Drinking Water

Perfluoroalkyl Substances **(PFAS)** Testing Guide

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Drinking Water

Drinking water has received the majority attention as a primary source of PFAS exposure. Drinking water has also been the most widely studied, notably through the USEPA Unregulated Contaminant Monitoring Rule (UCMR) program, initially using EPA Method 537.1 and more recently using EPA Method 533 with its expanded analyte list and attention to shorter chain PFAS and the GenX compounds. As analytical technology advances, method developers continue to create analytical methods for PFAS in drinking water with expanded analyte lists and advanced techniques, such as large volume direct injection and on-line Solid Phase Extraction (SPE). Although some of these modifications are not considered "official methods" for regulatory purposes, they are widely used for investigation and problem assessment.

1. EPA Method 537.1

PFAS in Drinking Water Using Strata™ SDB-L Solid Phase Extraction (SPE) and a Luna™ Omega 1.6 µm PS C18 UHPLC Column

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Overview

This application demonstrates the suitability and advantage of using Strata SDB-L SPE along with a Luna Omega 1.6 µm PS C18 UHPLC column in the performance of EPA Method 537.1, the official SPE liquid chromatography/tandem mass spectrometry (LC-MS/MS) method for the determination of selected per- and polyfluorinated alkyl substances (PFAS) in drinking water in the United States.

Introduction

EPA Method 537 Version 1.1, was first published in 2009 for use in the Third Unregulated Contaminant Rule (UCMR3) nationwide drinking water survey. This original PFAS method specified 14 target PFAS analytes, including Perfluorooctanesulfonic acid (PFOS) and perfluorooctanoic acid (PFOA), the two PFAS compounds of largest historic use. However, both the production and use of PFOS and PFOA were discontinued between 2000 and 2015 and were replaced by shorter chain PFAS compounds (informally referred to as the "GenX" compounds), which were thought to be less persistent in the environment and less toxic. Therefore, EPA Method 537.1 was introduced in 2018 as an update to EPA Method 537 Version 1.1. It included the original 14 PFAS analytes and added 4 of the shorter chain PFAS compounds for a total of 18 analytes. As originally published, EPA Method 537.1 specified that only SPE cartridges based upon SDVB (styrenedivinylbenzene) polymers could be used in the extraction procedure, owing to low recovery of the short chain PFAS compounds on non-SDVB polymers. This stipulation was continued in the most recent update: Method 537.1 V2, published in March, 2020.[1]

In this technical note we present analytical results for the analysis of drinking water by EPA Method 537.1 using Strata SDB-L SPE (based upon a SDVB polymer) and a Luna Omega 1.6 µm PS C18 UHPLC column. The data demonstrates excellent recovery for all 18 PFAS analytes on Strata SDB-L. Likewise, Luna Omega 1.6 µm PS C18 provides outstanding column efficiency and analyte resolution for greater method sensitivity and shorter run times.

Materials and Methods

Solid Phase Extraction Protocol

Following the procedures of EPA Method 537.1, V2, Sections 6.9 - 6.11 and 11.3 - 11.4

Cartridge: Strata SDB-L, 500 mg/6 mL
Part No.: 8B-S014-HCH
Load: 250 mL sample that has been fortified with surrogates
Elution: 2x 3 mL Methanol
Dry Down: With Nitrogen in a heated water bath
Reconstitute: Adjust final volume to 1 mL with 96:4 Water:Methanol (v/v) and add internal standards

HPLC Conditions

Following the procedures of EPA Method 537.1, V2, Sections 6.9 - 6.11 and 11.3 - 11.4

Column: Luna Omega 1.6 µm PS C18
Dimension: 100 x 2.1 mm
Part No.: 00D-4752-AN
Mobile Phase: A: 0.1 % Acetic Acid in Water
B: Methanol

Gradient:

Time (min)	%B
0	20
0.5	30
7	90
7.5	100
9	100

Flow Rate: 0.7 mL/min
Injection Volume: 4 µL
LC System: Agilent® 1260 Series HPLC
Detection: Agilent Ultivo™ Triple Quadrupole MS

Data and Results

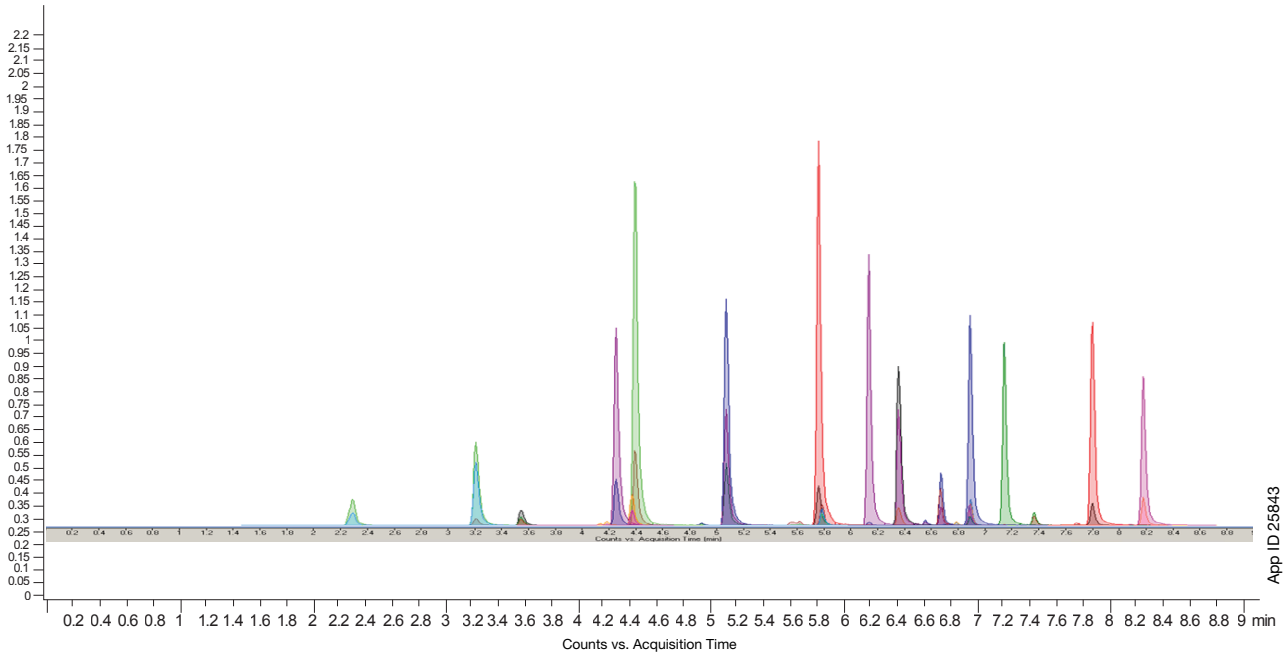
PFAS Target Analytes and UHPLC Retention Times

Analyte	RT (min)	Internal Standard
PFBS	2.29	13C4 -PFOS
PFHxA	3.20	13C2 -PFOA
HFPO-DA	3.55	13C2 -PFOA
PFHpA	4.24	13C2 -PFOA
PFHxS	4.39	13C4 -PFOS
ADONA	4.41	13C2 -PFOA
PFOA	5.08	13C2 -PFOA
PFOS	5.72	13C4 -PFOS
PFNA	5.77	13C2 -PFOA
9Cl-PF3ONS	6.15	13C4 -PFOS
PFDA	6.35	13C2 -PFOA
NMeFOSAA	6.70	d3 -NMeFOSAA
PFUnA	6.83	13C2 -PFOA
NEtFOSAA	6.88	d3 -NMeFOSAA
11Cl-PF3OUdS	7.17	13C4 -PFOS
PFDoA	7.37	13C2 -PFOA
PFTrDA	7.80	13C2 -PFOA
PFTA	8.18	13C2 -PFOA

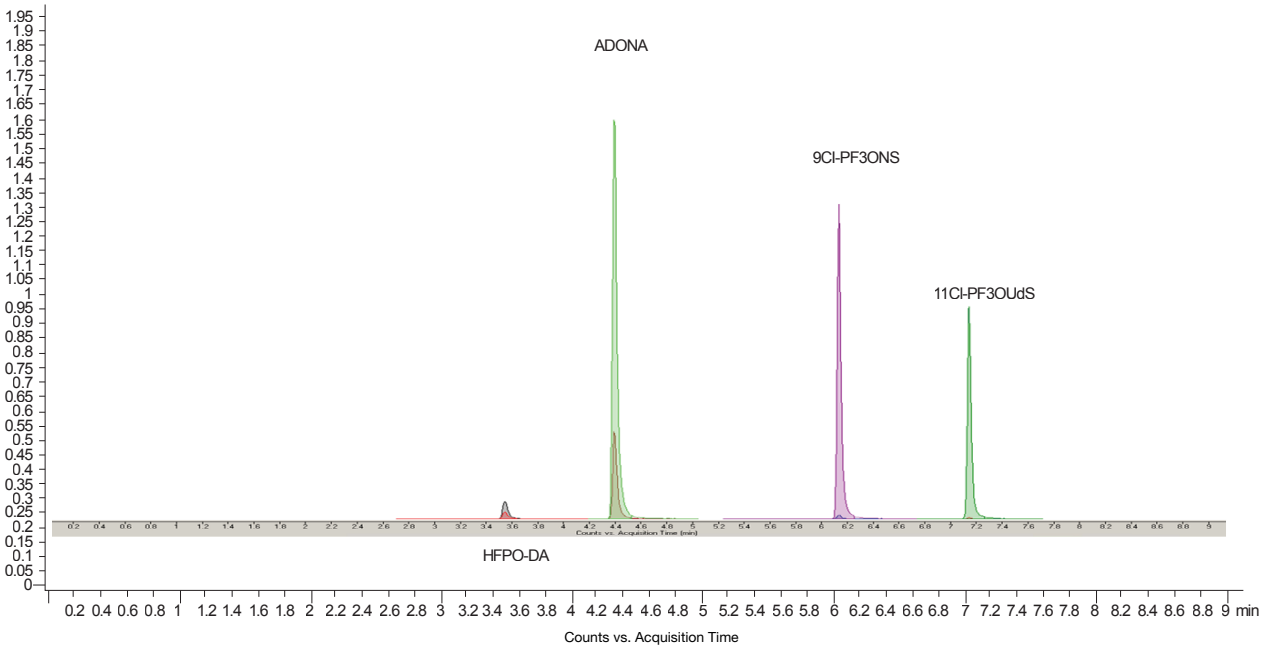
1. EPA Method 537.1 (continued)

