Tricks of the Trade, Keeping Your GC System Up Longer for the Analysis of Pesticides (and More!!)

Michelle Misselwitz, Jack Cochran, Julie Kowalski, Christopher Rattray

The Main Problems with GC-MS

- GC inlet
  - Liner
  - Seal

- GC column
  - Guard column
  - Analytical column

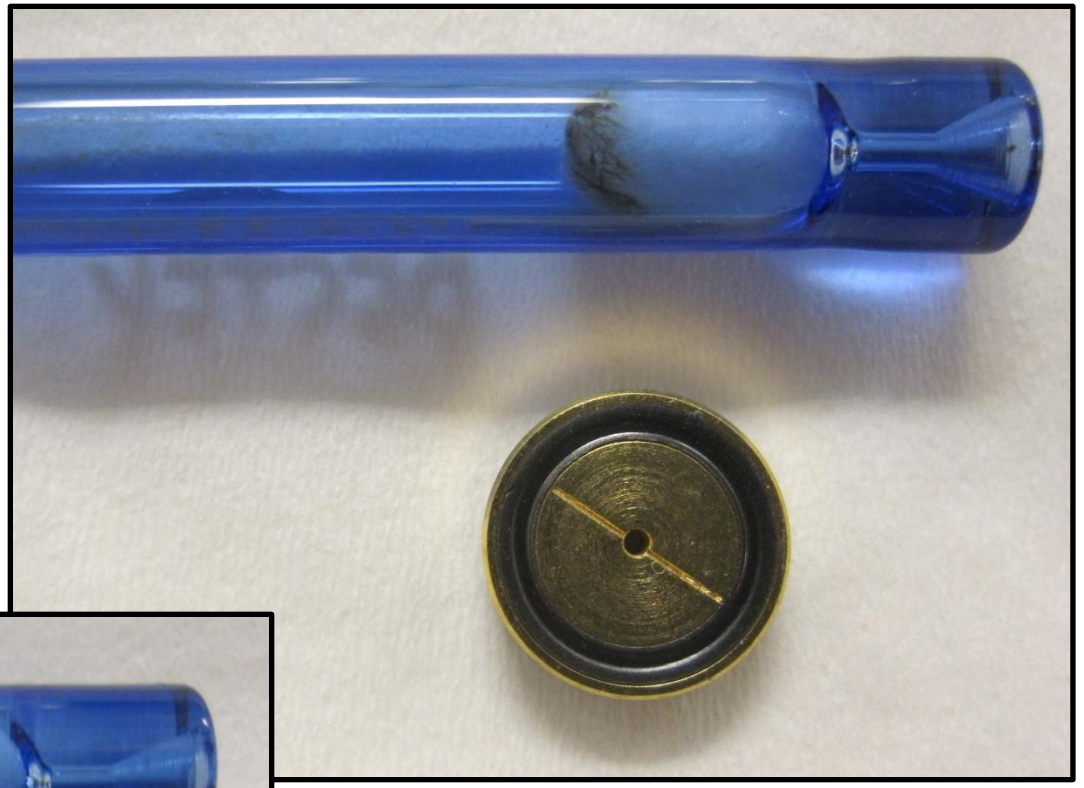
- Dirty samples contaminate liner wool and bottom seal
  - Poor compound transfer
  - Compound degradation

- Dirty samples contaminate front of column system
  - Poor compound transfer
  - Compound degradation

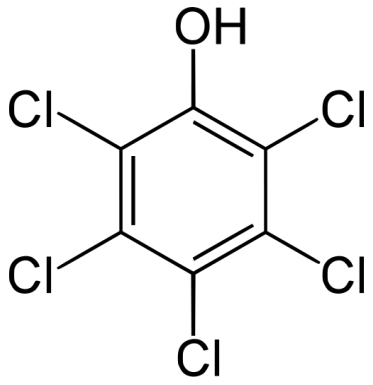
Both issues lead to poor data quality and downtime for maintenance…

Splitless injection

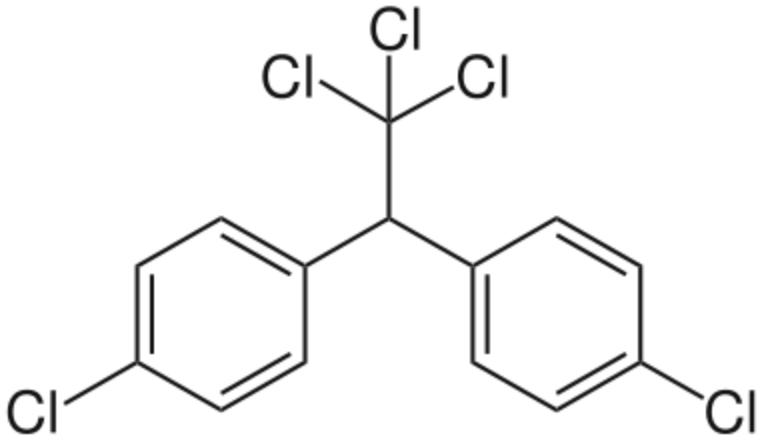
27 × Used Motor Oil
50,000 µg/mL



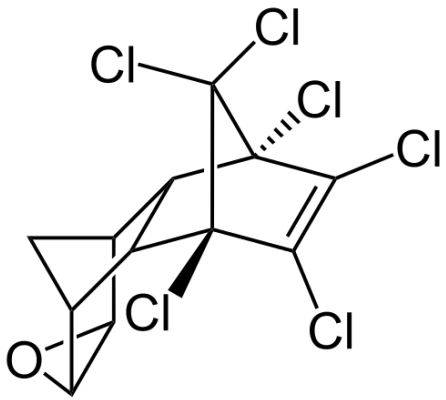
39 × Sediment Extract
(no dilution)



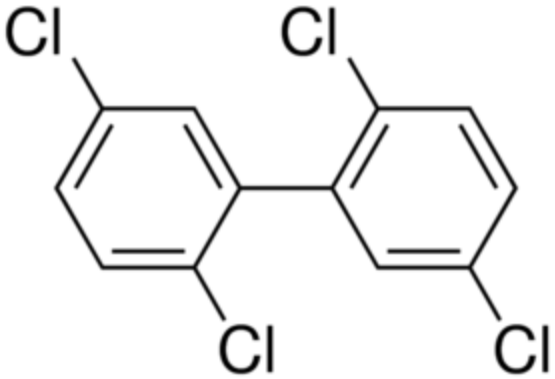
Pentachlorophenol



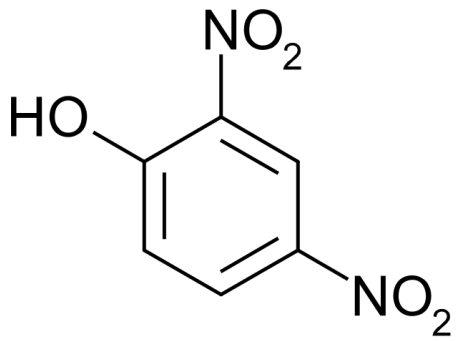
4,4’-DDT



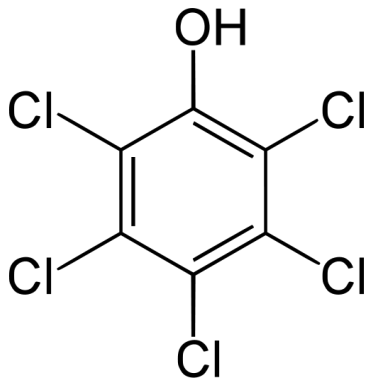
Endrin



PCB 52



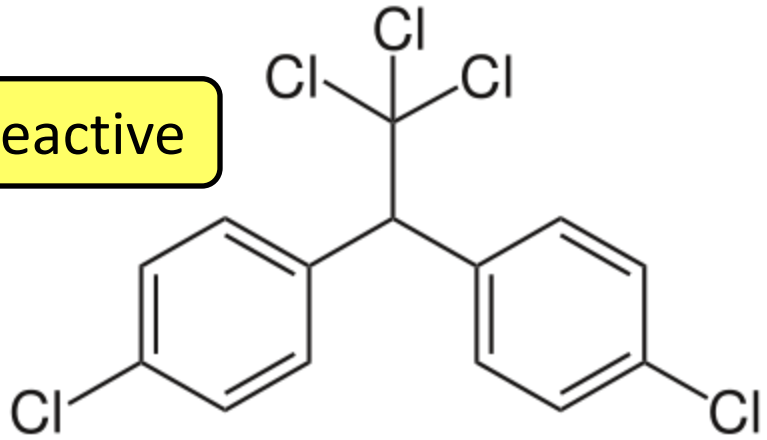
2,4-Dinitrophenol



Active

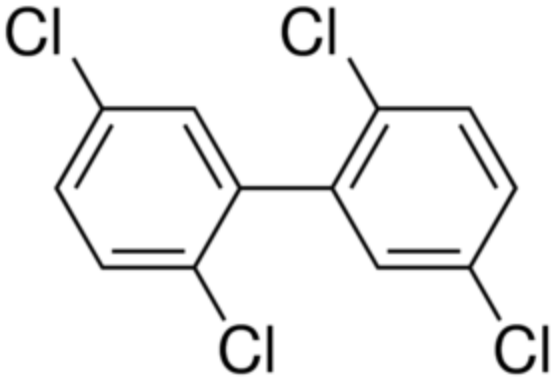
Pentachlorophenol

Reactive



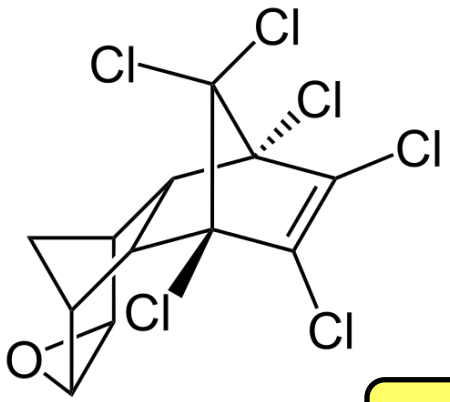
4,4’-DDT

Internal standard



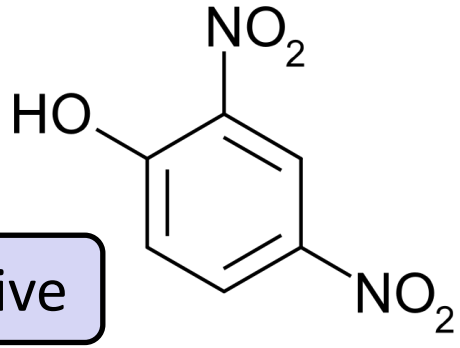
PCB 52

- Proof



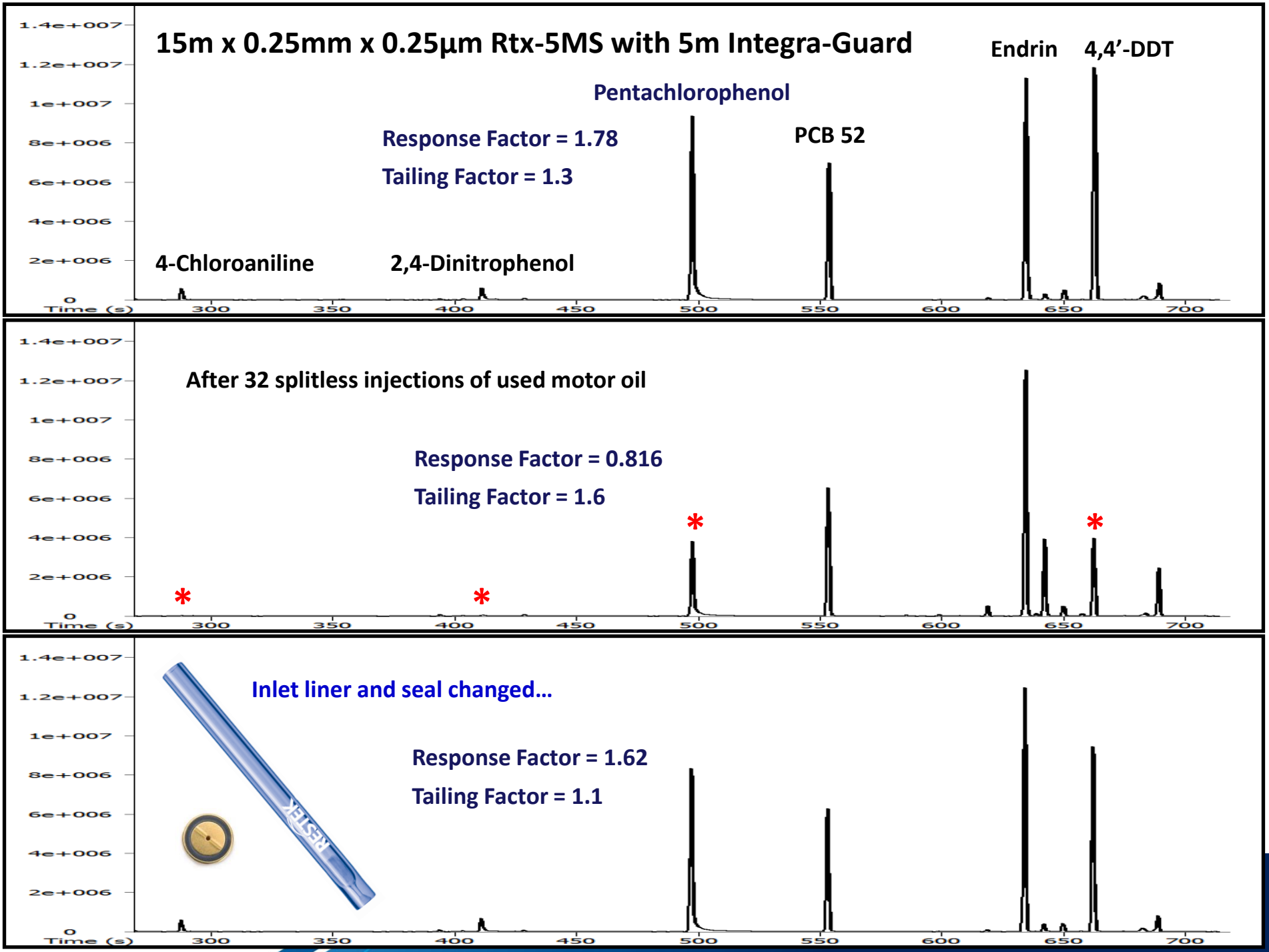
Endrin

Reactive

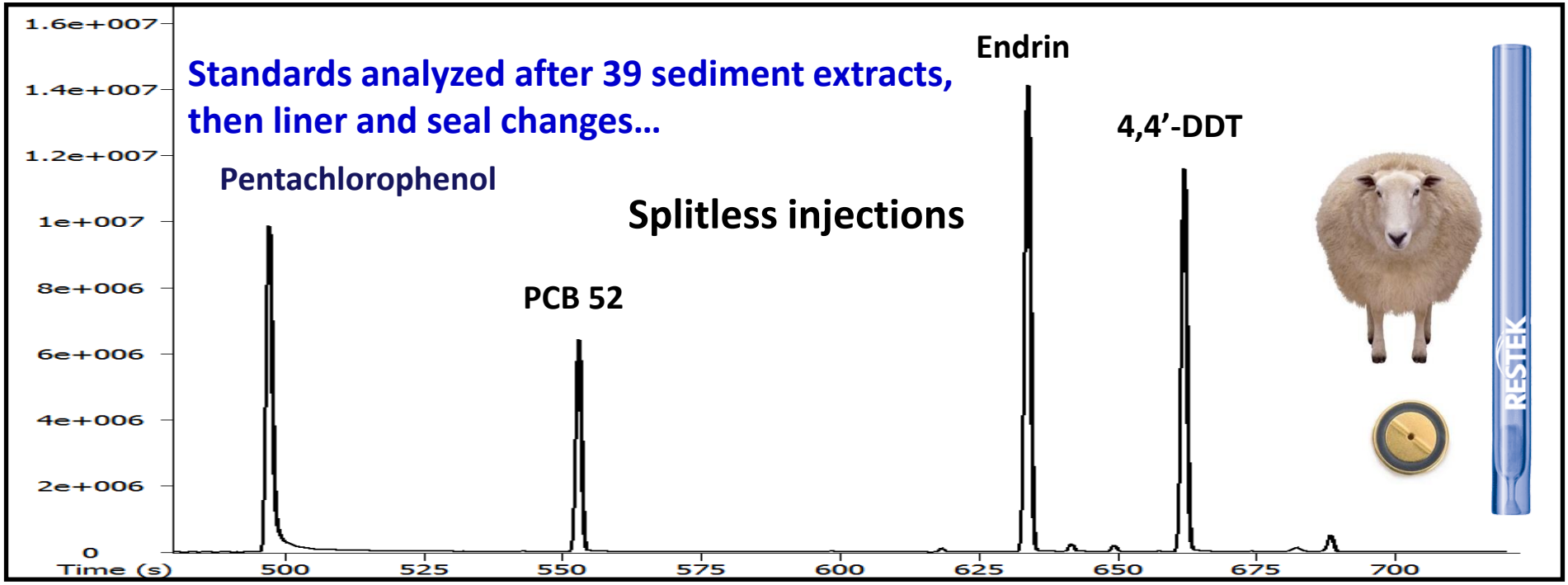


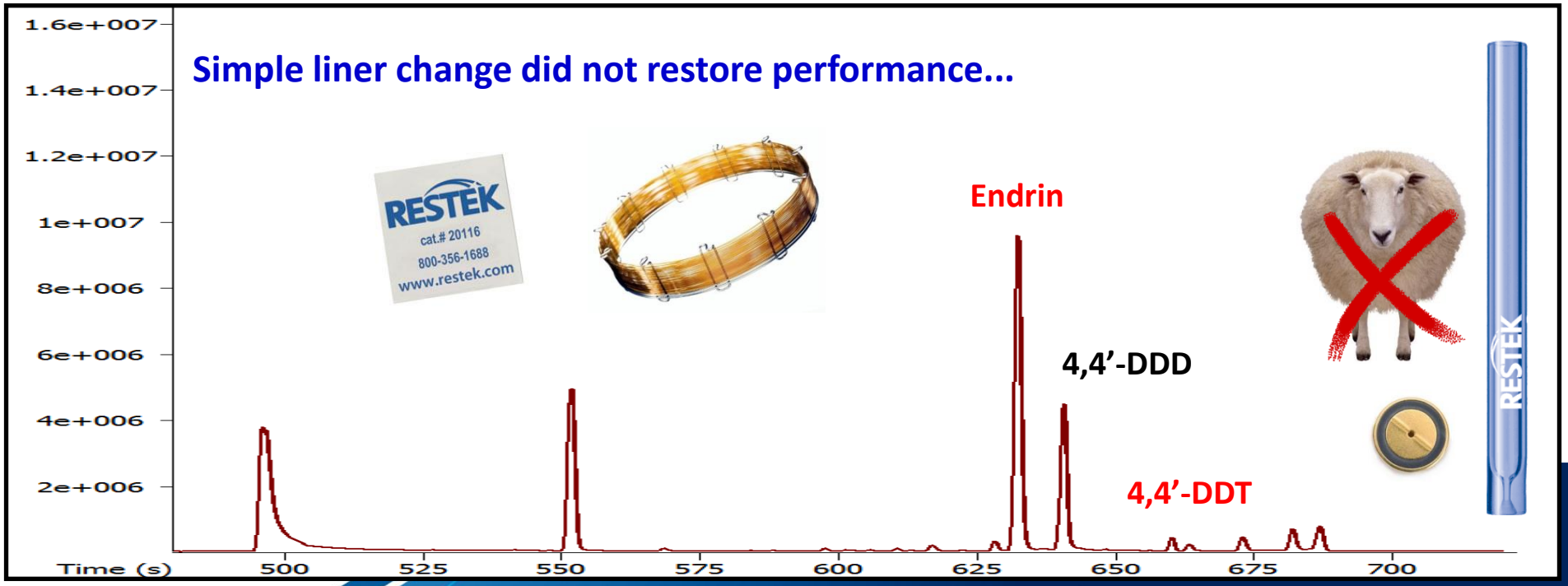
Active

2,4-Dinitrophenol


15m x 0.25mm x 0.25µm Rtx-5MS with 5m Integra-Guard
Endrin
4,4'-DDT
Pentachlorophenol
Response Factor = 1.78
Tailing Factor = 1.3
PCB 52
4-Chloroaniline
2,4-Dinitrophenol
After 32 splitless injections of used motor oil
Response Factor = 0.816
Tailing Factor = 1.6
Inlet liner and seal changed…
Response Factor = 1.62
Tailing Factor = 1.1
Time (s)

What about wool-packed versus non-wool-packed liners?


