

## ICP-OES

**Authors****Paul Krampitz****Stan Smith****PerkinElmer, Inc.  
Shelton, CT 06484 USA**

## Increased Laboratory Productivity for ICP-OES Applied to U.S. EPA Method 6010C

**Abstract**

The use of an ESI SC FAST autosampler coupled to a Perkin Elmer Optima 7300 DV ICP can dramatically improve productivity for the analysis of environmental samples using EPA SW-846 Method 6010C. Sample throughput, as determined by sample-to-sample run time can be improved by as much as 100% as compared

to traditional sample introduction systems and autosampler configurations. Both sample analysis time and rinse out time are significantly reduced, allowing for a doubling of overall productivity. In addition, stability of the plasma and instrument is very robust allowing for long, unattended run times while meeting calibration and method QC requirements. Valuable man hours spent on instrument maintenance and recalibration are reduced. This paper will demonstrate that these productivity enhancement claims can be accomplished for implementation SW-846 Method 6010C.

## Introduction

Since 1980, the EPA has maintained a publication entitled SW-846 Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, more commonly referred to simply as SW-846. Currently, SW-846 is in its third edition and includes several updates. Since the third edition was released in 1986, there have been 9 updates (Updates I, II, IIA, IIB, III, IIIA, IIIB, IVA, and IVB), the most recent of which was dated February, 2007. Included in SW-846 are over 200 documents related to quality control practices, analytical test methods, sampling methods, and other topics related to the United States Environmental Protection Agency (EPA) Resource Conservation and Recovery Act (RCRA). Essentially, SW-846 is the official compendium of analytical and sampling methods that have been evaluated and approved by the EPA for use in complying with RCRA regulations.

As indicated by the EPA, the analytical methods in SW-846 are intended to be guidance documents and are not intended to be overly prescriptive except in the cases where a particular analyte or parameter is considered method defined. Such method-defined parameters are where the analytical result is wholly dependent on the process and conditions of the test or preparation method such as the Toxicity Characteristic Leaching Procedure (TCLP), Method 1311, where the conditions specified in the method directly affect the concentration of analytes extracted into the leaching solution. However, despite this clear indication from the EPA that SW-846 methods are intended as guidance documents, many regulatory agencies invoke these methods with no permissible changes or modifications.

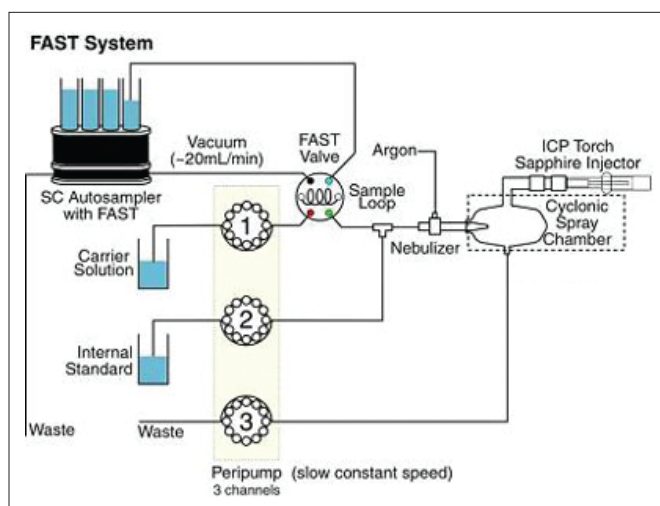


Figure 1. Schematic of FAST sample introduction system coupled to an Optima 7300 DV ICP spectrometer.

The analytical test methods found in SW-846 are commonly used by laboratories for the analysis of a wide range of sample matrices including, but not limited to: groundwater, surface water, leachates, soils, and a whole host of other solid and liquid wastes, both organic and aqueous. The RCRA regulatory programs for which SW-846 is most commonly used can be found in the U.S. Code of Federal Regulations (CFR), specifically Title 40 CFR Parts 122-270. One of the methods found in SW-846 that is commonly used by most environmental laboratories for the analyses of elements in environmental samples is 6010C Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES).

