

Application of ICP-MS to outlet water control in the Llobregat and Ter drinking water treatment plants

Abstract

Analytical characteristics of ICP-MS render this technique as suitable for drinking water treatment plant (DWTP) monitoring of those inorganic parameters usually included in the regulations relative to human drinking water quality (e.g., European Directive 98/83/EC), such as B, Al, Cr, Mn, Fe, Ni, Cu, As, Se, Cd, Sb and Pb. Furthermore, ICP-MS multielemental capacity allows to perform an exhaustive monitoring of other elements of interest for the DWTP's themselves, e.g., treatment processes control, or since the point of view of the local regional hydrochemical features (natural or anthropogenic). This work demonstrates this application in terms of limits of detection, precision and accuracy to the Llobregat and Ter DWTP's in north-eastern Spain, which supply water to more than four million inhabitants in the Barcelona and metropolitan area. The elements studied have been Ca, Mg, Na, K, Si, Li, Be, B, Al, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Y, Zr, Nb, Mo, Ag, Cd, Sn, Sb, Te, I, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, W, Pt, Au, Hg, Tl, Pb, Bi, Th and U.

Keywords: ICP-MS, trace elements, drinking water treatment plant, DWTP, Llobregat, Ter.

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Received February, 7th, 2000 / Accepted September, 4th, 2000

Introduction

The concentration of some inorganic parameters is a restrictive factor for drinking water quality, generally as consequence of their effects on the health. This fact makes necessary its regulation and monitoring [1-4].

The development of inductively coupled plasma - mass spectrometry (ICP-MS) has been one of the most important contributions to inorganic analytical chemistry in the last quarter of XX century. The first commercial instruments were installed in 1983, and its application to different problems related to water analysis has been shown by different authors [5-14], including the application to DWTP mainly related to specific elements as Al, Cu and B [15]. The analytical characteristics of this technique offer many possibilities for water analysis, mainly in relation to their multielemental character and excellent limits of detection. Furthermore, it can be coupled easily with other analytical techniques, e.g., liquid chromatography, hydride generation and electrothermal vaporization.

The aim of this work is to study the suitability of ICP-MS for outlet water control at the drinking water treatment plants (DWTP's) of Llobregat and Ter, which are located 30 and 35 km, NW and NE respectively, of the city of Barcelona (Catalonia, NE Spain). ATLL, a public company of the Autonomous Government of Catalonia (NE of Spain) has been appointed to manage the system. More than four millions of inhabitants in Barcelona and surrounding areas are supplied for both DWTP's. The Llobregat plant process 2.5 m³/s of water per day, while the Ter plant treats an average of 8.0 m³/s per day.

The two plants are representative of the treatment processes usually carried out in water purification: prechlorination, flocculation-sedimentation, filtration and postchlorination. The main difference in the design of both DWTP's lies in the filtration step. Thus, while only GAC (granular activated carbon) filtration is used in the Ter plant, the Llobregat plant uses sand followed by GAC filtration. Furthermore, because the Llobregat plant takes the water directly from river flow, has a

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sand sedimentation system as the first step in the treatment process. In spite of the similar behaviour of inorganic parameters in both DWTP, the different composition of the inlet waters determines the observed discrepancies in the finished water quality [16-21]. The main difference is due to the higher salinity of Llobregat River water. This river drains the Cardona - Súrria - Sallent - Balsareny Mining District, where important saline deposits are mined since the twenties. On the other hand, the high quality of the Ter DWTP raw water is taken from the Sau-Susqueda-Pasteral reservoir system, with a total capacity of 400 hm³, which regulates the hydrological basin of the River Ter.

Experimental procedure

Samples of 100 mL of finished (postchlorinated) water were sampled monthly since 1996 up to 1998 at each DWTP in pre-cleaned high density polyethylene (HDPE) containers [22]. Samples were acidified (1% v/v HNO₃), and stored at 4 °C until analysis.

