



Challenge

Seawater matrices cause spectral and physical interferences from its high dissolved salt content (3.5% m/v)

Solution

The aerosol dilution system of the PlasmaQuant MS allows for the direct analysis of seawater despite percent level of total dissolved solids (TDS) without prior sample dilution

Intended audience

Relevant for environmental, research, aquaculture, mining, and more industries

Multielement Determination of Trace Elements in Undiluted Seawater by ICP-MS

Introduction

Nowadays, inductively coupled plasma mass spectrometry (ICP-MS) has become one of the most powerful analytical techniques for trace element analysis with high sensitivity, wide linear dynamic range, and quasi-simultaneous multielement detection capability.^[1,2] However, having a principal disadvantage of polyatomic interferences combined with its weak tolerance for dissolved salts, makes it difficult for the ICP-MS to perform direct injection analysis of seawater due to high salt contents of approximately 3.5%. The high matrix load may possibly cause matrix effects, spectral interferences, clogging of the torch tip and the interface cone orifice. Furthermore, the concentrations of most trace metals in seawater are extremely low at ng/L levels.^[1]

To address these analytical challenges, a range of different sample preparation and introduction techniques have been used in combination with ICP-MS, such as solvent extraction,^[3,4] coprecipitation,^[5] and chelating resin adsorption.^[6] However, these procedures are time-consuming and, in addition, could be a source of trace element contamination. Therefore, direct seawater analysis is favored using online aerosol dilution in combination with collision/reaction cell technology to provide efficient removal of spectral interferences.

This application note demonstrates the capability of the PlasmaQuant MS to handle undiluted seawater, profiting from its high plasma robustness and sensitivity.

Materials and Methods

Instrument settings

A PlasmaQuant MS ICP in combination with the CETAC ASX-560 autosampler and ESI injection valve was used for the analysis of 30 elements in four Seawater Certified Reference Materials from National Research Council Canada. The PlasmaQuant MS used is equipped with 1) aerosol dilution which allows for e.g. 10-fold dilution; 2) a unique interface including larger orifices preventing salt build-up and a 9 mm cone separation to reduce material deposition and blockage; 3) Nitrox option which offers the addition of N₂ to the auxiliary gas to enhance the sensitivity of poorly ionized elements such as As and Se; 4) unique (patented) BOOST technology that allows a positive voltage (up to 10 V) on skimmer cone for sensitivity improvement in reaction mode; 5) a patented integrated Collision Reaction Cell (iCRC) to remove polyatomic species formed in the plasma and greatly improve the accuracy of an analysis.

All experiments were carried out in a routine analytical laboratory, and not under 'clean room' conditions. Instrument operating conditions are summarized in Table 1.

Table 1: Instrument settings – PlasmaQuant MS

Parameter	Specification	
Plasma Gas Flow	10.5 L/min	
Auxiliary Gas Flow	1.50 L/min	
Sheath Gas Flow	0.83 L/min	
Nebulizer Gas Flow	0.27 L/min	
Sampling depth	7.0 mm	
Plasma RF Power	1.60 kW	
Pump Rate	10 rpm – black/black PVC pump tubing (<1 mL/min)	
Stabilization delay	10 s	
iCRC Gas Setting	He 120 mL/min	¹¹ B and ⁴⁷ Ti
	He 180 mL/min	²⁷ Al, ⁵¹ V, ⁵² Cr, ⁵⁹ Co, ⁶⁰ Ni, and ⁶⁵ Cu
	No Gas	⁷ Li, ⁹ Be, ⁷¹ Ga, ⁸⁵ Rb, ⁸⁸ Sr, ⁹⁸ Mo, ¹⁰⁷ Ag, ¹¹⁴ Cd, ¹¹⁸ Sn, ¹²¹ Sb, ¹³⁷ Ba, ¹³⁹ La, ²⁰² Hg, ²⁰⁵ Tl, ²⁰⁶⁺²⁰⁷⁺²⁰⁸ Pb, ²⁰⁹ Bi, and ²³⁸ U
	H ₂ 180 mL/min	⁶⁶ Zn
	H ₂ 200 mL/min + Boost (4 V) + N ₂ 40 mL/min	⁵⁵ Mn, ⁵⁶ Fe, ⁷⁵ As, and ⁷⁸ Se
Dwell Time	30 ms	
Scan per Replicate	10 (peak hopping, 1 pt/peak)	
No. of replicates	3	
Sample uptake time	0 s – OneFAST Sample Introduction system used	
Internal Standards	Sc, Y, In, Ir, and Tb, 50 µg/L, interpolation correction	

