A New Solution for Trace-Level Analysis of 1,4-Dioxane in Drinking Water

Large Volume Injection in an Unmodified Splitless GC Inlet

Set up for Success

- Resprep® SPE cartridges assure clean extracts free of matrix interferences.
- Restek Premium inlet liner w/wool provides inert solvent reservoir improving reproducibility for 10 µL injections.
- Rxi® retention gap refocuses sample onto the analytical column resulting in narrow, symmetrical peaks.
- Rxi®-624Sil MS analytical column provides the selectivity needed to achieve resolution requirements and the high thermal stability (320 °C) to prevent carryover.

A New Solution for 1,4-Dioxane in Drinking Water: CSR-LVSI

- Perform large volume splitless injection with an unmodified Agilent-style split/splitless GC inlet.
- Reliably detect 1,4-dioxane down to 5.0 ppt in drinking water.
- Improve quantitative accuracy by introducing more analyte to the detector.

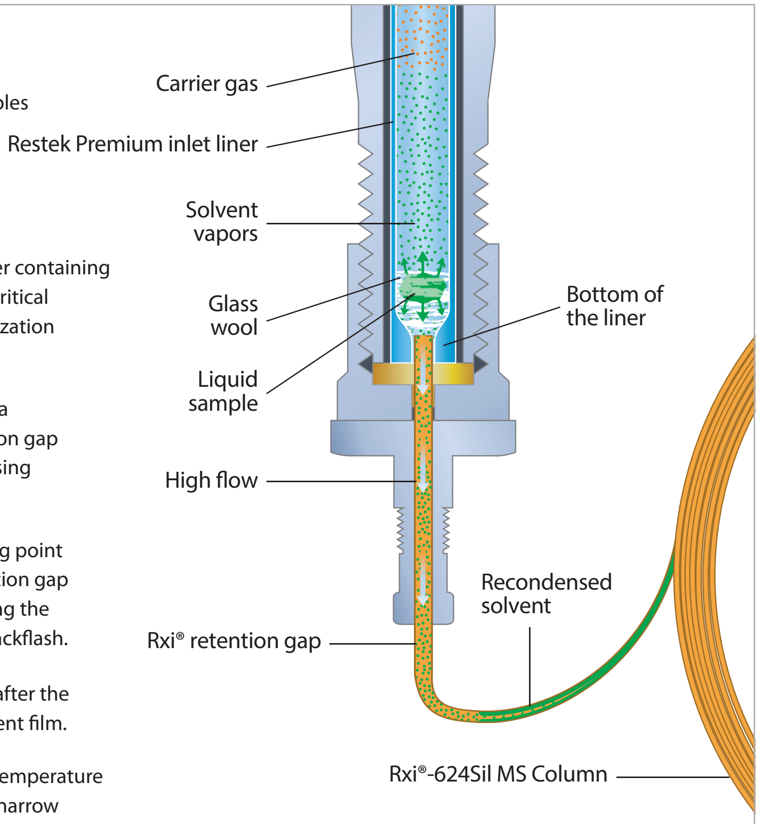
Global concern over the carcinogenic potential of 1,4-dioxane has led to greater regulatory interest in this compound. For example, as part of Unregulated Contaminant Monitoring Rule 3 (UCMR3), the U.S. EPA is requiring increased monitoring of 1,4-dioxane in drinking water and has revised the $1x10^{-6}$ cancer risk assessment level down to 0.35 µg/L. This risk level corresponds to the lifetime probability of one individual developing cancer in an exposed population of one million. As a result, the proposed minimum reporting level (MRL) for 1,4-dioxane as part of UCMR3 is 0.07 µg/L [1].

Large volume splitless injection (LVSI) can be advantageous when trying to analyze trace-level contaminants in clean matrices like drinking water. Since more target compound is introduced onto the analytical column, detectability is improved; however, a specialized injection port, such as a PTV, is generally required for LVSI [2]. PTV is not a viable option for this analysis, because the boiling points of the solutes (1,4-dioxane, and 1,4-dioxane-d8) and the SPE elution solvent (dichloromethane) are too similar. While PTV is not appropriate for analyzing 1,4-dioxane in water, a new option—concurrent solvent recondensation–large volume splitless injection (CSR-LVSI)—is highly effective.

