Fast Extraction and Dilution Flow Injection Mass Spectrometry (FED-FI-MS): Method Design, Applications, and Outlook

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What is FED-FI-MS?

Fast Extraction & Dilution
Flow Injection Mass Spectrometry

FED → **Simple sample extraction/preparation procedure**

FI-MS → **High-throughput instrumental analysis technique**

In principle, the overall technique is:
"Fast Extraction–Dilute & Shoot–ESI–FIA–MS"

- **High throughput**
- **Quantitative analysis**
- **in complex matrices**
- **At ppb (ng/g) levels**

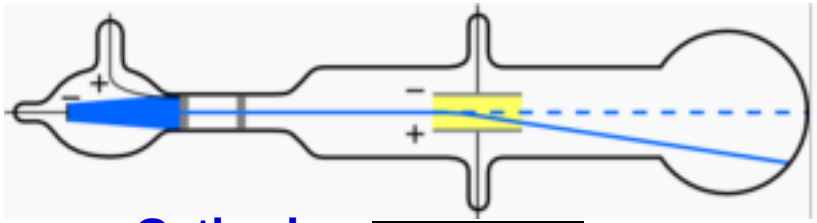
FED-FI-MS Project Description

- **Concept demonstrated in 2008**
- **Proposal approved in 2009**
- **Project fully funded internally by DuPont Co.**

Current objective → Develop analytical methodology that:

- Is more efficient
- Reduces environmental footprint
- Could be used **beyond DuPont**
- Improves screens to ensure **responsible use of agrochemicals**
- Increases capability to **ensure food safety**

Mass spectrometry without chromatography?



Cathode ray

Electric field

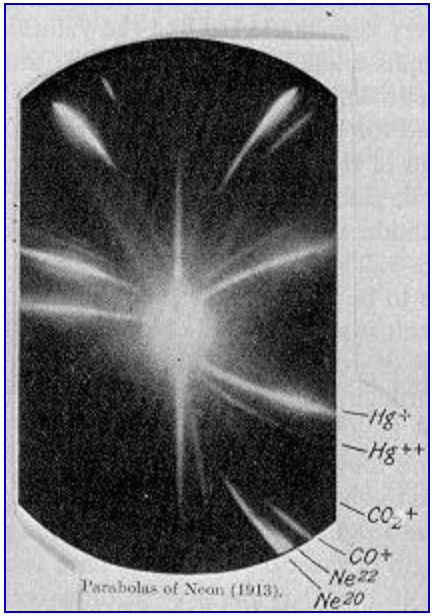
1897

J. J. Thomson

Thomson device replica

www.asms.org

Early mass spectra

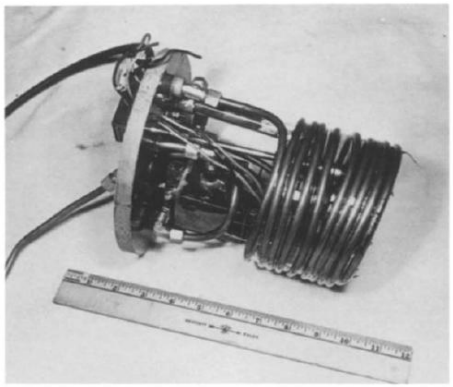


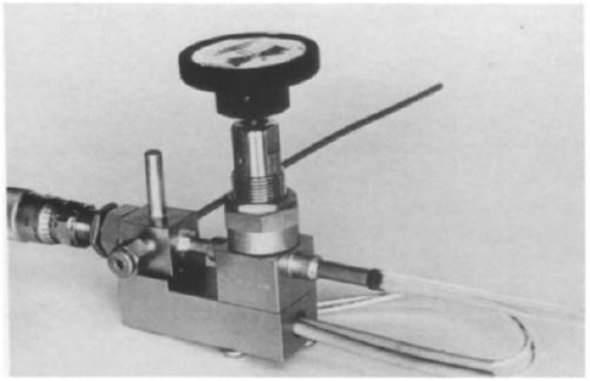
Parabolas of Neon, 1913

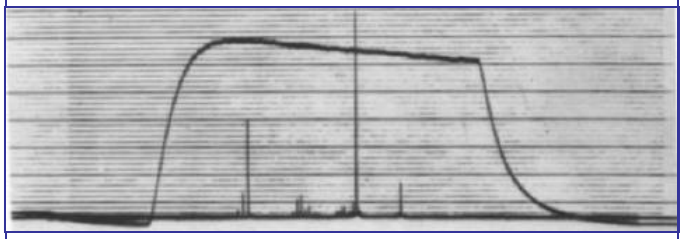
Thomson, J.J. Phil. Mag. **1897**, 44, 293.

Major historical events for MS with chromatography

Gas chromatography/mass spectrometry, 1950's





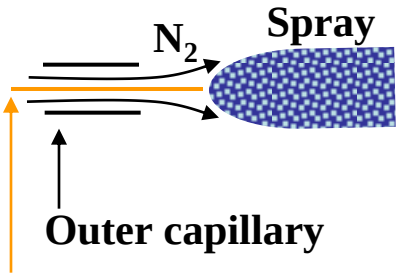


GC/MS of acetone

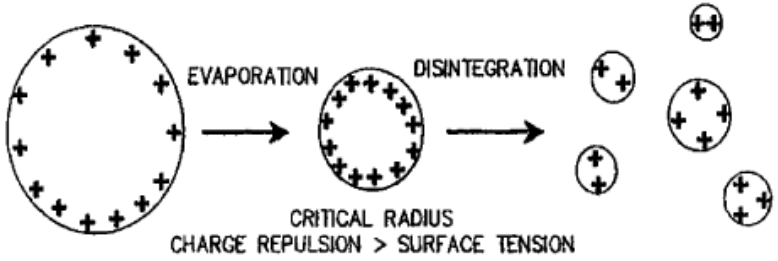
F.W. McLafferty et al – circa 1955
JASMS **1993**, 4, 367-371

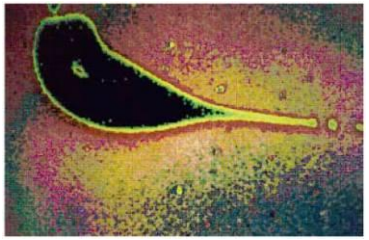
Liquid chromatography/mass spectrometry

HPLC/APCI/MS, 1970's
HPLC/ESI/MS, 1980's



ESI





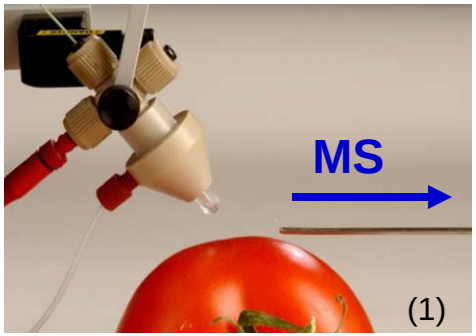
J. B. Fenn, et al. *Science* **1989,** *246*, 64-71

MS analysis without chromatography, 2000's

- **Improvements in MS allow direct analysis without HPLC:**

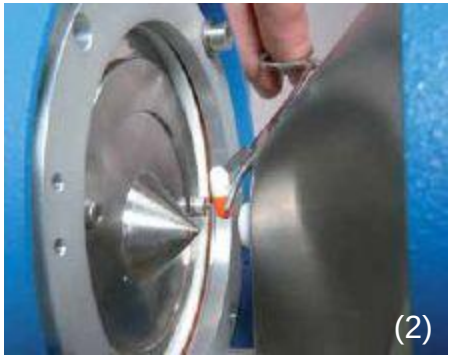
DESI

Purdue University
(R.G. Cooks)



DART

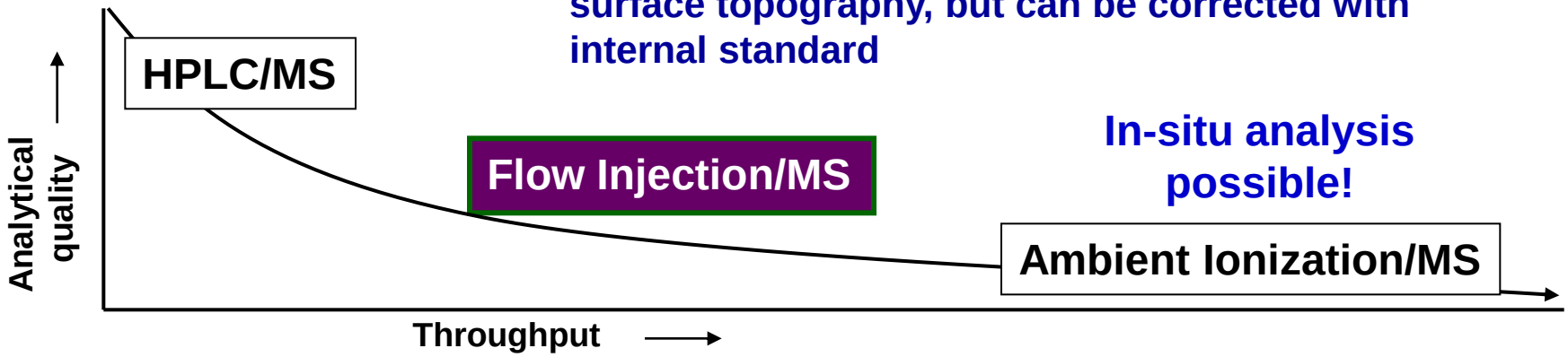
JEOL
(R. Cody)



ASAP

Univ. of the Sciences
(C.N. McEwen)

- **Suitable for analysis of surfaces or solids**
- **<u>Quantitation demonstrated:</u> Response affected by sample position, angle, surface topography, but can be corrected with internal standard**

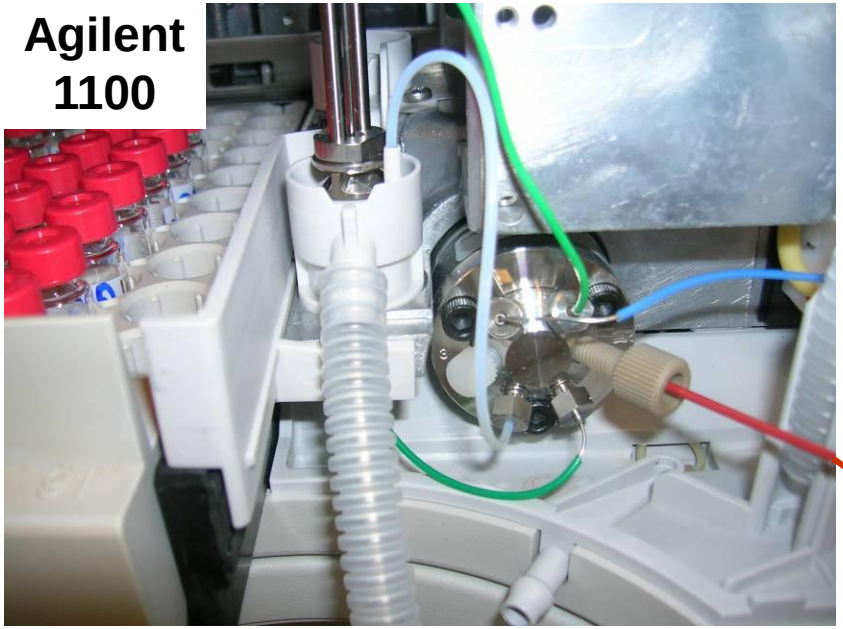


(1) www.prosolia.com (2) Spectroscopy Now, Sept 1, 2006 (3) www.usciences.edu

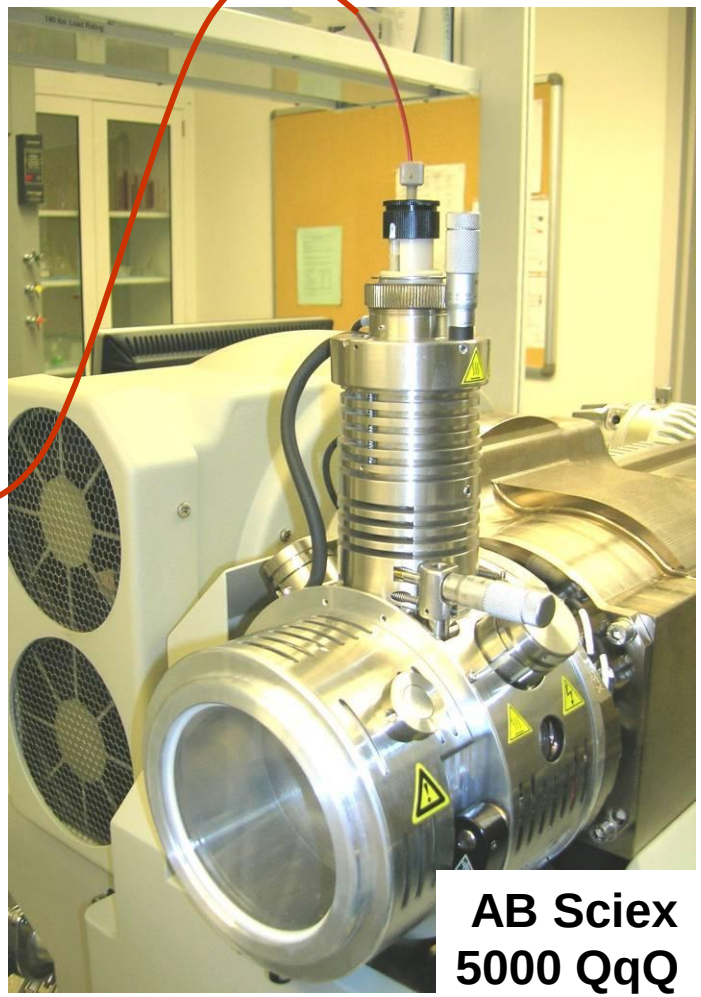
Flow Injection Mass Spectrometry Setup

Autosampler

Agilent 1100



ESI Source/Mass Spectrometer



AB Sciex 5000 QqQ

- **Bypass the column compartment**
- **Use 1- meter long red PEEK capillary** 1/16 in. O.D. and 0.13 mm I.D. (part no. 0890-1915, Agilent Technologies)
- **1- μL injection**

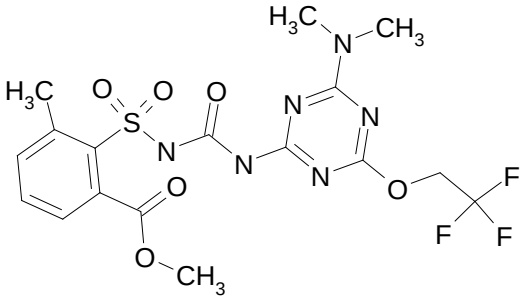
Nanita, Pentz, Bramble. *Anal. Chem.* **2009**, 81, 3134

Fast Extraction & Dilution Flow Injection Mass Spectrometry

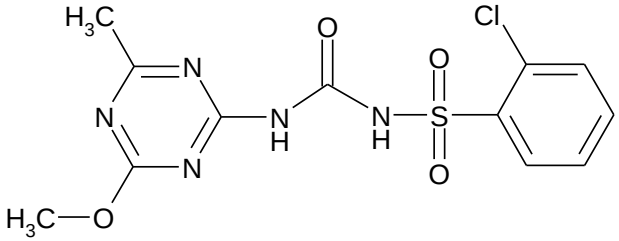
FED-FI-MS

Analytes Tested with Prototype Multiresidue Method

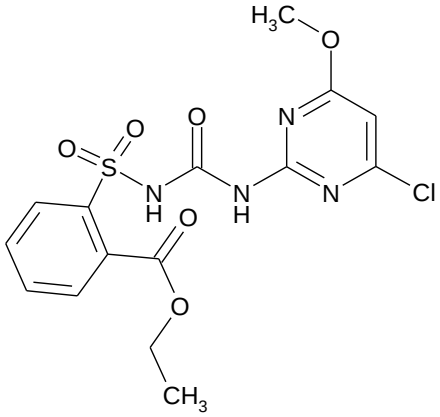
Sulfonylurea Herbicides



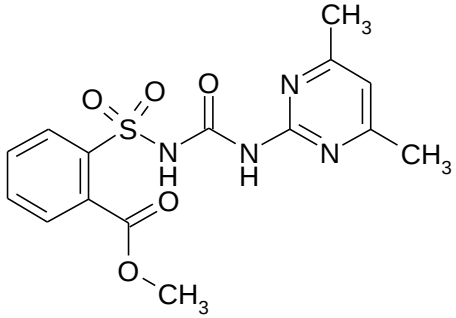
Triflusulfuron methyl



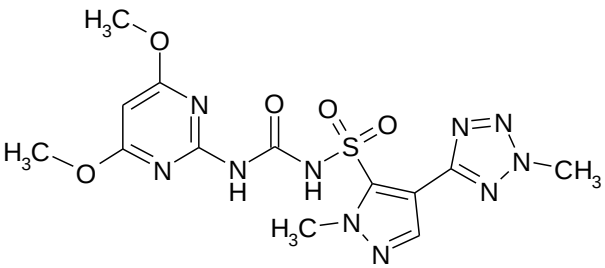
Chlorsulfuron



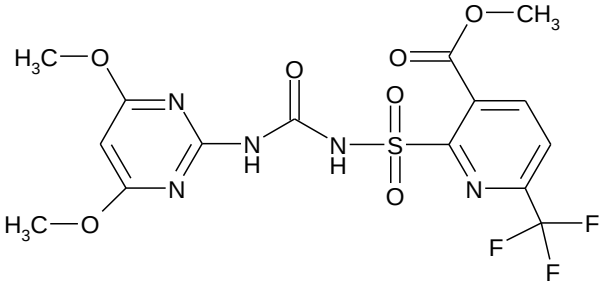
Chlorimuron ethyl



Sulfometuron methyl



Azimsulfuron



Flupyrsulfuron methyl

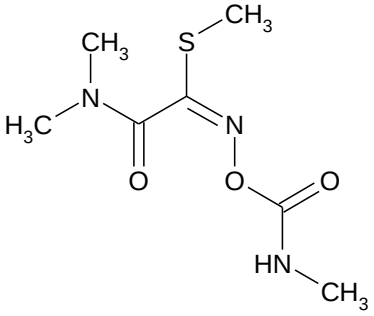
Nanita, Stry, et al. J. Agric Food Chem. **2011**, in press.

