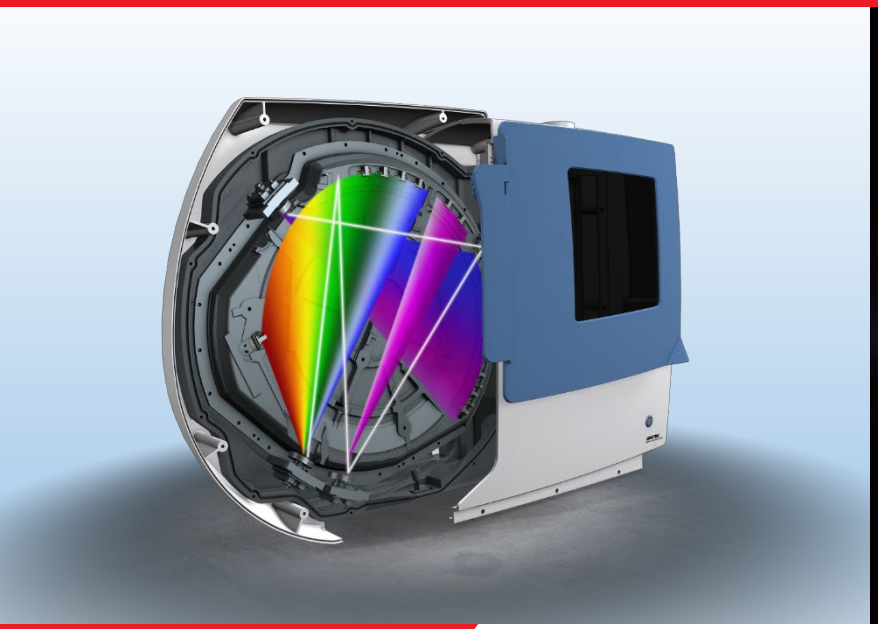
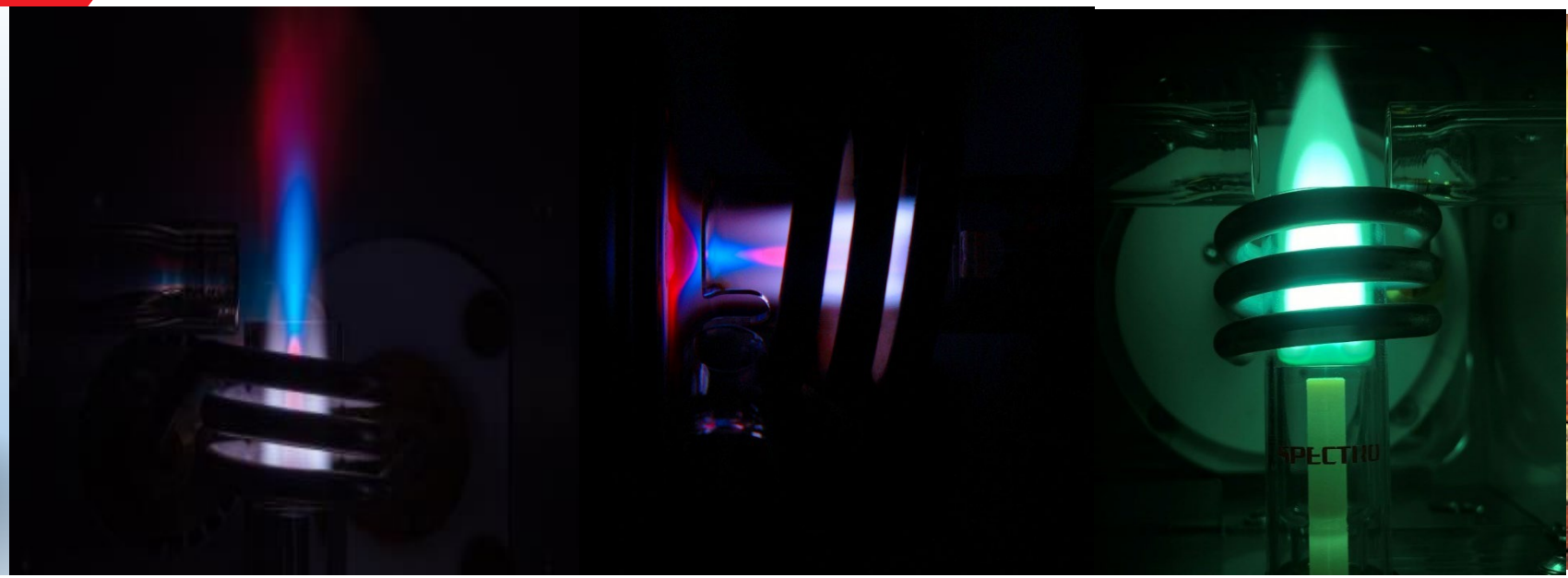
SPECTRO | AMETEK MATERIALS ANALYSIS DIVISION

LBMA ASSAYING & REFINING Conference 2025





Are there further challenges for ICP-OES in precious metals beyond the ISO regulations?

Dr. Dirk Wüstkamp, Senior Product Specialist ICP-OES, SPECTRO Analytical Instruments GmbH

ISO/TC 174 - Jewellery and precious metals

ISO/TC 174/WG 1
Methods for determining fineness

Precious metal	Fineness ‰	Recommended method
Ag	50 - 990	ISO DIS 19919 (DIN 32562)
	333 - 990	ISO 11427 + 13756
	800 - 990	ISO 11427 + 13756
	≥ 999	ISO 15096 + 18214
	999.9	ISO 15096
	999.99	ISO 15096
Au	100 - 999	ISO 11426
	50 - 990	ISO AWI 25644
	≥ 999	ISO 15093 + 18214
	999.9	ISO 15093
	999.99	ISO 15093
	999.999	ISO 5724
Pt	50 - 990	ISO 11210
	≤ 990	ISO 11494
	≥ 999	ISO 15093 + 18214
Pd	50 - 990	ISO 11490
	≤ 990	ISO 11495
	≥ 999	ISO 15093 + 18214

