



## ICP-Mass Spectrometry

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## Improved Performance in the Analysis of Drinking Waters and Wastewaters by U.S. EPA Method 200.8 with an SC-FAST System

### Introduction

U.S. EPA Method 200.8 contains a lengthy, detailed description of procedures, both required and recommended. A summary of the experiments that must be performed to establish the performance of the instrument, along with a 10-step daily analysis procedure, can be found in Table 1 (Page 2).

### Instrumental Conditions

A PerkinElmer® ELAN® 9000 ICP-MS was used for the analysis of natural and certified water samples described in this work. Sample introduction was accomplished with an Elemental Scientific, Inc. sampler changer SC-FAST sample introduction system. Instrumental conditions for the ICP-MS and SC-FAST, as well as experimental parameters used throughout this work, are presented in Tables 2 and 3 (Pages 3 and 4).

The SC-FAST is a sample introduction system consisting of an autosampler, diaphragm vacuum pump, 6-port switching valve, merging stream manifold, high-efficiency PFA-ST nebulizer, and a Peltier-cooled cyclonic spray chamber. The system is shown schematically in Figure 1 (Page 2). The contents of the sample loop, which is large enough to provide a steady state signal, are injected into an acid carrier stream that merges with the internal standard solution. The length of tubing connecting the output of the switching valve with the nebulizer is short so that the time between injection and measurement is minimized. The instrument response as a function of time for back-to-back sample injections is illustrated schematically in Figure 2 (Page 2).

**Table 1. Summary of Method 200.8.<sup>1</sup>**

**Established Initial Performance Data**

1. Linear range
2. Perform IDLs and MDLs
3. Analyze quality control sample with acceptable performance

**Daily Analysis**

1. Light plasma, allow 30 minute warm-up
2. Tune instrument
  - a. Per manufacturer's instructions
  - b. Use tuning solution specified in 200.8 (10 ppb Be, Mg, Co, In, Pb)
3. Perform mass calibration check, adjust if change >0.1 amu
4. Perform resolution check, adjust if >0.75 amu at 5% peak height
5. Calibrate using blank and standards
  - a. Monitor all masses necessary for interference correction
6. Screen new samples for relative levels and presence of internal standards
7. Run instrument performance quality control samples
8. Run analytical batch quality control samples
9. Run analytical samples
10. Review results of quality control samples for PASS/FAIL criteria

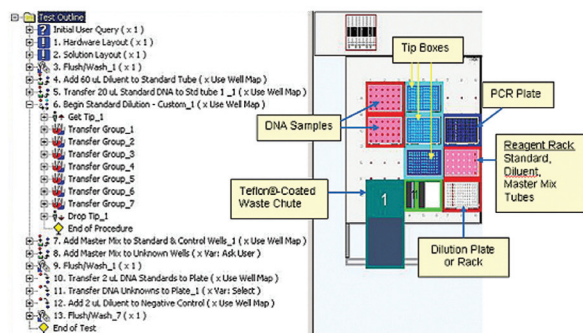


Figure 1. Schematic of an SC-FAST ICP-MS introduction system.<sup>2</sup>

The SC-FAST system has been designed to increase throughput and to decrease sample carryover compared to conventional sample introduction systems. The carrier and internal standard solutions provide a continuous flow of solution to the nebulizer, which creates a nearly constant steady-state situation. The constant plasma steady-state, combined with the short distance the sample travels to reach the nebulizer, allows sample uptake and stabilization to take place more rapidly (see Figure 2). Furthermore, during analysis, the SC-FAST system rinses the autosampler probe and moves it to the next sample vial. The SC-FAST system thus completes

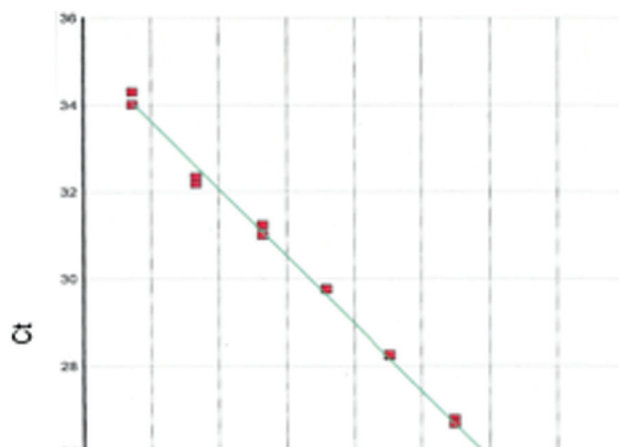


Figure 2. Profile for back-to-back sample injections of 1 ppb U.

the analysis of a sample (following Method 200.8 protocol) in 90 seconds (sample-to-sample), about half the time needed to perform the same analysis with conventional sample introduction. Increasing the sample throughput increases productivity and lowers costs, both labor- and instrument-related.