Fast Extraction & Dilution Flow Injection Mass Spectrometry

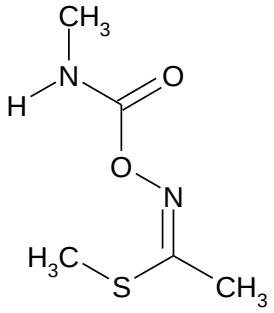
FED-FI-MS

Analytes Tested with Prototype Multiresidue Method

Carbamate Insecticides

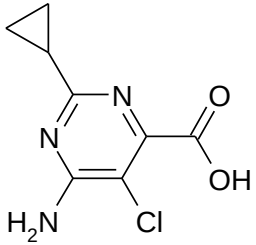


Oxamyl

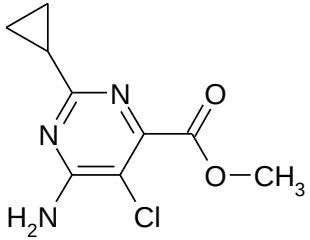


Methomyl

Pyrimidine Carboxylic Acid Herbicides

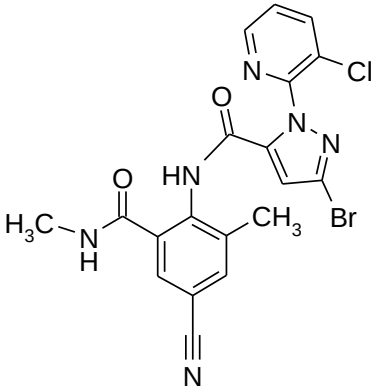


Aminocyclopyrachlor

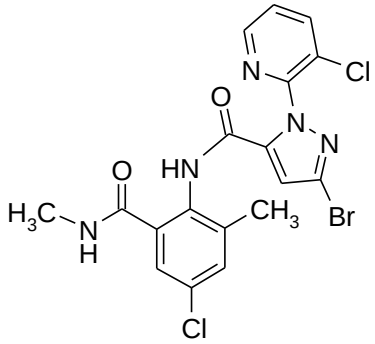


Aminocyclopyrachlor methyl

Anthranilic Diamide Insecticides



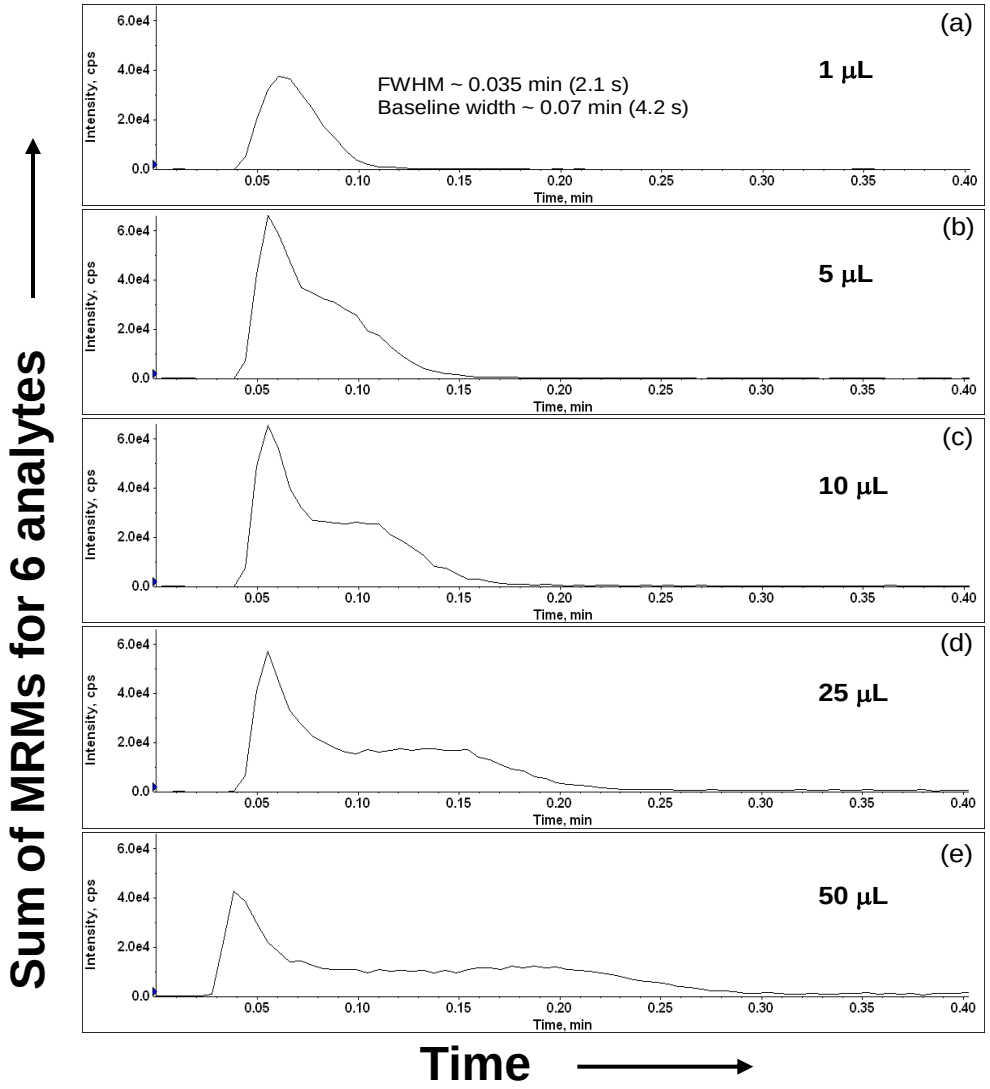
Cyantraniliprole



Chlorantraniliprole

Nanita, Stry, et al. J. Agric Food Chem. **2011**, in press.

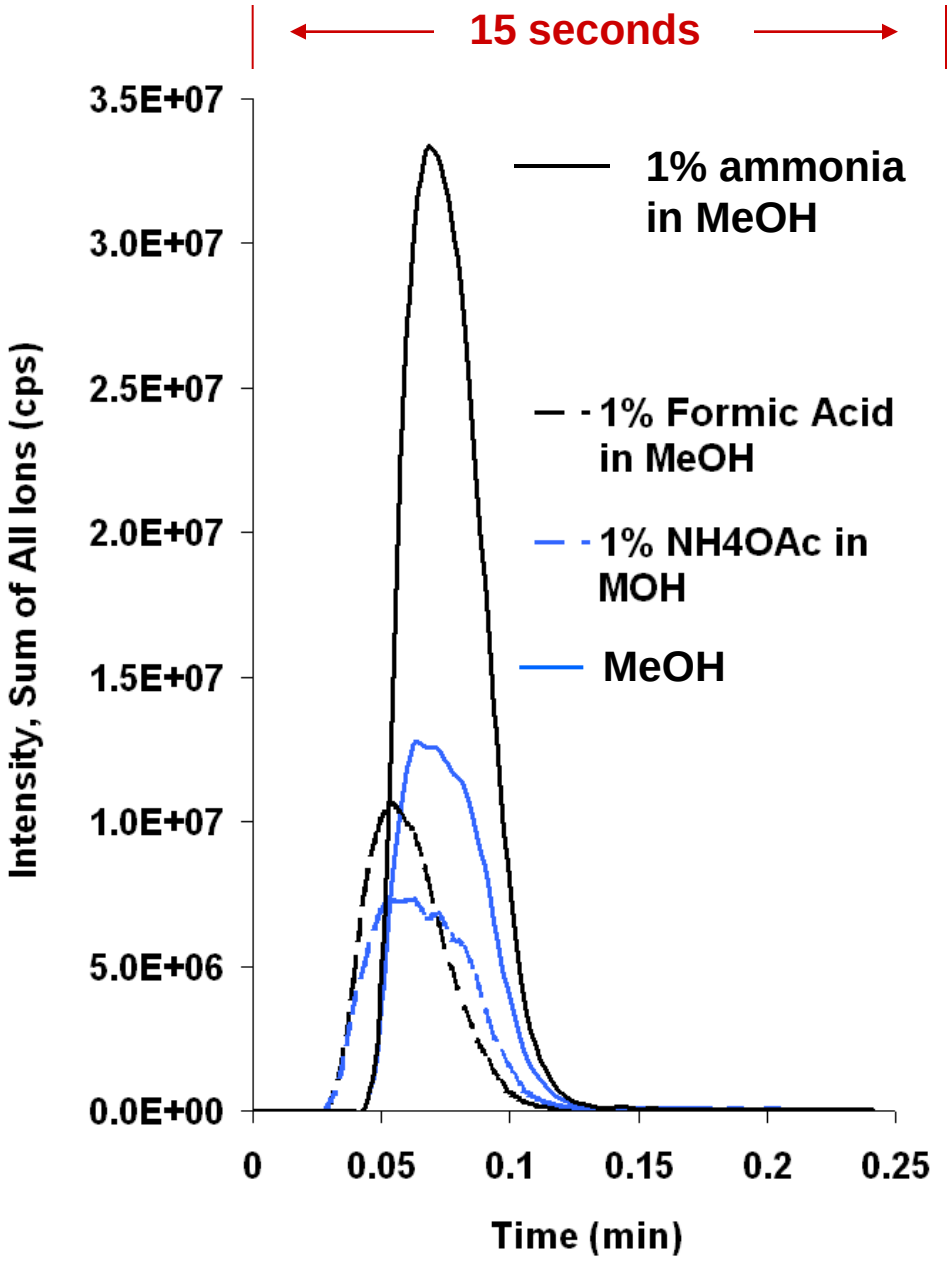
Effect of Injection Volume



- **A 1.0 ng/mL mixed standard was prepared in methanol and analyzed with different injection volumes.**
- **Small inner diameter PEEK tubing was used to connect autosampler to MS, minimizing dead volume.**
- **FI/MS/MS ion chronograms show that 1-5 µL injection volumes are adequate.**

Nanita, Pentz, Bramble. *Anal. Chem.* **2009**, 81, 3134

Ionization Efficiency Optimization: AB Sciex 5000 QqQ Mass Spectrometer, ESI source used.

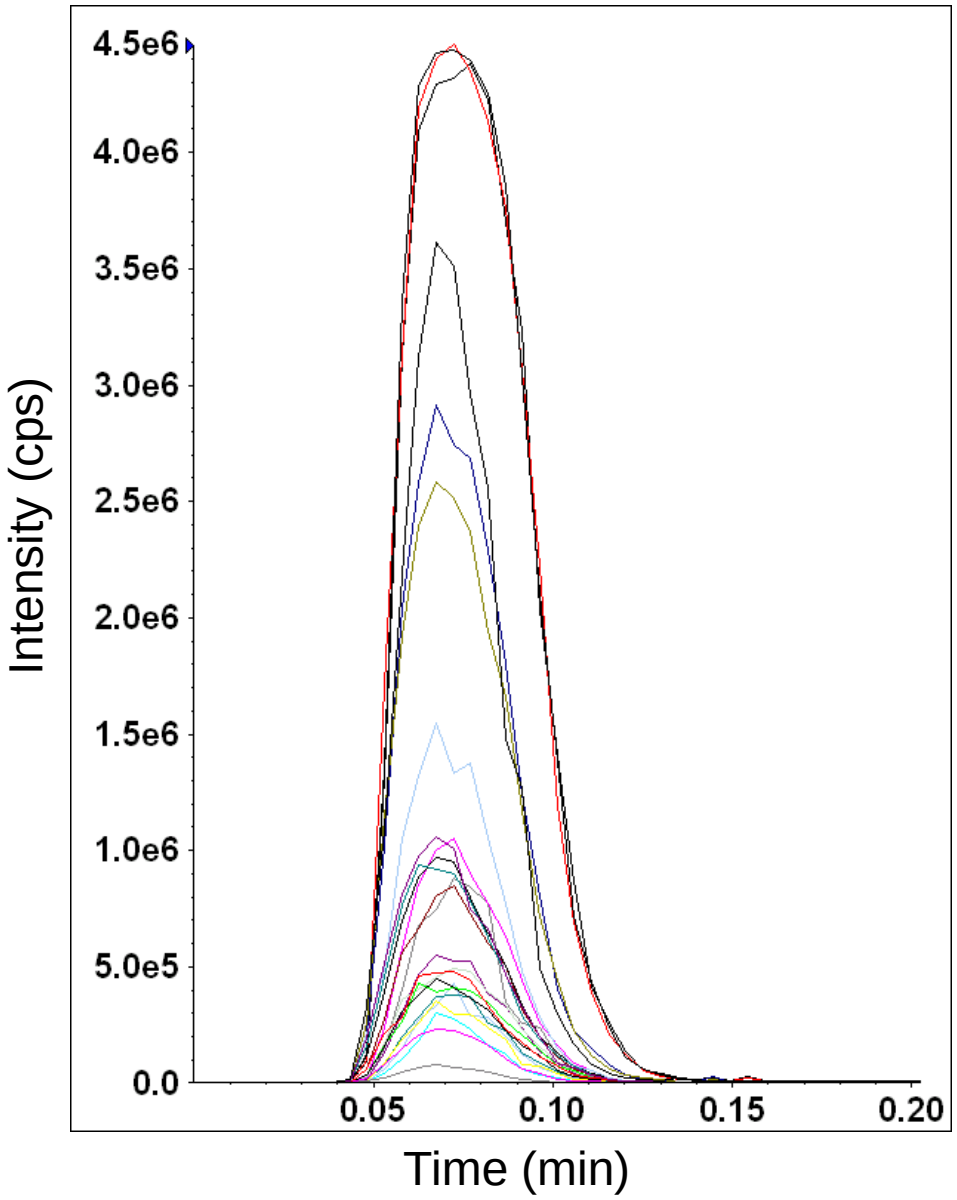


FI-MS advantages

- Can use any solvent
- Easy method development
- Very fast analysis!

Nanita, Stry, et al. J. Agric Food Chem. **2011**, in press.

Example chronogram



AB Sciex 5000 QqQ Mass Spectrometer with Electrospray Ion Source

- **12 analytes**
- **24 ions monitored**
- **Injected in example shown: 100 pg = 10^{-10} g**
- **Sensitivity limit: 100-500 fg = 1-5x10^{-13} g**

Nanita, Stry, et al. J. Agric Food Chem. **2011**, in press.

