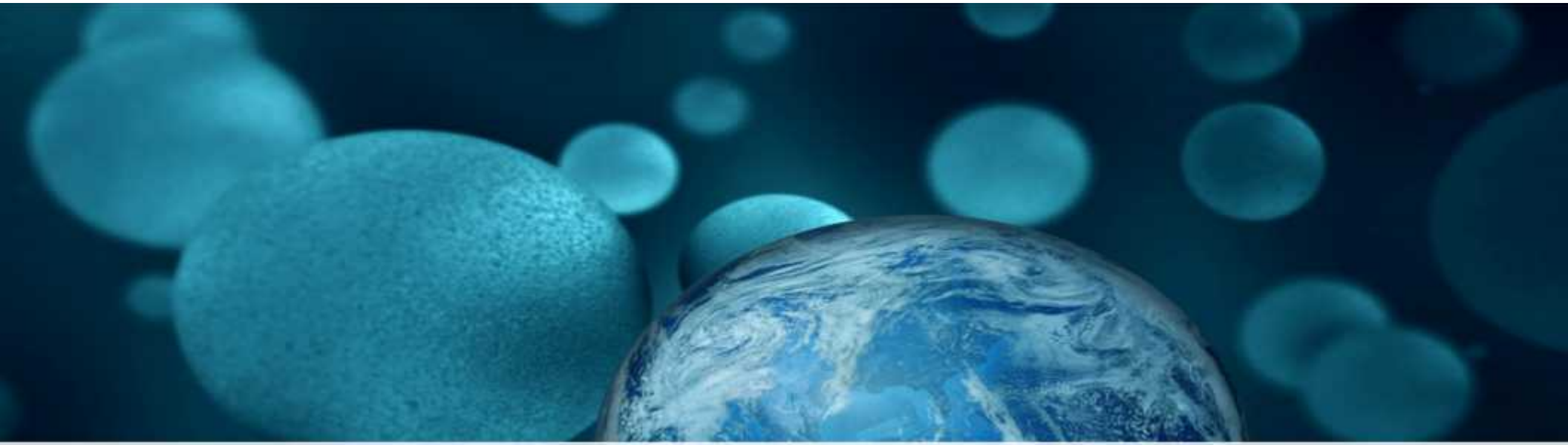

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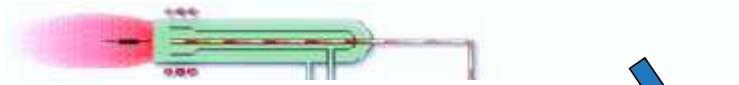
Determination of Elemental Impurities in Pharma and food samples by ICP-OES and ICP-MS

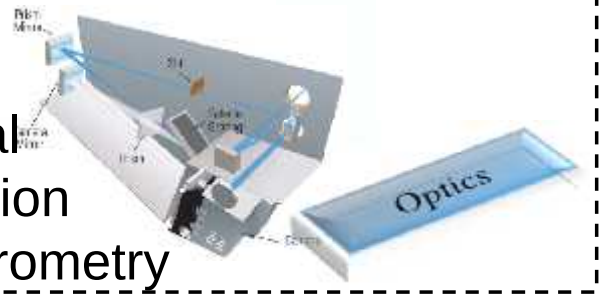
Matthew Cassap
TEA Specialist
UK

ICP – Optical Emission and Mass Spectrometry

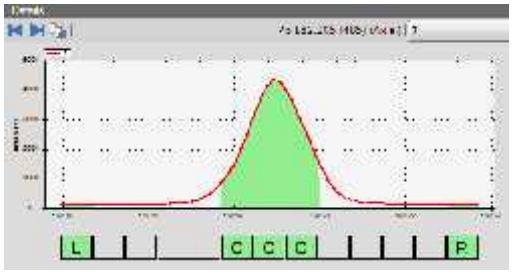


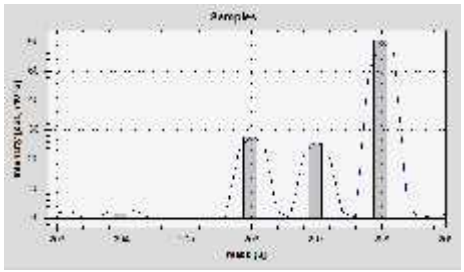
Sample introduction and Plasma

Optical **E**mission **S**pectrometry



Mass **S**pectrometry





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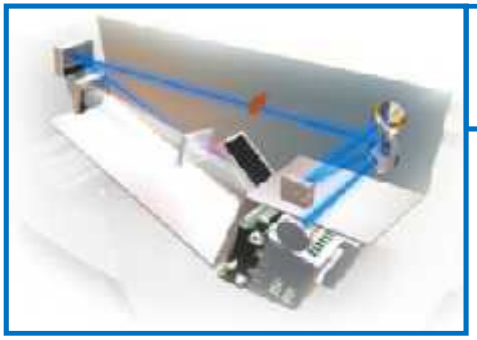
The iCAP 7000 Series ICP-OES Core Technologies

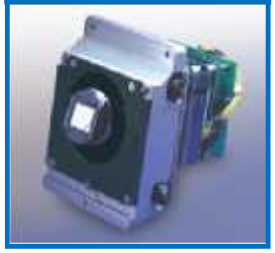


Optical design

EMT torch & Duo viewing

Clip-in sample intro systems

CID detector



Drain sensor

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What's the difference between a SQ and TQ-ICP-MS

iCAP RQ ICP-MS

iCAP TQ ICP-MS

Additional Q1 mass filter quadrupole

Additional electronics

Additional gases

Enhanced software

Same platform – there are more differences than you think!

Pharmaceutical Testing of Elemental Impurities – Why?

- Why are metal impurities of concern?
  - Reduced shelf-life
  - Inherent toxicity of certain elements
- How is heavy metals testing done?
  - USP General Chapter for Heavy Metals <231>
  - Hundred-year-old colorimetric test
  - Precipitation of ten sulfide-forming elements
  - Visual comparison of colour to that of a 10 ppm lead standard
- Is the test fit for purpose?
  - Unable to differentiate between the levels of individual contaminants
  - Safety issues with the use of hazardous solvents such as thioacetamide
  - Easy to lose volatiles such as mercury

Introduction to USP Chapters <232> and <233>

- Concerned with testing of elemental impurities in pharmaceutical products
- New USP Chapters introduced to replace <231>
  - <232> Elemental Impurities – Limits
  - <233> Elemental Impurities – Procedure
  - <2232> Elemental Contaminants in Dietary Supplements
- Chapter 232 sets out the limits for 24 elements
  - 'Big Four' arsenic, cadmium, lead and mercury – must test for these
  - Remainder are commonly used as catalysts – must test if thought to be present
- Chapter 233 describes two analytical procedures:
  - Procedure 1 – ICP-OES
  - Procedure 2 – ICP-MS
  - Acceptance criteria for alternative procedures

Status of Chapters <232> and <233>

- USP
- On January 1, 2018, USP General Chapters <232> Elemental Impurities — Limits, <233> Elemental Impurities — Procedures, and <2232> Elemental Contaminants in Dietary Supplements became applicable to drug products and dietary supplements.
- ICH Q3D
  - Date of USP and ICH are now closley alinged
- Other regulatory bodies like EMA...
  - Delayed implementation dates for compliance for e.g. marketed products

