20)	[34]	NIST-SRM976* IRMM	0.6915(15)
		65	0.30662–0.31017		0.30826(20)			0.3085(15)
30	Zn	64		r	0.491704(83)	[35]	IRMM-3702* IRMM	0.4917(75)
		66			0.27731(11)			0.2773(98)
		67			0.040401(18)			0.0404(16)
		68			0.184483(69)			0.1845(63)
		70			0.006106(11)			0.0061(10)
31	Ga	69			0.601079(62)	[36]	NIST-SRM994*	0.60108(9)
		71			0.398921(62)			0.39892(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 <sup>a</sup>	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-SRM977*	0.5069(7)
		81			0.493 14(26)			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-SRM984* IRMM	0.7217(2)
		87			0.278 346(132)			0.2783(2)
38	Sr	84	0.0055–0.0058	g,r	0.005 574(16) 2s C	[42]	NIST-SRM987*	0.0056(1)
		86	0.0975–0.0999		0.098 566(34)			0.0986(1)
		87	0.0694–0.0714		0.070 015(26)		NIST	0.0700(1) <sup>h</sup>
		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			0.173 8(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) <sup>o</sup> 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 <sup>a</sup>	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]	0.518 39(8)
		109			0.481 608(51)		NIST-SRM978*	0.481 61(8)
48	Cd	106		g	0.0125(2)	2s F	[49]	0.0125(6)
		108			0.0089(1)		IRMM 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) <sup>f</sup>			0.0066(1)
		115			0.003 39(3) <sup>f</sup>			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) <sup>i</sup>	2se N	[54]	0.0009(1)
		122			0.026 03(1) <sup>i</sup>			0.0255(12)
		123			0.009 08(1) <sup>i</sup>			0.0089(3)
		124			0.048 16(2) <sup>i</sup>			0.0474(14)
		125			0.071 39(2) <sup>i</sup>			0.0707(15)
		126			0.189 52(4) <sup>i</sup>			0.1884(25)
		128			0.316 87(4) <sup>i</sup>			0.3174(8)
		130			0.337 99(3) <sup>i</sup>			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 <sup>a</sup>	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	0.000952(3) 3s C	[56]		0.000952(3)
		126			0.000890(2)			0.000890(2)
		128			0.019102(8)			0.019102(8)
		129			0.264006(82)			0.264006(82)
		130			0.040710(13)			0.040710(13)
		131			0.212324(30)			0.212324(30)
		132			0.269086(33)			0.269086(33)
		134			0.104357(21)			0.104357(21)
		136			0.088573(44)			0.088573(44) (in air)
55	Cs	133			1	[20]		1
56	Ba	130			0.001058(2) 3se F	[57]		0.00106(1)
		132			0.001012(2)			0.00101(1)
		134			0.02417(3)			0.02417(18)
		135			0.06592(2)			0.06592(12)
		136			0.07853(4)			0.07854(24)
		137			0.11232(4)			0.11232(24)
		138			0.71699(7)			0.71698(42)
57	La	138		g	0.0008881(24) 2s N	[58]		0.0008881(71)
		139			0.9991119(24)			0.9991119(71)
58	Ce	136	0.00185–0.00186	g	0.00186(1) 2s C	[59]		0.00185(2)
		138	0.00251–0.00254		0.00251(1)			0.00251(2) <sup>h</sup>
		140	0.88446–0.88449		0.88449(34)			0.88450(51)
		142	0.11114–0.11114		0.11114(34)			0.11114(51)
59	Pr	141			1	[43]		1
60	Nd	142		g	0.27153(19) 2s C	[60]		0.27152(40)
		143			0.12173(18)			0.12174(26) <sup>h</sup>
		144			0.23798(12)			0.23798(19)
		145			0.08293(7)			0.08293(12)
		146			0.17189(17)			0.17189(32)
		148			0.05756(8)			0.05756(21)
		150			0.05638(9)			0.05638(28)
61	Pm				–			–
62	Sm	144		g	0.030734(9) 2s F	[61]		0.0307(7)
		147			0.149934(18)			0.1499(18)
		148			0.112406(15)			0.1124(10)
		149			0.138189(18)			0.1382(7)
		150			0.073796(14)			0.0738(1)
		152			0.267421(66)			0.2675(16)
		154			0.227520(68)			0.2275(29)
63	Eu	151		g	0.47810(42) 2se C	[62]		0.4781(6)
		153			0.52190(42)			0.5219(6)