In each sample were determined by ICP-MS: Ca, Mg, Na, K, Si, Cl, S, Li, Be, B, Al, P, Ti, V, Cr, Fe, Mn, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Y, Zr, Nb, Mo, Ag, Cd, Sn, Sb, Te, I, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, W, Pt, Au, Hg, Tl, Pb, Bi, Th and U. ICP-MS allows determine Cl and S concentrations, and given the physico-chemical conditions of the raw waters studied it is assumed that they can be expressed as Cl⁻ and SO₄²⁻. Anoxic conditions or extreme pH in water may invalidate this assumption.

Reagents: Nitric acid of analytical grade (Merck) was used to prepare samples and standards, and to clean the glassware. Purified water of 18.2 MW cm⁻¹ type Milli QPlus was used for preparation and/or dilution of solutions, if necessary. Mixed-element standard solutions were prepared from 1,000 mg L⁻¹ single-element standard solutions (Aldrich), from solid salts (NaCl, KBr and KI from Merck) for Na, Cl, Br and I, and from sulphuric acid (Merck) for S.

The ICP-MS equipment used was VG PlasmaQuad PQ2+ (VG Elemental Ltd., Thermo Group, Manchester, UK), equipped with a Gilson Minipuls 3 peristaltic pump (Gilson Medical Electronics, WI, USA) with an uptake rate of 0.9 mL min⁻¹, a De Galan (V-Groove) pneumatic nebulizer and a Scott-Fassel torch. The operation conditions were RF power, 1350 W; coolant gas flow, 14 L min⁻¹; auxiliary gas flow, 1 L min⁻¹; and nebulizer gas flow, 0.95 L min⁻¹.

The analytes to be determined were grouped in three sets, which were processed sequentially, in order to maximize the performance of the ICP-MS equipment. Set 1: Na, Mg, Si, S, Cl, K, and Ca; Set 2: B, Al, P, Cr, Fe, Mn, Ni, Cu, Zn, As, Se, Ag, Cd, Sb, Ba, Hg, and Pb; and Set 3: Li,

Be, Ti, V, Co, Ga, Ge, Br, Rb, Sr, Y, Zr, Nb, Mo, Sn, Te, I, Cs, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, W, Pt, Au, Tl, Bi, Th, and U. Timing of 90-10-90 seconds of uptake-acquisition-washout for Set 1, and 90-60-90 seconds for sets 2 and 3 were determined to be adequate for these procedures. The total actual time spent by each sample was 3.45 and 4.45 minutes for Set 1, and sets 2 and 3, respectively.

Dwell times of each isotope monitored are summarised in Tables 1 and 2. Acquisition mode has been "peak jumping" in all cases. Three points per spectral peak has been measured. These isotopes, except for 51V and 75As, are free of interferences for the purpose of this work. Interferences of Cl on 51V and 75As has been

Table 1. Analytical characteristics for ICP-MS determination of Sets 1 and 2 of elements in water. Comparison of precision of this work with the values indicated in the European Directive 98/83/EC [4]. LOD, limit of detection.

	Measured Mass	Dwell time (ms)	LOD (5s) ¹	Precision This work 2RSD (%) (n=10) ² %	Precision Directive 98/83/EC Parametric value
Set 1 (concentrations expressed in mg L ⁻¹)					
Na	23	0.05	0.01	9.3	10
Mg	25	1	0.001	7.5	
Si	29	1	0.004	16.5	
SO ₄ ²⁻	34 ³	10	0.82	14.4	10
Cl	35	10	0.13	9.7	10
K	39	1	0.03	11.5	
Ca	44	1	0.02	8.8	
Set 2 (concentrations expressed in µg L ⁻¹)					
B	11	10	2.30	4.6	10
Al	27	5	3.75	8.8	10
P	31	10	4.11	11.1	
Cr	52	10	0.23	9.4	10
Fe	55	10	10.9	9.1	10
Mn	54	10	0.16	9.4	10
Ni	60	10	0.21	7.3	10
Cu	65	10	0.17	8.9	10
Zn	66	10	1.91	9.2	
As	75	10	0.42	9.1	10
Se	78	10	1.94	9.7	10
Ag	107	10	0.07	25.1	
Cd	111	10	0.03	7.9	10
Sb	121	10	0.02	12.2	25
Ba	138	10	0.09	6.0	
Hg	202	10	0.03	9.4	10
Pb	208	10	0.04	7.2	10

¹ Based on five times standard deviation for ten replicate determinations of the reagent blank.