Method 6010C is the fourth version of this method and was released as part of SW-846 Update IV in February, 2007. As indicated in the method, all samples other than filtered, preserved groundwaters require acid digestion prior to analysis. There are more than 8 acid digestion methods applicable to ICP-AES found in SW-846 and some of those that are commonly used for the preparation of environmental samples include:

- 3005A Acid Digestion of Waters for Total Recoverable or Dissolved Metals for Analysis by FLAA or ICP Spectroscopy
- 3010A Acid Digestion of Aqueous Samples and Extracts for Total Metals for Analysis by FLAA or ICP Spectroscopy
- 3015A Microwave Assisted Acid Digestion of Aqueous Samples and Extracts
- 3050B Acid Digestion of Sediments, Sludges, and Soils
- 3051A Microwave Assisted Acid Digestion of Sediments, Sludges, Soils, and Oils

## Summary of Method

Method 6010C is a general analytical method that is applicable to a wide variety of liquid and solid samples and that provides specific procedures and references for sample collection, preservation, and preparation (i.e., acid digestion), in addition to recommended instrument procedures for calibration, detection limits, and interference correction. In addition, SW-846 6010C also contains procedures for the preparation, analysis, and acceptance limits for quality control samples needed for each batch of samples to be analyzed. While the method is intended only as a guidance document and is subject to interpretation and modification, implementation of the QC criteria as stated in the method was followed for the work performed and summarized in this paper. The EPA has approved this method for the analysis of 31 elements and Table I includes all the elements analyzed and their associated wavelengths. Following is a summary of the procedure from SW-846 6010C as performed in this work.

**Table I. Wavelengths Monitored and Viewing Modes Used for SW-846 6010C.**

Analyte	Symbol	Wavelength	
		Monitored (nm)	View
Aluminum	Al	308.215	Radial
Antimony	Sb	206.836	Axial
Arsenic	As	188.979	Axial
Barium	Ba	233.527	Axial
Beryllium	Be	234.861	Radial
Boron	B	249.677	Radial
Cadmium	Cd	226.502	Axial
Calcium	Ca	315.887	Radial
Chromium	Cr	267.716	Axial
Cobalt	Co	228.616	Axial
Copper	Cu	327.393	Axial
Iron	Fe	238.204	Radial
Lead	Pb	220.353	Axial
Lithium	Li	670.784	Radial
Magnesium	Mg	285.213	Radial
Manganese	Mn	257.610	Axial
Molybdenum	Mo	202.035	Axial
Nickel	Ni	231.604	Axial
Phosphorus	P	213.617	Axial
Potassium	K	766.490	Radial
Selenium	Se	196.026	Axial
Silicon	Si	251.611	Radial
Silver	Ag	328.068	Axial
Sodium	Na	589.592	Radial
Strontium	Sr	407.771	Radial
Thallium	Tl	190.801	Axial
Tin	Sn	189.927	Axial
Titanium	Ti	334.940	Axial
Vanadium	V	292.402	Axial
Zinc	Zn	206.200	Axial
<b>Internal Standards</b>			
Yttrium	Y	371.029	Radial/Axial
Tellurium	Te	214.281	Radial/Axial

## Summary of Method 6010C

### Establish Initial Demonstration of Performance

1. Perform Instrument Detection Limits (IDL)
2. Determine Linear Dynamic Range (LDR)
  - a. Recovery of elements must be  $\pm 10\%$  of the known values for each element
3. Determine whether interelement corrections are needed by analysis of an Interference Check Solution (ICS)

### Routine Analysis

1. Light plasma and warm up instrument, allow 15-30 minutes
2. Optimize instrument and plasma conditions per instrument manufacturer
3. Calibrate ICP using blank and minimum of one standard
  - a. Rinse with blank between each standard
  - b. Use the average of multiple readings (3 replicates in this study) for all standards and samples
4. Verify calibration by analyzing the Initial Calibration Verification (ICV) standard
  - a. ICV standard must be from a separate source as used for calibration standards
  - b. Recovery of elements must be  $\pm 10\%$  of the known values for each element
5. Verify the lowest quantification limit by analyzing the Lower Limit of Quantitation Check Sample (LLQC)
  - a. LLQC standard should be from the same source as the calibration standards
  - b. Recovery of elements must be  $\pm 30\%$  of the known values for each element
6. Analyze the Initial Calibration Blank (ICB)
  - a. Target elements should not be detected at or above the Lower Limit of Quantitation
7. Analyze test samples along with appropriate batch quality control samples
8. After every 10 samples, verify calibration by analyzing the Continuing Calibration Verification (CCV) standard
  - a. CCV standard should be from the same source as the calibration standards
  - b. Recovery of elements must be  $\pm 10\%$  of the known values for each element
9. Immediately following the analysis of each CCV, analyze the Continuing Calibration Blank (CCB)
  - a. Target elements should not be detected at or above the Lower Limit of Quantitation
10. The LLCCV must be analyzed at the end of each analytical batch but is also recommended to be analyzed after every 10 samples
  - a. Recovery of elements must be  $\pm 30\%$  of the known values for each element
11. At the end of the run, analyze the CCV and CCB
  - a. Acceptance limits are the same as in steps 8 and 9