Full PFAS Target Analytes

PFAS Replacement Compounds



Short Chain ("Gen X") PFAS Analytes



1. EPA Method 537.1 (continued)

Method Precision and Accuracy from the Analysis of 50 Consecutive Laboratory Control Samples (LCS)

	Mean % Recovery	Standard Deviation
13C2-PFDA	106	15.8
13C2-PFHxA	108	18.2
d5-EtFOSAA	104	19.8
13C2-HFPO-DA	104	17.1
11Cl-PF3OUdS	105	10.9
9Cl-PF3OUNS	104	11.9
ADONA	103	13.6
Et-FOSAA	111	13.8
HFPO-DA	104	15.6
Me-FOSAA	113	18.5
PFBS	104	14.7
PFDA	106	12
PFDoA	105	17.4
PFHpA	111	14.8
PFHxA	109	14.1
PFHxS	108	15.1
PFNA	109	12.7
PFOA	109	12.5
PFOS	111	13
PFTeDA	103	14.6
PFTrDA	104	13.7
PFUnA	107	13.7

Discussion

These results fully demonstrate the suitability of the combination of Strata™ SDB-L 500 mg/6 mL and Luna™ Omega 1.6 µm PS C18 for use in EPA Method 537.1. Luna Omega 1.6 µm PS C18 provides excellent separation of all analytes, including the shorter chain "Gen X" compounds. The accuracy and precision of the data, as demonstrated by the analysis of 50 consecutive LCS samples, are well within the requirements of the method. However, beyond meeting method requirements, the additional advantage of the Strata/Luna combination is its contribution to environmental laboratory productivity. In the published version of EPA Method 537.1, the run time for the 25 analytes (18 target analytes and 7 internal standards) was 25 minutes. In the data presented here, the equivalent run time is 8.5 minutes. Which represents a nearly 3-fold productivity increase in the chromatographic step compared to the method as originally published. This illustration of EPA Method 537.1 suitability and productivity demonstrates why the combination of Strata SDB-L and Luna Omega 1.6 µm PS C18 has become the environmental testing industry's go-to approach for PFAS drinking water analysis, regardless of the instrumentation platform used.

Conclusion

EPA Method 537.1 is an official US regulatory method to be used by environmental laboratories to quantitate PFAS in drinking water. Health advisory drinking water limits for PFOS and PFOA have been established at 70 µg/L and it is expected that official drinking water limits will be promulgated for these two compounds, and for additional PFAS in the near future. As drinking water utilities and water resource agencies opt (or are required) to routinely test for PFAS in drinking water or water supplies, EPA 537.1 is destined to transition from its prior status as an exotic analytical method to a common environmental laboratory test. The Strata/Luna combination is already widely used in EPA Method 537.1 testing in the United States owing to the combination of high accuracy and precision and reduced analysis time. These properties will allow for higher sample throughput at lower detection levels as PFAS water testing becomes ever more prevalent.

Acknowledgments

We would like to acknowledge the invaluable assistance of Weck Laboratories in demonstrating the suitability of Strata SDB-L and Luna Omega 1.6 µm PS C18 for this essential environmental application.

References

1. https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=348508&Lab=CESER&simpleSearch=0&showCriteria=2&searchAll=537.1&TIMSType=&dateBeginPublishedPresented=03%2F24%2F2018

PFAS Certified Reference Material
for EPA Methods 533 and 537.1

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Certified Reference Materials

To support U.S. EPA Methods for the determination of per- and polyfluorinated alkyl substances (PFAS) in drinking water, Phenova, a part of Phenomenex, has prepared native mixtures, at the same concentrations, that allow analytical labs to simply dilute the CRM and quickly make their standard curve. In addition, analytes are listed as acids to make calculations easier. The mixtures are technical grade standards that include branched and linear isomers.

Product	PN	Qty.	Conc.
EPA 533 mix	AL0-101838	1 mL	2 µg / mL in methanol
EPA 537.1 mix	AL0-101839	1 mL	2 µg / mL in methanol
EPA 533 + 537.1 mix	AL0-101840	1 mL	2 µg / mL in methanol

Part Number		AL0-101939	AL0-101838	AL0-101840
		CRMs are 2 µg / mL in methanol ea. In 1 mL volume		
	CAS RN	EPA 537.1	EPA 533	EPA 533 + 537.1
Perfluoroalkyl carboxylic acid (PFCA)				
Perfluorobutanoic acid (PFBA)	375-22-4	NA	✓	✓
Perfluoropentanoic acid (PFPeA)	2706-90-3	NA	✓	✓
Perfluorohexanoic acid (PFHxA)	307-24-4	✓	✓	✓
Perfluoroheptanoic acid (PFHpA)	375-85-9	✓	✓	✓
Perfluorooctanoic acid - br/lin (PFOA)	335-67-1	✓	✓	✓
Perfluorononanoic acid (PFNA)	375-95-1	✓	✓	✓
Perfluorodecanoic acid (PFDA)	335-76-2	✓	✓	✓
Perfluoroundecanoic acid (PFUnA)	2058-94-8	✓	✓	✓
Perfluorododecanoic acid (PFDoA)	307-55-1	✓	✓	✓
Perfluorotridecanoic acid (PFTrDA)	72629-94-8	✓	NA	✓
Perfluorotetradecanoic acid (PFTeDA)	376-06-7	✓	NA	✓
Perfluoroalkane sulfonic acid (PFSA)				
Perfluorobutanesulfonic acid (PFBS)	375-73-5	✓	✓	✓
Perfluoropentanesulfonic acid (PFPeS)	2706-91-4	NA	✓	✓
Perfluorohexanesulfonic acid - br/lin (PFHxS)	355-46-4	✓	✓	✓
Perfluoroheptanesulfonic acid (PFHpS)	375-92-8	NA	✓	✓
Perfluorooctanesulfonic acid - br/lin (PFOS)	1763-23-1	✓	✓	✓
Perfluoroalkane sulfonamides (FASA) and derivatives				
N-methyl perfluorooctanesulfonamidoacetic acid - br/lin (NMeFOSAA)	2355-31-9	✓	NA	✓
N-ethyl perfluorooctanesulfonamidoacetic acid - br/lin (NEtFOSAA)	2991-50-6	✓	NA	✓
Fluorotelomer sulfonic acid (FTSA)				
4:2 Fluorotelomer sulfonic acid (4:2 FTS)	757124-72-4	NA	✓	✓
6:2 Fluorotelomer sulfonic acid (6:2 FTS)	27619-97-2	NA	✓	✓
8:2 Fluorotelomer sulfonic acid (8:2 FTS)	39108-34-4	NA	✓	✓
Perfluoroalkyl ether carboxylic acid (PFECA)				
Perfluoro-3-methoxypropanoic acid (PFMPA)	377-73-1	NA	✓	✓
Perfluoro-4-methoxybutanoic acid (PFMBA)	863090-89-5	NA	✓	✓
Hexafluoropropylene oxide dimer acid (HFPO-DA/GenX)	13252-13-6	✓	✓	✓
Nonafluoro-3,6-dioxaheptanoic acid (NFDHA)	151772-58-6	NA	✓	✓
4,8-dioxa-3H-perfluorononanoic acid (ADONA)	919005-14-4	✓	✓	✓
Polyfluoroalkyl ether sulfonic acid (PFESA)				
Perfluoro(2-ethoxyethane)sulfonic acid (PFEESA)	113507-82-7	NA	✓	✓
9-Chlorohexadecafluoro-3-oxanone-1-sulfonic acid (9Cl-PF3ONS)	756426-58-1	✓	✓	✓
11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11Cl-PF3OUdS)	763051-92-9	✓	✓	✓

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2. EPA Method 533

PFAS in Drinking Water

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Introduction

The first official EPA method for Per- and Polyfluoroalkyl Substances (PFAS) was EPA 537 developed in 2009, in part to support the UCMR3 study for drinking water systems in the US. This method included 14 PFAS compounds, including both PFOS and PFOA, which were then considered to have potential impact on human health. In 2018, EPA 537.1 was introduced to include 4 of the "replacement" PFAS compounds which had replaced PFOA and PFOS in many manufacturing processes in the interim.

In 2019, EPA released their PFAS Action Plan, which outlined the steps that the EPA proposed to take to identify and regulate PFAS in the environment. The PFAS Action Plan called for the development and promulgation of new analytical methods that would allow scientists to effectively measure more PFAS compounds, with greater accuracy and precision. Published at the end of 2019, EPA 533 is the first of these new PFAS analytical methods.

EPA 533 is complementary to EPA 537.1. It analyzes 14 of the 18 compounds from EPA 537.1, plus an additional 11 "short chain" (C4-C12) PFAS compounds. Of the original EPA 537 and EPA 537.1 compounds, 4 were not included in EPA 533, since they had been shown not to be present in drinking water during the previous UCMR study. Of the new EPA 533 compounds, PFBA and PFPeA, had been intentionally excluded from EPA 537.1 because they were too polar to be extracted by a styrene divinylbenzene (SDVB) solid phase extraction (SPE) sorbent during the sample preparation step. However, EPA 533 was able to include these 2 compounds, along with the other short chain analytes, because this new method employs a polymeric weak anion-exchange (WAX) sorbent in the SPE sample preparation step which is very selective for the more polar/acidic PFAS analytes. An additional distinction of EPA 533 is that it uses the isotope dilution technique to enhance method accuracy and robustness.

Materials and Methods

The following is a summary of the prescribed experimental conditions taken from EPA 533. It should be noted that Strata™-X-AW and Gemini™ 3 µm C18 were the respective SPE sorbent and LC column used in the development of EPA 533 and in its subsequent multi-laboratory validation.