² Relative standard deviation (RSD) based on 10 replicate determinations of a tape water sample.

³ Determined as sulphur and expressed as SO₄²⁻.

corrected using experimental equations (i.e., $51V = [51\text{Peak} - 3.108] 53\text{Peak} + 0.3524 52\text{Peak}$), and $75As = [75\text{Peak} - 3.1278 77\text{Peak} + 1.0177 78\text{Peak}]$.

Indium ($10 \mu\text{g L}^{-1}$) was added to all of the solutions, including the calibration

blank. The isotope 115In was used as internal standard during the analytical process to correct for time-dependent parameters such as changes in sample matrix, mainly related to water salinity in the present case.

Table 2. Analytical characteristics for ICP-MS determination of Set 3 of elements in water. Comparison of precision of this work with the values indicated in the European Directive 98/83/EC [4]. LOD, limit of detection.

	Measured Mass	Dwell time (ms)	LOD (5s) ¹	Precision	Precision
				This work	Directive 98/83/EC
Set 3 (concentrations expressed in $\mu\text{g L}^{-1}$)					
				2RSD (%) (n=10) ² %	Parametric value
Li	7	20	0.036	10.1	
Be	9	20	0.014	7.8	
Ti	49	20	0.28	14.7	
V	51	20	0.066	8.1	
Co	59	20	0.015	6.3	
Ga	71	20	0.012	12.5	
Ge	74	20	0.015	5.2	
Br	81	10	8.2	23.6	25
Rb	85	20	0.032	10.6	
Sr	88	1	0.094	10.6	
Y	89	20	0.005	5.5	
Zr	90	20	0.009	5.0	
Nb	93	20	0.21	4.7	
Mo	98	20	0.027	10.1	
Sn	120	20	0.26	15.9	
Te	125	20	0.23	9.6	
I	127	20	0.90	22.8	
Cs	133	20	0.018	12.2	
La	139	20	0.006	3.3	
Ce	140	20	0.005	5.2	
Pr	141	20	0.002	6.6	
Nd	146	20	0.007	5.6	
Sm	147	20	0.013	8.5	
Eu	151	20	0.005	9.2	
Gd	157	20	0.014	4.4	
Tb	159	20	0.002	7.2	
Dy	162	20	0.007	2.5	
Ho	165	20	0.003	2.4	
Er	166	20	0.008	6.9	
Tm	169	20	0.003	4.0	
Yb	174	20	0.008	5.3	
Lu	175	20	0.002	4.4	
Hf	178	20	0.021	15.9	
Ta	181	20	0.033	11.7	
W	182	20	0.064	6.4	
Pt	195	20	0.037	19.3	
Au	197	20	0.043	9.0	
Tl	203	20	0.014	10.5	
Bi	209	20	0.080	13.8	
Th	232	20	0.007	22.5	
U	238	20	0.009	11.5	

¹ Based on five times standard deviation for ten replicate determinations of the reagent blank.

² Relative standard deviation (RSD) based on 10 replicate determinations of a tap water sample.

An in-house standard was analysed as monitor every ten samples. Laboratory tap water spiked with $0.1 \mu\text{g L}^{-1}$ of Be, Ga, Ge, Y, Zr, Nb, Ag, Cd, Te, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, W, Pt, Au, Tl and Bi, and $1.0 \mu\text{g L}^{-1}$ of Hg, and acidified with HNO_3 (1% v/v), was used to monitor the precision. The standard reference materials 'High carbonate content water - CRM 616' and 'Low carbonate content water - CRM 617' from European Commission (Brussels, Belgium), 'Riverine Water Reference Material for Trace Metals - SLRS-4' from National Research Council of Canada, 'Trace elements in water - 1643d' from National Institute for Standards and Technology's (Gaithersburg, USA), and the granite AC-E from GIT-IWG (Nancy, France) was used for accuracy verification. For the rock standard AC-E, 0.1 g of the solid sample was digested using a mixture of $\text{HF} + \text{HClO}_4 + \text{HNO}_3$ (5+2.5+2.5, v/v), evaporated twice to incipient dryness with addition of HNO_3 , and finally made up to 100 mL with 1% (v/v) HNO_3 . Precision and accuracy have been estimated from ten analyses carried out on different days under routine working conditions (Tables 1 to 4).