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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 <sup>a</sup>	Representative isotopic composition (mole fraction)
1	2	3	4	5	6	7	8	9
64	Gd	152		g	0.002029(4) 2se N	[63]		0.0020(1)
		154			0.021809(4)			0.0218(3)
		155			0.147998(17)			0.1480(12)
		156			0.204664(6)			0.2047(9)
		157			0.156518(9)			0.1565(2)
		158			0.248347(16)			0.2484(7)
		160			0.218635(7)			0.2186(19)
65	Tb	159			1	[43]		1
66	Dy	156		g	0.00056(2) 2s C	[64]		0.00056(3)
		158			0.00095(2)			0.00095(3)
		160			0.02329(12)			0.02329(18)
		161			0.18889(28)			0.18889(42)
		162			0.25475(24)			0.25475(36)
		163			0.24896(28)			0.24896(42)
		164			0.2826(36)			0.28260(54)
67	Ho	165			1	[43]		1
68	Er	162		g	0.001391(30) 2s C	[65]		0.00139(5)
		164			0.016006(20)			0.01601(3)
		166			0.335014(240)			0.33503(36)
		167			0.228724(60)			0.22869(9)
		168			0.269852(120)			0.26978(18)
		170			0.149013(240)			0.14910(36)
69	Tm	169			1	[43]		1
70	Yb	168		g	0.001232(4) 2s F	[66]		0.00123(3)
		170			0.02982(6)			0.02982(39)
		171			0.14086(20)			0.1409(14)
		172			0.21686(19)			0.2168(13)
		173			0.16103(9)			0.16103(63)
		174			0.32025(12)			0.32026(80)
		176			0.12995(13)			0.12996(83)
71	Lu	175		g	0.974013(12) 2s N	[67]		0.97401(13)
		176			0.025987(12)			0.02599(13)
72	Hf	174	0.001619–0.001621		0.001620(9) 2se N	[68]		0.0016(1)
		176	0.05206–0.05271		0.052604(56)			0.0526(7) <sup>h</sup>
		177	0.18593–0.18606		0.185953(12)			0.1860(9)
		178	0.27278–0.27297		0.272811(22)			0.2728(7)
		179	0.13619–0.1363		0.136210(9)			0.1362(2)
		180	0.35076–0.351		0.350802(26)			0.3508(16)
73	Ta	180			0.0001201(8) 2s L	[69]		0.0001201(32)
		181			0.9998799(8)			0.9998799(32)
74	W	180			0.001198(2) 1s N	[70]		0.0012(1)
		182			0.264985(49)			0.2650(16)
		183			0.143136(6)			0.1431(4)
		184			0.306422(13)			0.3064(2)
		186			0.284259(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 <sup>a</sup>	Representative isotopic composition (mole fraction)
1	2	3	4	5	6	7	8	9
75	Re	185 187			0.373 98(16) 2s C 0.626 02(16)	[71]	NIST-SRM989*	0.3740(2) 0.6260(2)
76	Os	184 186 187 188 189 190 192		g	0.000 197(5) 1s N 0.015 859(44) 0.019 644(12) 0.132 434(19) 0.161 466(16) 0.262 584(14) 0.407 815(22)	[72]		0.0002(1) 0.0159(3) 0.0196(2) <sup>h</sup> 0.1324(8) 0.1615(5) 0.2626(2) 0.4078(19)
77	Ir	191 193			0.372 72(15) 1s N 0.627 28(15)	[73]		0.373(2) 0.627(2)
78	Pt	190 192 194 195 196 198			0.000 1172(58) 1s F 0.007 818(80) 0.328 6(14) 0.337 75(79) 0.252 10(11) 0.073 56(43)	[74]	IRMM-010*	0.000 12(2) 0.007 82(24) 0.328 6(40) 0.337 8(24) 0.252 1(34) 0.073 56(130)
79	Au	197			1	[12]		1
80	Hg	196 198 199 200 201 202 204			0.001 5344(19) 1s N 0.099 68(13) 0.168 73(17) 0.230 96(26) 0.131 81(13) 0.298 63(33) 0.068 65(7)	[75]	IRMM NRC-CNRC	0.0015(1) 0.0997(20) 0.1687(22) 0.2310(19) 0.1318(9) 0.2986(26) 0.0687(15)
81	Tl	203 205	0.294 94–0.295 28 0.704 72–0.705 06		0.295 24(9) 2s C 0.704 76(9)	[76]	NIST-SRM997* IRMM	0.2952(1) 0.7048(1)
82	Pb	204 206 207 208	0.0104–0.0165 0.2084–0.2748 0.1762–0.2365 0.5128–0.5621	g,r	0.014 245(12) 2s C 0.241 447(57) 0.220 827(27) 0.523 481(86)	[77]	NIST-SRM981* NIST	0.014(1) 0.241(1) <sup>h</sup> 0.221(1) <sup>h</sup> 0.524(1) <sup>h</sup>
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