ISO 15096 – DSOI - Limit of detection in 50 g/L Silver

Element	LOD (3σ) in solution	LOD (3σ) solid material	Maximum limits according to ASTM 413-97a (Grade 99,99%)	Element	LOD (3σ) in solution	LOD (3σ) solid material	Maximum limits according to ASTM 413-97a (Grade 99,99%)
Line nm	mg/L	mg/kg	mg/kg	Line nm	mg/L	mg/kg	mg/kg
Al 167.078	0.0006	0.01	*	Mo 202.095	0.0007	0.01	*
As 189.042	0.003	0.07	*	Nb 316.340	0.002	0.05	*
Au 174.050	0.008	0.15	*	Ni 231.604	0.005	0.09	*
B 249.773	0.0013	0.03	*	P 177.495	0.002	0.04	*
Ba 233.527	0.0003	0.006	*	Pb 168.215	0.002	0.04	10
Be 234.861	0.000006	0.0001	*	Pd 324.270	0.025	0.5	10
Bi 223.061	0.005	0.09	5	Pt 214.423	0.002	0.05	*
Ca 396.847	0.002	0.05	*	Rh 233.477	0.015	0.3	*
Cd 214.438	0.0003	0.005	*	*Ru 240.272	0.024	0.47	*
Co 238.892	0.006	0.12	*	S 182.034	0.005	0.09	*
Cr 267.716	0.001	0.02	*	Sb 217.581	0.004	0.08	*
Cu 219.226	0.004	0.08	100	Se 196.090	0.004	0.07	5
Fe 259.941	0.0006	0.01	10	Sn 189.991	0.001	0.03	*
Ga 141.444	0.007	0.14	*	Sr 407.771	0.00008	0.002	*
Ge 164.919	0.004	0.08	*	Ta 226.230	0.004	0.09	*
Hf 264.141	0.002	0.04	*	Te 214.281	0.004	0.08	5
Hg 184.950	0.002	0.03	*	Ti 334.187	0.001	0.03	*
In 158.637	0.005	0.09	*	Tl 190.864	0.004	0.09	*
*Ir 183.250	0.002	0.05	*	V 292.402	0.001	0.03	*
Li 670.780	0.001	0.03	*	W 220.448	0.005	0.1	*
Mg 279.553	0.0004	0.008	*	Zn 213.856	0.0006	0.01	*
Mn 260.569	0.0003	0.005	*	Zr 339.198	0.002	0.04	*

*not defined in the ASTM method B413-97a

*(5) maximum Limits ASTM 99.99

What purity level can be assessed by ICP-OES ?

$$\sum LOD < 4\ mg/kg$$

99.9996

ASTM B413-97a

$$\sum LOD < 1\ mg/kg$$

99.9999

44 elements versus 7 elements

ISO 15093 - DSOI - Limit of detection in 20 g/L Gold

Element	LOD (3σ) in solution	LOD (3σ) solid material	Maximum limits according to ASTM 562-95 (Grade 99,995%)	Element	LOD (3σ) in solution	LOD (3σ) solid material	Maximum limits according to ASTM 562-95 (Grade 99,995%)
Line nm	mg/L	mg/kg	mg/kg	Line nm	mg/L	mg/kg	mg/kg
Ag 328.068	0.014	0.7	10	Ni 221.648	0.0007	0.04	3
Al 167.078	0.0002	0.01	*	P 177.495	0.0017	0.09	*
As 193.759	0.013	0.65	30	Pb 168.215	0.0018	0.09	10
B 182.641	0.0022	0.11	*	Pd 324.270	0.013	0.65	10
Ba 455.404	0.0003	0.02	*	Pt 177.708	0.012	0.6	*
Be 313.042	0.00005	0.003	*	Rh 343.489	0.033	1.65	*
Bi 223.061	0.013	0.65	10	Ru 240.272	0.005	0.25	*
Ca 396.847	0.001	0.05	*	S 182.034	0.0095	0.48	*
Cd 228.802	0.0005	0.03	*	Sb 206.833	0.0054	0.27	*
Co 230.786	0.0001	0.005	*	Se 196.090	0.0047	0.235	*
Cr 283.563	0.0013	0.07	3	Sn 189.991	0.0036	0.18	10
Cu 324.754	0.0026	0.13	10	Si 251.612	0.0054	0.27	10
Fe 239.562	0.001	0.05	10	Sr 421.552	0.0002	0.009	*
Ge 164.919	0.003	0.15	*	Ti 334.941	0.00037	0.02	*
Hg 194.227	0.0039	0.2	*	Tl 190.864	0.009	0.45	*
Ir 183.250	0.0038	0.19	*	V 292.402	0.001	0.05	*
Li 670.780	0.004	0.2	*	W 239.709	0.03	1.5	*
Mg 280.270	0.00034	0.02	10	Zn 213.856	0.0003	0.02	*
Mn 259.373	0.00022	0.01	3	Zr 343.823	0.0037	0.19	*
Mo 202.095	0.0025	0.13	*				

What purity level can be assessed by ICP-OES ?

$\sum LOD < 10\ mg/kg$

99.999

ASTM B 562 - 95

$\sum LOD < 4\ mg/kg$

99.9996

*(5) maximum Limits ASTM 99.995

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39 elements versus 13 elements

ISO 15093 - DSOI - Limit of detection in 20 g/L Platinum

Element	LOD (3σ) in solution	LOD (3σ) solid material	Maximum limits according to ASTM B561-94 (Grade 99.995%)	Element	LOD (3σ) in solution	LOD (3σ) solid material	Maximum limits according to ASTM B561-94 (Grade 99.995%)
Line nm	mg/L	mg/kg	mg/kg	Line nm	mg/L	mg/kg	mg/kg
Ag 338.289	0.014	0.72	30	Mo 281.615	0.004	0.19	40
Al 396.152	0.016	0.78	40	Nb 316.340	0.004	0.18	*
As 197.262	0.034	1.72	20	Ni 231.604	0.002	0.11	10
Au 267.595	0.007	0.34	50	P 213.618	0.018	0.90	*
B 249.677	0.005	0.26	*	Pb 220.353	0.015	0.74	10
Ba 455.404	0.0004	0.02	*	Pd 340.458	0.017	0.87	50
Be 313.042	0.000004	0.00	*	Rh 343.489	0.040	2.01	50
Bi 223.061	0.017	0.87	20	Ru 245.644	0.012	0.59	20
Ca 396.847	0.001	0.04	30	S 182.034	0.011	0.57	*
Cd 226.502	0.001	0.04	50	Sb 217.581	0.030	1.50	20
Co 238.892	0.002	0.10	*	Se 196.090	0.012	0.60	*
Cr 283.563	0.001	0.06	10	Sn 147.516	0.012	0.61	20
Cu 327.396	0.004	0.21	40	Sr 421.552	0.0002	0.01	*
Fe 261.187	0.004	0.22	50	Ta 240.063	0.006	0.31	*
Ga 417.206	0.032	1.61	*	Te 214.281	0.030	1.52	40
Ge 164.919	0.011	0.56	*	Ti 334.941	0.001	0.03	*
Hg 194.227	0.009	0.46	*	Tl 132.171	0.070	3.48	*
Ir 183.250	0.009	0.47	50	V 292.402	0.001	0.07	*
Li 670.780	0.002	0.09	*	W 220.448	0.009	0.46	*
Mg 280.270	0.001	0.07	30	Zn 213.856	0.001	0.07	20
Mn 257.611	0.000	0.02	10	Zr 339.198	0.001	0.07	*