Samples and reagents

The following high purity reagents were used for all solution preparations:

- Deionized water (>18.2 MΩ/cm, Millipore Milli-Q)
- Nitric acid Supra-quality 69 % (ROTIPURAN® Supra)
- Sodium Chloride 99.999% trace metals basis (Sigma-Aldrich)

Sample preparation

As part of the experiment, all undiluted CRMs were loaded onto the autosampler and the internal standards containing diluent were added online using a T-piece located directly after the exit port from the OneFast valve before the nebulizer. The final ratio of seawater to diluent was 1:20. Online dilution is recommended to minimize unwanted contamination. The CASS-5, CASS-6 and NASS-6 and NASS-7 Seawater Certified Reference Material for trace metals (National Research Council Canada, Ottawa, Ontario) were selected to evaluate accuracy. Spike recoveries of 1 and 10 ppb were also performed for most of the elements tested, except for some elements (e.g., Li, B and Sr) due to their relatively high concentration in the CRMs.

Calibration

A six-point external calibration was used for quantification with standard concentrations chosen relative to the expected concentration in the CRMs. Calibration solutions were prepared in 50 ml plastic tubes from SARSTEDT from

high-purity, single element solutions (CertiPUR® 1000 mg/L) in 1% (v/v) HNO₃ and 35 g/L of NaCl covering the following concentration ranges:

Table 2: Concentration Ranges

Element	Concentration range (µg/L)
Pb	0.01 - 2
Cd	0.02 - 2
Hg	0.1 - 2
Be, Co, Ni, Cu, Ga, Rb, Mo, Ag, Sn, Sb, Ba, La, Tl, Bi and U	0.1 - 20
for Cr, Mn, Fe and Zn	0.2 - 20
Al, Ti, V, As and Se	1 - 20
Li and Sr	1 - 200
B	10 - 200

The calibration graphs in Figure 1 show good examples of the performance from the PlasmaQuant MS at defined concentration levels. All calibrations were measured with correlation coefficients better than 0.9997.

Measurement

According to the expected interferences on certain mass/charge ratios, different isotopes were measured using collision gas (He) or a reaction gas (H₂) of the iCRC. Besides the two available gases, PlasmaQuant MS allows the users to recover analytes signals after reaction took place on iCRC through the Boost patented technology applied on skimmer cone.

Due to low ionization efficiency of some elements, such as As and Se, the Nitrox option allows for the addition of Nitrogen directly to the plasma through the auxiliary port which improves the ionization 3 - 4 x for As and Se.