Results and discussion

Tables 1 to 4 show the analytical characteristics of the described analytical procedure. Limits of detection and precision are in Tables 1 and 2. Accuracy is in Tables 3 and 4. The results obtained in the DWTP's of Llobregat and Ter are in Table 5.

The worse limits of detection have been obtained for those elements occurring as major elements in natural water, e.g., S, Cl, and K (Table 1). Thus, this fact is not a restrictive feature for their analysis by ICP-MS. Nevertheless, the precision for some of these parameters exceeds the value of 10%, like in the case of SO_4^{2-} , which is the maximum precision level indicated for SO_4^{2-} in the Directive 98/83/EC [4]. Although their accuracy is lower than 5%, the precision of the analytical procedure developed is not enough to arise the levels of precision regulated for parameters like SO_4^{2-} . ICP-

Table 3. Accuracy for ICP-MS determination of Sets 1 and 2 of elements in water. Comparison of accuracy of this work with the values indicated in the European Directive 98/83/EC [4]

	Accuracy (%) SLRS-4 (n=10)	Accuracy (%) NIST 1643d (n=10)	Accuracy (%) AC-E (n=10)	Accuracy (%) BCR 616 (n=10)	Accuracy (%) BCR 617 (n=10)	Accuracy (%) Others ¹ (n=10) %	Accuracy (%) Directive 98/83/EC Parametric value
Set 1 (concentrations expressed in mg L ⁻¹)							
Na	1.4	0.71		0.98	2.7		10
Mg	0.68	2.7		0.42	0.41		
Si		2.1					
SO ₄ ²⁻				2.1	0.38		10
Cl				0.60	0.76		10
K	3.7	0.88		3.5	4.1		
Ca	0.77	1.3		0.52	0.68		
Set 2 (concentrations expressed in µg L ⁻¹)							
B						3.4	10
Al	0.42	3.7					10
P							
Cr		6.4	7.1				10
Fe	1.3	1.5					10
Mn	2.0	1.4					10
Ni	6.1	2.3	8.0				10
Cu	7.1	2.6	4.0				10
Zn	4.5	5.1	3.6				10
As	1.4	5.6					10
Se		3.1					10
Ag		10.1					
Cd	6.7	4.6	1.7				10
Sb	5.9	2.3	2.5				25
Ba	0.60	1.2	1.5				
Hg						7.6	20
Pb	16.3	1.9	3.1				10

¹ Solution of 50 µg L⁻¹ of B from NIST951 and solution of 1 µg L⁻¹ for Hg.

AES (Inductively Coupled Plasma – Atomic Emission Spectrometry) could be a feasible alternative for these cases.

The limits of detection of minor and trace elements determined in the analytical sets 2 and 3 are in general lower than 0.100 µg L⁻¹, particularly for the elements of Set 3 (Table 2). The highest detection limits are shown by elements whose monitoring is indicated in practically all regulations on drinking water quality, being Fe > Al > B > Se > Zn and all of them higher than 1.0 µg L⁻¹. In spite of this fact, their precision and accuracy are lower than the value of 10% generally regulated [4]. Thus, the analytical

procedure can be applied to determine these parameters.

Precision is in general lower than 10% (2RSD for ten measures). Exceptions are Ag, Br, I, Th, Pt, Sn, and Hf, with precision values over 15%, and Ti, Bi, Ga, Cs, Sb, Ta, U, P, Sr, Rb, Tl, Li, and Mo, which have precision values ranging between 15 and 10% (Tables 1 and 2). Of these elements, only Br and Sb are considered in the Directive 98/83/EC [4], although the first parameter only under the form of bromate.

Accuracy is lower than 10% (Tables 3 and 4). The exception is Pb in SLRS-4 (16.28%). This unusual low accuracy value for Pb in con-

parison with the values obtained for the other standards could be related with the low concentration of this element in the standard SLRS-4 (0.086 µg L⁻¹). Taking into account the exceptionality of this case, the achieved levels of accuracy are adequate to measure all the elements regulated in the Directive 98/83/EC [4].