What purity level can be assessed by ICP-OES ?

$$\sum LOD < 24\ mg/kg$$

99.997

ASTM B561-94

$$\sum LOD < 14\ mg/kg$$

99.998

*(25) maximum Limits ASTM 999.9

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42 elements versus 24 elements

ISO 15093 - DSOI - Limit of detection in 20 g/L Paladium

Element	LOD (3σ) in solution	LOD (3σ) solid material	Maximum limits according to ASTM B589-94 (Grade 99.995%)	Element	LOD (3σ) in solution	LOD (3σ) solid material	Maximum limits according to ASTM B589-94 (Grade 99.995%)
Line nm	mg/L	mg/kg	mg/kg	Line nm	mg/L	mg/kg	mg/kg
Ag 328.068	0.003	0.13	100	Mo 281.615	0.003	0.16	*
Al 167.078	0.003	0.16	50	Nb 269.706	0.003	0.14	*
As 228.812	0.014	0.68	*	Ni 221.648	0.001	0.06	50
Au 201.265	0.006	0.28	100	P 213.618	0.01	0.48	*
B 249.773	0.003	0.15	*	Pb 168.215	0.042	2.1	50
Ba 455.404	0.0004	0.02	*	Pt 177.708	0.004	0.21	*
Be 313.042	0.00001	0.0003	*	Re 227.525	0.004	0.19	*
Bi 223.061	0.013	0.64	*	Rh 343.489	0.025	1.27	*
Ca 393.366	0.001	0.04	50	Ru 240.272	0.007	0.37	*
Cd 214.438	0.001	0.03	*	S 182.034	0.006	0.29	*
Co 230.786	0.002	0.08	10	Sb 217.581	0.01	0.49	20
Cr 267.716	0.002	0.1	10	Se 196.090	0.063	3.13	*
Cu 327.396	0.004	0.21	50	Si 251.612	0.012	0.58	50
Fe 261.187	0.004	0.18	50	Sn 147.516	0.058	2.92	50
Ga 141.444	0.021	1.03	*	Sr 407.771	0.0001	0.01	*
Ge 209.426	0.011	0.55	*	Ta 240.063	0.011	0.55	*
Hf 277.336	0.004	0.18	*	Te 214.281	0.01	0.49	*
Hg 194.227	0.002	0.11	*	Ti 336.121	0.001	0.06	*
In 158.637	0.017	0.87	*	Tl 132.171	0.07	3.49	*
Ir 183.250	0.005	0.25	*	V 292.402	0.001	0.06	*
Li 670.780	0.003	0.13	*	W 207.911	0.004	0.21	*
Mg 279.553	0.002	0.08	50	Zn 213.856	0.0004	0.02	25
Mn 260.569	0.0004	0.02	10	Zr 343.823	0.002	0.08	*

What purity level can be assessed by ICP-OES ?

$$\sum LOD < 23\ mg/kg$$

99.997

ASTM B589-94

$$\sum LOD < 10\ mg/kg$$

99.999

*(25) maximum Limits ASTM 999.5

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42 elements versus 20 elements

other precious metals

ASTM – Fineness of other precious metal alloys

Precious metal	ASTM specification	Fineness ‰	Element
Rh	B616-96	998	Pt, In, Pd, Ru, Pb, Sn, Zn, As, Bi, Cd, Fe
		999	Pt, In, Pd, Ru, Pb, Sn, Zn, As, Bi, Cd, Fe, Si, Ag, Au, Cu, Ni, Te, Mg, Ca, Al, Cr, Mn, Sb, Co, B
		9995	Pt, In, Pd, Ru, Pb, Sn, Zn, As, Bi, Cd, Fe, Si, Ag, Au, Cu, Ni, Te, Mg, Ca, Al, Cr, Mn, Sb, Co, B
Ir	B671-81	998	Rh, Pt, Pd, Ru, Pb, Si, Sn, Zn, As, Bi, Cd, Fe
		999	Rh, Pt, Pd, Ru, Pb, Si, Sn, Zn, As, Bi, Cd, Fe, Ag, Au, Cu, Ni, Cr
Ru	B717-96	998	Rh, Pt, Pd, Ir, Os, Fe, Si, Cu, Ca, Sn, Ag, Na, Au
		999	Rh, Pt, Pd, Ir, Os, Fe, Si, Cu, Ca, Sn, Ag, Na, Au

ASTM B616-96 – DSOI - Limit of detection in 25 g/L in Rhodium

Element Line [nm]	LOD 3s in solution [µg/L]	LOD 3s solid material [mg/kg]	Max. limits ASTM B616-96 (Grade 99.95%) [mg/kg]	Element Line [nm]	LOD 3s in solution [µg/L]	LOD 3s solid material [mg/kg]	Max. limits ASTM B616-96 (Grade 99.95%) [mg/kg]
Ag 338.289	4.7	0.19	50	Na 589.592	11	0.42	*
Al 167.078	0.47	0.019	50	Nb 309.418	2.5	0.10	*
As 189.042	10	0.4	30	Ni 300.249	14	0.56	30
Au 242.795	11	0.45	30	P 138.147	57	2.3	*
B 182.641	2.2	0.089	10	Pb 220.353	9.0	0.36	50
Ba 455.404	0.21	0.008	*	Pd 324.270	13	0.51	50
Be 313.042	0.039	0.002	*	Pt 177.708	13	0.53	200
Bi 223.061	8.9	0.36	50	Re 221.426	14	0.56	*
Ca 396.847	0.24	0.009	50	Ru 240.272	8.6	0.34	100
Cd 226.502	1.2	0.047	50	S 166.668	29	1.2	*
Co 228.616	1.7	0.069	10	Sb 217.581	9.2	0.37	30
Cr 267.716	1.4	0.057	50	Se 196.090	31	1.2	*
Cu 324.754	1.2	0.047	50	Sn 140.045	7.1	0.29	30
Fe 238.204	2.5	0.10	30	Sr 421.552	0.16	0.006	*
Ge 164.919	6.4	0.26	*	Ta 226.230	12	0.49	*
Hf 264.141	5.9	0.24	*	Te170.000	29	1.2	50
Hg 194.227	4.6	0.18	*	Ti 334.941	0.58	0.023	*
Ir 224.268	9.3	0.37	200	Tl 132.171	66	2.6	*
K 769.896	62	2.5	*	V 292.464	2.3	0.092	*
Li 670.78	1.3	0.052	*	W 220.448	9.6	0.38	*
Mg 280.270	0.077	0.003	50	Zn 202.613	1.4	0.055	30
Mn 403.076	18	0.71	50	Zr 339.198	3.6	0.14	*
Mo 203.909	2.8	0.11	*				

not defined in the ASTM method B616-96

What purity level can be assessed by ICP-OES ?