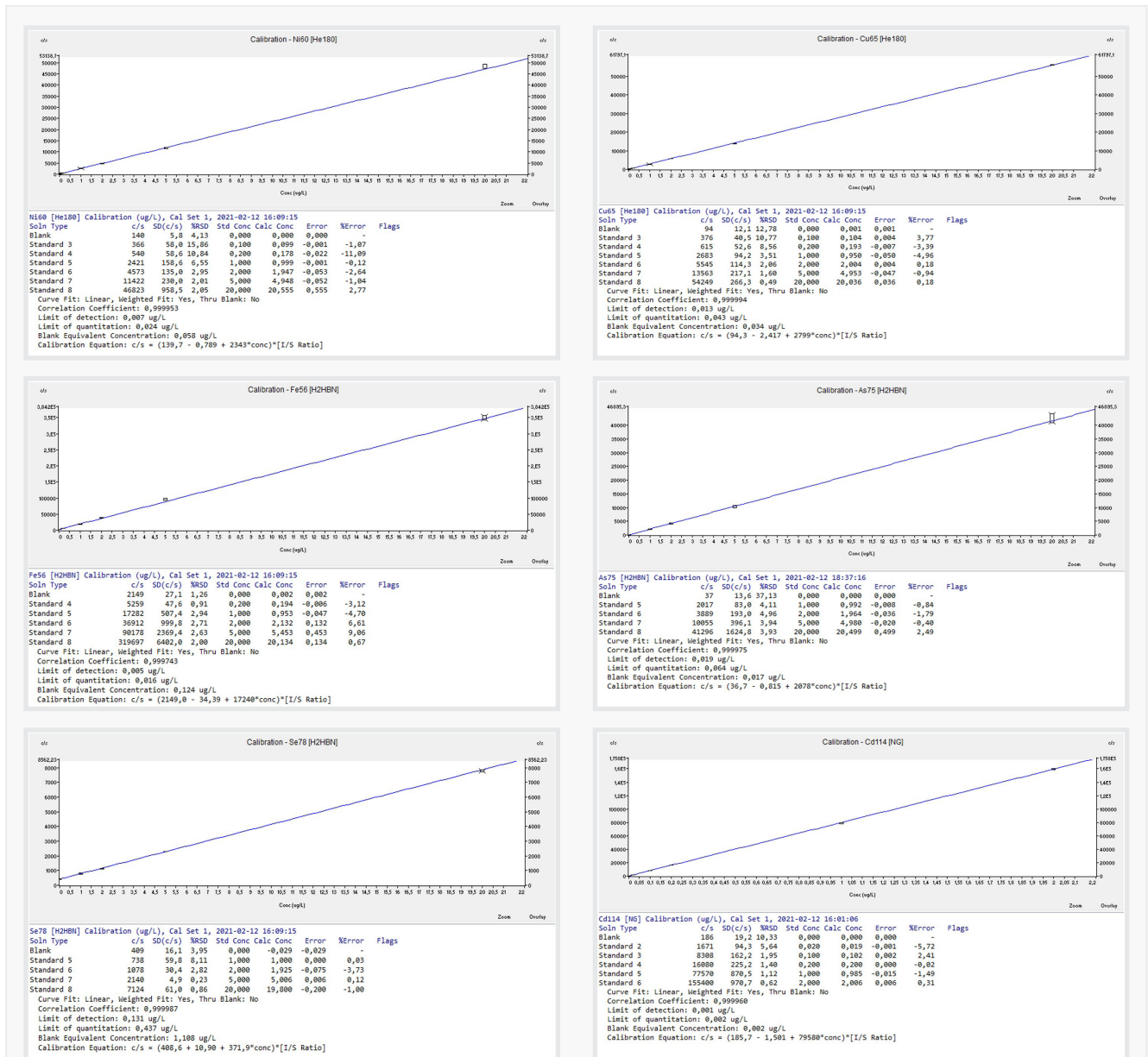
To ensure the highest precision and accuracy in our measurements, we selected five different condition sets for each measurement. These condition sets involved varying gas flows, including Helium at 120 and 180 mL/min, No Gas, Hydrogen at 180 and 200 mL/min combined with Boost (4 V), and Nitrogen at 40 mL/min. Each condition set was associated with specific isotopes, as detailed in Table 3.

During the experiments, all condition sets were run with switching times set at 10 seconds. For data recording purposes, we calculated three average values from ten scans each. These average values, along with their standard deviations, were used in the final calculations.

The total sampling time, including rinse and sample uptake delays, was about three minutes per sample.

Table 3: Expected interferences and used iCRC gases

Isotope	Expected interference	iCRC mode	Isotope	Expected interference	iCRC mode
⁷ Li	-	No Gas	⁷⁸ Se	⁴⁰ Ar ³⁸ Ar	H ₂
⁹ Be	-	No Gas	⁸⁵ Rb	-	No Gas
¹¹ B	-	He (due to high concentration)	⁸⁸ Sr	-	No Gas
²⁷ Al	¹¹ B ¹⁶ O	He	⁹⁸ Mo	-	No Gas
⁴⁷ Ti	³¹ P ¹⁶ O	He	¹⁰⁷ Ag	-	No Gas
⁵¹ V	³⁵ Cl ¹⁶ O	He	¹¹⁴ Cd	⁹⁸ Mo ¹⁶ O	No Gas
⁵² Cr	⁴⁰ Ar ¹² C; ³⁵ Cl ¹⁶ O ¹ H	He	¹¹⁸ Sn	-	No Gas
⁵⁵ Mn	³⁹ K ¹⁶ O	H ₂	¹²¹ Sb	-	No Gas
⁵⁶ Fe	⁴⁰ Ar ¹⁶ O; ⁴⁰ Ca ¹⁶ O	H ₂	¹³⁷ Ba	-	No Gas
⁵⁹ Co	⁴³ Ca ¹⁶ O; ⁴² Ca ¹⁶ O ¹ H; ²⁴ Mg ³⁵ Cl	He	¹³⁹ La	-	No Gas
⁶⁰ Ni	⁴⁴ Ca ¹⁶ O; ²⁵ Mg ³⁵ Cl; ²³ Na ³⁷ Cl	He	²⁰² Hg	-	No Gas
⁶⁵ Cu	⁴⁹ Ti ¹⁶ O; ²⁵ Mg ⁴⁰ Ar	He	²⁰⁵ Tl	-	No Gas
⁶⁶ Zn	²⁶ Mg ⁴⁰ Ar; ³¹ P ³⁵ Cl	H ₂	²⁰⁶⁺²⁰⁷⁺²⁰⁸ Pb	-	No Gas
⁷¹ Ga	-	No Gas	²⁰⁹ Bi	-	No Gas
⁷⁵ As	⁴⁰ Ar ³⁵ Cl; ⁴⁰ Ca ³⁵ Cl	H ₂	²³⁸ U	-	No Gas

Figure 1: Calibration graphs of some of the most challenging elements investigated (e.g., ^{60}Ni , ^{65}Cu , ^{56}Fe , ^{75}As , ^{78}Se , and ^{114}Cd)

Results and Discussion

The obtained results for Seawater CRMs samples are given in Table 4, 5, 6 and 7.