USP <232> Elemental Impurities – Limits ug/day

Element	Class	Oral PDE	Parenteral PDE	Inhalation PDE
Cd	1	5	2	2
Pb	1	5	5	5
As	1	115	15	2
Hg	1	30	3	1
Co	2A	50	5	3
V	2A	100	10	1
Ni	2A	200	20	5
Tl	2B	8	8	8
Au	2B	100	100	1
Pd	2B	100	10	1
Ir	2B	100	10	1
Os	2B	100	10	1
Rh	2B	100	10	1
Ru	2B	100	10	1
Se	2B	150	80	130
Ag	2B	150	10	7
Pt	2B	100	10	1
Li	3	550	250	25
Sb	3	1200	90	20
Ba	3	1400	700	300
Mo	3	3000	1500	10
Cu	3	3000	300	30
Sn	3	6000	600	60
Cr	3	11000	1100	3

[a] PDE = permitted daily exposure based on a 50 kg person

* Not a safety concern

Instrumentation

ICP-OES
Procedure 1

ICP-MS
Procedure 2

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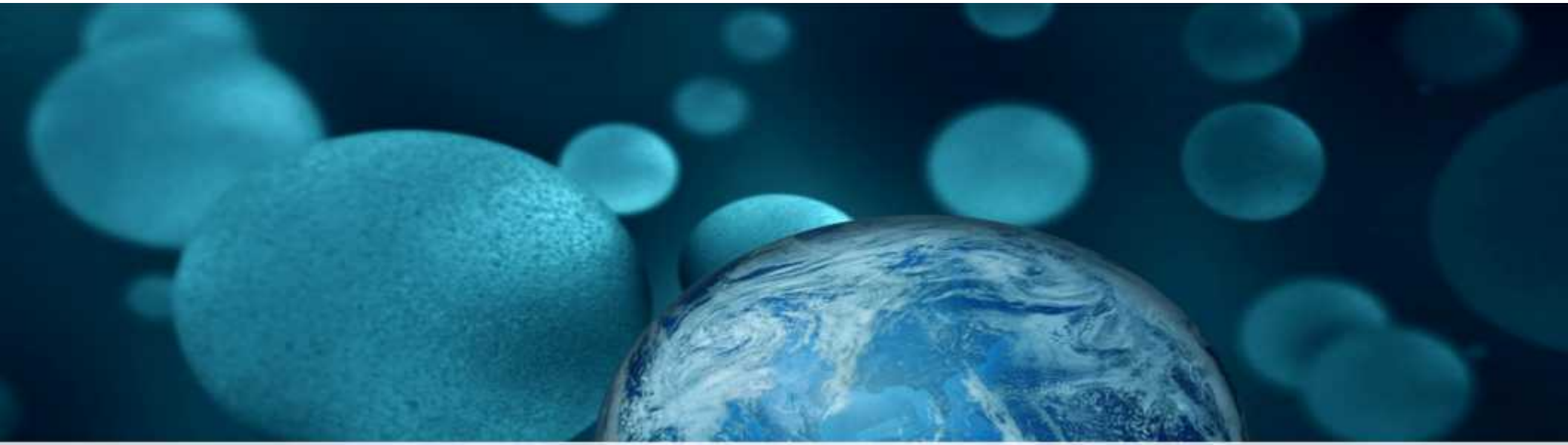

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Implementation of USP Elemental Impurities Testing in *Your* Facility?

Instrument Decision Matrix

Expected amount of analysis

✓Analysis Speed

Instrument performance

✓Detection Limits
✓Measurement range

ICP-OES or ICP-MS ?

Cost of ownership

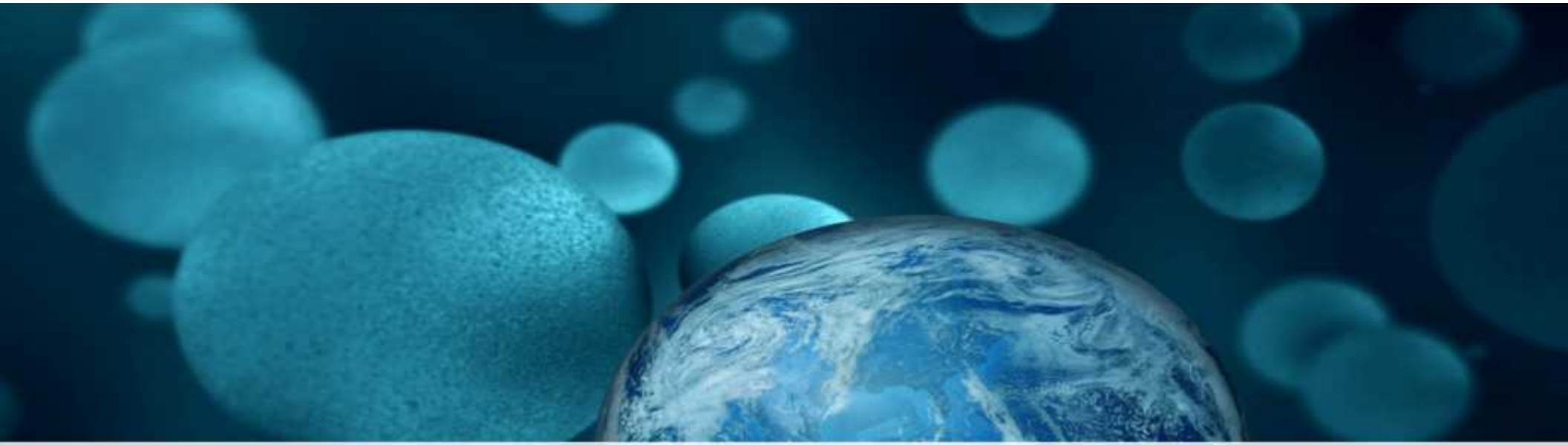
✓Installation Requirements
✓Bench space requirements

Operator skills

✓Automation
✓Automated software routines

ICP-OES or ICP-MS ???

Technology		
	ICP-OES	**ICP-MS**
Detection Power (USP)	+	+++
Dynamic Range	++	+++
Speciation Capabilities	+	+++
Lab Requirements	+++	+++
Operating Cost	++	++
Software	+++	+++
Investment	+++	++
Future Proof (USP)	+	+++



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ICP-OES Analysis Example

ICP-OES Procedure 1 USP <233>

The key benefits of ICP-OES

- Easy to use, learn & maintain
- Fast multi-element capability
- Robust plasma and flexibility for complex sample matrices

Flexible Matrix Handling

- Ability to analyse multiple matrix types in a single method
- Wide dynamic range spectrometer capable of analysing ppb to % in a single solution
- Axial viewing of plasma used to further improve detection limits

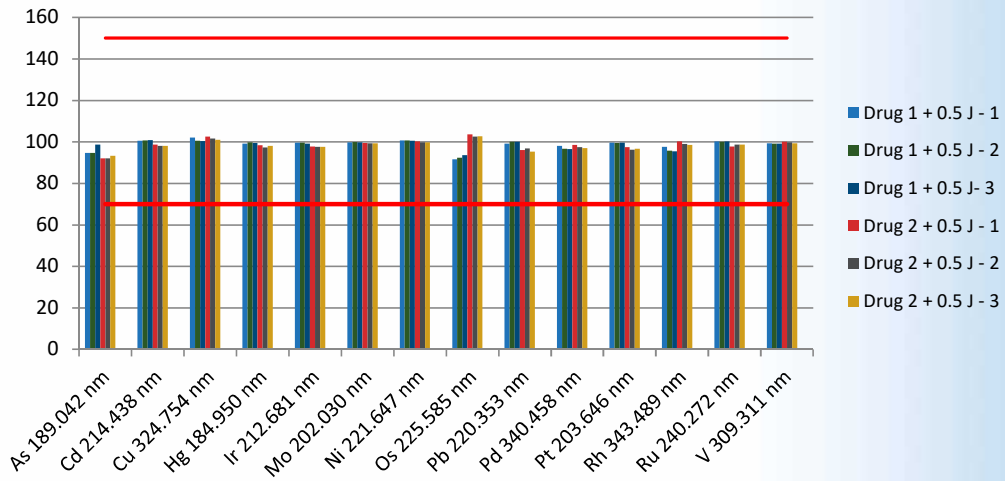
As, Cd, Hg and Pb	'The big four'
Cr, Cu, Mn, Mo, Ni, Pd, Pt, V, Os, Rh, Ru, Ir	Common catalysts

