Analysis of Environmental Samples, Routine or Specialized Using the Agilent QQQ-ICPMS

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ICP-MS, ICP-MS/MS

Agilent
Trusted Answers

Most Compact Instruments on the Market

Agilent 7800

Agilent 7900

Agilent 8800

Agilent 8900

Some of the Benefits of Single Quad ICP-MS

- Multi-elemental technique
- High sensitivity, ppq/ppt for most elements
- Short analysis time (~ 3 min to <60sec)
- Extremely linear with wide dynamic range
- Minimum number of interferences
- High Productivity

Most Important Performance Consideration for Environmental Analysis

- Sensitivity
- Interference Removal
- Matrix Tolerance
- Linear Dynamic Range

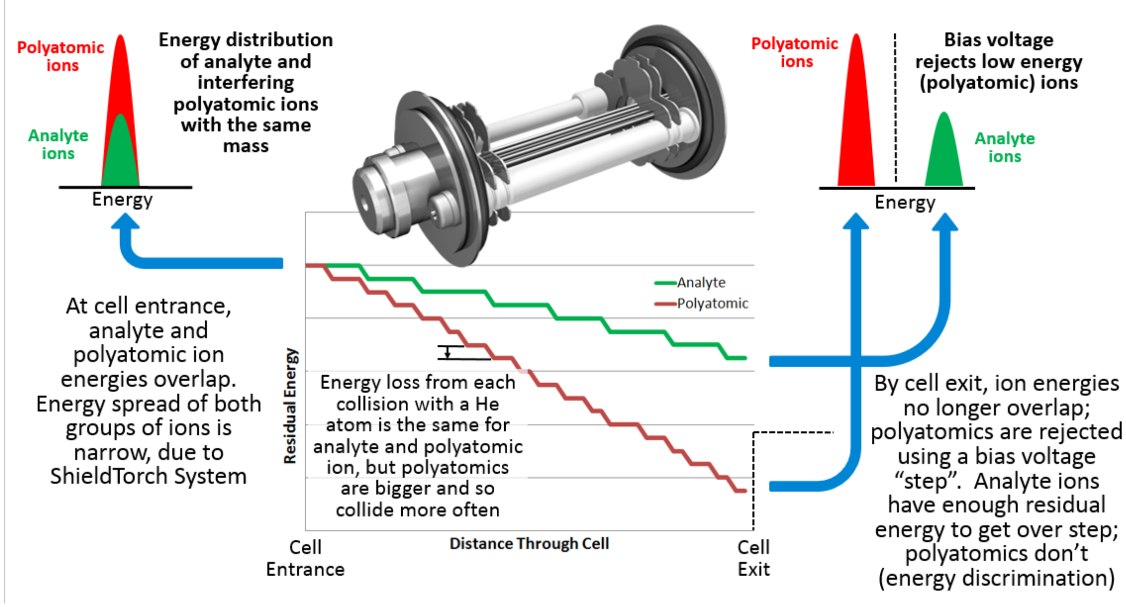
The QQQ-ICPMS allows for Interference Removal in more specialized applications

Interference removal; Transitioning from ICP-SQMS to ICP-MSMS

- Modes of Interference Removal:
  - Collision Mode

He Gas

Kinetic Energy Discrimination



Isotope	Principal Interfering Species (mixed matrix)
^{45}Sc	$^{13}C^{16}O_2$, $^{12}C^{16}O_2H$, ^{44}CaH, $^{32}S^{12}CH$, $^{32}S^{13}C$, $^{33}S^{12}C$
^{47}Ti	$^{31}P^{16}O$, ^{46}CaH, $^{35}Cl^{12}C$, $^{32}S^{14}NH$, $^{33}S^{14}N$
^{49}Ti	$^{31}P^{18}O$, ^{48}CaH, $^{35}Cl^{14}N$, $^{37}Cl^{12}C$, $^{32}S^{16}OH$, $^{33}S^{16}O$
^{50}Ti	$^{34}S^{16}O$, $^{32}S^{18}O$, $^{35}Cl^{14}NH$, $^{37}Cl^{12}CH$
^{51}V	$^{35}Cl^{16}O$, $^{37}Cl^{14}N$, $^{34}S^{16}OH$
^{52}Cr	$^{36}Ar^{16}O$, $^{40}Ar^{12}C$, $^{35}Cl^{16}OH$, $^{37}Cl^{14}NH$, $^{34}S^{18}O$
^{53}Cr	$^{36}Ar^{16}OH$, $^{40}Ar^{13}C$, $^{37}Cl^{16}O$, $^{35}Cl^{18}O$, $^{40}Ar^{12}CH$
^{54}Fe	$^{40}Ar^{14}N$, $^{40}Ca^{14}N$, $^{23}Na^{31}P$
^{55}Mn	$^{37}Cl^{18}O$, $^{23}Na^{32}S$, $^{23}Na^{31}PH$
^{56}Fe	$^{40}Ar^{16}O$, $^{40}Ca^{16}O$
^{57}Fe	$^{40}Ar^{16}OH$, $^{40}Ca^{16}OH$
^{58}Ni	$^{40}Ar^{18}O$, $^{40}Ca^{18}O$, $^{23}Na^{35}Cl$
^{59}Co	$^{40}Ar^{18}OH$, $^{43}Ca^{16}O$, $^{23}Na^{35}ClH$
^{60}Ni	$^{44}Ca^{16}O$, $^{23}Na^{37}Cl$
^{61}Ni	$^{44}Ca^{16}OH$, $^{38}Ar^{23}Na$, $^{23}Na^{37}ClH$
^{63}Cu	$^{40}Ar^{23}Na$, $^{12}C^{16}O^{35}Cl$, $^{12}C^{14}N^{37}Cl$, $^{31}P^{32}S$, $^{31}P^{16}O_2$
^{64}Zn	$^{32}S^{16}O_2$, $^{32}S_2$, $^{36}Ar^{12}C^{16}O$, $^{38}Ar^{12}C^{14}N$, $^{48}Ca^{16}O$
^{65}Cu	$^{32}S^{16}O_2H$, $^{32}S_2H$, $^{14}N^{16}O^{35}Cl$, $^{48}Ca^{16}OH$
^{66}Zn	$^{34}S^{16}O_2$, $^{32}S^{34}S$, $^{33}S_2$, $^{48}Ca^{18}O$
^{67}Zn	$^{32}S^{34}SH$, $^{33}S_2H$, $^{48}Ca^{18}OH$, $^{14}N^{16}O^{37}Cl$, $^{16}O_2{}^{35}Cl$
^{68}Zn	$^{32}S^{18}O_2$, $^{34}S_2$
^{69}Ga	$^{32}S^{18}O_2H$, $^{34}S_2H$, $^{16}O_2{}^{37}Cl$
^{70}Zn	$^{34}S^{18}O_2$, $^{35}Cl_2$
^{71}Ga	$^{34}S^{18}O_2H$, $^{35}Cl_2H$, $^{40}Ar^{31}P$
^{72}Ge	$^{40}Ar^{32}S$, $^{35}Cl^{37}Cl$, $^{40}Ar^{16}O_2$
^{73}Ge	$^{40}Ar^{32}SH$, $^{40}Ar^{33}S$, $^{35}Cl^{37}ClH$, $^{40}Ar^{16}O_2H$
^{74}Ge	$^{40}Ar^{34}S$, $^{37}Cl_2$
^{75}As	$^{40}Ar^{34}SH$, $^{40}Ar\,^{35}Cl$, $^{40}Ca\,^{35}Cl$, $^{37}Cl_2H$
^{77}Se	$^{40}Ar\,^{37}Cl$, $^{40}Ca\,^{37}Cl$
^{78}Se	$^{40}Ar\,^{38}Ar$
^{80}Se	$^{40}Ar_2$, $^{40}Ca_2$, $^{40}Ar^{40}Ca$, $^{32}S_2\,^{16}O$, $^{32}S^{16}O_3$

- Modes of Interference Removal Continued: Typically yielding the lowest DL
  - Reaction Mode

$M^+ + H_2 \rightarrow M + H_2^+$

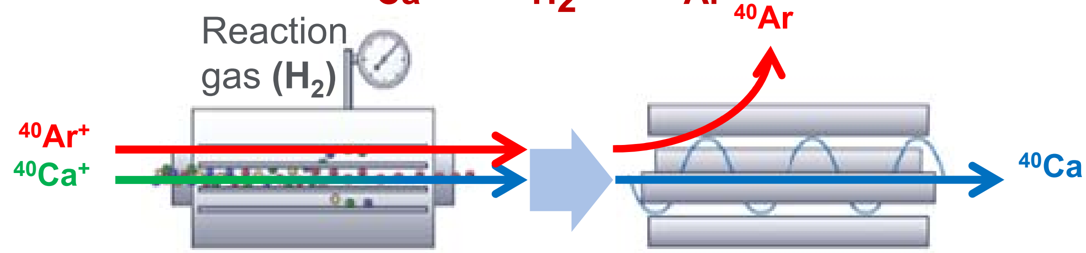
$M^+ + CH_4 \rightarrow M(CH_n)_x$

$M^+ + NH_3 \rightarrow M(NH_n)_x$

$M^+ + O_2 \rightarrow M(O)_x$

$^{40}Ca^+ + {}^{40}Ar^+ + H_2\,(g) \rightarrow {}^{40}Ca^+ + Ar + H_2^+$

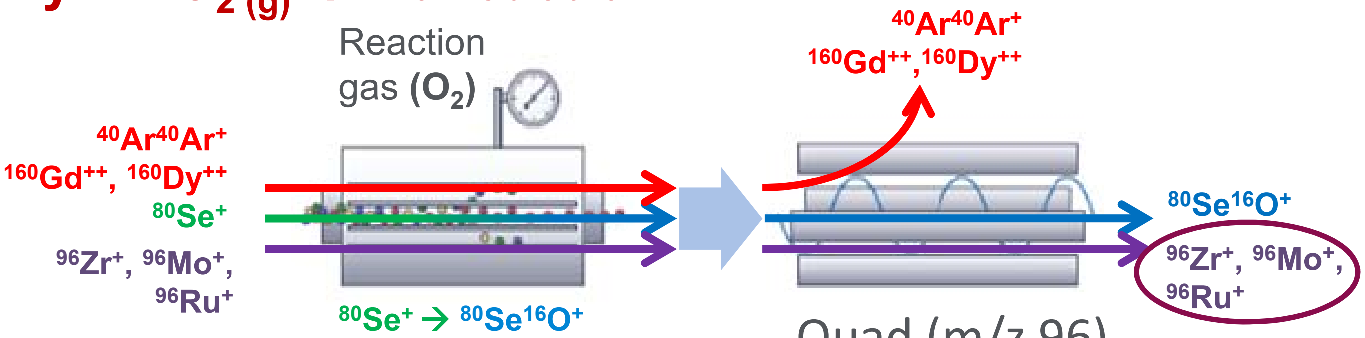
$IP_{Ca} < IP_{H_2} < IP_{Ar}$



Quad (m/z 40)

$^{80}Se^+ + O_{2\,(g)} \rightarrow {}^{80}Se^{16}O^+$ (*m/z* 96)

$^{40}Ar_2^+$, Gd^{++}, Dy^{++} + $O_{2\,(g)}$ → no reaction



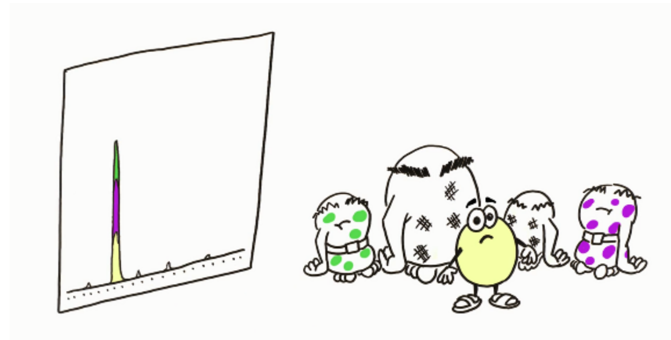
Quad (m/z 96)

No Q1 - all ions enter the cell

Allows through all ions at m/z 96

The Problem with Single Q ICP-MS (BPMS)

In quadrupole ICP-MS (ICP-QMS), the analyzer comes after the collision/ reaction cell (with or without bandpass). There is **no 1amu mass filter** before the cell, which means there is practically no control on which ions enter the cell.



No control of what comes out

Reaction chemistry can be used to separate analytes from **known**, on-mass **interferences**.

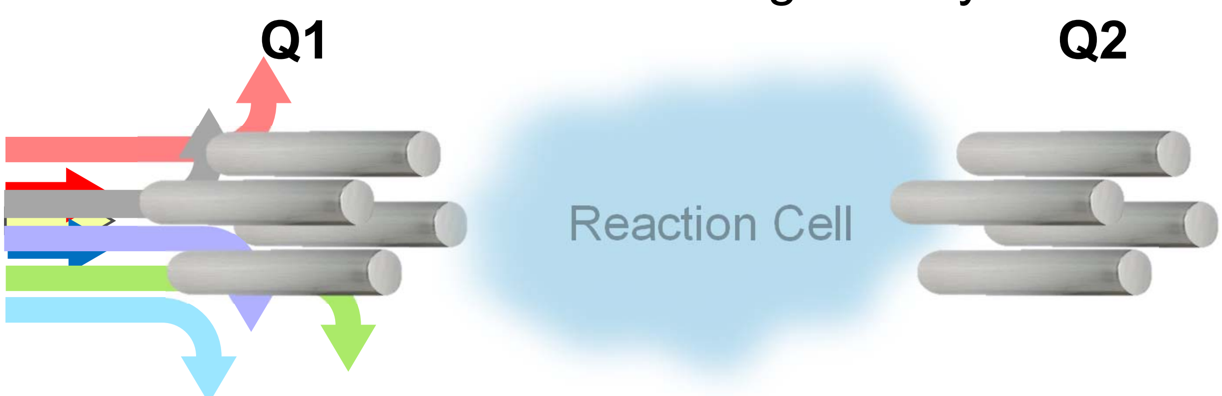
But **all other ions enter** the cell and can react to form new product ions

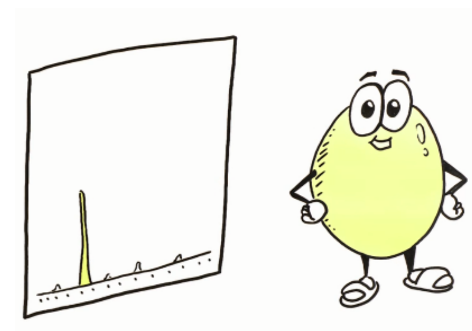
Many different ions and product ions can contribute to the measured signal, giving errors

The Answer: ICP-QQQ using **MS/MS Mode**

With Triple Quadrupole ICP-MS (ICP-QQQ) there is an additional mass filter **before** the reaction cell, controlling which ions enter and react in the cell

Q2 ensures that only the intended target analyte reaches the detector





Q1 rejects all masses except target ion *m/z*.