Building on work by chemists at Thermo Scientific [3,4], Restek has been exploring the use of CSR-LVSI with a completely unmodified Agilent-style inlet. We used a typical SPE method for sample preparation, a fast autosampler injection with liquid sample band formation in a liner containing glass wool, a retention gap (precolumn) press-fitted to the analytical column, and a starting GC oven temperature below the boiling point of the solvent (Figure 1). By employing CSR-LVSI, detection limits for 1,4-dioxane in drinking water can be lowered without investing in specialized equipment.

Figure 1: How it Works: The CSR-LVSI Setup.

1. Clean, interference-free extracts from drinking water samples are produced using Resprep® SPE cartridges.
2. A fast autosampler injection with liquid band formation is used to make large volume (10 µL) injections.
3. The liquid sample enters a 4 mm Restek Premium inlet liner containing deactivated quartz glass wool at the bottom. The wool is critical since it acts as a "solvent reservoir". It also enhances vaporization and improves injection-to-injection reproducibility.
4. Rapid solvent evaporation occurs in the hot inlet, causing a pressure surge and a high rate of flow onto an Rxi® retention gap (precolumn), which is attached to the analytical column using a Press-Tight® connector.
5. Because the starting oven temperature is below the boiling point of the solvent, solvent recondensation occurs in the retention gap at the same rate that evaporation occurs in the inlet, driving the rapid transfer of material to the column and preventing backflash.
6. Higher boiling point solutes transfer to the retention gap after the solvent transfer, and are trapped by the recondensed solvent film.
7. After total sample transfer to the retention gap, the oven temperature ramp evaporates the solvent, focusing the analytes into a narrow band prior to analysis on the Rxi®-624Sil MS analytical column.

