

Automating the Workflow for the Analysis of Soils by ICP-OES

Productive analysis of high matrix samples using the Agilent 5800 ICP-OES with Advanced Dilution System



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Introduction

To manage the large sample loads that are typical of many environmental testing laboratories, ICP-OES users need instruments that deliver fast sample-to-sample analysis times, while generating consistently high-quality results. Agilent has developed the Advanced Dilution System (ADS 2) for Agilent ICP-OES (and ICP-MS) instruments. The ADS 2 is an intelligent autodilution system, which includes an Advanced Valve System (AVS). The system improves the productivity of ICP-OES workflows by automating many manual tasks throughout the analytical sequence.¹

The successful running of an ICP-OES method has traditionally relied on manual tasks performed by an analyst. Examples of these actions include the preparation of calibration standards and dilution of samples as a part of a general sample preparation procedure. Also, if initial measurements of the samples produce results that are above the calibration range and/or linear dynamic range, the analyst would further dilute the samples. Contamination from reagents or user errors can be introduced at each of these manual stages, potentially compromising the quality of the results.

Inclusion of a switching valve as a part of the ICP-OES sample introduction system can significantly increase sample throughput. The further inclusion of an autodilution accessory can assist with eliminating the user errors associated with performing dilutions manually. However, many autodilution accessories operate in a way that partially negate the sample throughput benefits of a switching valve, impacting sample throughput when dilutions are not being performed. With the ADS 2 autodilution system, however, users can enjoy all the benefits of automating labor-intensive and error-prone actions involved in preparation of calibration standards and sample dilution. All these benefits can be achieved without compromising on the sample throughput benefits achieved using the AVS 7 switching valve. When dilutions are not required, the accessory has minimal impact on the sample-to-sample measurement time.

In this study, an Agilent 5800 Vertical Dual View (VDV) ICP-OES fitted with an AVS 7 switching valve and ADS 2 autodilution system (Figure 1) was used to analyze soil samples according to the EPA 6010D standard method.² As the content of soil samples is highly variable, the method requires that a wide range of calibration standards are used. The ability of the ADS 2 to create linear calibrations and reactively dilute overrange samples enabled the 5800 ICP-OES with AVS 7 to obtain high-quality data and achieve sample-to-sample times suitable for high-throughput applications.

Soil samples were prepared by microwave assisted nitric acid (HNO₃) digestion according to EPA method 3051A.³ The 32 elements reported in this study include silver, aluminum, arsenic, boron, barium, beryllium, calcium, cadmium, cerium, cobalt, chromium, copper, iron, mercury, potassium, lithium, magnesium, manganese, molybdenum, sodium, nickel, phosphorus, lead, antimony, selenium, tin, strontium, titanium, thallium, vanadium, zinc, and zirconium.

Experimental

Instrumentation

ICP-OES

All measurements were carried out using the 5800 VDV ICP-OES operated using Agilent ICP Expert Pro software. The vertical torch of the 5800 ICP-OES ensures robust measurements over extended periods for a range of samples, including the highly variable soil samples that can be run using the EPA 6010D method. Also, the instrument's sophisticated VistaChip III detector provides high-speed continuous wavelength coverage, allowing the analyst to choose multiple wavelengths for each element without adding a time delay to the analysis.



Figure 1. Agilent 5800 VDV ICP-OES with integrated AVS switching valve (left), Agilent ADS 2 (middle), and Agilent SPS 4 autosampler (right).

Autodilution and sample preparation system

For autodilution, fast sample analysis, and high sample throughput, the 5800 VDV ICP-OES was fitted with the ADS 2 and an Agilent SPS 4 autosampler (Figure 1).

The ADS 2 is a dual-syringe, three-valve autodilution system that is located next to the instrument and is fully controlled via the ICP Expert Pro software*. When performing an autodilution, the syringes rapidly deliver diluent and sample into a loop at a precise ratio to achieve dilution factors between 2 and 400. When not performing an autodilution, a switching valve allows the sample to bypass the ADS 2 system almost entirely. This design ensures that the benefits of fast sample uptake and high sample throughput are maintained when samples do not require dilution.