FED-FI-MS Analytical Procedure

Method for samples with Low water content

10-g pecan sample extracted with 10 mL of organic solvent, 2 min in GenoGrinder with 3 metal beads

- **Fat freeze-out (1h)**
- **Centrifuge 10 min**
- **Dilute 1/50**
- **Flow injection MS**

LOQ = 0.05 mg/kg
LOD ~ 0.02 mg/kg

Diluted 1/50 **Diluted 1/10**

Method for samples with High water content

5-g lemon sample extracted with 25 mL of organic solvent, 2 min in GenoGrinder with 3 metal beads

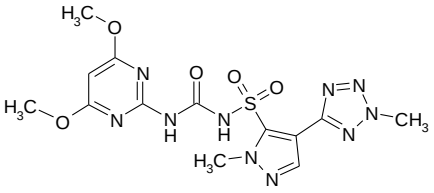
- **Centrifuge 10 min**
- **Dilute 1/10**
- **Flow injection MS**

LOQ = 0.05 mg/kg
LOD ~ 0.02 mg/kg

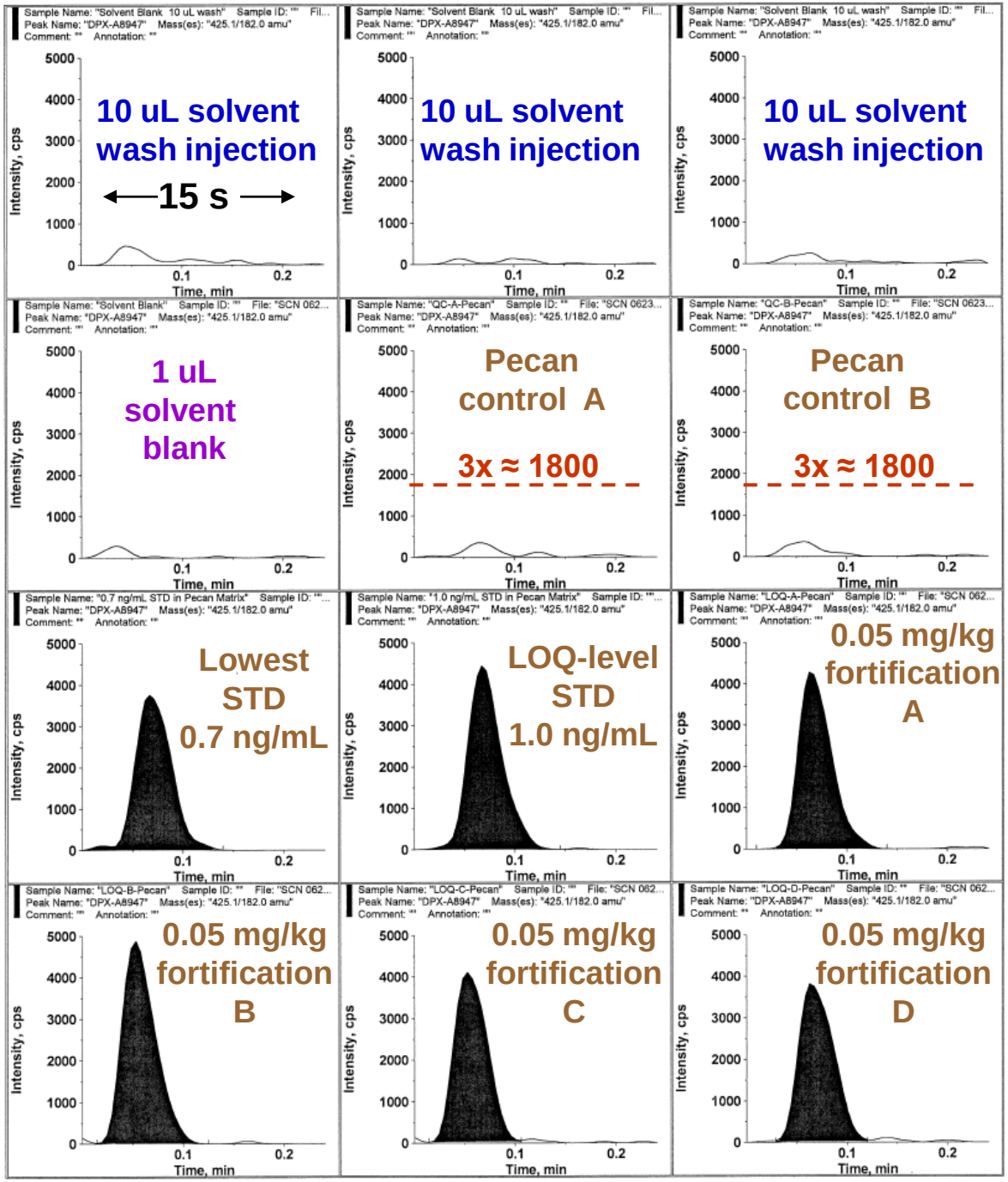
Extraction solvent = Methanol
Dilution solvent = 98.5% Methanol, 1.5% conc. ammonia

Nanita, S.C. *Analyst* **2011**, 136, 285-287.

Validation Raw Data Example, Pecan, Azimsulfuron



- **Quantitative ion transition shown: m/z 425 → m/z 182**
- **Confirmatory ion transition monitored: m/z 425 → m/z 156**

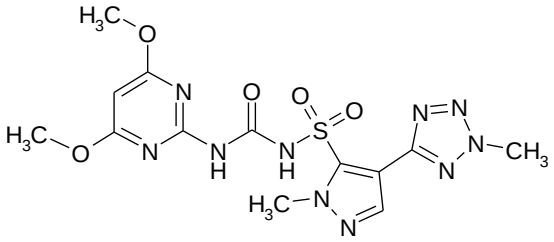


Detection threshold must be defined for each analyte

Analyst **2011**, 136, 285.

J. Agric Food Chem. **2011**, in press.

Validation Raw Data Example, Pecan, Azimsulfuron



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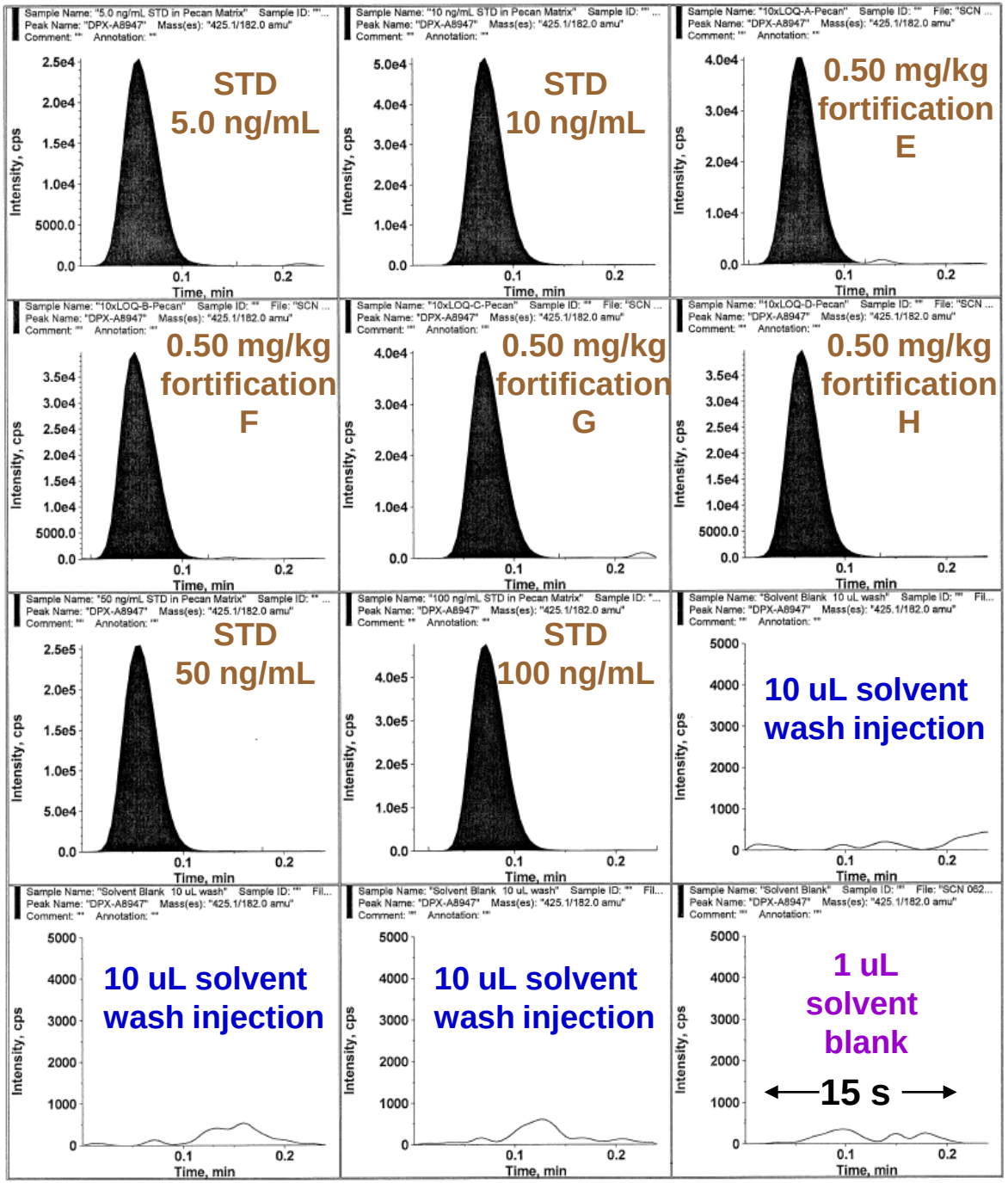
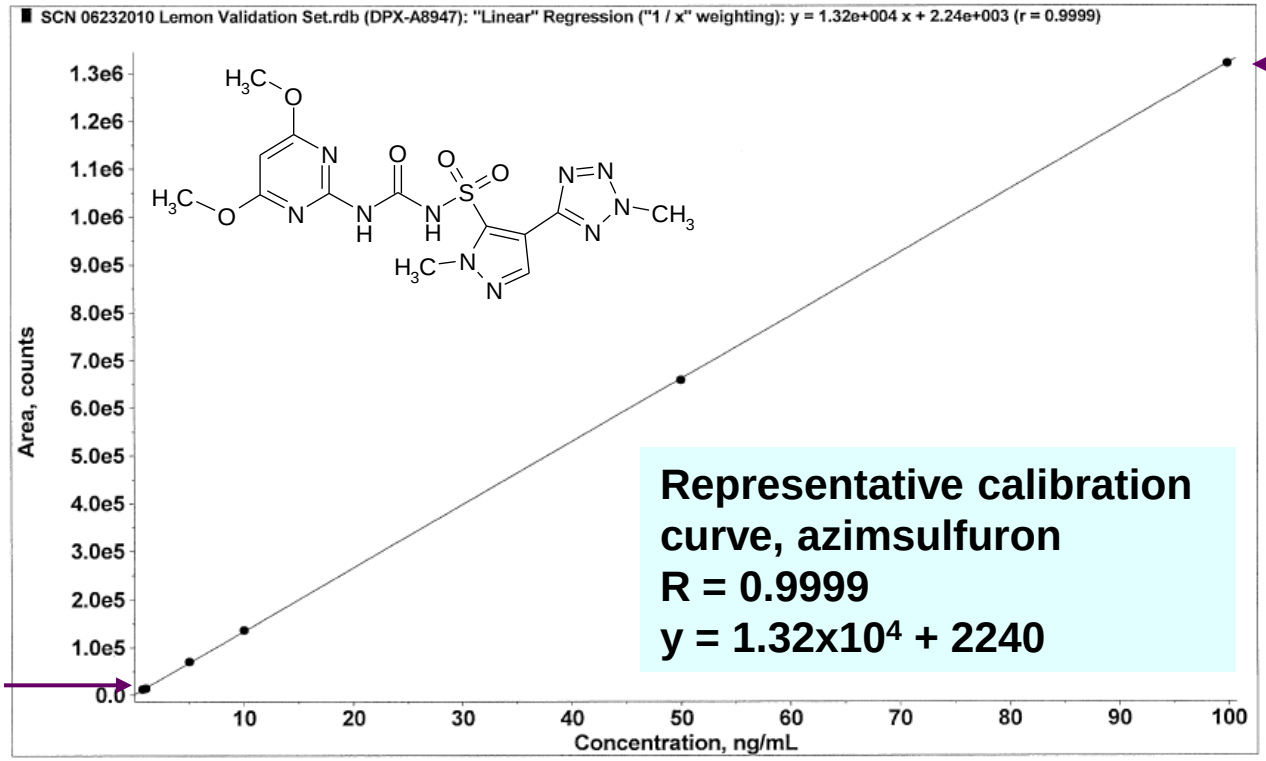


Analyst **2011**, 136, 285.

J. Agric Food Chem. **2011**, in press.

FED-FI-MS Matrix-Matched Standard Calibration High Water Content (Lemon)



100 ng/mL (5.0 mg/kg)

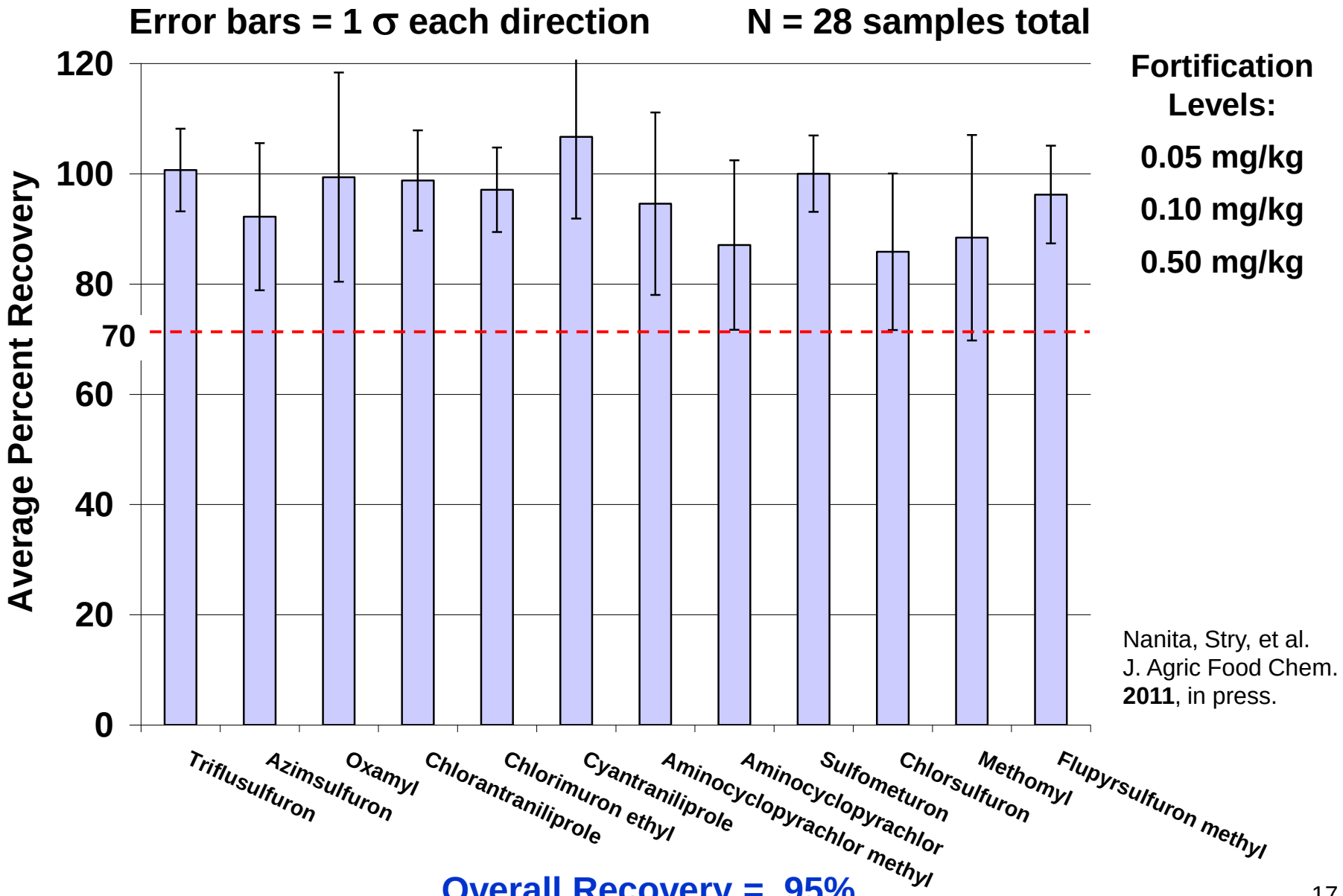
0.7 ng/mL (0.035 mg/kg)

Representative calibration curve, azimsulfuron
R = 0.9999
$y = 1.32x10^4 + 2240$

Analyte	Correlation, R	Linear Equation	Analyte	Correlation, R	Linear Equation
Triflusulfuron methyl	0.9997	$y = 2.93x10^4$ (x) + 2470	Methomyl	0.9993	$y = 2.86x10^3$ (x) + 1240
Azimsulfuron	0.9999	$y = 1.32x10^4$ (x) + 2240	Oxamyl	0.9997	$y = 1.61x10^3$ (x) + 1830
Chlorimuron ethyl	1.0000	$y = 1.07x10^4$ (x) + 321	Aminocyclopyrachlor	0.9999	$y = 7.91x10^3$ (x) + 2680
Sulfometuron methyl	0.9999	$y = 2.07x10^4$ (x) + 1510	Aminocyclopyrachlor methyl	0.9999	$y = 2.04x10^4$ (x) + 5070
Chlorsulfuron	0.9999	$y = 3.45x10^3$ (x) + 1940	Cyantraniliprole	0.9998	$y = 3.32x10^3$ (x) + 557
Flupyrsulfuron methyl	1.0000	$y = 2.46x10^4$ (x) + 3260	Chlorantraniliprole	0.9999	$y = 6.20x10^3$ (x) + 488

Nanita, Stry, et al. J. Agric Food Chem. **2011**, in press.