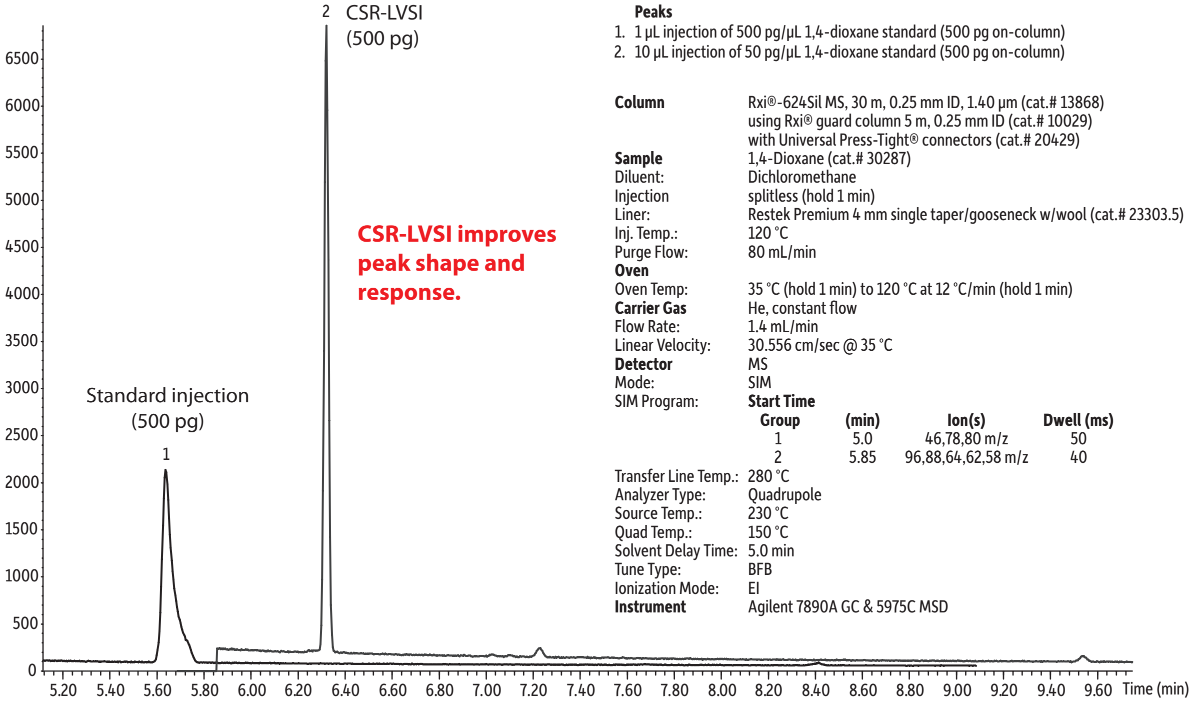


Comparing CSR-LVSI to Standard Injection

With large volume injections, there can be concern about analyte loss. Comparing peaks from CSR-LVSI and standard volume injections that delivered equivalent analyte masses on-column is a good way to determine if loss is occurring. As shown in Figure 2, retention time and peak shape vary greatly, but peak areas are comparable, demonstrating that no sample was lost when using the CSR-LVSI technique.

In addition, the use of CSR-LVSI improves peak shape, which is a phenomenon that has been reported before [5]. The recondensation of the solvent and analytes in the cool oven and subsequent re-evaporation of the dichloromethane solvent as the oven program passes 40 °C focuses the solutes into a very narrow band before they are separated by the analytical column. The result is a narrow, symmetrical 1,4-dioxane peak that can be easily and accurately integrated.

Figure 2: Overlay of CSR-LVSI and standard volume injections. Comparable areas for equivalent on-column amounts from both injection techniques indicate no loss of sample occurred when using CSR-LVSI.



CSR-LVSI improves peak shape and response.

Peaks
1. 1 µL injection of 500 pg/µL 1,4-dioxane standard (500 pg on-column)
2. 10 µL injection of 50 pg/µL 1,4-dioxane standard (500 pg on-column)

Column	Rxi®-624Sil MS, 30 m, 0.25 mm ID, 1.40 µm (cat.# 13868) using Rxi® guard column 5 m, 0.25 mm ID (cat.# 10029) with Universal Press-Tight® connectors (cat.# 20429)
Sample	1,4-Dioxane (cat.# 30287)
Diluent:	Dichloromethane
Injection	splitless (hold 1 min)
Liner:	Restek Premium 4 mm single taper/gooseneck w/wool (cat.# 23303.5)
Inj. Temp.:	120 °C
Purge Flow:	80 mL/min
Oven	
Oven Temp:	35 °C (hold 1 min) to 120 °C at 12 °C/min (hold 1 min)
Carrier Gas	He, constant flow
Flow Rate:	1.4 mL/min
Linear Velocity:	30.556 cm/sec @ 35 °C
Detector	MS
Mode:	SIM
SIM Program:	

Group	Start Time (min)	Ion(s)	Dwell (ms)
1	5.0	46,78,80 m/z	50
2	5.85	96,88,64,62,58 m/z	40

Transfer Line Temp.:	280 °C
Analyzer Type:	Quadrupole
Source Temp.:	230 °C
Quad Temp.:	150 °C
Solvent Delay Time:	5.0 min
Tune Type:	BFB
Ionization Mode:	EI
Instrument	Agilent 7890A GC & 5975C MSD

GC_EV1260

The improved peak shape and response obtained using CSR-LVSI results in linear responses across a wide concentration range. Calibration curves at levels well below typical minimum detection limits displayed excellent correlations ($R^2 = 0.9998$ for 1 to 1,000 pg/µL [10 to 10,000 pg on-column] and $R^2 = 0.9996$ for 0.5 to 50 pg/µL [5 to 500 pg on-column]). Calibration levels and equivalent concentrations are shown in Table I. Achieving linear calibrations for trace-levels makes CSR-LVSI a viable technique for meeting lower detection limits.

Table I: Calibration curve (0.5-50 pg/µL) for CSR-LVSI.