The Table 5 allows comparing the outlet water composition of Llobregat and Ter DWTP's with the average composition of surface waters in natural raw streams [23] and with the levels indicated in different regulations applied to drinking water. Respect to the average in streams, the main differential feature of the studied waters is the salinity. The concentration of parameters (arithmetic mean) related to salinity exceeds 10-40 times the average in streams comparing with the Llobregat plant outlet water (43 times for SO₄²⁻, 38 for Br, 36 for Cl, 23 for Na, 15 for K and Cs, and 13 for Rb). These parameters are 3 to 7 times lower in the Ter outlet waters.

The high salinity of Llobregat water is the main restriction for its use as drinking water, and in sometimes the values regulated are exceeded (e.g., Cl and Na, Table 5). In the present case, the source of the water salinity is related to the exploitation of saline minerals in deposits occurring in the upper part of the Llobregat river basin. Because salinity cannot be reduced during treatment, since eighties the brines of this exploitations are collected and conducted through a pipeline to the lower part of the river [24], to minimize its levels in the inlet water plant.

The trace elements not related with the salinity are in the same order of magnitude in the Llobregat and Ter outlet waters than in the stream average, being in general higher the concentrations in the outlet water of Llobregat plant. Representative exceptions to this general behaviour are elements like U, Se and Sb. The highest concen-

tration of U is related to uranium mineralizations in some regional geological formations. In the case of Se and Sb, the high concentration should associated with pollution processes.

Taking into account the trace elements regulated, the mean concentrations observed of these elements in both DWTP are lower than the maximum levels indicated (Table 5).

Exceptionally, the maximum concentrations observed have exceeded these values for Al and Se. The maximum values of Al have been measured in summer. Among the studied elements, Mn in both DWTP and V in the Llobregat DWTP share this behaviour with Al. On the other hand, the concentrations of Si, Cr, Cu, Zn and Sb are apparently erratic during the period studied. Instead, the parameters Ca, Mg, Na, K, Li, B, Fe, Co, Ni, As, Br, Rb, Sr, Mo, Ba, Pb, and U show concentrations very similar in that period.

Finally we can remark that in spite of the major use of classical analytical techniques such as AAS for the determination of inorganic compounds, mainly in routine laboratories, the amount of information, its sensitivity and versatility render ICP-MS a suitable analytical technique for the hydrochemical characterisation of aqueous matrixes in DWTP, and allows to get levels of accuracy and precision according with legal requirements.

Acknowledgements

This work was performed by means of a collaborative agreement between ATLL and CSIC. The authors would like to thank M.E. Medina, A. Roig and M. Britos for their technical assistance.

References

[1] JEEC. Directive 80/778/CEE of the Council of 15th July of 1980 relative to human drinking water quality. Official Journal of European Communities. L299/11, 30th August 1980.

Table 4. Accuracy for ICP-MS determination of Set 3 of elements in water

	Accuracy (%) SLRS-4 (n=10)	Accuracy (%) NIST 1643d (n=10)	Accuracy (%) AC-E (n=10)
Set 3 (concentrations expressed in $\mu\text{g L}^{-1}$)			
Li			1.3
Be			1.7
Ti			
V	0.23	6.4	6.0
Co		2.8	5.0
Ga			1.0
Ge			
Br			
Rb		0.53	2.6
Sr	4.4	1.9	4.3
Y			6.0
Zr			2.1
Nb			
Mo	0.46	2.9	3.6
Sn			3.1
Te			
I			
Cs			5.7
La			0.17
Ce			0.13
Pr			1.8
Nd			0.43
Sm			1.2
Eu			4.0
Gd			0.38
Tb			0.83
Dy			1.7
Ho			1.9
Er			1.1
Tm			0.77
Yb			1.1
Lu			1.6
Hf			5.8
Ta			
W			2.0
Pt			
Au			
Tl		1.7	
Bi		6.3	
Th			1.1
U	3.9		1.3

Table 5. Comparison of outlet waters of DWTP's Llobregat and Ter (July 1996 - December 1998) with the average composition of water in streams [23] and with the levels indicated in different regulations: EU, European Directive 98/83/EC (B and C, Parts B and C) [4], USEPA, United States Environmental Protection Agency (P and S, Primary and Secondary drinking water regulations) [2], and WHO, World Health Organization [3]. Statistics: x, arithmetic mean; s, standard deviation; m, minimum; M, maximum; n, number of samples). LOD, limit of detection.