The 5800 ICP-OES was fitted with a double-pass glass cyclonic spray chamber, Easy-fit demountable VDV torch with a 1.8 mm injector, and SeaSpray nebulizer. Instrument operating conditions are listed in Tables 1 to 3.

Table 1. Agilent 5800 VDV ICP-OES instrument and method parameters.

Parameter	Setting	
	Axial	Radial
Viewing Mode	Axial	Radial
Read Time (s)	10	10
Replicates	3	3
Sample Uptake Delay (s)	0	
Stabilization Time (s)	10	0
Rinse Time (s)	0	
Pump Speed (rpm)	12	
RF Power (kW)	1.2	
Aux Flow (L/min)	1	
Plasma Flow (L/min)	12	
Nebulizer Flow (L/min)	0.7	
Viewing Height (mm)	NA	8
Sample Pump Tubing	White-white	
Internal Standard Pump Tubing	Black-black	
Waste Pump Tubing	Blue-blue	
Background Correction	Off-peak left/right*	

*Off-peak background correction and inter-element correction (IEC) are typically used by analysts running the US EPA 6010D method.

Table 2. Agilent AVS 7 switching valve system parameters.

Parameter	Setting
Sample Loop Size (mL)	1.5
Pump Rate - Uptake (mL/min)	40
Pump Rate - Inject (mL/min)	7
Valve Uptake Delay (s)	11
Bubble Inject Time (s)	1.4
Pre-emptive Rinse Time (s)	2

Table 3. Agilent ADS 2 autodilution system parameters.

Parameter	Setting
Dilution Loop Size (mL)	1.5
Carrier Syringe Volume (mL)	5
Diluent Syringe Volume (mL)	10

Standard and sample preparation

Calibration standards

The calibration standard stock solutions and interference correction standards were prepared from various single-element stock solutions bought from High-Purity Standards (Charleston, SC, USA)*. Four high-concentration stock solutions comprising different combinations of the single-element standards were prepared in 10% HNO₃.

Multiple dilutions of the calibration standard stock solutions were then automatically prepared inline and introduced to the 5800 ICP-OES by the ADS 2 system. The calibration standards were analyzed at dilution factors of 100, 10, and 1 (undiluted). If the calibration range needs to cover more orders of magnitude, the ADS 2 system allows for multiple separate stock standards containing elements at different concentrations to be used.

Reference materials and samples

The accuracy of the method was evaluated by analyzing three NIST standard reference materials (SRMs): 2709a San Joaquin Soil, 2710a Montana Soil I, and 2711a Montana Soil II. An internal standard solution (IS), containing 5 ppm yttrium (Y), 5 ppm lutetium (Lu), 5 ppm iridium (Ir), and 100 ppm rubidium (Rb) in 10% HNO₃ was automatically added inline to all solutions by the AVS 7.

Sample preparation

The soil SRM samples were prepared for analysis according to the guidelines given in EPA 3051A. Around 0.75 g of each sample was accurately weighed and transferred to a clean quartz microwave vessel. Samples were left to predigest in 6 mL of 18 MΩ de-ionized (DI) water (Millipore) and 6 mL of HNO₃ (Merck) for approximately 15 minutes. The vessel was then capped and placed in a CEM Blade Microwave Digestion System (CEM Corporation, NC, USA) for digestion using the program given in Table 4. Once cooled, the solutions were made up to 50 mL with DI water. The samples were thoroughly mixed using a vortex mixer and then centrifuged at 3000 rpm for 10 minutes.

*Agilent single-element standards are also available.

Table 4. Microwave method parameters.