As the sample solution is not in contact with the peristaltic pump tubing, washout times and memory effects are decreased. The sample is contained within the sample loop, which is made of chemically resistant PTFE. As the volume of sample introduced into the nebulizer is decreased, the amount of salt that is deposited on the cones is also decreased. The SC-FAST system uses a total pump flow rate between 300 and 400  $\mu\text{L}/\text{min}$ , much lower than flow rates used with conventional introduction systems. These lower pump flow rates, combined with the shorter analysis time, reduce the amount of salt deposition on the cones, reagent consumption, and waste production, all of which lower maintenance and operational costs.

In addition to higher throughput and reduced memory effects, the SC-FAST system allows for the online addition of internal standards, simplifying sample preparation and decreasing the opportunities for contamination.

### SC-FAST Method

The SC-FAST system is controlled through the ELAN software. Since the SC-FAST system allows for direct nebulization using a fixed sample volume, a sample injection profile was first taken to determine an appropriate read delay and analysis window. The read delay and analysis window chosen for a 1 mL sample volume injected by a carrier moving at 0.5 mL/min were 20 s and 60 s, respectively. The timing parameters of the quantitative analysis were set to be within this read window. Therefore, the read parameters listed in Table 2 (Page 3) were chosen such that three replicate measurements of the twenty-six elements outlined in this method could be made in 60 s. For samples with the

tendency to foam or outgas, a 5 s rinse step was added to the end of each measurement to pump air through the probe tubing. Evacuating the loop also reduces hydrodynamic resistance when trying to rapidly load the subsequent sample.

The SC-FAST method consists of three steps. The first step is to load the sample loop. The injection valve remains in the “load” position while a sample solution fills the sample loop at 20 mL/min (via a diaphragm vacuum pump) at 3 to 4 times its volume. Excess solution from the sample loop is sent directly to waste. While the loop loads, carrier and internal standard solutions are pumped continuously into the nebulizer (see Table 2 for identity, concentration, and flow rate of carrier and internal standard solutions).

The second step involves switching the valve to the “inject” position, allowing the carrier stream to push the contents of the sample loop into the nebulizer. All data collection occurs during this step. While data collection occurs, the sample probe performs a 4 s rinse at a rinsing station located at the end of the autosampler. The rinse station consists of two flowing reservoirs, which allows the user to program two individual rinse steps, if desired. The injection valve is in the “inject” position during the rinse step which directs the rinse solution through the sample probe tubing and directly to waste. Therefore, a relatively aggressive rinse solution could be used without concern that it would pass through the nebulizer and affect subsequent measurements.

The third step is to rinse and reload the sample loop. The valve is switched back to the “load” position where first air, and then the next sample solution are pumped through the loop. In this step, the next sample is used to rinse the loop of the previous sample before it is loaded into the loop for analysis.

## Standards

All solutions were prepared using 18 megaohm-cm water and double-distilled nitric acid. All acid concentrations reported in this document are described as a relative (v/v) percentage. Reference materials for this work were obtained from High Purity Standards (Charleston, SC) and from NIST®, (Gaithersburg, MD). Double distilled nitric and hydrochloric acids were purchased from GFS Chemicals, Inc. (Sidney, BC, Canada).

## Tuning

A 1 ppb solution containing Be, In, Ce, U, Rh, Mg, Co, Pb, Na, Fe, Cu, K, Ba in 1% HNO<sub>3</sub> was used for all instrument optimizations. This tuning solution was used to measure all performance aspects of the instrument, including mass calibration, resolution, nebulizer gas flow, AutoLens calibration, and daily performance checks. The tuning solution is prepared by diluting 50 µL of a 10 ppm multi-element stock solution into 500 mL of 1% HNO<sub>3</sub>. The multi-element stock solution

is prepared from 1000 ppm single-element stock solutions of the elements listed above by diluting 500 µL of each element into 50 mL of 1% HNO<sub>3</sub>.

