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Inductively Coupled Plasma Mass Spectrometry ICPMS-2050 LF

Application News

Determination of 23 Nutritional, Essential and Toxic Elements in Urine by ICP-MS Using Alkaline Dilution

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User Benefits

- Urine calibrator allows for simple preparation and quick measurement of 23 elements
- Alkaline media ensures safe determination of iodine and excellent mercury washout capabilities
- LabSolutions™ ICPMS allows for high degree of automation by Extended Rinsing function and e.g. control of QC sample or internal standard recovery

■ Introduction

The analysis of nutritional, essential, and toxic elements in urine is a critical tool for assessing human health, environmental exposure, and metabolic function. Urine serves as a non-invasive biological matrix that reflects the body's excretion of trace elements, providing valuable insights into nutritional deficiencies, toxic metal exposure, and the status of essential minerals.

Inductively Coupled Plasma Mass Spectrometry (ICP-MS) is a highly sensitive and precise analytical technique that enables the detection of trace elements at ultra-low concentrations, making it ideal for comprehensive urine analysis.

■ Urine Composition

Urine is mainly composed of water, which accounts for approximately 91–96% of its total volume. The remaining portion consists of inorganic salts, urea, organic compounds, and organic ammonium salts.[1)]

Among the organic compounds, urea is the most abundant, typically present at concentrations of 9–23 g/L.

Inorganic salts and electrolytes are also significant constituents of urine. The total dissolved solids (TDS) in urine ranges between 20 and 40 g/L. Sodium and chloride are the predominant ions, with sodium levels ranging from 1 to 4 g/L and chloride levels from 2 to 8 g/L. Potassium is another key electrolyte, typically present at concentrations of 1–3 g/L. Other inorganic substances include calcium, magnesium, phosphate, and sulfate, which are excreted in smaller amounts.[2)]

Trace elements such as zinc, copper, and selenium are present in minute quantities, typically in the microgram per liter range, while toxic elements like lead, mercury, and cadmium are usually found at even lower levels under normal conditions.

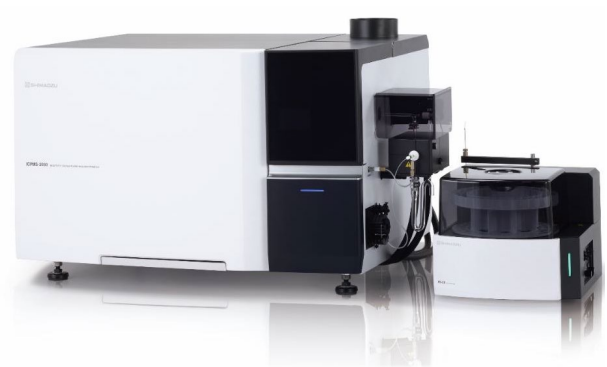

Fig. 1 ICPMS-2050 LF with AS-20 Autosampler

■ Sample Preparation and Calibration

Considering the elevated TDS level, sample dilution is recommended to achieve a stable and durable analysis method and subsequently to increase overall sample throughput.

While applying acidic dilution to body fluid samples might cause clogging the sample line or nebulizer due to denatured proteins, alkaline dilution media (Table 1) was selected to 10-fold dilute the urine samples. Alkaline media also allows for stabilization of further elements like iodine, which is partially volatile in acidic media.[3)]

Table 1 Components of Alkaline Diluent prepared in Water*1

Reagent	Description	Purpose
Ammonia	25% (v/v), Suprapur®, Merck, Germany	adjusts alkaline pH
Triton®X-100	p.A., Merck, Belgium	Homogenizes sample & supports lyse of cells
EDTA (Na-free)	>99.999% Sigma-Aldrich, USA	stabilizes ions in solution
Isopropanol	Electronic Grade SLSI, VWR, USA	compensates carbon enhancement effect*2

*1 All solutions are prepared using ASTM Type 1 ultrapure water (18.2 MΩ resistivity, Arium® Pro VF, Sartorius AG).

*2 Carbon present in sample will otherwise increase response of less ionized elements (e.g. As, Se), resulting in false positives.

For matrix matched calibration, Urine Calibrator was injected in different dilution levels (ClinCal® 9988, Recipe, cf. Table 2). For quality control, Urine Control Level 1-2 (ClinCheck® 8847-8849, Recipe) and Trace Elements in urine L-2 (Seronorm™, SERO) were measured in beginning and end of the batch (more frequent repetitions can also be selected).