Parameter	Setting
Temperature (°C)	115
Pressure (psi)	700
Ramp (min)	5
Hold (min)	10

Prescriptive autodilution

The ADS 2 autodilution system can be used to perform additional prescriptive dilution of the sample. The analyst specifies a dilution factor in the ICP Expert software and the ADS 2 will then perform the dilution automatically as part of the worksheet run. Prescriptive autodilution is a useful tool for labs that traditionally perform a manual dilution of some or all samples before measurement. This pre-dilution is typically performed for samples that need an extra dilution step after initial preparation, samples with known overrange elements (especially hard to rinse elements like boron), or excessively high matrix samples. Prescriptive autodilution can also be used to prepare quality control (QC) solutions such as initial and continuing calibration verification (ICV, CCV), and low level (LL)QC solutions at a known dilution factor from a pre-made stock solution. Automating the preparation of QC solutions removes another potential source of error and allows the user to perform data analysis with the certainty that the solutions have been prepared correctly. The ADS 2 was used to prepare the QC solutions in this study.

Reactive autodilution and result summaries

The ADS 2 system performs automated dilution of any samples that exceed the QC parameters. If a sample exceeds the concentration limits defined by the user, the ICP Expert software calculates the appropriate dilution factor needed to bring the out-of-range analytes within the calibration range. The relevant sample is then reanalyzed following autodilution.

ADS 2 users have a high degree of control over which results trigger a reactive autodilution. Users can easily turn reactive autodilution on or off for their methods on a per wavelength basis and apply those settings across all samples in their worksheet. It is also possible to define precisely which wavelengths should trigger an autodilution for different batches of samples within a worksheet, or on a per sample basis. This option can allow for significant time savings in situations where it may not be necessary to achieve in-range results for all analytes in all samples.

Furthermore, users have a degree of control over which dilution factors will be generated by the software when a calibration overrange occurs. With the ICP Expert software, users can opt to reactively dilute to bring overrange concentrations down to either the middle or low-end of the analyte's calibration range. This option allows for dilutions to deliver the highest accuracy result by measuring the diluted concentration at a point where the calibration is known to be linear.

When multiple sets of results have been achieved for a sample through reanalysis of multiple dilutions, the ICP Expert software is able to provide a single 'summary' result to the user. The summary result consists of only the analyte results that are acceptable (according to the user's defined QC parameters) from each dilution. No analyst interaction is required for either the dilution or the creation of the result summary, providing significant labor savings and improving sample result acceptance rates.

Results and discussion

Instrument and method detection limits

Instrument detection limits (IDL) were determined using the 5800 VDV ICP-OES operating conditions given in Table 1. Once the IDLs had been determined, a spiked solution was prepared at a concentration of 300 to 500 times the IDL in 10% HNO₃ (the same matrix as used for the calibration solutions). This solution was then diluted for measurement at three to five times the IDL using the ADS 2 autodilution system. To determine the method detection limit (MDL), the solution was analyzed 10 times over three days. The MDL was calculated as three sigma of the spiked measurement (Table 5).

Table 5. MDLs in solution and in the sample based on 0.75 g of sample in 50 mL.

Element	Wavelength (nm)	MDL in Solution (mg/L)	MDL in Sample (mg/kg)	Element	Wavelength (nm)	MDL in Solution (mg/L)	MDL in Sample (mg/kg)
Ag	328.068	0.0004	0.0225	Mn	257.610	0.0001	0.0072
Al	237.312	0.0214	1.37	Mo	204.598	0.0011	0.0692
As	188.980	0.0039	0.252	Na	589.592	0.0071	0.454
B	249.678	0.0003	0.0158	Ni	231.604	0.0005	0.034
Ba	233.527	0.0002	0.0117	P	213.618	0.0004	0.0264
Be	313.107	2E-05	0.0013	Pb	220.353	0.0028	0.175
Ca	317.933	0.0036	0.231	Sb	217.582	0.0063	0.399
Cd	214.439	0.0001	0.0068	Se	196.026	0.0038	0.244
Ce	418.659	0.001	0.0653	Si	251.611	0.0013	0.0817
Co	230.786	0.0006	0.0348	Sn	189.925	0.0038	0.239
Cr	205.56	0.0003	0.0181	Sr	421.552	0.0001	0.0044
Cu	327.395	0.0004	0.0239	Ti	334.941	0.0001	0.0053
Fe	238.204	0.0008	0.0487	Tl	190.794	0.0046	0.29
Hg	184.887	0.001	0.0644	V	292.401	0.0008	0.0527
K	766.491	0.0903	5.75	Zn	206.2	0.0005	0.0331
Li	670.783	0.0012	0.0779	Zr	327.307	0.0002	0.0127
Mg	285.213	0.0005	0.0295				