## Internal Standards

A multi-element internal standard solution containing 20 ppb <sup>6</sup>Li, Sc, Y, Ga, Ho, In, Rh, Ir, Tb and Te was used for all analyses. Both Li and Sc were used as internal standards for the analysis of Be and Al because Li, often naturally present in real samples, resulted in poor recoveries when analyzing local drinking water and standard reference materials. In these situations, Sc was used instead of Li. The internal standard solution was prepared from a 10 ppm stock solution by diluting 1 mL of the stock into 500 mL of 1% nitric acid. No internal standard spikes were added to individual blanks, standards and samples, as the internal standard was added online.

**Table 2. SC-FAST-ELAN 9000 Instrumental Conditions and Experimental Parameters.**

<b>ELAN 9000 Parameters</b>	
RF Power	1500 watts
Plasma Gas Flow	15 L/min
Auxiliary Gas Flow	1 L/min
Nebulizer Gas Flow	0.83-0.88 L/min
Peristaltic Pump Speed	0.5 mL/min
Nebulizer/Spray Chamber	PFA-ST/Peltier-cooled cyclonic
Spray Chamber Temp	2 °C
Detector Mode	Dual
Lens	AutoLens Enabled
Sampler/Skimmer Cones	Nickel
Scanning Mode	Peak Hopping
Number of Points/Peak	1
Number of Sweeps/Reading	10
Number of Readings/Replicate	1
Number of Replicates	3
<b>SC-FAST Parameters</b>	
Sample Loop Volume	1 mL
Sample Loop Fill Rate	20 mL/min
Carrier Pump Tubing	Black/Black (0.76 mm i.d.)
Internal Std Pump Tubing	Orange/Green (0.38 mm i.d.)
Read Delay	20 s
Rinse	5 s
Analysis Time (total)	90 s (sample-to-sample)
<b>Experimental Parameters</b>	
Carrier Solution	3% HNO <sub>3</sub>
Internal Std Solution	1% HNO <sub>3</sub> + 100 ppb Au
Rinse Solution	3% HNO <sub>3</sub>
Acidity of Stds/Samples	3% HNO <sub>3</sub>

**Table 3. Elements, Analytical Masses, Correction Equations, and Dwell Times.**

Analyte	m/z	Dwell Time (ms)	Correction Equations
Li	6	50	
Be	9	50	
B	11	50	
Al	27	20	
Sc	45	20	
V	51	50	$V51 = -3.127 * (ClO53 - (0.113 * Cr52))$
Cr	52, 53	50	
Mn	55	20	
Co	59	20	
Ni	60, 62	20	
Cu	63, 65	20	
Zn	66, 67, 68	20	
Ga	71	50	
As	75	150	$As75 = -3.127 * (Se77 - (0.185 * Se82))$
Se	77, 82	150	$Se82 = -1.007833 * Kr83$
Mo	95, 97, 98	20	$Mo98 = -0.110588 * Ru101$
Ag	107, 109	10	
Cd	106, 108, 111, 114	10	$Cd106 = -1.223914 * Pd105$ $Cd108 = -1.184953 * Pd105$ $Cd111 = -1.073 * (MoO108 - (0.712 * Pd106))$ $Cd114 = -0.027520 * Sn118$
In	115	10	
Sb	121, 123	10	$Sb123 = -0.127189 * Te125$
Ba	135, 137	10	
Ho	165	10	
Ir	193	10	
Tl	203, 205	10	
Pb	208	10	$Pb208 = +1 * Pb206 + 1 * Pb207$
Th	232	10	
U	238	10	
Na	23	10	
Mg	24	10	
Ca	44	10	
Fe	54	10	$Fe54 = -0.028226 * Cr52$

## Calibration

Since this method outlines the analysis of drinking and wastewater samples, elements were calibrated at levels typically found in those types of samples. Method 200.8 does not include Na, Ca, Mg, K and Fe; however, these elements were monitored for informational purposes at m/z = 23, 44, 24, 39 and 54, respectively. The calibration blank and standards were prepared in 3% nitric acid for all experiments except for those used to determine detection limits. As illustrated in the results section, a higher acid concentration results in improved sample washout and analyte recovery, although detection limits deteriorate slightly. The concentrations used in the calibration standards are listed in Table 4.