Sample Preparation Protocol

Pre-treatment: 100-250 mL sample is fortified with isotopically labeled analogues of the method analytes
Cartridge: Strata-X-AW 500 mg/6 mL
Part No.: 8B-S038-HCH
Load: Pass pre-treated sample through the cartridge
Wash 1: Aqueous Ammonium acetate followed by Methanol
Wash 2: Methanol
Elute: Ammonium hydroxide in Methanol
Dry Down: Under a gentle stream of Nitrogen in a heated water bath
Reconstitute: Adjust the final volume to 1 mL with 20 % Water in Methanol (v/v) before analyzing by LC-MS

LC Conditions

Column: Gemini 3 µm C18
Dimension: 50 x 2.0 mm
Part No.: 00B-4439-B0
Mobile Phase: A: 20 mM Ammonium Acetate
B: Methanol
Gradient:

Time (min)	%B
0	5
0.5	5
3	40
16	80
18	80
20	95
22	95
25	5
35	5

Flow Rate: 0.25 mL/min
Injection Volume: 2 µL
MS Detection: Electrospray Ionization Tandem Mass Spectrometer (ESI-MS/MS)

Table 1.
EPA Method Comparison

EPA 537.1	EPA 533
18 analytes	25 analytes (including 14 from 537.1 and 11 new short chain compounds)
SDVB SPE sorbent	WAX SPE sorbent
Isotopic Internal Standards	Isotopic Internal Standards plus Isotope Dilution standards for each analyte

2. EPA Method 533 (continued)

Results

Table 2.
Isotopically Labeled Isotope Performance Standards and Retention Times

Isotopes Analytes	RT (min)
$^{13}C_3$-PFBA	4.14
$^{13}C_2$-PFOA	12.19
$^{13}C_4$-PFOS	13.73

Table 3.
Isotope Dilution Analogues: RTs and Suggested Isotope Performance Standard References

Isotopically Labeled Analyte	RT (min)	Suggested Isotope Performance Standard
$^{13}C_4$-PFBA	4.14	$^{13}C_3$-PFBA
$^{13}C_5$-PFPeA	6.13	$^{13}C_3$-PFBA
$^{13}C_3$-PFBS	6.62	$^{13}C_4$-PFOS
$^{13}C_2$-4:2FTS	8.12	$^{13}C_4$-PFOS
$^{13}C_5$-PFHxA	8.35	$^{13}C_2$-PFOA
$^{13}C_3$-HFPO-DA	9.06	$^{13}C_2$-PFOA
$^{13}C_4$-PFHpA	10.34	$^{13}C_2$-PFOA
$^{13}C_3$-PFHxS	10.61	$^{13}C_4$-PFOS
$^{13}C_2$-6:2FTS	12.05	^{13}C4-PFOS
$^{13}C_8$-PFOA	12.19	$^{13}C_2$-PFOA
$^{13}C_9$-PFNA	13.70	$^{13}C_2$-PFOA
$^{13}C_8$-PFOS	13.73	$_{13}C_4$-PFOS
$^{13}C_2$-8:2FTS	14.94	$^{13}C_4$-PFOS
$^{13}C_6$-PFDA	15.00	$^{13}C_2$-PFOA
$^{13}C_7$-PFUnA	16.14	$^{13}C_2$-PFOA
$^{13}C_2$-PFDoA	17.13	$^{13}C_2$-PFOA

Table 4.
Method Analytes, Retention Times, and Suggested Isotope Dilution Analogue References

Analyte	Peak No. (Figure 1)	RT (min)	Isotope Dilution Analogue
PFBA	3	4.15	$^{13}C_4$-PFBA
PFMPA	4	4.84	$^{13}C_4$-PFBA
PFPeA	6	6.13	$^{13}C_5$-PFPeA
PFBS	8	6.62	$^{13}C_3$-PFBS
PFMBA	9	6.81	$^{13}C_5$-PFPeA
PFEESA	10	7.53	$^{13}C_3$-PFBS
NFDHA	11	8.01	$^{13}C_5$-PFHxA
4:2FTS	13	8.12	$^{13}C_2$-4:2FTS
PFHxA	15	8.36	$^{13}C_5$-PFHxA
PFPeS	16	8.69	$^{13}C_3$-PFHxS
HFPO-DA	18	9.06	$^{13}C_3$-HFPO-DA
PFHpA	20	10.42	$^{13}C_4$-PFHpA
PFHxS	22	10.62	$^{13}C_3$-PFHxS
ADONA	23	10.73	$^{13}C_4$-PFHpA
6:2FTS	25	12.04	$^{13}C_2$-6:2FTS
PFOA	28	12.19	$^{13}C_8$-PFOA
PFHpS	29	12.28	$^{13}C_8$-PFOS
PFNA	31	13.70	$^{13}C_9$-PFNA
PFOS	34	13.74	$^{13}C_8$-PFOS
9Cl-PF3ONS	35	14.53	$^{13}C_8$-PFOS
8:2 FTS	37	14.94	$^{13}C_2$-8:2FTS
PFDA	39	15.00	$^{13}C_6$-PFDA
PFUnA	41	16.14	$^{13}C_7$-PFUnA
11Cl-PF3OUdS	42	16.70	$^{13}C_8$-PFOS
PFDoA	44	17.13	$^{13}C_2$-PFDoA

2. EPA Method 533 (continued)

Table 5.
Precision and Accuracy Data for Reagent Water

Analyte	Low Fortification (ng/L)	Mean % R_a (n=7)	% RSD_a	High Fortification (ng/L)	Mean % R_a (n=5)	% RSD
PFBA	10	128	8.6	80	98.4	2.4
PFMPA	10	108	4.5	80	98.1	2.2
PFPeA	10	107	4.9	80	99.6	3.6
PFBS	10	102	9.1	80	96.2	2.9
PFMBA	10	111	6.8	80	101	3.4
PFEESA	10	107	10	80	98.8	4.0
NFDHA	10	110	15	80	98.5	5.4
4:2FTS	10	94.4	14	80	100	5.7
PFHxA	10	102	8.0	80	97	7.7
PFPeS	10	99.5	19	80	101	7.8
HFPO-DA	10	102	9.7	80	102	4.7
PFHpA	10	108	7.0	80	104	4.1
PFHxS	10	103	9.0	80	97.7	5.5
ADONA	10	96.3	3.1	80	96.8	5.6
6:2FTS	10	109	15	80	111	11
PFOA	10	108	7.4	80	98.5	6.9
PFHpS	10	98.8	8.9	80	102	7.0
PFNA	10	109	6.2	80	99.6	5.6
PFOS	10	104	8.7	80	98.0	4.3
9Cl-PF3ONS	10	99.7	4.6	80	103	6.8
8:2FTS	10	100	17	80	100	13
PFDA	10	100	4.2	80	100	1.8
PFUnA	10	102	10	80	97.3	8.1
11Cl-PF3OUdS	10	106	5.3	80	102	6.1
PFDoA	10	101	6.2	80	96.3	5.1

2. EPA Method 533 (continued)

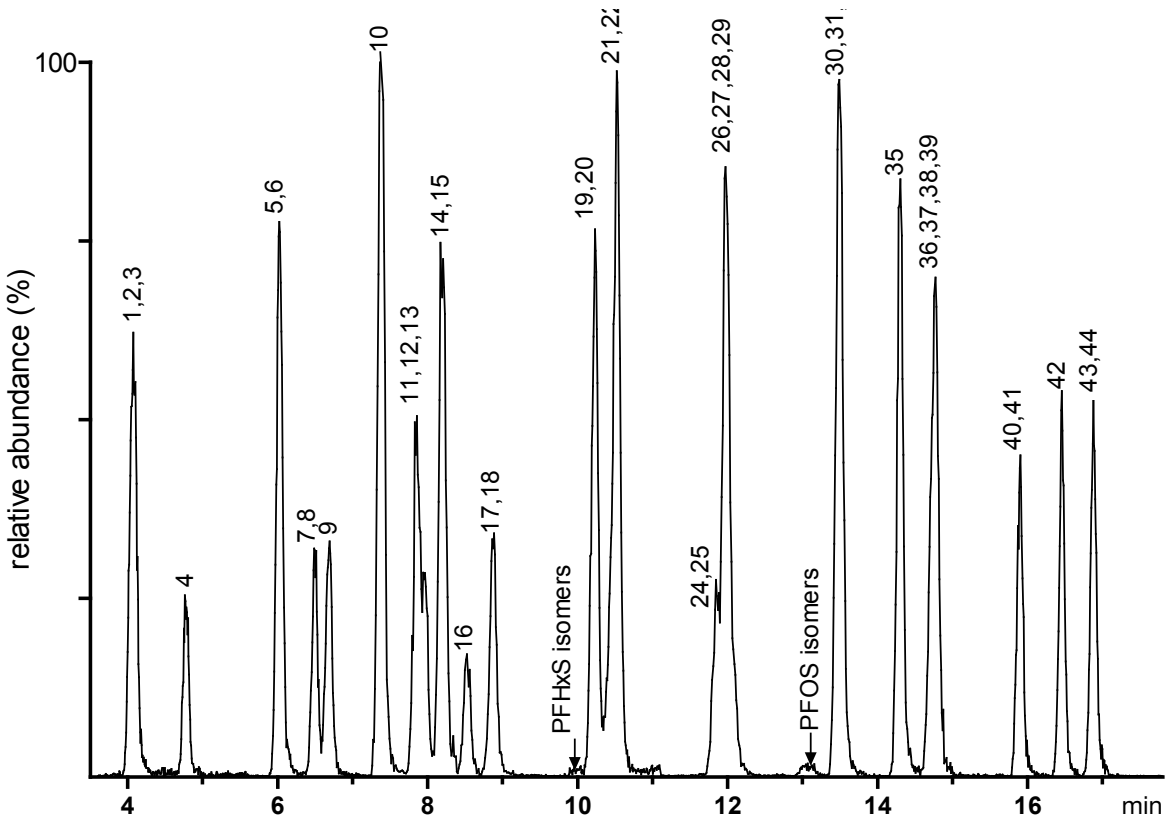
Table 6.
EPA 533 Precision and Accuracy Data from a Commercial Laboratory

Analyte	MS %	MSD %	BS %	BSD %
11Cl-PF3OUdS	85	84	95	86
4-2FTS	113	104	109	100
6-2 FTS	94	96	108	102
8-2 FTS	97	100	89	101
9Cl-PF3OUdS	101	107	99	119
ADONA	118	116	111	99
HFPO-DA	100	97	110	101
NFDHA	117	126	117	114
PFBA	102	116	89	95
PFBS	117	106	97	105
PFDA	102	99	112	104
PFDoA	104	107	108	109
PFEESA	116	109	119	115

Analyte	MS %	MSD %	BS %	BSD %
PFHpA	112	115	94	97 %
PFHpS	119	117	119	114 %
PFHxA	113	107	91	95 %
PFHxS	96	101	108	110 %
PFMBA	106	101	111	118 %
PFMPA	99	100	108	117 %
PFNA	107	104	105	110 %
PFOA	101	104	101	100 %
PFOS	117	115	108	108 %
PFPeA	97	96	92	88 %
PFPeS	86	99	103	104 %
PFUnA	105	103	115	113 %

Continued in next column

Figure 1.
Chromatogram from EPA Method 533



2. EPA Method 533 (continued)

Discussion

In this application, the method is outlined for both the SPE method and the HPLC conditions. In **Table 1**, the EPA methods are compared to show where they differ. **Tables 2-4** outline the specifics for the analytes in EPA Method 533 and then the suggested isotopes in relation to each. Specified retention times (RT) are also mentioned for each of the analytes. In **Table 5**, the acceptable precision and accuracy data is presented. In **Table 6** the data is displayed from an actual laboratory example that displays the results of how a laboratory implements EPA 533 and in **Figure 1** all necessary peaks from the specified method are shown in the example chromatogram. These data demonstrate that EPA Method 533 using Strata™-X-AW SPE for clean-up and a Gemini™ C18 column for analysis provide accurate and sufficient results for a commercial laboratory running this method.