## Batch Quality Control Samples

1. Analyze the Method Blank
  - a. Target elements should not be detected at or above 10% of the Lower Limit of Quantitation
2. Analyze the Laboratory Control Sample (LCS)
  - a. Recovery of elements must be  $\pm 20\%$  of the spiked values for each element
3. Analyze the Matrix Spike
  - a. Recovery of elements must be  $\pm 25\%$  of the spiked values for each element
4. Analyze the Sample Duplicate or Matrix Spike Duplicate
  - a. The precision criterion for duplicates is a relative percent difference of no greater than 20%

## Experimental

### Instrument

An Optima 7300 DV (PerkinElmer, Shelton, CT) was used in conjunction with an SC-FAST (Elemental Scientific Inc., Omaha, NE) for the analysis of all samples described in this work. The FAST sample introduction system is controlled through the Optima WinLab32™ software and a schematic of the FAST is shown in Figure 1. The elements, wavelengths, and plasma viewing modes used are listed in Table I. The instrument conditions for both the Optima ICP-OES and the SC-FAST as well as the experimental parameters used are provided in Table II.

### Standards

All calibration standards and non-sample solutions were prepared with ASTM Type I (i.e.,  $>18\text{M}\Omega\text{-cm}$ ) deionized water and trace metals grade or better nitric acid.

### Internal Standards

All samples were spiked with 1.5 mg/L of yttrium and 2.5 mg/L of tellurium. The spiking solution was made from 1000 mg/L single element stock solutions.

### Calibration

The calibration blank and standards were prepared in 1% nitric acid. Calibration was performed using a calibration blank and a single standard containing all elements at 1 mg/L. The calibration standard was prepared from a combination of single element and multi-element stock solutions, all containing elements at 1000 mg/L.

### Monitored Wavelengths

As previously mentioned, the monitored elements, wavelengths, and plasma viewing modes used are listed in Table I.

## Initial Performance Demonstration

### Instrument Detection Limits

The Instrument Detection Limits (IDL) for all elements were determined using a reagent blank solution according to the procedures in Section 9.3 of SW-846 6010C. Specifically, a reagent blank was analyzed seven consecutive times, with routine rinsing procedures between each analysis, for all elements three times on non-consecutive days. The IDLs were then estimated by calculating the average of each element's standard deviation. The obtained IDLs are presented in Table III.

### Evaluation of Interferences

Interferences were evaluated according to Section 4.2.10 of Method 6010C. An interference check solution containing 500 mg/L of Al, Ca, Mg, Na, 200 mg/L of Fe and 50 mg/L of K was used for evaluation.

**Table II. FAST-Optima 7300 DV Instrumental Conditions and Experimental Parameters.**

<b>Optima 7300 DV Parameters</b>	
RF Power	1450 watts
Plasma Gas Flow	15 L/min
Auxiliary Gas Flow	0.2 L/min
Nebulizer Gas Flow	0.6 L/min
Peristaltic Pump Speed	0.85 mL/min
Nebulizer/Spray Chamber	Sea Spray/Glass cyclonic
Torch Cassette Position	-3
Purge	Normal
Resolution	Normal
Integration Time	2 s min/5 s max
Read Delay	14 s
Wash Time	1 s
Number of Replicates	3
<b>FAST Parameters</b>	
Sample Loop Volume	2 mL
Sample Loop Fill Rate	27 mL/min
Carrier Pump Tubing	Black/Black (0.76 mm i.d.)
Sample Load Time	7 s
Rinse	1 s
Analysis Time (total)	75 s (sample-to-sample)
<b>Experimental Parameters</b>	
Carrier Solution	1% HNO <sub>3</sub> plus 0.05% surfactant
Rinse Solution	1% HNO <sub>3</sub>
Acidity of Stds/Samples	1% HNO <sub>3</sub>