$$\sum LOD < 20\ mg/kg$$

99.998

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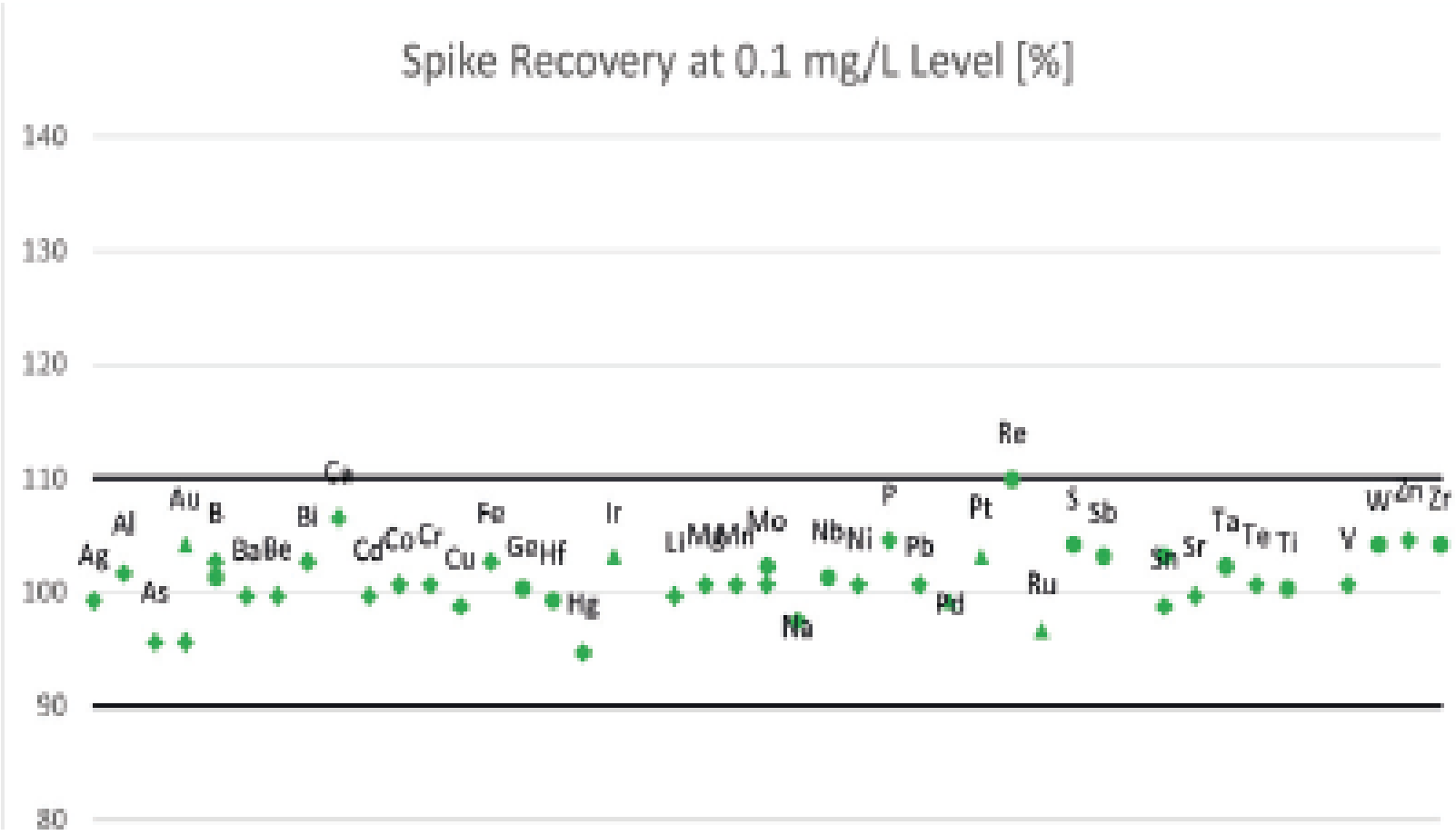
ASTM B616-96

$$\sum LOD < 7\ mg/kg$$

99.9993

45 elements versus 24 elements

ISO 15096 - DSOI – Spike Recovery in 25 g/L Rhodium



Spike Recovery Multi Element Standards

- CCS 2 0,1 mg/l ≙ 2 mg/kg
- CCS 5 0,1mg/l ≙ 2 mg/kg
- Merck VI 0,1mg/l ≙ 2 mg/kg

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ASTM B616-96 – DSOI - Limit of detection in 25 g/L in Iridium

Element Line [nm]	LOD 3s in solution [µg/L]	LOD 3s solid material [mg/kg]	Max. limits ASTM B671-81 (Grade 99,90%) [mg/kg]	Element Line [nm]	LOD 3s in solution [µg/L]	LOD 3s solid material [mg/kg]	Max. limits ASTM B671-81 (Grade 99,90%) [mg/kg]
Ag 328.068	3.4	0.14	200	Nb 316.340	2.1	0.083	*
Al 167.078	0.47	0.019	*	Ni 231.604	2.4	0.096	200
As 193.759	20	0.81	50	P 177.495	11	0.46	*
Au 174.050	71	2.9	200	Pb 405.778	76	3.0	150
B 249.773	11	0.43	*	Pd 340.458	11	0.43	500
Ba 455.404	0.19	0.007	*	Pt 299.797	27	1.1	500
Be 313.042	0.033	0.001	*	Re 227.525	5.3	0.21	*
Bi 223.061	30	1.2	50	Rh 343.489	33	1.3	500
Ca 393.366	0.52	0.021	*	Ru 240.272	8.4	0.34	500
Cd 226.502	12	0.49	50	S 143.328	69	2.8	*
Co 230.786	3.7	0.15	*	Sb 217.581	24	0.95	*
Cr 284.325	2.3	0.092	200	Se 196.090	46	1.8	*
Cu 327.396	2.1	0.084	200	Sn 189.991	11	0.45	100
Fe 259.941	8.1	0.32	100	Sr 421.552	0.12	0.005	*
Ge 265.118	5.4	0.22	*	Ta 240.063	6.6	0.27	*
Hf 264.141	6.1	0.24	*	Te 214.281	35	1.4	*
Hg 194.227	13	0.51	*	Ti 334.941	0.54	0.021	*
Li 670.780	1.0	0.041	*	Tl 190.864	38	1.5	*
Mg 280.270	0.14	0.006	*	V 311.071	1.0	0.041	*
Mn 260.569	0.29	0.012	*	W 224.875	13	0.51	*
Mo 202.095	3.5	0.14	*	Zn 202.613	1.3	0.053	100
Na 589.592	8.5	0.34	*	Zr 339.198	1.2	0.047	*