## Monitored Isotopes

As outlined in a previous application note,<sup>1</sup> multiple isotopes for each element often have to be monitored to mathematically correct for isobaric and molecular interferences on isotopes of interest. Table 3 lists the isotopes monitored, correction equations for applicable isotopes, and dwell times used.

## Initial Performance Demonstration

### IDLs

Instrument detection limits (IDLs) were determined using ten replicate measurements of the calibration blank (1% nitric acid). The IDLs were calculated to be the concentration equal to three times the standard deviation of those replicate measurements; results are shown in Table 5 (Page 5). The IDL calculations were followed according to the procedure outlined in Section 3.5 of Method 200.8.<sup>4</sup>

### MDLs

Method detection limits (MDLs) were based upon seven replicate measurements of a series of spiked calibration blanks. Each blank solution was spiked with analytes at concentrations between 2 and 5 times the calculated IDLs. The MDLs were calculated by multiplying the standard deviation of the seven replicate measurements by the appropriate Student's t test value according to:

$$MDL = (S) \times (t)$$

Note that the Student's t-value is based on a 99% confidence level. Both the Student's t-value and the standard deviation are based on n-1 degrees of freedom (t = 3.14 for six degrees of freedom).

The calculated MDLs are listed in Table 5, along with the concentrations of each spiked analyte. The spike concentrations cover several orders of magnitude to comply with the requirement that each analyte be spiked at a level that is 2 to 5 times the IDL. Detection limit studies were performed with standards in both a 1% and 3% nitric acid matrix. As expected, an increase in acid concentration degraded detection limits, both IDLs and MDLs, across the entire mass range due to higher contamination levels present in the more concentrated acid. For this reason, detection limit studies are reported with standards in 1% nitric acid. The ELAN 9000 is a highly sensitive instrument and provides detection limits well below typical sample concentrations, regardless of the acidity used to calculate the detection limits. If a priority is to reduce memory effects throughout sample analysis, higher acid concentrations improve sample washout at the expense of slightly poorer detection limits.

### Linear Range

A linear calibration range was established for each element listed in Method 200.8. The dual detector mode of the ELAN was used for this study, as the use of both the analog and pulse modes of the detector extends the linear range of the instrument. The upper linear range was further extended optimizing the analog stage by achieving a target gain of 7000, while aspirating a solution of 200 ppb Na. A dual-detector calibration was performed, following the detector optimization, using a solution containing 200 ppb of Method 200.8 elements and internal standards and 1 ppm of Na, Ca, Mg, K and Fe, all in a 1% nitric acid matrix.

Upon completion of the dual-detector calibration, the instrument was calibrated with a 3% nitric acid blank and the standards listed in Table 4. A series of standards of increasing concentration were then measured, and recovery values (in concentration units) were calculated. The linear dynamic range for each analyte was established as the highest concentration for which the recovery was within  $\pm 10\%$  of the true (i.e. known) value of the standard. The results from this study are given in Table 5.

The linear range results should be viewed with the understanding that a combination of elements in the presence of a complicated matrix can cause precipitation and interference effects, thus reducing the linear range for a number of elements. The results of this study are based upon multi-element standards in a 3% nitric acid matrix. For results that more accurately reflect an individual experiment, the linear range should be established using standards in a matrix that replicates the sample matrix as closely as possible.