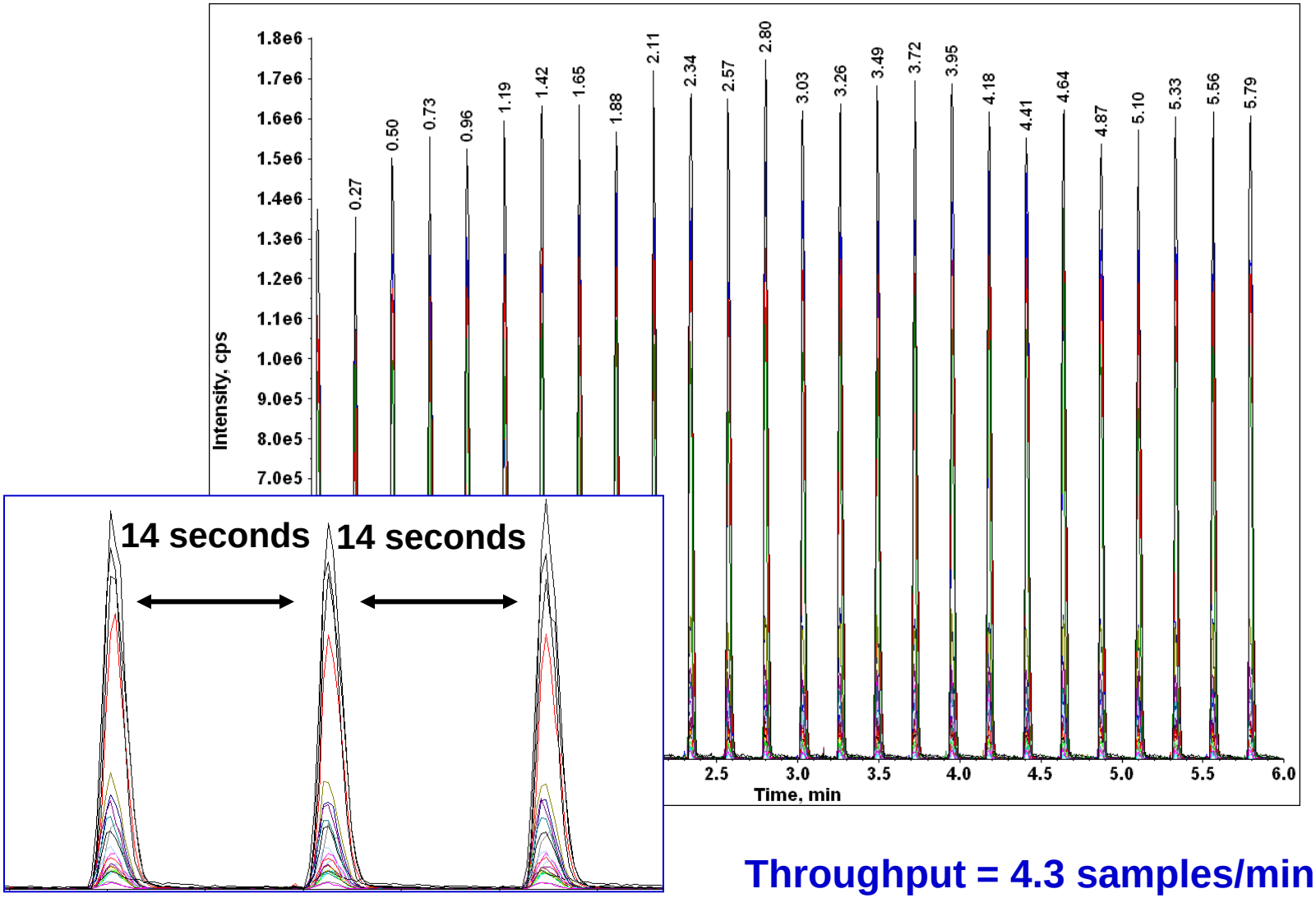
FED-FI-MS Method Validation Recoveries, Food of Plant Origin: Soybean Oil, Corn Meal, Pecan, Lemon



Nanita, Stry, et al.
J. Agric Food Chem.
2011, in press.

Overall Recovery = 95%

FI-MS Throughput Potential



Throughput = 4.3 samples/min possible!

Validated run time = 15 s, throughput = 1 sample/min

Nanita, Stry, et al. J. Agric Food Chem. **2011**, in press.

How fast is FED-FI-MS?

- **Very fast!**
- **High throughput!**

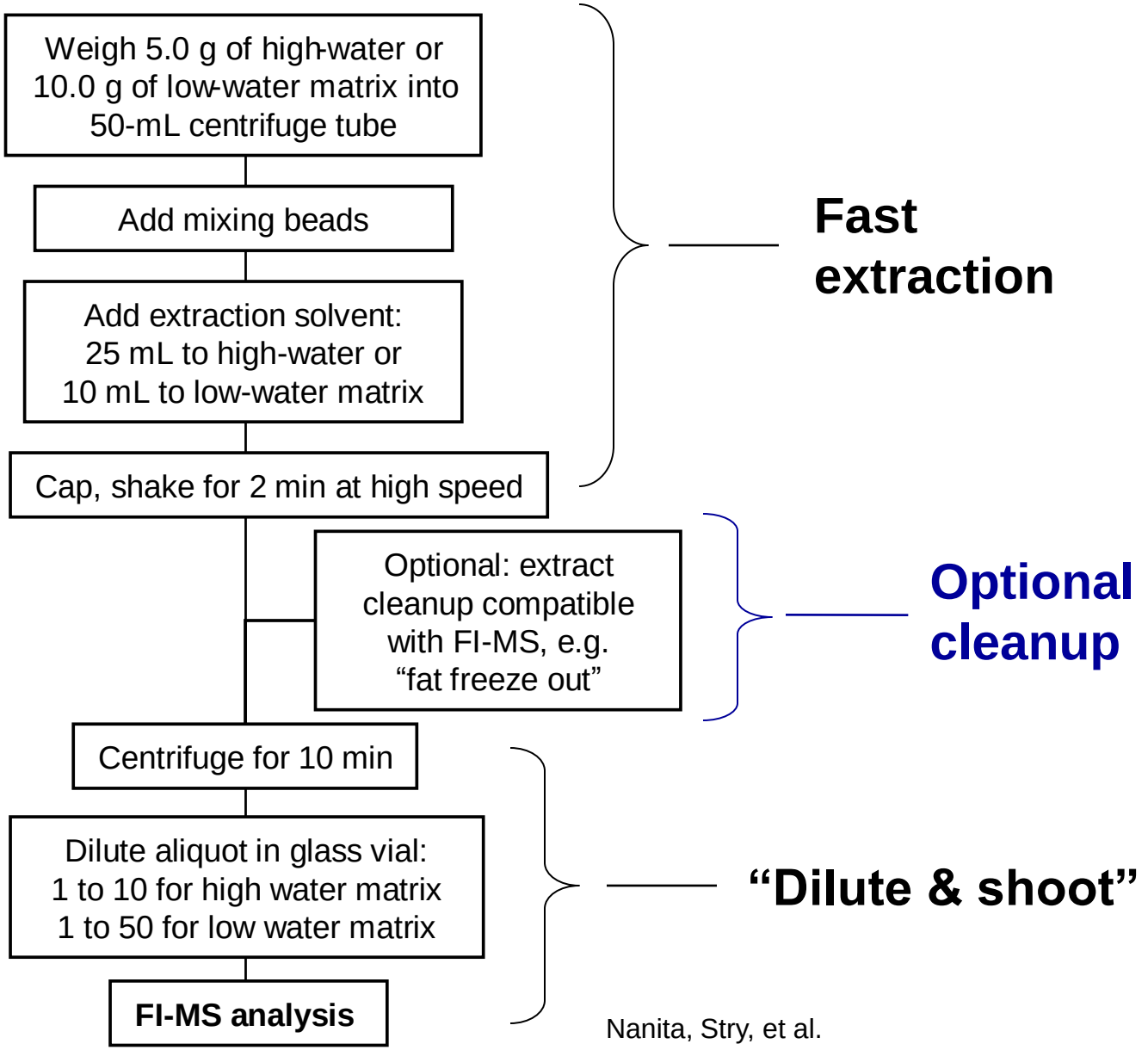
Sample homogenization is the main limiting step!

High-throughput and/or multiplex devices needed for sample communition!

(1) www.robotcoupe-si.com

FED-FI-MS Project at DuPont: Most Recent Results – Year 2011

FED-FI-MS Prototype
Multiresidue Method



Nanita, Stry, et al.
J. Agric Food Chem. **2011**, in press.

Acetonitrile/Water Phase Separation "Salting Out"

Common Salt Out

$$ACN/H_2O \text{ mixture} \xrightarrow{NaCl} ACN \text{ phase} + H_2O \text{ phase}$$

Problem for Flow Injection MS:

- NaCl boiling point > 1400 ^oC
- Analytes form $(M+Na)^+$
- $(M+H)^+$ signal suppressed

ESI Source Temperature: 400-500^{o}C

Solution: Ammonium Salts!

Decomposition Reactions at < 400^{o}C (ESI Source Temperature):

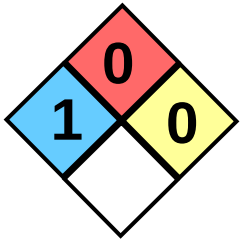
- $NH_4Cl\ (s) \rightarrow NH_3\uparrow + HCl\uparrow$
- $CH_3COONH_4\ (s) \rightarrow CH_3CONH_2\uparrow + H_2O\uparrow$
- $(NH_4)_2CO_3\ (s) \rightarrow 2NH_3\uparrow + H_2O\uparrow + CO_2\uparrow$

S.C. Nanita, unpublished

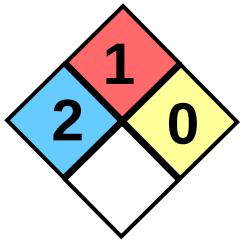
Acetonitrile/Water Salting Out: NH_4^+ Candidates

Most safe

NH_4Cl
Ammonium Chloride

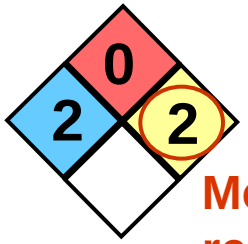


$HCOONH_4$
Ammonium Formate



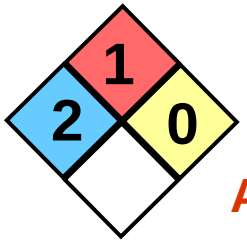
2nd choice

$(NH_4)_2CO_3$
Ammonium Carbonate



Most reactive

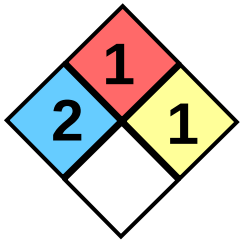
$(NH_4)_2SO_4$
Ammonium Sulfate



ACN/H_2O emulsion layer observed

3rd choice

CH_3COONH_4
Ammonium Acetate

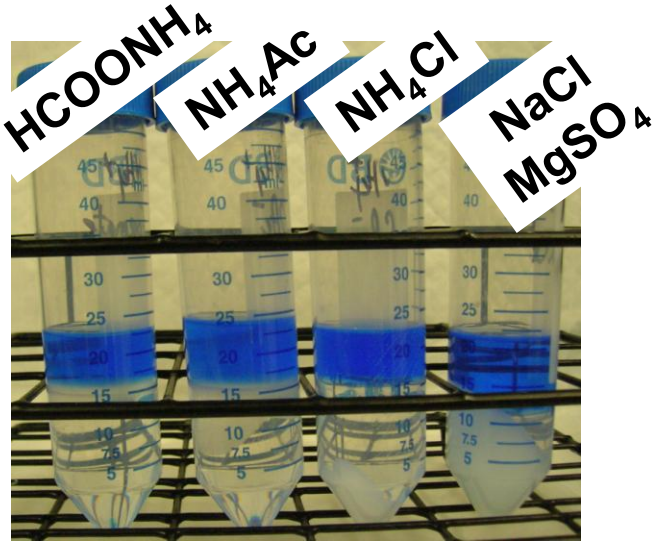


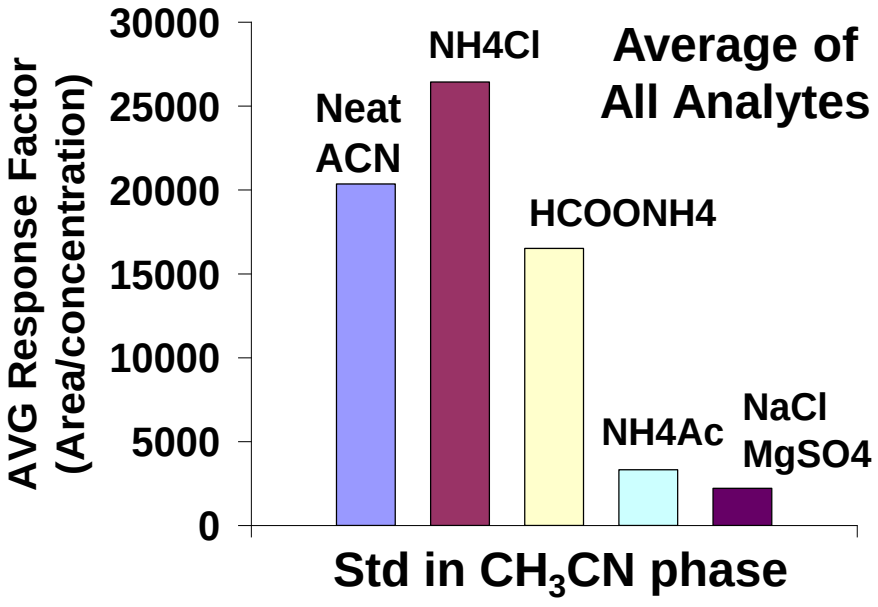
S.C. Nanita, unpublished

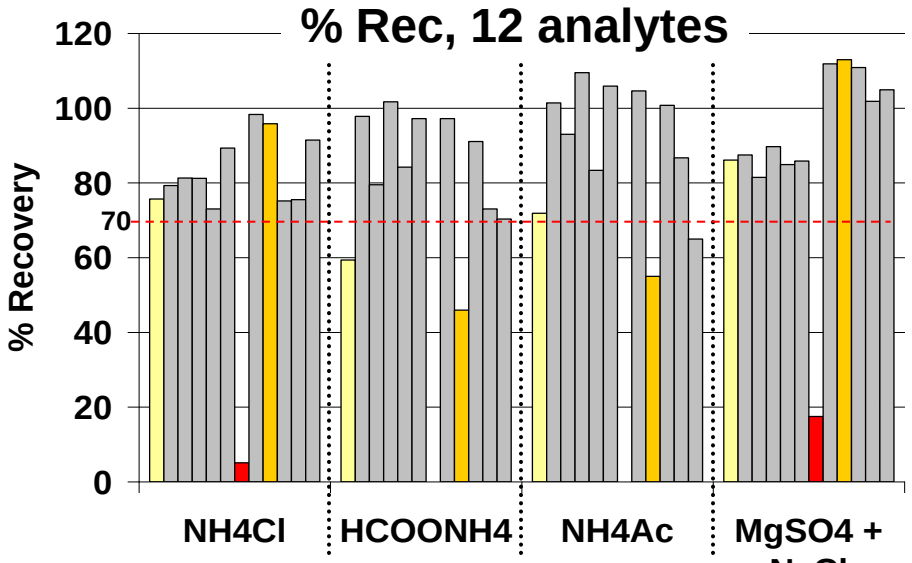
Acetonitrile/Water "Ammonium Salting Out"

- NH_4^+ Salt Out
- 10 mL of H_2O
- 10 mL of CH_3CN
- 5.0 g of NH_4^+ salt
- Shaken for 1 min
- Centrifuged for 5 min

CH_3CN phase in blue (dye added for picture)







> 70%: 11/12 9/12 9/12 11/12

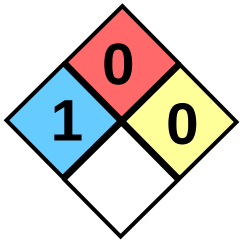
S.C. Nanita, unpublished

NH_4Cl Selected for Salting Out

Best choice: NH_4Cl ✓

- #1 in safety
- Good ACN/H_2O phase separation
- Best recoveries
- Best MS instrument response
- Affordable → 99.5% pure costs ~ $60/kg
  5g = $0.30/sample

NH_4Cl
Ammonium Chloride



S.C. Nanita, unpublished

FED-FI-MS method with NH_4Cl salting out

Matrices tested
- **Milk**
- **Eggs**
- **Blood plasma**
- **Urine**

5 g NH_4Cl

9 mL H_2O

1 g sample

10 mL CH_3CN

Fast Extraction
1-min shaking by hand

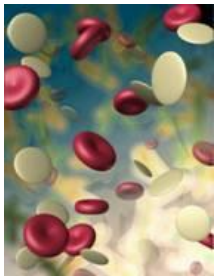
Dilution factor = 5
(200 μL aliquot + 800 μL diluent)