Level	Prepared Standard (pg/µL)	10 µL Injection On-Column Amount (pg)	Equivalent Concentration in 500 mL Samples (µg/L)
1	0.50	5.0	0.010
2	1.0	10	0.020
3	5.0	50	0.10
4	10	100	0.20
5	50	500	1.0

Lower Detection Limits for 1,4-Dioxane in Drinking Water Using CSR-LVSI

While chromatographic and linearity results for injected standards clearly show that CSR-LVSI holds great promise for trace-level analysis of 1,4-dioxane, this analysis is very sensitive to interference from coextracted matrix components. Combining CSR-LVSI in an unmodified inlet with effective sample preparation creates an opportunity to lower detection limits without investing in new equipment. As shown in this excerpt (full application note available at www.restek.com/dioxane) labs can accurately report 1,4-dioxane down to 5.0 ppt using this setup and procedure.

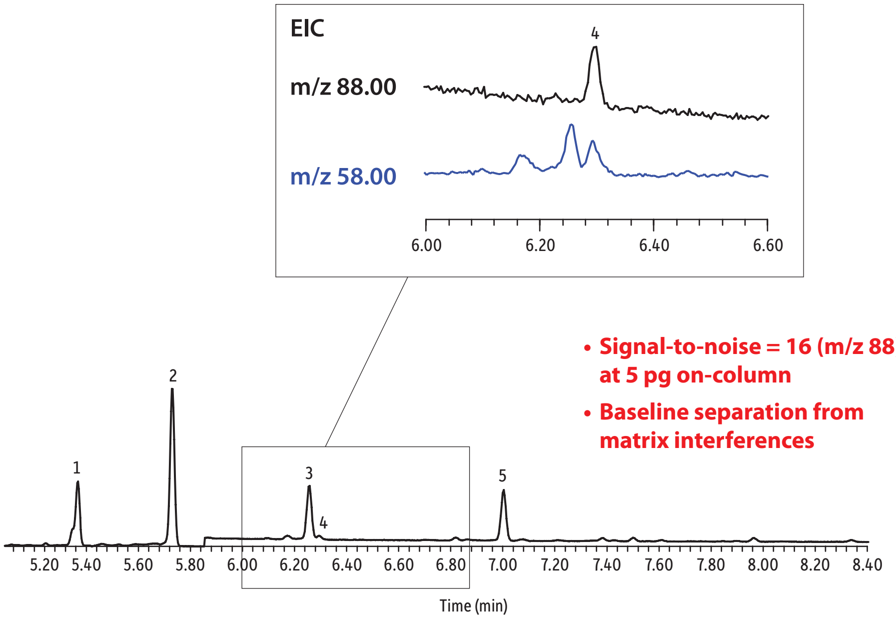
Sample Preparation: Reliably Eliminate Interferences With Resprep® SPE Cartridges

A typical SPE sample preparation procedure involves extracting a sample using a tube packed with activated charcoal, and then drying the extract and concentrating it to a final volume of 1 mL. However, due to the high volatility of 1,4-dioxane and tetrahydrofuran-d8, this approach is not recommended for 1,4-dioxane analysis. In fact, the concentration step is expressly forbidden in EPA Method 522 [6] in order to prevent evaporative loss of the target analytes.

For our CSR-LVSI work, we used a 6 mL Resprep® SPE cartridge containing 2 g activated charcoal (cat.# 26032). This cartridge was designed specifically for extraction of 1,4-dioxane from drinking water and is intended for samples ranging from 0.5 L to 1 L. A very thorough evaluation of this cartridge is described in Grimmett and Munch's paper on the development of the Method 522 [2] and average recoveries of 1,4-dioxane in the mid 80 to low 90 percentile with %RSDs less than 5 (n = 7 for each matrix) were reported.

Extraction with Resprep® SPE cartridges produces accurate, reproducible results for 1,4-dioxane in drinking water; however, when making large volume injections, the potential for increased interferences exists as more coextracted material is injected onto the column. In this case, 10 times the normal amount of sample and cartridge matrix is being injected, so it is critical to verify the absence of interferences for both the quantitation ion (m/z 88) and the confirmation ion (m/z 58). The analysis of fortified drinking water extracts shown in Figure 3 clearly demonstrates that both ions are fully separated from matrix interferences and this was consistent through testing.

Figure 3: 1,4-Dioxane extracted ion chromatogram of a 10 µL CSR-LVSI of a 0.5 pg/µL fortified drinking water extract (5 pg on-column). Note that the 1,4-dioxane quantification ion (m/z 88) and confirmation ion (m/z 58) are fully separated from matrix interferences and good peak responses were obtained.