**Table 5. ELAN 9000 IDLs, MDLs, and Linear Ranges for Method 200.8.**

Analyte	Mass	IDL ( $\mu\text{g/L}$ )	MDL ( $\mu\text{g/L}$ )	MDL Spike Level ( $\mu\text{g/L}$ )	Linear Range (mg/L)
Be	9	0.008	0.022	0.050	20
B	11	0.375	0.186	0.500	20
Al	27	0.042	0.083	0.500	20
V	51	0.017	0.016	0.050	10
Cr	52	0.039	0.059	0.500	10
Mn	55	0.003	0.007	0.050	20
Co	59	0.003	0.007	0.050	10
Ni	60	0.010	0.023	0.050	10
Cu	63	0.006	0.006	0.050	10
Zn	66	0.028	0.028	0.050	10
As	75	0.243	0.023	0.500	20
Se	82	0.133	0.161	0.500	20
Mo	98	0.004	0.010	0.050	20
Ag	107	0.006	0.020	0.050	20
Cd	111	0.025	0.033	0.050	20
Sb	123	0.010	0.024	0.050	20
Ba	135	0.034	0.089	0.500	20
Tl	205	0.003	0.002	0.005	20
Pb	208	0.008	0.010	0.050	20
Th	232	0.006	0.009	0.050	10
U	238	0.002	0.003	0.005	10
Na*	23	0.120	0.081	0.500	100
Ca*	44	5.24	3.85	10	100
Mg*	24	0.093	0.082	0.500	100
K*	39	2.16	0.784	10	50
Fe*	54	3.51	8.17	10	100

\*For information only.

**Table 4. Calibration Standard Concentrations.**

Analytes	Standard 1 Concentration ( $\mu\text{g/L}$ )	Standard 2 Concentration ( $\mu\text{g/L}$ )	Standard 3 Concentration ( $\mu\text{g/L}$ )	Standard 4 Concentration ( $\mu\text{g/L}$ )
Al, Sb, As, Ba, Be, Cd, Cr, Co, Cu, Pb, Mn, Mo, Ni, Se, Ag, Tl, Th, U, V, Zn	1	10	50	100
Na, Ca, Mg, K, Fe	10	100	1,000	10,000

## Memory Effects

Memory effect studies were performed to estimate the rinse time needed between sample injections. These studies were performed by measuring a high-level standard, followed by a series of calibration blanks that were measured until each analyte produced a signal at or below 10 times the MDL calculated previously. Each blank measurement, termed a "cycle", followed the analysis cycle defined in Table 6. The high-level standard contained analytes at 10 times their upper linear range, as suggested in Method 200.8.

**Table 6. SC-FAST Analysis Cycle Time.**

Load Time	20 s
Analysis Time	65 s
Rinse Time	5 s
Total Time	90 s

The results from the first 3 cycles, along with the analyte concentrations in the high-level standard, are shown in Table 7. As illustrated in the table, one or two cycles have to be completed before several of the measured analytes are present at concentrations below 10 times the MDL.

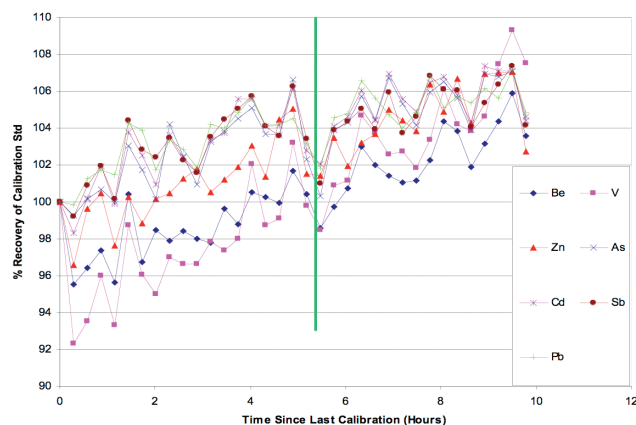
**Table 7. Estimated Rinse Times.**

Tested Analyte	Measured Concentration (µg/L)	Cycles			10* MDL (µg/L)	MDL (µg/L)
		Cycle 1	Cycle 2	Cycle 3		
Be	5000	1.077	0.043	0.012	0.015	0.15
B	500	0.075	0.011	0.019	0.040	0.40
Al	5000	0.995	0.020	0.002	0.031	0.31
V	5000	0.946	0.024	0.003	0.009	0.09
Cr	5000	0.954	0.038	0.040	0.025	0.25
Mn	5000	0.940	0.041	0.022	0.006	0.06
Co	5000	1.004	0.042	0.020	0.003	0.03
Ni	5000	0.922	0.048	0.002	0.016	0.16
Cu	5000	0.953	0.036	0.015	0.011	0.11
Zn	20000	3.73	0.128	0.043	0.027	0.27
As	20000	6.15	1.85	1.36	0.127	1.27
Se	20000	3.18	0.082	0.126	0.263	2.63
Mo	5000	0.799	0.042	0.015	0.005	0.05
Ag	500	8.56	1.66	0.479	0.009	0.09
Cd	5000	0.732	0.002	0.002	0.029	0.29
Sb	10000	1.56	0.085	0.052	0.013	0.13
Ba	5000	0.662	0.080	0.020	0.029	0.29
Tl	5000	0.754	0.048	0.008	0.011	0.11
Pb	5000	0.838	0.046	0.015	0.007	0.07
Th	5000	0.802	0.039	0.005	0.002	0.02
U	5000	0.825	0.027	0.004	0.003	0.03