Dilution of aliquot from CH_3CN phase

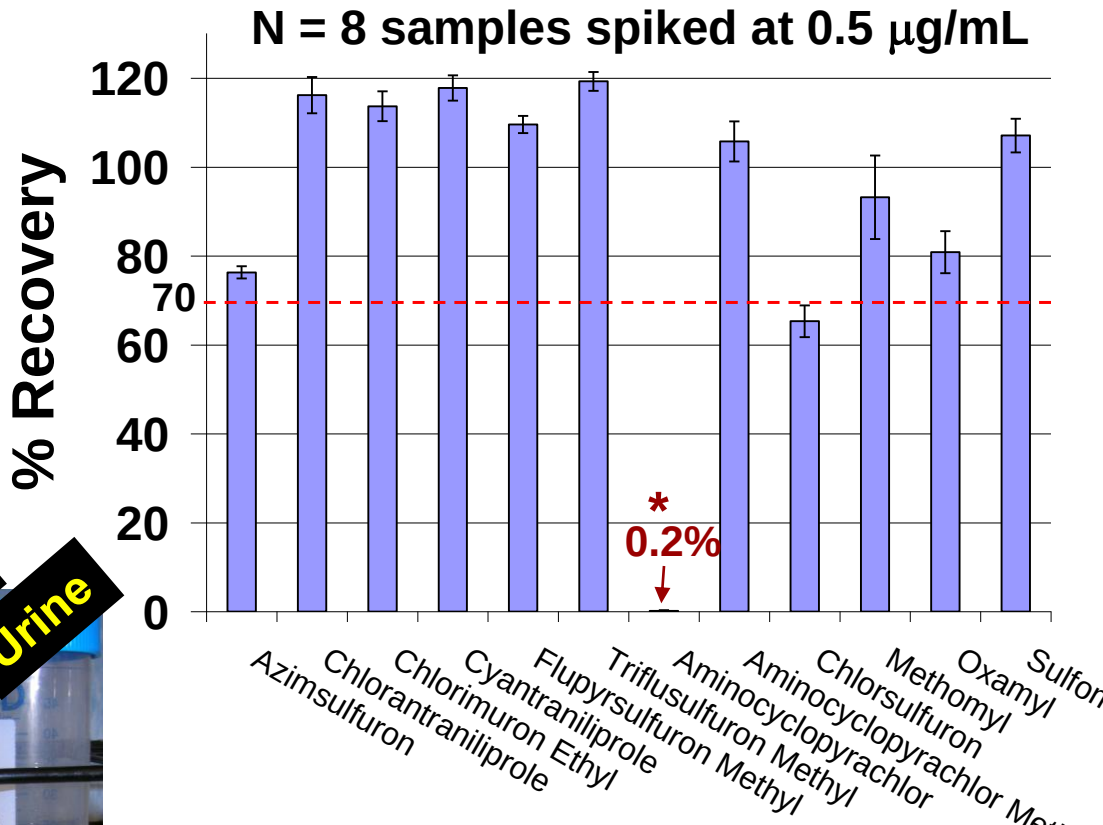
Instrument: AB Sciex 5000 QqQ MS/MS

S.C. Nanita, unpublished

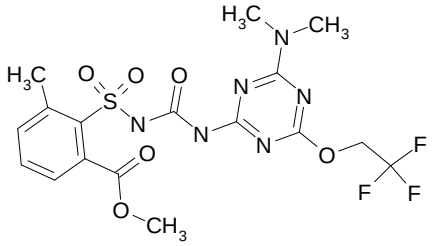
FED-FI-MS with NH_4Cl Salting Out

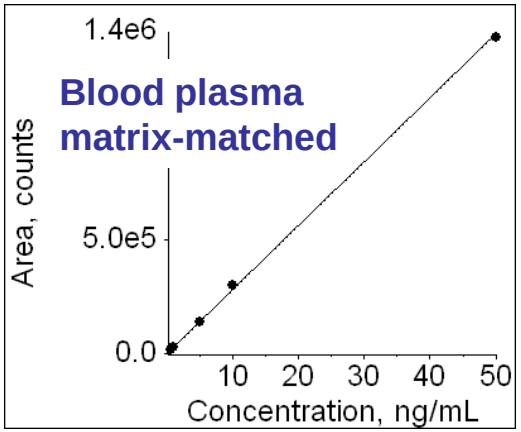


Body fluids:
Rat blood plasma & urine



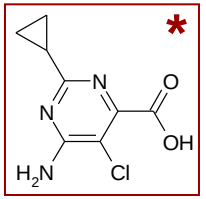
Example calibration:
Triflusulfuron methyl





- **10 of 12 analytes > 70%**
- **11 of 12 analytes > 60%**

Overall Recovery (11 of 12) = 100%



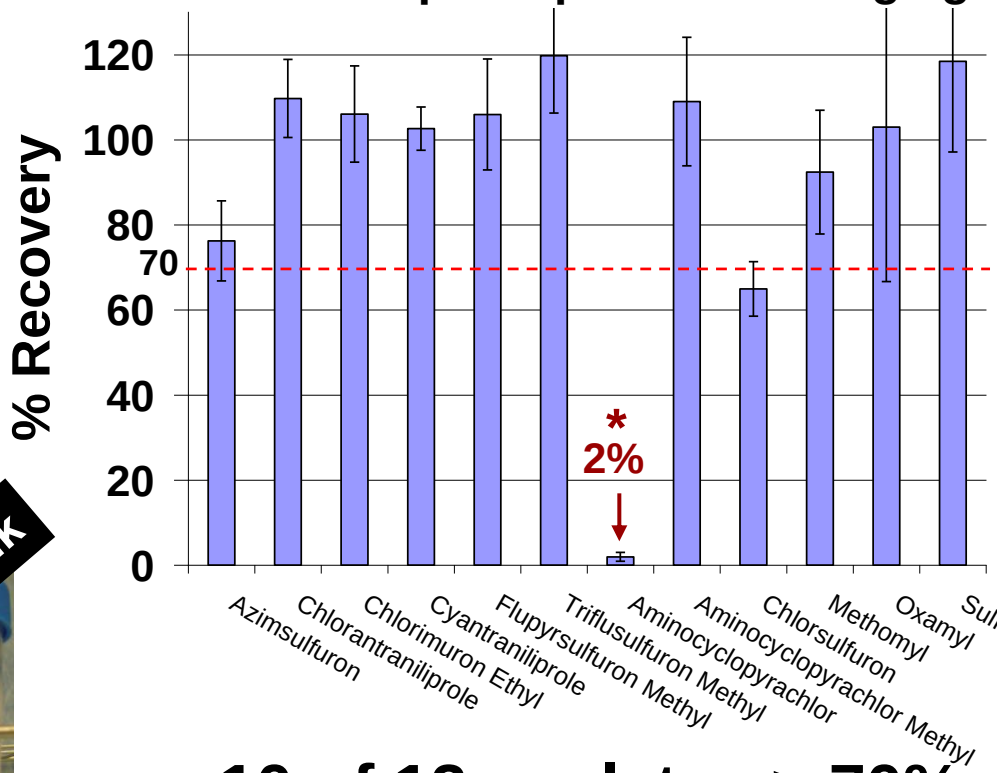
Remains in aqueous phase

S.C. Nanita, unpublished

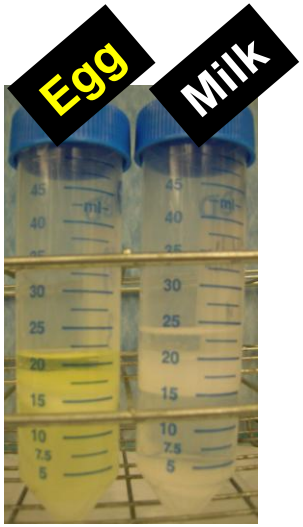
FED-FI-MS with NH_4Cl Salting Out

Food of animal origin: milk and eggs

N = 8 samples spiked at 0.5 mg/kg



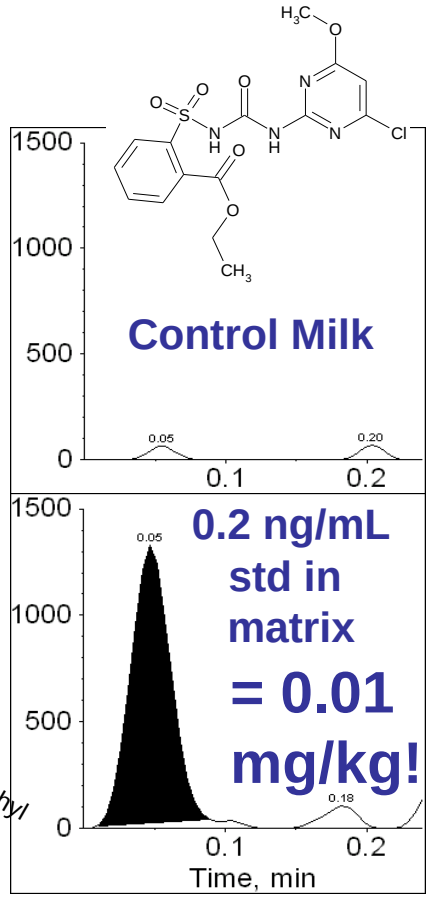
- LOD & LOQ to be determined

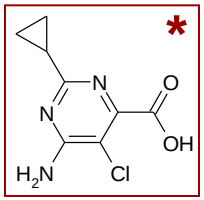


- 10 of 12 analytes > 70%
- 11 of 12 analytes > 60%

Overall Recovery (11 of 12) = 101%

Example chronograms: Chlorimuron ethyl





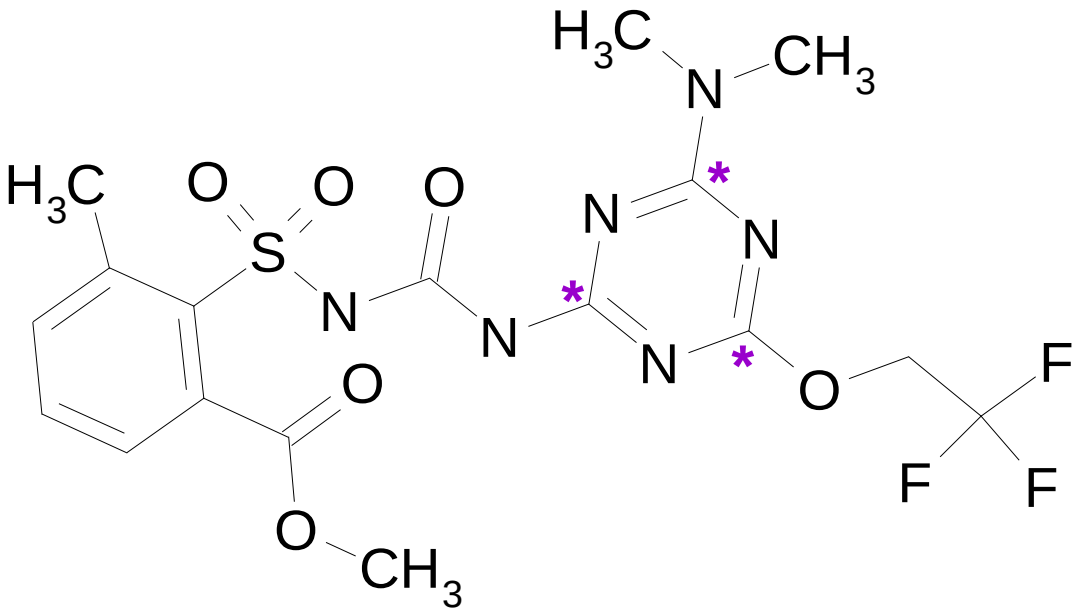
Remains in aqueous phase

S.C. Nanita, unpublished

Isotope-labeled standard

Just received at my laboratory!

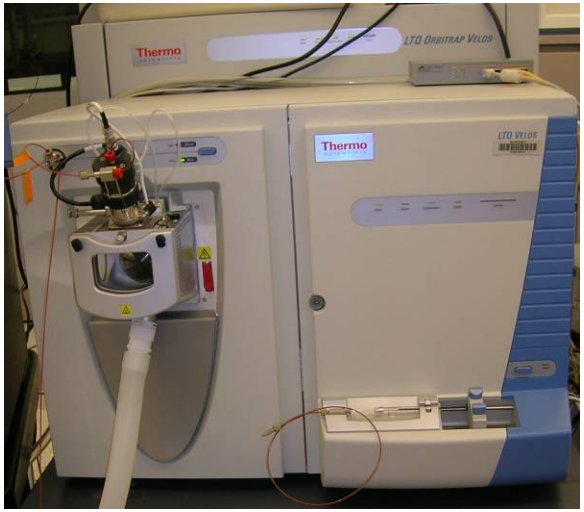
Triflusulfuron Methyl



*** Heavy isotopes (^{13}C)**

Molecular weight = 495 Da (3 Da from heavy isotopes)

New instrument acquisitions: High resolution mass spectrometers



Thermo
LTQ-Orbitrap Velos

Agilent
6538 Q-TOF

Just arrived at DuPont Stine-Haskell Research Center!

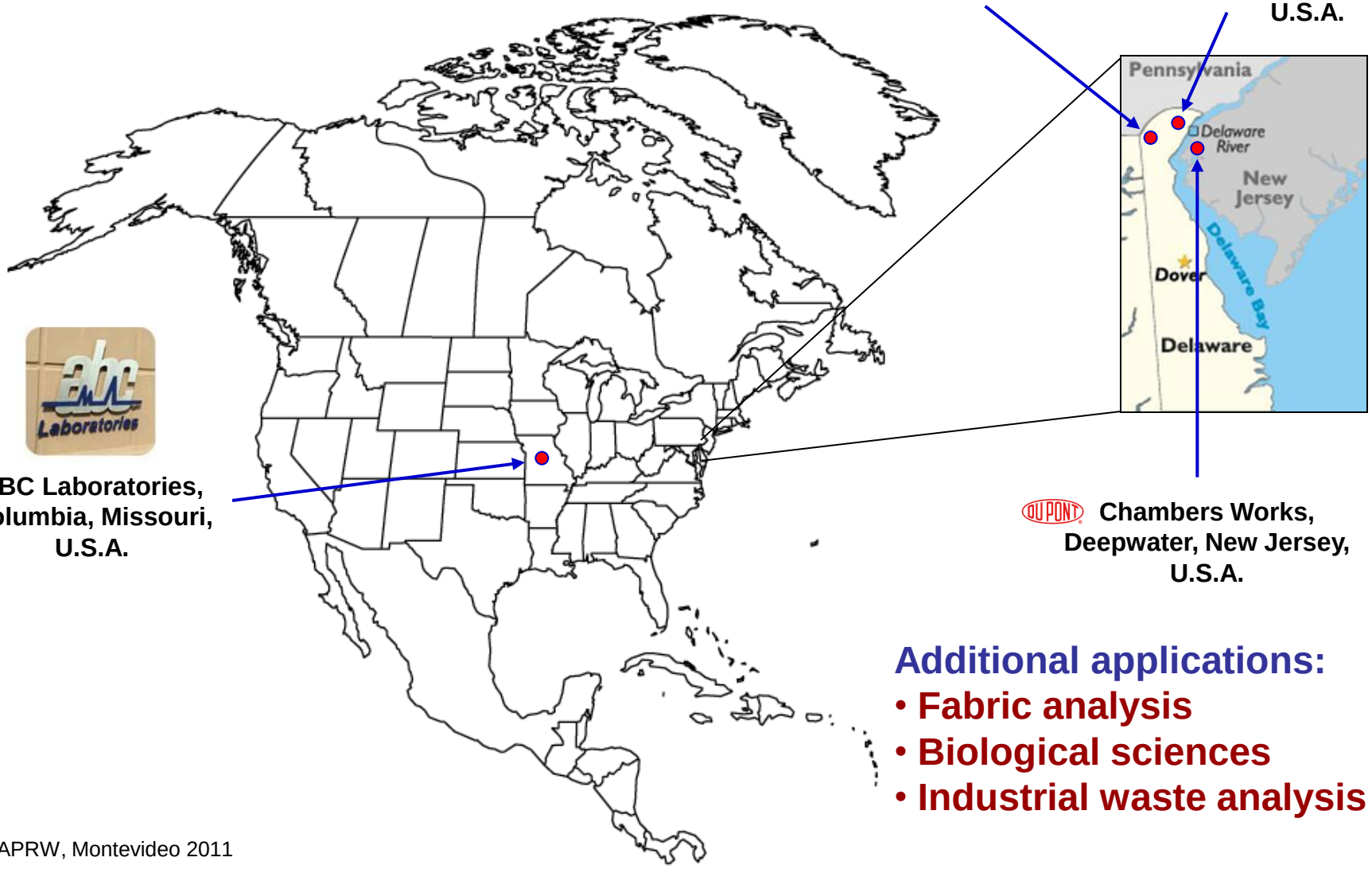
FED-FI-MS Research Project

Next objective (2011-2012)

- **Collaborations for corporate-wide implementation at DuPont**
- **Seeking collaborations for implementation at universities and laboratories**

- **Applications beyond residue analysis in food!**

DuPont Flow Injection Mass Spectrometry Analytical Method Map as of May 2011



Additional applications:

- **Fabric analysis**
- **Biological sciences**
- **Industrial waste analysis**

DuPont Chambers Works
Deepwater, New Jersey, U.S.A.

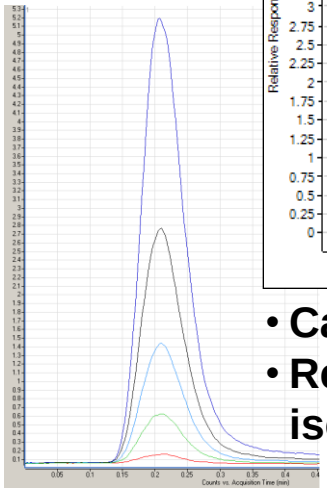
Method by
Amber Wellman

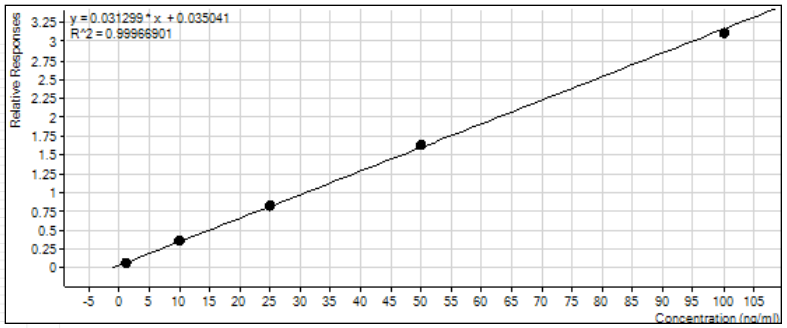
APPLICATION: Industrial waste analysis

Trace-level analysis of industrial chemical in complex waste samples

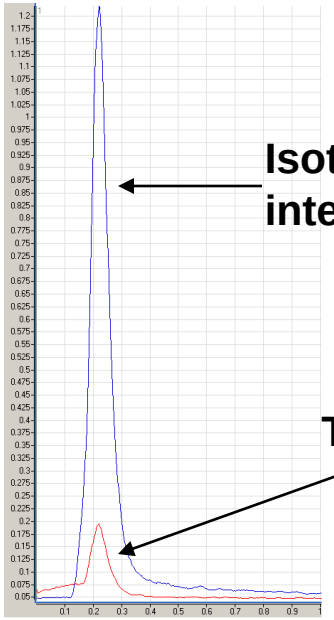
1. Liquid waste sample diluted
2. Direct FI/MS/MS analysis

- **Instrument: Agilent 6460 triple quadrupole**
- **Method under development: Rapid screening tool**
- **Method LOQ needed: 20 μg/mL (ppm)**
- **Analyte easily detected in diluted sample at 20 ng/mL (ppb) – 1000-fold dilution**





- **Calibration range from 1-100 ng/mL**
- **Relative response calculated using isotopically labeled internal standard**



Isotopically labeled internal standard

Target Analyte

Amber Wellman, unpublished

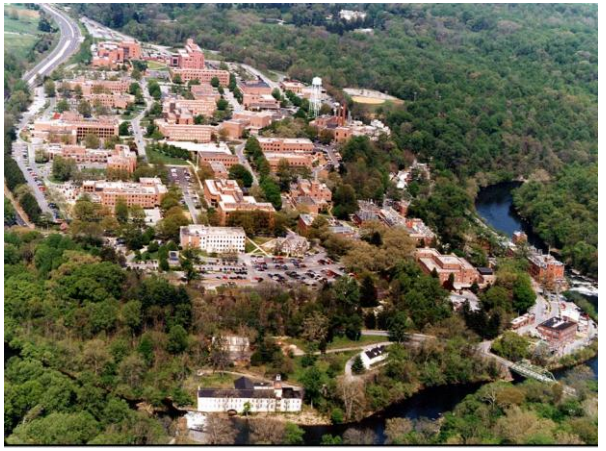
DuPont Experimental Station
Wilmington, Delaware, U.S.A.