Peaks
1. Tetrahydrofuran-d8 (IS)
2. Co-extracted material
3. 1,4-Dioxane-d8 (SS)
4. 1,4-Dioxane
5. Co-extracted material

See Figure 2 for conditions.

- **Signal-to-noise = 16 (m/z 88) at 5 pg on-column**
- **Baseline separation from matrix interferences**

GC_EV1263

Analysis: Choose Columns and Conditions for Detection Down to 5.0 ppt

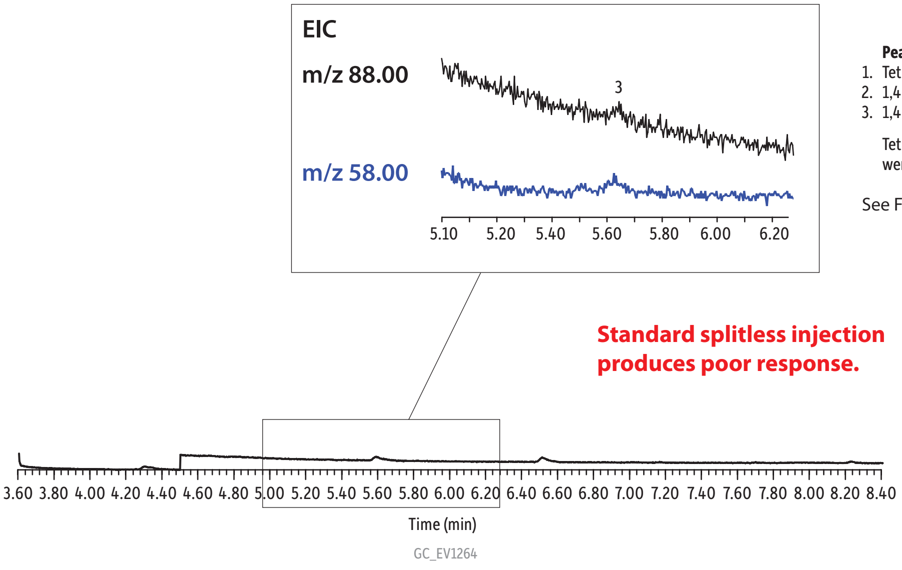
CSR-LVSI offers improved peak shape and response for 1,4-dioxane compared to standard injection volume methods. These chromatographic improvements allow quantification even at 5.0 ppt using the setup and procedure shown here. The use of a Restek Premium inlet liner with wool is critical as it provides an inert reservoir for the large sample volume, enhances vaporization, and helps assure good repeatability across injections. Peak shape and response are also improved because the CSR-LVSI technique recondenses the solvent and analytes in the cool oven and then subsequently re-evaporates the dichloromethane solvent as the oven program passes 40 °C. These conditions, along with the use of a deactivated Rxi® retention gap, focus the solutes into a tight band, which helps produce narrow, symmetrical peaks on the analytical column. A 0.25 mm ID retention gap at least 5 meters long is required for a 10 µL injection. Focusing is especially critical for this application, because 1,4-dioxane and tetrahydrofuran have high vapor pressures and some material is expected to transfer to the retention gap with the solvent vapors. Without this step, the chromatography of the target analytes would suffer.

Once the solutes enter the analytical column, separation begins. Choosing an analytical column with an appropriate stationary phase is vital in getting the best separation of 1,4-dioxane from any interferences. An Rxi®-624Sil MS column was chosen for this analysis because it offers the selectivity necessary to separate the target analytes from any coextracted matrix components. As shown in Figure 3, when using CSR-LVSI both the quantification ion and confirmation ion for 1,4-dioxane are fully separated from matrix interferences and good peak responses were obtained at just 5 pg on-column. In contrast, when 1 µL of the same extract was injected, the resulting peak is barely distinguishable from the noise and the confirmation ion cannot be seen (Figure 4). Ultimately, the improved signal-to-noise ratios obtained using CSR-LVSI resulted in recoveries that were within the expected range (Table II) and that matched published method development data very well [2].