Standards analyzed after 39 sediment extracts, then liner and seal changes…
Pentachlorophenol
PCB 52
Splitless injections
Endrin
4,4'-DDT
RESTEK
1.6e+007
1.4e+007
1.2e+007
1e+007
8e+006
6e+006
4e+006
2e+006
0
Time (s)
500
525
550
575
600
625
650
675
700


Simple liner change did not restore performance...
RESTEK
cat.# 20116
800-356-1688
www.restek.com
Endrin
4,4'-DDD
4,4'-DDT
RESTEK
1.6e+007
1.4e+007
1.2e+007
1e+007
8e+006
6e+006
4e+006
2e+006
Time (s)
500
525
550
575
600
625
650
675
700

A Better Way?

- Analyte Protectants
  - GC system active site masking compounds
  - Improve compound transfer from GC inlet
  - Allow better peak shape from GC column
- Split injection (shoot-and-dilute)
  - High GC inlet flow improves compound transfer
  - Less “dirt” on GC column improves peak shapes
  - System stays up longer

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JOURNAL OF CHROMATOGRAPHY A

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Evaluation of analyte protectants to improve gas chromatographic analysis of pesticides☆

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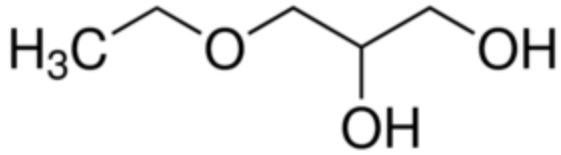
Significant peak quality improvements obtained when matrix components are present to fill active sites and reduce analyte interactions.

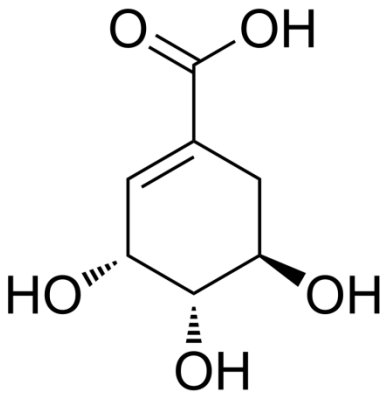
"Matrix-induced chromatographic response enhancement".

Addition of "analyte protectants" (e.g. sugars, acids, etc.) to standards and samples.

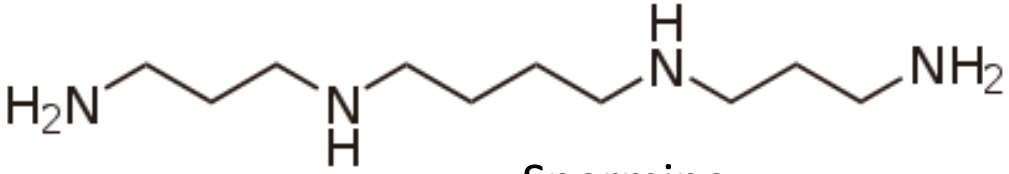
Provides chromatographic enhancement effect for analytes in a very dirty GC system.



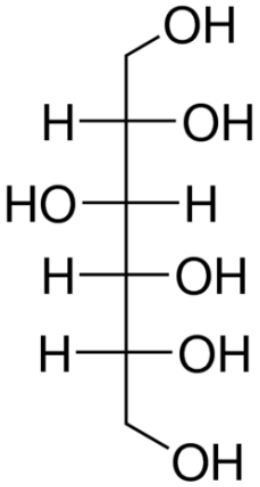
3-Ethoxy-1,2-propanediol



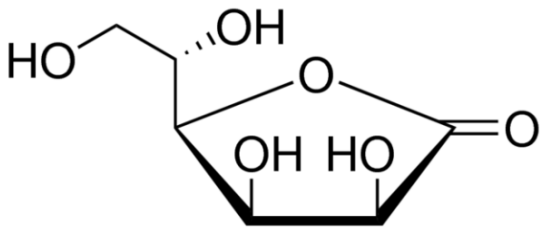
Shikimic acid



Spermine

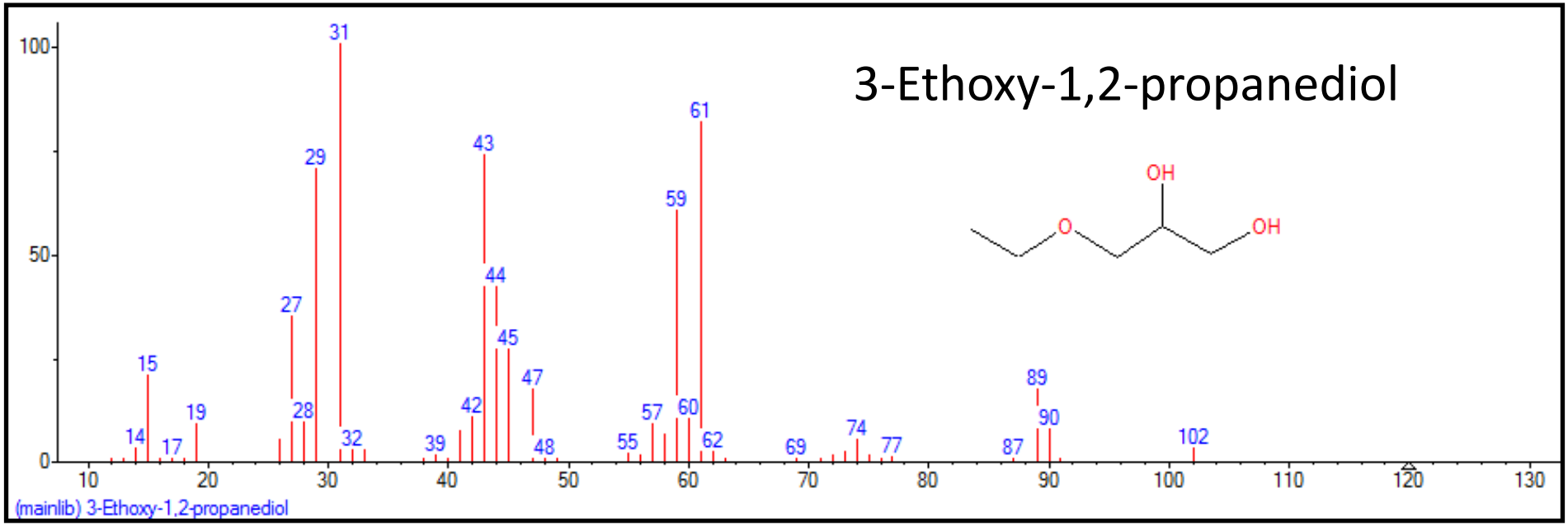


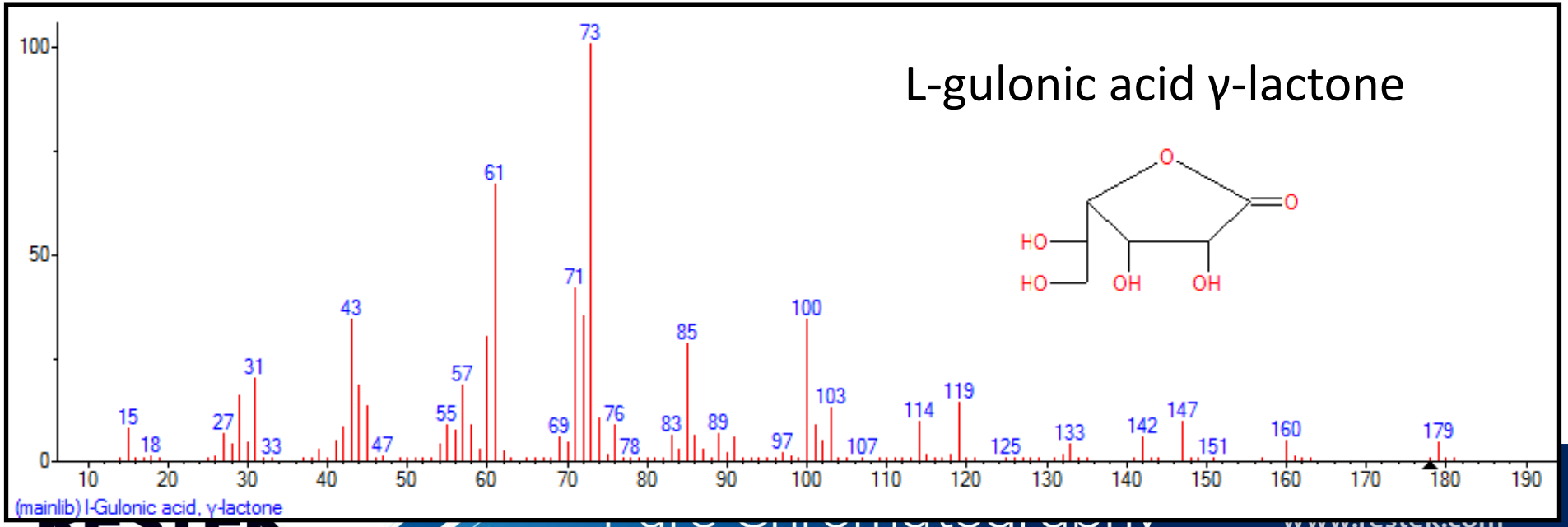
D-sorbitol



L-gulonic acid γ-lactone

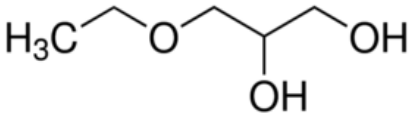
Analyte protectants

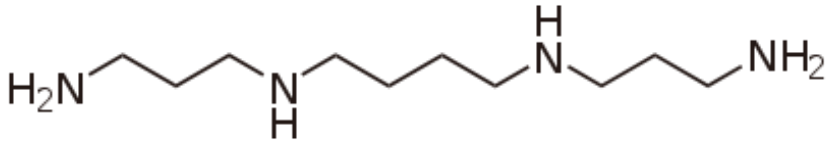

3-Ethoxy-1,2-propanediol
OH
O
OH
(mainlib) 3-Ethoxy-1,2-propanediol


L-gulonic acid γ-lactone
O
O
HO
HO
OH
OH
(mainlib) l-Gulonic acid, γ-lactone

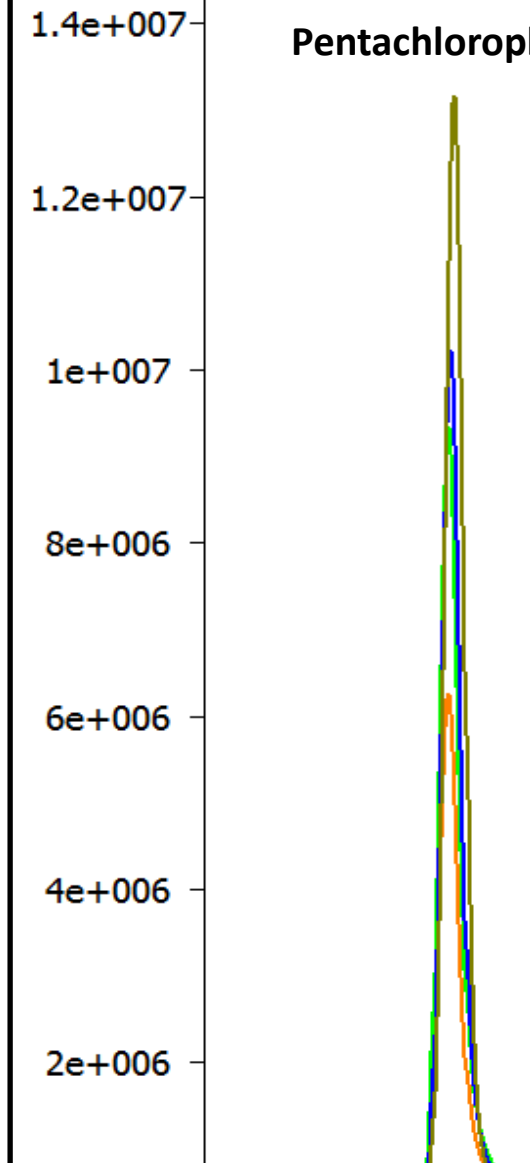
Analyte Protectant Criteria

- Rich in hydroxys/aminos to deactivate systems
- Volatile so they gas chromatograph
- Several may perform better than one
- Volatility range similar to compounds analyzed
- Added in high concentration
- Low m/z ions to avoid quantification bias
- Inexpensive
- Injected with each standard and sample