Analysis of Two Over the Counter Medicines

- Preparing samples in DMSO
  - DMSO (dimethyl sulfoxide) is a very strong solvent
  - Less toxic than DMF (dimethylformamide)
  - High-boiling point
- Drawbacks of using DMSO
  - Require silicone pump tubing
  - O-rings on spray-chamber require changing more often
  - Will not dissolve all excipients
    - For example: silica, titanium dioxide

Analysis of Two Over the Counter Medicines

- Two over-counter-medicines were tested according to USP <233>
  - Drug 1 – anti-inflamatory
  - Drug 2 – antihistamine
- 0.5 g of dehydrated sample was dissolved in 25 g of DMSO
  - J defined as the w/w concentration of analyte at Target Limit <u>after</u> dilution
  - Target Limit > MDL; recoveries tested at the 0.5J and 1.5J



Elements	0.5 J (µg/kg)
Cadmium	125
Lead	25
Inorganic As	7.5
Inorganic Hg	75
Iridium	500
Osmium	500
Palladium	500
Platinum	500
Rhodium	500
Ruthenium	500
Molybdenum	500
Nickel	2500
Vanadium	500
Copper	5000

J Value

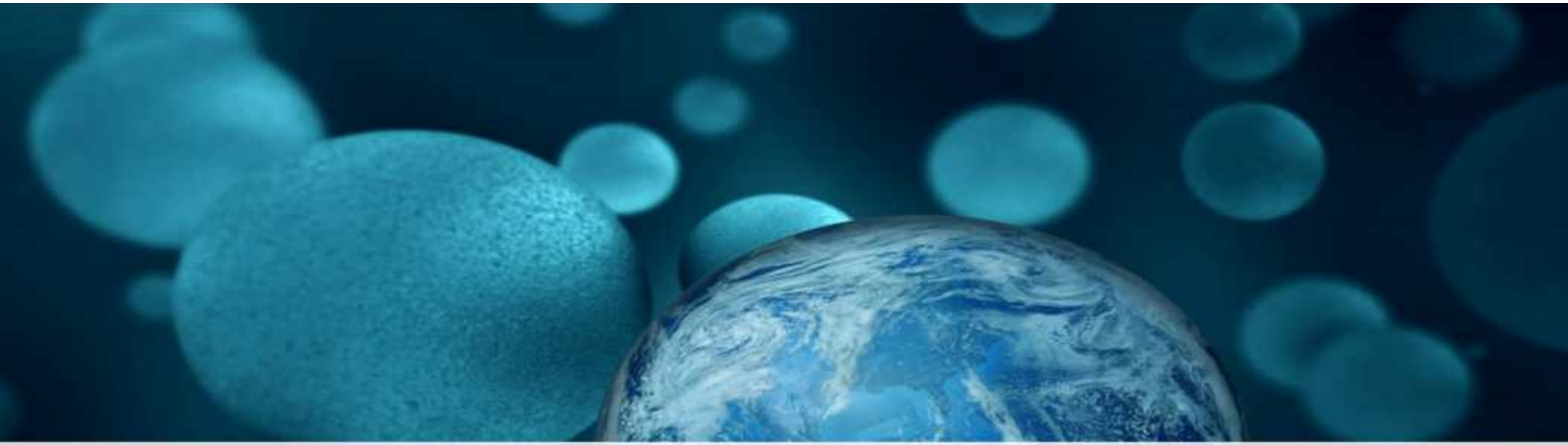
- J = The concentration of the element(s) of interest at the target limit, appropriately diluted to the working range of the instrument

- http://www.jvaluecalculator.com/

Analysis of Two Over the Counter Medicines

- Precision
  - Determined by analyzing six individual samples
  - Samples spiked at J
  - USP acceptance criteria < 20%

Elements	Drug 1 Run 1 µg/L	Drug 1 Run 2 µg/L	Drug 1 Run 3 µg/L	Drug 1 Run 4 µg/L	Drug 1 Run 5 µg/L	Drug 1 Run 6 µg/L	RSD %
Cadmium	232.4	232.7	234.7	239.1	235.6	229.9	1.4
Lead	45.9	45.2	44.6	47	46.6	43	3.2
Inorganic arsenic	12.1	12.7	12.8	14	12.9	11.4	6.9
Inorganic mercury	130.7	130.8	132,5	136.5	131.8	127.4	2.3
Iridium	944.5	941.3	948.2	963.7	950.9	924.5	1.4
Osmium	954.8	952.7	959	974.9	960.5	940	1.2
Palladium	918.8	914.7	914.6	928.6	929.4	890.6	1.5
Platinum	924.4	917.6	931.5	949.9	934.6	910.7	1.5
Rhodium	921.5	907.2	907.5	917.6	915.8	874.9	1.9
Ruthenium	955.5	966.5	953.6	972.8	967.5	932.7	1.5
Molybdenum	956.8	952	959.6	974	959.5	937.7	1.2
Nickel	4669	4666	4706	4787	4718	4610	1.3
Vanadium	962.5	952.9	945.5	960.1	961.7	928.9	1.4
Copper	9680	9590	9522	9666	9668	9318	1.5



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ICP-MS Application Examples

ICP-MS Procedure 2 USP Chapter 233

- The key benefits of ICP-MS relative to ICP-OES are:
  - Improved detection limits:
    - Up to 1000x lower for USP regulated elements such As, Cd, Hg and Pb
    - More future proof with flexibility for future changes in target levels
  - Able to access a broader elemental package
  - Wider dynamic range, ppt to ppm
  - Straightforward interfacing to speciation techniques (IC etc.)

Microwave Sample Preparation

- Four over-the-counter products were locally sourced
- Two samples of each were weighed into 15 ml disposable glass vials
- 3 ml of conc. HNO_3 was added to each vial
- System was closed, and pressurized with N_2 at 40 bar
- Microwave digestion recipe:

Step	Time (min)	Temperature (℃)	Power (kW)
1	15	200	1.5
2	10	200	1.5

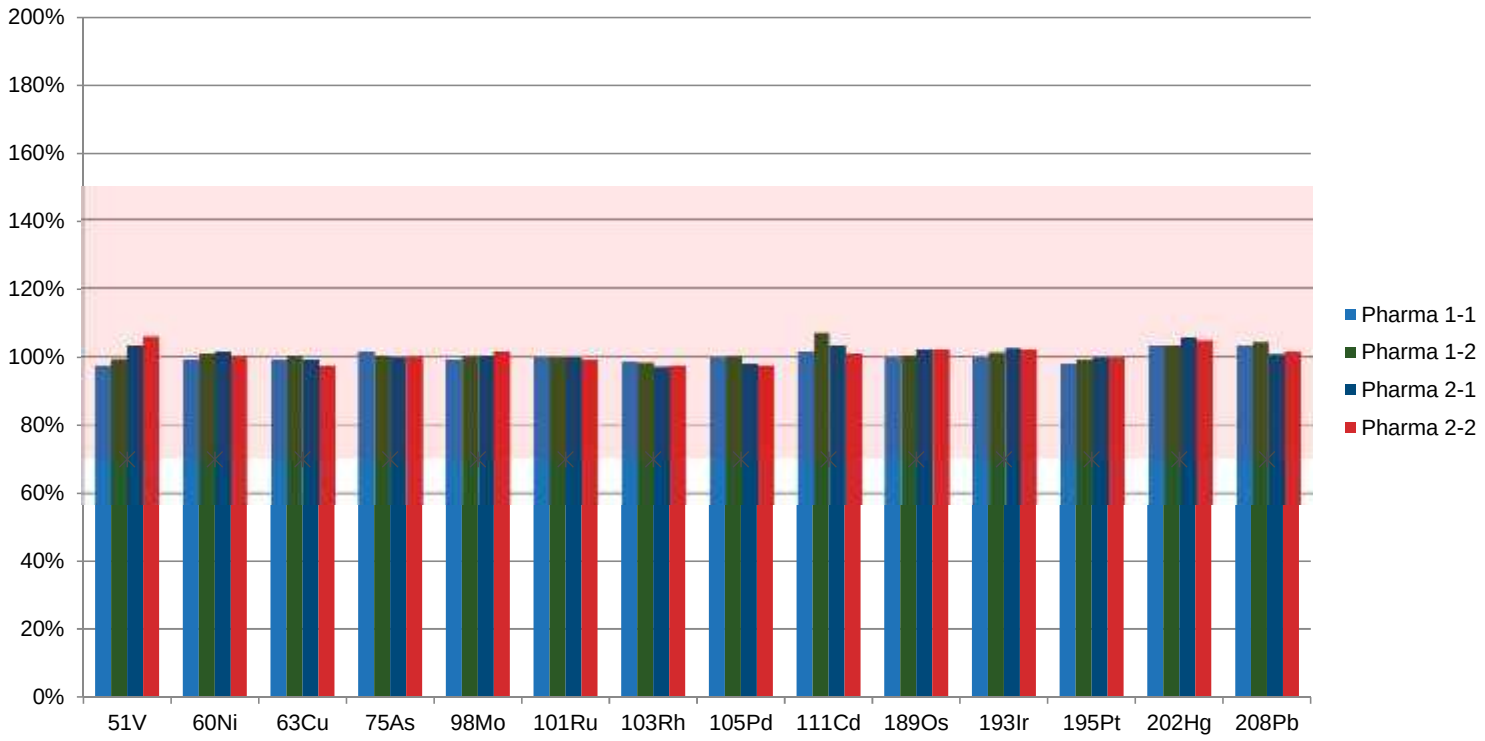
- When <60 ℃, the digest was transferred to a polypropylene vial and made up to 50 ml with 1% HCl
- Samples were further diluted before analysis (with high purity 2% HNO_3) to give total dilution factors of between *100 and *1000

ICP-MS Instrumentation and Standardization:

- ICP-MS:
  - PFA-ST nebulizer
  - Quartz peltier cooled spraychamber (~ 2.7 ℃)
  - 2.5mm ID quartz injector
  - Ni cones
- Analysis
  - Single mode KED for all analytes
    - 5.5 mL/min 100% He
    - 3 V voltage step

- Standardization:
  - Internal standardization with Ga, In and Tl (at 10, 5 and 5 ppb respectively) automatically added via a T-piece during analysis
  - External calibration with standards (at 0.5 J, J and 2 J) for quantification
  - For ICP-MS analysis, J values were defined as 1000 times lower than the oral solid drug product with a daily dose of 10 g/day

Results: Spike Recoveries (0.5 J)



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ICP-MS Detection Limits Compared to Maximum Daily Dose

Element	Instrumental Detection Limit (ng/mL)	Method Detection Limit (µg/g)	Concentration Limit Max. Daily Dose of ≤10 g/day (µg/g)
Cadmium	0.0001	0.0001	0.5
Lead	0.0005	0.0005	0.5
Inorganic arsenic	0.0005	0.0005	1.5
Inorganic mercury	0.003	0.003	1.5
Iridium	0.002	0.002	10
Osmium	0.0006	0.0006	10
Palladium	0.0008	0.0008	10
Platinum	0.0005	0.0005	10
Rhodium	0.0007	0.0007	10
Ruthenium	0.001	0.001	10
Molybdenum	0.003	0.003	18
Nickel	0.003	0.003	60
Vanadium	0.006	0.006	12
Copper	0.009	0.009	130

Arsenic measurement in the presence of cobalt with iCAP TQ ICP-MS

- Determination of elemental impurities in Vitamin B12
- Vitamin B12 contains Co (approx. 4% (w/w))
- Elements to be measured As, Cd, Pb and Hg – the so-called ‘Big Four’ in pharmaceutical analysis

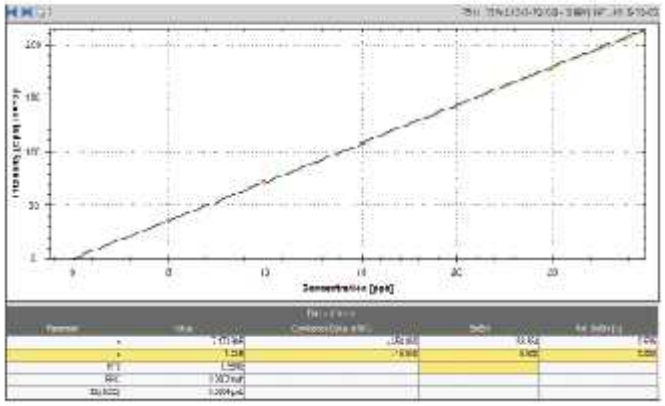
- Digest sample in nitric acid
- Run all elements in SQ-KED mode and also As in TQ-O_2 mode (as $^{75}As^{16}O$)

Performance in SQ and TQ modes

Concentration Vitamin B12	Signal at *m/z*=59 (SQ-KED) [CPS]	Signal at *m/z*=75 (SQ-KED) [CPS]	BEC in SQ-KED mode [ng·g^{-1}]	Signal at *m/z*=75 (TQ-O_2)	BEC in TQ-O_2 mode [ng·g^{-1}]	Spike recovery in TQ-O_2 mode [%]
BLK	73	2	0.0008	4	0.0007	N/A
0.0001 mg·mL^{-1}	202,455	13	0.003	9	0.001	100.1
0.001 mg·mL^{-1}	2,174,144	88	0.02	10	0.001	99.5
0.01 mg·mL^{-1}	24,003,087	852	0.21	8	0.001	101.8
0.1 mg·mL^{-1}	243,093,619	8711	2.17	18	0.002	106.1