ONLY the target analyte and on-mass interferences enter the cell.

Interferences are removed by reaction chemistry

It is beyond doubt what will come out.

Only the target analyte ions can contribute to the measured signal

ICP-MSMS; Unsurpassed Interference Removal Capabilities

Plasma-source mass spectrometer
- High ionization efficiency

Full-size quad before reaction cell
- Unit mass resolution (MS/MS)

Octopole Reaction System (ORS)
- High transmission efficiency cell

5-stage vacuum system

Full-size quad after reaction cell

High speed 11-order detector
- Wide dynamic range
- Fast acquisition for nano

Operational Modes

Single Quad	• Q1 opens allowing all ions into ORS^3
Single Quad with Band Pass Filter	• Q1 allows a range of $^m/_z$ into ORS^3
MS/MS – On Mass	• Both Q1 and Q2 set to same mass
MS/MS – Mass Shift	• Q1 and Q2 set to different masses

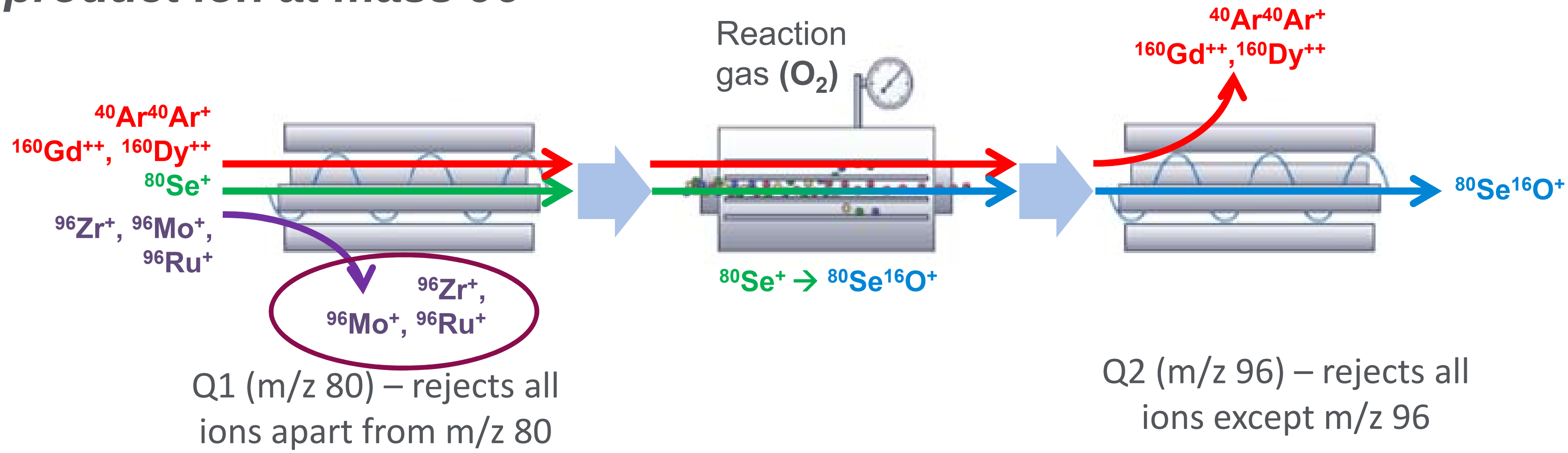
Example: Mass-Shift Mode by **ICP-MSMS**
Selenium Analysis by Mass-Shift with O_2 Reaction Gas

Same reaction with O_2 cell gas for Se on 8900 ICP-QQQ with MS/MS:

$^{80}Se^+ + O_{2\ (g)} \rightarrow {}^{80}Se^{16}O^+$ (*m/z* 96)

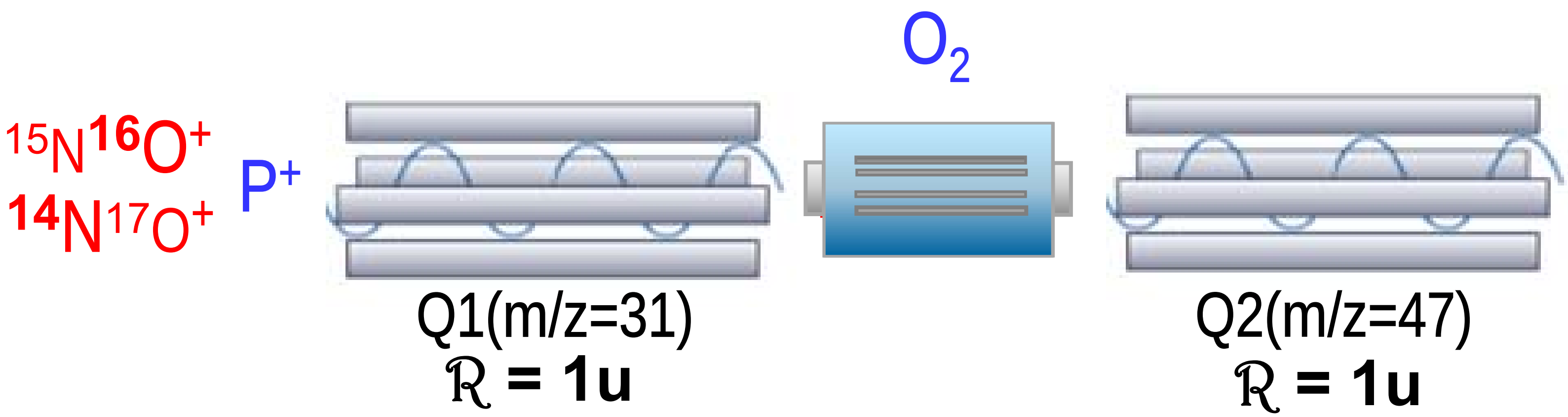
$^{40}Ar_2^+$, Gd^{++}, Dy^{++} + O_2 → no reaction

In MS/MS, Q1 rejects any ions (Zr^+, Mo^+, Ru^+) that could overlap SeO^+ product ion at mass 96



Allows measurement of SeO^+ at product ion mass, after removal of original Ar_2^+/REE^{++} interference, <u>and</u> existing ions at SeO^+ product ion mass

The Determination of 31P+ as P+O, Q1 @ 1u res

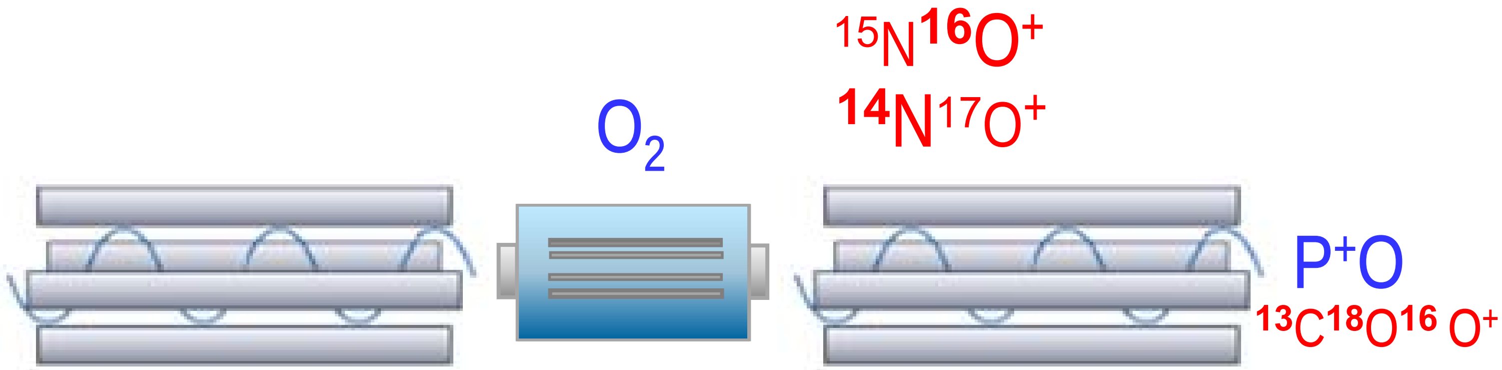


1s IT	31 -> 47 X [O2]		
Sample Name	Conc. [ppb]	CPS	3SD [ppb]
UPW	0.00	1,089	
2PPB P	2.14	7,395	
10PPB P	10.07	30,762	
25PPB P	24.96	74,679	
UPW LOD	0.01	1,109	0.03

30ppt LOD

Contamination?

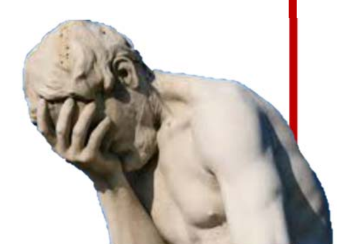
Accuracy of P+O Analysis with Q1 @ 1u and 2u Resolution



Q1(m/z=31) Q1(m/z=30-32)
ℛ = 1u ℛ = 2u

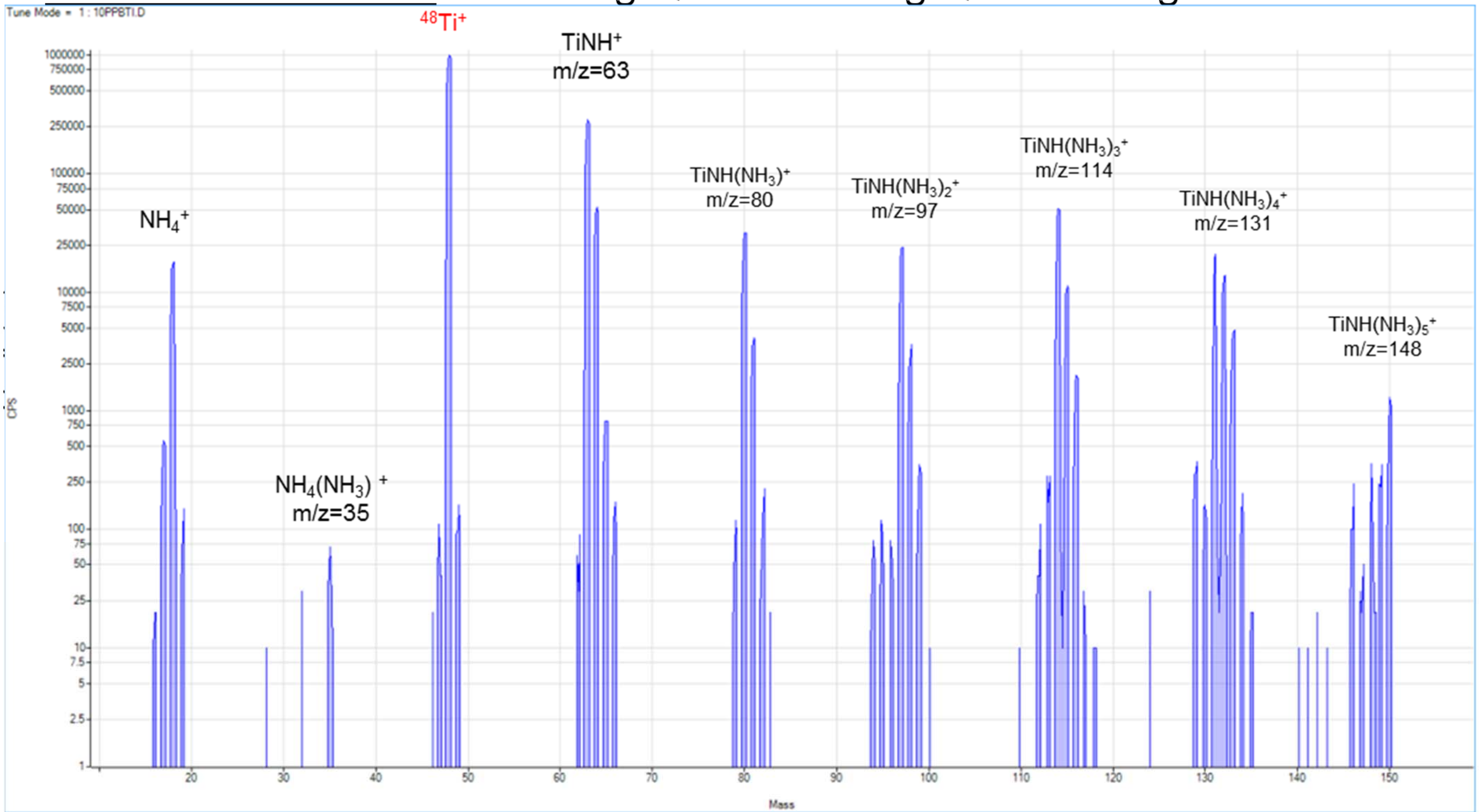
Q2(m/z=47)
ℛ = 1u

1s IT	1s IT	31 -> 47 X [O2]		
Sample Name	Sample Name	Conc. [ppb]	CPS	3SD [ppb]
UPW	UPW	0.00	1,089	
2PPB P	2PPB P	2.14	7,395	
10PPB P	10PPB P	10.07	30,762	
25PPB P	25PPB P	24.96	74,679	
UPW LOD	UPW LOD	0.01	1,109	0.03
100PPM SI LOD	100PPM SI LOD	1.5	5,449	0.09
10% CH3COOH LOD	10% CH3COOH LOD	3.1	10,217	0.06