15m x 0.25mm x 0.25µm Rtx-5MS with 5m Integra-Guard



Pentachlorophenol

Standard 10 µg/µL AP

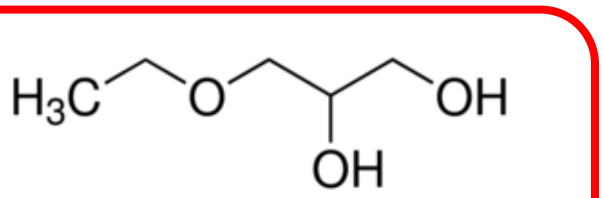
Standard 2.5 µg/µL AP

Standard 0.5 µg/µL AP

Standard No AP

Tailing Factor = 1.1

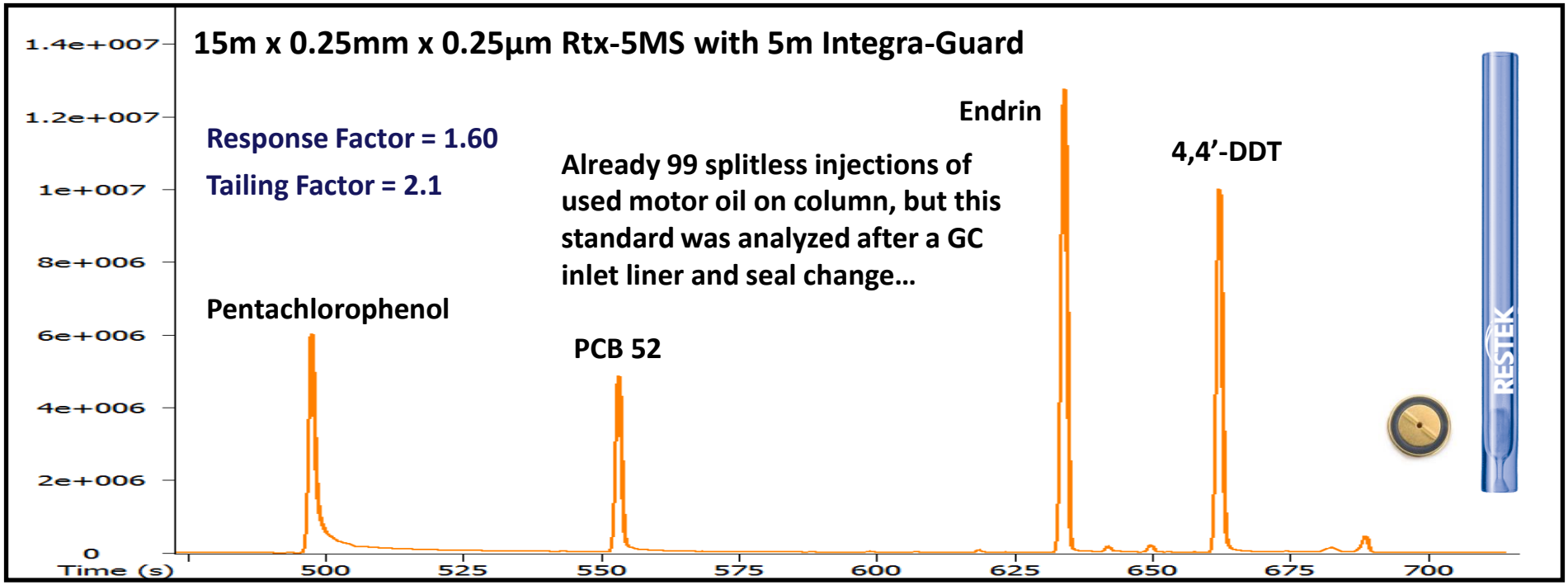
Tailing Factor = 2.1

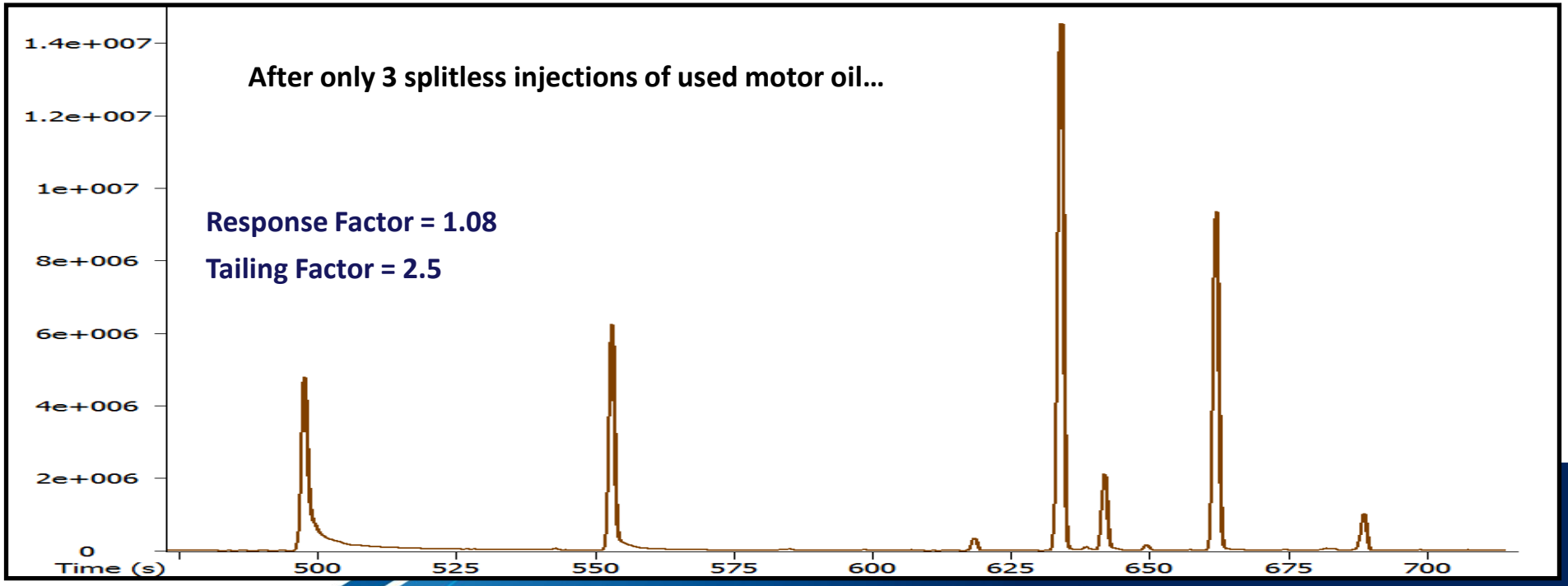


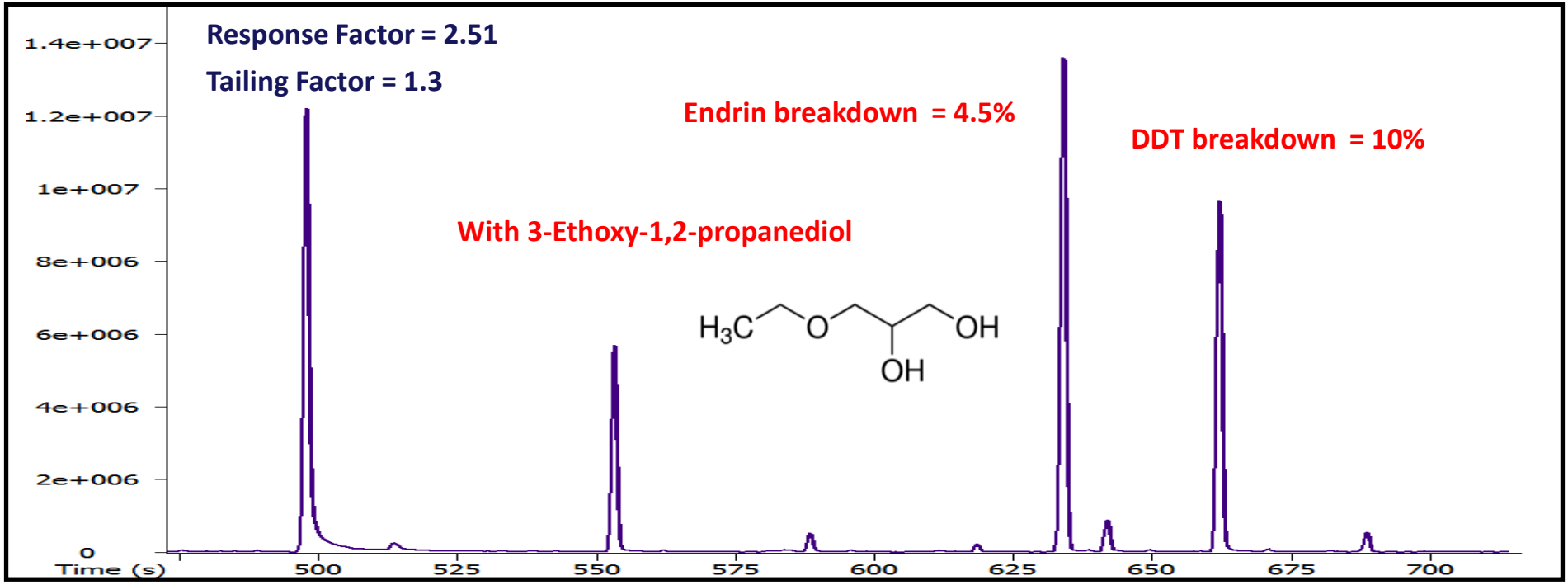
3-Ethoxy-1,2-propanediol

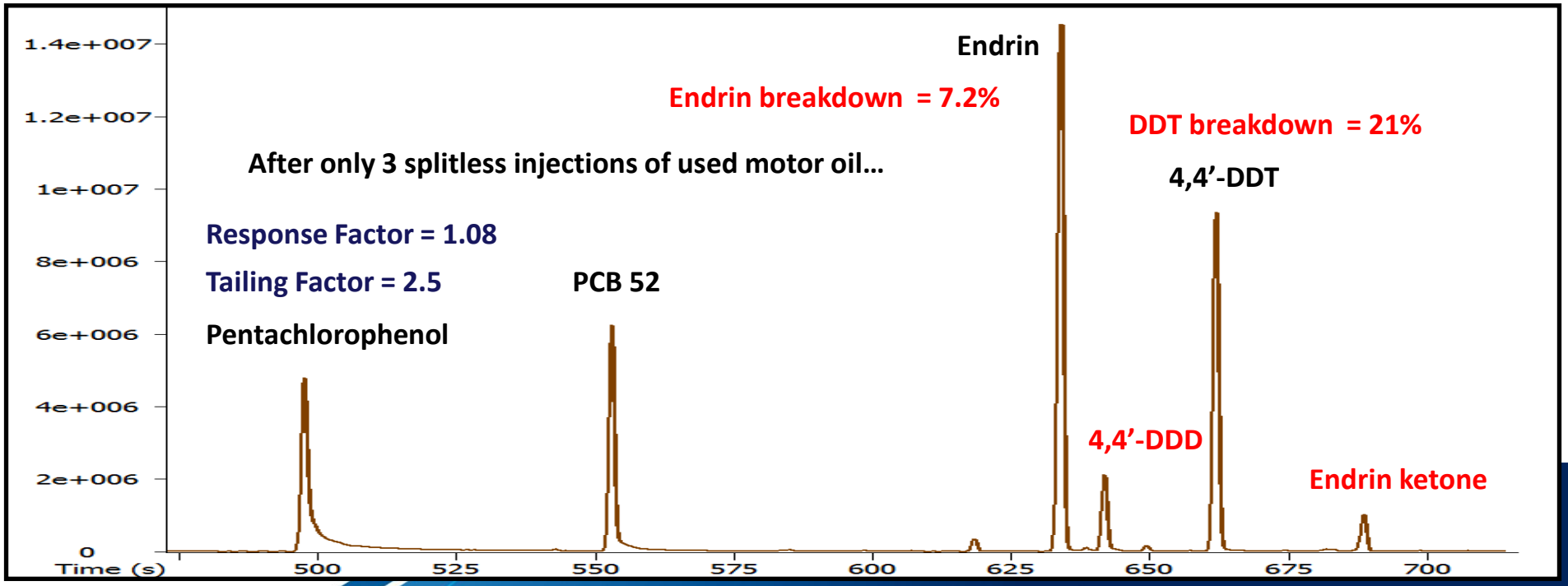
PCB 52

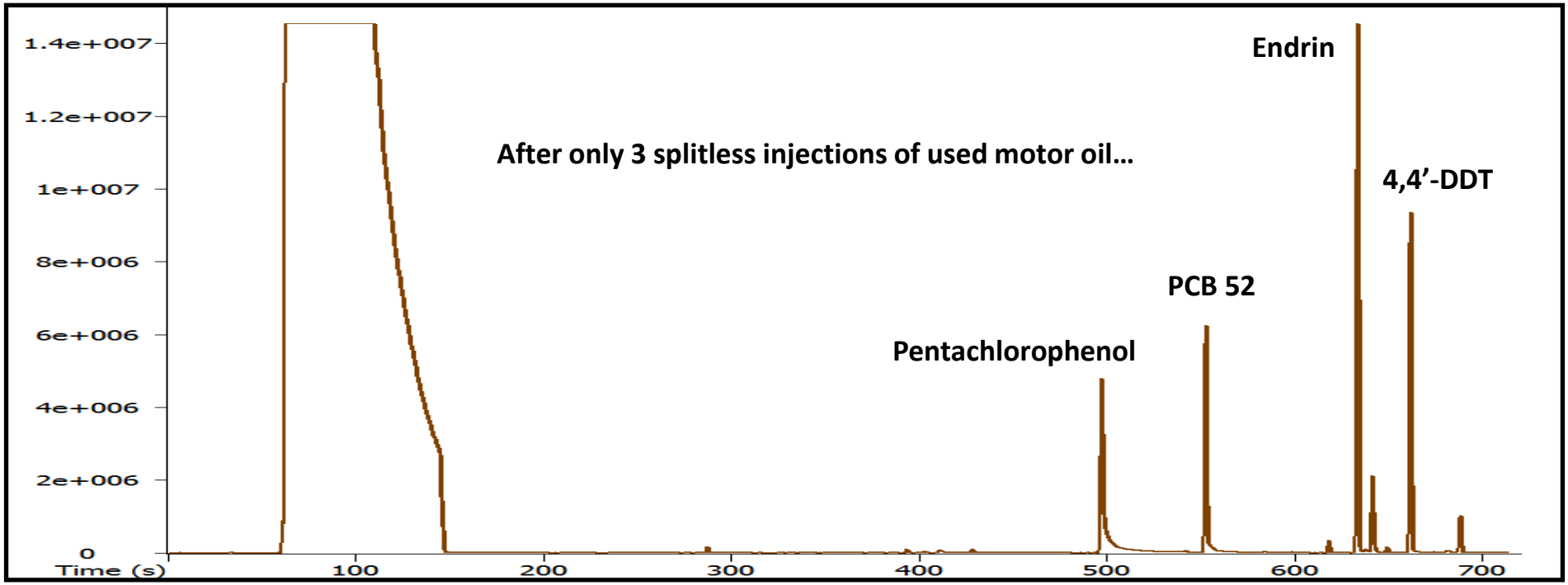
Analyzed after one injection of used motor oil…

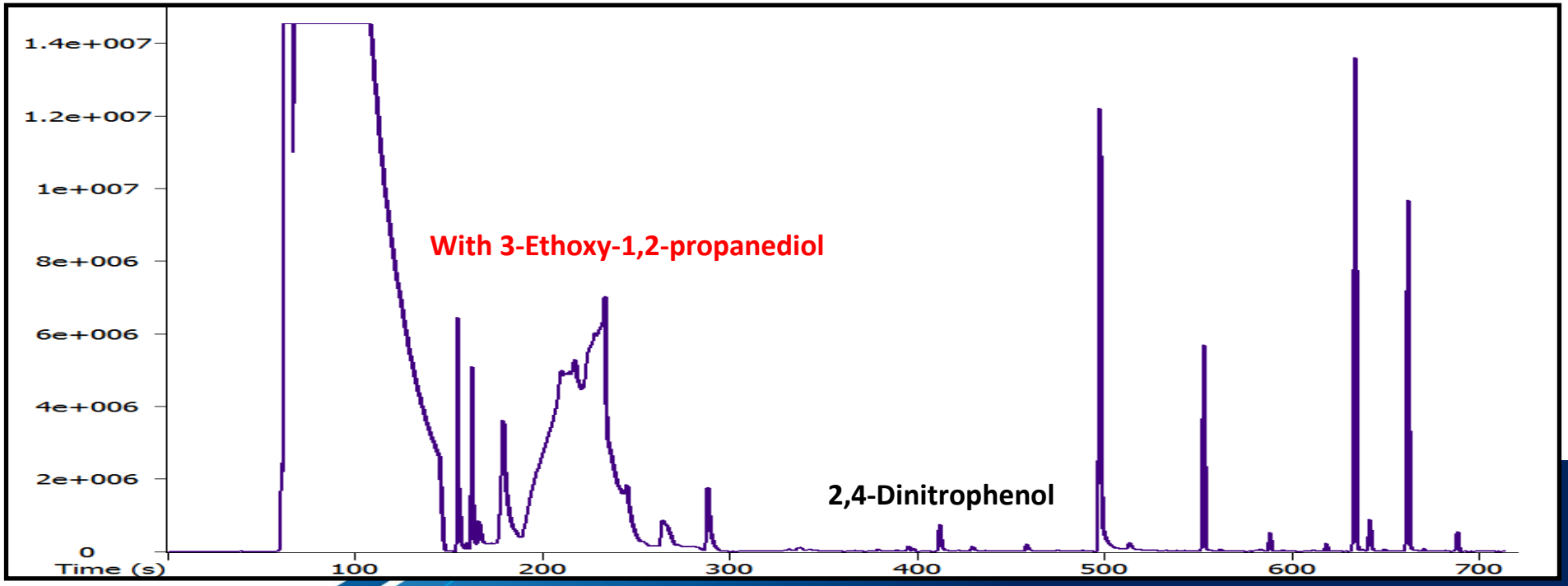

15m x 0.25mm x 0.25µm Rtx-5MS with 5m Integra-Guard
Response Factor = 1.60
Tailing Factor = 2.1
Already 99 splitless injections of used motor oil on column, but this standard was analyzed after a GC inlet liner and seal change…
Pentachlorophenol
PCB 52
Endrin
4,4'-DDT
1.4e+007
1.2e+007
1e+007
8e+006
6e+006
4e+006
2e+006
0
Time (s)
500
525
550
575
600
625
650
675
700
RESTEK


After only 3 splitless injections of used motor oil…
Response Factor = 1.08
Tailing Factor = 2.5
1.4e+007
1.2e+007
1e+007
8e+006
6e+006
4e+006
2e+006
0
Time (s)
500
525
550
575
600
625
650
675
700

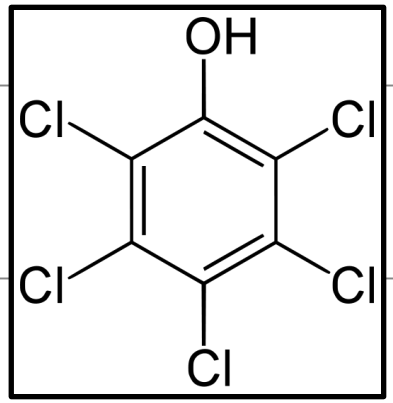

Response Factor = 2.51
Tailing Factor = 1.3
Endrin breakdown = 4.5%
DDT breakdown = 10%
With 3-Ethoxy-1,2-propanediol
H3C
O
OH
OH
1.4e+007
1.2e+007
1e+007
8e+006
6e+006
4e+006
2e+006
0
Time (s)
500
525
550
575
600
625
650
675
700


Endrin
Endrin breakdown = 7.2%
DDT breakdown = 21%
4,4'-DDT
After only 3 splitless injections of used motor oil…
Response Factor = 1.08
Tailing Factor = 2.5
PCB 52
Pentachlorophenol
4,4'-DDD
Endrin ketone
1.4e+007
1.2e+007
1e+007
8e+006
6e+006
4e+006
2e+006
0
Time (s)
500
525
550
575
600
625
650
675
700

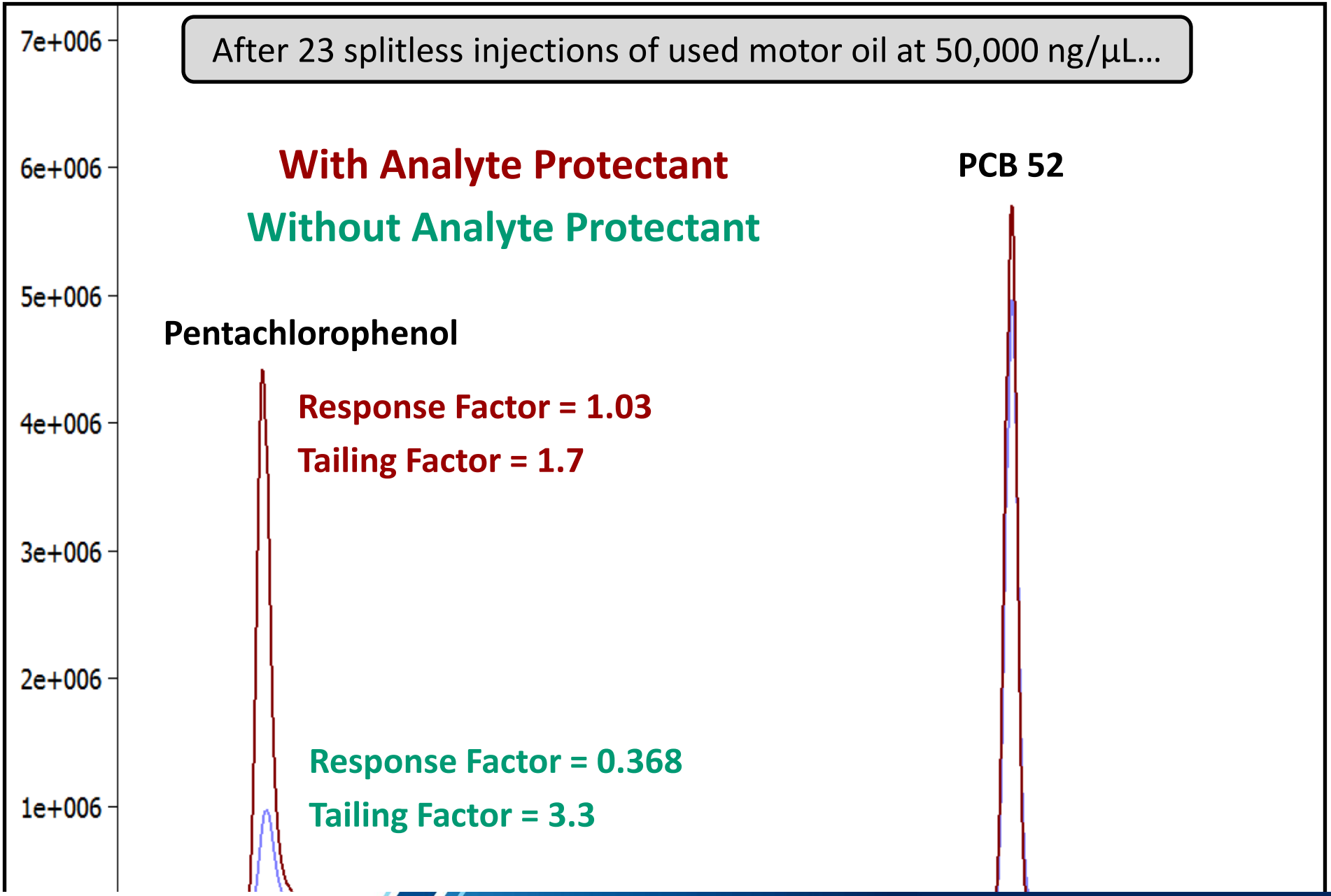

1.4e+007
1.2e+007
1e+007
8e+006
6e+006
4e+006
2e+006
0
Time (s)
100
200
300
400
500
600
700
After only 3 splitless injections of used motor oil…
Endrin
4,4'-DDT
PCB 52
Pentachlorophenol


1.4e+007
1.2e+007
1e+007
8e+006
6e+006
4e+006
2e+006
0
Time (s)
100
200
300
400
500
600
700
With 3-Ethoxy-1,2-propanediol
2,4-Dinitrophenol

23 injections of used motor oil at 50,000 ng/µL…



After 23 splitless injections of used motor oil at 50,000 ng/µL…



Analyte Protectants Summary for Splitless Injection GC

- Approach shows promise for better GC of active compounds, including pesticides
  - Increased response factors and less peak tailing
- Less successful for reactive compounds
  - Endrin and DDT still subject to degradation
- Additional analyte protectants need testing
  - GC-MS will increase protectant choices

Splitless Injection GC Issues

- Active/polar/thermal sensitive analytes
- Dirty samples
- Matrix enhanced/degraded responses
- Limited transfer from GC inlet to column
- Poor detectability
- Significant quantification bias
- Frequent GC inlet and column maintenance
- Offline cleanup

Pesticide Analysis with GC

- Active/polar/thermal sensitive analytes
- Dirty samples
- Matrix enhanced/degraded responses
- Limited transfer from GC inlet to column
- Poor detectability
- Significant quantification bias
- Frequent GC inlet and column maintenance
- Offline cleanup