Conclusion

EPA 533 is a significant improvement over EPA 537.1 for the analysis of PFAS in drinking water. This new method eliminates the 4 compounds from the EPA 537.1 analyte list that were not detected over the 10 year period that EPA 537.1 was being used to monitor these compounds. However, it also i.e. features the addition of 11 new PFAS compounds that were not included in EPA 537.1 which are believed to be of greater environmental significance. These 11 compounds include many of the "replacement" compounds that are currently being used in the manufacturing of products that utilize PFAS chemistry. This makes EPA 533 a much more relevant environmental method. Furthermore, EPA 533 is a more robust analytical method owing to the use of the isotope dilution technique which provides a means to correct for the loss of analytes during sample preparation step, as well as to offset the potential effects of ion suppression or enhancement arising from matrix variation. Consequently, EPA 533 will play a critical role in the UCMR5 cycle beginning in 2021 to assess the safety of US public drinking water systems. In this way, EPA 533 will play an essential role in the EPA PFAS Action Plan, potentially leading to official PFAS drinking water regulations.

However, there are a few specific requirements in this method that the analyst must carefully follow. The SPE sorbent mass (in mg) must be at least 2x the sample volume (in mL) to prevent potential overloading of the sorbent. To illustrate, a 100 mL sample must be extracted with an SPE mass of at least 200 mg, a 250 mL sample must use an SPE sorbent mass of at least 500 mg and so forth. In addition, the SPE media must meet the following specifications listed in the method:

- Approximately 33 µm particle size
- Employ a mixed-mode polymeric sorbent mechanism (polymeric backbone and a diamino ligand functional group)
- Display a pK_a above 8 so that the SPE media remains positively charged during extraction

Strata-X-AW meets all these requirements and was found to show excellent performance in EPA 533 during routine laboratory operation as demonstrated by the performance data presented above. In addition, as has also been noted, both the Strata-X-AW SPE sorbent and the Gemini 3 µm C18 HPLC column were used in the development of EPA 533 and its validation. Understandably, both products are now widely employed in environmental laboratories for the routine analysis of PFAS by EPA 533.

Acknowledgement

The assistance of Dr. Agustin Pierri, Weck Laboratories, in providing the operational recovery data is gratefully acknowledged.

Reference

EPA Method 533 'Determination of Per- and Polyfluoroalkyl Substances in Drinking Water By Isotope Dilution Anion Exchange Solid Phase Extraction and Liquid Chromatography / Tandem Mass Spectrometry' (2019) https://www.epa.gov/sites/production/files/2019-12/documents/method-533-815b19020.pdf

3. Large-Volume Direct Injection

Quantitation of PFAS in Water Samples using LC-MS/MS Large-Volume Direct Injection and Solid Phase Extraction

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Introduction

PFASs are unique chemicals whose physiochemical properties make them important for use in a variety of industrial and consumer products including carpets, cookware, food packaging, fire suppressants, and others (1). Chemically, PFASs are aliphatic structures containing one or more C atoms on which H substituents have been replaced by F atoms. Classification and naming is typically by the particular functional group present, such as carboxylic acids, sulfonates, phosphonic acids, etc., as well as the length of the carbon chain. Desirable in various industrial applications for their chemical stability and low reactivity, these properties also make PFAS highly resistant to degradation in aquatic environments. Typical concentrations of PFASs found in various environmental water sources range from pg/L to µg/L levels (2).

Human exposure to PFAS residues has been implicated in the incidence of cancer, obesity, endocrine system disruption, and other adverse health effects (3-4). In recognition of these potential risks, sources of human exposure to these chemicals (e.g., via drinking water) are receiving public and scientific attention.

PFASs exhibit relatively high aqueous solubility and can be transported and bioaccumulated from contaminated water sources. The US EPA maintains health advisory limits for select PFASs (e.g., perfluorooctanoic acid (PFOA) at a limit of 70 ng/L) in water, but these levels have been exceeded in some areas experiencing extreme point source inputs of these chemicals (5).

Given the tremendous persistence of PFASs in the environment and their known presence in human populations exposed via drinking water and other environmental routes, demonstration of the capability for accurate and precise low-level quantitation is paramount for research and testing laboratories. Robust quantitative analytical methods utilize the specificity and sensitivity of LC-MS/MS with MRM monitoring. However, a primary analytical challenge to this assay is the prevention and reduction of background PFASs originating from the LC system and contamination during sample collection and preparation.

This application note presents two methods for the quantitation of per- and polyfluorinated alkyl substances (PFASs) in water samples. While the MS/MS detection method using the SCIEX Triple Quad™ 5500 System is similar between the two methods, the sample preparation and injection volume differ significantly.

Key features of PFAS methods

- LC-MS detection using a Shimadzu® LC-20ADXR coupled to a SCIEX® Triple Quad 5500 System
- Special modifications to the pumps and autosampler are described to mitigate laboratory-based contamination of PFASs.
- Use of a delay column for separation of a contamination PFAS peak from the analytical peak
- The first method presented here utilizes a weak-anion exchange solid phase extraction (SPE) method to concentrate water samples for analysis using a 7.5 minute HPLC gradient.
- The second method utilizes dilution of a water sample in methanol and direct injection of 950 µL of the diluted sample using a 17.5 minute HPLC gradient.
- Large volume injection of an aqueous sample is intended to achieve method sensitivity while reducing accumulated background during sample concentration steps.
- Both methods achieved accurate quantitation at levels of approximately 1-10 ng/L for more than 17 PFASs.

3. Large-Volume Direct Injection (continued)

Methods

Standards and internal standards (IS): The PFAS standards and internal standards were obtained from Wellington Laboratories (Guelph, Ontario) and were prepared in Baker HPLC-grade methanol. Standard stock solutions were prepared by dilution with 96 % methanol and 4 % water (purified using a Millipore® water purification system).

Sampling and sample preparation: Water samples were obtained anonymously from various sources in the United States. Samples were stored in the dark at 4 °C in 250 mL high density polyethlyene bottles until analysis.

Chromatography: Shimadzu® LC-20ADXR binary pumps with a Shimadzu DGU-20A5 degasser was used for separations. All fluoroethylene polymer (FEP) tubing on the Shimadzu pumps and degasser was replaced with PEEK tubing with similar internal and external dimensions. A Phenomenex Luna™ C18(2) column (dimensions shown in **Table 1**) was installed between the pump mixing chamber and the column, outside of a Shimadzu CTO-20AC column oven. This column served as a delay or hold-up column to isolate PFAS contamination originating from the pumps and eluents. A longer and/or larger diameter Luna C18(2) column must be installed on heavily contaminated systems to prevent breakthrough of contamination.

Chromatographic separation was performed using a Phenomenex Gemini™ C18 HPLC column at 0.6 mL/min (**Table 1**). The Gemini C18 column was heated to 40 °C in the column oven. A PAL-HTC-xt autosampler with dynamic load-wash (DLW) was modified by replacing all FEP tubing from the rinse solvent lines, the needle seal, and the sample holding loop with PEEK or stainless steel. The autosampler syringe and sample holding loop was rinsed with methanol and 1:1 methanol:acetonitrile between samples.

Table 1. LC columns for methods 1 and 2.

Method	Column	Dimensions
Delay column	Phenomenex Luna C18 (2), 5 µm	30 x 2 mm
Method 1 HPLC Column	Phenomenex Gemini C18, 3 µm	50 x 2 mm
Method 2 HPLC Column	Phenomenex Gemini C18, 3 µm	100 x 3 mm

Method 1: Solid phase extraction and 10 µL injection: A mixture of surrogate standards (25 ng) was added to 250 mL water samples in the sampling bottle, and the entire volume was extracted using weak anion exchange SPE as recommended by ISO standard 251016. The empty sample container was rinsed with 10 mL of methanol with 0.3 % NH_4OH, which was then added to the SPE tube to elute the PFASs. The extract was evaporated to dryness, reconstituted in 500 µL of 80 % methanol/20 % water, and transferred to a polypropylene vial for analysis. All standards and blanks were also prepared at a final methanol concentration of 80 %.

For Method 1, 10 µL injections of the standards and samples were analyzed using a 6.5 min gradient method (**Table 2**) with a 7.5 min total runtime, including the 1 min autosampler injection cycle. Water with 20 mM ammonium acetate was used as the "A" solvent and methanol was the "B" solvent.

Table 2. LC gradient for method 1 at a flow rate of 0.6 mL/min.

Step	Time (min)	A (%)	B (%)
0	0.00	90	10
1	0.10	45	55
2	4.50	1	99
3	4.95	1	99
4	5.00	90	10
End	6.50		

Method 2: Dilution and large volume injection: A 1 mL aliquot of a water sample was added to a 2 mL clear glass autosampler vial with a polyethylene septum cap containing 0.65 mL of methanol and a mix of surrogate standards at a final concentration of 50 ng/L. The final concentration of methanol in the diluted sample was 40 %, and standards, blanks, and quality control samples were all prepared at the same concentration. A PAL HTC-xt autosampler was modified to inject 950 µL of the diluted samples and standards.

For Method 2, samples were analyzed using an extended 15.5 min gradient method (**Table 3**) with a 17.5 min total runtime, including the 2 min autosampler injection cycle. Water with 20 mM ammonium acetate was used as the "A" solvent, and methanol was the "B" solvent.

MS/MS detection: A SCIEX® Triple Quad™ 5500 System with a Turbo V™ Ion Source and ESI probe was used for analysis in negative polarity. The ion source parameters were optimized for the LC conditions using the Compound Optimization (FIA) function in Analyst® Software (**Table 4**).

Table 3. LC gradient for method 2 at a Flow Rate of 0.6 mL/min.