	Stream water average	EU	USEPA	WHO	Llobregat DWTP					Ter DWTP				
					x	s	m	M	n	x	s	m	M	n
Set 1 (concentrations expressed in mg L ⁻¹)														
Na	6.3	200(C)		200	145.6	51.1	67.5	296.2	28	41.6	70.1	8.7	387.0	27
Mg	4.1				32.6	11.3	19.7	77.0	28	11.0	2.3	7.8	17.7	27
Si	6.5				1.2	0.6	0.3	2.9	28	2.2	0.8	1.2	4.4	27
SO ₄ ²⁻	3.7	250(C)	250(S)	400	160.2	41.1	100.3	251.2	16	93.2	54.3	44.1	229.3	15
Cl	7.8	250(C)	250(S)	250	277.7	102.2	115.9	473.9	16	36.5	30.7	4.0	108.0	15
K	2.3				34.5	16.9	13.5	100.9	28	8.8	12.9	0.4	63.3	27
Ca	15				96.5	20.5	68.8	153.6	28	59.2	14.2	46.5	101.2	27
Set 2 (concentrations expressed in µg L ⁻¹)														
B	10	1000(B)			104.3	36.5	41.6	171.0	28	47.9	26.2	7.4	105.5	27
Al	50	200(C)	50-200(S)	200	133.9	95.8	39.49	378.3	28	73.9	38.5	12.5	214.9	27
P	20				43.32	18.41	20.28	82.38	16	17.8	13.7	2.50	52.55	15
Cr	1	50(B)	100(P)	50	2.48	1.47	0.35	4.95	28	2.19	1.72	0.51	9.02	27
Fe	40	200(C)	300(S)	300	62.8	33.8	10.0	115.0	28	42.4	18.0	2.21	77.0	27
Mn	7	50(C)	50(S)	100	1.38	0.72	0.55	2.75	28	0.91	0.78	0.30	3.70	27
Ni	0.3	20(B)			4.11	2.22	1.37	9.09	28	2.94	2.16	1.10	8.77	27
Cu	7	2000(B)	1300(P)	1000	6.00	5.78	1.36	30.64	28	2.07	1.56	0.11	7.46	27
Zn	20		5000(S)	5000	7.4	5.7	1.6	23.0	28	5.7	11.5	0.9	58.0	27
As	2	10(B)	50(P)	50	3.66	2.66	1.01	11.52	28	2.02	0.96	0.62	4.17	27
Se	0.05	10(B)	50(P)	10	8.7	20.6	1.7	76.3	28	8.3	17.6	0.3	88.5	27
Ag	0.3		100(S)		0.25	0.52	<LOD	2.46	28	0.02	0.04	<LOD	0.18	27
Cd	0.01	5(B)	5(P)	5	0.03	0.04	<LOD	0.17	28	0.02	0.05	<LOD	0.23	27
Sb	0.07	5(B)	6(P)		1.33	0.65	0.29	2.55	28	0.55	0.14	0.30	0.84	27
Ba	20		2000(P)		57.3	8.5	43.2	78.2	28	33.0	3.3	26.0	40.2	27
Hg	0.07	1(B)	2(P)	1	0.03		0.01	0.26	28	<LOD		<LOD	<LOD	27
Pb	1	10(B)	15(P)	50	0.20	0.23	0.01	1.03	28	0.34	0.41	0.01	2.08	27