*not defined in the ASTM method B671-81

What purity level can be assessed by ICP-OES ?

$$\sum LOD < 25\ mg/kg$$

99.9975

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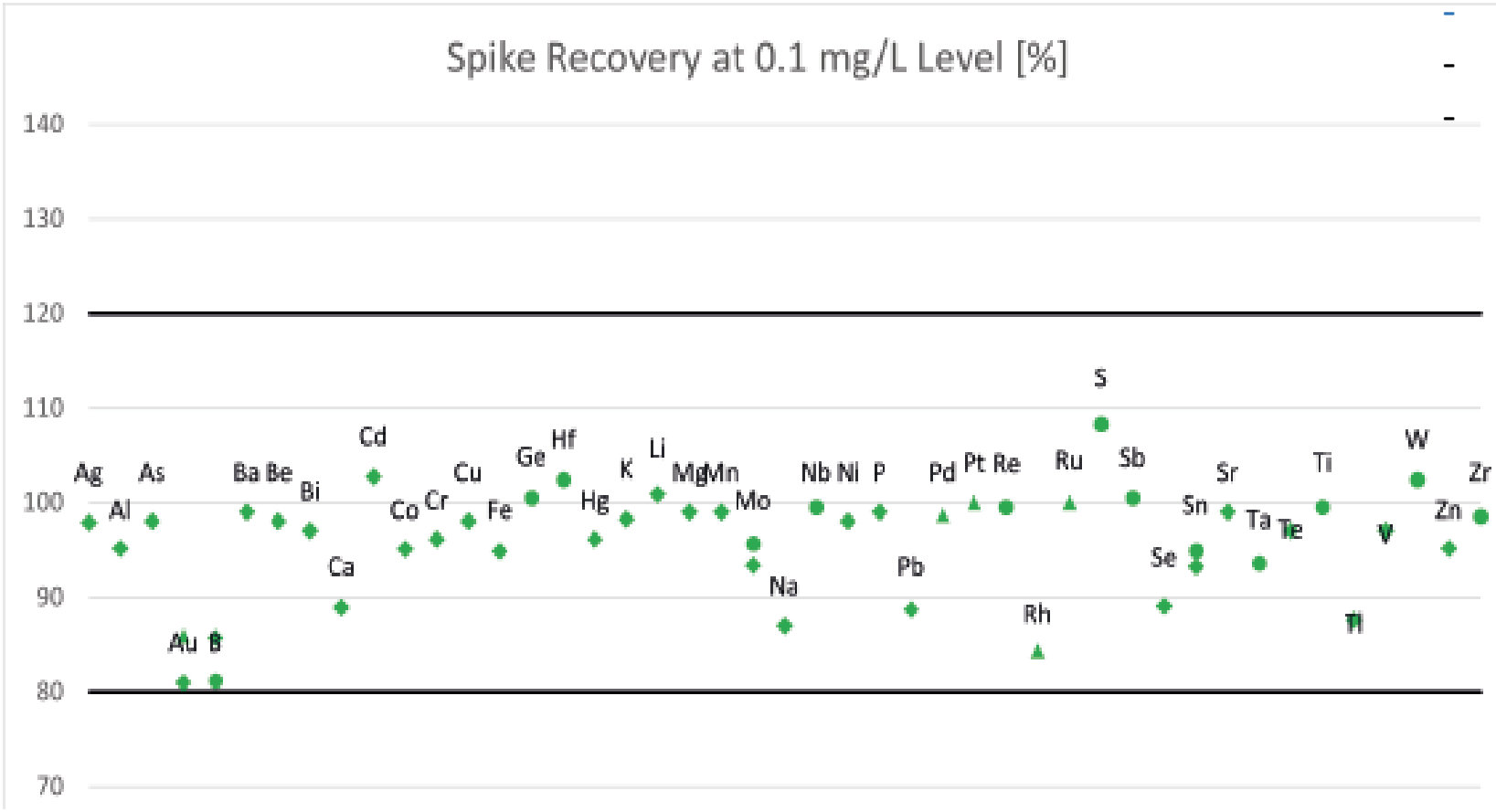
ASTM B671-81

$$\sum LOD < 13\ mg/kg$$

99.9987

44 elements versus 16 elements

ISO 15096 - DSOI – Spike Recovery in 25 g/L Iridium



Spike Recovery Multi Element Standards

- CCS 2 0,1 mg/l ≙ 2 mg/kg
- CCS 5 0,1mg/l ≙ 2 mg/kg
- Merck VI 0,1mg/l ≙ 2 mg/kg

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ASTM B616-96 – DSOI - Limit of detection in 25 g/L in Ruthenium

Element Line [nm]	LOD 3s in solution [µg/L]	LOD 3s solid material [mg/kg]	Max. limits ASTM B717-96 (Grade 99.90%) [mg/kg]	Element Line [nm]	LOD 3s in solution [µg/L]	LOD 3s solid material [mg/kg]	Max. limits ASTM B717-96 (Grade 99.90%) [mg/kg]
Ag 338.289	1.9	0.075	50	Nb 316.34	4.0	0.16	*
Al 167.078	0.59	0.024	*	Ni 221.648	3.5	0.14	*
As 189.042	20	0.82	*	P 177.495	8.6	0.34	*
Au 242.795	8.5	0.34	50	Pb 168.215	17	0.67	*
B 182.641	3.8	0.15	*	Pd 360,955	23	0.90	50
Ba 455.404	2.6	0.10	*	Pt 177.708	20	0.81	100
Be 313.042	0.045	0.002	*	Re 221.426	7.4	0.30	*
Bi 223.061	37	1.5	*	Rh 343.489	51	2.0	100
Ca 396.847	0.34	0.014	50	Sb 206.833	26	1.0	*
Cd 226.502	2.5	0.10	*	Se 196.090	52	2.1	*
Co 238.892	2.5	0.10	*	Si 251.612	47	1.9	50
Cr 283.563	1.7	0.066	*	Sn 140.045	8.1	0.32	50
Cu 324.754	2.0	0.080	50	Sr 407.771	0.093	0.004	*
Fe 239.562	23	0.92	200	Ta 226.230	12	0.47	*
Ge 164.919	5.9	0.24	*	Te 214.281	48	1.9	*
Hf 277.336	9.2	0.37	*	Ti 334.941	1.2	0.049	*
Hg 184.950	9.3	0.37	*	Tl 190.864	190.864	190.864	*
Ir 212.681	15	0.58	50	V 309.311	0.82	0.033	*
Li 670.780	1.8	0.072	*	W 207.911	16	0.63	*
Mg 279.553	0.32	0.013	*	Zn 202.613	1.5	0.060	*
Mn 260.569	1.6	0.062	*	Zr 257.139	9.6	0.39	*
Mo 281.615	4.9	0.20	*				