Step	Time (min)	A (%)	B (%)
0	0.0	90	10
1	1.5	35	65
2	8.0	5	95
3	8.1	1	99
4	12.0	1	99
5	12.5	90	10
End	15.5		

One characteristic MRM transition was monitored for each analyte and internal standard (Appendix **Table 1**). The Scheduled MRM™ algorithm was activated to monitor compounds only during a 60 second expected retention time window to maximize dwell times and optimize the cycle time of the method. As a result, all of the peaks in the calibration contained >12 points per peak.

3. Large-Volume Direct Injection (continued)

Table 4. Ion source parameters for methods 1 and 2.

Parameter	Value
Curtain Gas (CUR)	35 psi
IonSpray voltage (IS)	-4500 V
Temperature (TEM)	600 ˚C
Nebulizer Gas (GS1)	50 psi
Heater Gas (GS2)	50 psi

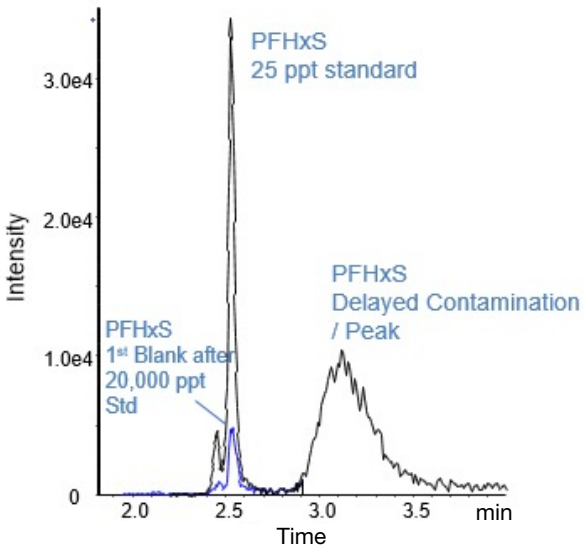
Calibration was performed using a 7-point curve at concentrations of 25, 50, 250, 1000, 2500, 10000, and 20000 ng/L for Method 1 and 1, 2, 5, 20, 50, 100, and 200 ng/L for Method 2. Quantitation was performed using MultiQuant™ Software 3.0.2 using 1.0 Gaussian smoothing and 1/x2 weighted linear regression. PFASs with matched isotopically labeled surrogate standards were quantified using isotope dilution, while PFASs without matched surrogate standards were quantified using internal standard calibration with structurally similar isotopically labeled standards (full analyte and internal standard list shown in Appendix **Figure 1**). A concentration factor of 500 was applied to samples analyzed using Method 1, and a dilution factor of 1.65 was applied to samples analyzed using Method 2.

Method 1 chromatography results

The Gemini™ C18 column was selected for both methods based on its strong retention and predictable resolution of PFASs. All of the other columns tested exhibited breakthrough of the short chain acids in the column dead volume during optimization of the 950 µL injection method. The Luna™ C18(2) column was selected as the delay column for both methods after initial testing indicated that it provided better separation of PFAS contamination than other columns. For PFASs, blank contamination is a major concern for analysis due to potential contamination during sample preparation or contamination originating from analytical instrumentation. **Figure 1** shows a small carryover peak at 2.5 min for PFHxS in a blank analyzed immediately following the injection of the highest calibration standard of 20,000 ng/L. The area of the carryover peak was only 0.078 % of the highest standard and 21 % of the lowest calibration standard for Method 1 (25 ng/L). The second peak at 3.2 min in **Figure 1** is attributed to delayed PFHxS contamination originating from the HPLC pumps. Without the delay column, this contamination would instead focus on the analytical column and elute at 2.5 min along with the standard and sample peak.

A 50 mm x 2 mm, 3 µm Gemini C18 column was selected for Method 1, which utilized a 10 µL injection volume. The chromatographic separation of 25 PFASs is shown in **Figure 2**. The average peak asymmetry factor for the first 2 eluting peaks (PFBA and PFBS) in the initial calibration standards was calculated to be 1.3 in Method 1 using MultiQuant Software.

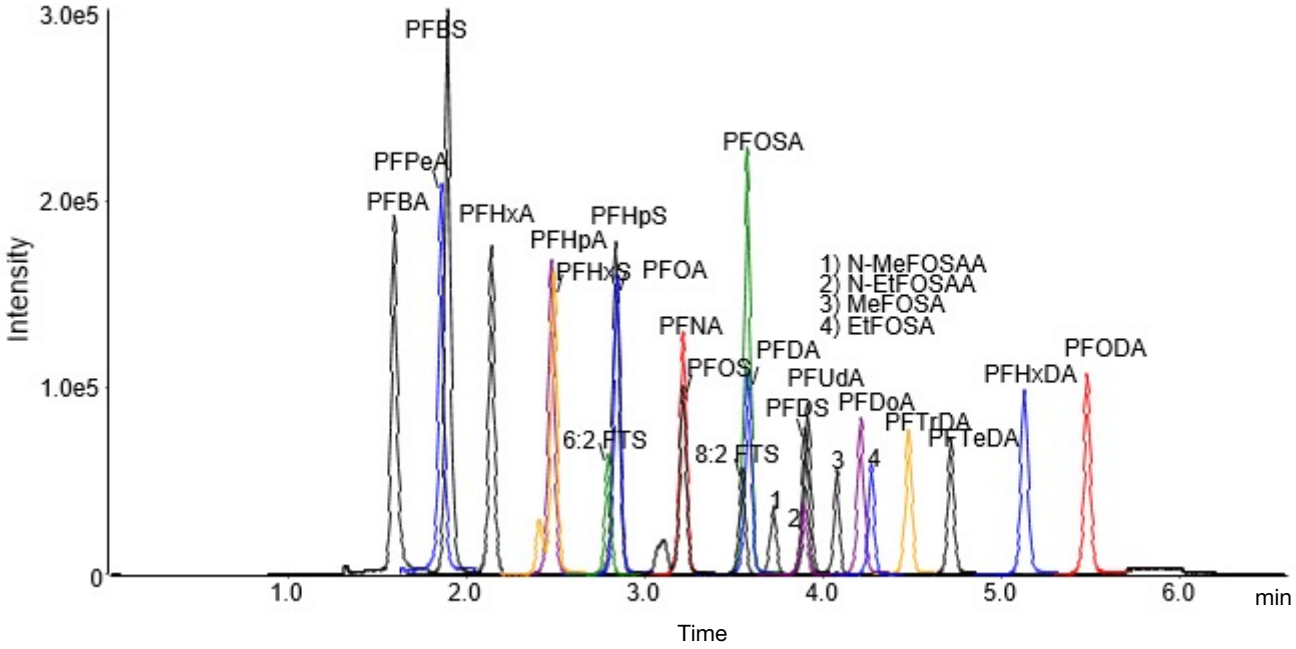
Figure 1.
Evaluating carryover



Overlaid MRM traces for PFHxS in the lowest calibration standard (black, 25 ng/L) and a blank injection (blue) that followed the highest concentration standard (20 µg/L). The delayed peak in the calibration standard trace represents the ambient LC system contamination retained by the delay column.

3. Large-Volume Direct Injection (continued)

Figure 2.
Method 1 chromatography: Weak anion exchange SPE with 10 µL injection



Overlaid Chromatograms of a 1 µg/L Standard Injected using Method 1.

3.0.2. This is within the acceptance criteria set by EPA 537 of 0.8-1.5 7.

Partial resolution of the branched and linear isotopes is necessary for PFAS analysis to distinguish between samples containing only linear isotopes or isotope mixtures. As shown in **Figure 2**, the earlier eluting branched isotopes are clearly distinguishable from the major peak corresponding to the linear isotopes for the 2 compounds that contained both branched and linear isotopes in the standards (PFHxS and PFOS). Most methods recommend that these two peaks are summed for quantitation, which was performed in this method using MultiQuant™ Software 3.0.2.

Method 1 calibration

The initial 7-point calibration for Method 1 exhibited good accuracy within +/- 30 % of the expected values for all points, accuracy within +/- 10 % for the lowest calibrator, and R2 coefficients of >0.990, as shown in Table 5. Based on the S/N ratio of the low calibrator and the linearity of the curve, the calibration range could be extended on both the high and low levels to improve the dynamic range. A water sample analyzed using Method 1 exhibited concentrations of several PFASs ranging from 0.974 to 53.3 ng/L, as shown in Figure 3.

3. Large-Volume Direct Injection (continued)

Method 2 chromatography

Method 2 is a large-volume, direct aqueous injection method designed for drinking, surface, and ground water samples. After the addition of surrogate standards and a simple dilution with methanol, 950 µL of the sample was injected directly onto the Gemini™ C18 column. In contrast to Method 1, a longer and larger diameter column was used to improve retention of the analytes in the large volume injection. This resulted in a longer total runtime (17.5 minutes compared with 7.5 minutes), but provided robust results for the large volume injection and minimal retention time shift (**Figure 4**). The only compound that exhibited deteriorated peak shape due to the large injection volume was PFBA. However, the broadened peak shape of PFBA did not affect quantitation accuracy or precision.

Figure 3.
Overlaid chromatograms of PFASs quantified in a water sample using method 1.
This method uses a solid-phase extraction and a 10 µL injection.

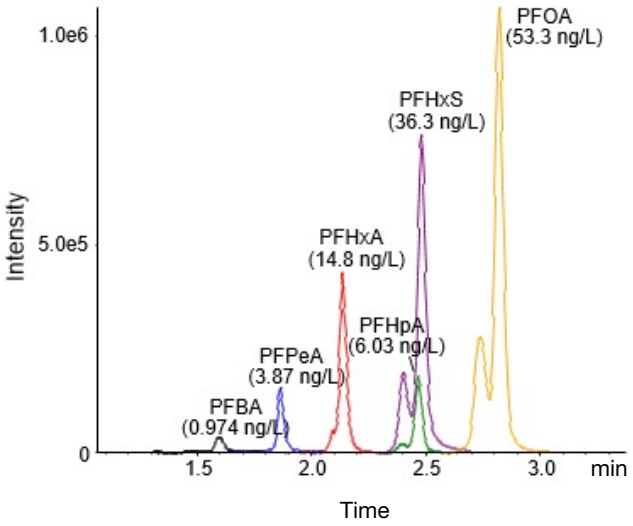


Table 5.
Calibration curves for method 1 and 2.
Sensitivity and linearity from 25 to 20,000 ng/L and 1 to 200 ng/L (coefficient of regression, R2) using Method 1 and Method 2, respectively. S/N calculated using MultiQuant™ Software 3.0.2.