Pesticide Analysis with GC

Split injection

Matrix *effect* diluted to the point where it doesn't negatively impact *GC inlet* efficiency

Shoot-and-Dilute GC

Relies on detector sensitivity and selectivity improvements, e.g. MS/MS

- Frequent GC inlet and column maintenance
- Offline cleanup

Sky® 4mm ID Single Taper Inlet Liner with Quartz Wool Splitless Injections

Sky® 4mm ID Precision® Inlet Liner with Quartz Wool Split Injections

- Goal is for part of sample to make it to GC column
  - Based on split ratio
- Wool wipes needle and helps homogenize sample
  - Excellent for repeatability
  - High split ratio reduces wool and “dirt” impact on compounds prone to breakdown or sorption losses

1

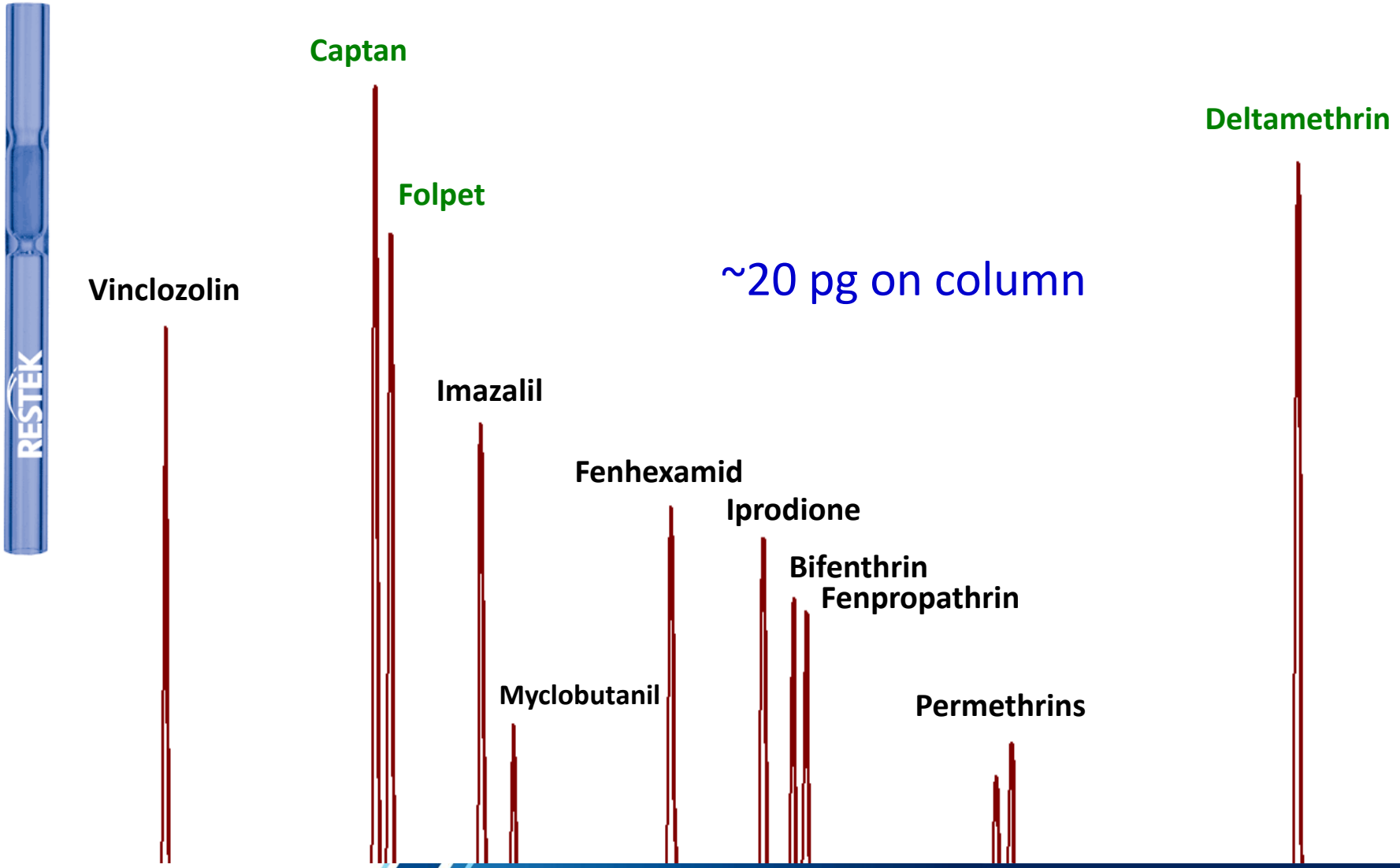
QuEChERS Performance Standards Kit

- Designed for use in all QuEChERS methods for pesticides in fruits and vegetables, including the original unbuffered method, AOAC 2007.01, and EN15662.
- Kit contains organochlorine, organonitrogen, organophosphorus, and carbamate pesticides commonly used on fruits and vegetables.
- Volatile, polar, active, base-sensitive, and nonvolatile compounds are included to allow comprehensive evaluation of QuEChERS extraction and cleanup efficiencies, and optimization of GC and LC instrumental conditions.
- Ideal for initial method evaluations and ongoing method performance validations.
- Analytes are divided into three ampuls based on compatibility for maximum stability and shelf life.*
- Precise formulations improve data quality and operational efficiency; spend more time running samples and less time sourcing and preparing standards.
- Quantitatively analyzed to confirm the composition and stability of each mixture.
- Produced and tested in accordance with ISO Guide 34 and 17025 accreditation.

Organochlorine
Organonitrogen
Organophosphorus
Carbamate
Pesticides

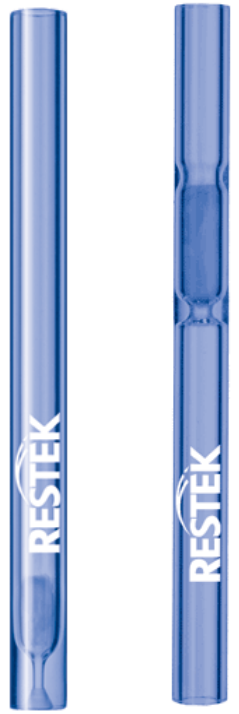
Standard C contains difficult pesticides such as Captan, Folpet, Deltamethrin...

QuEChERS Performance Standard C – 200 pg/µL – 1 µL – Split Ratio 10
GC-ECD – 15m x 0.25mm x 0.25µm Rxi-5ms column



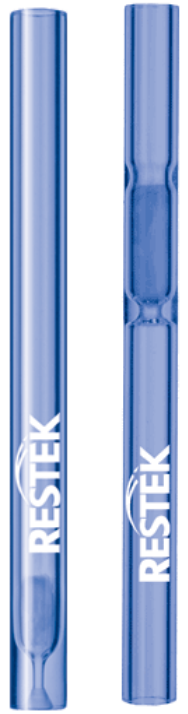
Splitless and Split Injections of Strawberry Extracts

- EN QuEChERS organic strawberry extracts
  - dSPE cleaned with 50 mg per mL PSA and C18
  - Spiked to 100 pg/µL each pesticide
- GC-ECD
  - 15m x 0.25mm x 0.25µm Rxi-5ms column
- Splitless injection at 250°C
  - 4mm ID single taper liner with wool
- Split injection at 250°C, split ratio 10
  - 4mm ID Precision split liner with wool



Inlet Ruggedness GC-ECD

- Sample queue
- Two 100 pg/µL solvent-only standards
- Two 100 pg/µL spiked strawberry extracts
- Repeat
- 40 analyses each of standards and extracts

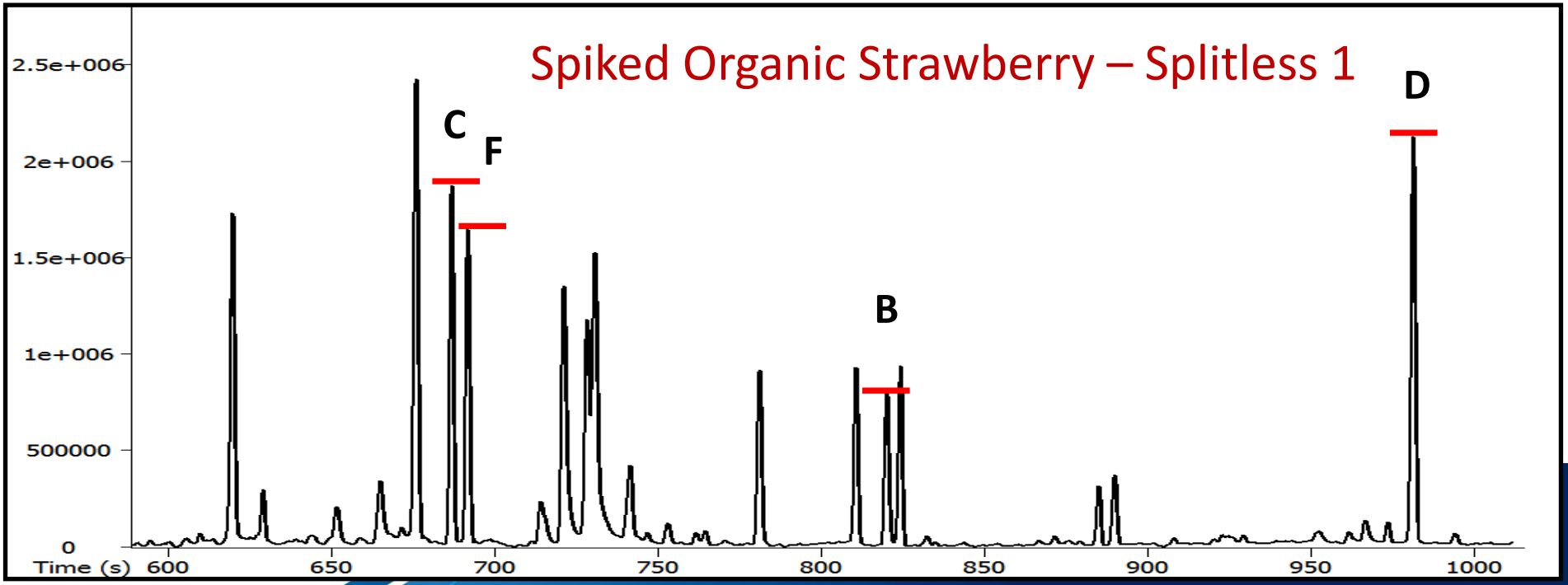


Splitless Injection GC-ECD Method

- 4mm single taper liner with quartz wool
  - 1 µL, 250°C, 1.4 min splitless valve time
- 15m x 0.25mm x 0.25µm Rxi-5ms column
  - Constant flow He, 1.4 mL/min
  - 70°C (1.4 min), 15.2°C/min to 330°C (1.5 min)
  - Total run time: 20 min
- Electron capture detector
  - 350°C, 20 Hz
  - Make-up (nitrogen) + column flow 50 mL/min