## Quality Control

A quality control standard (QCS) was measured throughout the course of a series of stability runs. Local tap water was measured over a period of 10 hours to model a "typical" day of sample measurement. The QCS, measured after every ten samples of local tap water, is plotted in Figure 3. As the figure illustrates, the QCS was recovered within  $\pm 10\%$  of its true value, which is compliant with the requirement outlined in Method 200.8. For simplicity, a small number of elements that span across the entire mass range have been selected for illustration. It should be noted that the throughput with an SC-FAST introduction system is roughly double that of a sample introduction system using a peristaltic pump. Therefore, the number of plotted points in Figure 1 is almost double the number of points plotted in the previous application note. The vertical green line in Figure 1 indicates the number of samples run in 10 hours using conventional sample introduction.

It should also be noted that the SC-FAST system package for environmental analysis includes one 5 L rinse bottle. As mentioned above, the SC-FAST method includes a 4 s rinse step after every injection. This step was reduced to 2 s for all stability runs to provide enough rinsing solution for 10 hours worth of samples.



**Figure 3.** Stability of a quality control standard over a 10-hour period. The vertical green line represents the number of samples that can be processed in 10 hours using a conventional introduction system.

## Data Handling

All data from the ELAN 9000 was collected using a desktop computer attached to the instrument. The analytical results in this document were computed using the ELAN software v.3.3 and exported as report files. The text and supporting data tables were generated using Microsoft® Word and Excel®.

## Sample Analysis

The accuracy and precision of the above-described method were verified using certified reference materials and a local drinking water sample. Certified reference materials were analyzed without modification to determine the accuracy

as compared to the certified values. Recoveries of multi-element spikes were calculated for the following reference materials: High Purity Standards "Trace Metals in Drinking Water", NIST® SRM 1643e "Trace Elements in Water", High Purity Standards "INFCs I + INFCs IV" and a local drinking water sample. The results for these samples are shown in Tables 8-11 (Pages 7-10). The majority of elements were recovered within ±10% of the true (certified or spiked) value.

## Conclusions

The SC-FAST system has been shown to produce results that meet the requirements outlined in U.S. EPA Method 200.8. In addition, the SC-FAST system significantly increases sample throughput, while lowering maintenance and labor costs. The online addition of internal standards helps to simplify sample preparation and reduces the potential for dilution and sample preparation errors, as well as sample contamination.

When used in conjunction with the SC autosampler, the SC-FAST system provides a rugged, automated sample introduction system that can significantly increase the efficiency of routine sample analysis, resulting in higher laboratory productivity.

## References

1. R.E. Wolf, E. Denoyer and Z. Grosser, "U.S. EPA Method 200.8 for the Analysis of Drinking Waters and Wastewaters," 2001.
2. Reproduced with permission by ESI.
3. <http://www.epa.gov/safewater/contaminants/index.html#mcls>
4. "Methods for the Determination of Metals in Environmental Samples – Supplement 1", EPA-600/R-94-111, May 1994, Available at NTIS, PB 94-184942.