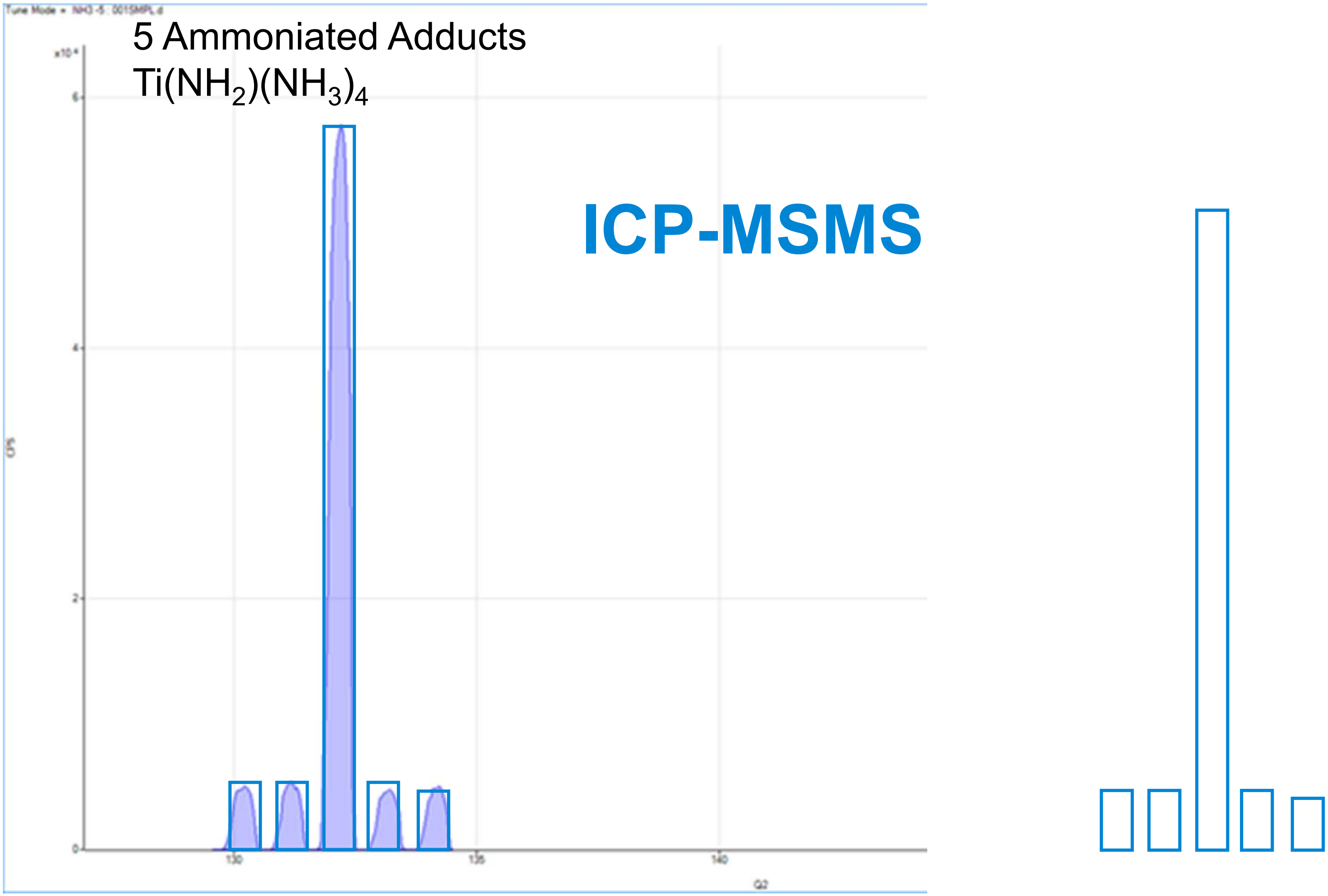


Ti Analysis; MSMS with Unit Mass Resolution

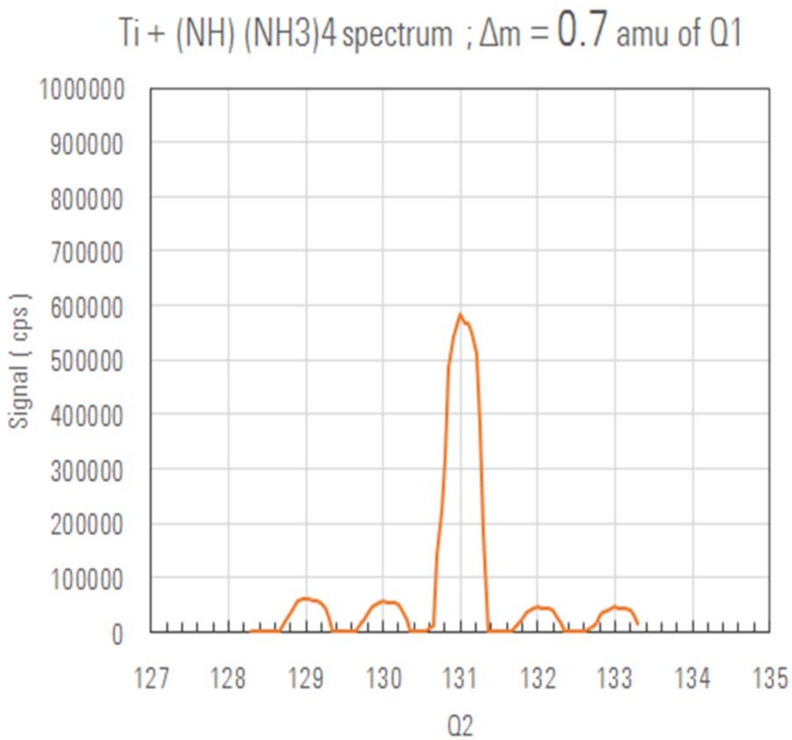
<u>Product Ion Scan</u>: Setting Q1 on a single mass and scanning Q2
<u>Precursor Ion Scan</u>: Scanning Q1 and setting Q2 on a single mass



Ti Analysis; ICP-MS Vs. ICP-MSMS



8900 – Ti analysis under MS/MS



MS/MS capability using fixed mass Q1/Q2 scanning (Neutral Gain Scan) shows true isotopic pattern under mass shift ammonia mode for Ti

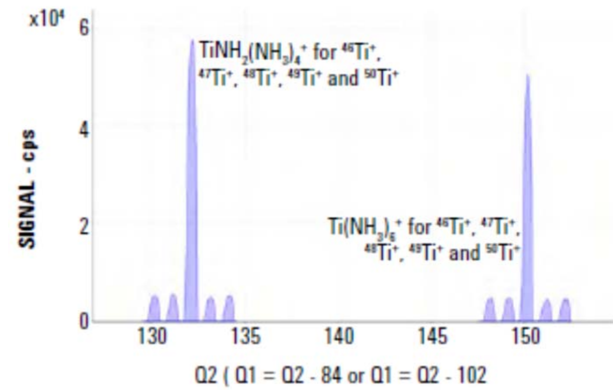
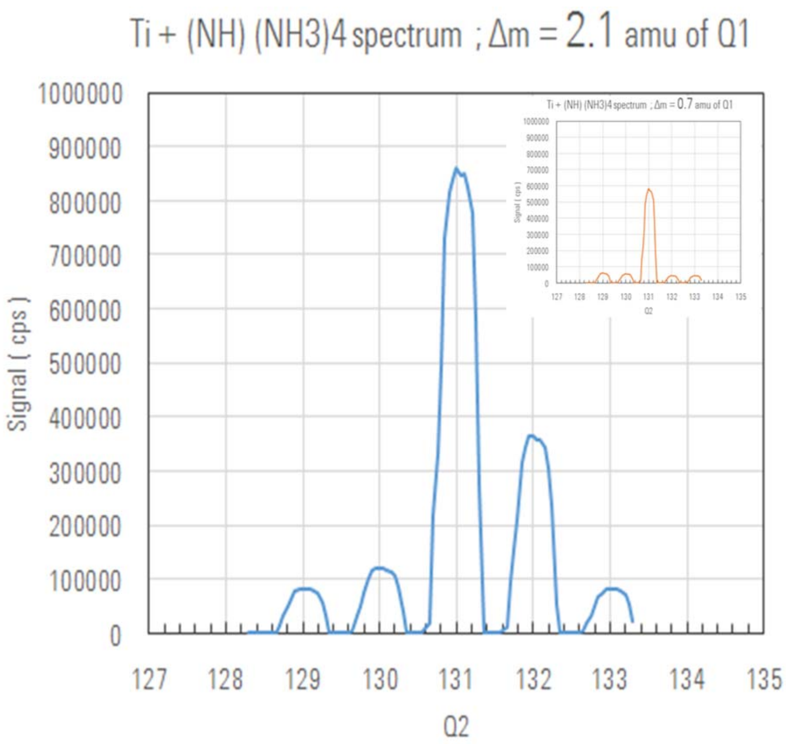


Figure 2. Neutral gain scan for two Ti → Ti cluster ion transitions: For $TiNH_2(NH_3)_4^+$ cluster ions, Q2 = Q1+ 84 amu, and for $Ti(NH_3)_6^+$ cluster ions, Q2 = Q1+102 amu. The preservation of the natural Ti isotope abundance pattern ($^{46}Ti^+$, $^{47}Ti^+$, $^{48}Ti^+$, $^{49}Ti^+$ and $^{50}Ti^+$) can be seen, confirming that MS/MS mode provides complete control over the complex $Ti\text{-}NH_3$ reaction chemistry.

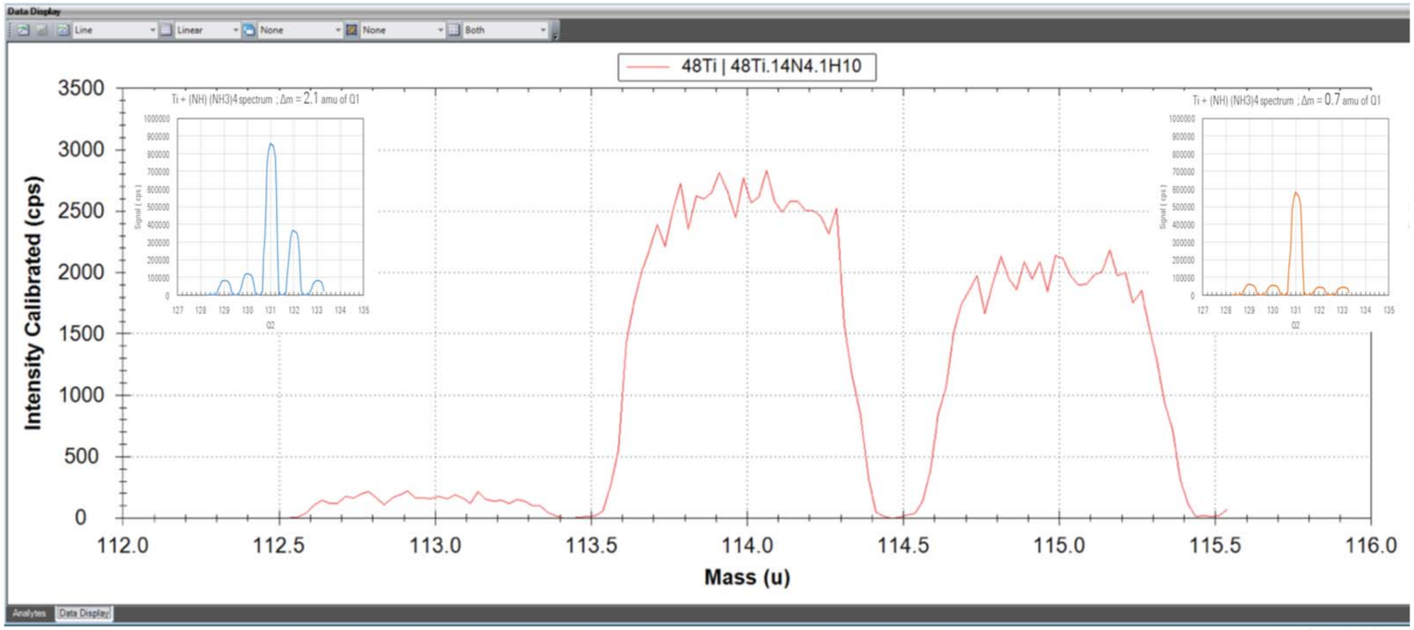
8900 – Ti analysis under Bandpass mode



When using restricted bandpass mode for Q1 (2.1amu window) the reaction is not as controlled and other reaction by-products are formed – isotopic information is not preserved as unwanted side-reactions can still occur