Autocalibration and linearity

Figure 2 displays representative calibration curves for a major (Al) and trace (As) element. All calibrations maintained a minimum correlation coefficient ≥ 0.9998 . Each calibration for all elements was created by the ADS 2 auto diluting single stock standards at 100x, 10x, and 1x dilution factors. The inclusion of a blank provided a four-point calibration for each element across a wide concentration range.

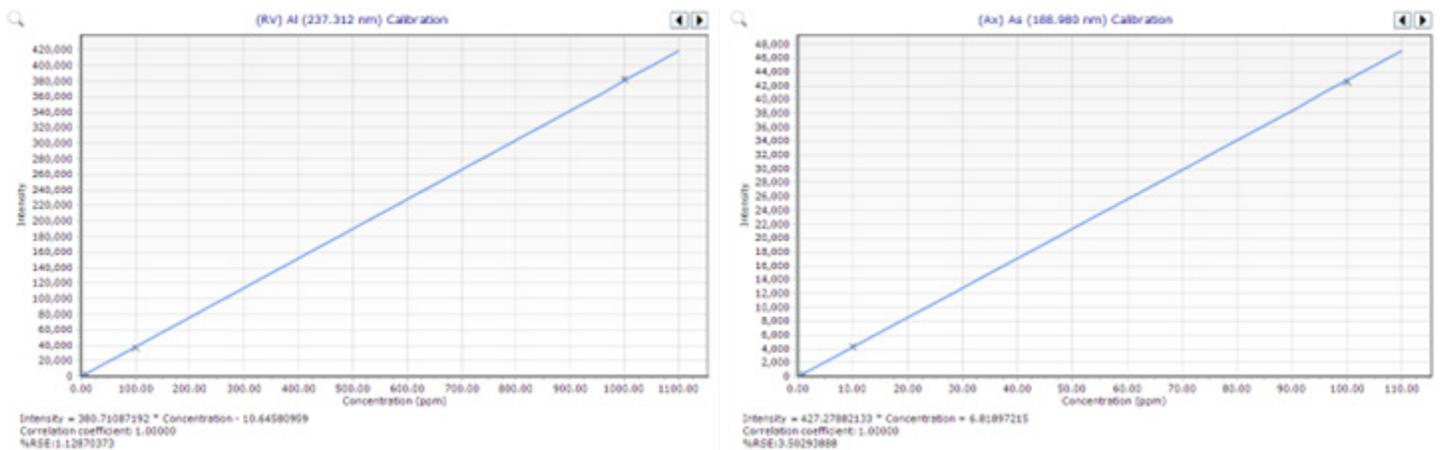


Figure 2. Representative calibration curves for Al and As containing a blank, 1, 10, and 100 ppm standards. The calibration points were generated through dilution of single element stock standards using the Agilent ADS 2 autodilution system.

SRM and matrix spike (MS) recovery tests

Table 6 outlines the results from the analysis of the three soil SRMs using the 5800 VDV ICP-OES with ADS 2. All elements were measured within the expected range following the EPA 3051A HNO₃ microwave extraction procedure. Soils typically contain elements over a wide concentration range, with metals such as Al, Ca, Fe, K, Mg, and Na often present at high levels.

Sample dilution of the SRMs was therefore necessary to ensure that in-range results could be reported for all analytes. These dilutions were done automatically using the reactive dilution capability of the ADS 2, and the ICP Expert software automatically collated a single summary of the results for each sample.