*not defined in the ASTM method – B717 - 96

What purity level can be assessed by ICP-OES ?

$$\sum LOD < 23\ mg/kg$$

99.997

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ASTM B616-96

$$\sum LOD < 8\ mg/kg$$

99.9992

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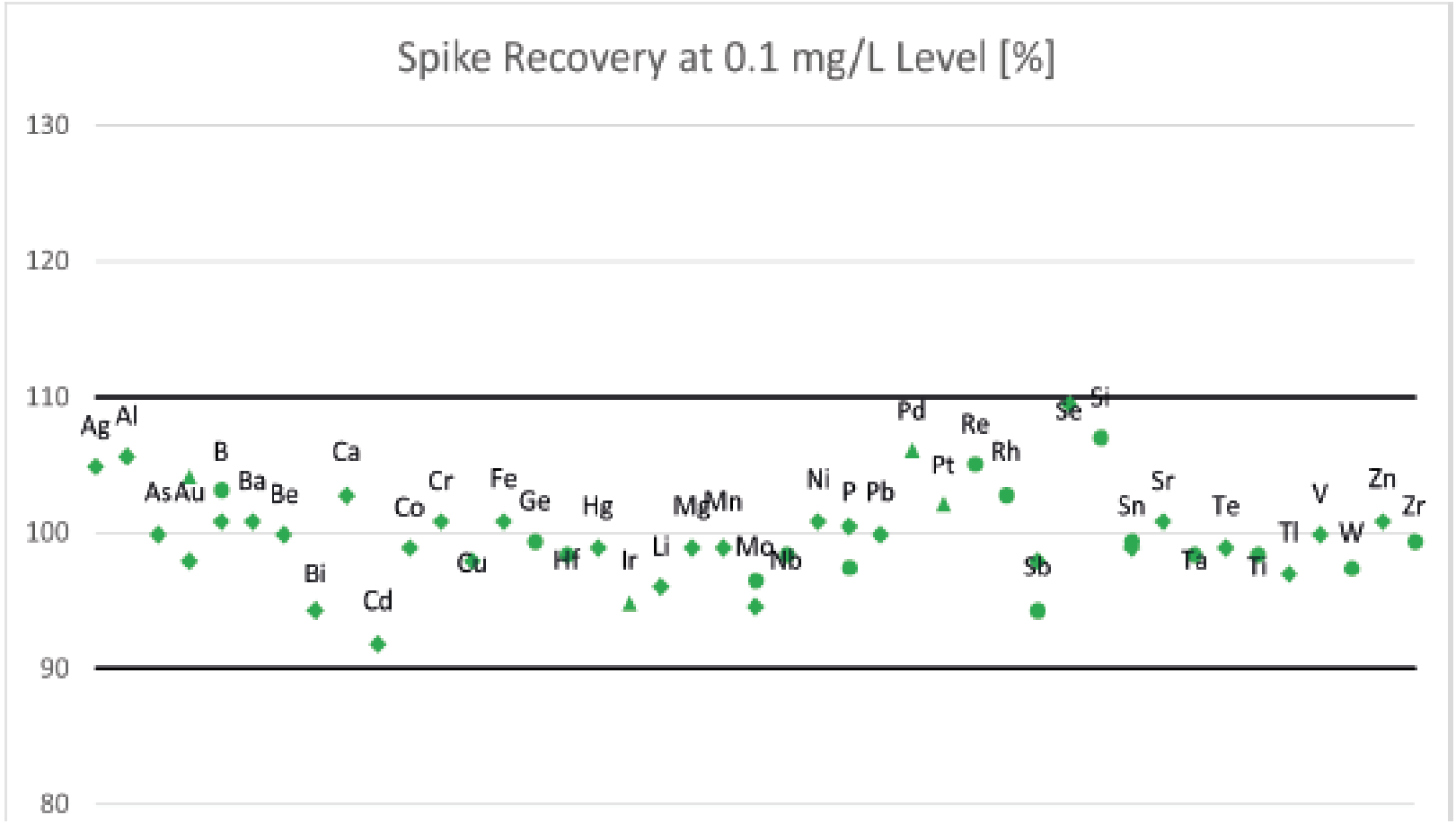
43 elements versus 11 elements

ISO 15096 - DSOI – Spike Recovery in 25 g/L Ruthenium



Spike Recovery Multi Element Standards

- CCS 2 0,1 mg/l ≙ 2 mg/kg
- CCS 5 0,1mg/l ≙ 2 mg/kg
- Merck VI 0,1mg/l ≙ 2 mg/kg

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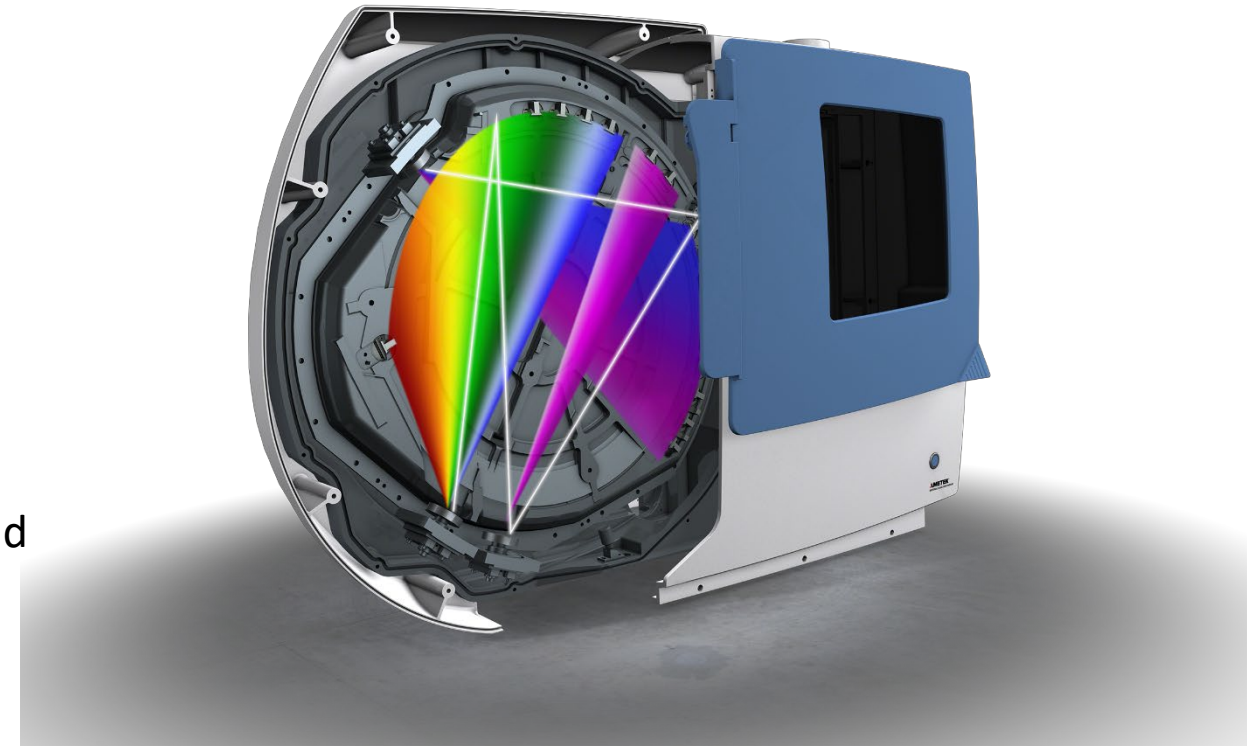
Bracketing - Highest accuracy and precision