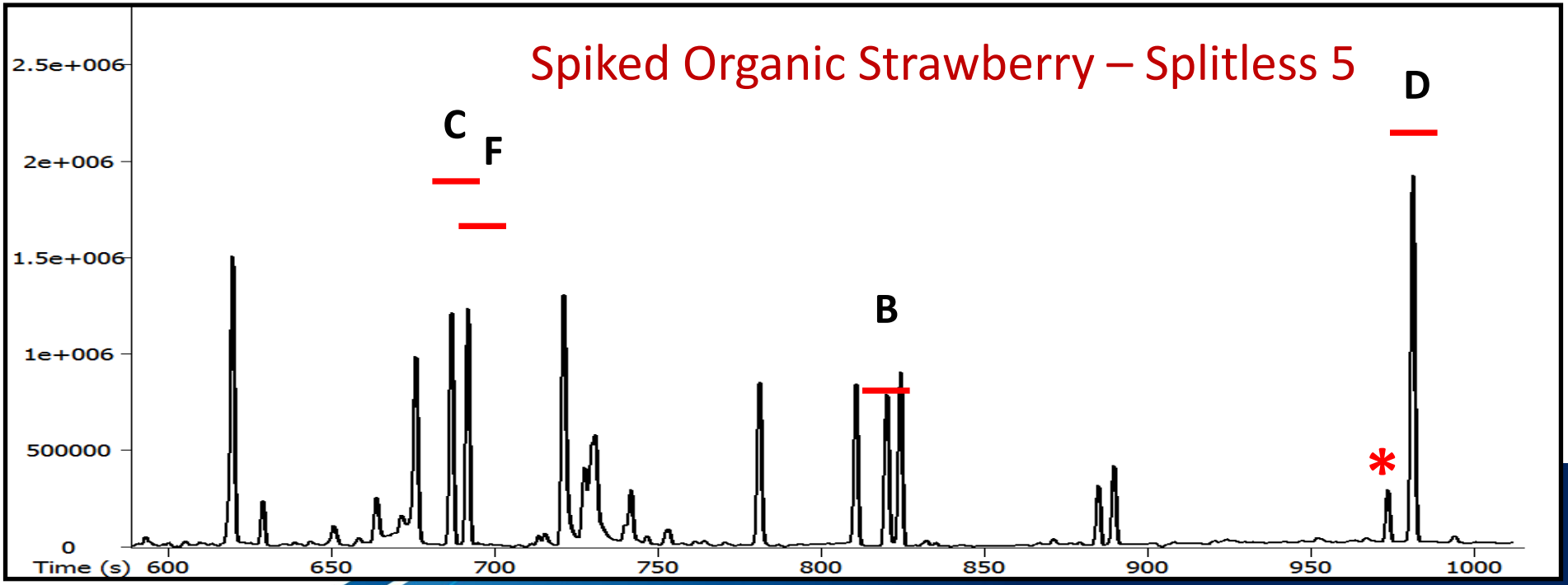
Spiked Organic Strawberry – Splitless 1

Spiked Organic Strawberry – Splitless 1



Spiked Organic Strawberry – Splitless 1

Spiked Organic Strawberry – Splitless 5

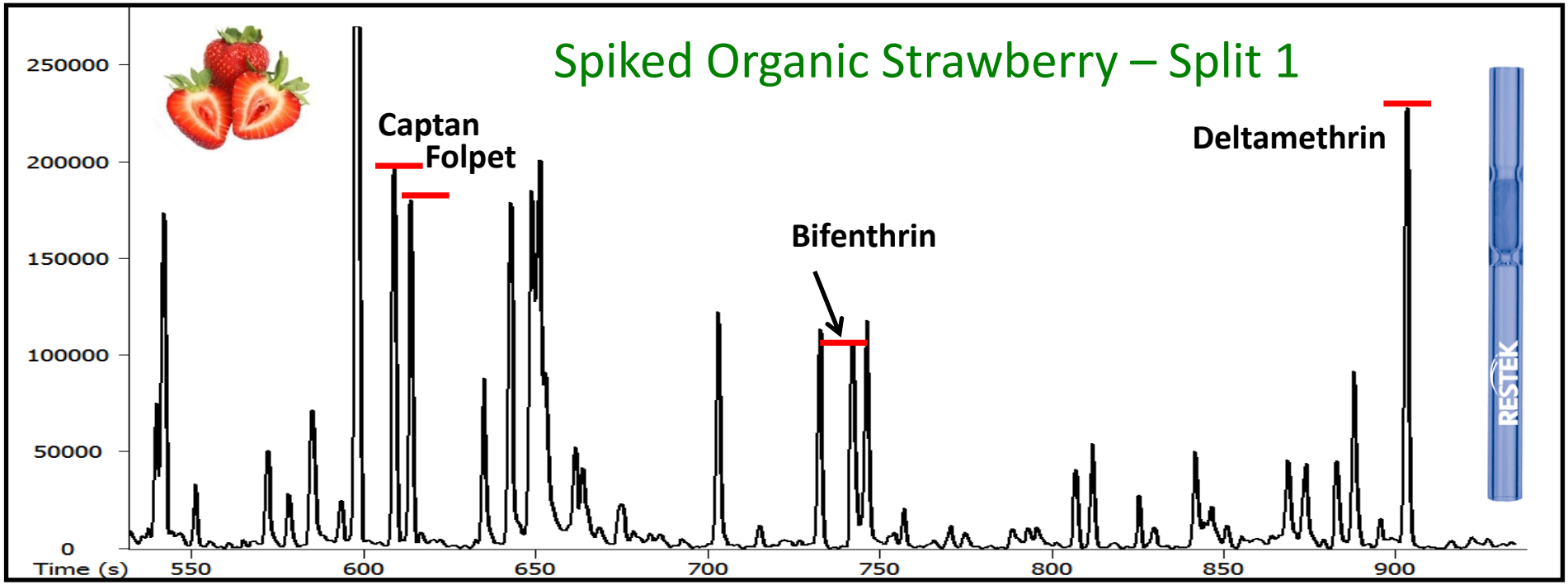


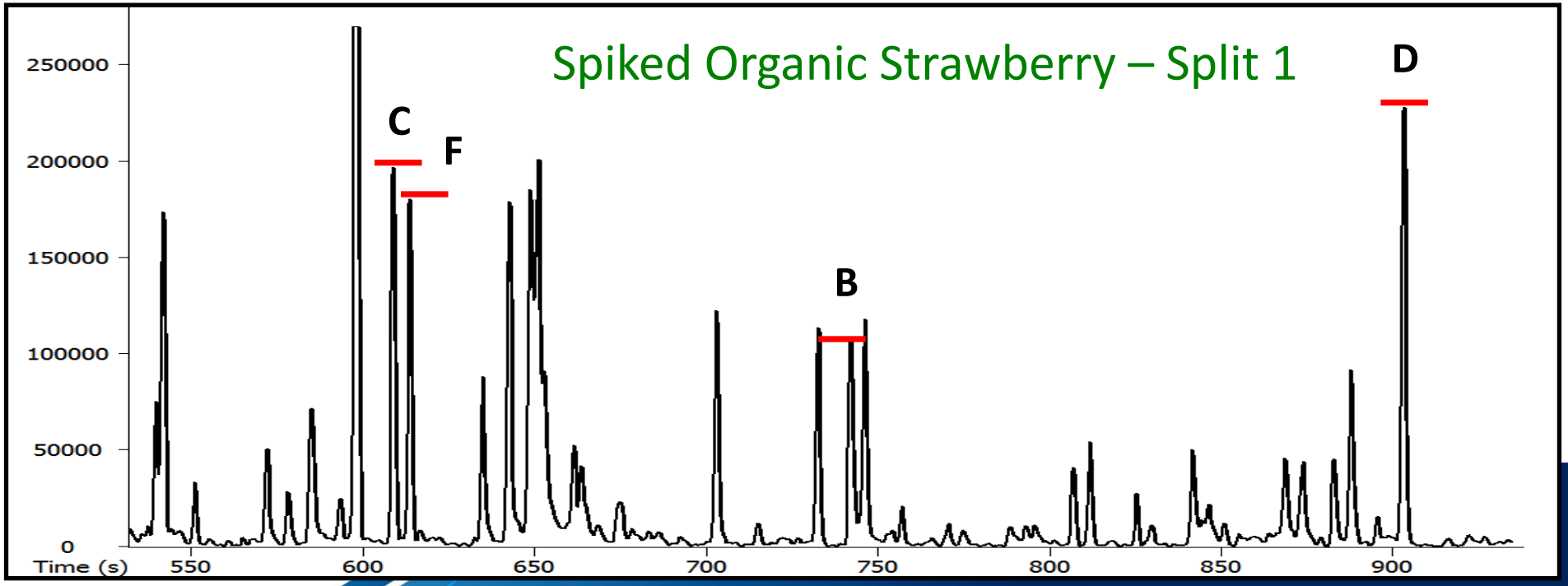
Split Injection GC-ECD Method

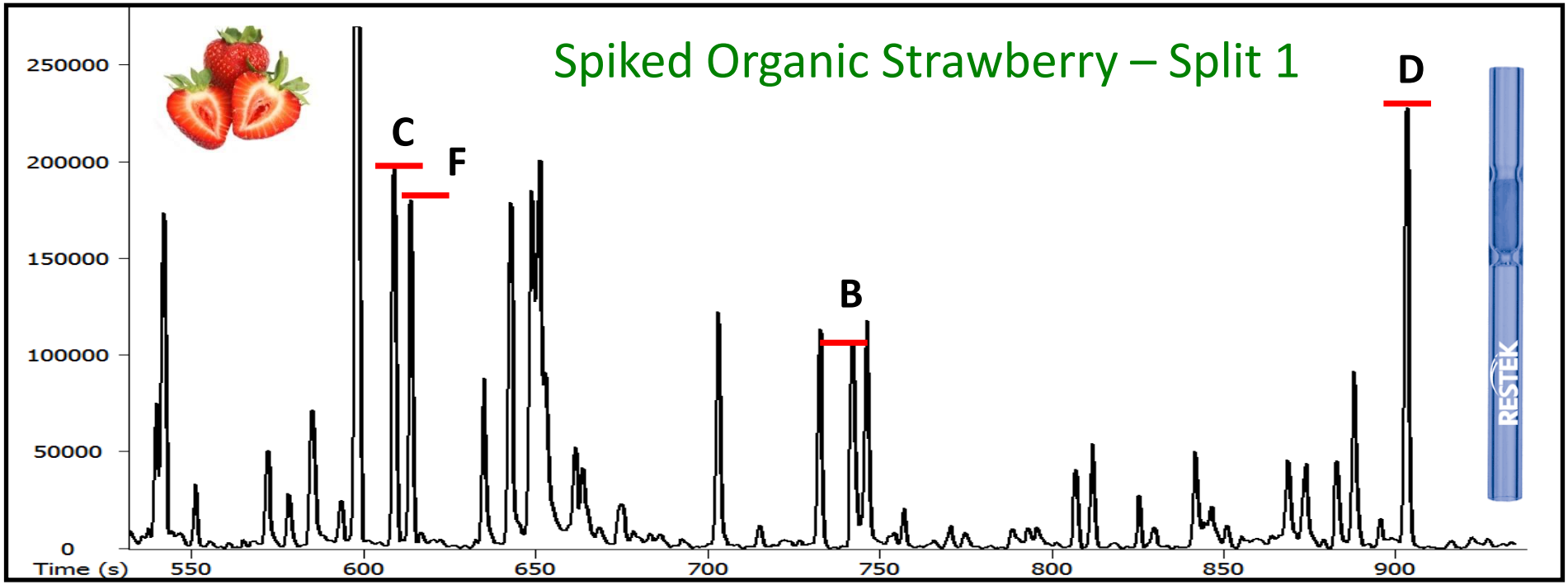
- 4mm focus-type split liner with quartz wool
  - 1 µL, 250°C, split ratio 10
- 15m x 0.25mm x 0.25µm 5ms column
  - Constant flow He, 1.4 mL/min
  - 70°C (0.1 min), 15.2°C/min to 330°C (0.8 min)
  - Total run time: 18 min
- Electron capture detector
  - 350°C, 20 Hz
  - Make-up (nitrogen) + column flow 50 mL/min

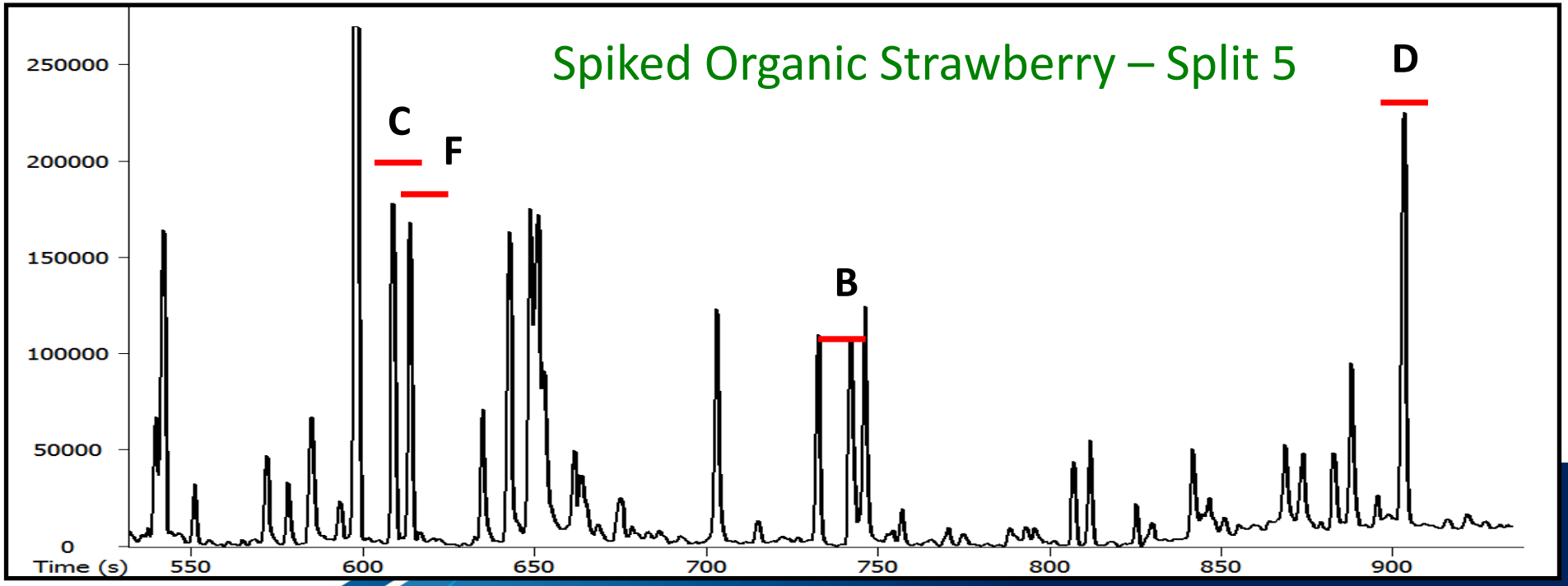
Splitless

Split

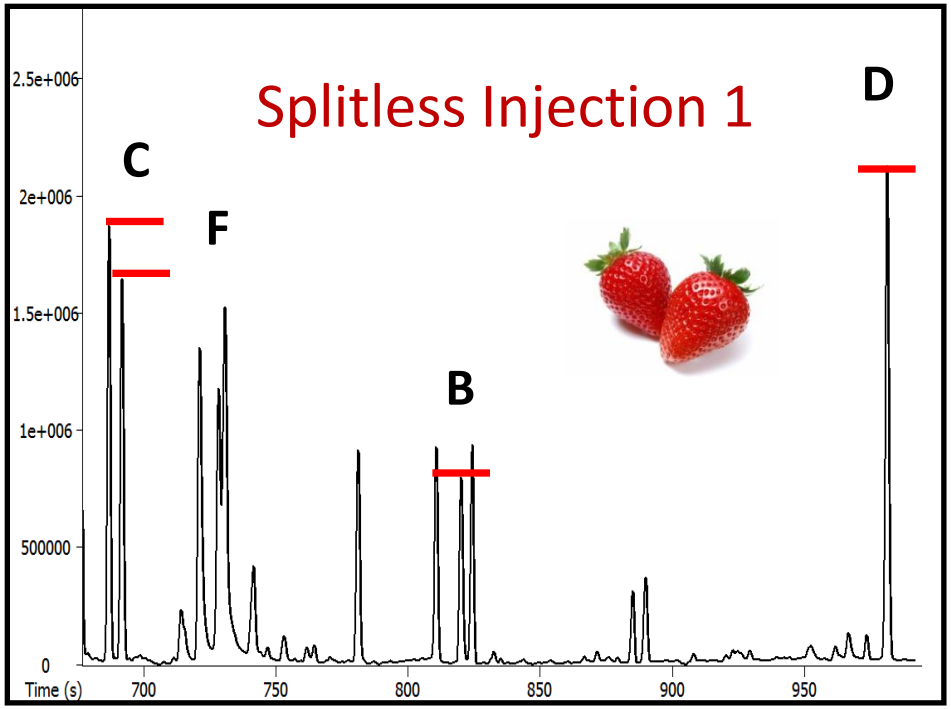

Spiked Organic Strawberry – Split 1
Captan
Folpet
Bifenthrin
Deltamethrin
250000
200000
150000
100000
50000
0
Time (s)
550
600
650
700
750
800
850
900
RESTEK


Spiked Organic Strawberry – Split 1
C
F
B
D
250000
200000
150000
100000
50000
0
Time (s)
550
600
650
700
750
800
850
900

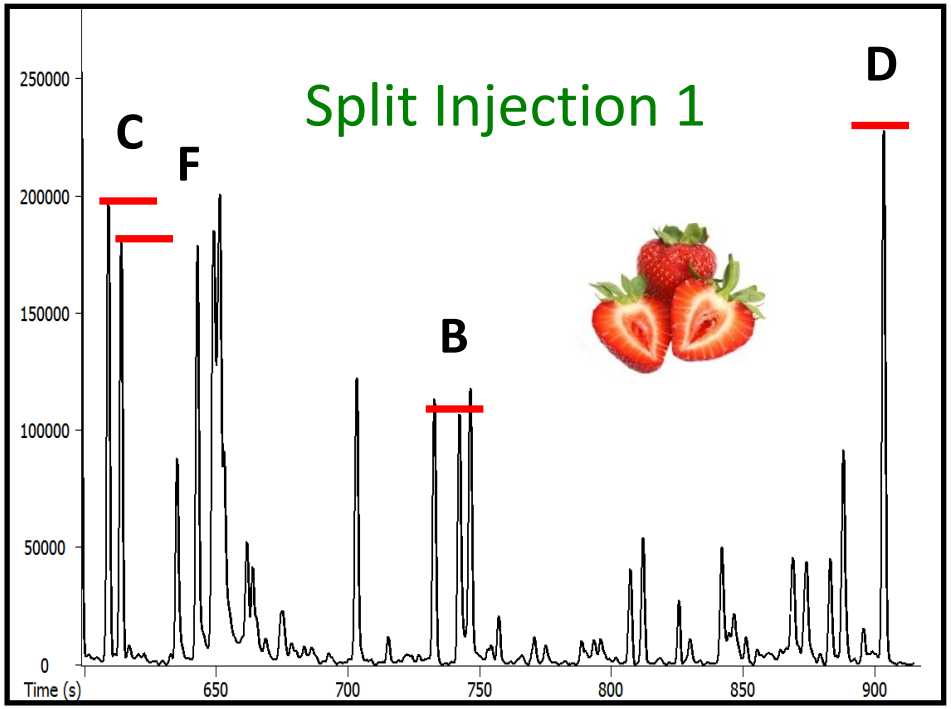

Spiked Organic Strawberry – Split 1
C
F
B
D
250000
200000
150000
100000
50000
0
Time (s)
550
600
650
700
750
800
850
900
RESTEK


Spiked Organic Strawberry – Split 5
C
F
B
D
250000
200000
150000
100000
50000
0
Time (s)
550
600
650
700
750
800
850
900