MS/MS is essential for precise reaction control

BP Ti Neutral Gain Scan

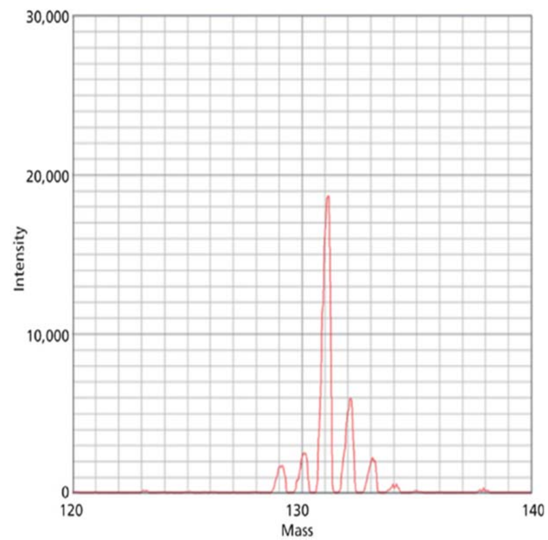


Limited isotope Neutral Gain Scan for Ti on TQ

The isotopic pattern does not fit the true, expected isotopic template

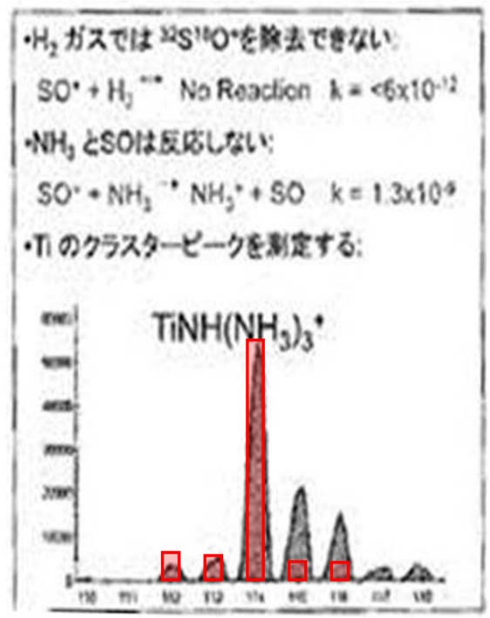
Similar to 8900 under bandpass mode

BPMS Ti Analysis



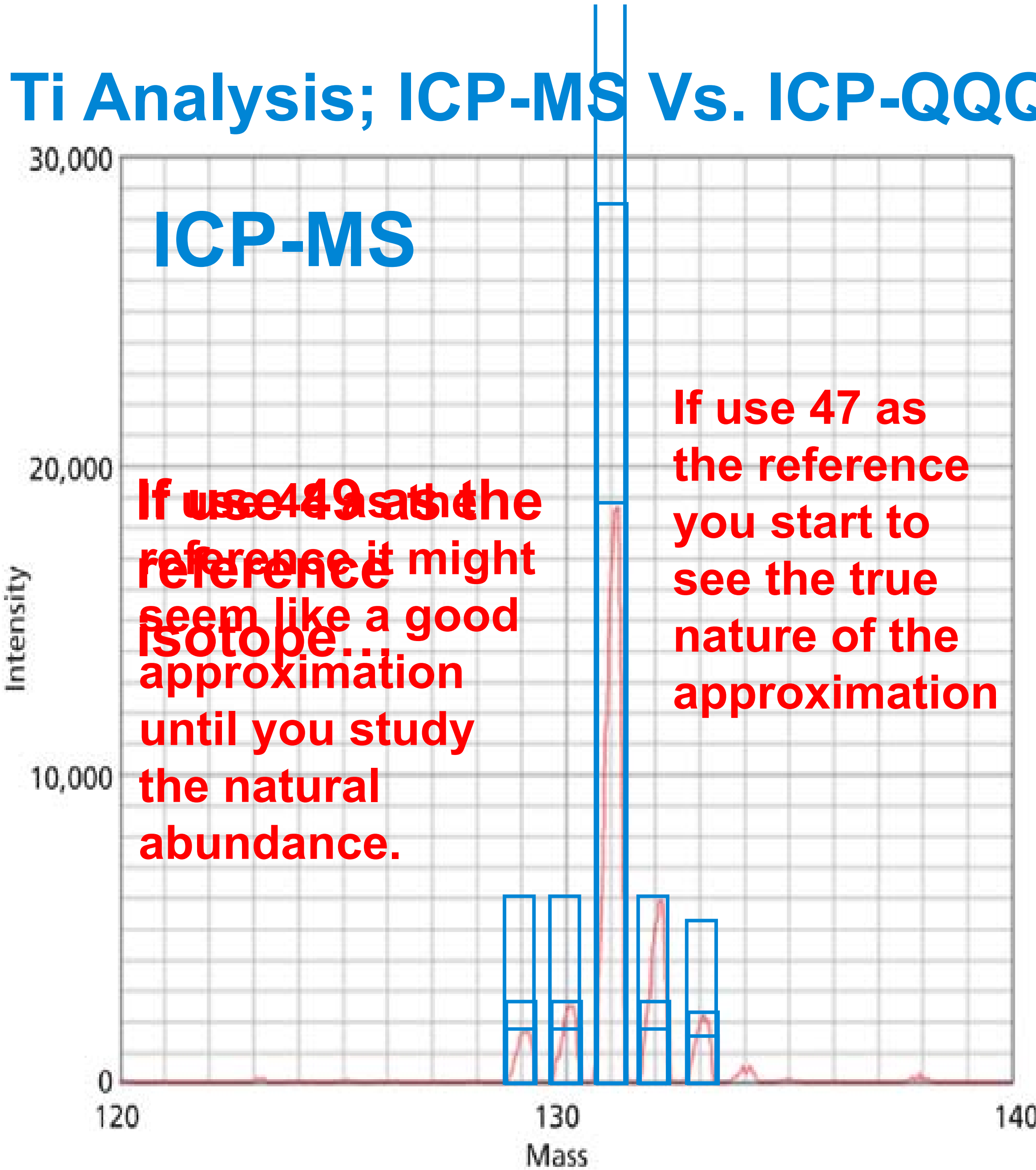
"It can be clearly seen that the isotopic fingerprint of the molecular ions APPROXIMATES with the isotopic abundances of the five major titanium isotopes at m/z 46, 47, 48, 49 and 50"

http://www.spectroscopyonline.com/spectroscopy/article/articleDetail.jsp?id=828042&sk=&date=&%0A%09%09%09&pageID=2



(Bunseki Kagaku Conference September 2016)

Ti Analysis; ICP-MS Vs. ICP-QQQ



Natural Abundance

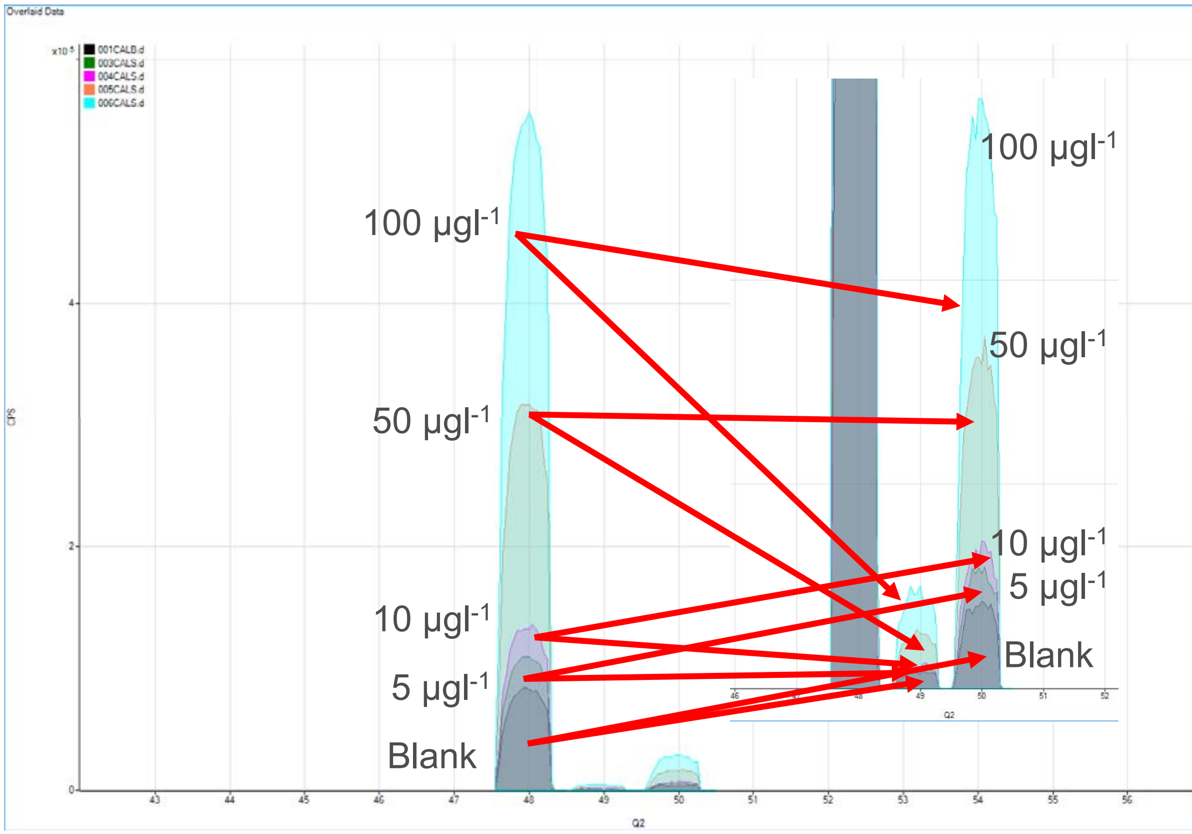
Ti46-8.25% (Ca-0.004%)
Ti47-7.44%
Ti48-73.72% (Ca-0.187%)
Ti49-5.41%
Ti50-5.18% (V-0.25%, Cr-4.345%)

"It can be clearly seen that the isotopic fingerprint of the molecular ions APPROXIMATES with the isotopic abundances of the five major titanium isotopes at m/z 46, 47, 48, 49 and 50"

http://www.spectroscopyonline.com/spectroscopy/article/articleDetail.jsp?id=828042&sk=&date=&%0A%09%09%09&pageID=2

Isotope Analysis and Qualifying Ions

When using reaction chemistry, it is an absolute MUST to control the reaction cell chemistry.

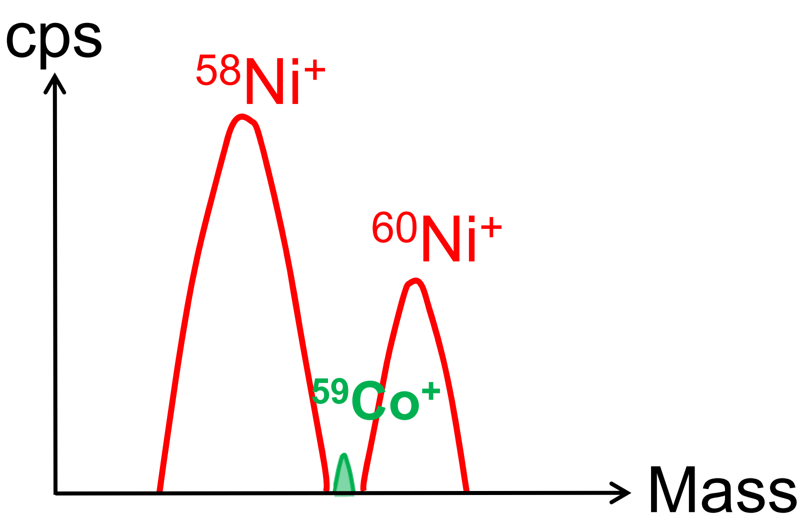


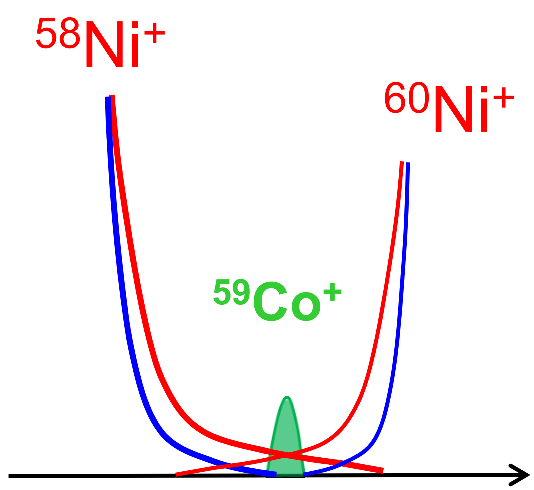
:entration	Certified value
4 µg g^{-1}	
7 µg g^{-1}	
1 µg g^{-1}	
1 µg g^{-1}	7.39 ± 0.39 µg g^{-1}
3 µg g^{-1}	
1 µg g^{-1} ± 0.015 µg g^{-1}	

Two Full Size Quads; Dealing with Peak Overlaps

Analysis of Trace Co in a High Ni Matrix

	Co Natural Abundance %		Ni Natural Abundance %	Interferences
^{59}Co	100	^{58}Ni ^{60}Ni	67.8 26.2	$^{58}NiH^+$ $^{58}Ni + ^{60}Ni^+$ Tails



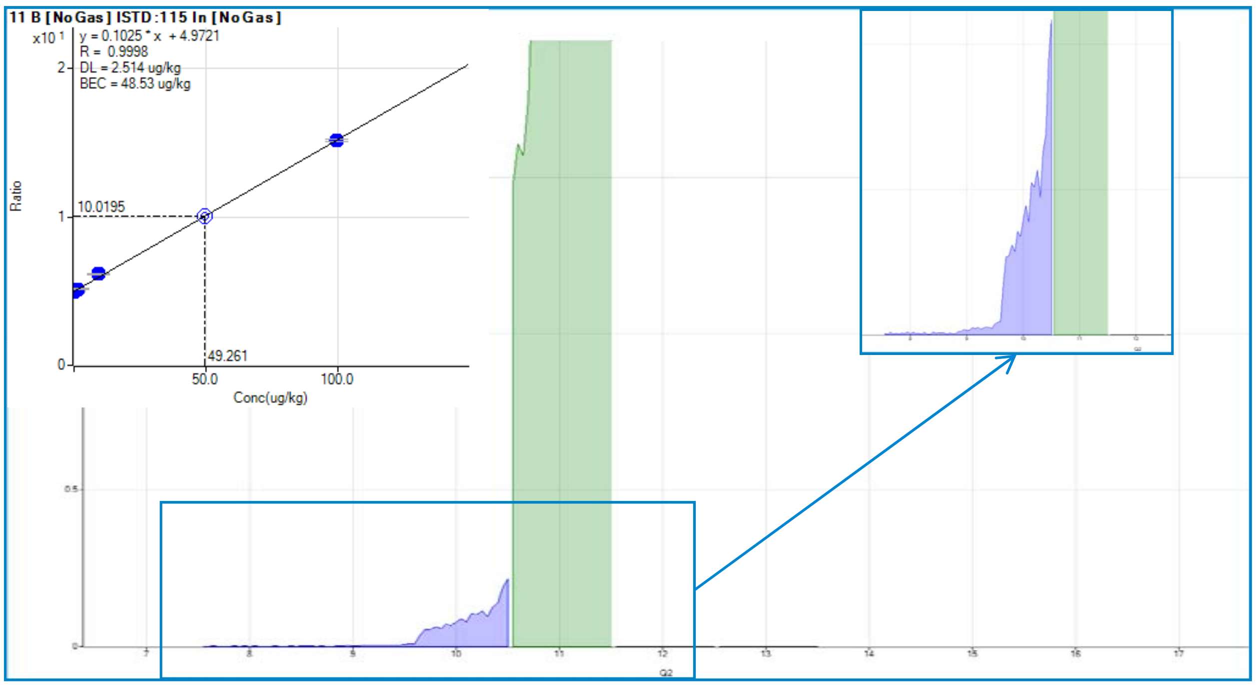


Two Full-Size Quadrupole Mass Filters

	Abundance Sensitivity based on $^{133}Cs^+$	Mass 132	Mass 134
	Q1	5×10^{-7}	1×10^{-7}
	Q2	5×10^{-7}	1×10^{-7}
Theoretical	Q1 * Q2	2.5×10^{-13}	1×10^{-14}
	Guarantee	10^{-10}	10^{-10}