**Table III. Instrument Detection Limit (IDL) Data and Linear Dynamic Ranges (LDR).**

Analyte	Wavelength	IDL RUN 1	IDL RUN 2	IDL RUN 3	6010C, IDL, ug/L	LDR, mg/L
Ag	328.068	0.159	0.103	0.172	0.14	100
Al	308.215	1.732	0.630	1.898	1.42	2000
As	188.979	0.349	0.415	0.774	0.51	100
B	249.677	4.504	1.400	1.109	2.34	2000
Ba	233.527	0.056	0.016	0.034	0.04	25
Be	234.861	0.034	0.018	0.075	0.04	50
Ca	317.933	0.544	0.550	0.783	0.63	900
Cd	226.502	0.041	0.037	0.073	0.05	100
Co	228.616	0.076	0.092	0.078	0.08	250
Cr	267.716	0.086	0.099	0.071	0.09	100
Cu	327.393	0.062	0.047	0.158	0.09	300
Fe	259.939	0.256	0.230	0.168	0.22	400
K	766.49	7.269	5.270	5.499	6.01(0.24)	2000
Mg	279.077	1.763	2.030	3.108	2.30	700
Mn	257.61	0.005	0.009	0.018	0.01	40
Mo	202.031	0.132	0.097	0.180	0.14	125
Na	589.592	1.147	2.364	1.609	1.71(0.2)	900
Ni	231.604	0.178	0.188	0.161	0.18	125
Pb	220.353	0.427	0.229	0.368	0.34	100
P	213.617	1.543	1.091	1.249	1.29	3000
Li	670.784	0.214	0.176	0.364	0.25(0.03)	200
Sb	206.836	0.662	0.586	0.226	0.49	100
Se	196.026	0.875	0.953	0.485	0.77	100
Si	251.611	2.546	0.569	1.080	1.40	2500
Sr	421.552	0.025	0.029	1.139	0.40(0.01)	50
Sn	189.927	1.928	1.218	0.095	1.08(0.35)	2000
Ti	334.94	0.017	0.018	1.863	0.63	50
Tl	190.801	0.574	0.568	0.114	0.42	100
V	292.402	0.070	0.059	0.781	0.30	50
Zn	206.2	0.051	0.039	0.086	0.06	100

( ) = Axial

**Linear Range**

The Linear Dynamic Range (LDR) was determined for each element and met the criterion in Section 10.4 of SW-846 6010C as found in Table III. That is, the upper linear range was established by analyzing standards against the same calibration used for analyzing samples and obtaining recoveries within  $\pm 10\%$  of the known concentration value. The Lower Limit of Quantitation was confirmed through the analysis of the Lower Level Check Standard (LLICV and LLCCV) and obtaining recoveries within  $\pm 30\%$  of the known concentration value. The LLICV and LLCCV were run at a concentration of 500 ug/L for this study.

**Memory Effects**

Memory effect studies were performed to obtain the rinse time needed between sample measurements using the ESI FAST system. The elements studied were the most likely elements to be high for environmental samples run under SW 846: Al, Ca, Fe, K, Mg, and Na. All of the data can be found in Figure 2. Five blanks were run, then five standards, then five blanks again to obtain the rinse out profiles. Al, Ca, Mg, and Na were run at 500 mg/L. Fe was run at 200 mg/L and K was run at 50 mg/L. The FAST parameters used were the same as listed in Table II above.