	Stream water average	EU	USEPA	WHO	Llobregat DWTP					Ter DWTP				
					x	s	m	M	n	x	s	m	M	n
Set 3 (concentrations expressed in $\mu\text{g L}^{-1}$)														
Li	3				15.44	4.93	7.17	30.33	28	4.67	1.64	2.35	9.99	27
Be	0.01		4 (P)		0.02	0.05	<LOD	0.15	16	0.02	0.03	<LOD	0.09	15
Ti	3				5.32	5.69	0.50	27.52	28	2.45	3.23	<0.10	17.34	27
V	0.9				1.90	0.79	-0.21	3.69	28	1.09	0.40	0.59	2.21	27
Co	0.1				0.50	0.17	0.22	0.76	28	0.30	0.14	0.09	0.48	27
Ga	0.09				0.02	0.02	<LOD	0.07	28	0.06	0.05	<LOD	0.15	27
Ge	0.005				0.03	0.03	<LOD	0.12	28	<LOD	<LOD	<LOD	0.03	27
Br	20	10 (B) ¹			753	601	274	3490	27	129	84	20	365	26
Rb	1				13.01	3.32	5.12	18.43	28	1.93	0.69	1.05	3.48	27
Sr	70				1599	305	1057	2263	28	511	85	333	673	27
Y	0.04				0.02	0.02	<LOD	0.06	28	0.02	0.01	<LOD	0.05	27
Zr					0.04	0.07	<LOD	0.31	28	0.03	0.06	<LOD	0.26	27
Nb					0.01	0.02	<LOD	0.08	28	<LOD	<LOD	<LOD	0.05	27
Mo	0.6				1.78	0.72	1.37	5.33	28	0.81	0.15	0.57	1.13	27
Sn	0.03				0.08	0.11	<LOD	0.40	28	0.16	0.34	0.01	1.60	27
Te					<LOD		<LOD	<LOD	12	<LOD		<LOD	<LOD	27
I	7				4.69	3.78	0.57	11.67	28	3.23	2.68	0.40	9.20	27
Cs	0.02				0.31	0.33	<LOD	1.17	28	0.09	0.34	0.01	1.74	27
La	0.048				0.75	1.55	<LOD	7.56	28	0.16	0.38	<LOD	1.87	27
Ce	0.079				0.02	0.02	<LOD	0.09	28	0.02	0.05	<LOD	0.24	27
Pr	0.0073				<LOD		<LOD	0.02	28	<LOD		<LOD	0.03	27
Nd	0.038				<LOD		<LOD	0.04	28	<LOD		<LOD	0.11	27
Sm	0.0078				<LOD		<LOD	0.01	28	<LOD		<LOD	<LOD	27
Eu	0.0015				<LOD		<LOD	0.05	28	<LOD		<LOD	<LOD	27
Gd	0.0085				<LOD		<LOD	0.12	28	<LOD		<LOD	<LOD	27
Tb	0.0012				<LOD		<LOD	0.01	28	<LOD		<LOD	<LOD	27
Dy	0.0072				<LOD		<LOD	0.03	28	<LOD		<LOD	<LOD	27
Ho	0.0014				<LOD		<LOD	0.03	28	<LOD	0.00	<LOD	<LOD	27
Er	0.0042				<LOD		<LOD	<LOD	28	<LOD		<LOD	<LOD	27
Tm	0.00061				<LOD		<LOD	<LOD	25	<LOD		<LOD	<LOD	24
Yb	0.0036				<LOD		<LOD	<LOD	28	<LOD		<LOD	<LOD	27
Lu	0.00064				<LOD		<LOD	<LOD	25	<LOD		<LOD	<LOD	24
Hf					0.01		<LOD	0.11	28	<LOD		<LOD	0.09	27
Ta					<LOD		<LOD	0.04	28	<LOD		<LOD	<LOD	27
W	0.03				0.02		<LOD	0.18	28	<LOD		<LOD	0.03	27
Pt					<LOD		<LOD	<LOD	28	<LOD		<LOD	<LOD	27
Au	0.002				<LOD		<LOD	<LOD	28	<LOD		<LOD	<LOD	27
Tl		2 (P)			<LOD		<LOD	<LOD	28	<LOD		<LOD	<LOD	27
Bi					0.02		<LOD	0.17	28	<LOD		<LOD	0.04	27
Th	<0.1				0.02		<LOD	0.17	28	<LOD		<LOD	0.06	27
U	0.04				1.89	0.60	1.23	3.48	28	0.71	0.32	0.16	1.34	27

¹ Bromate is the form of Br considered by the Part B of European Directive 98/83/EC [4].

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