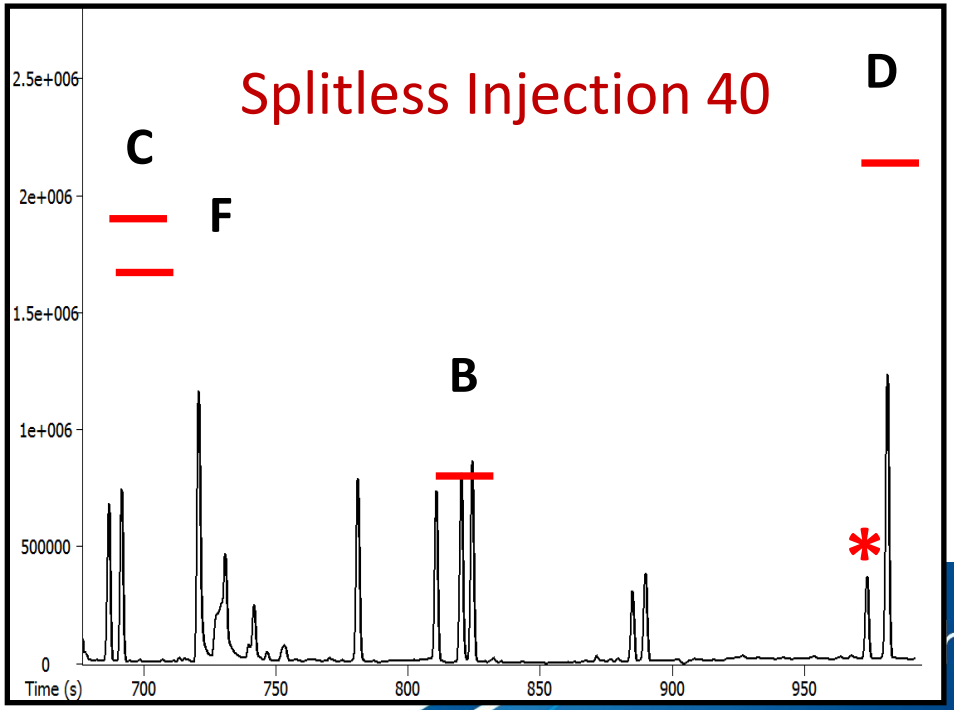
Splitless Injection 1



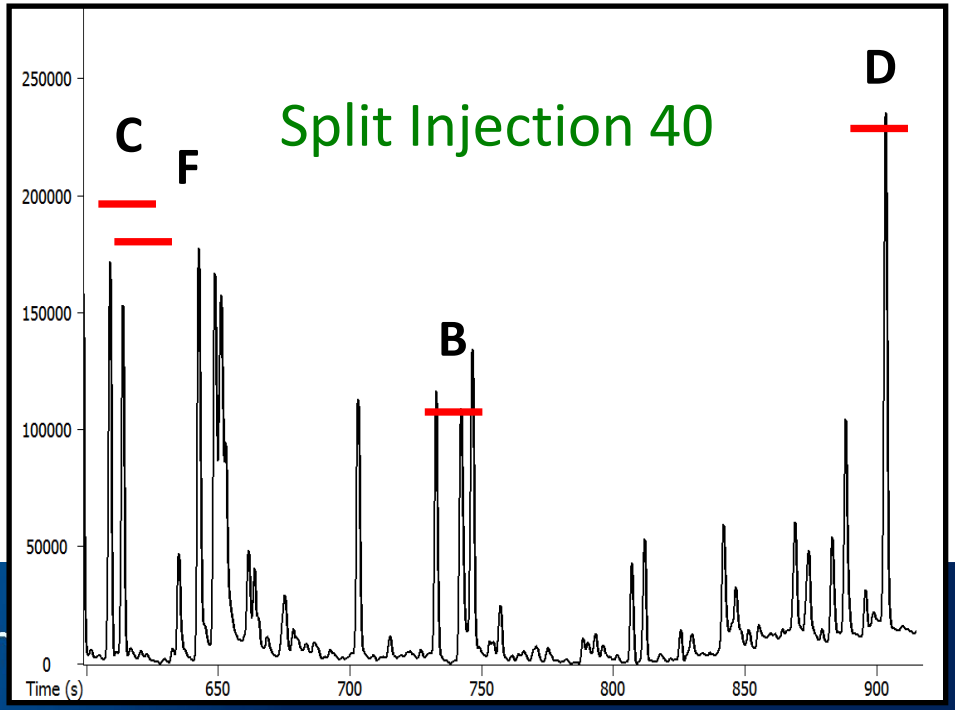
Split Injection 1



Splitless Injection 40



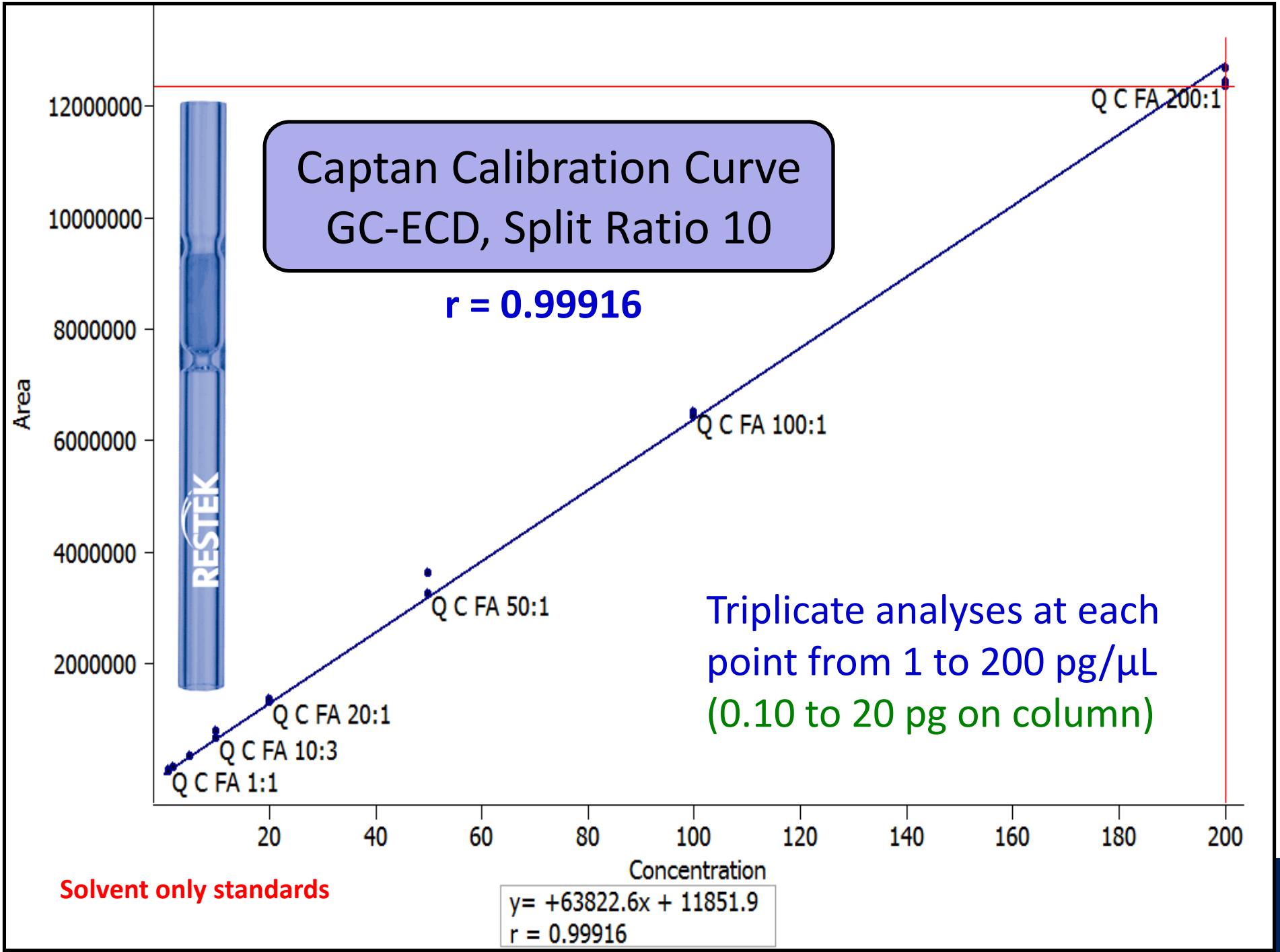
Split Injection 40

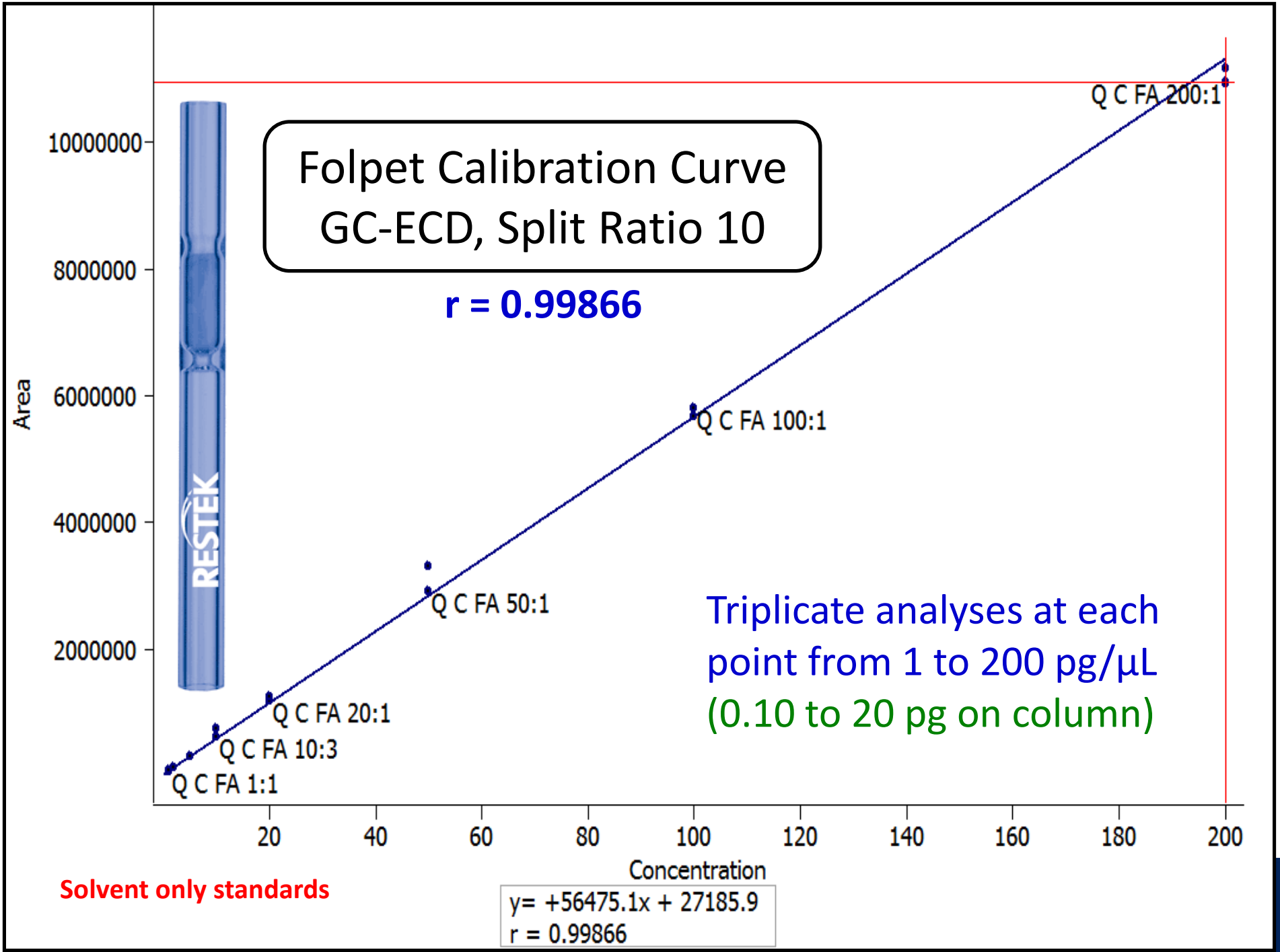


Comparing Average Response Factor (RF) and % RSD RF for Splitless and Split Injection

Pesticide	Splitless Avg RF	Split Avg RF		Splitless % RSD RF	Split % RSD RF
Captan	**2480**	**4550**		**31**	**5.6**
Folpet	**2540**	**4200**		**26**	**5.7**
Myclobutanil	**3240**	**2810**		**24**	**7.4**
Fenhexamid	2460	3820		8.4	8.4
Iprodione	2220	3180		6.2	3.3
Bifenthrin	2360	3490		1.9	3.0
Fenpropathrin	2420	4180		3.1	7.6
Deltamethrin	**4380**	**6620**		**15**	**2.4**

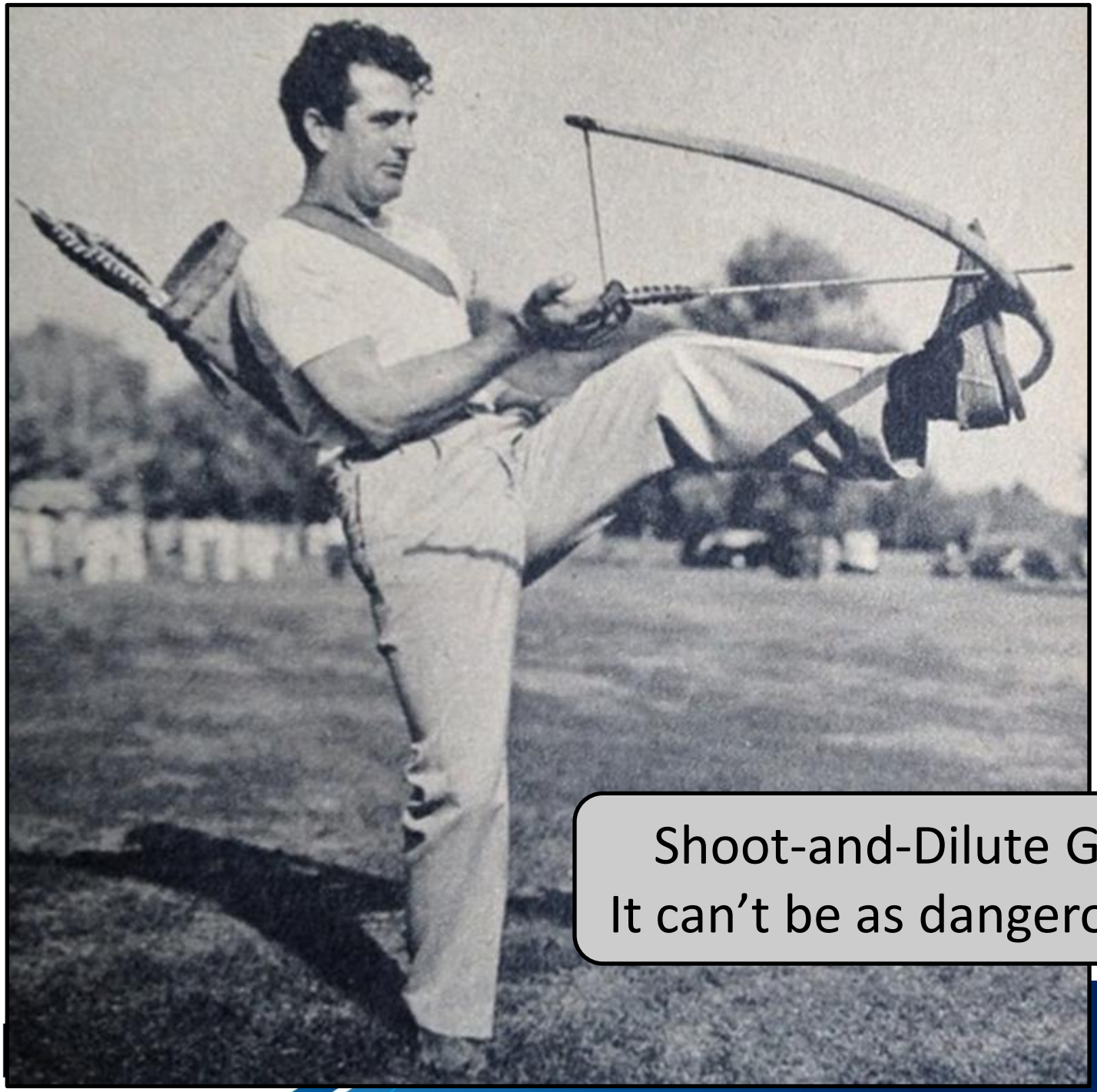
QuEChERS strawberry extracts spiked with 100 pg/µL pesticide standards.
Avg RF calculated from 40 analyses of spiked strawberry extracts.


Captan Calibration Curve
GC-ECD, Split Ratio 10
r = 0.99916
Area
12000000
10000000
8000000
6000000
4000000
2000000
Q C FA 200:1
Q C FA 100:1
Q C FA 50:1
Q C FA 20:1
Q C FA 10:3
Q C FA 1:1
20
40
60
80
100
120
140
160
180
200
Concentration
y= +63822.6x + 11851.9
r = 0.99916
Triplicate analyses at each point from 1 to 200 pg/µL (0.10 to 20 pg on column)
Solvent only standards


Folpet Calibration Curve
GC-ECD, Split Ratio 10
r = 0.99866
Triplicate analyses at each point from 1 to 200 pg/µL
(0.10 to 20 pg on column)
Solvent only standards
Area
Concentration
10000000
8000000
6000000
4000000
2000000
20
40
60
80
100
120
140
160
180
200
Q C FA 1:1
Q C FA 10:3
Q C FA 20:1
Q C FA 50:1
Q C FA 100:1
Q C FA 200:1
y= +56475.1x + 27185.9
r = 0.99866
RESTEK

Conclusions
Shoot-and-Dilute GC-ECD

- Splitless injection for sensitive pesticides like Captan, Folpet, and Deltamethrin is not robust
  - Response factors quickly fall off when analyzing QuEChERS extracts of strawberries
- Split injection for these same pesticides shows better repeatability for response factors
  - Higher flow through inlet leads to decreased pesticide degradation and sorption losses



Shoot-and-Dilute GC-MS/MS
It can’t be as dangerous as this...

Shoot-and-Dilute GC-MS/MS
Fruit and Vegetable

Celery
Low pigment
“Easy”

Orange
Low pH
“Hard”

Green pepper
Medium pigment
“Moderate”

All of the above are high water content…

USDA ORGANIC

1

GC Multiresidue Pesticide Kit

- Accurately identify and quantify pesticide residues by GC-MS/MS in fruits, vegetables, botanicals, and herbals like tea, ginseng, ginger, Echinacea, and dietary supplements.
- Comprehensive 203-compound kit covers food safety lists by the FDA, USDA, and other global governmental agencies; individual ampuls also sold separately.
- Formulated and grouped for maximum long-term stability*.
- Quantitatively tested to confirm composition; detailed support documentation provided.
- Optimized multiresidue pesticide method is offered free of charge; downloadable XLS file includes conditions and transition tables.
- Certified reference material (CRM) manufactured and QC-tested in Restek's ISO-accredited labs satisfies your ISO requirements.

9 stable mixes containing 203 GC-able pesticides

Organophosphorus (3), organochlorine (1), organonitrogen (3), synthetic pyrethroid (1), herbicide methyl ester (1) compounds

Downloadable transitions table for TSQ 8000

EN QuEChERS Extraction

Homogenize

10 g + 10 mL MeCN

Shake 1 min

Add EN salts

Shake 1 min

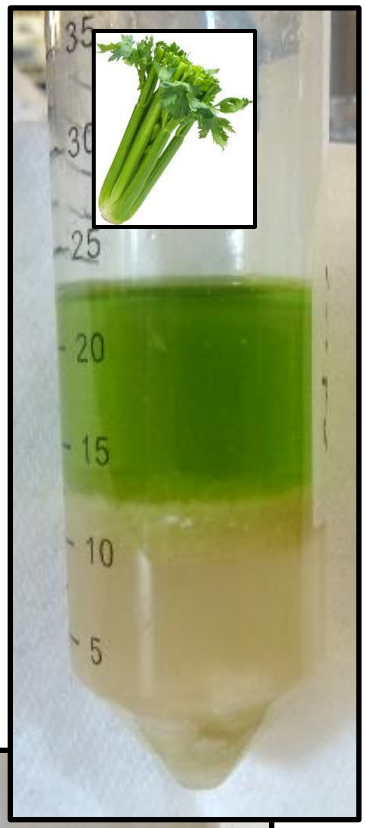
Centrifuge 5 min

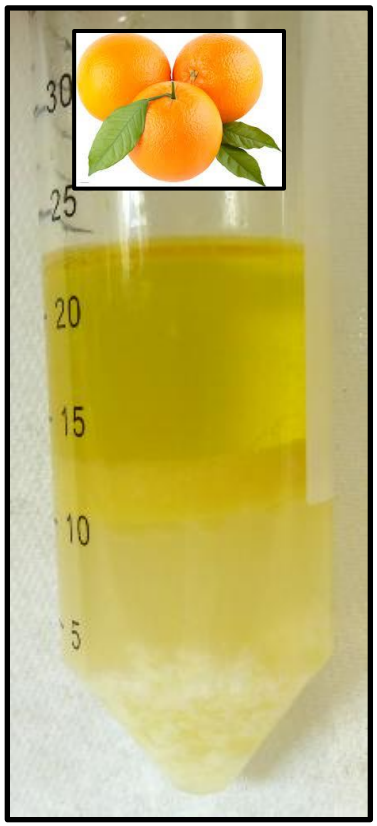
dSPE Cleanup

Shake 30 sec

Centrifuge 5 min

Formic acid





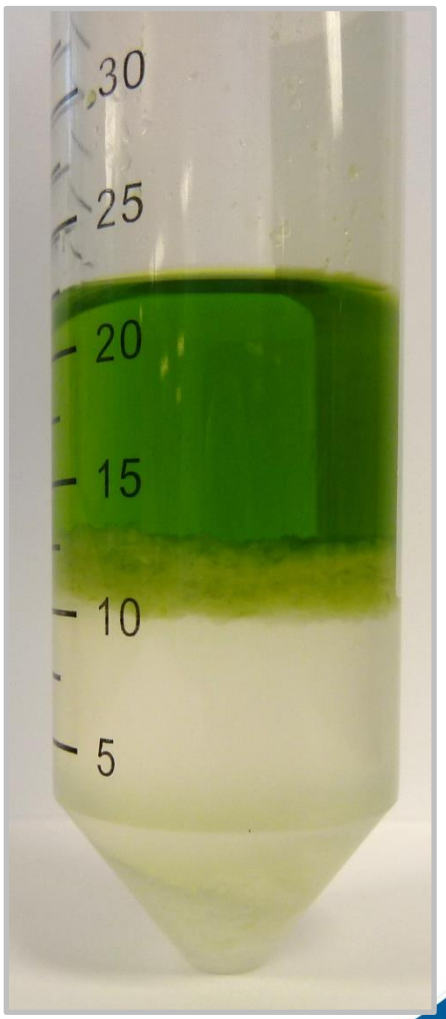
mL Extract

150 mg MgSO4

50 mg PSA

50 mg C18

7.5 mg GCB



mL Extract
150 mg MgSO4
50 mg PSA
50 mg C18

We want it slightly dirty for our ruggedness experiment (and for planar pesticide recovery)...

Shoot-and-Dilute GC-MS/MS for Multiresidue Pesticide Analysis?

Detectability

Ruggedness

Splitless injection

4mm single taper liner with quartz wool

1 µL MeCN, 250°C

Splitless valve, 1.7 min

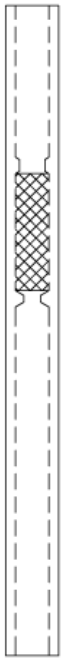
GC Conditions

30m x 0.25mm x 0.25µm 5ms-type column

Constant flow helium, 1.4 mL/min

GC oven program:

90°C (1.7 min), 8.9°C/min to 330°C (hold 5 min)



Split injection

4mm focus-type split liner with quartz wool

1 µL MeCN, 250°C

Split ratio 10

Thermo Scientific TSQ 8000 GC-MS/MS

Transfer line: 290°C

Source temperature: 325°C

Electron ionization: 70 eV

Stored mass range: 2 SRMs per

Minimum Dwell: 26 msec

Shoot-and-Dilute GC-MS/MS for Multiresidue Pesticide Analysis?