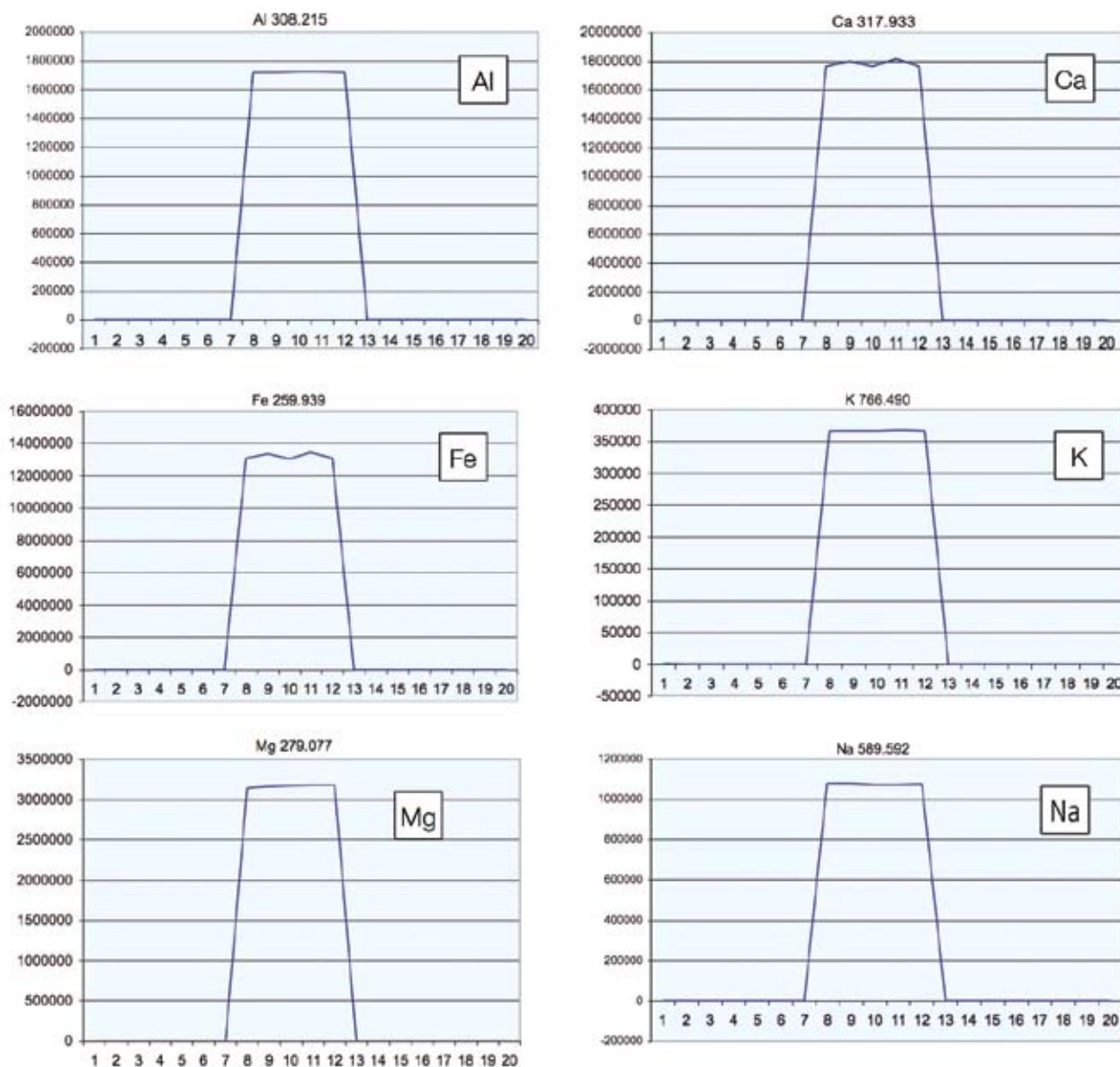


Figure 2. Above figures show the rinse out time using the ESI FAST system. Al, Ca, Mg, and Na were run at 500 mg/L. Fe was run at 200 mg/L and K was run at 50 mg/L. Samples were rinsed out to near baseline in 7 seconds.