**Table 8. Precision and Recovery Data for High Purity "Trace Metals in Drinking Water" (CRM).**

Analyte	Mass	Average Measured			Certified Value (µg/L)	Recovery (%)	Spike Level (µg/L)	Average Spike		Standard Deviation of Spike Recovery	RSD (%)
		Conc. (µg/L)	Standard Deviation	RSD (%)				Recovery (%)	Recovery (%)		
Be	9	19.5	0.23	1.20	20	97	50	102	1.55	2.20	
B	11	0.10	0.44	463	–	–	50	100	1.09	2.19	
Na	23	6116	51	0.83	6000	102	–	–	–	–	
Mg	24	8192	88	1.08	9000	91	–	–	–	–	
Al	27	116	0.53	0.46	120	97	50	102	3.60	2.15	
K	39	3140	13.5	0.43	2500	126	–	–	–	–	
Ca	44	32075	148	0.46	35000	92	50	–	–	–	
V	51	29.5	0.38	1.29	30	98	50	103	0.50	0.62	
Cr	52	19.2	0.19	0.97	20	96	50	102	0.64	0.91	
Fe	54	101	8.25	8.14	100	101	50	106	2.39	1.54	
Mn	55	38.3	0.38	0.99	40	96	50	100	0.47	0.53	
Co	59	24.2	0.37	1.52	25	97	50	101	0.13	0.17	
Ni	60	57.3	0.90	1.58	60	95	50	100	0.84	0.79	
Cu	63	19.5	0.14	0.74	20	97	50	101	0.06	0.09	
Zn	66	68	0.72	1.06	70	97	50	104	1.09	0.91	
As	75	78.1	1.59	2.03	80	98	50	101	1.19	0.93	
Se	82	10.2	0.12	1.16	10	102	50	102	0.45	0.73	
Mo	98	94.6	2.11	2.23	100	95	50	100	3.83	2.65	
Ag	107	1.95	0.03	1.29	2	98	50	102	1.65	3.12	
Cd	111	9.87	0.14	1.47	10	99	50	102	1.70	2.79	
Sb	121	9.56	0.11	1.12	10	96	50	101	1.66	2.76	
Ba	135	46.7	0.71	1.52	50	93	50	103	1.40	1.43	
Tl	205	9.54	0.07	0.78	10	95	50	100	0.16	0.27	
Pb	208	38.4	0.10	0.27	40	96	50	98	1.15	1.32	
Th	232	0.02	0.09	–	–	–	50	105	0.53	1.00	
U	238	10.5	0.13	1.29	10	105	50	106	0.61	0.97	

– = Not Applicable

**Table 9. Precision and Recovery Data for NIST® SRM 1643e “Trace Elements in Water”.**

Analyte	Mass	Average Measured Conc. (µg/L)	Standard Deviation	RSD (%)	Certified Value (µg/L)	Recovery (%)	Spike Level (µg/L)	Average Spike Recovery (%)	Standard Deviation of Spike Recovery	RSD (%)
Be	9	12.1	0.47	3.9	14	87	50	94	0.58	0.98
B	11	158	5.10	3.2	157.9	100	50	105	1.66	0.79
Na	23	22266	886	4.0	20740	107	–	–	194	0.87
Mg	24	8608	353	4.1	8037	107	–	–	16.4	0.19
Al	27	138	3.13	2.3	141.8	97	50	118	0.97	0.49
K	39	2025	81.0	4.0	2034	100	–	–	0.97	0.49
Ca	44	33450	1082	3.2	32300	104	–	–	372	1.11
V	51	36.0	0.31	0.9	37.86	95	50	101	0.82	0.95
Cr	52	20.0	0.25	1.3	20.4	98	50	99	0.65	0.94
Mn	55	36.3	0.50	1.4	38.97	93	50	106	0.98	1.10
Co	59	24.9	0.35	1.4	27.06	92	50	99	1.00	1.35
Ni	60	57.3	0.85	1.5	62.41	92	50	95	1.09	1.04
Cu	63	21.3	0.36	1.7	22.76	94	50	99	0.67	0.96
Zn	66	66.7	0.91	1.4	78.5	85	50	87	1.26	1.15
As	75	53.7	0.85	1.6	60.45	89	50	91	1.28	1.29
Se	82	9.69	0.19	2.0	11.97	81	50	86	0.29	0.55
Mo	98	117	3.08	2.6	121.4	97	50	99	0.41	0.24
Ag	107	1.00	0.02	1.6	1.062	94	50	99	1.09	2.15
Cd	111	6.04	0.13	2.1	6.568	92	50	96	0.50	0.94
Sb	121	53.1	1.48	2.8	58.3	91	50	97	0.61	0.60
Ba	135	510	16.3	3.2	544.2	94	50	86	4.62	0.84
Tl	205	6.81	0.22	3.2	7.445	91	50	100	1.13	1.98
Pb	208	18.5	0.49	2.7	19.6	94	50	100	1.23	1.80
Th	232	0.01	0.00	9.1	–	–	50	100	1.05	2.10
U	238	0.00	0.00	45.8	–	–	50	100	1.14	2.28