Method by Michael Gagnon

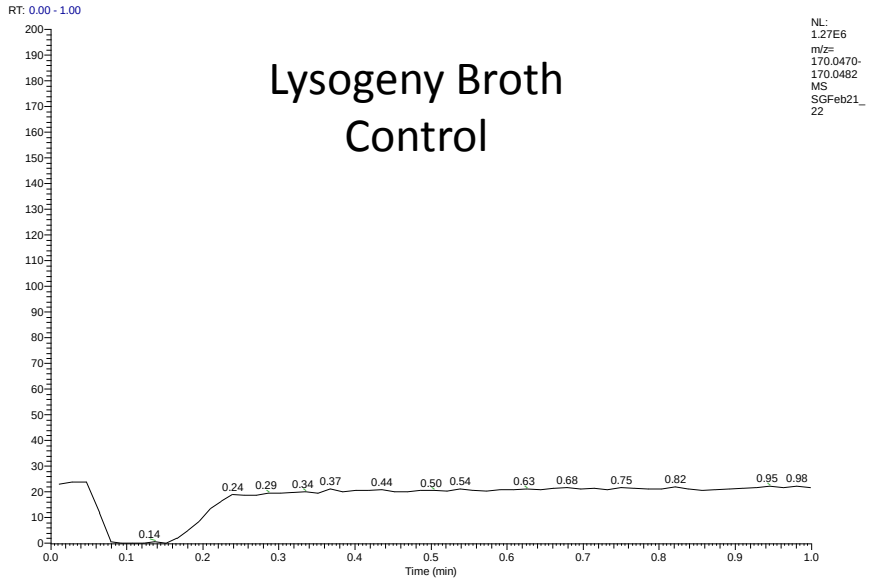
APPLICATION: Biological sciences, genomics

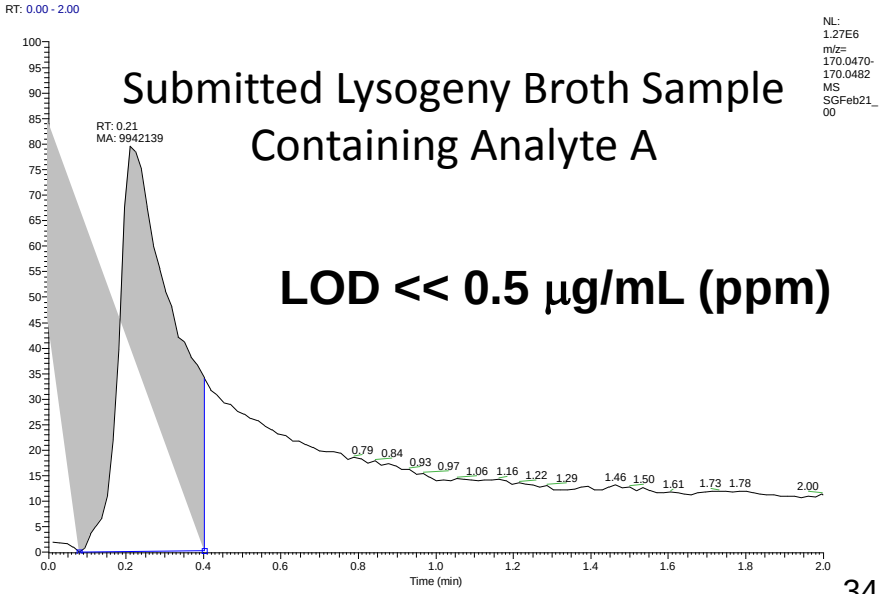
Trace-level screening of small molecule in complex bacteria culture and lysogeny broth media

- **Direct high-resolution FI-MS analysis**



- **Instrument: Thermo Orbitrap Exactive**
- **Qualitative screening**
- **Method fully implemented**
- **Accurate mass range = 0.0012 m/z units = 1.2 mDa**





LOD << 0.5 μg/mL (ppm)

Michael Gagnon, unpublished

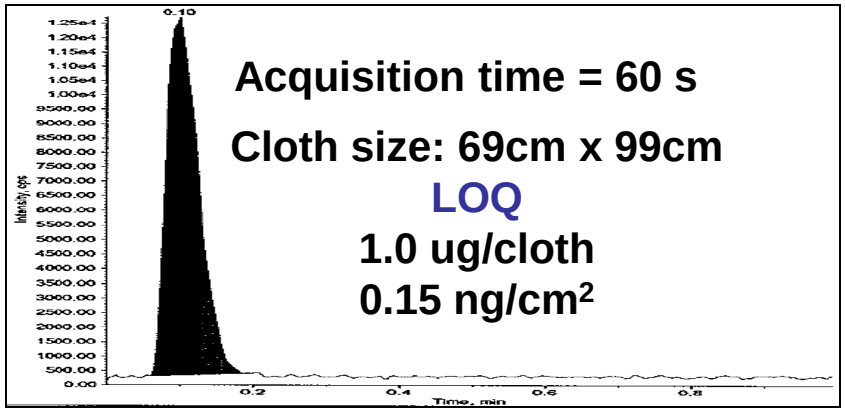
ABC Laboratories
Columbia, Missouri, U.S.A.

Method by Lisa Swaim

APPLICATION: Agrochemical R&D

Turf Transferable Residue Study for Experimental Fungicide

1. **Cotton fabric extracted with methanol**
2. **Direct FI/MS/MS analysis of extract**



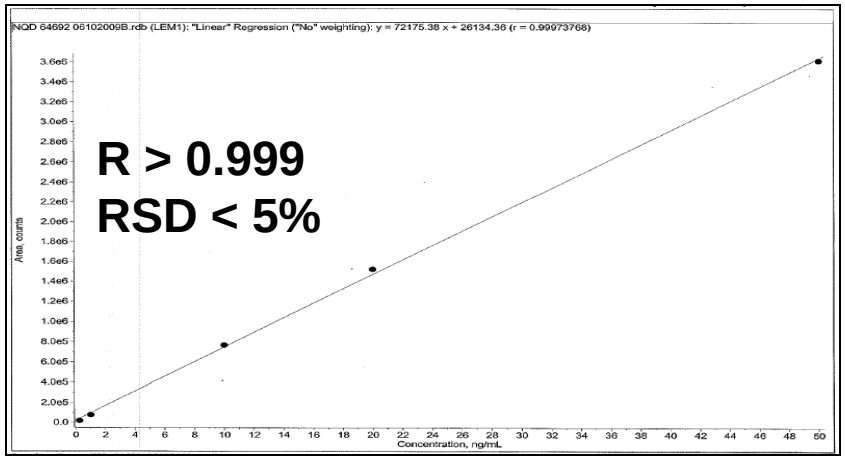
Acquisition time = 60 s

Cloth size: 69cm x 99cm

LOQ

1.0 ug/cloth

0.15 ng/cm²



R > 0.999

RSD < 5%

AB/Sciex API-5000 QqQ MS Method Validation Results

Avg Recovery LOQ = 109%

Avg Recovery Overall = 106%

Minimum = 100%

Maximum = 113%

RSD = 4.3%

15 samples, single analysis

Cotton Fabric Samples from the Field

> 300 samples analyzed

Field fortifications avg rec = 99% ± 5%

Lisa Swaim, S.C. Nanita, unpublished

FED-FI-MS Summary

Advantages

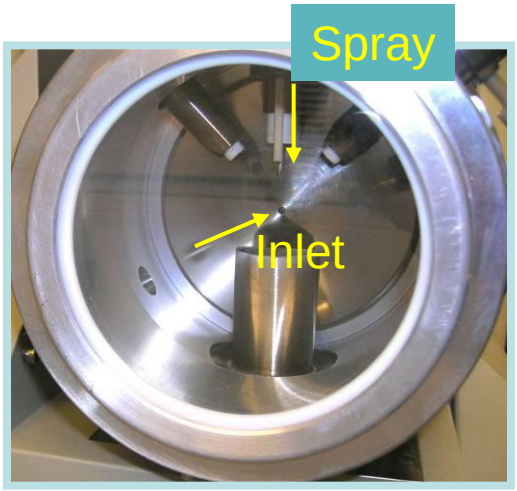
Increased throughput
- 15 s data acquisition time.

Less solvent
- ~ 0.4 L/1000 sample injections.
- No liquid waste.

Simpler methods
- Eliminates the need for columns, and other HPLC components.

Requirements

- Matrix-matched standards
- Highly-sensitive and rugged MS instrument
- **Highly-selective fragmentation**
- Avoid non-volatile salts like those containing Na^+, K^+



Matrices successfully tested thus far:

"SPE-FI-MS"
Anal. Chem. **2009,** 81, 3134
- **Corn grain**
- **Water (LOQ = 0.1 μg/L)**
- **Lemon**
- **Pecan**

"Dilute & Shoot"
JAFC **2011,** in press
- **Soybean oil**
- **Corn meal**
- **Lemon**
- **Pecan**

"NH_4Cl Salting Out"
Unpublished
- **Plasma**
- **Urine**
- **Milk**
- **Eggs**

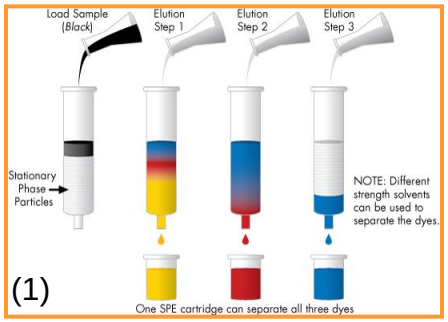
LOQ 10 ppb?

"Customized FI-MS methods"
Unpublished
- **Bacteria culture**
- **Industrial waste**
- **Cotton fabric**

Evolution of Trace-Level (ppb) Quantitative Multiresidue Analysis

Liquid-Liquid Extractions

SPE



QuEChERS d-SPE

"Dilute & Shoot"

Larger → **Smaller**

1950's – 1980s | **1980s – 2000s** | **2010 →**

GC/FID GC/MS LC/UV | **LC/MS** | **FI-MS**

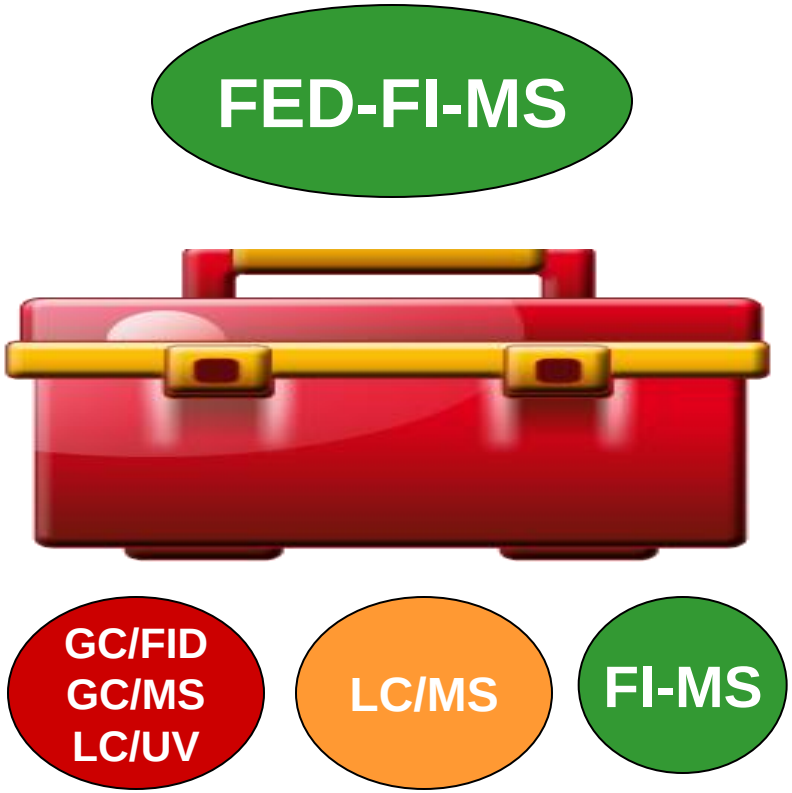
Slower → **Faster**

(1) www.waters.com (2) www.restek.com

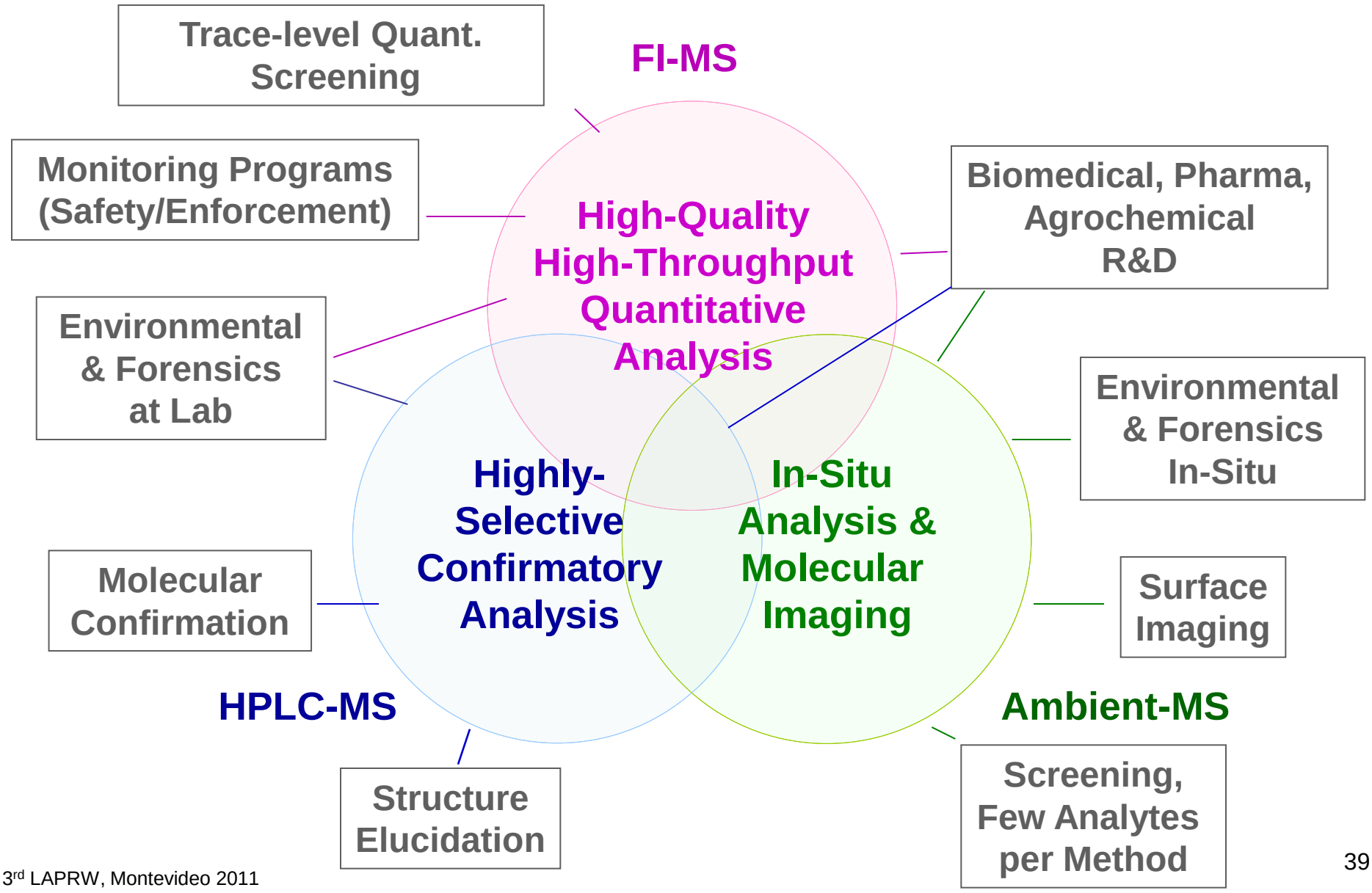
Analytical Toolbox Today

All technologies are available and useful!