Procedure described in :

- **ISO 11494** **Platinum in alloys**
- **ISO 11495** **Palladium in alloys**
- **ISO DIS 19919** **Silver in alloys**
- **ISO AWI 25644** **Gold in alloys**

General requirements:

- Mandatory use of an internal standard.
- High precision, weight-based preparations (analyte and internal standard).
- Repeated measurements (“cycles”) of the sample and two standards of a lower and higher concentration.

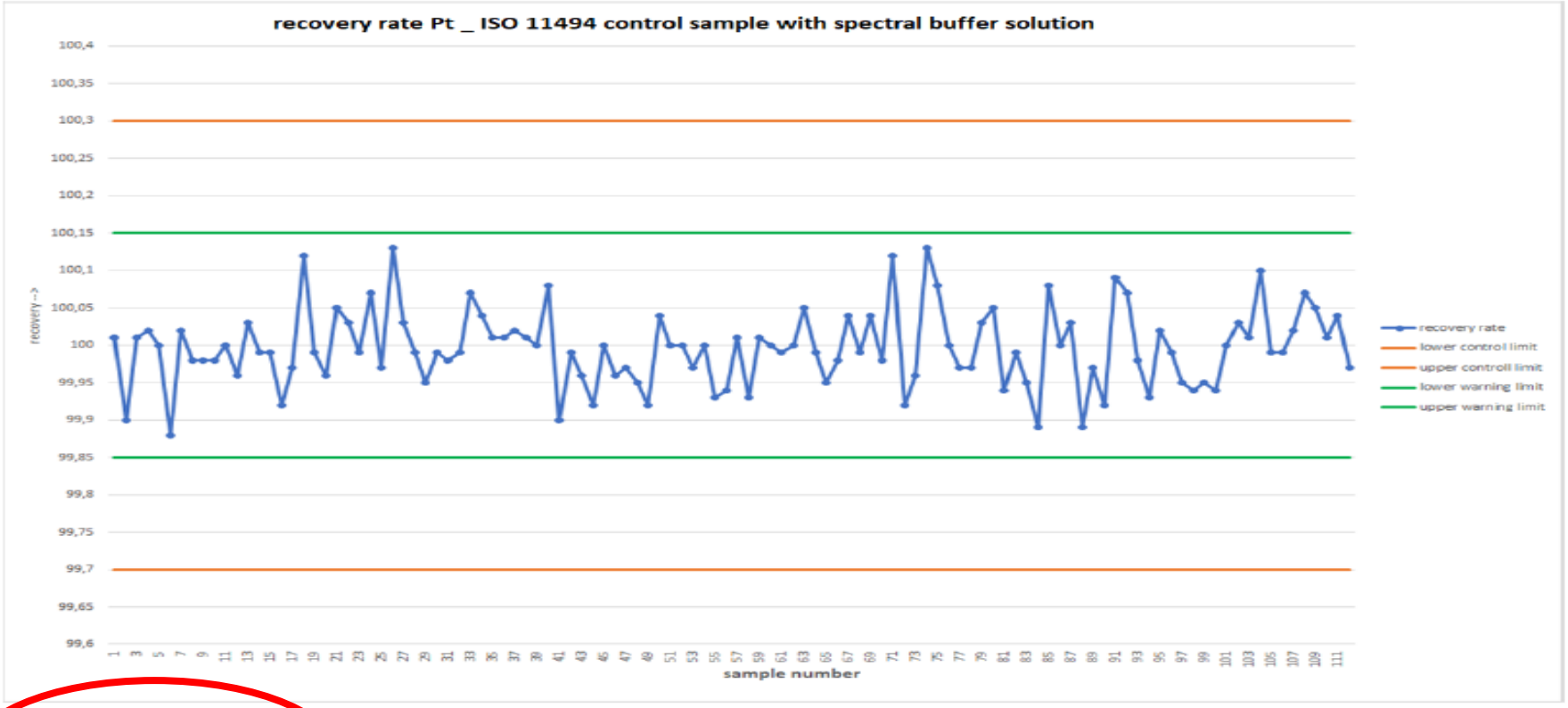


Consideration of the expanded uncertainty of measurement ISO 11494

Platinum by ICP bracketing

Agosi
Part of Umicore

Consideration of the expanded uncertainty of measurement - ISO 11494



Epanded Uncertainty Ucs
UCS = 2* Uc = 0,10 %
Uc= combined uncerainty

umicore

SPECTRO | AMETEK
MATERIALS ANALYSIS DIVISION

ISO CD 19919 – ILS Silver-wire (Ag/Cu/Zn)

Comparison of Potentiometry versus ICP bracketing

Laboratory	All	Potentiometry	ICP-OES
average M [g/kg]*	935,26	935,33	935,18
M+SD*	935,8	935,8	935,6
M-SD	934,7	934,9	934,7
Max**	936,9	936,9	936,7
Min**	933,8	934,2	933,8
Quantity**	105	73	32

	Ag g/kg	Cu g/kg	Zn g/kg	total ‰
1	935.1	48.9	15.6	
2	935.3	48.8	15.8	
3	935.1	48.8	15.7	
4	935.7	48.6	15.6	
5	935.0	48.7	15.7	
6	935.3	48.8	15.6	
7	935.1	48.9	15.8	
8	935.5	48.6	15.7	
mean	**935.26**	**48.8**	**15.7**	**999.7**
SD	0.24	0.12	0.08	

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ISO CD 19919 – ILS Silver-wire (Ag/Cu/Zn)