### Quality Control and Sample Analysis

The accuracy and precision of the implementation of Method 6010C was demonstrated through the analysis of several reference materials and a local filtered, treated surface water sample (Lake Michigan). The quality control procedures specified in SW-846 were followed throughout the work performed. Immediately following calibration, the ICV (second source), LLICV, and ICB were analyzed and all results were determined to be within method-specified criteria,  $\pm 10\%$ ,  $\pm 30\%$ , and  $< \text{LLQC}$  respectively. Following the analysis of each sequence of ten samples, the CCV, LLCCV, and CCB were analyzed and found to be within the method-specified criteria (same as for ICV, LLICV, and ICB). In addition to the sequential run QC (10% frequency), batch QC samples were also prepared and analyzed. As all

samples analyzed were synthetic or natural water samples with no detectable turbidity or suspended solids, no acid digestion procedures were performed. The batch QC consisted of a method blank, a sample duplicate (DUP), a Laboratory Control Sample (LCS), a Matrix Spike (MS), and a Matrix Spike Duplicate (MSD). A natural surface water sample was used to prepare the DUP, MS, and MSD. Results of all batch QC samples were found to be within method-specified criteria. That is, no elements were detected within 10% of the LLQC, all elements detected in the sample and the sample DUP above the LLQC had relative percent differences of less than 20, all elements in the LCS were recovered within 20% of the known spike concentration, all elements in both the MS and MSD recovered within 25% of the known spike concentration, and all spiked elements in the MS and MSD had relative percent differences of less than 20.

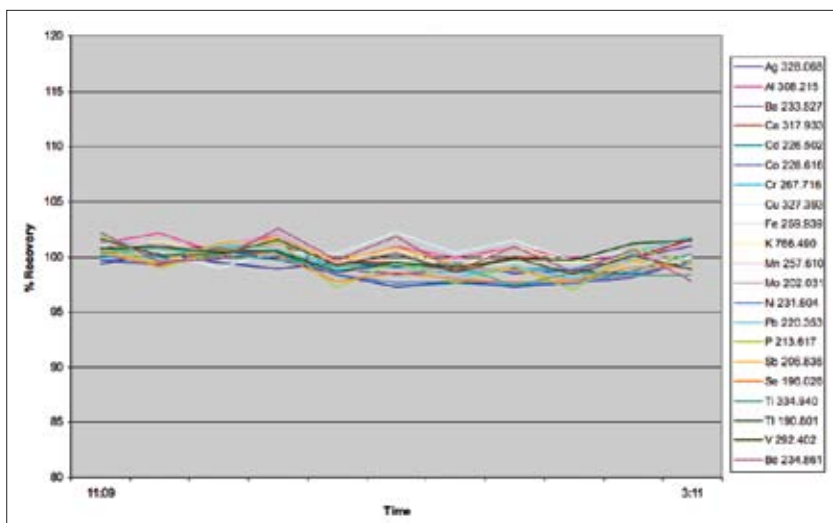


Figure 3. Four hour CCV stability.

Table IV. NIST 1640 Trace Elements in Natural Water.

	Run 1	Run 2	Average	Certified mg/L units	% REC.
Ag 328.068	0.007683478	0.007578301	0.00763089	0.0076	100
As 188.979	0.027794979	0.027058423	0.027426701	0.027	102
B 249.677	0.321778774	0.31648758	0.319133177	0.3	106
Ba 233.527	0.148039192	0.146252596	0.147145894	0.148	99
Ca 317.933	7.287467245	7.29179424	7.289630743	7.045	103
Cd 226.502	0.02461	0.024202	0.024406	0.0228	107
Co 228.616	0.022373993	0.022173326	0.02227366	0.022	101
Cr 267.716	0.041212275	0.040675621	0.040943948	0.0386	106
Cu 327.393	0.090707058	0.088824718	0.089765888	0.0852	105
Fe 259.939	0.034529324	0.033692193	0.034110759	0.0343	99
K 766.490	1.015084221	1.007176206	1.011130214	0.994	102
Mg 279.077	5.648166692	5.633282915	5.640724804	5.819	97
Mn 257.610	0.124362054	0.122821057	0.123591555	0.1215	102
Mo 202.031	0.049788978	0.049545748	0.049667363	0.04675	106
Na 589.592	29.22808031	28.92173556	29.07490794	29.35	99
Ni 231.604	0.029560106	0.029416086	0.029488096	0.0274	108
Pb 220.353	0.027413987	0.027680616	0.027547302	0.02789	99
Li 670.784	0.05139438	0.050218507	0.050806444	0.0507	100
Se 196.026	0.023501	0.023504	0.0235025	0.022	107
Si 251.611	4.747666191	4.644475617	4.696070904	4.73	99
Sr 421.552	0.12522384	0.125293217	0.125258528	0.124	101
V 292.402	0.013012505	0.012822827	0.012917666	0.013	99
Zn 206.200	0.057402	0.056602	0.057002	0.0532	107
Be 234.861	0.036510499	0.036158461	0.03633448	0.035	104