Table II: CSR-LVSI resulted in good recovery of both 1,4-dioxane and surrogate 1,4-dioxane-d8 from extracted fortified samples.

Matrix	Fortified Sample Conc. (µg/L)	Volume of Sample Extracted (L)	Theoretical Extract Conc. (pg/µL)	Recovery (pg/µL)	1,4-Dioxane % Recovery	Surrogate % Recovery
Bottled drinking water	0.0050	1.0	0.50	0.40	80	125
Bottled drinking water	0.20	0.50	10	9.2	92	102
Bottled drinking water	0.20	1.0	20	18	87	96
Reagent water	0.020	0.50	1.0	1.0	100	88
Reagent water	0.20	0.50	10	8.4	84	92
Reagent water	0.0	0.50	0.0	-	-	86

Figure 4: 1,4-Dioxane extracted ion chromatogram of a standard splitless 1 µL injection of a 0.5 pg/µL fortified drinking water extract (0.5 pg on-column). Peaks are barely distinguishable from background noise.



GC_EV1264

Standard splitless injection produces poor response.

Peaks
1. Tetrahydrofuran-d8 (IS)
2. 1,4-Dioxane-d8 (SS)
3. 1,4-Dioxane

Tetrahydrofuran-d8 (IS) and 1,4-dioxane-d8 (SS) were not detected.

See Figure 2 for conditions.

Since CSR-LVSI introduces more matrix onto the column than a typical injection, having an analytical column that has a high thermal stability is also a benefit. While most 624 type columns have maximum operating temperatures of 240–260 °C, the Rxi®-624Sil MS column has an extended maximum operating temperature of 320 °C. This allows a high temperature period following analysis to be used to remove contaminants from the column, which reduces the potential for the carryover of interfering coextracted material between samples. This can also increase sample throughput, given that less volatile compounds will elute faster at 320 °C than at 260 °C.

Summary

Concurrent solvent recondensation–large volume splitless injection (CSR-LVSI) with an unmodified Agilent-style split/splitless GC inlet is a viable approach for analyzing 1,4-dioxane in drinking water. While large volume injection usually involves specialized equipment, using it with a completely unmodified split/splitless inlet provides a cost-effective way to meet ever decreasing detection limits. From SPE cartridges and analytical reference materials to inlet supplies and GC columns, Restek provides all of the products to support this important application.

References

[1] U.S. EPA, Unregulated Contaminant Monitoring Rule 3. http://water.epa.gov/lawsregs/rulesregs/sdwa/ucmr/ucmr3/index.cfm (accessed March 2, 2012).

[2] P. Grimmett, J. Munch, Method Development for the Analysis of 1,4-Dioxane in Drinking Water Using Solid-Phase Extraction and Gas Chromatography-Mass Spectrometry, J. of Chromatographic Science 47 (2009) 31.

[3] P. Magni, T. Porzano, Concurrent Solvent Recondensation Large Sample Volume Splitless Injection, J. Sep. Sci. 26 (2003) 1491.

[4] Patent No: US 6,955,709 B2.

[5] J. Cochran, The Solvent Effect in Concurrent Solvent Recondensation Large Volume Splitless Injection with Methylene Chloride – EPA Method 8270 Semivolatiles, ChromaBLOGraphy, Restek Corporation, 2011 http://blog.restek.com/?p=1902 (accessed March 2, 2012).

[6] U.S. Environmental Protection Agency, Method 522, Determination of 1,4-Dioxane in Drinking Water by Solid Phase Extraction (SPE) and Gas Chromatography/Mass Spectrometry (GC/MS) with Selected Ion Monitoring (SIM), September 2008.

For the complete application note, visit **www.restek.com/dioxane**

Product Listing

Tetrahydrofuran-d8 Standard

tetrahydrofuran-d8

2,000 µg/mL in P&T methanol, 1 mL/ampul
cat.# 30112 (ea.)

1,4-Dioxane-d8

1,4-dioxane-d8

2,000 µg/mL in P&T methanol, 1 mL/ampul
cat.# 30614 (ea.)

1,4-Dioxane

1,4-dioxane

2,000 µg/mL in P&T methanol, 1 mL/ampul
cat.# 30287 (ea.)