Table 6. Results for three soil SRMs measured using the Agilent 5800 VDV ICP-OES with ADS 2. All units: mg/kg.

Element	Dilution Used	SRM 2709a			SRM 2710a			SRM 2711a		
		Lower Limit	Upper Limit	Measured	Lower Limit	Upper Limit	Measured	Lower Limit	Upper Limit	Measured
Al	10	13000	17000	16262	8200	12000	9441	9800	15000	14075
Ca	10	12000	14000	13748	1700	2000	1855	14000	17000	16028
Fe	10	22000	26000	25923	30000	36000	34262	14000	18000	15464
K	10	2600	4000	3023	3800	4700	4189	3300	4600	4174
Mg	10	9700	11000	10932	3200	3600	3427	5000	6600	6292
Na	10	460	610	527	550	650	582	140	210	145
Ag	1	0.14	4.1	0.6	31	39	3.8	4	6.1	5.5
As	1	6.4	10.0	10.0	1300	1600	1577	81	110	102
B	1			30.0			3.5			7.2
Ba	1	350	400	384	490	540	515	170	220	185
Be	1	0.5	0.72	0.7	0.24	0.51	0.5	0.73	1.10	1.05
Cd	1	0.33	0.66	0.33	9.6	12	12.0	43	56	53
Ce	1			30.1			23.1			42.1
Co	1	8.2	13	10.2	2.8	5.2	3.0	5.5	9	7.0
Cr	1	46	67	55.7	9.2	11	9.2	12	18	13.8
Cu	1	24	28	28	3100	3500	3242	120	160	130
Hg	1	0.79	0.92	0.8	9.3	12	9.9	6.3	8.3	7.7
Li	1			28.2			9.3			11.3
Mn	1	380	450	450	1500	1800	1578	450	580	504
Mo	1			1.1			7.5			1.1
Ni	1	59	71	70.5	4.8	6	5.1	13	18	15.0
P	1			567			915			715
Pb	1	8.1	11	10.0	4700	5800	5259	1100	1400	1294
Sb	1	1.2	1.5	1.2	5	12	6.2	2.8	7.2	3.1
Se	1	0.69	1.9	0.8	1.5	2.6	2.1	1.4	1.9	1.8
Sn	1			0.8			7.6			2.6
Sr	1			98.8			53.9			36.7
Ti	1			147			622			174
Tl	1	0.74	1.6	0.8	1.3	3.6	3.2	0.71	3.1	2.8
V	1	43	71	53.5	35	43	36.2	24	34	27.5
Zn	1	69	87	84.9	3300	4400	3882	310	380	361
Zr	1			5.6			8.1			8.1

The results given in Table 6 were obtained without the addition of HCl, which is often added to samples to ensure the stability of trace levels of elements such as Ag, Sb, and Hg in solution. Recoveries were obtained within the expected range for Ag in two of the SRMs and for Sb and Hg in all three SRMs. To determine the accuracy of the measurement of all trace elements without the addition of HCl, 0.4 mL of a spiked solution was added to 10 mL of each SRM digest resulting in the spike addition shown in the 'Spiked Concentration' column in Table 7. The spike recovery results for all elements, including Ag, Sb, and Hg were within the $\pm 25\%$ acceptance criteria specified in EPA 6010D. The measured and expected values for the spiked samples are shown in mg/L in solution.

Table 7. Spike recovery results for trace elements added to the soil SRM digests. All units: mg/L.