Table 4: Concentration results (in µg/L) of CASS-5, precision, and accuracy (n=3; n.d. not determined)

Isotope	mean	%RSD	Certified	Unc.	%REC	1 ppb Spike REC., %	10 ppb Spike REC., %
⁷ Li	162	0.7	-	-	-	-	-
⁹ Be	<0.0003	-	-	-	-	94	104
¹¹ B	4153	1.7	-	-	-	-	-
²⁷ Al	0.26	38.1	-	-	-	109	99
⁴⁷ Ti	0.11	-	-	-	-	-	-
⁵¹ V	1.28	3.1	1.32	0.14	97	88	113
⁵² Cr	0.098	20.9	0.106	0.013	92	100	97
⁵⁵ Mn	2.64	6.1	2.62	0.2	101	99	97
⁵⁶ Fe	1.58	6.1	1.44	0.11	110	86	86
⁵⁹ Co	0.111	7.6	0.095	-	117	99	102
⁶⁰ Ni	0.32	8.4	0.33	0.023	97	101	112
⁶⁵ Cu	0.37	2.1	0.38	0.028	97	97	113
⁶⁶ Zn	0.70	8.3	0.719	0.068	97	96	122
⁷¹ Ga	0.03	12.9	-	-	-	96	96
⁷⁵ As	1.37	4.4	1.24	0.09	110	100	96
⁷⁸ Se	0.18	3.0	-	-	-	92	93
⁸⁵ Rb	96.4	0.1	-	-	-	93	96
⁸⁸ Sr	6425	0.6	-	-	-	-	-
⁹⁸ Mo	10.0	0.4	9.82	0.72	102	110	104
¹⁰⁷ Ag	<0.002	-	-	-	-	91	100
¹¹⁴ Cd	0.025	2.8	0.0215	0.0018	116	95	96
¹¹⁸ Sn	<0.08	-	-	-	-	86	94
¹²¹ Sb	0.38	3.9	-	-	-	91	101
¹³⁷ Ba	7.02	1.5	-	-	-	101	104
¹³⁹ La	0.010	0.0	-	-	-	93	102
²⁰² Hg	0.012	8.2	-	-	-	82	92
²⁰⁵ Tl	0.012	0.0	-	-	-	92	99
²⁰⁶⁺²⁰⁷⁺²⁰⁸ Pb	0.013	0.0	0.011	0.002	114	89	97
²⁰⁹ Bi	<0.001	-	-	-	-	90	99
²³⁸ U	3.03	1.4	3.18	0.11	95	91	100

Table 5: Concentration results (in µg/L) of CASS-6, precision, and accuracy (n=3; n.d. not determined)

Isotope	mean	%RSD	Certified	Unc.	%REC	1 ppb Spike REC., %	10 ppb Spike REC., %
⁷ Li	n.d.	-	-	-	-	-	-
⁹ Be	n.d.	-	-	-	-	-	-
¹¹ B	4102	1.2	4090	100	100	-	-
²⁷ Al	n.d.	-	-	-	-	-	-
⁴⁷ Ti	n.d.	-	-	-	-	-	-
⁵¹ V	0.53	-	0.5	0.12	106	99	106
⁵² Cr	0.12	-	0.1	0.016	120	101	116
⁵⁵ Mn	2.19	2.7	2.22	0.12	99	98	97
⁵⁶ Fe	1.48	8.1	1.56	0.12	95	103	110
⁵⁹ Co	0.07	10.0	0.067	0.005	105	99	97
⁶⁰ Ni	0.52	0.4	0.418	0.04	124	102	98
⁶⁵ Cu	0.57	3.5	0.53	0.032	108	95	95
⁶⁶ Zn	1.27	1.6	1.27	0.18	100	104	91
⁷¹ Ga	n.d.	-	-	-	-	-	-
⁷⁵ As	1.32	-	1.04	0.1	127	101	86
⁷⁸ Se	2.91	-	-	-	-	100	101
⁸⁵ Rb	n.d.	-	-	-	-	-	-
⁸⁸ Sr	n.d.	-	-	-	-	-	-
⁹⁸ Mo	9.15	0.8	9.15	0.52	-	-	-
¹⁰⁷ Ag	n.d.	-	-	-	-	-	-
¹¹⁴ Cd	0.020	10.0	0.022	0.002	91	99	99
¹¹⁸ Sn	n.d.	-	-	-	-	-	-
¹²¹ Sb	n.d.	-	-	-	-	-	-
¹³⁷ Ba	7.95	-	-	-	-	102	103
¹³⁹ La	n.d.	-	-	-	-	-	-
²⁰² Hg	n.d.	-	-	-	-	-	-
²⁰⁵ Tl	n.d.	-	-	-	-	-	-
²⁰⁶⁺²⁰⁷⁺²⁰⁸ Pb	0.01	0.0	0.011	0.004	91	99	105
²⁰⁹ Bi	n.d.	-	-	-	-	-	-
²³⁸ U	2.60	4.6	2.92	0.42	-	-	-