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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 <sup>a</sup>	Representative isotopic composition (mole fraction)
1	2	3	4	5	6	7	8	9
92	U	234	0.000050–0.000059	g,m	0.00005420(42) 2s C	[80]	IRMM-184*	[0.000054(5)]
		235	0.007198–0.007207		0.007200(1)		IRMM	[0.007204(6)] <sup>c</sup>
		238	0.992739–0.992752		0.992745(10)		NBL	[0.992742(10)]

<sup>a</sup>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).

<sup>b</sup>Tank hydrogen has reported <sup>2</sup>H mole fractions as low as 0.000032.

<sup>c</sup>Materials depleted in <sup>6</sup>Li and <sup>235</sup>U are commercial sources of laboratory shelf reagents. In the case of Li, such samples are known to have <sup>6</sup>Li mole fractions in the range of 0.02007 to 0.07672, with natural materials at the higher end of this range. In the case of U, the <sup>235</sup>U mole fractions are reported to range from 0.0021 to 0.007207, far removed from the natural value.

<sup>d</sup>CIAAW recommends that a value of 272 be employed for  $N(^{14}\text{N})/N(^{15}\text{N})$  of N<sub>2</sub> in air where  $N$  is the number fraction, for the calculation of the mole fraction of <sup>15</sup>N from measured (<sup>15</sup>N) values.

<sup>e</sup>The best measurement was derived by combining independent analyses of the  $N(^{18}\text{O}/^{16}\text{O})$  and  $N(^{17}\text{O}/^{16}\text{O})$  ratios in VSMOW.

<sup>f</sup>The original data for Sn were adjusted to account for possible errors due to <sup>115</sup>In contamination, and an error in the <sup>114</sup>Sn abundance.

<sup>h</sup>The abundance of this radiogenic isotope may vary substantially.

<sup>i</sup>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.

<sup>o</sup>During its biennial evaluation in 2007, SIAM found that the best measurement of the isotope-amount abundance of <sup>92</sup>Mo published in [44] is incorrect. It appears as 0.145246(15), but based on data that appears in the paper, it should be 0.14525(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 < <a href="http://www.iaea.org/programmes/aqcs/">http://www.iaea.org/programmes/aqcs/</a> >
NIST	Standard Reference Materials <sup>®</sup> Program NIST 100 Bureau Drive, Stop 2300 Gaithersburg, MD 20899-2300, USA < <a href="http://ts.nist.gov/measurementservices/referencematerials/">http://ts.nist.gov/measurementservices/referencematerials/</a> >
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 < <a href="http://irmm.jrc.ec.europa.eu/html/reference_materials_catalogue/">http://irmm.jrc.ec.europa.eu/html/reference_materials_catalogue/</a> >
NBL	U.S. Department of Energy New Brunswick Laboratory, Bldg. 350 ATTN: Reference Materials Sales 9800 South Cass Avenue Argonne, IL 60439, USA < <a href="http://www.nbl.doe.gov/htm/certified_reference_materials.htm">http://www.nbl.doe.gov/htm/certified_reference_materials.htm</a> >

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

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