Element	Spiked Concentration	SRM 2709a			SRM 2710a			SRM 2711a		
		Measured	Expected	Recovery %	Measured	Expected	Recovery %	Measured	Expected	Recovery %
Ag	0.96	1.04	0.97	107	1.05	1.02	103	1.11	1.04	107
As	0.96	1.09	1.11	99	23.58	23.76	81	2.45	2.43	102
B	0.10	0.53	0.53	103	0.14	0.15	98	0.21	0.20	106
Be	0.10	0.11	0.11	102	0.10	0.10	99	0.11	0.11	103
Cd	0.10	0.10	0.10	98	0.27	0.27	98	0.87	0.86	116
Ce	0.96	1.39	1.39	99	1.27	1.29	98	1.57	1.57	100
Co	0.10	0.23	0.24	92	0.13	0.14	93	0.19	0.20	97
Cr	0.96	1.76	1.76	100	1.08	1.09	98	1.18	1.16	102
Cu	0.96	1.33	1.36	97	47.69	47.85	84	2.85	2.83	101
Hg	0.10	0.11	0.11	103	0.23	0.24	96	0.21	0.21	106
Li	0.96	1.37	1.37	100	1.07	1.10	97	1.15	1.13	102
Mo	0.10	0.11	0.11	102	0.20	0.20	100	0.12	0.11	104
Ni	0.10	1.10	1.11	93	0.17	0.17	96	0.31	0.31	101
P	0.96	9.06	9.13	93	14.10	14.20	90	11.39	11.30	110
Sb	0.10	0.11	0.11	97	0.20	0.19	109	0.14	0.14	101
Se	0.10	0.11	0.11	98	0.11	0.13	84	0.14	0.12	118
Sn	0.10	0.11	0.11	99	0.20	0.21	96	0.14	0.13	102
Ti	0.96	3.19	3.09	111	10.07	9.96	111	3.59	3.47	112
Tl	0.10	0.10	0.11	96	0.14	0.14	94	0.13	0.14	89
V	0.96	1.76	1.73	103	1.49	1.48	101	1.41	1.36	106
Zr	0.10	0.17	0.18	96	0.21	0.21	93	0.21	0.21	99
Sr	0.10	1.52	1.52	99	0.87	0.88	96	0.64	0.63	118

Long-term stability

Figure 3 shows the level of dilution accuracy that is achievable using the ADS 2 to prepare QC solutions. To determine the stability of the 5800 VDV ICP-OES and the consistency of repeated auto dilutions by the ADS 2 over time, 258 solutions were analyzed over seven hours. The solutions consisted of a digested soil sample and the CCV solution, which was created through 10x dilution from a stock for each measurement using the ADS 2 autodilution system. The CCV was measured after every 10 samples. To show the stability of the 5800 ICP-OES and the dilution consistency of the ADS 2 over an extended run, the recovery of the CCV solution was plotted against time. All results for the CCV were within $\pm 10\%$ of expected values, and the RSD was $<2\%$ for all elements.

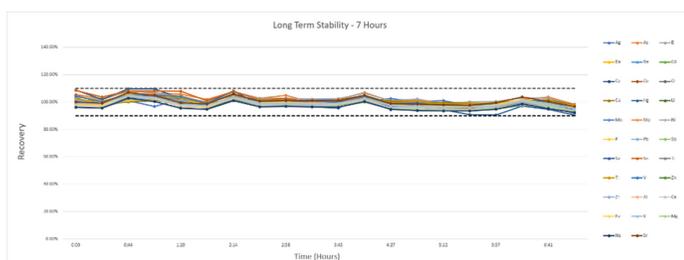


Figure 3. Long-term stability test showing recovery of the CCV solution analyzed over seven hours. The dotted lines show the $\pm 10\%$ control limits.

Sample throughput

Table 8 shows the sample-to-sample times achieved by this method at several dilution factors using the ADS 2. The timings were taken by averaging the sample-to-sample times across 10 duplicate measurements of samples at each dilution factor. All timings include the 60 s of total measurement time, as outlined in Table 1.

Table 8. Sample-to-sample times achieved using the ADS 2 at several different dilution factors.

Dilution Factor	Total Sample Time
1 (Undiluted)	1 min 30 s
10	1 min 56 s
100	1 min 58 s
200	2 min 1 s

The undiluted sample-to-sample time achieved in this application adds only two seconds to the timing achieved in a previous study on the analysis of waste samples by 5800 ICP-OES with AVS 7 according to US EPA Method 6010D.⁴ No autodilution system was used in the previous study. The timings highlight the minimal impact that the ADS 2 has on sample throughput when sample dilution is not required.