Compound	Method 1				Method 2			
	Calibration range (ng/L)	Linear correlation (R2)	S/N of 25 ng/L standard	Accuracy of 25 ng/L standard	Calibration range (ng/L)	Linear correlation (R2)	S/N of 1 ng/L standard	Accuracy of 1 ng/L standard
PFCAs								
PFBA	25-20,000	0.997	108	104 %	1-200	0.997	328	97 %
PFPeA	25-20,000	0.998	88	103 %	1-200	0.999	137	101 %
PFHxA	25-20,000	0.998	104	93 %	1-200	0.999	284	101 %
PFHpA	50-20,000	0.999	116	101 %	1-200	0.993	267	96 %
PFOA	25-20,000	0.999	117	106 %	1-200	0.999	113	99 %
PFNA	25-20,000	0.990	91	109 %	1-200	0.999	137	101 %
PFDA	25-20,000	0.998	103	105 %	1-200	0.997	176	96 %
PFUdA	25-20,000	0.995	84	101 %	1-200	0.998	168	99 %
PFDoA	25-20,000	0.998	60	101 %	1-200	0.994	127	94 %
PFTrDA	25-20,000	0.998	32	104 %	1-200	0.995	125	95 %
PFTeDA	25-20,000	0.994	15	107 %	1-200	0.998	56	98 %
PFHxDA	25-20,000	0.999	21	103 %				
PFODA	25-20,000	0.999	33	102 %				
PFSAs								
PFBS	25-20,000	0.995	31	92 %	2-200	0.994	1178	100 %
PFHxS	25-20,000	0.999	604	103 %	1-200	0.998	229	96 %
PFHpS	25-20,000	0.997	103	105 %	1-200	0.999	327	99 %
PFOS	25-20,000	0.995	312	105 %	1-200	0.999	251	99 %
PFDS	25-20,000	0.998	88	102 %	1-200	0.999	516	98 %
Other PFASs								
6:2 FTS	25-20,000	0.991	100	98 %				
8:2 FTS	25-20,000	0.992	113	97 %				
PFOSA	25-20,000	0.997	118	104 %	1-100	0.997	1012	96 %
MeFOSA	25-20,000	0.996	96	103 %				
EtFOSA	25-20,000	0.994	90	101 %				
N-MeFOSAA	25-20,000	0.996	109	100 %				
N-EtFOSAA	25-20,000	0.994	61	103 %				

3. Large-Volume Direct Injection (continued)

Similar to Method 1, blank contamination from the instrument was minimized by using a delay column in Method 2. Blank contamination from sample preparation was also minimized in Method 2 by reducing the number of pipetting steps and testing all new batches of solvents prior to use. The integrated areas of the first blank after the highest concentration sample (200 ng/L) were less than 50 % of the lowest calibrator. For example, the area of the first blank analyzed after the 200 ng/L calibration standard was 22 % of the area of the 1 ng/L standard for PFOA as shown in **Figure 5**. The other blanks shown in **Figure 5** exhibited even lower response for PFOA, which could be contributed to laboratory contamination for the method blank and solvent contamination for the instrument blank.

To be compatible with common sampling practices, the Method 2 was not optimized for recovery of the longest chain PFASs, PFHxDA and PFODA, from the sample container or from the autosampler vial. Due to the stronger hydrophobicity of these compounds compared with the shorter chain PFAS, PFHxDA and PFODA appeared to bind to polypropylene containers when the methanol concentration was <40 %. Modifications to this method to improve the recovery and precision of PFHxDA and PFODA analysis may include collecting smaller samples (10-20 mL), diluting the entire sample with methanol in the sampling container, and adding surrogate standard directly to the sampling container.

Direct analysis of water samples is impaired by the presence of 5 g/L Trizma in samples, which is added to drinking water samples as a requirement by EPA method 537. Trizma suppresses ionization of the PFASs and elutes slowly from the column for minutes after the injection. Therefore, Trizma should not be added to samples that will be analyzed using direct aqueous injection, but is fully compatible with SPE as performed in Method 1.

Method 2 calibration

Similar to Method 1, the initial calibration results for Method 2 exhibited good accuracy within +/- 30 % of the expected values for all points, accuracy within +/- 10 % for the lowest calibrator, and R2 coefficients >0.990, as shown in **Table 5**. In the development of Method 2, calibration standards for 6:2 and 8:2 FTS, MeFOSA, EtFOSA, MeFOSAA, and EtFOSAA were not analyzed in the full calibration curve.

3. Large-Volume Direct Injection (continued)

Figure 4.
Method 2 chromatography: Dilution of water sample in methanol and 950 µL direct injection

Chromatogram of a 10 ng/L matrix spike into groundwater that was diluted with methanol and injected according to Method 2.

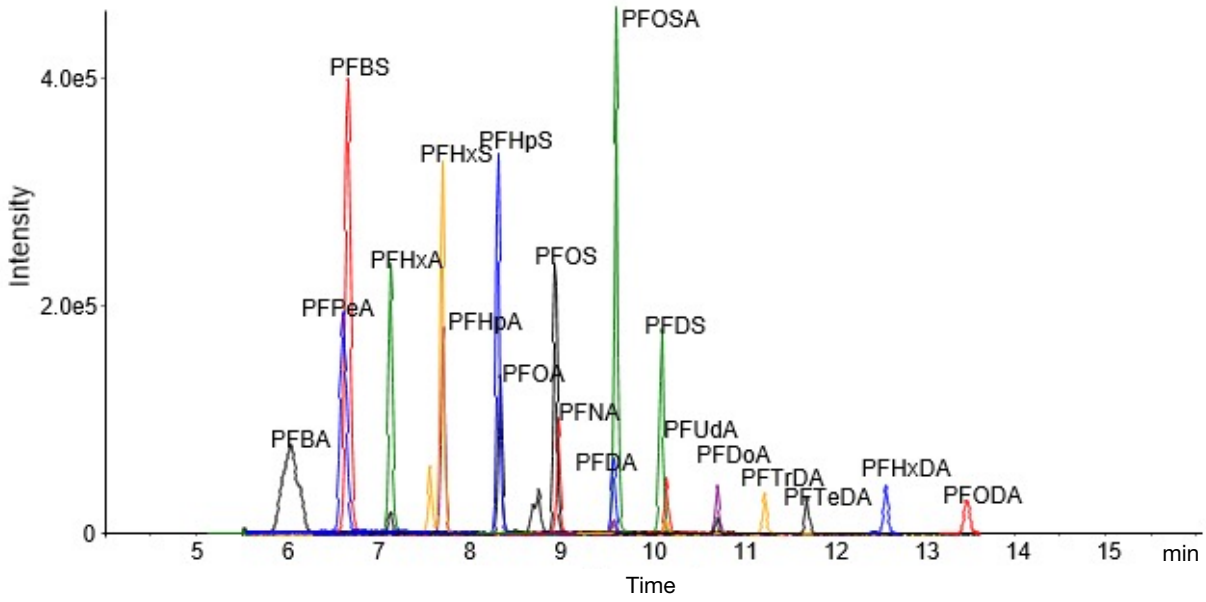
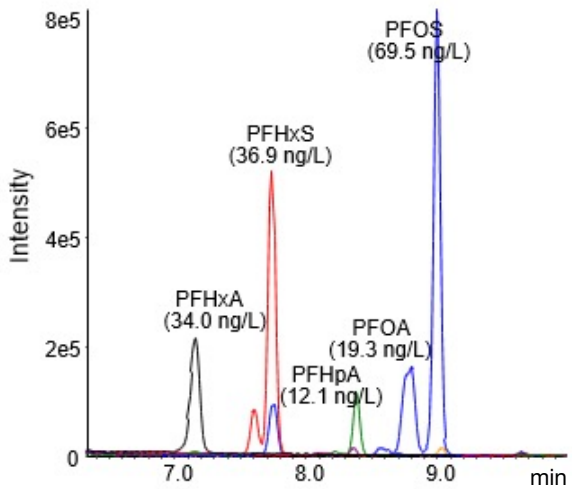


Figure 6.
Overlaid MRM traces of PFASs detected in a groundwater sample with the calculated concentrations of each PFAS.

The sample was prepared and analyzed using Method 2.



Method 2 performance

Because large-volume injection methods are less common for PFASs compared with offline extraction methods, this application note reports the recovery and precision of continuing calibration standards over 1 week of continuous water sample analysis to demonstrate the robustness and accuracy of Method 2. The chromatogram and quantitated values for several PFASs in one of these water samples are shown **Figure 6**.

As shown in **Table 6**, a continuing calibration standard at 20 ng/L analyzed 1 week after the initial calibration exhibited quantitative accuracy of 92-99 % for all compounds with the exception of PFTrDA (81 %) and PFBS (84 %). Due to limited availability of surrogate standards, PFBS was analyzed using 18O2 PFHxS as an internal standard, and PFTrDA was analyzed using 13C2 PFDoA. The absence of an exact isotope-labelled surrogate for these two compounds likely contributed to the decreased accuracy of the ongoing calibration standard.

During the 1 week period of full-time water sample analysis, 9 replicates of the 20 ng/L continuing calibration verification (CCV) were analyzed as shown in **Table 6**. The precision (%CV) for all of the PFASs was <5 %, which indicates excellent precision for the large volume injections. The surrogate recovery, calculated as the response of the surrogate standard in the 20 ng/L ongoing calibration standard divided by the response of the surrogate standard during the initial calibration, was within 73-120 % for all of the PFASs analyzed.

3. Large-Volume Direct Injection (continued)

Summary

The 2 methods reported here were designed for optimum robustness using the SCIEX® Triple Quad™ 5500 System as the analytical platform. Both methods may be expanded to include soil, sediment, and biological extracts. Minimum and maximum reporting limits of approximately 1 ng/L to 400 µg/L could be achieved using both methods. These ranges could be expanded by increasing the extracted volume in Method 1 or by further dilutions in Method 2. The example chromatograms shown in this application note also demonstrate that the lower calibration levels than the levels analyzed here could be included in initial calibration curves to further improve the sensitivity of the method.

Method 1 has the advantage of compatibility with EPA Method 537 (7) and allows sample concentration using solid phase extraction. Method 2 has the advantages of minimal sample preparation and fewer steps to introduce lab-based PFAS contamination. With the growing need for PFAS analysis of environmental samples, these versatile methods will be useful for labs aiming to evaluate growing lists of PFASs.