Boron in Organic Solvent – Xylene SQ/BP mode

5.77 µg Kg^{-1} B spike into pure xylene

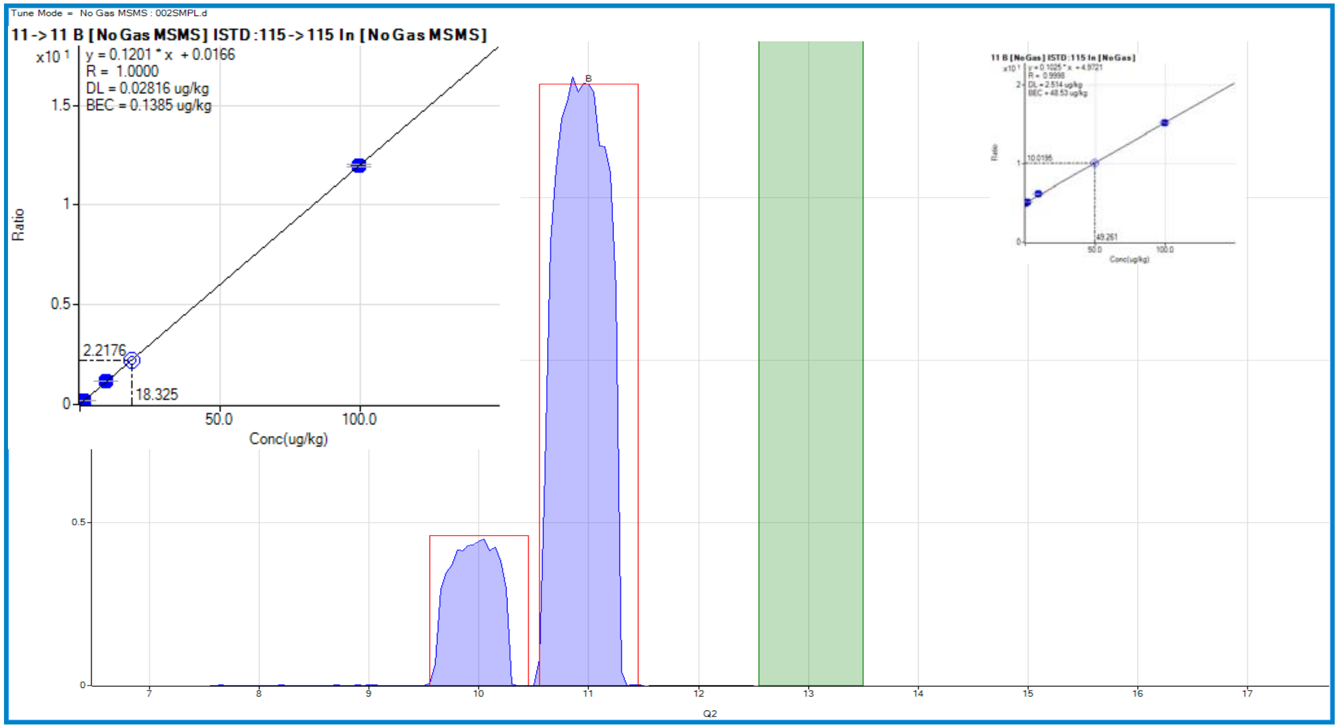


Boron's main isotope is at 11amu if there are large amounts of carbon present the ^{12}C peak can interfere with the neighbouring ^{11}B peak.

In extreme cases (as here) it can even spread to the ^{10}B peak even under B.P. mode

Boron in Organic Solvent – Xylene MS/MS mode

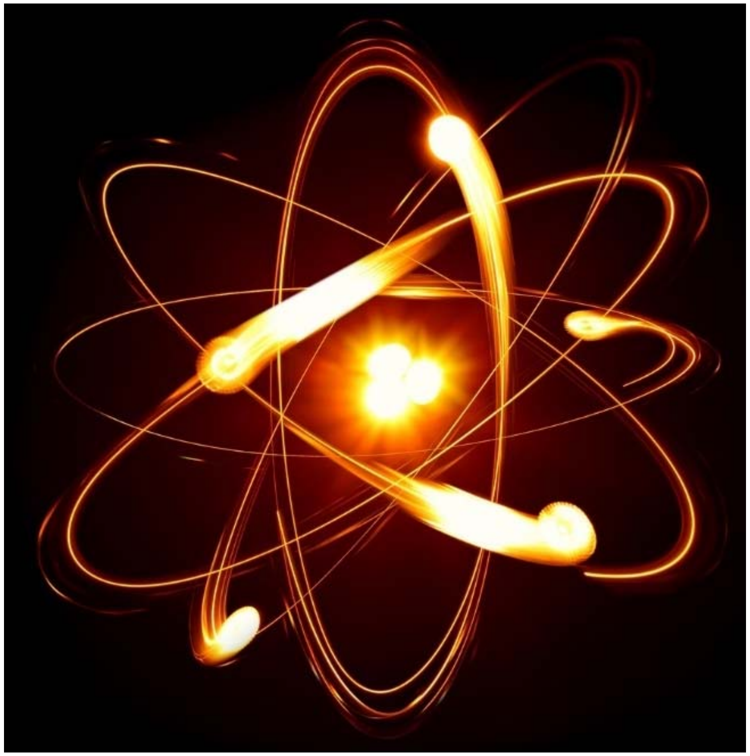
5.77 µg Kg^{-1} B spike into pure xylene



- Operating under MS/MS mode completely eliminates the ^{12}C overlap on all boron isotopes
- BEC collapses from ~50ppb to ~0.14ppb (due to B in the blank solvent)
- The effect is similar for less intense C peaks (e.g. B in acetic or alcohol base

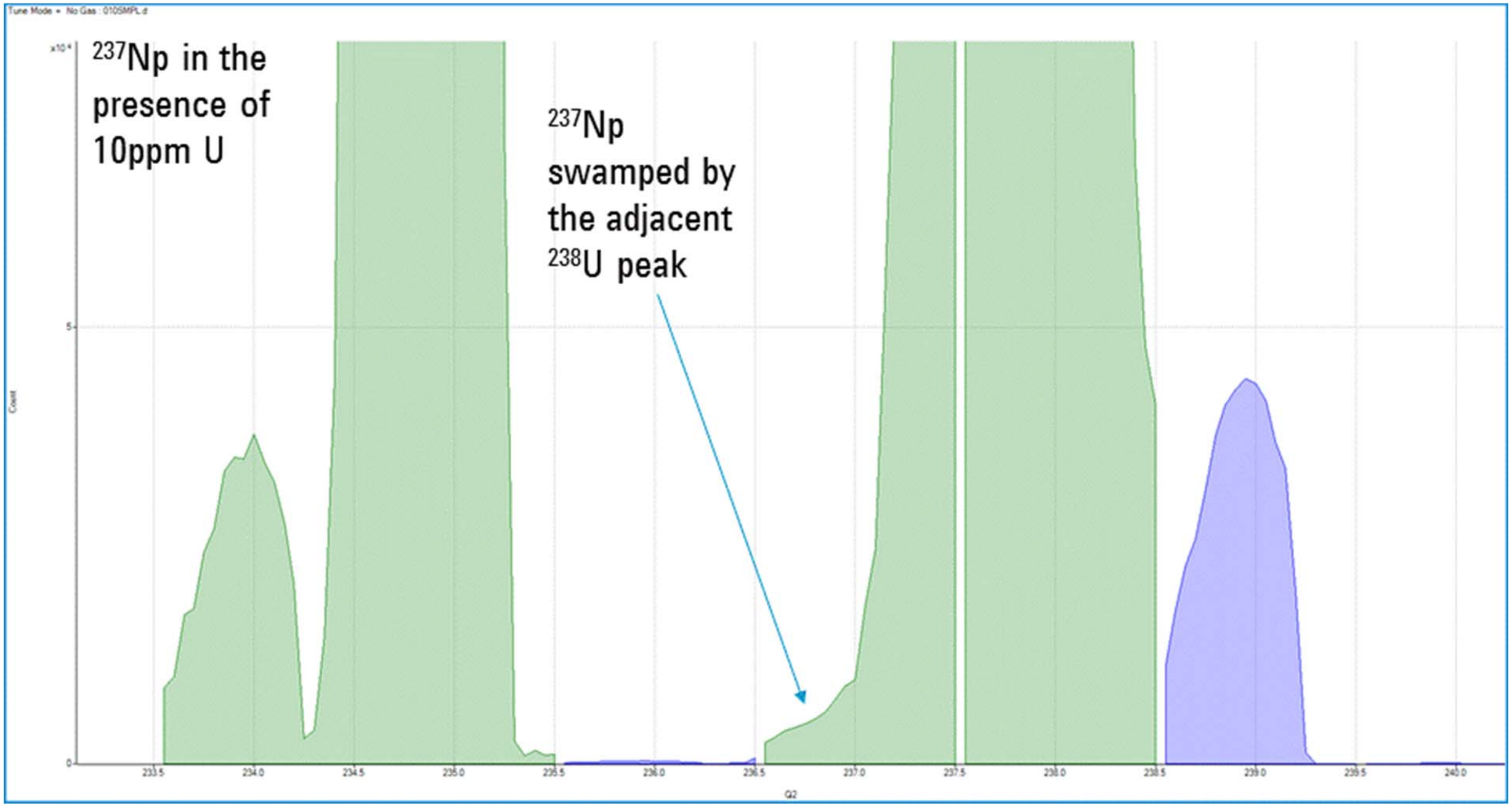
Nuclear Chemistry – Radioisotopes in the Environment

- ISO20899 is a new proposal for the measurement of Pu and Np in the environment
- Residual Pu & Np from leaks, disposal and bomb testing
- Natural Np formation from neutron capture in U deposits
- Np from Am decay used in smoke detectors
- Both difficult & suffer from U-based interferences



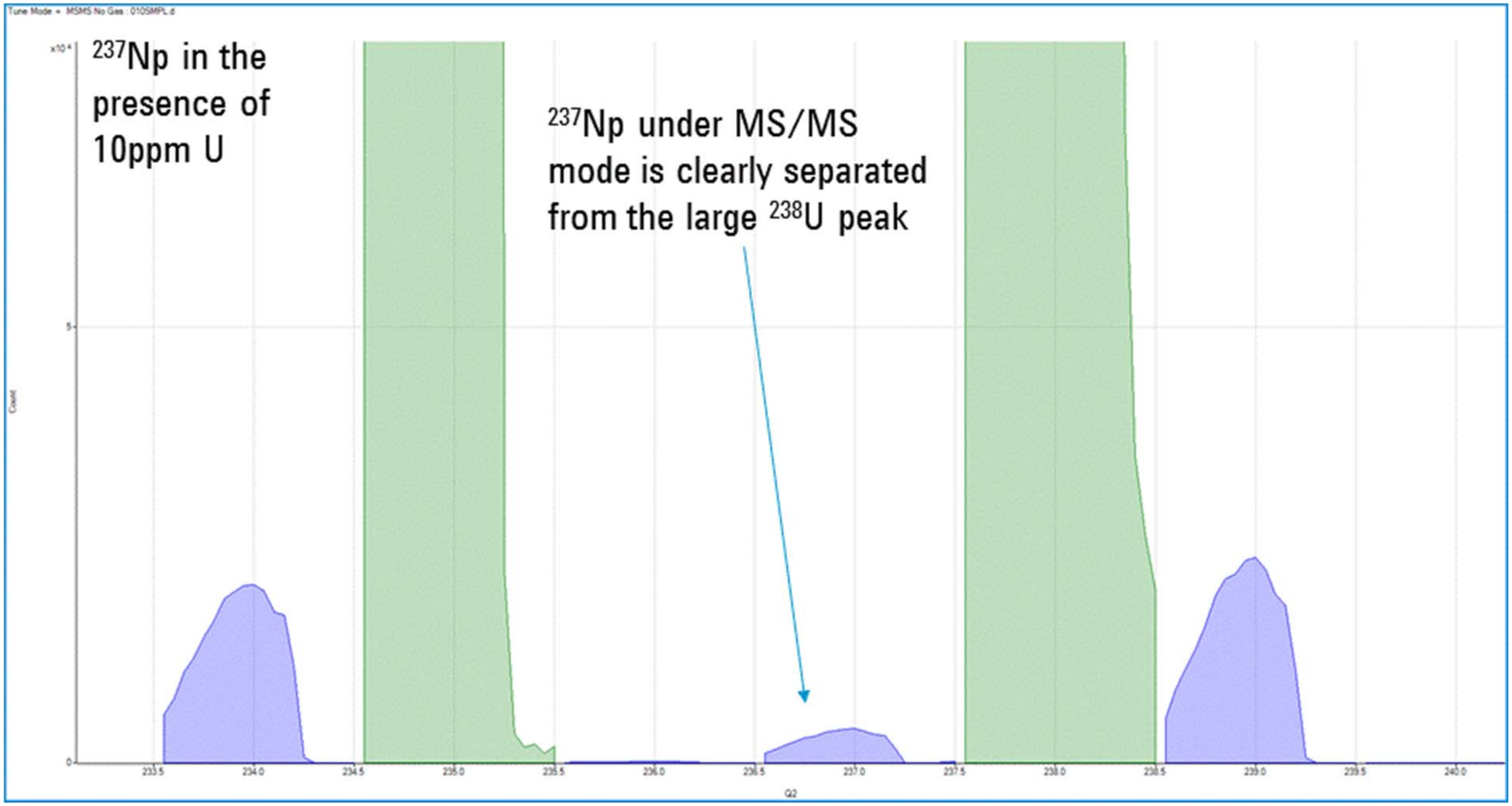
Nuclear Chemistry – Radioisotopes in the Environment Neptunium