Table 6: Concentration results (in µg/L) of NASS-6, precision, and accuracy (n=3; n.d. not determined)

Isotope	mean	%RSD	Certified	Unc.	%REC	1 ppb Spike REC., %	10 ppb Spike REC., %
⁷ Li	166	0.2	-	-	-	-	-
⁹ Be	<0.0003	-	-	-	-	98	96
¹¹ B	4262	0.5	-	-	-	-	-
²⁷ Al	<0.04	-	-	-	-	-	91
⁴⁷ Ti	0.08	12.0	-	-	-	-	-
⁵¹ V	1.49	10.0	1.46	0.17	102	87	99
⁵² Cr	0.12	-	0.118	0.008	102	103	100
⁵⁵ Mn	0.52	0.7	0.53	0.05	98	99	95
⁵⁶ Fe	1.19	1.9	0.495	0.046	241**	114	88
⁵⁹ Co	0.014	2.0	0.015	-	93	99	99
⁶⁰ Ni	0.29	2.5	0.301	0.025	98	109	99
⁶⁵ Cu	0.242	2.3	0.248	0.025	98	81	95
⁶⁶ Zn	<0.008	-	0.257	0.02	-	117	92
⁷¹ Ga	0.033	1.7	-	-	-	97	97
⁷⁵ As	1.71	3.6	1.43	0.12	119	113	97
⁷⁸ Se	<0.13	-	-	-	-	-	107
⁸⁵ Rb	96.8	0.5	-	-	-	-	92
⁸⁸ Sr	6440	0.2	-	-	-	-	-
⁹⁸ Mo	9.35	0.4	9.89	0.72	95	105	93
¹⁰⁷ Ag	<0.002	-	-	-	-	97	87
¹¹⁴ Cd	0.036	7.9	0.0311	0.0019	116	96	96
¹¹⁸ Sn	<0.002	-	-	-	-	76	78
¹²¹ Sb	0.25	2.2	-	-	-	94	93
¹³⁷ Ba	6.56	0.4	-	-	-	97	92
¹³⁹ La	0.008	9.4	-	-	-	97	97
²⁰² Hg	<0.005	-	-	-	-	99	93
²⁰⁵ Tl	0.004	2.0	-	-	-	95	97
²⁰⁶⁺²⁰⁷⁺²⁰⁸ Pb	<0.0003	-	0.006	0.002	-	97	99
²⁰⁹ Bi	<0.001	-	-	-	-	98	99
²³⁸ U	3.00	0.4	3	-	100	101	99

** Fe contaminated at 0.5 ppb level due to a contamination of the sample

Table 7: Concentration results (in µg/L) of NASS-7, precision, and accuracy (n=3; n.d. not determined)