– = Not Applicable

**Table 10. QCS Results and Spike Recoveries for Local Drinking Water.**

<b>Analyte</b>	<b>Mass</b>	<b>LDW Conc. (µg/L)</b>	<b>Low Spike Level (µg/L)</b>	<b>Low Spike Results (µg/L)</b>	<b>Low Spike Recovery (%)</b>	<b>High Spike Level (µg/L)</b>	<b>High Spike Results (µg/L)</b>	<b>High Spike Recovery (%)</b>
Be	9	0.00	10	9.86	99	50	48.8	98
B	11	14.6	10	25.6	110	50	68.5	108
Na	23	14171	–	–	–	–	–	–
Mg	24	2341	–	–	–	–	–	–
Al	27	21.1	10	29.8	85	50	68.6	94
K	39	1535	–	–	–	–	–	–
Ca	44	11448	–	–	–	–	–	–
V	51	0.22	10	10.3	101	50	50.3	100
Cr	52	0.26	10	10.3	100	50	50.0	99
Fe	54	37.2	–	–	–	–	–	–
Mn	55	1.53	10	11.7	101	50	51.1	99
Co	59	0.01	10	10.3	103	50	50.2	100
Ni	60	1.25	10	11.2	99	50	50.9	99
Cu	63	78.2	10	88.8	106	50	130	104
Zn	66	165	10	176	108	50	214	99
As	75	0.10	10	9.79	97	50	47.4	95
Se	82	0.13	10	9.13	90	50	44.2	88
Mo	98	0.08	10	10.2	101	50	49.0	98
Ag	107	0.06	10	9.94	99	50	49.3	99
Cd	111	0.00	10	9.88	99	50	47.5	95
Sb	121	0.04	10	9.92	99	50	48.3	96
Ba	135	7.31	10	17.6	103	50	56.2	99
Tl	205	0.00	10	9.97	100	50	49.1	98
Pb	208	0.32	10	10.5	102	50	50.2	100
Th	232	0.00	10	10.1	101	50	51.1	102
U	238	0.00	10	10.2	102	50	50.9	102

– = Not Applicable

**Table 11. Results for High Purity INFCS I + INFCS IV.**

Analyte	INFCS Mass	INFCS Run #1 (µg/L)	INFCS Run #2 (µg/L)	Duplicate Avg. Result (µg/L)	INFCS RPD (µg/L)	True Value (µg/L)	% Recovery
Be	9	9.62	10.33	9.98	7.1	10	99.8
Mg	24	4843.53	5148.77	4996.15	6.1	5000	99.9
Al	27	4586.60	4824.84	4705.72	4.8	5000	94.1
Ca	44	4955.98	5079.40	5017.69	2.5	5000	100.4
V	51	29.04	29.41	29.22	1.2	30	97.4
Cr	52	28.95	29.35	29.15	1.3	30	97.2
Mn	55	19.81	19.64	19.72	0.8	20	98.6
Fe	54	4794.66	5040.00	4917.33	4.9	5000	98.3
Co	59	28.73	29.15	28.94	1.4	30	96.5
Ni	60	28.37	28.28	28.32	0.3	30	94.4
Cu	63	29.04	29.41	29.23	1.2	30	97.4
Zn	66	29.96	29.86	29.91	0.3	30	99.7
As	75	97.34	97.91	97.62	0.6	100	97.6
Se	82	48.62	48.65	48.63	0.1	50	97.3
Cd	111	29.06	29.06	29.06	0.0	30	96.9
Cd	114	29.10	29.52	29.31	1.4	30	97.7
Ba	135	28.46	28.33	28.39	0.4	30	94.6
Ba	137	28.06	28.38	28.22	1.1	30	94.1
Hg	202	6.24	6.34	6.29	2.0	5	125.8
Tl	205	95.59	94.28	94.93	1.3	100	94.9
Pb	208	98.13	98.62	98.37	0.5	100	98.4