^{237}Np – abundance sensitivity overlap from ^{238}U in ICP-MS



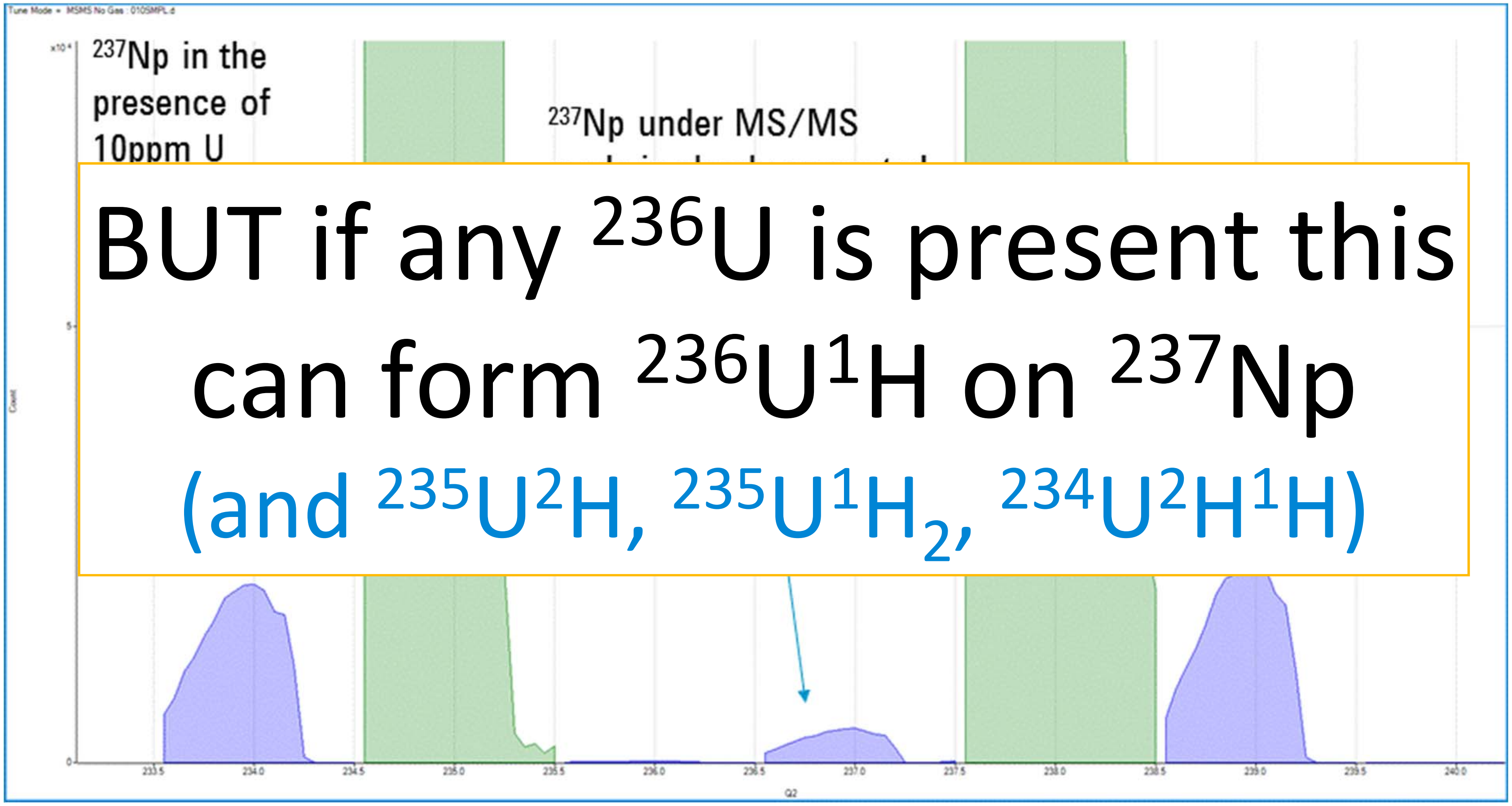
Nuclear Chemistry – Radioisotopes in the Environment
Neptunium

^{237}Np – ^{238}U overlap removed under MS/MS



Nuclear Chemistry – Radioisotopes in the Environment
Neptunium

^{237}Np – ^{238}U overlap removed under MS/MS

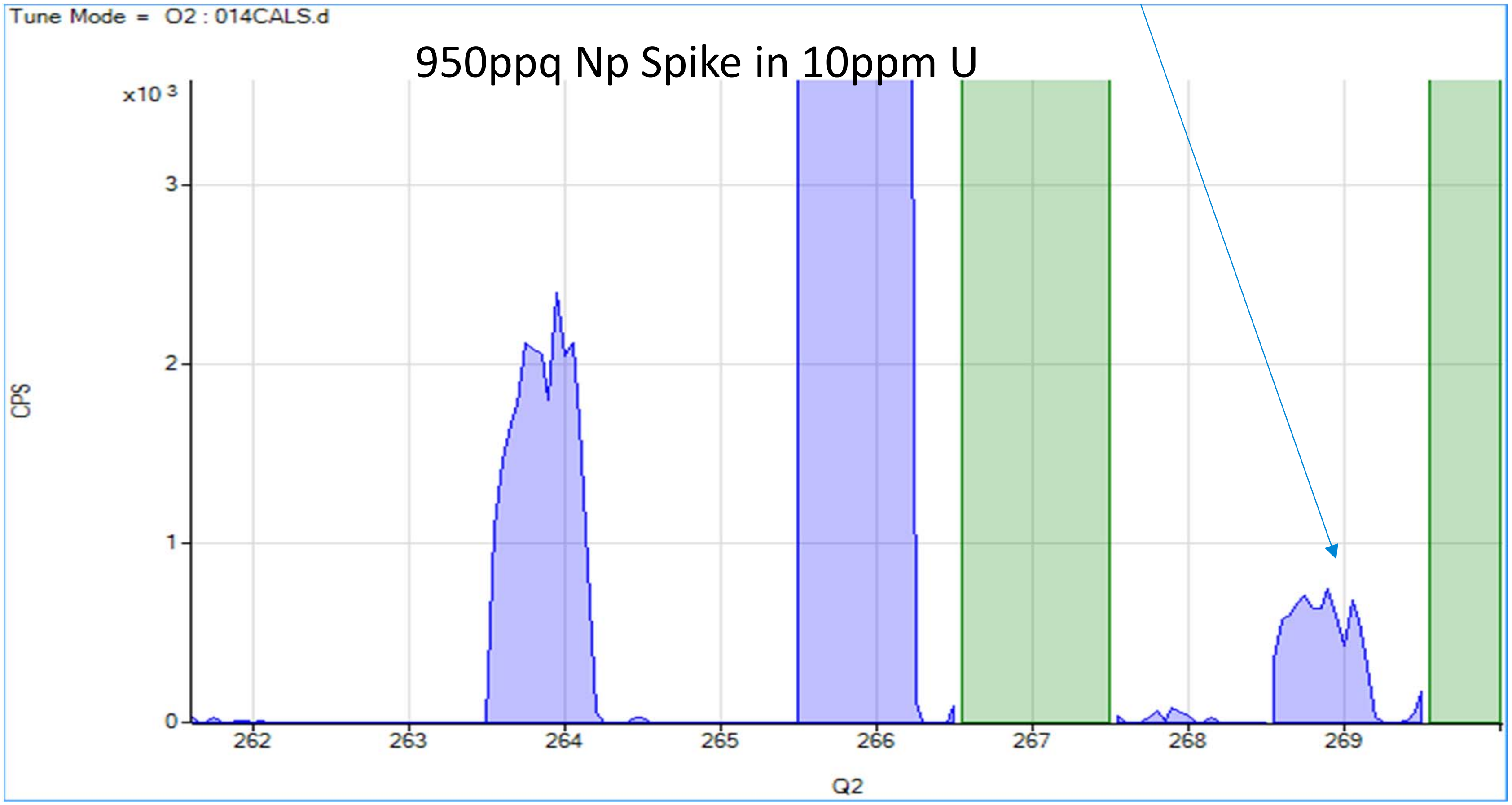


BUT if any ^{236}U is present this can form $^{236}U^{1}H$ on ^{237}Np

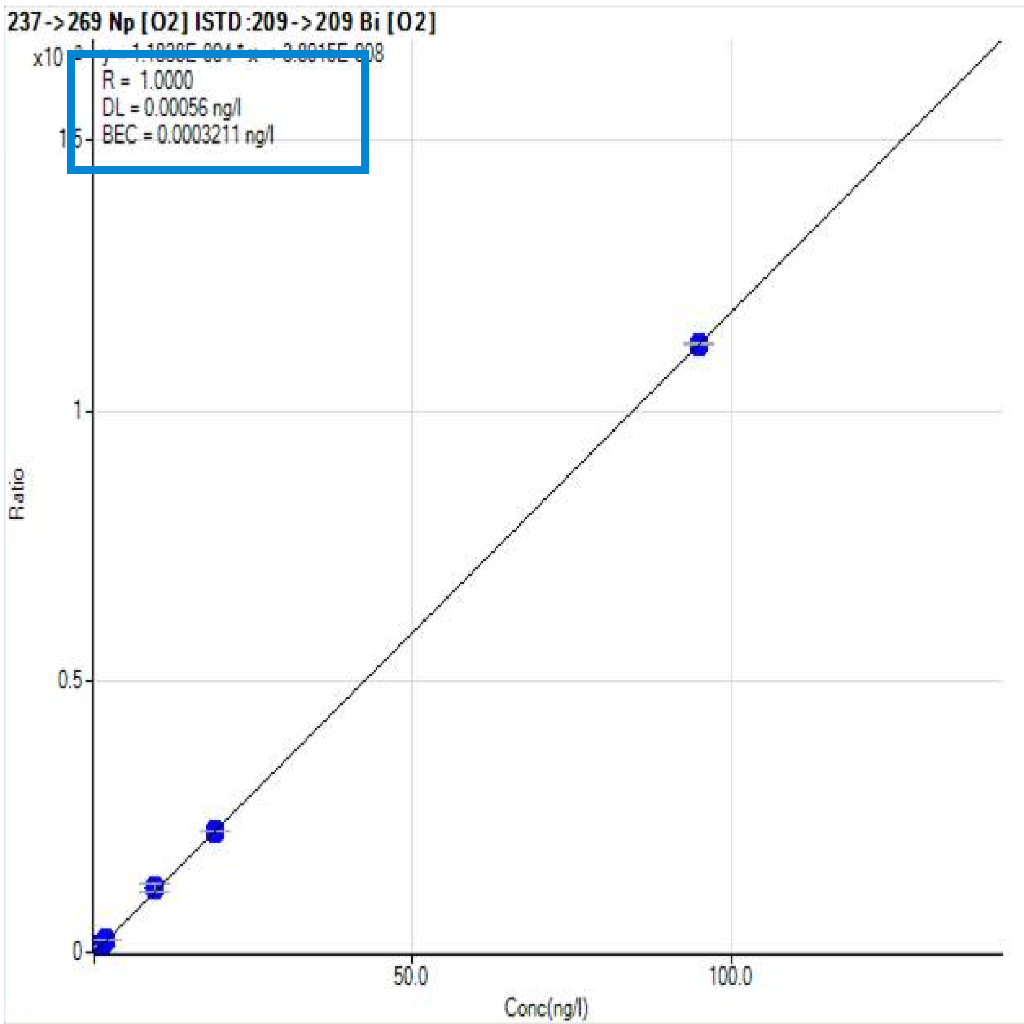
(and $^{235}U^{2}H$, $^{235}U^{1}H_2$, $^{234}U^{2}H^{1}H$)

Nuclear Chemistry – Radioisotopes in the Environment
Neptunium

Use O2 reaction mode! $^{237}Np + O_2 \rightarrow {}^{237}Np^{16}O_2$



Nuclear Chemistry – Radioisotopes in the Environment Neptunium



Analyte Information (237 -> 269 Np [O2] ISTD: 209 -> 209 Bi [O2])

Current Sample	Calc Conc.	CPS	Ratio	Det.	Conc. RSD
Cal 95	94.962	67567.17	0.0112	P	0.4

Calibration

Level	Rjct	Conc.	Calc Conc.	CPS	Ratio	Det.	RSD
1	☐	0.000	0.000	0.23	0.0000	P	58.1
2	☐	0.190	0.199	144.40	0.0000	P	2.6
3	☐	0.950	0.937	677.55	0.0001	P	2.4
4	☐	1.900	1.938	1387.58	0.0002	P	1.1
5	☐	9.500	10.102	6873.29	0.0012	P	9.8
6	☐	19.000	18.887	13546.28	0.0022	P	0.3
7	☐	95.000	94.962	67567.17	0.0112	P	0.4

DL = 0.56ppq (pg l^{-1})
BEC = 0.32ppq (pg l^{-1})

Nuclear Chemistry – Radioisotopes in the Environment Plutonium

	NMBU results				Certified results / *Literature results				*n
	^{239}Pu, ng/kg	SD	^{240}Pu, ng/kg	SD	^{239}Pu, ng/kg	SD	^{240}Pu, ng/kg	SD	
IAEA 384	41	0.8	2.18	0.003	42	2	2	0.2	
NIST 4353a	5.0	0.50	0.30	0.020	*5.26	*0.060	*0.30	*0.010	19
NIST 4357a	2.1	0.10	0.56	0.050	*2.27	*0.070	*0.53	0.11	19
IAEA13 5	49	1.0	10.2	0.40	*54	*3	*11.2	*0.90	28
IAEA 315	15,0	0.30	3.11	0.070	*16	*2.0	*3.3	*0.60	2

Confirming Accuracy by Natural Abundance

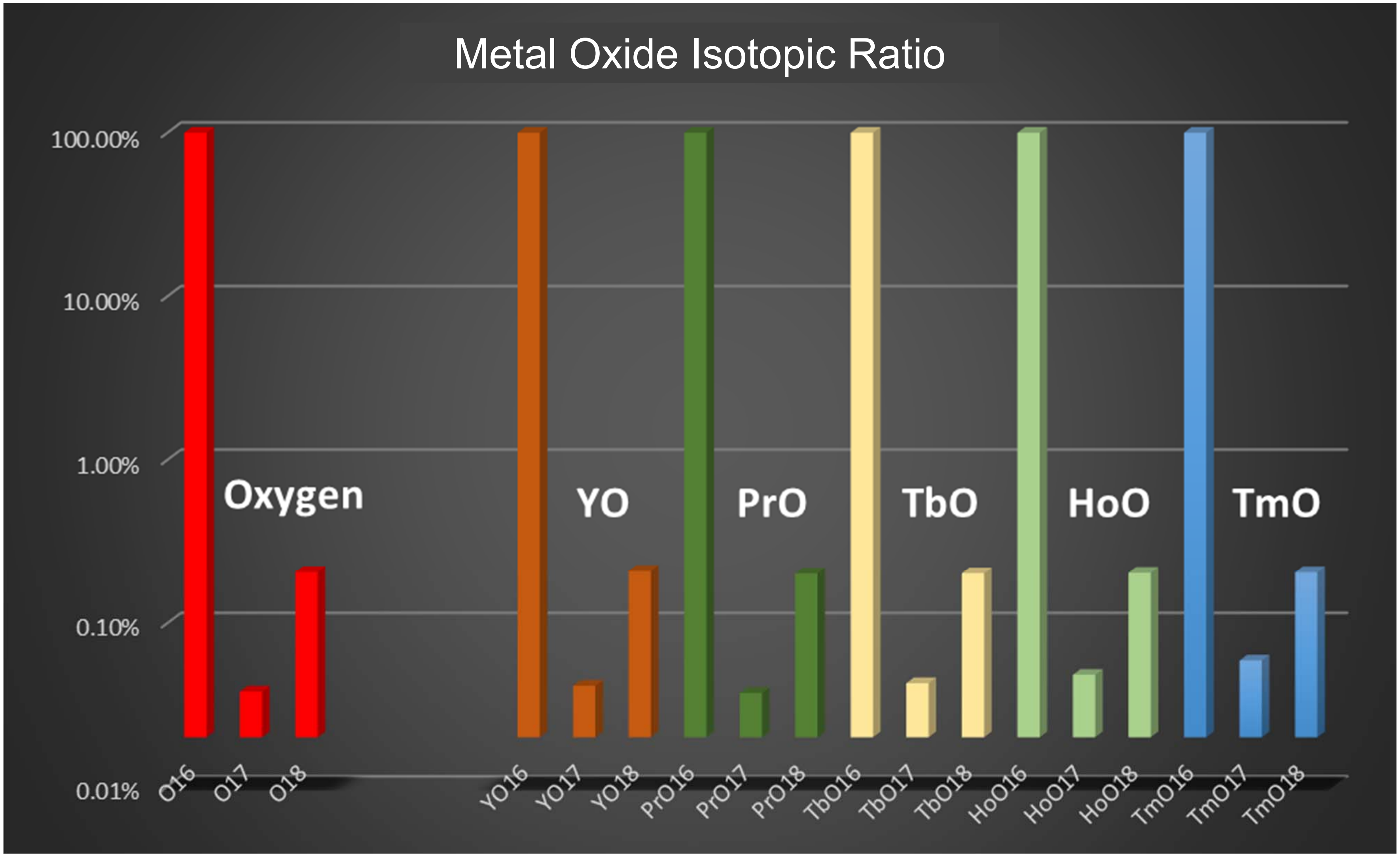
What if there is a way of confirming monoisotopic elements by ICP-MS?