EZ Twist Top® Split/Splitless Injection Port

for Agilent 7890 GCs

Description	qty.	cat.#
Injection Port Assembly Kit, Siltek Treated Includes: Siltek weldment, Siltek shell weldment, 2 weldment O-rings, Siltek dual Vespel ring inlet seal, septum nut, reducing nut, stainless steel capillary nut for use with 1/16" ferrules, and weldment removal tool	kit	22178
Shell Weldment, Siltek Treated	ea.	22176
Weldment O-rings	10-pk.	22729
High Temperature Weldment O-Rings	10-pk.	23405
Septum Nut, Autosampler & PTV (for 23-gauge needles)	ea.	20631
Stainless Steel Capillary Column Nut (for use with standard 1/16" ferrules)	2-pk.	20883
Reducing Nut	ea.	22078
0.8 mm Dual Vespel Ring Inlet Seal, Siltek-Treated	2-pk.	21242
	10-pk.	21243
Weldment Removal Tool	ea.	22728

Visit www.restek.com/slideshows for an educational video on our EZ Twist Top® injection port system.

Press-Tight® Connectors

Description	5-pk.	25-pk.	100-pk.
Universal Press-Tight Connectors	20400	20401	20402
Universal Press-Tight Connectors, Deactivated	20429	20430	—

Flip Seal™ Dual Vespel® Ring Inlet Seals

Reversible, two-sided design allows significantly more analyses than other seals, at the same price—simply use, flip, then use again!

1.2 mm ID Flip Seal Dual Vespel Ring Inlet Seal	2-pk.	10-pk.
Gold-Plated	23411	23413
Siltek-Deactivated	23412	23414
Flip Seal Dual Vespel Ring Inlet Seal Kit	**qty.**	**cat.#**
Includes: gold-plated 1.2 mm ID inlet seal, reducing nut adaptor, 1/16" SS nut	kit	23406

Note: The Flip Seal™ inlet seal requires a special reducing nut adaptor fitting, which is included in the kit. The Flip Seal™ Adaptor can be used with standard 1/16" ferrules.

Method Specific SPE Cartridges

These cartridges have been specifically designed to provide consistent and reproducible results for the method or application stated.

Description	Applications	Tube Volume, Bed Weight	qty.	cat.#
EPA Methods 521 & 522	For use in EPA Method 521: Nitrosamines in Drinking Water and EPA Method 522 for 1,4-Dioxane in Drinking Water. Activated charcoal packing.	6 mL, 2 g	30-pk.	26032

Rxi®-624Sil MS Columns (fused silica)

(midpolarity Crossbond® silarylene phase; similar to 6% cyanopropylphenyl/94% dimethyl polysiloxane)

Description	temp. limits	qty.	cat.
30 m, 0.25 mm ID, 1.40 µm	-20 to 300/320 °C	ea.	13868

Rxi® Guard/Retention Gap Columns (fused silica)

Description	qty.	cat.#
5 m, 0.25 mm ID, 0.37 ± 0.04 mm OD	ea.	10029
5 m, 0.25 mm ID, 0.37 ± 0.04 mm OD	6-pk.	10029-600