Isotope	mean	%RSD	Certified	Unc.	%REC	1 ppb Spike REC., %	10 ppb Spike REC., %
⁷ Li	153	0.0	-	-	-	-	-
⁹ Be	<0.0003	-	-	-	-	98	104
¹¹ B	3718	1.9	3750	120	99	-	-
²⁷ Al	0.36	5.0	-	-	-	80	107
⁴⁷ Ti	<0.05	-	-	-	-	-	-
⁵¹ V	1.34	-	1.3	0.08	103	-	111
⁵² Cr	n.d.	-	0.107	0.016	-	-	-
⁵⁵ Mn	0.74	3.4	0.75	0.06	99	105	95
⁵⁶ Fe	0.37	1.9	0.351	0.026	106	105	96
⁵⁹ Co	0.020	3.2	0.0146	0.0014	133**	102	100
⁶⁰ Ni	0.28	1.4	0.248	0.018	113	105	99
⁶⁵ Cu	0.19	0.4	0.199	0.014	93	105	100
⁶⁶ Zn	0.42	1.5	0.42	0.08	100	112	111
⁷¹ Ga	0.06	1.3	-	-	-	101	102
⁷⁵ As	1.34	7.2	1.26	0.06	107	95	80
⁷⁸ Se	<0.13	-	-	-	-	97	93
⁸⁵ Rb	98.0	0.1	-	-	-	-	109
⁸⁸ Sr	6459	0.2	-	-	-	-	-
⁹⁸ Mo	9.7	0.5	9.29	0.4	104	95	101
¹⁰⁷ Ag	<0.002	-	-	-	-	93	103
¹¹⁴ Cd	0.016	17.7	0.0161	0.0016	100	101	103
¹¹⁸ Sn	<0.08	-	-	-	-	90	96
¹²¹ Sb	0.17	2.6	-	-	-	92	102
¹³⁷ Ba	4.74	0.9	-	-	-	97	104
¹³⁹ La	0.007	10.9	0.006	-	108	94	101
²⁰² Hg	0.63	-	-	-	-	84	102
²⁰⁵ Tl	0.011	6.7	-	-	-	92	99
²⁰⁶⁺²⁰⁷⁺²⁰⁸ Pb	0.004	-	0.0026	0.0008	133***	98	104
²⁰⁹ Bi	0.002	-	-	-	-	91	96
²³⁸ U	2.86	0.5	2.87	0.16	100	93	100

** Co contaminated at 5 ppt; *** Pb contaminated 0.5 ppt level due to a contamination of the sample

Accuracy

Certified reference materials were used to evaluate accuracy besides spike recovery efficiency. The mean results are in good agreement with the expected or assigned values provided. All certified elements were within 80-120% recovery range (Figure 2). It should be mentioned that such accuracy can only be achieved with sensitive and precise measurement.

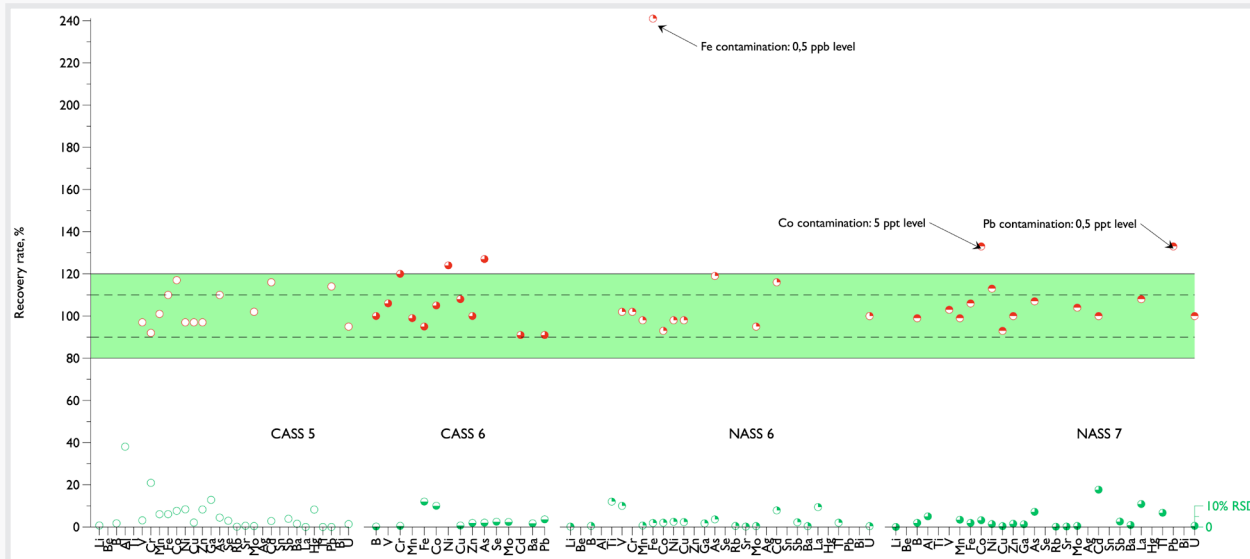


Figure 2: Recovery rate (%) of four CRMs measured. All measurements are within the range specified, except the contamination levels found for Fe, Co and Pb.

Figure 3 shows excellent spike recoveries for all elements in the certified reference materials at both spike levels (1 and 10 ppb). Most spike recoveries are within 90-110% range.