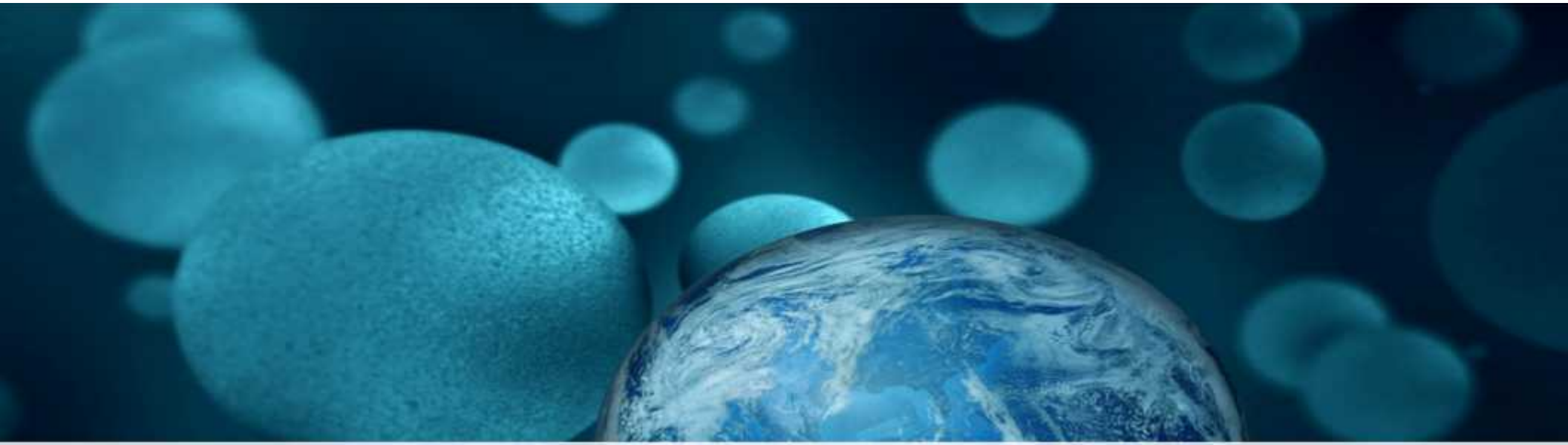
- SQ-KED mode elevated BEC due to CoO contribution that cannot be suppressed with He KED.
- TQ-O_2 mode - measure AsO at m/z 91 free from CoO interference
- Accurate spike recovery (1 ng/g As) achieved with increasing concentrations of Vitamin B12 in TQ-O_2 mode

Calibration and results for a Vitamin B12 supplement



- Sample prepared according to manufacturers instructions, then diluted 1:100 for analysis
- Sensitivity – 7000 cps/ppb
- BEC – 0.0002 ppb
- Spike recovery determined (at 10 ng/g As)
- Recovery compared with and without butanol addition to the diluent

Element	Mode	Result [ng·g^{-1}]	Spiked concentration [ng·g^{-1}]	Recovery [%]	Recovery with butanol [%]
As	TQ-O_2	0.019	9.87	179	99
As	SQ-KED	0.150	9.87	171	100
Cd	SQ-KED	Below IDL	3.29	97	98
Hg	SQ-KED	0.05	1.32	98	98
Pb	SQ-KED	0.1	6.58	105	107



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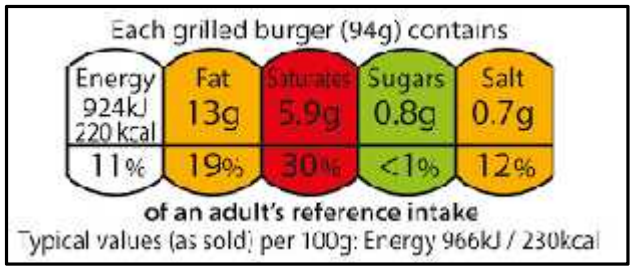
Elemental analysis of food samples

Country/Region Specific Legislation for Food

Gov. body/directive	Matrix	Elements
US FDA 21 CFR	•107 Infant Formula •136 Bakery Products •137 Cereal Flours •165 Bottled water •172 Bakers yeast •573 Animal feeds	•Fe, I, Na, K (chloride) •*Bromate*, Ca, Fe •*Bromate*, Ca, Fe •Fe, Mn, Zn, As, Sb, Ba, Be, Cd, Cr, Cu, Pb, Hg, Ni, Se, Tl, U •Zn, As, Cd, Se, Pb •*Se (IV, VI and yeast)*
US FDA: **Guidance for Industry** **Guidance docs** **Recommendations** **Action levels**	 •Candy •Shellfish (crustacean, molluscs) •Fish •Fish, wheat •Pottery leachate	 •Pb •As, Cd, Cr, Pb, Ni •Hg (*MeHg*) •Hg •Cd, Pb
EU 1881/2006 EC	•Variety defined foodstuffs	•Pb, Cd, Hg, inorganic Sn
WHO/FAO, JEFCA	•Acceptable DIs Food Additives	•As, Cd, Hg, Pb
FSANZ	•Reporting limits	•As, Sb, Cd, Cu, Pb, Hg, Se, Sn, Zn
Hong Kong Food Adulteration Legislations	•Variety defined foodstuffs	•As, Sb, Cd, Cr, Pb, Hg, Sn
Japan	•Potable and Drinking Waters •Plastics for milk storage	•*Cr(VI),* Cd, Hg, Pb, As, P, Zn, Fe, Cu, Mn, Ca, Mg, Se, B •As, heavy metals (Cd and Pb) Sb, Ge, *dibutyltin*

Food labelling information



Nutrition Facts

Serving Size 1 cup (228g)
Servings per Container 2

Amount Per Serving

Calories 280	**Calories from Fat** 120
	% Daily Value*
Total Fat 13g	20%
Saturated Fat 5g	25%
Trans Fat 2g	
Cholesterol 2mg	10%
Sodium 660mg	28%
Total Carbohydrate 31g	10%
Dietary Fiber 3g	0%
Sugars 5g	
Protein 5g	

Vitamin A 4%	Vitamin C 2%
Calcium 15%	Iron 4%

*Percent Daily Values are based on a 2,000-calorie diet. Your daily values may be higher or lower depending on your calorie needs.

	Calories:	2,000	2,500
Total Fat	Less than	65g	80g
Sat Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2,400mg	2,400mg
Total Carbohydrate		300g	375g
Fiber		25g	30g

Calories per gram:
Fat 9 • Carbohydrate 4 • Protein 4

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Analysis of elements in food stuff by ICP-OES

- ICP-OES is ideal for analysis of trace elements from sub ppm to % (in solid samples)
- Ideally use Duo view instrument – iCAP 7400 ICP-OES Duo
  - Axial view allows the lowest detection limits whilst radial view allows analysis of higher concentrations
  - Total dissolved solids is relatively low (1%)
- Samples prepared by microwave assisted acid digestion and diluted to 0.5% HNO_3 with DI water
- Creation of method using the standard sample introduction kit

Parameter	Setting
Pump Tubing (Standard)	Sample Tygon® orange/white Drain Tygon® white/white
Spraychamber	Glass cyclonic
Nebulizer	Glass concentric
Center Tube	2.0 mm
Pump Speed	50 rpm
Nebulizer Gas Flow	0.6 L·min^{-1}
Auxiliary Gas Flow	0.5 L·min^{-1}
Coolant Gas Flow	12 L·min^{-1}
RF Power	1150 W
Exposure Time	UV 15 s, Vis 5 s

Element	Wavelength (nm)	View
Ca	317.933	Radial
Cu	327.396	Axial
Fe	274.932	Radial
Mg	285.213	Radial
Mn	257.61	Axial
Ni	231.604	Axial
P	178.284	Axial
Zn	206.2	Axial

Analysis of elements in food stuff by ICP-OES Results

- MDLs sub ppm in solid & IDLs of sub ppb (Dilution factor of 100)
- Ability to analyze over a wide concertation range
- A simple method of analysis after a digestion

- All results in $mg \cdot kg^{-1}$. Total Diet (ARC182), Wheat Flour (NBS1567), Bovine Liver (NBS1577a).