In addition to the batch QC samples, several reference materials were analyzed and included two Standard Reference Materials® (SRM) from the National Institute of Standards & Technology (NIST), one Certified Reference Material (CRM) from the National Research Council Canada (NRCC), and two commercially available water Proficiency Test (PT) samples. The NIST samples included SRM 1643e Trace Elements in Water and SRM 1640 Trace Elements in Natural Water. The NRCC sample was SLRS-4 River Water Reference Material for Trace Metals. This CRM is typically used for ICP-MS instrumentation due to the low concentrations of elements, however, it has been included to show the excellent sensitivity of the Optima 7300 DV. The two commercial PT samples included WP Trace Metals and WS Trace Metals. Results of all five reference materials are presented in Table IV – Table VIII.

### Stability

The Continuing Calibration Verification (CCV) standard was analyzed repeatedly throughout each analytical run and no less frequently than after every 10 samples. The recoveries for each of the CCVs obtained have been plotted against time for a period of four hours. The results are shown in Figure 3. All 30 elements monitored in this study were well within the method-specified acceptance criterion of  $\pm 10\%$  of the known value. Typical drift for most elements was less than 3%.

### Data Handling

All data obtained from the Optima 7300 DV was collected using the WinLab32 software loaded on a desktop PC attached to the instrument. Analytical results were computed using the WinLab32 software and exported into Microsoft® Excel®. The text and data tables used in this report were created using Microsoft® Excel® and Word.

**Table V. NIST 1643e Trace Elements in Water.**

	Run 1	Run 2	Average	Certified mg/L units	% REC.
Ag 328.068	0.00082799	0.000982703	0.000905346	0.001	91
Al 308.215	0.14958319	0.145968533	0.147775861	0.142	104
As 188.979	0.05863297	0.060202348	0.059417659	0.0605	98
Ba 233.527	0.526201428	0.53185025	0.529025839	0.544	97
Ca 317.933	31.36350994	31.38490986	31.3742099	32.3	97
Cd 226.502	0.006803606	0.006802601	0.006803103	0.00657	104
Co 228.616	0.027229571	0.027465911	0.027347741	0.02706	101
Cr 267.716	0.021901845	0.021954832	0.021928339	0.0204	107
Cu 327.393	0.022717423	0.022755897	0.02273666	0.02276	100
Fe 259.939	0.09995466	0.10046584	0.10021025	0.0981	102
K 766.490	2.115235445	2.134464228	2.124849837	2.034	104
Mg 279.077	7.594261315	7.676997678	7.635629497	8.037	95
Mn 257.610	0.036795431	0.037161031	0.036978231	0.03897	95
Mo 202.031	0.127822547	0.128341294	0.128081921	0.1214	106
Na 589.592	19.36434423	19.37433937	19.3693418	20.74	93
Ni 231.604	0.062047849	0.062322707	0.062185278	0.0624	100
Pb 220.353	0.017716846	0.018946104	0.018331475	0.01963	93
Li 670.784	0.018412973	0.018762553	0.018587763	0.0174	107
Sb 206.836	0.056414629	0.057170312	0.05679247	0.0583	97
Se 196.026	0.011186647	0.012221246	0.011703946	0.01197	98
Sr 421.552	0.313265799	0.31293833	0.313102065	0.323	97
Tl 190.801	0.006104	0.00703	0.006567	0.007445	88
V 292.402	0.036212595	0.036634849	0.036423722	0.03786	96
Zn 206.200	0.074767001	0.075143809	0.074955405	0.0785	95
Be 234.861	0.014348862	0.014500296	0.014424579	0.014	103