Conclusion

The Agilent 5800 VDV ICP-OES is the ideal instrument for labs looking to achieve excellent result accuracy and high sample throughput while adhering to the requirements of US EPA 6010D methodology. Integrating the Agilent ADS 2 autodilution system with the 5800 ICP-OES and AVS 7 switching valve improves the efficiency of the workflow, especially for the analysis of complex samples, such as soil. Benefits of the Agilent ICP-OES workflow automation system for the analysis of environmental samples include:

- Autocalibration that performs automated, real-time creation of multilevel calibrations from single initial stock solutions. Dilutions of up to 400 times are achievable using the ADS 2, allowing for autocalibrations to span a wide concentration range. The system also generates exceptionally repeatable dilutions over long time periods ensuing consistent day-to-day calibration.
- Prescriptive autodilution that enables an analyst to specify a dilution factor for a sample premeasurement and have the ADS 2 perform that dilution automatically as a part of the worksheet run. Compared to more traditional manual dilutions performed in many labs, prescriptive autodilution allows for considerable time saving, reduces the risk of human error, and lowers the risk of contamination.
- Reactive autodilution prompts the ADS 2 to automatically dilute samples if an analyte or internal standard result falls outside the acceptable ranges defined by the user. This intelligent autodilution function significantly reduces the need for samples to be reanalyzed at the end of a run, improving turnaround times and reducing overall cost-per-sample.
- The result summary capability of the Agilent ICP Expert software saves further time by automatically collating the results achieved across multiple dilutions of a sample into a single, easy-to-interpret row on the analysis page.

The 5800 ICP-OES with ADS 2 provided MDLs below 1 mg/kg for most elements in the sample, highlighting the sensitivity of the method for the multi-elemental analysis of soils. The recoveries of elements in the soil SRMs within the expected range confirmed the suitability of the sample preparation method. Trace analytes spiked into the soil SRMs recovered within $\pm 20\%$, demonstrating the accuracy of the method. The 5800 VDV ICP-OES displayed excellent stability over seven hours, with QC measurement recoveries between $\pm 10\%$ and average %RSDs below 2%.

References

1. Agilent Advanced Dilution System (ADS 2) – Technical overview, Agilent publication, [5994-7211EN](#)
2. EPA Method 6010D (SW-846): Inductively Coupled Plasma - Atomic Emission Spectrometry, Revision 5, July 2018, accessed January 2024, <https://www.epa.gov/esam/epa-method-6010d-sw-846-inductively-coupled-plasma-atomic-emission-spectrometry>
3. EPA Method 3051A Microwave Assisted Acid Digestion of Sediments, Sludges, Soils, and Oils, Revision 1, February 2007, accessed January 2024, <https://www.epa.gov/sites/default/files/2015-12/documents/3051a.pdf>
4. Riles, P., Analysis of Waste Samples According to US EPA Method 6010D, Agilent publication, [5994-2027EN](#)

Note: A consumables guide for the analysis of waste samples using ICP-OES is [available](#).

Agilent part numbers

Description	Part Number
Easy-fit 1.8 mm semi-demountable torch for 5000 series VDV/SVDV ICP-OES	G8010-60228
Double-pass spray chamber, glass cyclonic design with ball joint socket and UniFit drain outlet, for Agilent 5000 series ICP-OES	G8010-60256
SeaSpray concentric glass nebulizer for 5000 series ICP-OES	G8010-60255
Peristaltic pump tubing, white/white, 12/pk	3710034400
Peristaltic pump tubing, black/black, 12/pk	3710027200
Peristaltic pump tubing, blue/blue, 12/pk.	3710034600