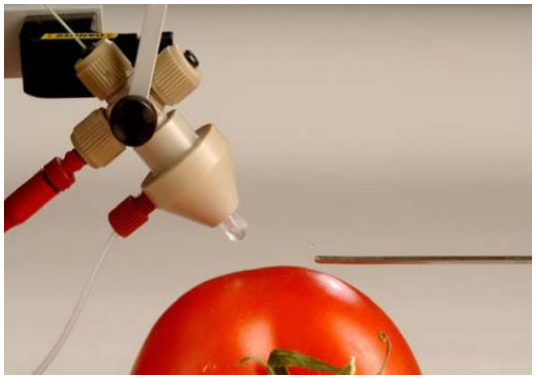
Our research focus:
High-throughput, efficient, green methods

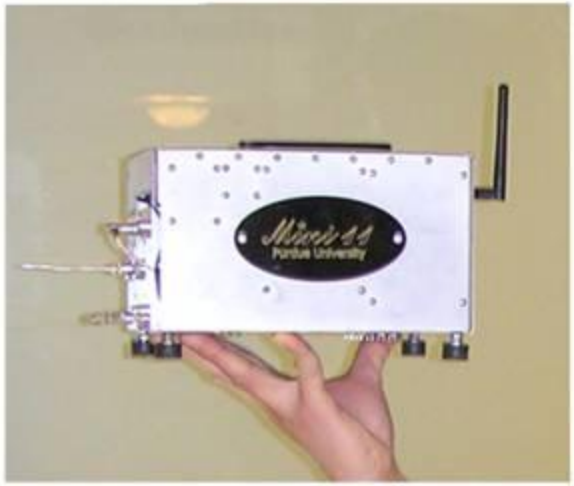


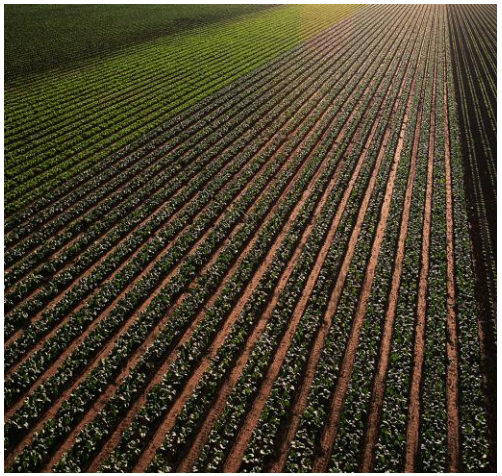
Applications of Sample Introduction Technology in MS: Sergio Nanita's Perspective 2011-2020



The Future of Pesticide Residue Analysis…







Ambient ionization + **Portable MS** = **In-situ analysis!**

- **DESI**
- **Paper Spray Ioniz.**
- **Many other methods**

- **4 kilograms**
- **Battery operated**

- **Pre-harvest**
- **At supermarket**
- **At home?**

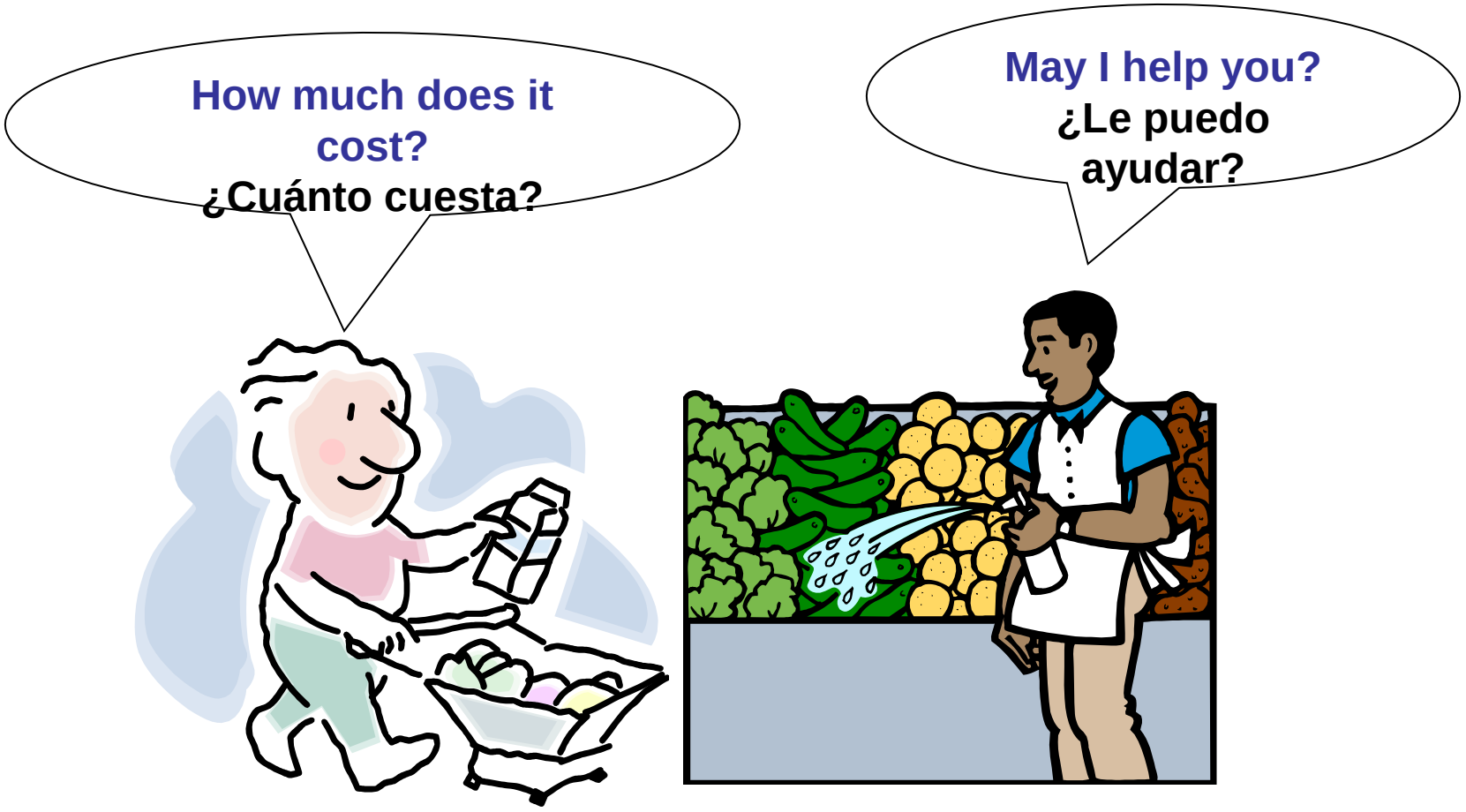
- **Not science fiction anymore**
- **Many academic research groups engineering miniature MS instruments**
- **Highlighted in this slide – work of Prof. R. Graham Cooks' group, Purdue Univ.**

http://aston.chem.purdue.edu

R.G. Cooks et al. *Faraday Discussions* , **2011** , 149, 247 -267

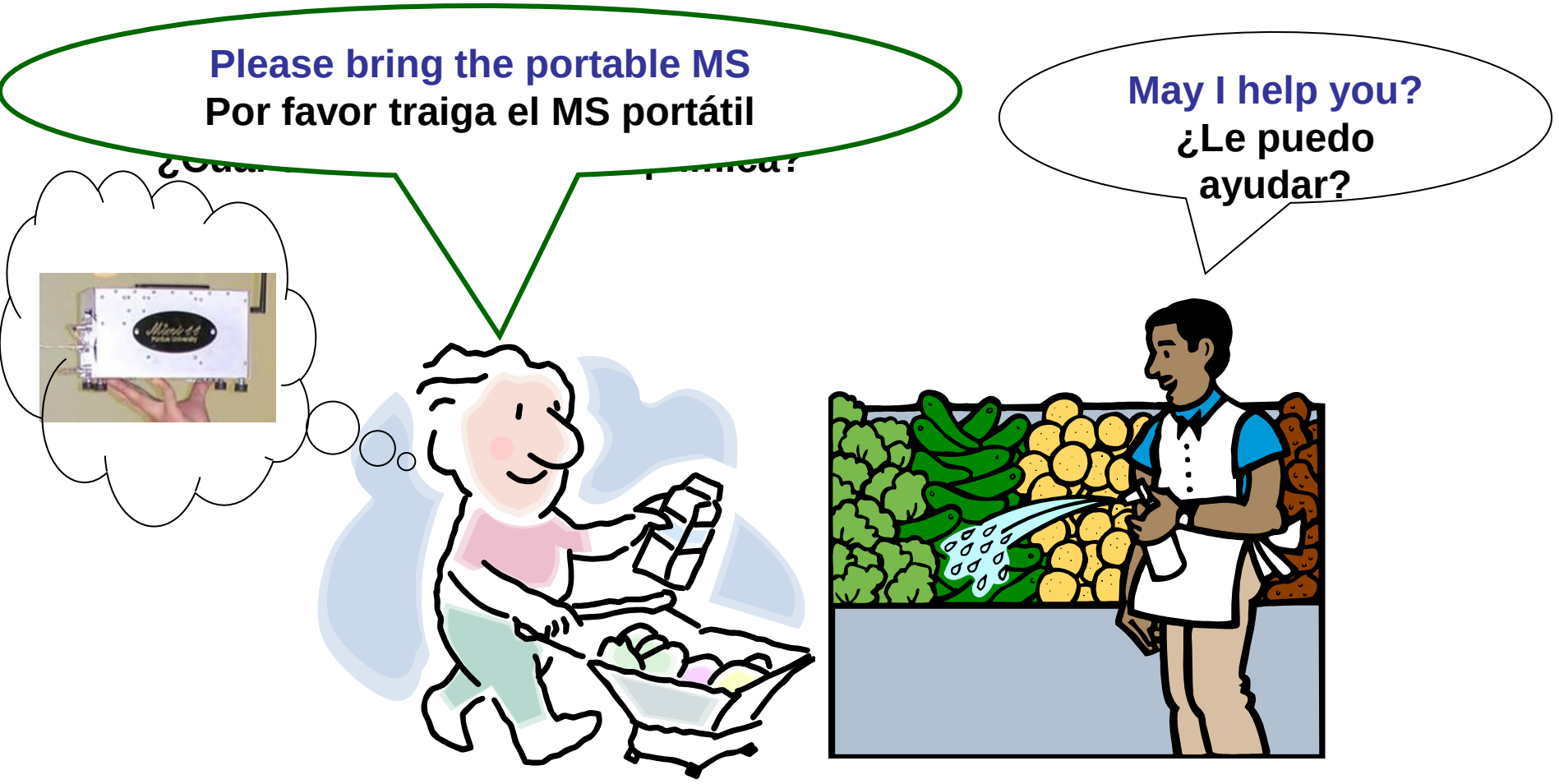
Conversation at the supermarket today

Conversación en el supermercado de hoy



Conversation at the supermarket of the future

Conversación en el supermercado del futuro



Acknowledgements

FED-FI-MS Research Collaborators

DuPont Stine-Haskell Research Center (Core Team)

Anne Pentz
Joseph McClory
James Stry
John May

DuPont Chambers Works

Amber Wellman

DuPont Experimental Station

Michael Gagnon

ABC Laboratories

Lisa Swaim
Bob Plastridge
Del Koch
Clark Chickering
Emily Vogl

DuPont Management Sponsors

Teri Gray (2009-2010)
Peter Stchur (2010-present)

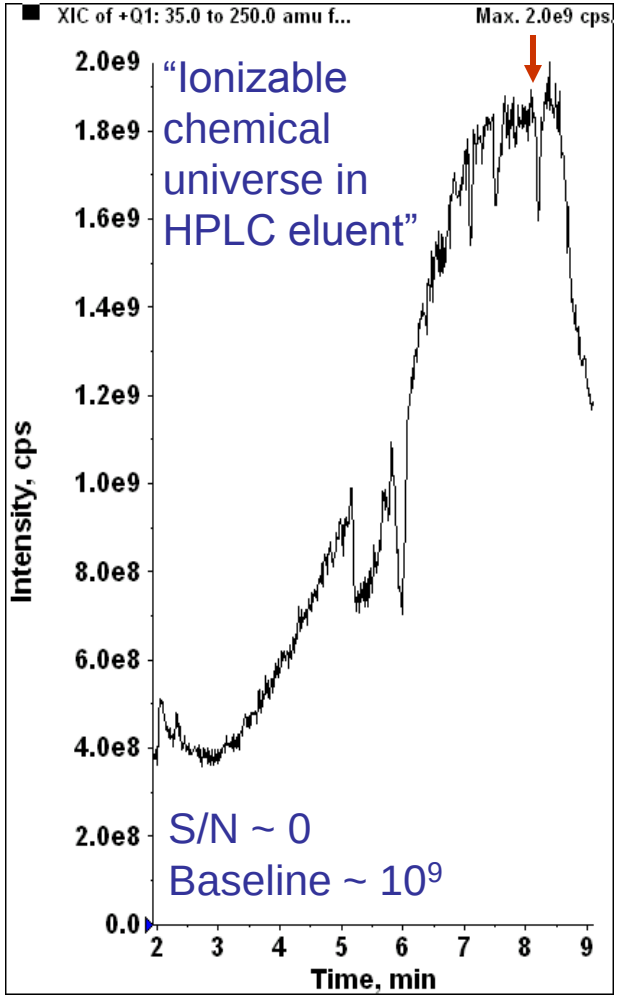
The miracles of science

Los milagros de la ciencia

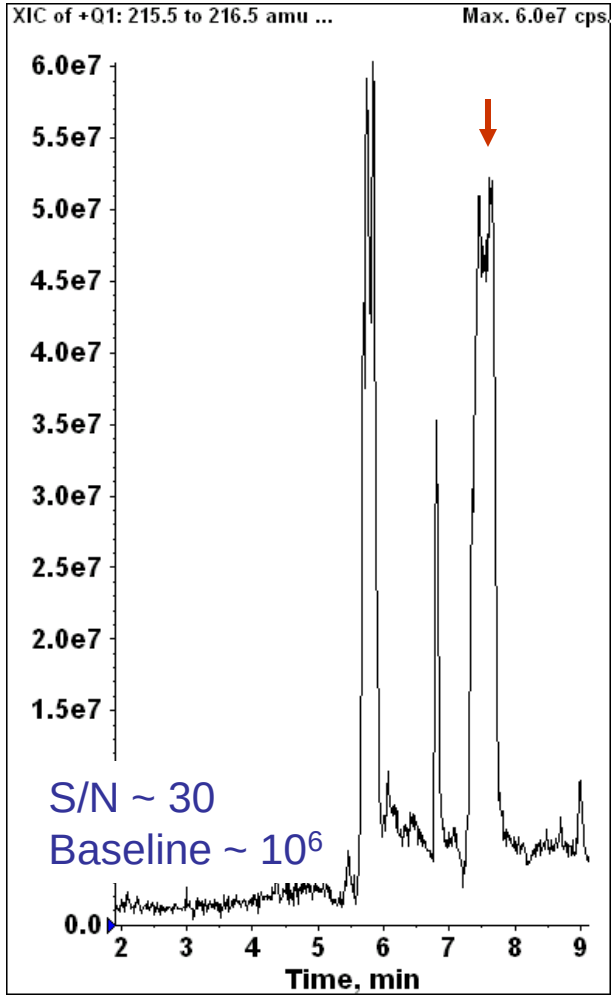
EXTRA SLIDES

Selectivity for Quantitative Analysis

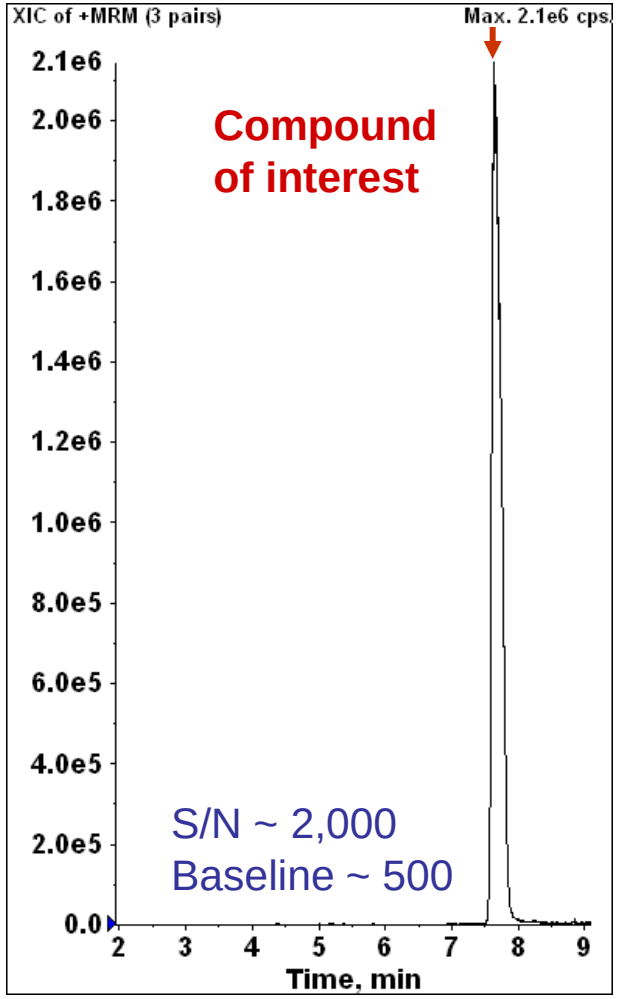
Mass Spectrum (Full MS Mode)



Single m/z Data (SIM Mode)



Single Fragment Data (MS/MS Mode)



S.C. Nanita, unpublished

FED-FI-MS Blind Test

Sample Name	Analyte Peak Name	Calculated Concentration (ng/mL)	Analyte Added (mg/kg)	Analyte Reported (mg/kg)	Accuracy: Passed, Failed, or Percent %
Pecan #10	Triflusulfuron methyl	24.3	**1.200**	**1.22**	**102**
Pecan #10	Azimsulfuron	No Peak	**n.a**	**< LOD**	**Passed**
Pecan #10	Chlorimuron ethyl	0.947	**0.065**	**0.047**	**72**
Pecan #10	Flupyrsulfuron methyl	26.9	**1.500**	**1.35**	**90**
Pecan #10	Sulfometuron methyl	No Peak	**n.a**	**< LOD**	**Passed**
Pecan #10	Chlorsulfuron	No Peak	**n.a**	**< LOD**	**Passed**
Pecan #10	Aminocyclopyrachlor	8.76	**0.600**	**0.44**	**73**
Pecan #10	Aminocyclopyrachlor methyl	1.48	**0.080**	**0.074**	**93**
Pecan #10	Methomyl	1.74	**0.080**	**0.087**	**109**
Pecan #10	Oxamyl	No Peak	**n.a**	**< LOD**	**Passed**
Pecan #10	Cyantraniliprole	No Peak	**n.a**	**< LOD**	**Passed**
Pecan #10	Chlorantraniliprole	No Peak	**n.a**	**< LOD**	**Passed**

n.a. = Analyte not added

LOQ = 0.05 mg/kg
LOD ~ 0.02 mg/kg

Summary Results for 20 Samples (Lemon & Pecan)

FED-FI-MS passed for all 12 analytes

- Zero false positive
- Zero false negative
- 240 accurate results (20 samples x 12 analytes)
- Average accuracy for all compounds detected = 88%

Nanita, Stry, et al. J. Agric Food Chem. **2011**, in press.