**Table VI. National Research Council Canada Riverine Water.**

	Run 1	Certified mg/L units	% REC.
Ca 317.933	6.088272145	6.2	98
Fe 259.939	0.108512603	0.103	105
K 766.490	0.671190352	0.68	99
Mg 279.077	1.544935545	1.6	97
Na 589.592	2.189781306	2.4	91
Sn 189.927	0.028264829	0.0263	107
K 766.490	0.000887947	0.00093	95
Mg 279.077	0.661790584	0.68	97
Na 589.592	1.660975302	1.6	104
Li 670.784	2.193887808	2.4	91
Be 234.861	0.058305976	0.054	108

**Table VII. WP Trace Metals.**

	Run 1	Run 2	Average	Certified mg/L units	% REC.
Ag 328.068	0.415039553	0.415691157	0.415365355	0.4	104
Al 308.215	2.161214156	2.178741769	2.169977963	2.25	96
As 188.979	0.206215282	0.211098072	0.208656677	0.198	105
Be 313.107	0.104177959	0.104164917	0.104171438	0.107	97
Cd 226.502	0.162228771	0.162383871	0.162306321	0.162	100
Co 228.616	0.596703569	0.596119333	0.596411451	0.575	104
Cr 267.716	0.172615602	0.172950538	0.17278307	0.162	107
Cu 327.393	0.405182422	0.405208121	0.405195272	0.378	107
Fe 259.939	1.392941099	1.392462656	1.392701878	1.41	99
Mn 257.610	1.925099213	1.927471996	1.926285605	1.95	99
Ni 231.604	0.325614799	0.326326585	0.325970692	0.317	103
Pb 220.353	0.475584088	0.478602286	0.477093187	0.496	96
Se 196.026	0.752168839	0.766870842	0.75951984	0.721	105
Sr 421.552	0.122143791	0.122530301	0.122337046	0.122	100
Tl 190.801	0.65022971	0.657954117	0.654091913	0.633	103
V 292.402	1.122841516	1.12365243	1.123246973	1.13	99
Zn 206.200	0.610901508	0.611869781	0.611385645	0.613	100
Be 234.861	0.101283259	0.101227224	0.101255241	0.107	95

**Table VIII. WS Trace Metals.**

	Run 1	Run 2	Average	Certified mg/L units	% REC.
Ag 328.068	0.205841482	0.206784064	0.206312773	0.201	103
Al 308.215	1.503360942	1.509021475	1.506191209	1.5	100
As 188.979	0.04707919	0.048926848	0.048003019	0.0485	99
Ba 233.527	0.67227925	0.67399818	0.673138715	0.647	104
Be 313.107	0.009084418	0.009042679	0.009063548	0.0087	104
Cd 226.502	0.00998403	0.01004741	0.01001572	0.00927	108
Cr 267.716	0.136730412	0.137652362	0.137191387	0.132	104
Cu 327.393	0.715153403	0.720991073	0.718072238	0.677	106
Fe 259.939	0.913585704	0.915318141	0.914451923	0.93	98
Mn 257.610	0.358912563	0.357960513	0.358436538	0.366	98
Mo 202.031	0.043977706	0.044482171	0.044229939	0.0437	101
Ni 231.604	0.109153638	0.109458221	0.109305929	0.107	102
Pb 220.353	0.068196964	0.06857344	0.068385202	0.0668	102
Sb 206.836	0.043471699	0.042509311	0.042990505	0.0432	100
Se 196.026	0.074839851	0.074040603	0.074440227	0.0747	100
Tl 190.801	0.006336361	0.006970729	0.006653545	0.00717	93
V 292.402	0.480020599	0.481743476	0.480882038	0.456	105
Zn 206.200	0.712322194	0.711716612	0.712019403	0.706	101

## Conclusion

The FAST system coupled with the Optima 7300 DV has been shown to produce results that meet the requirements outlined in U.S. EPA Method SW-846 while doubling sample productivity when compared to analyses with conventional introduction systems. Since the FAST system eliminates virtually all of the rinse and read delay times, most of the time is now spent running samples, therefore increasing productivity. The user will also have much less torch and injector maintenance since the system will see the sample matrix for a much shorter period of time. Also, since the FAST reaches a steady state signal much more quickly than conventional sample introduction, instrument detection limits are improved almost 2-fold for many analytes. Consequently, the Optima 7300 DV when used in conjunction with the SC-FAST autosampler provides a rugged, automated sample introduction system that can significantly reduce labor costs and improve laboratory productivity.