Element	NBS1577a			NBS1567			ARC182			MDL
	Found in solid	CRM	Recovery (%)	Found in solid	CRM	Recovery (%)	Found in solid	CRM	Recovery (%)	in solid
Ca	133.6	120	111.33	195	190	102.63	2670	2860	93.36	0.99
Cu	153.3	158	97.03	2.105	2	105.25	N/A	N/A	N/A	0.16
Fe	192.9	194	99.43	18.86	18.3	103.06	N/A	N/A	N/A	4.3
Mg	576.5	600	96.08	N/A	N/A	N/A	719.2	785	91.62	0.46
Mn	10.14	9.9	102.42	8.634	8.5	101.58	12.98	12.9	100.62	0.01
Ni	N/A	N/A	N/A	0.1719	0.18	95.5	0.2863	0.271	105.65	0.03
P	11490	11100	103.51	N/A	N/A	N/A	N/A	N/A	N/A	0.24
Zn	122.2	123	99.35	10.96	10.6	103.4	29.16	28.9	100.9	0.03

ICP-MS Overview: Single and Triple Quadrupole ICP-MS

iCAP RQ ICP-MS

Innovative collision cell

Intuitive user-friendly software

Simplified power connections

Robust RF generator

Quick connect and push-fit sample intro components

Compact footprint

Bench-level easy-access interface

iCAP TQ ICP-MS

Built-in safety for handling reactive gases

4 mass flow controllers: He, O_2, H_2, NH_3

Additional quadrupole for superior interference removal

Analysis with SQ and TQ in a single sample run

Reaction Finder Software

Elemental impurities in Food by ICP-MS

- iCAP RQ ICP-MS using single He KED mode for analysis of all analytes regardless of concertation
  - Li, 0-100 µg·L^{-1} and Na, 0-100 mg·L^{-1}
- Samples prepared by microwave assisted acid digestion (0.5g sample → 50ml)

Parameter	Value
Forward Power	1500 W
Nebulizer Gas	0.9 L·min^{-1}
Auxiliary Gas	0.8 L·min^{-1}
Cool Gas Flow	14.0 L·min^{-1}
CRC Conditions	4.5 mL·min^{-1} at He, 3V KED
Sample Uptake/Wash Time	45 s each
Dwell Times	Optimized per analyte
Total Acquisition Time	3 min

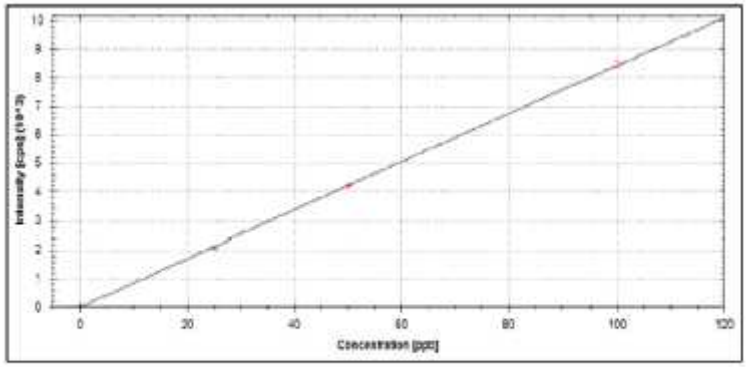


Figure 1. Calibration curve for ^{7}Li in He KED mode.

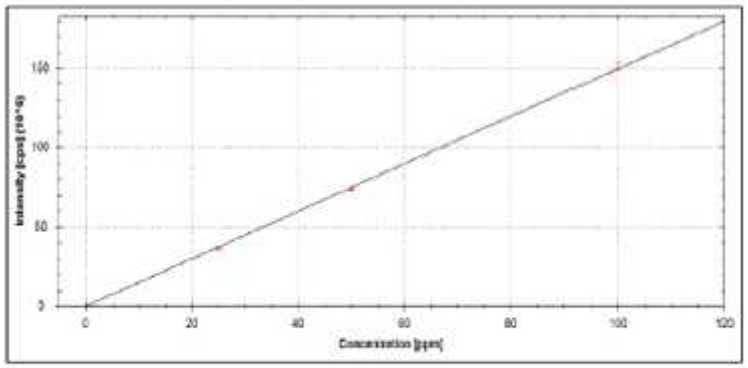


Figure 2. Calibration curve for ^{23}Na in He KED mode.

Elemental impurities in Food by ICP-MS Results

- MDL are orders magnitude lower than ICP-OES
- Ability to measure trace and major in one analysis
- Simple analysis using one analysis mode He KED

- All results in $\mu g \cdot L^{-1}$

Isotope	Method detection limit (MDL)	IRMM-804 Rice			NCS ZC73016 Chicken		
		Measured	Certified	% RSD	Measured	Certified	% RSD
^{7}Li	3	-	-	-	28 ± 1	34 ± 7	1.9
^{11}B	10	-	-	-	730 ± 23	760 ± 130	1.9
^{23}Na	0.3 (mg·L^{-1})	-	-	-	1310 ± 25	1440 ± 90	1.3
^{25}Mg	0.01 (mg·L^{-1})	-	-	-	1200 ± 22	1280 ± 100	1.1
^{31}P	0.6 (mg·L^{-1})	-	-	-	8950 ± 220	9600 ± 800	1.7
^{34}S	9 (mg·L^{-1})	-	-	-	8310 ± 220	8600 ± 500	1.9
^{39}K	0.5 (mg·L^{-1})	-	-	-	14000 ± 480	14600 ± 700	1.8
^{44}Ca	0.2 (mg·L^{-1})	-	-	-	200 ± 4	220 ± 20	1.7
^{52}Cr	0.2	-	-	-	450 ± 10	590 ± 110	0.9
^{55}Mn	1	35800 ± 470	34200 ± 2300	0.5	1640 ± 20	1650 ± 70	0.8
^{56}Fe	4	-	-	-	32700 ± 260	31300 ± 3000	0.7
^{60}Ni	2	-	-	-	153 ± 2	150 ± 30	0.8
^{65}Cu	0.8	2650 ± 30	2740 ± 240	0.4	1350 ± 11	1460 ± 120	0.7
^{66}Zn	2	23100 ± 270	23100 ± 1900	0.7	25300 ± 220	26000 ± 1000	0.6
^{75}As	0.2	52.3 ± 0.8	49 ± 4	1.4	115 ± 1	109 ± 13	0.9
^{78}Se	1	35.1 ± 1.0	38 (Reference value)	1.3	549 ± 11	490 ± 60	1.6
^{88}Sr	0.1	-	-	-	611 ± 11	640 ± 80	1.6
^{98}Mo	1	-	-	-	112 ± 1	110 ± 10	1.9
^{111}Cd	0.3	1620 ± 9	1610 ± 70	0.7	-	-	-
^{138}Ba	0.3	-	-	-	1610 ± 16	1500 ± 400	1.4
^{141}Pr	0.02	-	-	-	2.6 ± 0.1	2.8 ± 0.6	1.6
^{208}Pb	0.1	460 ± 8	420 ± 70	0.8	90.7 ± 2.0	110 ± 20	1.0