Table 6.
Method 2

Accuracy of a 20 ng/L CCV analyzed 1 week after the initial calibration and precision of 9 replicates of a 20 ng/L CCV analyzed between 5 and 7 days after the initial calibration using Method 2.

Compound	Calculated conc of 20 ng/L CCV	Accuracy of 20 ng/L CCV	Surrogate standard recovery	Precision of 20 ng/L CCVs (%CV)
PFCAs				
PFBA	19.4	96 %	107 %	1.50
PFPeA	19.7	98 %	107 %	1.40
PFHxA	19.7	99 %	108 %	2.26
PFHpA*	18.5	92 %	103 %	3.11
PFOA	19.2	96 %	105 %	2.07
PFNA	19.3	97 %	107 %	1.11
PFDA	19.4	97 %	107 %	2.62
PFUdA	18.8	94 %	109 %	2.90
PFDoA	18.7	94 %	99 %	1.90
PFTrDA	16.3	81 %	99 %	4.77
PFTeDA	18.9	95 %	73 %	1.43
PFSAs				
PFBS	16.8	84 %	112 %	2.65
PFHxS	19.2	96 %	112 %	1.94
PFHpS	19.4	97 %	112 %	3.85
PFOS	18.8	94 %	120 %	2.62
PFDS	18.6	93 %	120 %	2.69
Other PFASs				
PFOSA	19.0	95 %	112 %	0.98

3. Large-Volume Direct Injection (continued)

Applications

Aknowledgements

SCIEX® acknowledges TestAmerica (Sacramento, CA) for collaborating with SCIEX by providing and conducting the analysis of standards for this application note. SCIEX also acknowledges Phenomenex (Torrance, CA) for providing HPLC columns and expertise for this application note and other method development efforts.

References

1. Buck et al., Integr Environ Assess Manag. (2011), 7(4), 513-541)
2. Rahman, M. F.; Peldszus, S.; Anderson, W. B. Water Research (2014), 50, 318-340.
3. Braun, J. M.; Chen, A.; Romano, M. E.; Calafat, A. M.; Webster, G. M.; Yolton, K.; Lanphear, B. P. Obesity (2016), 24, 231–237.
4. Barry, V.; Winquist, A.; Steenland, K. Environ. Health Perspect. (2013), 121 (11–12), 1313– 1318.
5. Hu, X. C.; Andrews, D. Q.; Lindstrom, A. B.; Bruton, T. A.; Schaider, L. A.; Grandjean, P.; Lohmann, R.; Carignan, C. C.; Blum, A.; Balan, S. A.; Higgins, C. P.; Sunderland, E. M. Environ. Sci. Technol. Lett. (2016).
6. ISO. 2009. Water quality – Determination of perfluorooctanesulfonate (PFOS) and perfluorooctanoate (PFOA) – Method for unfiltered samples using solid phase extraction and liquid chromatography/mass spectrometry. International Organization for Standardization, ISO 25101:2009 (TC 47/ SC 2). 19 pp.
7. EPA Method 537 'Determination of Selected Perfluorinated Alkyl Acids in Drinking Water by Solid Phase Extraction and Liquid Chromatography / Tandem Mass Spectrometry LC/MS/MS)' version 1.1 (2009) http://www.epa.gov/microbes/documents/Method%2053 7_FI NAL_rev1.1.pdf

Appendix Table 1.
MRM masses for methods 1 and 2.

Analytes are shown in bold font, and internal standards are shown in italic font.

Compound	Q1	Q3	DP	CE
PFBA	212.9	169	-25	-12
PFPeA	262.9	219	-20	-12
PFHxA	313	269	-25	-12
PFHpA	363	319	-25	-12
PFOA	413	369	-25	-14
PFNA	463	419	-25	-14
PFDA	513	469	-25	-16
PFUdA	563	519	-25	-18
PFDoA	613	569	-25	-18
PFTrDA	663	619	-25	-20
PFTeDA	713	669	-25	-22
PFHxDA	813	769	-25	-24
PFODA	913	869	-25	-26
PFBS	298.9	80	-55	-58
PFHxS	399	80	-60	-74
PFHpS	449	80	-65	-88
PFOS	499	80	-65	-108
PFDS	599	80	-85	-118
6:2 FTS	427	407	-50	-32
8:2 FTS	527	507	-50	-40
PFOSA	498	78	-60	-85
MeFOSA	512	169	-75	-37
EtFOSA	526	169	-75	-37
N-MeFOSAA	570	419	-40	-36
N-EtFOSAA	584	419	-50	-36
13C4_PFBA	217	172	-25	-12
13C5_PFPeA	268	223	-20	-12
13C2_PFHxA	315	270	-25	-12
13C4_PFHpA	367	322	-25	-12
13C2_PFOA	415	370	-25	-14
13C4_PFOA	417	372	-25	-14
13C5_PFNA	468	423	-25	-14
13C2_PFDA	515	470	-25	-16
13C2_PFUdA	565	520	-25	-18
13C2_PFDoA	615	570	-25	-18
13C2_PFTeDA	715	670	-25	-22
13C2_PFHxDA	815	770	-25	-24
1802_PFHxS	403	84	-60	-74
13C4_PFOS	503	80	-65	-108
13C8_PFOSA	506	78	-60	-85
M2-6:2FTS	429	409	-50	-32
M2-8:2FTS	529	509	-50	-40
d3MeFOSA	515	169	-75	-37
d5EtFOSA	531	169	-75	-37
d3-MeFOSAA	573	419	-40	-36
d3-EtFOSAA	589	419	-50	-36

Product Guide for PFAS Analysis

Phenomenex PFAS Products Referenced or Applicable in Official Methods

Regulatory Method	Product	Part Number
USEPA 537.1: Determination of Selected Per-and Polyfluorinated Alkyl Substances in Drinking Water by Solid Phase Extraction and Liquid Chromatography/ Tandem Mass Spectrometry (LC/MS/MS) (5)	**PFAS CRM EPA 537.1 mix 1mL 2µg/mL in methanol**	AL0-101839
	PFAS CRM EPA 533 + 537.1 mix 1mL 2µg/mL in methanol	AL0-101840
	Strata™ SDB-L 500 mg/6 mL	8B-S014-HCH
	Gemini™ 3 µm C18, 50 x 3 mm or	00B-4439-B0
	Luna™ Omega 1.6 µm PS C18 100 x 2.1 mm	00D-4752-AN
USEPA Method 533: Determination of Per- and Polyfluoroalkyl Substances in Drinking Water by Isotope Dilution, Anion Exchange Solid Phase Extraction and LC-MS/MS. (1)	**PFAS CRM EPA 533 mix 1mL 2µg/mL in methanol**	AL0-101838
	PFAS CRM EPA 533 + 537.1 mix 1mL 2µg/mL in methanol	AL0-101840
	Strata-X-AW 500 mg/6 mL	8B-S038-HCH
	Gemini 3 µm C18 50 x 2 mm or	00B-4758-Y0
	Luna Omega 1.6 µm PS C18 100 x 2.1 mm	00D-4752-AN
US Food and Drug Administration: Determination of 16 Perfluoroalkyl and Polyfluoroalkyl Substances(PFAS) in Food using Liquid Chromatography-Tandem Mass Spectrometry (LC-MS/MS). (2)	**Strata-XL-AW 200 mg/3 mL**	8B-S051-FBJ
US Department of Agriculture: Screening, Determiation and Confirmation of PFAS by UPLC-MS-MS (3)	**Luna C8(2) 3 µm 50 x 2 mm**	00B-4248-B0
US Department of Defense: Quality Systems Manual (QSM) for Environmental Laboratories (4)	**Strata PFAS (WAX/GCB)** 200 mg/50 mg/6 mL, 30/box 500 mg/50 mg/6 mL, 30/box	 CSO-9207 CSO-9208
	Gemini 3 µm C18 50 x 2 mm	00B-4439-B0

References

1. Method 537.1: Determination of Selected Per- and Polyfluorinated Alkyl Substances in Drinking Water by Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry (LC/MS/MS) | Science Inventory | US EPA
2. Method 533: Determination of Per- and Polyfluoroalkyl Substances in Drinking Water by Isotope Dilution Anion Exchange Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry | Methods Approved to Analyze Drinking Water Samples to Ensure Compliance with Regulations | US EPA
3. Determination of 16 Perfluoroalkyl and Polyfluoroalkyl Substances in Food using Liquid Chromatography-Tandem Mass Spectrometry (fda.gov)
4. Screening, Determination and Confirmation of PFAS by UPLC-MS-MS (usda.gov)
5. https://denix.osd.mil/edqw/documents/manuals/qsm-version-5-3-final/

Recommended HPLC Products for Routine PFAS Analysis

Description and Function	Product	Part Number
Analytical Column (UHPLC)	**Kinetex™ 5 µm EVO C18 100 x 2.1 mm**	00D-4633-AN
	Luna Omega C18 1.6 µm 50 x 2.1	00B-4752-AN
	Gemini 3 µm C18 50 x 3 mm	00B-4439-Y0
Analytical Column	**Gemini 3 µm C18 50 x 3 mm**	00B-4439-Y0
Analytical Column (> 100 µL injection)	**Gemini 3 µm C18 100 x 3 mm**	00D-4439-Y0
Analytical Column (improved. lmwt acids)	**Luna Omega 3 µm PS C18 50 x 3 mm**	00B-4758-Y0
Delay Column	**Kinetex 5 µm EVO C18, 50 x 2.1 mm**	00B-4633-AN 00A-4252-Y0
SecurityGuard	**Luna Omega PS C18** **4 x 3.0/10 pack for ID: 3.2-8.0 mm** **4 x 2.0/10 pack for ID: 2.0-3.0 mm**	 AJ0-7606 AJ0-7605

Product Guide for PFAS Analysis (continued)

Recommended SPE Products

Description and Function	Product	Part Number
SPE Cartridge for EPA 537.1	**Strata™ SDB-L 500 mg/6 mL, 30/box**	8B-S014-HCH
SPE Cartridge for EPA 533	**Strata-X-AW 33um Polymeric Weak Anion, 500 mg/6 mL, 30/box**	8B-S038-HCH
SPE Cartridge (Rev. Phase, High Perf.)	**Strata-XL 500 mg/6 mL, 30/box**	8B-S043-HCH
SPE Stacked Cartridge (DOD QSM 5.3)	**Strata PFAS (WAX/GCB) 200 mg/50 mg/6 mL, 30/box**	CS0-9207
SPE Stacked Cartridge (DOD QSM 5.3)	**Strata PFAS (WAX/GCB) 500 mg/50 mg/6 mL, 30/box**	CS0-9208
SPE Cartridge (WAX for DOD QSM 5.3)	**Strata-XL-AW 500 mg/6 mL, 30/box**	8B-S051-HCH
GCB** Cartridge (GCB for DOD QSM 5.3)	**Strata GCB 250 mg/6 mL, 30/box**	8B-S528-FCH
SPE Cartridge (WAX* for FDA Method)	**Strata-XL-AW 100 µm 200 mg/3 mL, 50/box**	8B-S051-FBJ