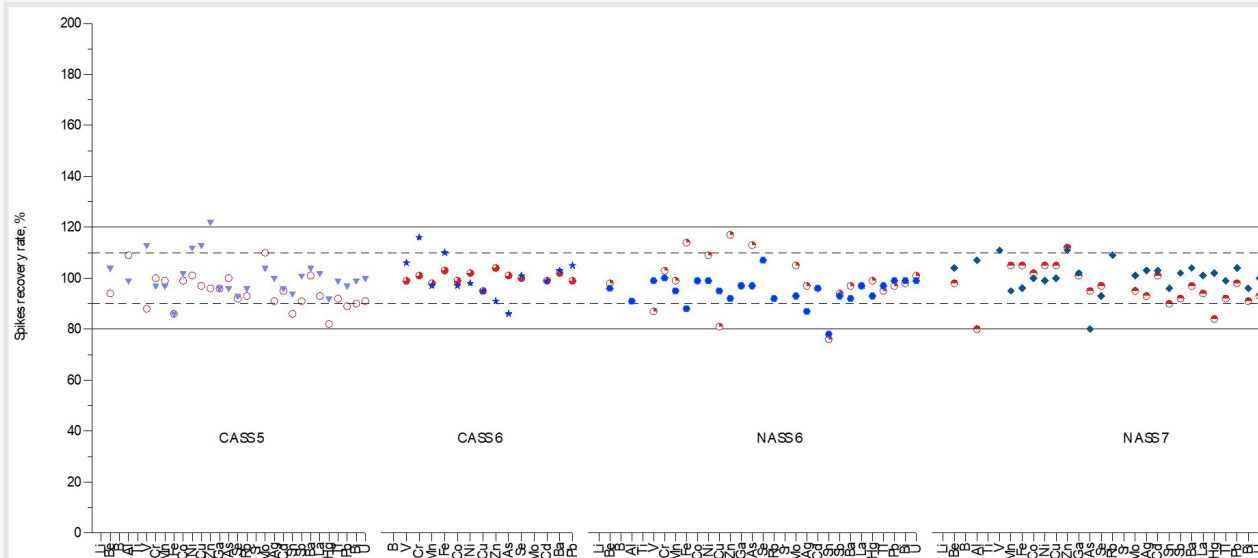


Figure 3: Recovery rate (%) for 1 and 10 ppb spike levels tested in all the four seawater CRMs

Precision

The relative standard deviation (RSD) was used as a parameter to assess the precision of the measurements (Figure 2). On average RSD of 4.2% was achieved. Besides the fact, that RSDs are near or higher than 10%, mainly due to contamination level in the ppt concentration range, all the results with the range of ppt to ppb showed great precision and accuracy with the methodology applied during all the measurements.

Detection limits

Table 7 provides two types of detection limits:

- Detection Limits (DLs): These correspond to three times the standard deviation of the calibration blank, calculated based on three measurements ($n=3$).
- Method Detection Limits (MDLs): These were determined by taking ten measurements of blank seawater (composed of 35 g/L NaCl with 1% (v/v) HNO_3) at different points during the experiment. The MDLs were then calculated by multiplying the standard deviation of these ten measurements by three.

Although the MDLs are mostly single-digit ppt levels, some MDLs could be improved by using high-purity NaCl or artificial seawater.

Table 8: Detection Limits and Method detection limits for all the measured elements; Values in ng/L

Isotope	DL	MDL	Isotope	DL	MDL
^7Li	2	14	^{78}Se	131	38
^9Be	0.3	2	^{85}Rb	6	4
^{11}B	116	1199	^{88}Sr	7	5
^{27}Al	43	205	^{98}Mo	0.3	10
^{47}Ti	51	21	^{107}Ag	2	4
^{51}V	115	15	^{114}Cd	1	2
^{52}Cr	14	11	^{118}Sn	2	2
^{55}Mn	17	3	^{121}Sb	1	3
^{56}Fe	5	15	^{137}Ba	2	2
^{59}Co	2	2	^{139}La	0.1	2
^{60}Ni	7	51	^{202}Hg	5	11
^{65}Cu	13	29	^{205}Tl	0.1	3
^{66}Zn	8	63	$^{206+207+208}\text{Pb}$	0.3	2
^{71}Ga	2	2	^{209}Bi	1	2
^{75}As	19	4	^{238}U	0.1	0.1

Internal Standard Stability

Seawater matrices create several impacts on ICP-MS, among them, sample uptake, nebulization, and aerosol transport, as well ionization suppression on plasma are the most common ones. The superior robustness of the PlasmaQuant MS interface combined with aerosol dilution and ESI switching valve allows high solids matrices to be aspirated, such as Seawaters for a prolonged period of time without any significant drift or loss of sensitivity which is currently observed in this kind of matrices. Such robustness extends maintenance time on the cones, better performance of Control Checks without compromising DLs over time.