Comparison of Potentiometry versus ICP bracketing

Analysis results [g/kg]																	
Laboratory	l 2	Labor 14	l 6	Labor 13	Labor 1	Labor 15	Labor 9	Labor 4	l 4	l 1	Labor 6	l 5	Labor 5	Labor 3	Labor 7	l 3	Labor 10	Labor 2
single results - Analysis [g/kg]																		
	934,6	934,8	934,6	935,0	935,1	935,0	935,0	935,3	935,8	935,1	935,2	935,5	935,3	935,4	935,7	936,1	935,0	934,7
	933,8	934,2	935,2	935,0	935,0	935,0	935,0	935,3	934,4	935,3	934,8	934,6	935,0	935,6	935,8	934,4	936,3	936,5
	934,8	935,4	934,6	935,1	935,0	934,9	935,0	935,1	935,7	935,1	935,6	935,2	935,5	935,5	935,6	935,9	936,1	935,8
	934,0	934,5	935,4	934,9	935,0	935,0	935,2	934,9	935,0	935,7	935,5	935,8	935,2	935,4	935,9	936,7	936,9	936,8
	935,3	934,9		935,2	934,9	935,3	935,2	935,5		935,0			935,5	935,3	935,9		935,8	936,2
	934,6	935,4		935,0	935,3	935,2		934,9		935,3			935,6	935,4	935,5		934,8	936,0
	935,1			935,1				935,2		935,1								
	934,4			935,1				935,2		935,5								
average [g/kg]	**934,58**	**934,90**	**934,95**	**935,05**	**935,05**	**935,08**	**935,10**	**935,17**	**935,22**	**935,26**	**935,27**	**935,27**	**935,35**	**935,45**	**935,70**	**935,78**	**935,82**	**936,00**
s [g/kg]	0,51	0,48	0,41	0,77	0,14	0,15	0,11	0,20	0,66	0,24	0,35	0,54	0,23	0,11	0,16	1,01	0,79	0,73
sr [%]	0,05 %	0,05 %	0,04 %	0,08 %	0,01 %	0,02 %	0,01 %	0,02 %	0,07 %	0,03 %	0,04 %	0,06 %	0,02 %	0,01 %	0,02 %	0,11 %	0,08 %	0,08 %
Max [g/kg]	935,30	935,44	935,40	936,55	935,30	935,30	935,23	935,46	935,80	935,70	935,57	935,81	935,60	935,63	935,89	936,74	936,91	936,80
Min [g/kg]	933,80	934,25	934,60	934,60	934,90	934,91	935,00	934,89	934,39	935,00	934,79	934,57	935,00	935,34	935,48	934,35	934,79	934,70
Diff - Max-Min	1,50	1,19	0,80	1,95	0,40	0,39	0,23	0,57	1,41	0,70	0,77	1,24	0,60	0,29	0,41	2,39	2,12	2,10
quantity [n]	8	6	4	8	6	6	5	8	4	8	4	4	6	6	6	4	6	6
average M [g/kg]*	935,26	935,26	935,26	935,26	**935,26**	935,26	935,26	935,26	935,26	935,26	935,26	935,26	935,26	935,26	935,26	935,26	935,26	935,26
M+SD*	935,79	935,79	935,79	935,79	935,79	935,79	935,79	935,79	935,79	935,79	935,79	935,79	935,79	935,79	935,79	935,79	935,79	935,79
M-SD	934,72	934,72	934,72	934,72	934,72	934,72	934,72	934,72	934,72	934,72	934,72	934,72	934,72	934,72	934,72	934,72	934,72	934,72
Max**	936,91																	
Min**	933,8																	
Quantity**	105																	

Grubbs 97,5%

*outlier-adjusted (calculated from laboratory mean values)

**calculated from individual values

Measurement uncertainty at internal reference material

Comparison of Potentiometry versus ICP bracketing

ICP-OES

	Ag	Cu	Sn	Zn	total
Results in g/kg	602,0	228,9	29,3	140,2	1000,4
	602,7	228,7	28,7	139,6	999,7

Titration

	Ag
Results in g/kg	602,2
	602,3

Measurement uncertainty	1,3 ‰	0,5 ‰

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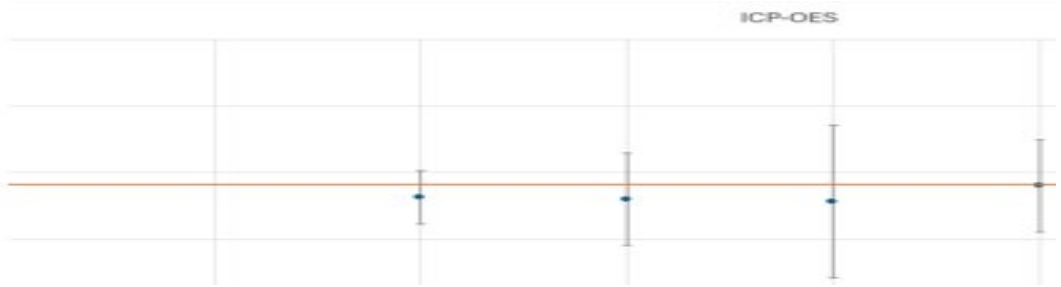
ISO AWI 25644 – ILS gold-wire (Au/Ag/Cu/Pd/Zn)

Comparison of fire assay versus ICP bracketing



	Ag	Au 267	Cu	Pd	Zn	total
	g/kg	g/kg	g/kg	g/kg	g/kg	g/kg
1	29.07	751.4	86.17	129.6	2.89	999.13
2	29.08	752.6	86.07	129.7	2.89	1000.34
3	29.09	751.2	86.14	129.6	2.86	998.89
4	29.61	752.1	86.33	129.6	2.89	1000.53
5	29.68	752.4	86.30	129.7	2.89	1000.97
6	29.62	752.6	86.12	129.7	2.92	1000.96
7	29.70	750.8	86.22	129.5	2.85	999.07
8	29.62	751.6	86.18	129.6	2.87	999.87
mean	29.43	751.8	86.19	129.6	2.88	999.97
SD	0.28	0.64	0.09	0.07	0.02	0.80
RSD	0.94	0.09	0.10	0.05	0.71	0.08

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Multi-element bracketing

Example for precious metal scrap
same procedure as in single element bracketing

	Pt	Ag	Au	Pd	Ir	Rh	Ru
g/kg	**207,94**	**32,83**	**81,85**	**73,87**	**47,92**	**11,82**	**18,66**
mg/l	80,90	12,77	31,85	28,74	18,64	4,60	7,26
RSD	0,07	0,12	0,13	0,10	0,23	0,26	0,46

SPECTRO ICP-OES