www.agilent.com/chem/5800icp-oes

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Agilent Multi-element Quality Control Standard 27	5190-9418
Syringe, 5 mL, ADS diluter (for ICP-OES and ICP-MS carrier)	5299-0037
Syringe, 10 mL, ADS diluter (for ICP-OES diluent)	5299-0038
Sample loop ADS/AVS 1.50 mL 1.00 mm ID 1/pk	5005-0425
Diluent/carrier bottle kit for ADS 2 and Autosampler (6 L HDPE)	5005-0435
Aluminum (Al) standard, 10,000 µg/mL, in 5% HNO ₃ , 500 mL	5190-8353
Antimony (Sb) standard, 10,000 µg/mL, in 1% HNO ₃ , 1% tartaric acid, 500 mL	5190-8355
Arsenic (As) standard, 10,000 µg/mL, in 5% HNO ₃ , 500 mL	5190-8357
Barium (Ba) standard, 10,000 µg/mL, in 5% HNO ₃ , 500 mL	5190-8359
Beryllium (Be) standard, 10,000 µg/mL, in 5% HNO ₃ , 500 mL	5190-8361
Boron (B) standard, 10,000 µg/mL, in 1% NH ₄ OH, 500 mL	5190-8365
Cadmium (Cd) standard, 10,000 µg/mL, in 5% HNO ₃ , 500 mL	5190-8367
Calcium (Ca) standard, 10,000 µg/mL, in 5% HNO ₃ , 500 mL	5190-8369
Cerium (Ce) standard, 10,000 µg/mL, in 5% HNO ₃ , 500 mL	5190-8371
Chromium (Cr) standard, 10,000 µg/mL, in 5% HNO ₃ , 500 mL	5190-8375
Cobalt (Co) standard, 10,000 µg/mL, in 5% HNO ₃ , 500 mL	5190-8377
Copper (Cu) standard, 10,000 µg/mL, in 5% HNO ₃ , 500 mL	5190-8379
Lead (Pb) standard, 10,000 µg/mL, in 5% HNO ₃ , 500 mL	5190-8407
Lithium (Li) standard, 10,000 µg/mL, in 5% HNO ₃ , 500 mL	5190-8409
Magnesium (Mg) standard, 10,000 µg/mL, in 5% HNO ₃ , 500 mL	5190-8413
Manganese (Mn) standard, 10,000 µg/mL, in 5% HNO ₃ , 500 mL	5190-8415
Mercury (Hg) standard, 10,000 µg/mL, in 5% HNO ₃ , 500 mL	5190-8417
Nickel (Ni) standard, 10,000 µg/mL, in 5% HNO ₃ , 500 mL	5190-8423
Phosphorus (P) standard, 10,000 µg/mL, in 5% HNO ₃ , 500 mL	5190-8429
Potassium (K) standard, 10,000 µg/mL, in 5% HNO ₃ , 500 mL	5190-8433
Selenium (Se) standard, 10,000 µg/mL, in 5% HNO ₃ , 500 mL	5190-8449
Silver (Ag) standard, 10,000 µg/mL, in 5% HNO ₃ , 500 mL	5190-8453
Sodium (Na) standard, for ICP-OES and MP-AES, 10,000 µg/mL 500 mL	5190-8206
Strontium (Sr) standard, for ICP-OES and MP-AES, 10,000 µg/mL 500 mL	5190-8208
Titanium (Ti) standard, 10,000 µg/mL, in H ₂ O, 500 mL	5190-8225
Vanadium (V) standard, 10,000 µg/mL, in 5% HNO ₃ , 500 mL	5190-8229
Zinc (Zn) standard, 10,000 µg/mL, in 5% HNO ₃ , 500 mL	5190-8235
Iron (Fe) standard, 10,000 µg/mL, in 5% HNO ₃ , 100 mL	5190-8402
Molybdenum (Mo) standard, 10,000 µg/mL, in 1% NH ₄ OH, 100 mL	5190-8418
Thallium (Tl) standard, 10,000 µg/mL, in 5% HNO ₃ , 100 mL	5190-8217
Tin (Sn) standard, 10,000 µg/mL, in 20% HCl, 100 mL	5190-8221
Zirconium (Zr) standard, 10,000 µg/mL, in 5% HNO ₃ , 100 mL	5190-8236