How about looking at the isotopic pattern that the metal oxide forms?

	10ppb	
89 -> 105 Y	367616	99.75%
89 -> 106 Y	152	0.04%
89 -> 107 Y	767	0.2%
141 -> 157 Pr	710690	99.76%
141 -> 158 Pr	266	0.04%
141 -> 159 Pr	1431	0.2%
159 -> 175 Tb	722870	99.76%
159 -> 176 Tb	310	0.04%
159 -> 177 Tb	1461	0.2%
165 -> 181 Ho	668866	99.75%
165 -> 182 Ho	323	0.05%
165 -> 183 Ho	1362	0.2%
169 -> 185 Tm	717574	99.74%
169 -> 186 Tm	424	0.06%
169 -> 187 Tm	1471	0.2%

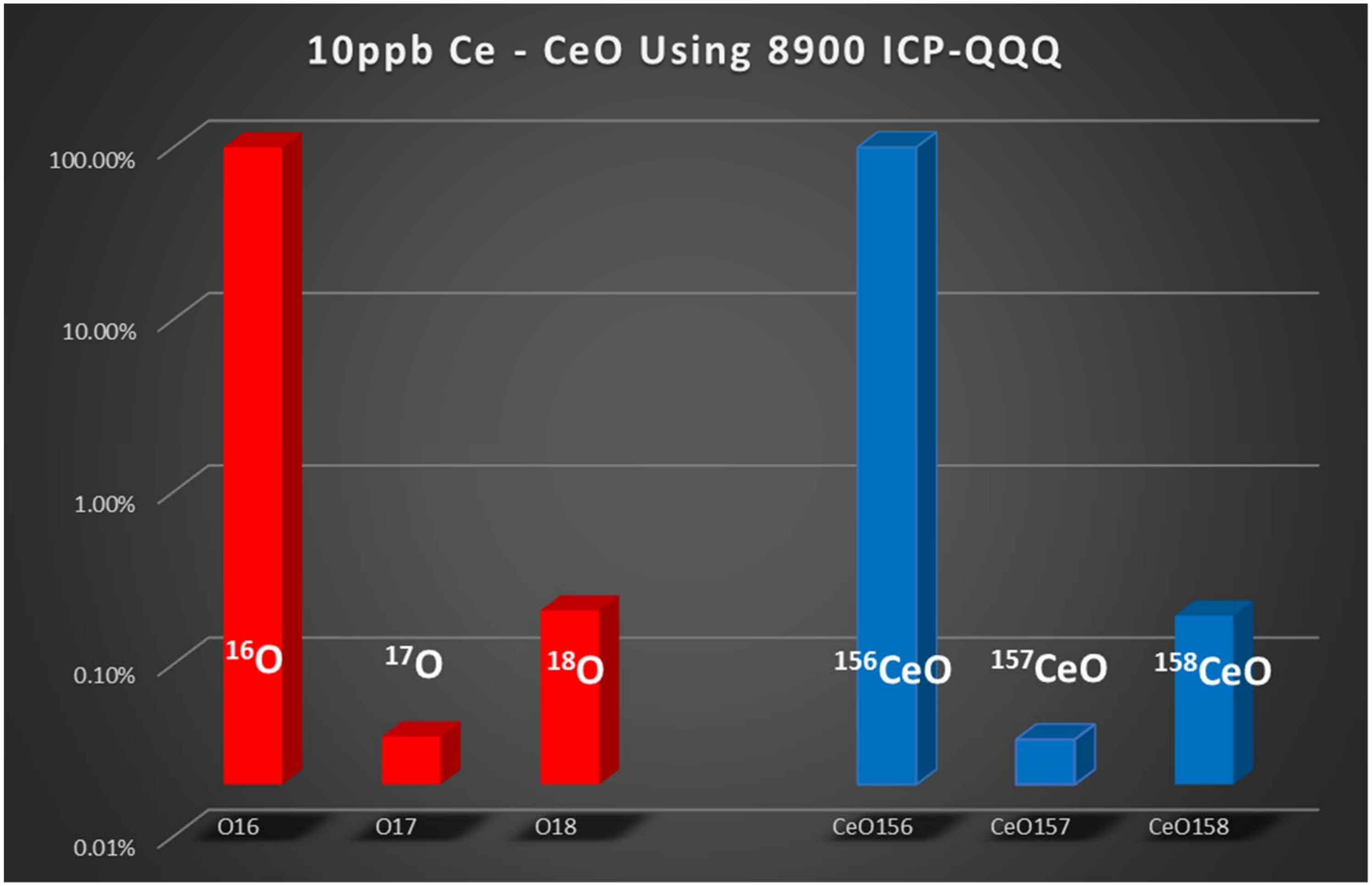
^{16}O-99.762%, ^{17}O-0.038%, ^{18}O-0.205%

MSMS O_2 – Confirming Accuracy by Natural Abundance



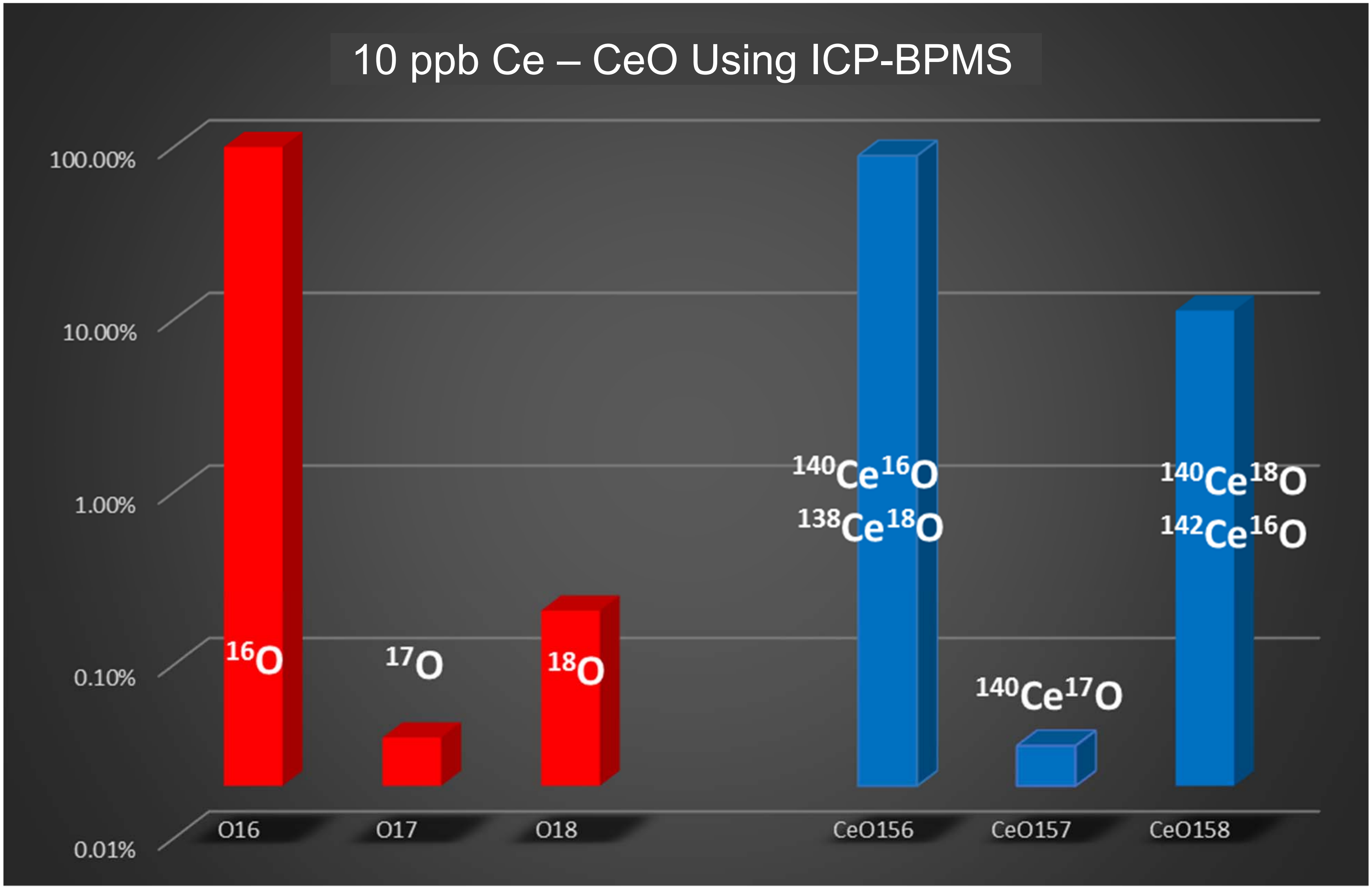
Unit mass resolution MSMS vs Bandpass – 8900

$^{140}Ce^{+} + O_{2\,(g)} \rightarrow {}^{140}Ce^{16}O^{+} + {}^{140}Ce^{17}O^{+} + {}^{140}Ce^{18}O^{+}$