Matrix Effects in FED-FI-MS

Table 4. Matrix Effects as a Function of Dilution Factors in the FED-FI-MS Method

dilution factor[b]	matrix equivalent[c] (mg/mL)	relative response[a] (%) triflusulfuron methyl	azimsulfuron	chlorimuron ethyl	sulfometuron methyl	chlorsulfuron	flupyrsulfuron methyl	aminocyclo-pyrachlor	aminocyclo-pyrachlor methyl	methomyl	oxamyl	cyantrani-liprole	chlorantrani-liprole
						Lemon Matrix							
2000	0.1	87	92	89	88	80	91	93	145	191	119	79	85
1000	0.2	94	101	90	87	86	101	110	156	305	163	83	85
200	1.0	71	90	78	61	70	72	106	151	290	93	49	54
100	2.0	73	95	81	69	80	77	112	167	344	109	44	52
20	10	37	56	45	36	45	39	61	91	186	65	22	23
10	20	20	34	24	20	29	21	35	53	117	33	10	14
						Pecan Matrix							
10000	0.1	96	103	99	92	98	98	108	98	128	135	84	93
5000	0.2	103	107	107	96	101	73	97	105	131	128	85	98
1000	1.0	91	91	89	84	83	55	101	119	117	123	58	80
500	2.0	76	88	72	71	77	48	104	112	156	118	45	63
100	10	43	59	48	43	47	52	88	75	108	95	18	25
50	20	40	55	40	40	46	38	86	69	98	81	12	20
						Corn Meal Matrix							
10000	0.1	104	102	113	103	98	78	110	88	85	82	96	101
5000	0.2	97	95	111	97	95	67	103	76	87	68	89	95
1000	1.0	80	81	90	78	83	60	91	86	112	62	72	82
500	2.0	73	78	79	70	71	53	86	87	148	65	63	66
100	10	44	59	52	43	56	51	91	75	150	50	33	35
50	20	36	49	44	36	44	37	70	73	161	41	27	28
						Soybean Oil Matrix							
10000	0.1	106	96	101	107	95	82	85	96	101	97	89	96
5000	0.2	104	101	108	97	95	89	80	102	108	91	84	98
1000	1.0	134	118	124	122	103	63	87	132	148	122	86	111
500	2.0	117	97	107	113	92	61	77	141	148	124	70	88
100	10	110	82	86	126	73	85	60	95	122	155	48	59
50	20	91	69	67	120	58	82	52	99	132	149	37	46

[a] Results expressed relative to the response obtained for a neat standard; bold text = 80−120% (matrix effect not significant); results <80% show significant matrix suppression; results >120% show significant matrix enhancement. [b] Dilution factor applied to the original extract prior to analysis. [c] Matrix equivalent is a measurement of how much matrix is contained in the injected sample, here defined as ME = (SW/EV) ÷ DF, where ME = matrix equivalent (mg/mL), SW = sample weight (mg), EV = extract volume (mL), and DF = dilution factor prior to injection.

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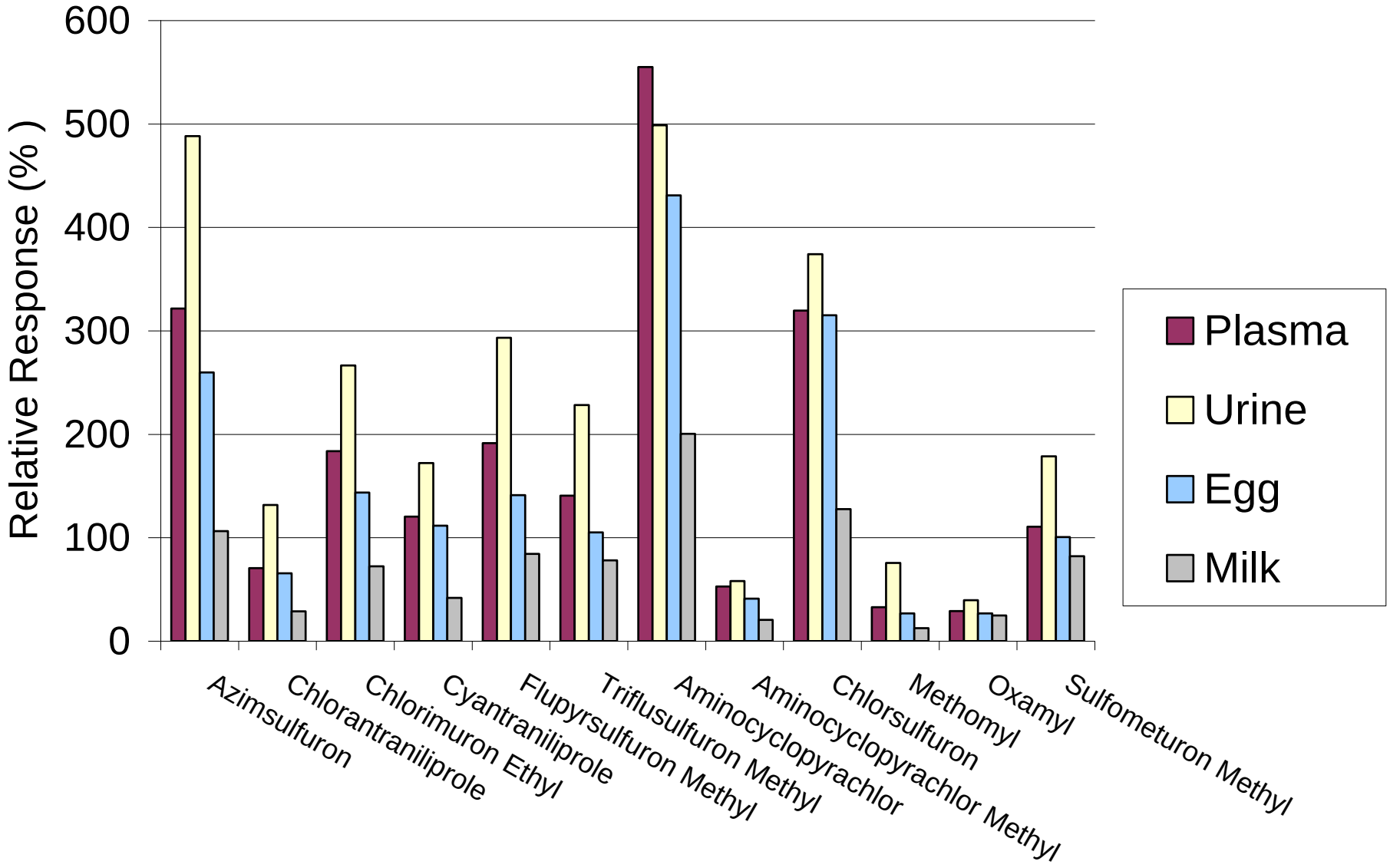
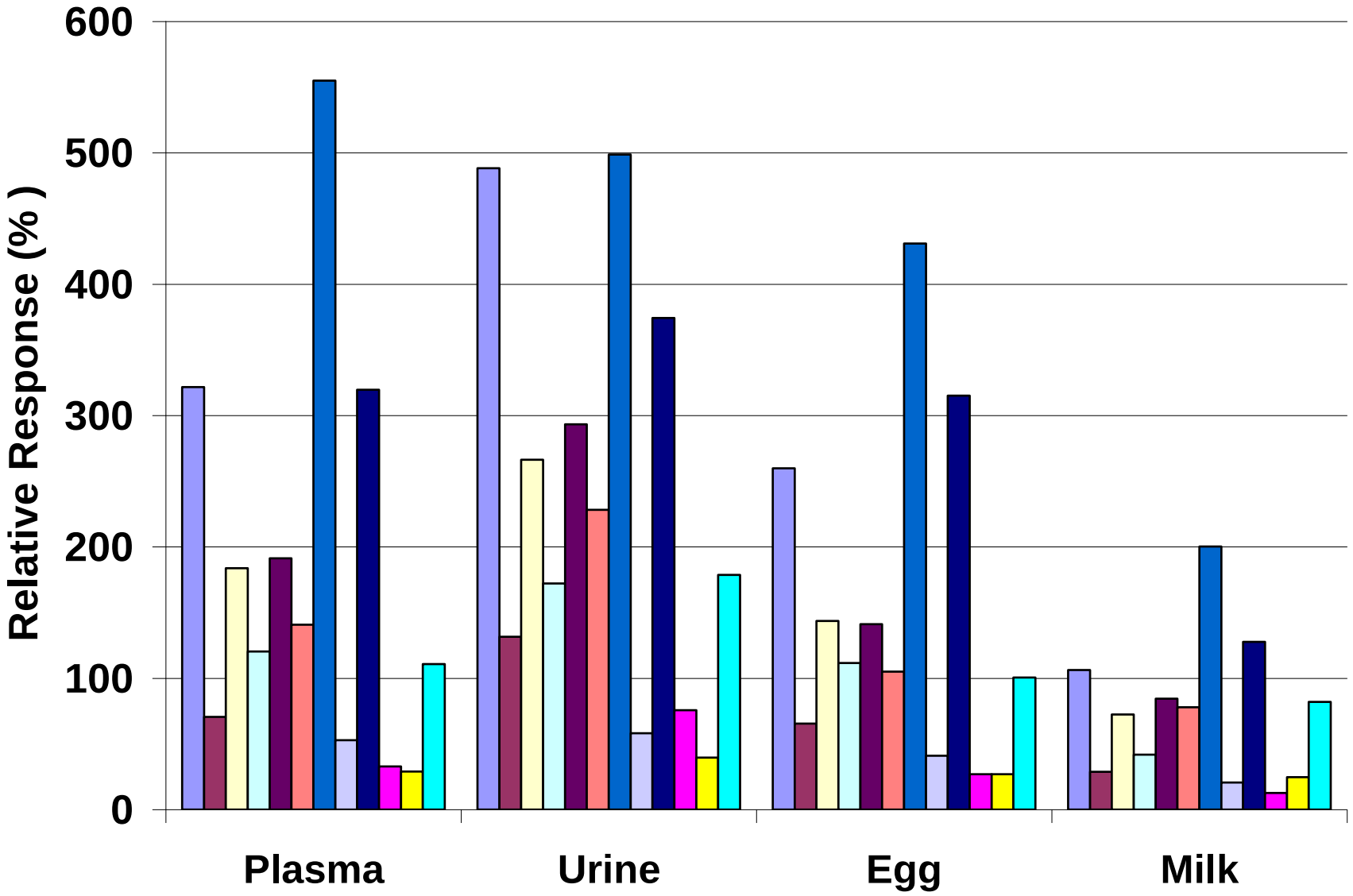
Standards in Matrix Response as Percent (%) of Response of Standards in ACN Phase from Neat Solvent NH4Cl Salt Out



Standards in Matrix Response as Percent (%) of Response of Standards in ACN Phase from Neat Solvent NH4Cl Salt Out



SPE-FI-MS: Method Validated for Corn, Lemon, Pecan, and Water

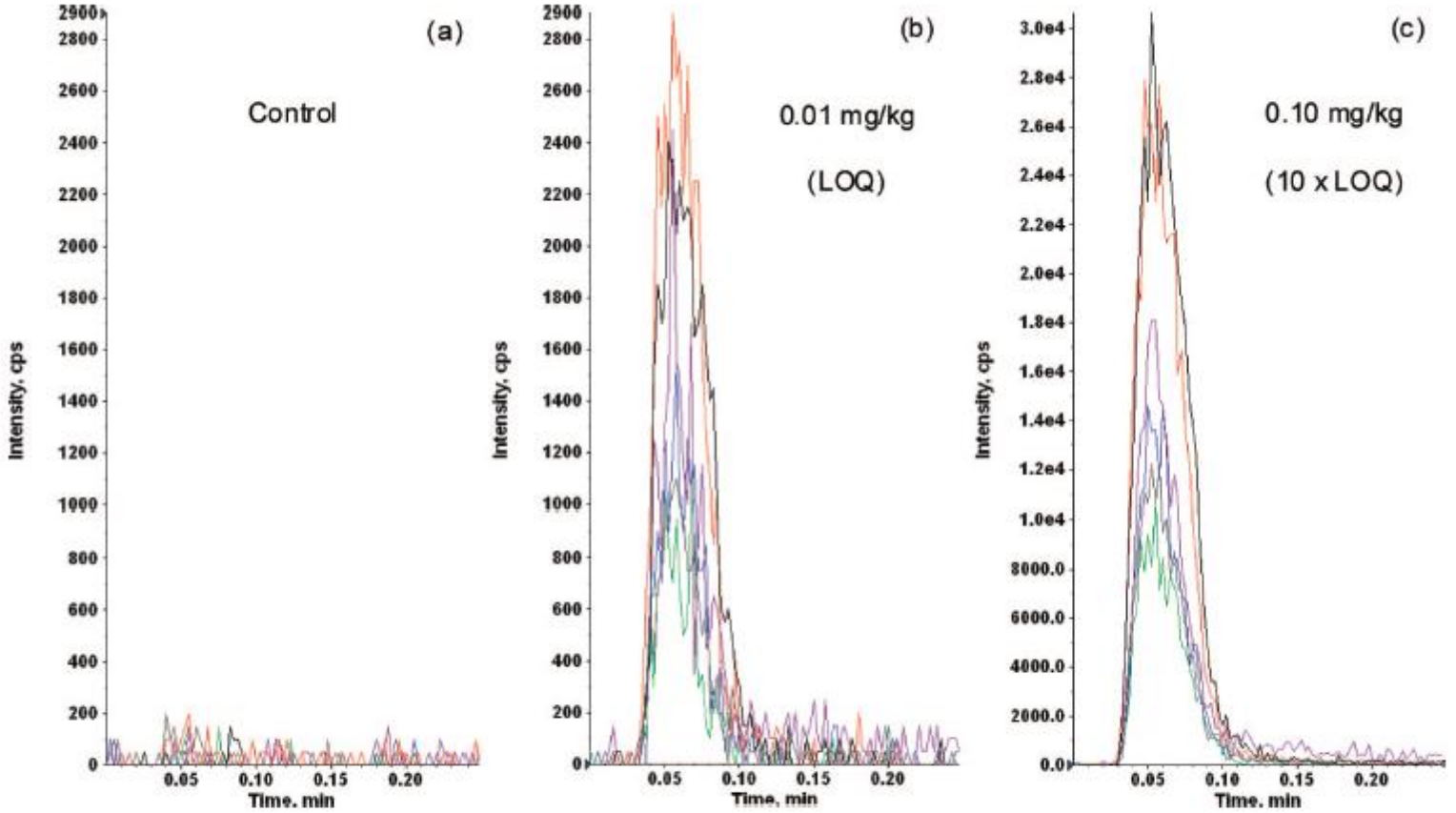


Figure 5. Multianalyte flow injection MS/MS ion chronograms[36] obtained for corn samples during method validation: (a) control, (b) 0.01 mg/kg fortification, and (c) 0.10 mg/kg fortification. The relative response observed for the analytes was as follows: sulfometuron-methyl ≈ triflusulfuron-methyl > methomyl > rimsulfuron > oxamyl > flupyrsulfuron.

Nanita, Pentz, Bramble. *Anal. Chem.* **2009**, 81, 3134