Propachlor Matrix-Matched Calibration Curve

Splitless

$R^2 = 0.9987$

Four analyses at each point from 5 to 100 pg/µL (5 to 100 pg on column)

10 pg

Propachlor Matrix-Matched Calibration Curve

Split

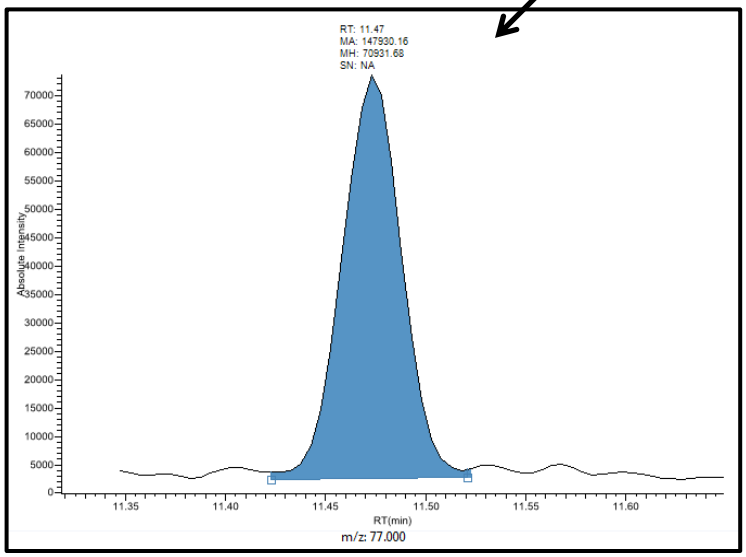
$R^2 = 0.9983$

Four analyses at each point from 5 to 100 pg/µL (0.5 to 10 pg on column)

Area Ratio

Concentration (pg/µL)

1 pg



Deltamethrin Matrix-Matched Calibration Curve

Splitless

$R^2 = 0.9903$

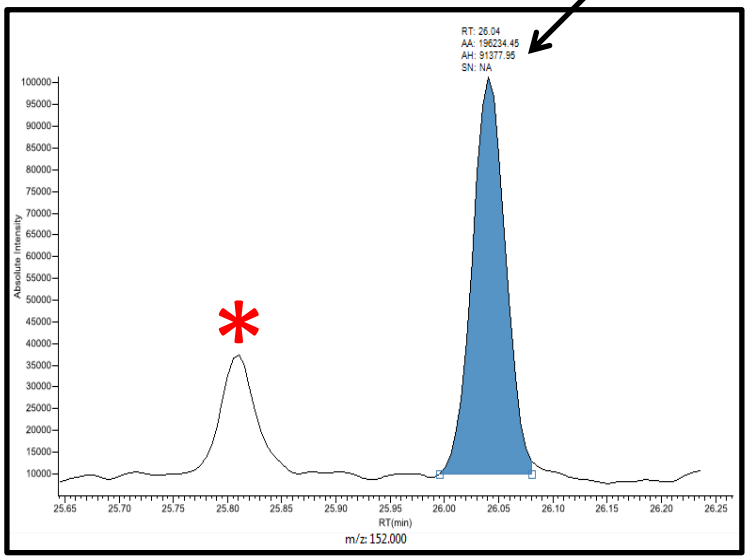
Four analyses at each point from 5 to 100 pg/µL (5 to 100 pg on column)

Area Ratio

0.029
0.028
0.027
0.026
0.025
0.024
0.023
0.022
0.021
0.020
0.019
0.018
0.017
0.016
0.015
0.014
0.013
0.012
0.011
0.010
0.009
0.008
0.007
0.006
0.005
0.004
0.003

Concentration (pg/µL)

10 pg



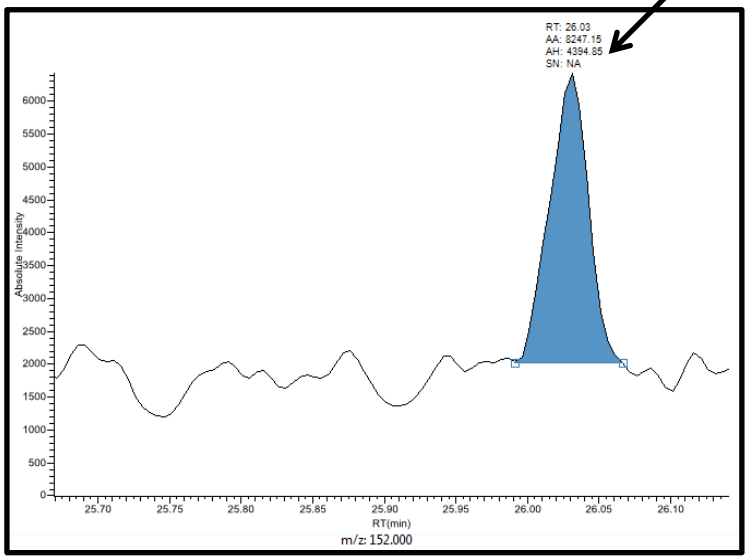
Deltamethrin Matrix-Matched Calibration Curve

Split

$R^2 = 0.9937$

Four analyses at each point from 5 to 100 pg/µL (0.5 to 10 pg on column)

1 pg



Area Ratio

Concentration (pg/µL)

Captan Matrix-Matched Calibration Curve

Splitless

$R^2 = 0.9828$

Four analyses at each point from 5 to 100 pg/µL (5 to 100 pg on column)

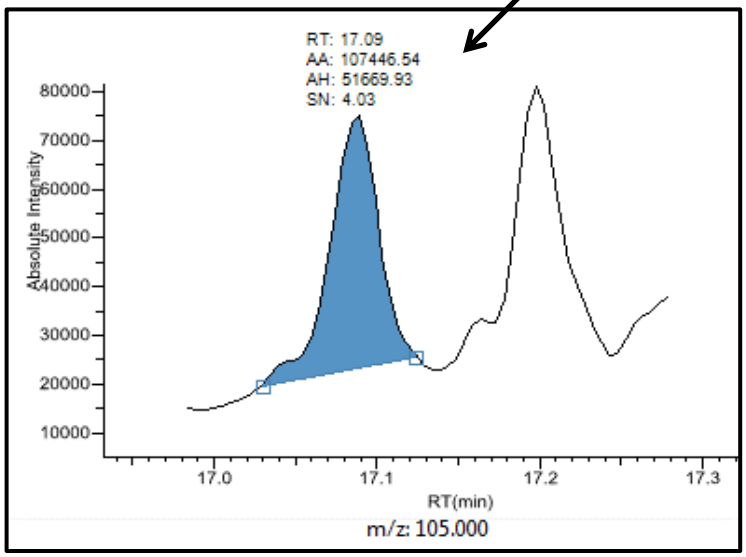
Area Ratio

Area Ratio

0.019
0.018
0.017
0.016
0.015
0.014
0.013
0.012
0.011
0.010
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002

Concentration (pg/µL)

10 pg



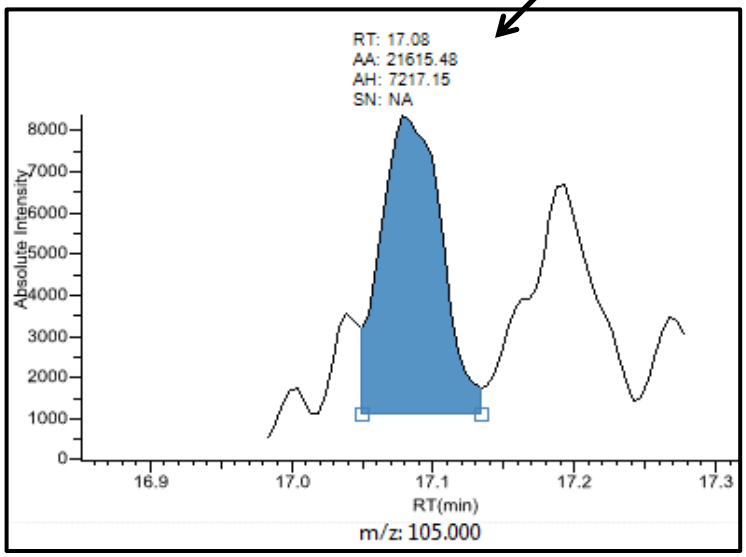
Captan Matrix-Matched Calibration Curve

Split

$R^2 = 0.9319$

Four analyses at each point from 5 to 100 pg/µL (0.5 to 10 pg on column)

1 pg



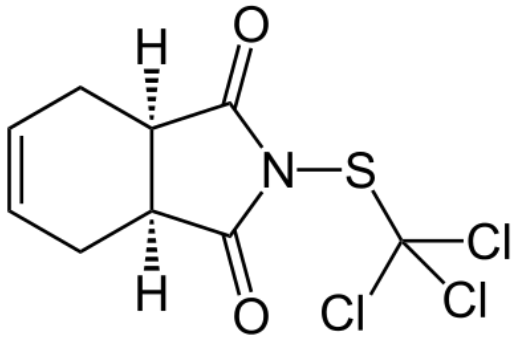
Area Ratio

Concentration (pg/µL)

0.021 0.020 0.019 0.018 0.017 0.016 0.015 0.014 0.013 0.012 0.011 0.010 0.009 0.008 0.007 0.006 0.005 0.004 0.003 0.002 0.001 0.000

0 1 2 3 4 5 6 7 8 9 10

Captan



Quant SRM, 149 to 105

Qual SRM, 149 to 79

Detectability Summary

- 203 pesticides in celery and orange extracts
  - ~180 pesticides detected < 1 pg on column
  - ~195 pesticides detected 1 pg on column
- Captan and Folpet detected > 1 pg on column
  - Low m/z precursor and product ions
- Isomeric pesticides detected > 1 pg on column
  - Cyfluthrins and cypermethrins, e.g., split response

Calibration Summary
Splitless and Split Injection

- 203 pesticides in celery and orange extracts
  - Matrix-matched standards
  - 5, 7.5, 10, 50, 100 pg/µL – 4 replicates each
- Calibration curve correlation coefficients
  - Large majority of pesticides > 0.99
- Calibration curve Average RF RSD% values
  - Large majority of pesticides < 20%

Calibration Summary
Splitless and Split Injection

- Splitless
- Detectability advantage
- "Generic" data processing
- Quicker review

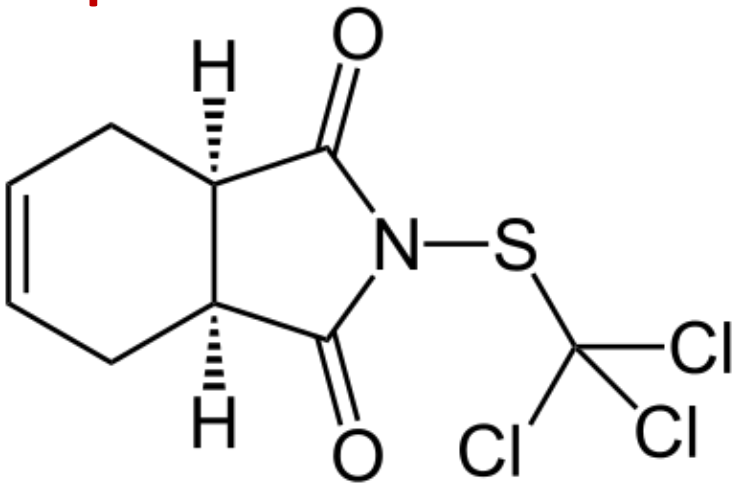
- Split
- Detectability reasonable
- "Manual" data processing
- Lengthy review

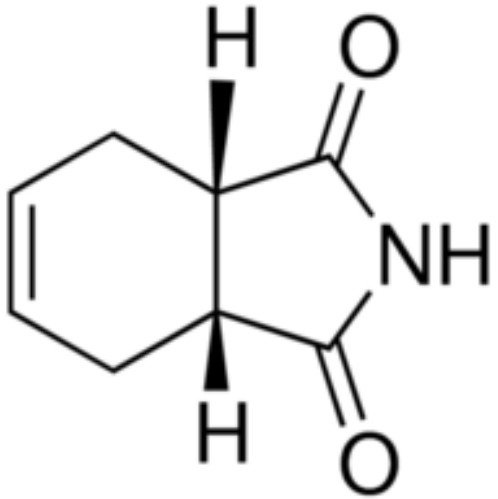
Does the possibility of longer GC system uptime and more stable response factors from split injection offset some detectability and data processing issues?

Screening method?


Ruggedness
Does the split injection GC system stay up longer?

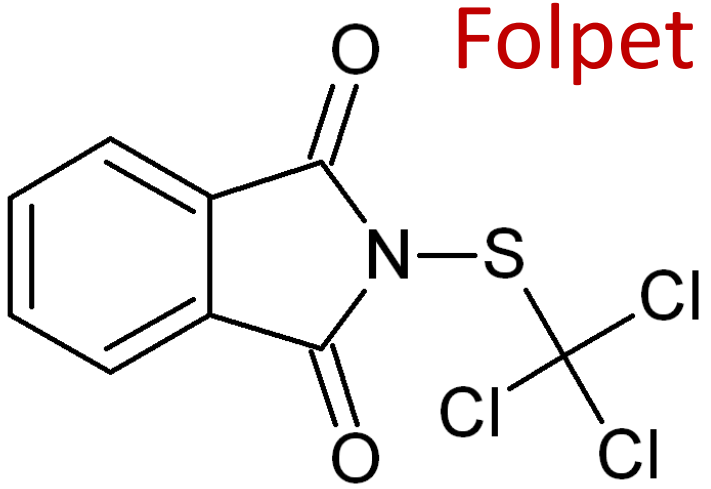
Captan

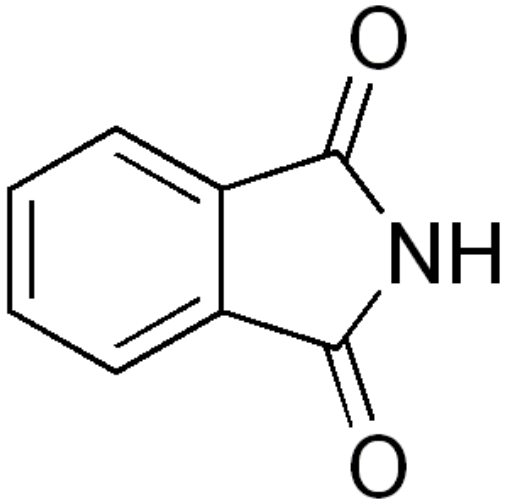




Tetrahydrophthalimide (THPI)