iCAP TQ ICP-MS - Food CRM NIST 1515 Apple leaves

NIST 1515 0.3g

↓

Add 4mL HNO_3 / 2mL HCl – Microwave

↓

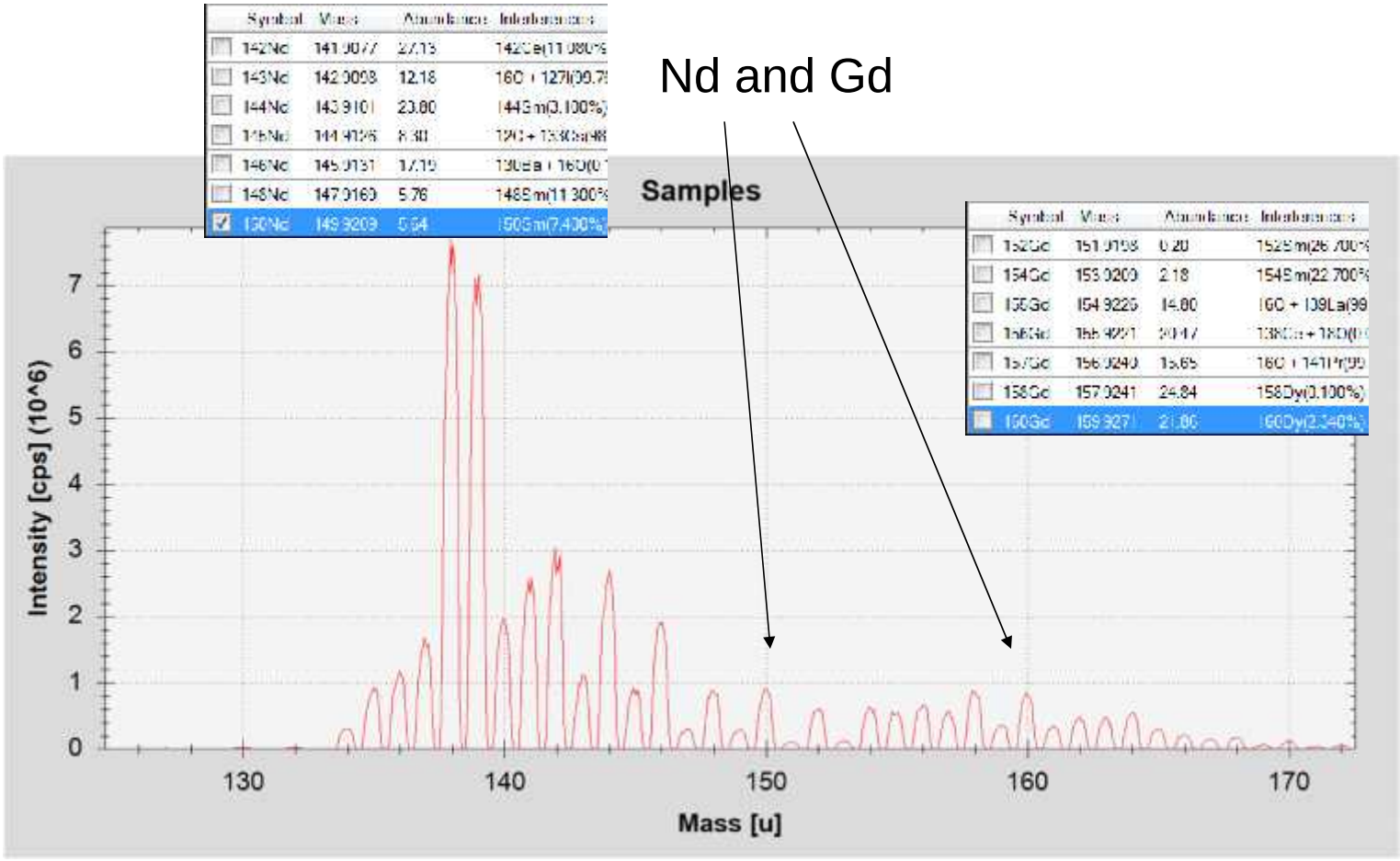
Add 3mL water

↓

10 fold dilution with 0.1% HNO_3 - total 100mL

Parameter	Value
Spray chamber	PFA cyclonic spray chamber cooled at 3°C
Nebulizer	100µL PFA nebulizer
Injector	2.0 mm Sapphire injector
Interface	Ni sampler and Ni skimmer with 2.8mm insert
TQ-O_2 Mass shift mode	Pure Oxygen 0.3mL/min
Dwell time	0.3 sec, 5 sweeps