(*WAX = Weak Anion Exchange)
(**GCB = Graphitized Carbon Black)

Recommended QuEChERs Products

Description and Function	Product	Part Number
QuEChERs Extraction (Soil/Sediment)	**roQ QuEChERs Extraction Kit**	KS0-8911
QuEChERs dSPE (Soil/Sediment)	**roQ QuEChERs dSPE Kit, 15 mL**	KS0-9516
QuEChERs Extraction (Dairy/Eggs/Fish)	**roQ QuEChERs Extraction Kit**	KS0-8910
QuEChERs dSPE (Dairy/Eggs/Fish)	**roQ QuEChERs dSPE Kit**	KS0-9511

Recommended Accessories

Description and Function	Product	Part Number
SPE Sample Reservoir	**75 mL Sample Reservoir**	H0-7005
Large Volume SPE	**Adaptor Cap for 12,20, 60 mL SPE Tubes**	AH0-7379
Autosampler Vials	**Polypropylene, 300 µm + PE Starburst Cap**	AR0-9995-12-C
Polypropylene Vials	**Vial 9 mm Screw Thd PP 2 mL, 1000 Pk**	AR0-89C7-13
Vial Caps	**Cap 9 mm Solid Top Black Unlined**	8B-S528-FCH
PEEK Capillary Tubing	**Capillary Tubing Kit, Various Sizes**	AT0-1964
PEEK Tubing Cutter	**Cutter for PEEK Capillary Tubing**	AT0-1110

Strata™ Solid Phase Extraction (SPE)

Strata-X

Ordering Information

Format	Sorbent Mass	Part Number	Unit
Tube			
	30 mg	8B-S100-TAK**	1 mL (100/box)
	30 mg	8B-S100-TBJ	3 mL (50/box)
	60 mg	8B-S100-UBJ**	3 mL (50/box)
	100 mg	8B-S100-EBJ	3 mL (50/box)
	100 mg	8B-S100-ECH	6 mL (30/box)
	200 mg	8B-S100-FBJ	3 mL (50/box)
	200 mg	8B-S100-FCH	6 mL (30/box)
	500 mg	8B-S100-HBJ	3 mL (50/box)
	500 mg	8B-S100-HCH	6 mL (30/box)
Giga™ Tube			
	500 mg	8B-S100-HDG	12 mL (20/box)
	1 g	8B-S100-JDG	12 mL (20/box)
	1 g	8B-S100-JEG	20 mL (20/box)
	2 g	8B-S100-KEG	20 mL (20/box)
	5 g	8B-S100-LFF	60 mL (16/box)
Teflon® Tube			
	200 mg	8B-S100-FBJ-T	3 mL (50/box)
	200 mg	8B-S100-FDG-T	12 mL (20/box)

On-line Extraction Cartridge

Description	Part Number	Unit/Box
Strata-X on-line extraction cartridge, 20 x 2.0 mm	00M-S033-B0-CB	ea
Cartridge holder, 20 mm	CH0-5845	ea

**Tab-less tubes available. Contact Phenomenex for details.

Strata-XL

Ordering Information

Format	Sorbent Mass	Part Number	Unit
Tube			
	30 mg	8B-S043-TAK	1 mL (100/box)
	60 mg	8B-S043-UBJ	3 mL (50/box)
	100 mg	8B-S043-EBJ	3 mL (50/box)
	200 mg	8B-S043-FBJ	3 mL (50/box)
	200 mg	8B-S043-FCH	6 mL (30/box)
	500 mg	8B-S043-HCH	6 mL (30/box)
Giga Tube			
	2 g	8B-S043-KDG	12 mL (20/box)
	2 g	8B-S043-KEG	20 mL (20/box)
	5 g	8B-S043-LEG	20 mL (20/box)
	5 g	8B-S043-LFF	60 mL (16/box)
	10 g	8B-S043-MFF	60 mL (16/box)
	30 mg	8E-S043-TGB	2 Plates/Box

* To control flow rate with Strata-XL, use a stopcock (AH0-6048) when processing samples with a vacuum manifold.

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Gemini™ pH Flexible LC Columns

Ordering Information

3 µm Microbore, Minibore and MidBore™ Columns (mm)										SecurityGuard™ Cartridges (mm)
Phases	50 x 1.0	20 x 2.0	30 x 2.0	50 x 2.0	100 x 2.0	150 x 2.0	50 x 3.0	100 x 3.0	150 x 3.0	4 x 2.0* /10pk
C18	00B-4439-A0	00M-4439-B0	00A-4439-B0	00B-4439-B0	00D-4439-B0	00F-4439-B0	00B-4439-Y0	00D-4439-Y0	00F-4439-Y0	AJ0-7596

for ID: 2.0-3.0 mm

3 µm Analytical Columns (mm)						SecurityGuard™ Cartridges (mm)
Phases	30 x 4.6	50 x 4.6	100 x 4.6	150 x 4.6	250 x 4.6	4 x 3.0* /10pk
C18	00A-4439-E0	00B-4439-E0	00D-4439-E0	00F-4439-E0	00G-4439-E0	AJ0-7597

for ID: 3.2-8.0 mm

Kinetex™ Core-Shell LC Columns

Ordering Information

2.6 µm Micro LC Columns (mm)						
Phases	30 x 0.3	50 x 0.3	100 x 0.3	150 x 0.3	50 x 0.5	150 x 0.5
EVO C18	—	00B-4725-AC	—	00F-4725-AC	00B-4725-AF	—

2.6 µm MercuryMS™ LC-MS Cartridges (mm)		
Phases	20 x 2.0	20 x 4.0
Biphenyl	00M-4622-B0-CE	00M-4622-D0-CE

MercuryMS Cartridge Holders		
Part No.	Description	Unit
CH0-7188	Direct-Connect Cartridge Holder, 20 mm	ea
CH0-5845	Standard Cartridge Holder, 20 mm	ea

2.6 µm Minibore Columns (mm)						SecurityGuard ULTRA Cartridges‡
Phases	30 x 2.1	50 x 2.1	75 x 2.1	100 x 2.1	150 x 2.1	3/pk
EVO C18	00A-4725-AN	00B-4725-AN	—	00D-4725-AN	00F-4725-AN	AJ0-9298

for 2.1 mm ID

2.6 µm MidBore™ Columns (mm)						SecurityGuard ULTRA Cartridges‡
Phases	30 x 3.0	50 x 3.0	75 x 3.0	100 x 3.0	150 x 3.0	3/pk
EVO C18	00A-4725-Y0	00B-4725-Y0	—	00D-4725-Y0	00F-4725-Y0	AJ0-9297

for 3.0 mm ID

Ordering Information

5 µm Minibore Columns (mm)					SecurityGuard™ ULTRA Cartridges‡
Phases	30 x 2.1	50 x 2.1	100 x 2.1	150 x 2.1	3/pk
EVO C18	00A-4633-AN	00B-4633-AN	00D-4633-AN	00F-4633-AN	AJ0-9298

for 2.1 mm ID

5 µm MidBore™ Columns (mm)					SecurityGuard ULTRA Cartridges‡
Phases	30 x 3.0	50 x 3.0	100 x 3.0	150 x 3.0	3/pk
EVO C18	00A-4633-Y0	00B-4633-Y0	00D-4633-Y0	00F-4633-Y0	AJ0-9297

for 3.0 mm ID

5 µm Analytical Columns (mm)					SecurityGuard ULTRA Cartridges‡
Phases	50 x 4.6	100 x 4.6	150 x 4.6	250 x 4.6	3/pk
EVO C18	00B-4633-E0	00D-4633-E0	00F-4633-E0	00G-4633-E0	AJ0-9296

for 4.6 mm ID

‡SecurityGuard ULTRA Cartridges require holder, Part No.: AJ0-9000
***SemiPrep SecurityGuard Cartridges require holder, Part No.: AJ0-9281
*PREP SecurityGuard Cartridges require holder, Part No.: AJ0-8223

Luna™ One of The World's Leading LC Columns

Luna C18

Ordering Information

5 µm MidBore and Analytical Columns (mm)								SecurityGuard™ Cartridges (mm)	
Phases	30 x 3.0	50 x 3.0	150 x 3.0	250 x 3.0	30 x 4.6	50 x 4.6	75 x 4.6	4 x 2.0*	4 x 3.0*
								/10pk	/10pk
C18(2)	00A-4252-Y0	00B-4252-Y0	00F-4252-Y0	00G-4252-Y0	00A-4252-E0	00B-4252-E0	00C-4252-E0	AJ0-4286	AJ0-4287
								for ID: 2.0-3.0 mm	3.2-8.0 mm

5 µm Analytical and Semi-Prep Columns (mm)					SecurityGuard™ Cartridges (mm)	
Phases	100 x 4.6	150 x 4.6	250 x 4.6	250 x 10	4 x 3.0*	10 x 10‡
					/10pk	/3pk
C18(2)	00D-4252-E0	00F-4252-E0	00G-4252-E0	00G-4252-N0	AJ0-4287	AJ0-7221
					for ID: 3.2-8.0 mm	9-16 mm

*SecurityGuard™ Analytical Cartridges require holder, Part No.: KJ0-4282
‡SemiPrep SecurityGuard™ Cartridges require holder, Part No.: AJ0-9281

Luna Omega PS C18 and Luna C18

Ordering Information

1.6 µm Microbore Columns (mm)			
Phases	50 x 1.0	100 x 1.0	150 x 1.0
PS C18	—	00D-4752-A0	—
C18	00B-4742-A0	00D-4742-A0	00F-4742-A0

1.6 µm Minibore Columns (mm)					SecurityGuard™ ULTRA Cartridges‡
Phases	30 x 2.1	50 x 2.1	100 x 2.1	150 x 2.1	3/pk
PS C18	00A-4752-AN	00B-4752-AN	00D-4752-AN	00F-4752-AN	AJ0-9508
C18	00A-4742-AN	00B-4742-AN	00D-4742-AN	00F-4742-AN	AJ0-9502
					for 2.1 mm ID

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