Folpet





Phthalimide

Splitless

Split

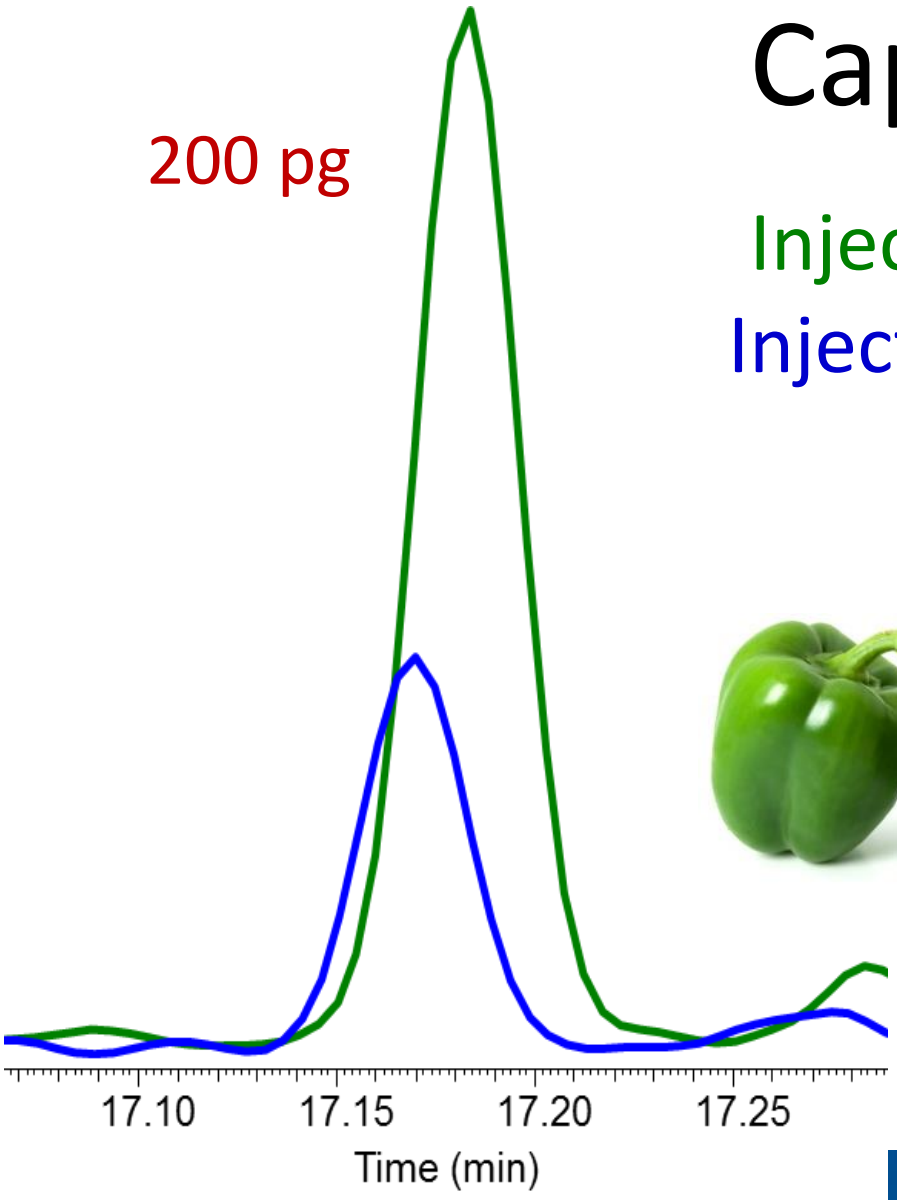
Captan

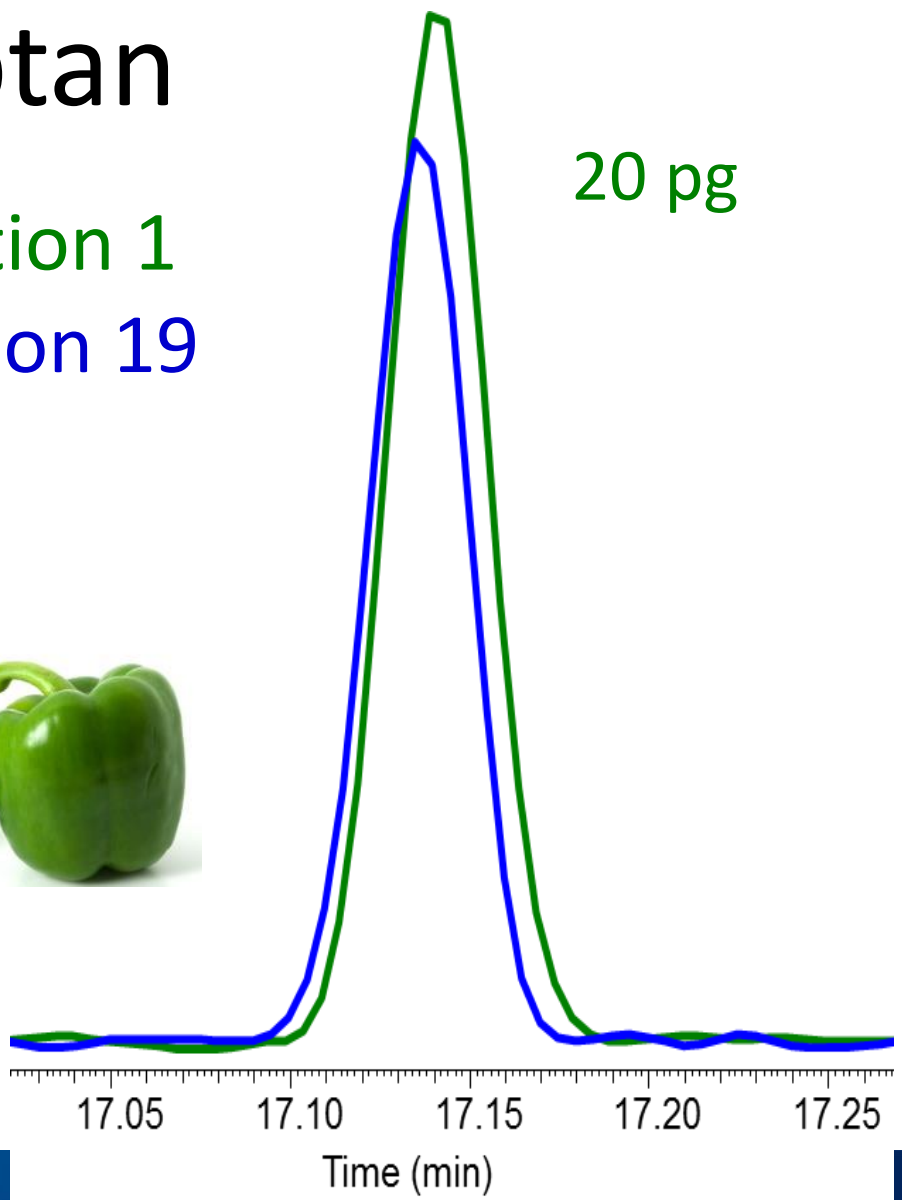
200 pg

20 pg

Injection 1

Injection 19





Splitless

Split

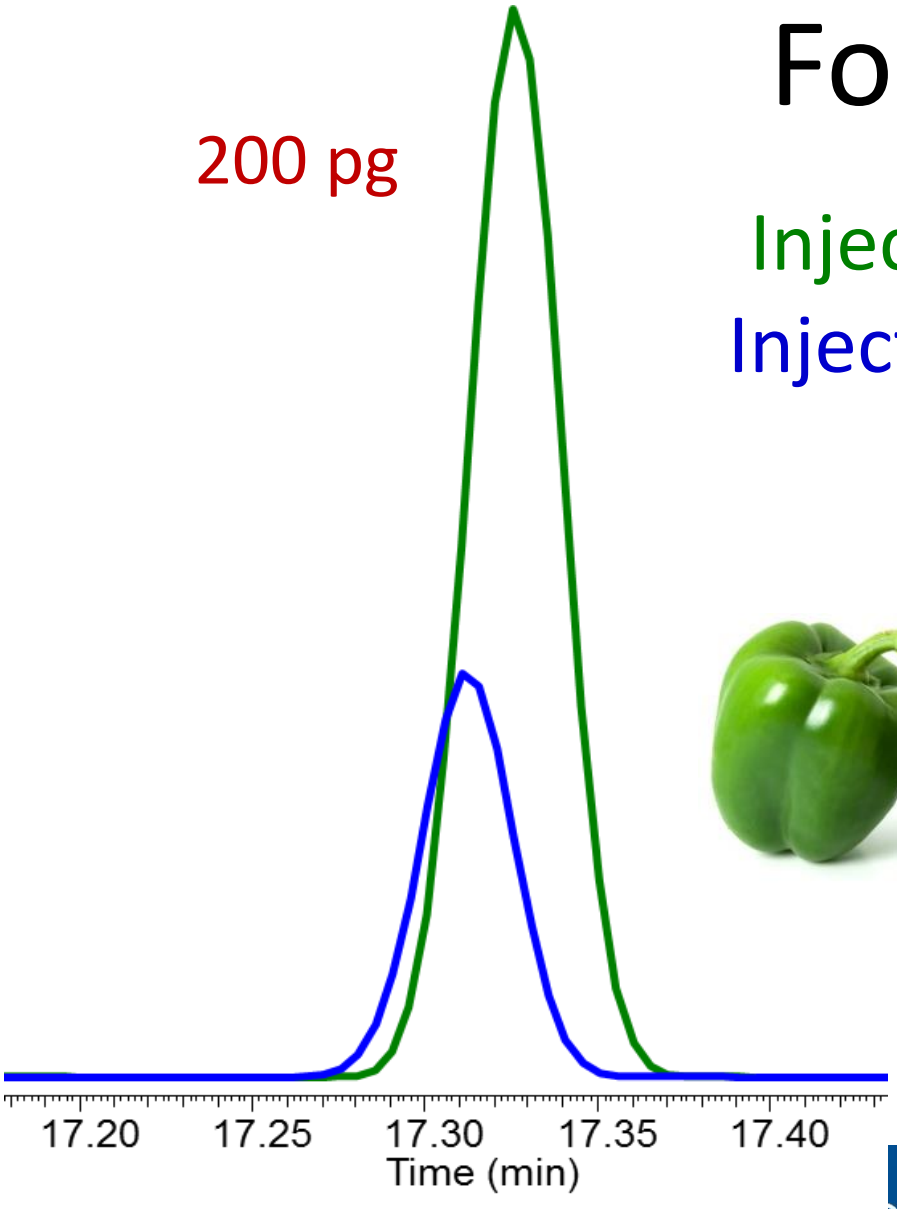
Folpet

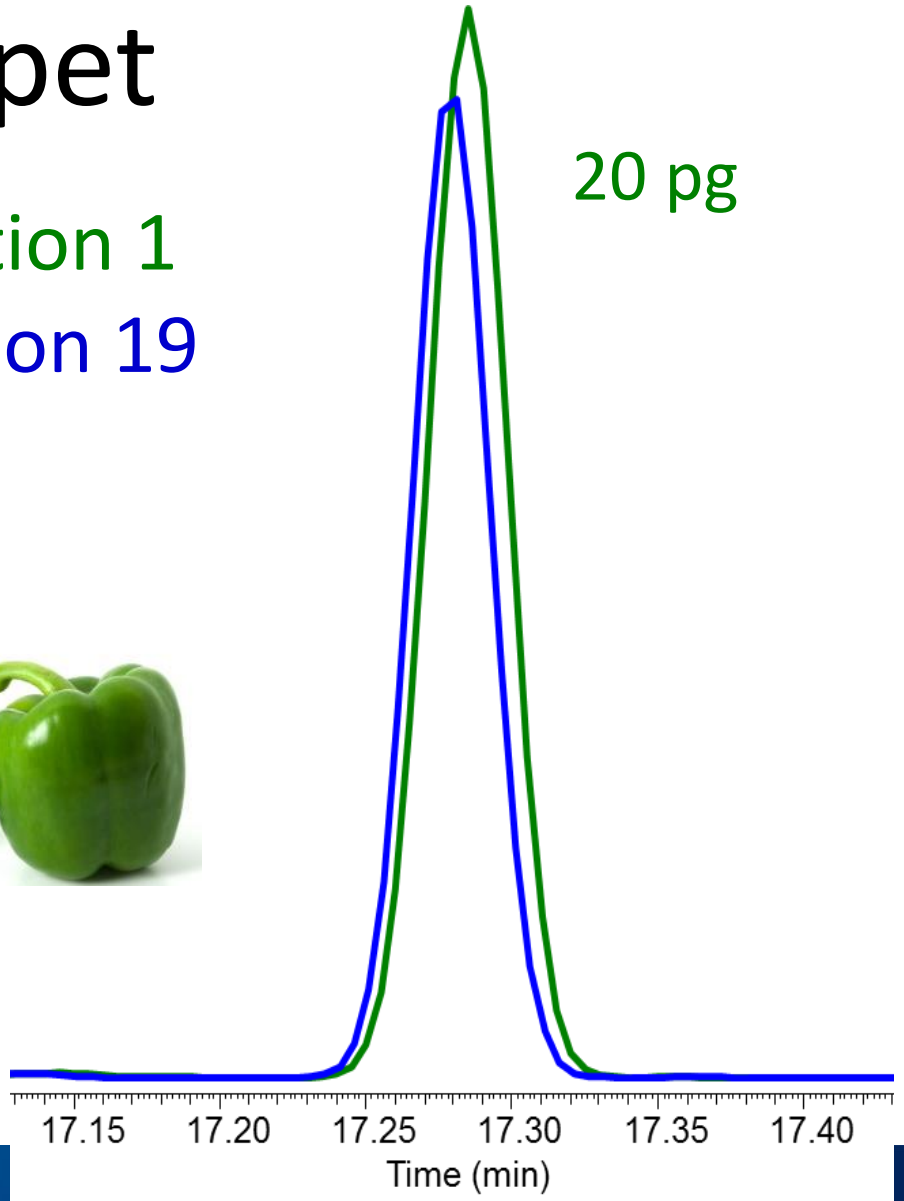
200 pg

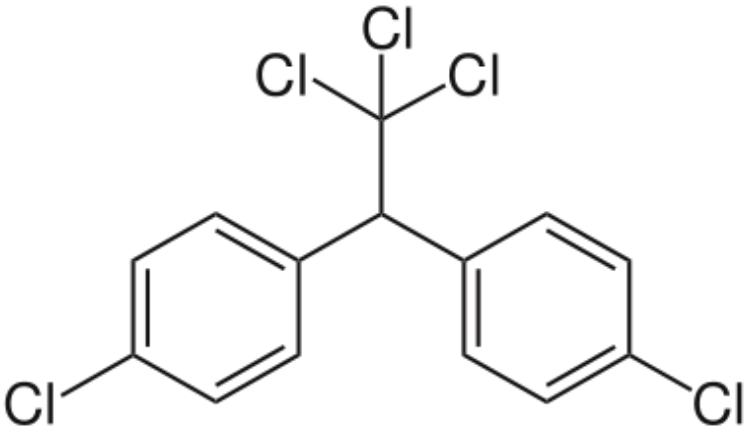
20 pg

Injection 1

Injection 19



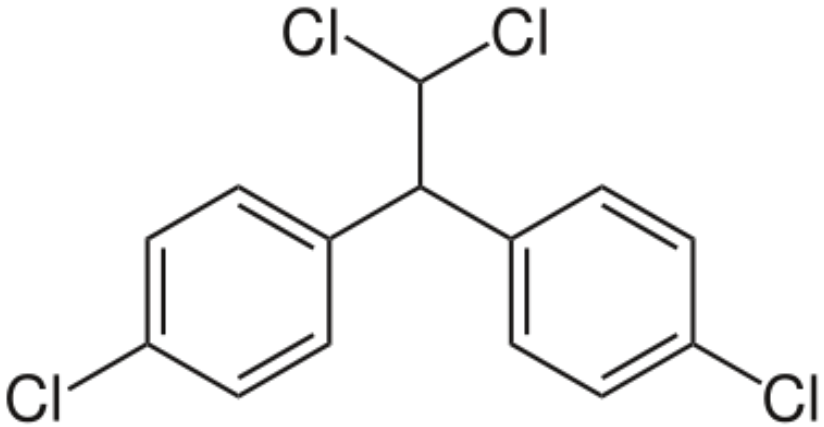




4,4’-DDT

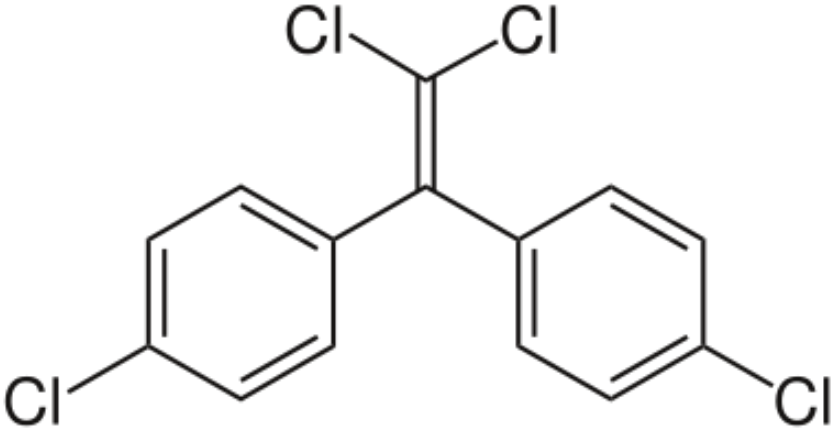
+

+



4,4’-DDD

+



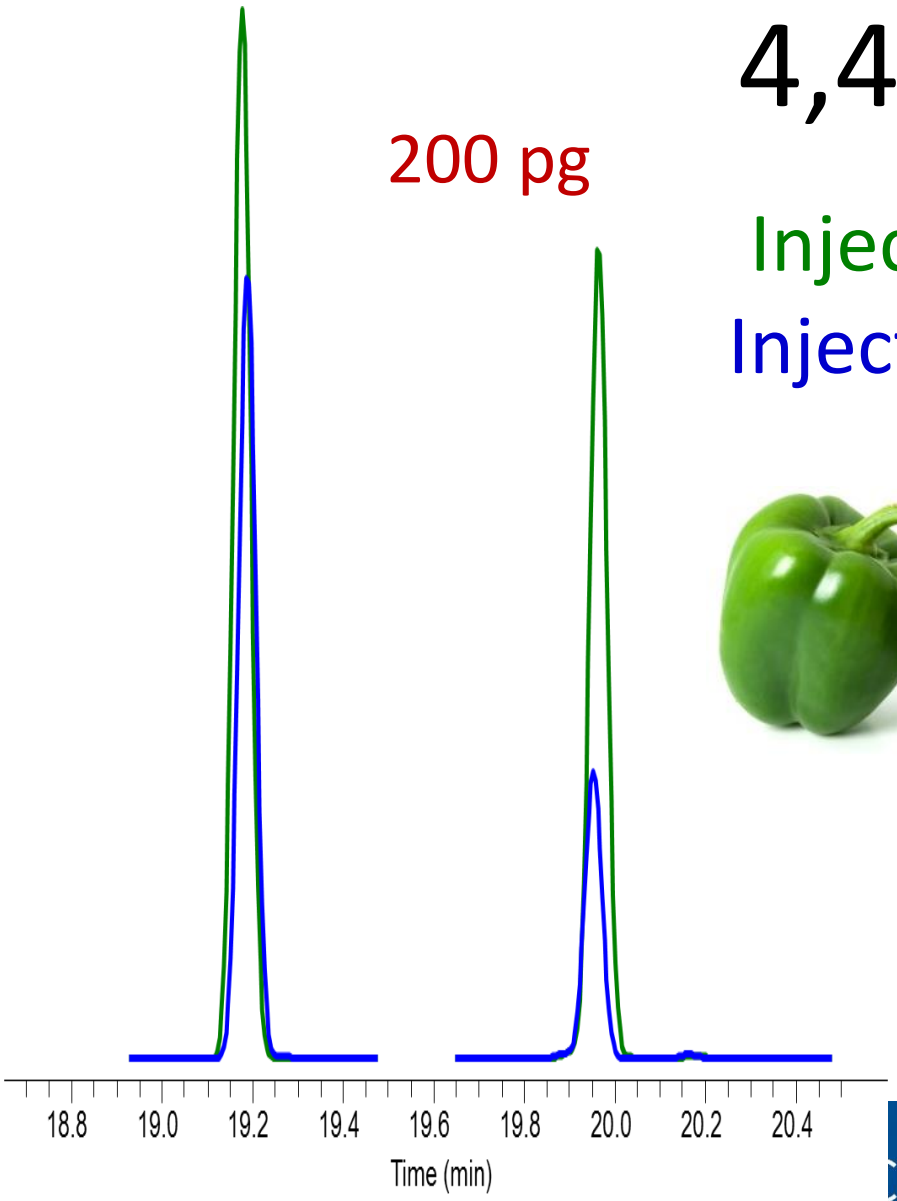
4,4’-DDE

4,4’-DDT

Splitless

4,4’-DDD

200 pg



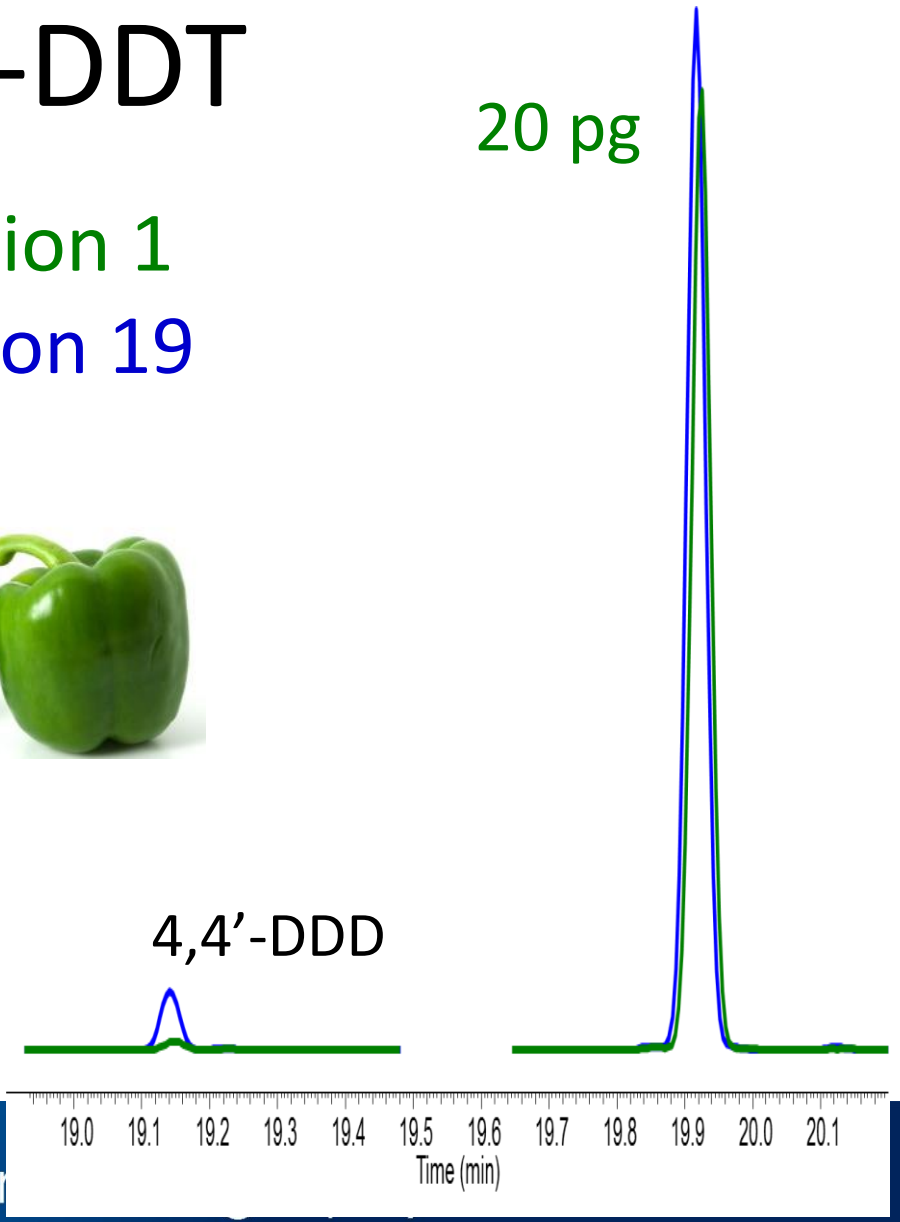
Injection 1

Injection 19

Split

20 pg

4,4’-DDD



Comparing Average Response Factor (RF) and % RSD RF for Splitless and Split Injection

Pesticide	Splitless Avg RF	Split Avg RF		Splitless % RSD RF	Split % RSD RF
gamma-BHC	0.131	0.199		7.6	3.2
Chlorothalonil	0.056	0.070		7.6	3.2
Carbaryl	0.078	0.129		7.7	2.2
Methiocarb	0.254	0.302		6.8	2.1
Dichlofluanid	0.381	0.444		4.9	1.6
Captan	**0.004**	**0.034**		**25**	**9.3**
4,4'-DDT	**0.117**	**0.480**		**30**	**3.6**
Deltamethrin	**0.073**	**0.051**		**14**	**4.9**

QuEChERS green pepper extracts spiked with 200 pg/µL pesticide standards.
Avg RF calculated from 19 analyses of spiked green pepper extracts.

Splitless

Methamidophos

Dichlorvos

Acephate

200 pg/µL
1 µL MeCN

Split

200 pg/µL
1 µL MeCN

Split ratio 10
0.1 µL MeCN
20 pg

Conclusions
Shoot-and-Dilute GC-MS/MS

- Split injection shows promise for GC-MS/MS
  - Ruggedness is superior to splitless injection
- Need better detectability for some pesticides
  - Further optimization of MS/MS parameters
- Data review is somewhat lengthy when LODs and LOQs are approached
  - Better choice of auto integration settings

Other Points

- Food matrix quantification bias (theoretically) the same for splitless and split injections
  - Quantification accuracy defined by split LODs
- Possibility of avoiding dSPE cleanup
  - Split injection keeps the system up longer
  - Better base-sensitive pesticide recoveries (no PSA)
  - Better planar pesticide recoveries (no GCB)
- Possibility of using solvent-only standards instead of matrix-matched standards for split injection
  - High inlet flow encourages good pesticide transfer

Recent Success of Shoot-and-Dilute GC

- Split injection GC-MS (NCI) approach for straightforward analysis of problematic phthalimide fungicides and chlorothalonil
  - K. Lichtmannegger, J. Cochran, H. Unterluggauer, F. Steemann, S. Masselter
  - Analytical and Bioanalytical Chemistry (submitted)
- QuEChERS extracts of apple, fish, oilseed, feed, kidney fat, and honey
- 3x reduction in GC-MS run time
- 3x increase in GC-MS up time

Thank you!

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