Apple Leaves survey result

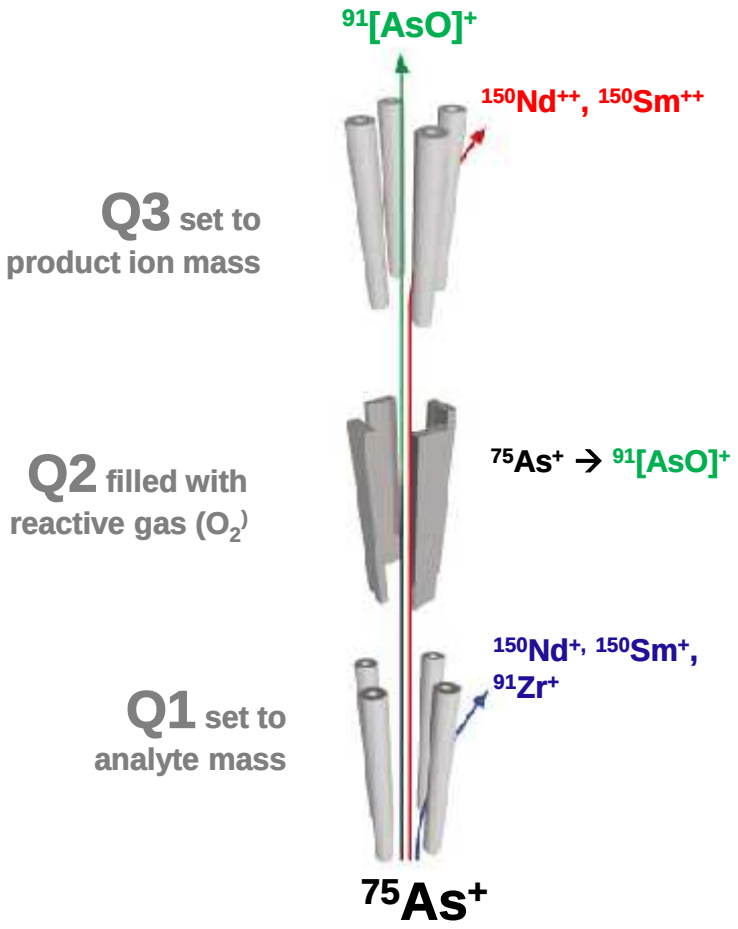


ThermoFisher SCIENTIFIC

Accurate Analysis of Arsenic and Selenium in REE Matrix

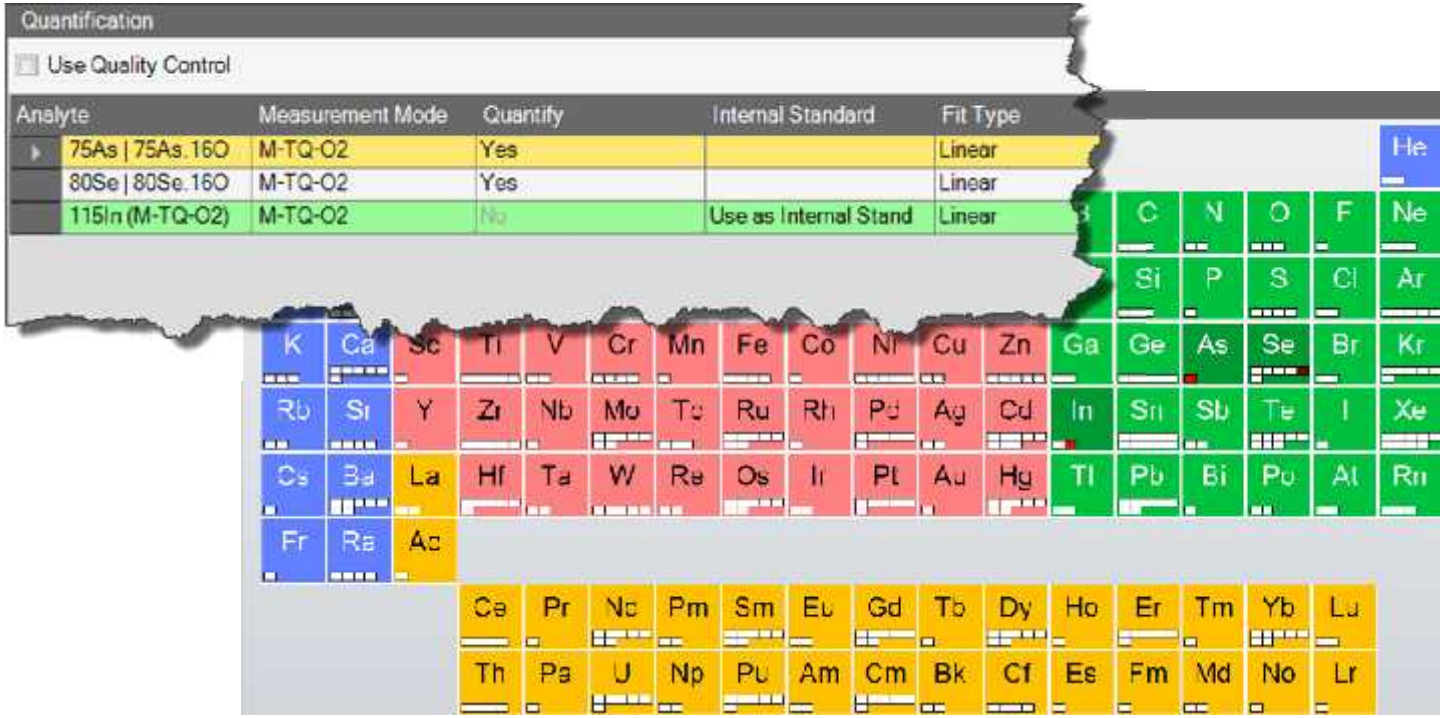
- Solution is TQ-ICP-MS:
  - Control ions entering the cell using Q1
  - Use O_2 to efficiently convert As and Se to AsO and SeO in Q2
  - REE^{++} species don‘t react
  - Selectively detect AsO and SeO free from REE^{++} interference, using Q3

Type of Interference	^{75}As	Measure Mode	^{78}Se	Measure Mode
Polyatomic	$^{40}Ar^{35}Cl$	KED	$^{40}Ar^{38}Ar$	KED, H_2
	$^{40}Ca^{35}Cl$			
Isobaric	$^{150}Nd^{2+}$	O_2	$^{156}Gd^{2+}$	O_2
	$^{150}Sm^{2+}$		$^{156}Dy^{2+}$	



ThermoFisher SCIENTIFIC

Analysis Se and As result of Apple leaves NIST 1515



Reaction finder choose the analysis mode automatically – improve *Ease of use* and *Productivity* (minimum method developing time)

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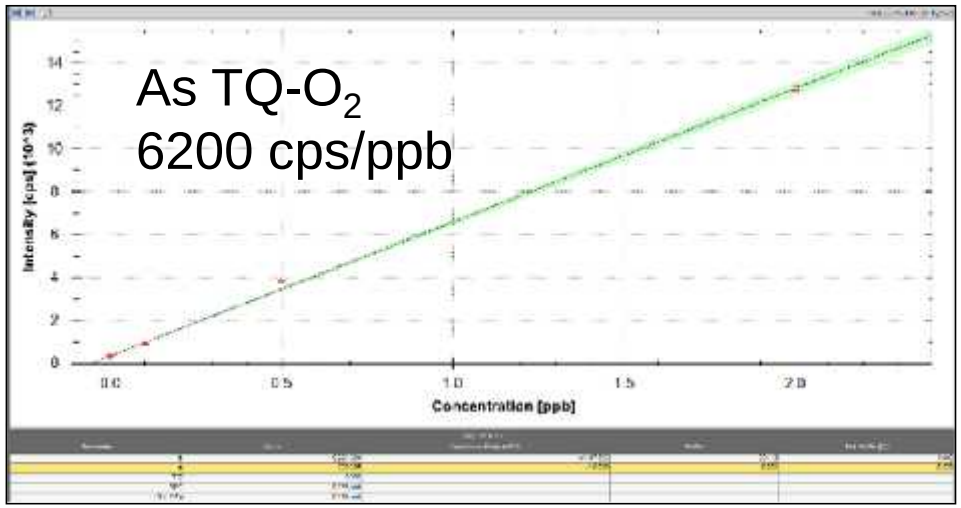
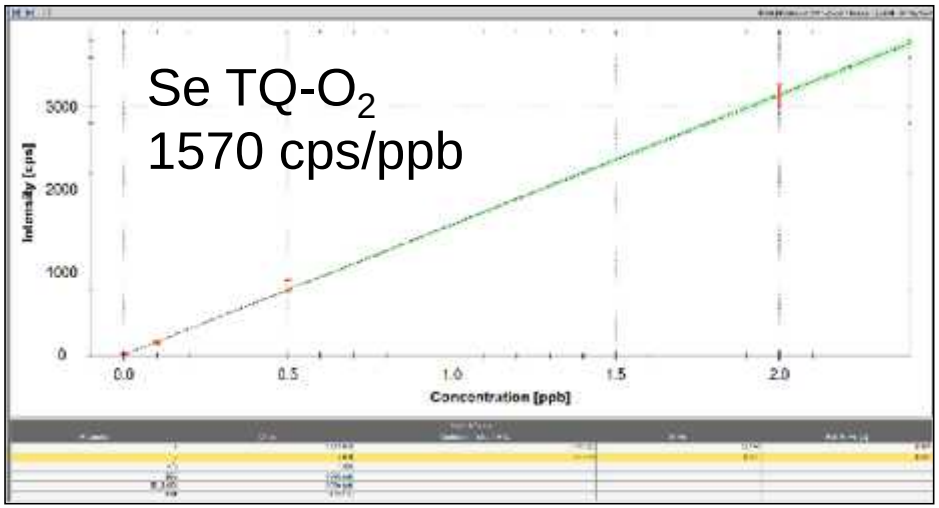
As and Se result KED vs TQ-O_2



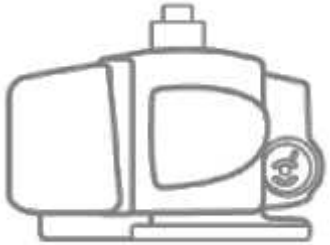


	Reference value mg/kg	SQ KED mode mg/kg	TQ-O2 mode mg/kg
As	0.038	**1730**	**0.037**
Se	0.050	**4800**	**0.049**

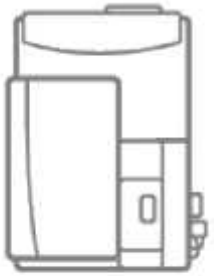
ThermoFisher SCIENTIFIC

Conclusions

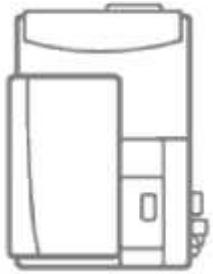
- ICP-OES
  - Fast multi element analysis
  - Detection limits in ppb range and below
  - For laboratories with low and high sample throughput



- SQ-ICP-MS
  - Detection limits in the ppt range
  - Wide quantification range – ideal for many different sample types
  - Single mode He KED with low mass cut off



- TQ-ICP-MS
  - Detection limits in the ppt range
  - Enhanced interference removal for challenging samples (TQ-ICP-MS)



Thank You!
Questions?

thermofisher.com/TEA