Figure 4 shows the Internal standards stability remained within the $\pm 20\%$ control limits in all condition's modes used during 1 hour and 20 minutes run of PlasmaQuant MS while analyzing 25 undiluted seawater CRMs samples including blanks and calibration standards.

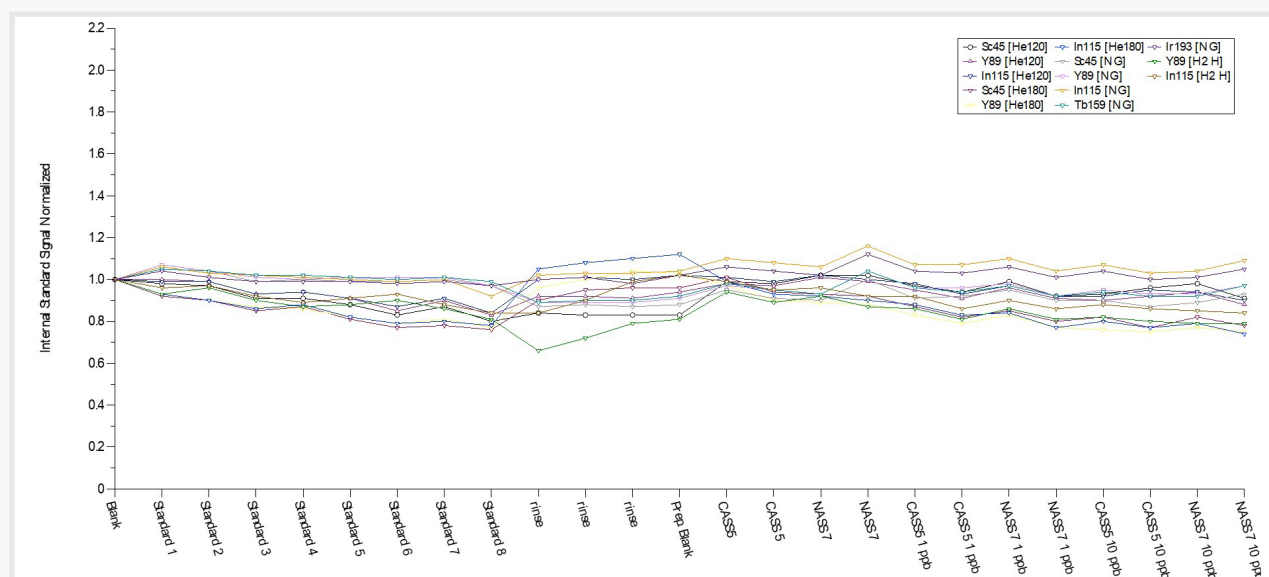


Figure 4: Internal standards stability in all condition's modes during undiluted seawater CRMs analyzes over 1 hour and 20 minutes for 25 samples

Summary

The PlasmaQuant MS with aerosol dilution system allows for the direct analysis of undiluted seawater or any high matrix samples above 0.2% TDS limit frequently established for ICP-MS. Time consuming sample preparation and potential contamination due to samples liquid dilution are significantly reduced in combination with ESI injection valve which is an effective way of measuring ultra-trace concentration in high matrices.

Worldwide, the use of an accurate method is invaluable for environmental laboratories that require high-throughput seawater analysis capabilities.

The unique PlasmaQuant MS interface with larger orifices prevents salt build-up, reduces material deposition and blockage which reduces instrument downtime which is also important for high-throughput labs.



Figure 5: PlasmaQuant MS

Recommended device configuration

Table 9: Overview of devices, accessories, and consumables

Article	Article number	Description
PlasmaQuant MS - highly sensitive, robust, and reliable ICP-MS Instrument	818-08010-2	PlasmaQuant MS is optimized for the analysis of tough samples such as seawater, soil, sludge, and combustibles
Cetac ASXpress Plus for PQMS	810-88017-0	The ASXpress plus Rapid Sample Introduction Accessory reduces time required for autosampler movement, sample uptake, stabilization, and rinse operations, thereby reducing sample run times significantly
Nitrox upgrade Kit for PQMS and PQMS Elite instruments	810-88025-0	Nitrox is vital in petrochemical processes, enabling carbon removal with oxygen. It's also advised for applications demanding low arsenic or selenium detection limits, enhancing sensitivity through nitrogen addition

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