Restek Premium 4.0mm ID Single Taper Inlet Liner w/ Wool

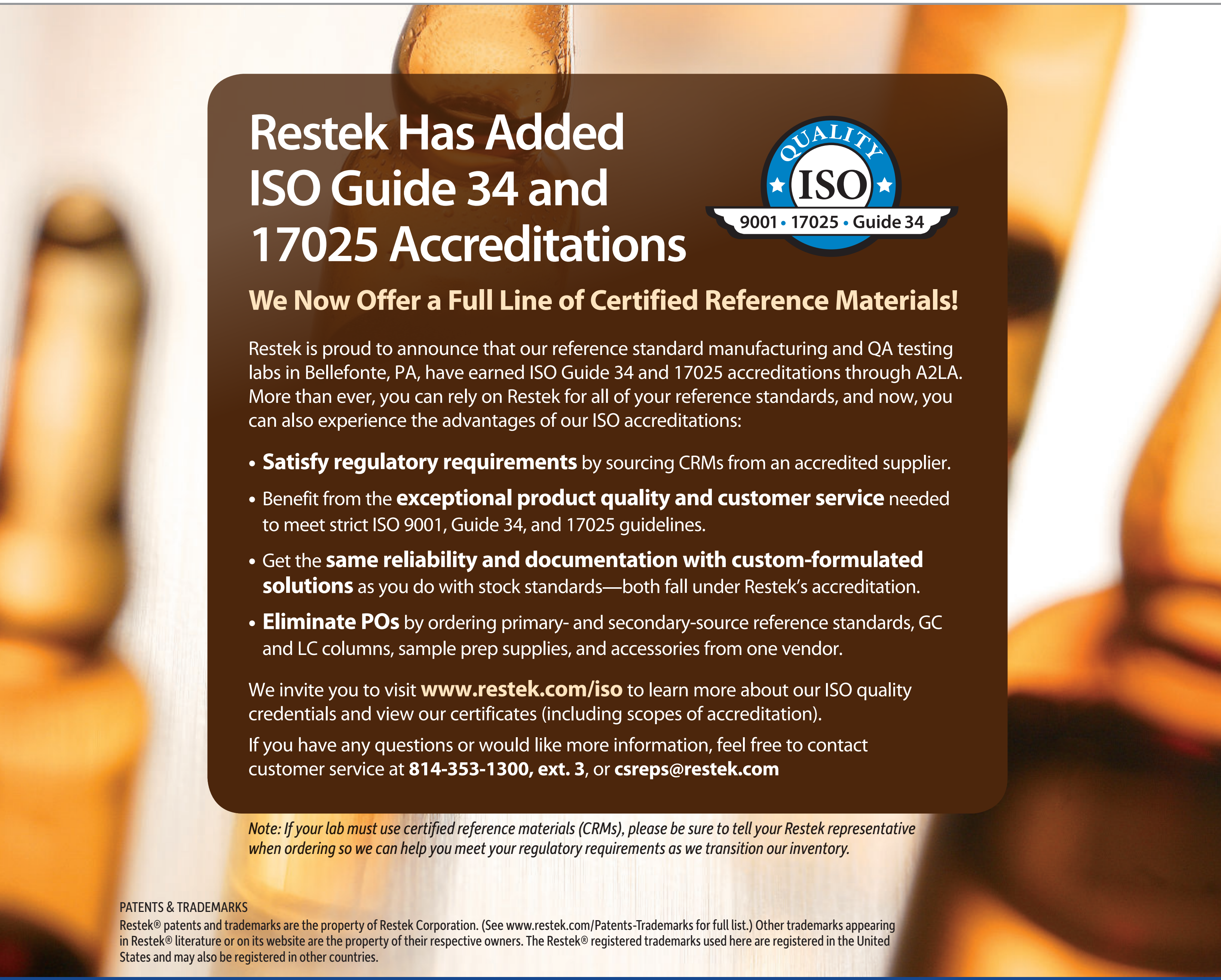
For Agilent GCs equipped with split/splitless inlets

ID x OD x Length	qty.	cat.#
Single Taper, Restek Premium Technology, Wool, Borosilicate Glass 4.0 mm x 6.5 mm x 78.5 mm	ea.	23303.1
Single Taper, Restek Premium Technology, Wool, Borosilicate Glass 4.0 mm x 6.5 mm x 78.5 mm	5-pk.	23303.5
Single Taper, Restek Premium Technology, Wool, Borosilicate Glass 4.0 mm x 6.5 mm x 78.5 mm	25-pk.	23303.25

Restek Electronic Leak Detector

Don't let a small leak turn into a costly repair—protect your analytical column by using a Restek leak detector.

Description	qty.	cat.#
Leak Detector With Hard-Sided Carrying Case and Universal Charger Set (U.S., UK, European, Australian)	ea.	22655
Small Probe Adaptor for Leak Detector	ea.	22658
Dynamic Duo Combo Pack (Restek Leak Detector and ProFLOW 6000 Flowmeter)	kit	22654
Soft-Sided Storage Case for Leak Detector or ProFLOW 6000 Flowmeter	ea.	22657



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