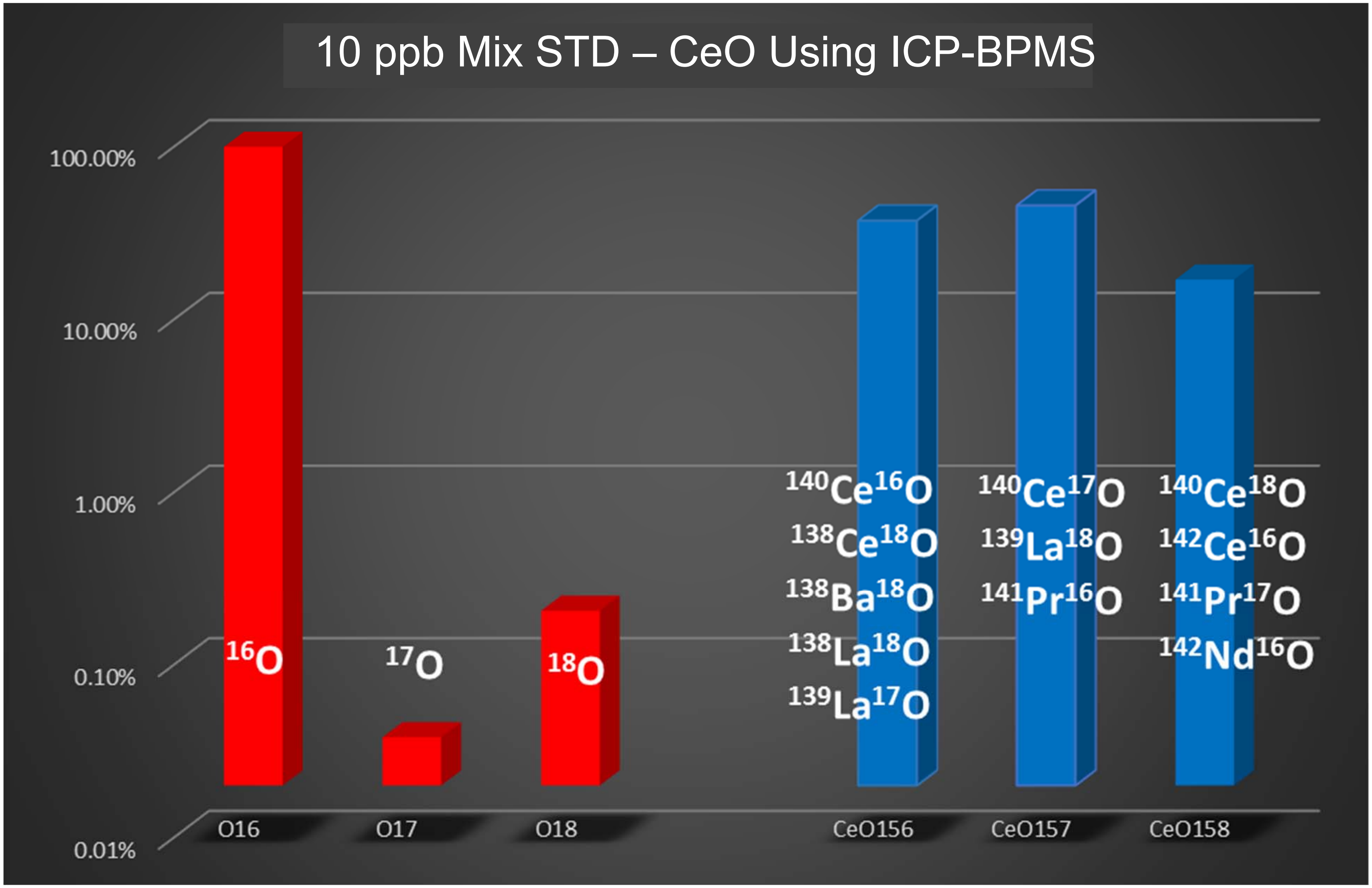


^{136}Ce-0.19%
^{138}Ce-0.25%
^{140}Ce-88.45%
^{142}Ce-11.11%

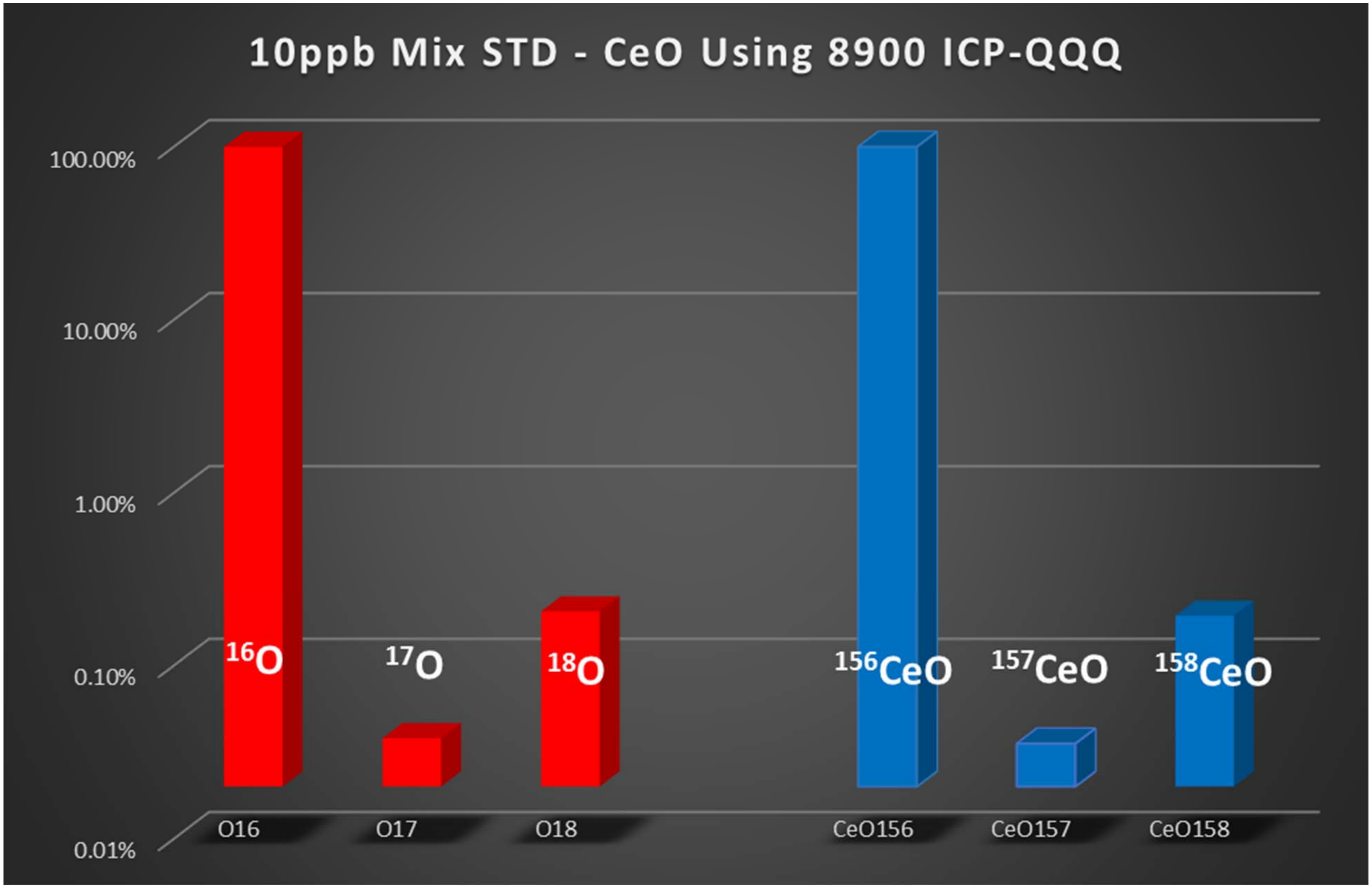
True MSMS vs Bandpass - Bandpass



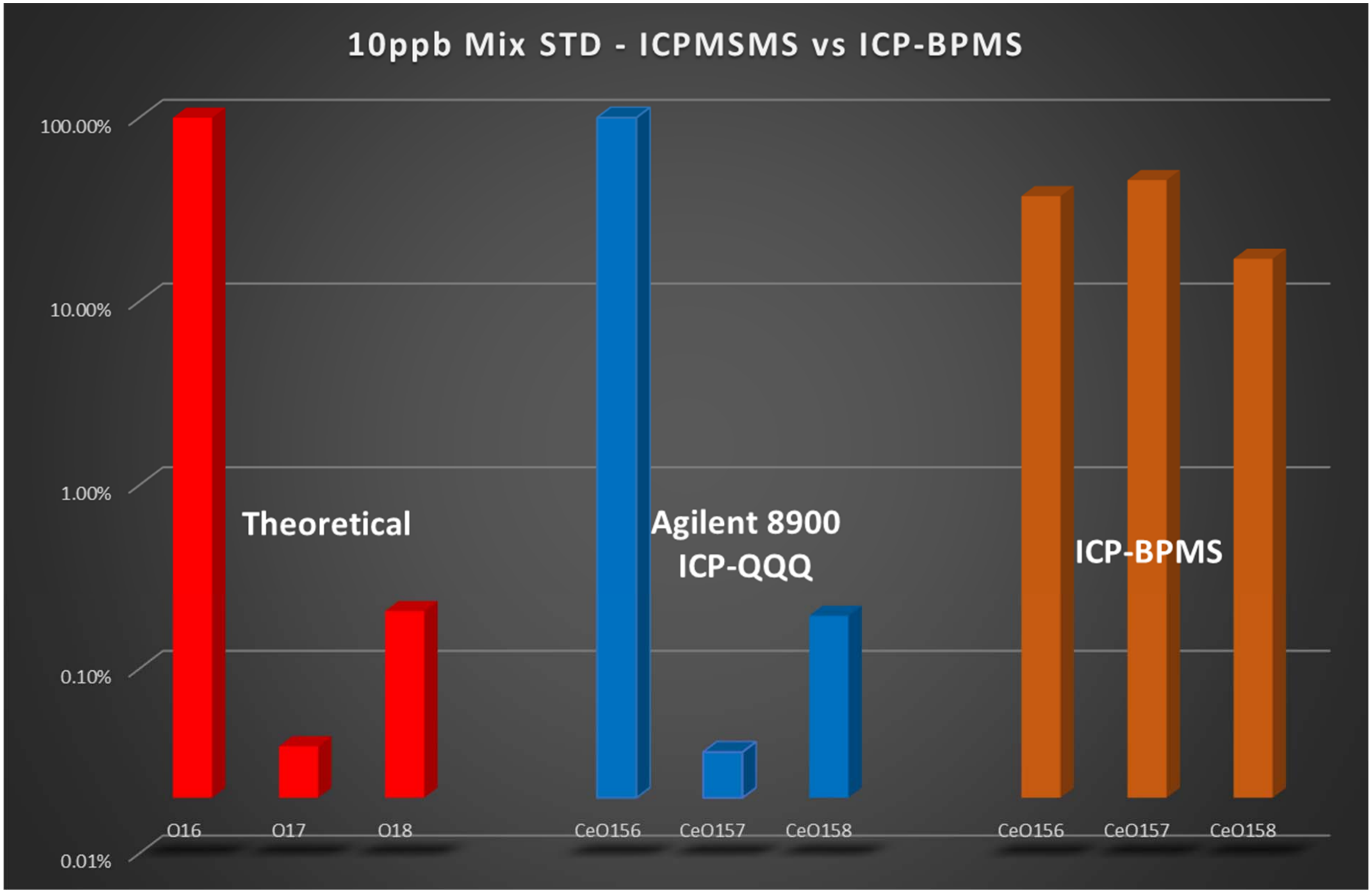
True MSMS vs Bandpass - Bandpass



True MSMS vs Bandpass – 8900



True MSMS vs Bandpass – 8900



Single Quad ICP-MS with bandpass filter in or before the cell.

What do you want to analyze?

What elements enter the cell?

This excluding the polyatomics !

ICP-MS/MS with Unit Mass Resolution Before the Cell

What do you want to analyze?

What elements enter the cell?

True MS/MS with unit mass resolution before the cell… when you must have Trusted Answers!

Single Quad ICP-MS with bandpass filter in or before the cell.

Element of Interest	Isotopes entering the Cell
Ti-50, V-50, Cr-50	Sc-45, Ca-46, Ti-46, Ti-47, Ca-48, Ti-48, Ti-50, V-50, Cr-50, V-51, V-51, Cr-52, Cr-53, Cr-54, Fe-54 and Mn-55
V-51	Ca-46, Ti-46, Ti-47, Ca-48, Ti-48, Ti-49, V-51, Cr-52, Cr-52, Cr-53, Cr-54, Fe-54, Mn-55 and Fe-56
Cr-52	Ti-47, Ca-48, Ti-48, Ti-49, Ti-50, V-50, Cr-50, Cr-52, Cr-53, Cr-53, Cr-54, Fe-54, Mn-55, Fe-56 and Fe-57
Cr-53	Ca-48, Ti-48, Ti-49, Ti-50, V-50, Cr-50, V-51, Cr-53, Cr-54, Fe-54, Cr-54, Fe-54, Mn-55, Fe-56, Fe-57, Fe-58 and Ni-58
Cr-54, Fe-54	Ti-49, Ti-50, V-50, Cr-50, V-51, Cr-52, Cr-54, Fe-54, Mn-55, Mn-55, Fe-56, Fe-57, Fe-58, Ni-58 and Co-59
Mn-55	Ti-50, V-50, Cr-50, V-51, Cr-52, Cr-53, Mn-55, Fe-56, Fe-56, Fe-57, Fe-58, Ni-58, Co-59 and Ni-60
Fe-56	V-51, Cr-52, Cr-53, Cr-54, Fe-54, Fe-56, Fe-57, Fe-57, Fe-58, Ni-58, Co-59, Ni-60 and Ni-61
Fe-57	Cr-52, Cr-53, Cr-54, Fe-54, Mn-55, Fe-57, Fe-58, Ni-58, Fe-58, Ni-58, Co-59, Ni-60, Ni-61 and Ni-62
Fe-58, Ni-58	Cr-53, Cr-54, Fe-54, Mn-55, Fe-56, Fe-58, Ni-58, Co-59, Co-59, Ni-60, Ni-61, Ni-62 and Cu-63
Co-59	Cr-54, Fe-54, Mn-55, Fe-56, Fe-57, Co-59, Ni-60, Ni-60, Ni-61, Ni-62, Cu-63, Ni-64 and Zn-64
Ni-60	Mn-55, Fe-56, Fe-57, Fe-58, Ni-58, Ni-60, Ni-61, Ni-61, Ni-62, Cu-63, Ni-64, Zn-64 and Cu-65
Ni-61	Fe-56, Fe-57, Fe-58, Ni-58, Co-59, Ni-61, Ni-62, Ni-62, Cu-63, Ni-64, Zn-64, Cu-65 and Zn-66
Ni-62	Fe-57, Fe-58, Ni-58, Co-59, Ni-60, Ni-62, Cu-63, Cu-63, Ni-64, Zn-64, Cu-65, Zn-66 and Zn-67
Cu-63	Fe-58, Ni-58, Co-59, Ni-60, Ni-61, Cu-63, Ni-64, Zn-64, Ni-64, Zn-64, Cu-65, Zn-66, Zn-67 and Zn-68
Ni-64, Zn-64	Co-59, Ni-60, Ni-61, Ni-62, Ni-64, Zn-64, Cu-65, Cu-65, Zn-66, Zn-67, Zn-68 and Ga-69
Cu-65	Ni-60, Ni-61, Ni-62, Cu-63, Cu-65, Zn-66, Zn-66, Zn-67, Zn-68, Ga-69, Zn-70 and Ge-70
Zn-66	Ni-61, Ni-62, Cu-63, Ni-64, Zn-64, Zn-66, Zn-67, Zn-67, Zn-68, Ga-69, Zn-70, Ge-70 and Ga-71
Zn-67	Ni-62, Cu-63, Ni-64, Zn-64, Cu-65, Zn-67, Zn-68, Zn-68, Ga-69, Zn-70, Ge-70, Ga-71 and Ge-72
Zn-68	Cu-63, Ni-64, Zn-64, Cu-65, Zn-66, Zn-68, Ga-69, Ga-69, Zn-70, Ge-70, Ga-71, Ge-72 and Ge-73
Ga-69	Ni-64, Zn-64, Cu-65, Zn-66, Zn-67, Ga-69, Zn-70, Ge-70, Zn-70, Ge-70, Ga-71, Ge-72, Ge-73, Ge-74 and Se-74
Zn-70, Ge-70	Cu-65, Zn-66, Zn-67, Zn-68, Zn-70, Ge-70, Ga-71, Ga-71, Ge-72, Ge-73, Ge-74, Se-74 and As-75

ICP-MS/MS with Unit Mass Resolution Before the Cell

Element of Interest	Isotopes entering the Cell
Ti-50, V-50, Cr-50	Ti-50, V-50, Cr-50
V-51	V-51
Cr-52	Cr-52
Cr-53	Cr-53
Cr-54, Fe-54	Cr-54, Fe-54
Mn-55	Mn-55
Fe-56	Fe-56
Fe-57	Fe-57
Fe-58, Ni-58	Fe-58, Ni-58
Co-59	Co-59
Ni-60	Ni-60
Ni-61	Ni-61
Ni-62	Ni-62
Cu-63	Cu-63
Ni-64, Zn-64	Ni-64, Zn-64
Cu-65	Cu-65
Zn-66	Zn-66
Zn-67	Zn-67
Zn-68	Zn-68
Ga-69	Ga-69
Zn-70, Ge-70	Zn-70, Ge-70

Questions?

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