Table 2 Calibration scheme using Recipe® ClinCal® 9988 Urine Calibrator in different dilution levels, in µg/L

Element	CAL 1 Diluent Blank	Cal 2 12.5%	Cal 3 25%	Cal 4 50%	Cal 5 100%
Al	0	15.8	31.5	63.0	126
As	0	9.1	18.1	36.3	72.5
Ba	0	9.7	19.4	38.9	77.7
Be	0	0.04	0.08	0.15	0.30
Cd	0	2.4	4.8	9.7	19.3
Co	0	2.5	5.0	9.9	19.8
Cr	0	2.5	5.1	10.2	20.3
Cu	0	18.4	36.8	73.5	147
Fe	0	32.5	65.0	130	260
Hg	0	4.1	8.1	16.3	32.5
Hg	single element solution prepared in diluent only →		Cal 6 2.5	Cal 7 10.0	Cal8 25.0
I	0	75.3	151	301	602
Mg	0	7475	14950	29900	59800
Mn	0	2.5	5.1	10.2	20.3
Mo	0	14.9	29.8	59.5	119
Ni	0	3.7	7.3	14.7	29.3
Pb	0	13.8	27.5	55.0	110
Pt	0	0.24	0.48	0.95	1.90
Sb	0	7.4	14.7	29.5	58.9
Se	0	13.5	27.0	54.0	108
Sn	0	1.6	3.2	6.4	12.8
Tl	0	3.0	6.0	12.0	23.9
V	0	7.8	15.6	31.2	62.4
Zn	0	83.5	167	334	668

■ Configuration & Measurement Condition

The ICPMS-2050 LF system configuration is summarized in Table 3. More than 20 elements have been selected for quantification (Table 4).

To remove interferences the ICPMS-2050 highly efficient collision- and reaction cell was applied by adding He or H_2.

In most cases the trace region is of interest. To improve the precision in the low-end trace region all calibration curves (Fig. 2) are inversely weighted (1/I).

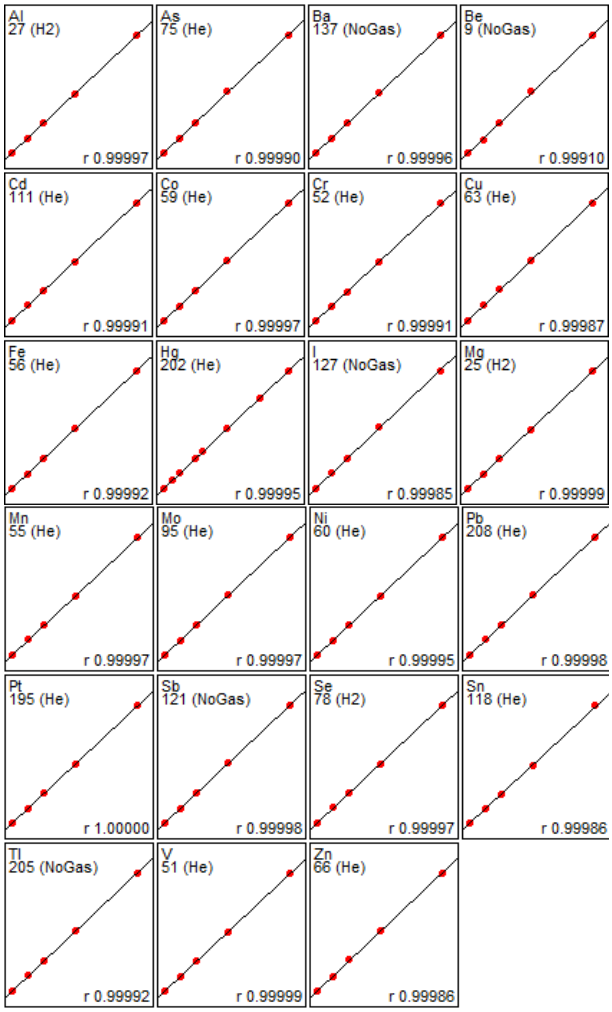

Fig. 2 Calibration Curves

Table 3 ICPMS-2050 LF Configuration and Basic Method Settings

Autosampler	:	AS-20 Round Table / Dual Rinse with 5x spacer for low dead volume
Spray Chamber	:	Cyclonic Twister
Chamber Temperature	:	5 °C
Nebulizer	:	Coaxial 04UES, ~ 0.4 ml/min
Peristaltic Pump	:	4 Channels, 12-roller @ 20 rpm
Internal Standard Tubing	:	PVC, flared-end, orange-blue
Sample Tubing	:	PVC, flared-end, black-black
Drain	:	Automatic overflow type
Torch	:	Shimadzu Mini-Torch
Cone Material	:	Ni
Sampling Depth	:	9.0 mm
RF-Power	:	1.2 kW
Plasma Gas	:	Ar 9.00 L/min
Auxiliary Gas	:	Ar 1.10 L/min
Carrier Gas	:	Ar 0.85 L/min
Cell Gas	:	He 6.0 mL/min H_2 7.0 mL/min
Cell Voltage	:	-21.0 V
Energy Filter	:	7.0 V

Table 4 Elements and Isotopes

Element	Isotope	Integration time [s]	Cell Gas	Internal Standard
Al	27	3	H_2	^{45}Sc
As	75	0.3	He	^{89}Y
Ba	137	0.1	NoGas	^{103}Rh
Be	9	3	NoGas	^{45}Sc
Cd	111	2	He	^{103}Rh
Co	59	0.5	He	^{45}Sc
Cr	52	1	He	^{103}Rh
Cu	63	0.1	He	^{89}Y
Fe	56	0.2	He	^{45}Sc
Hg	202	0.5	He	^{193}Ir
I	127	0.1	NoGas	^{103}Rh
Mg	25	0.1	H_2	^{45}Sc
Mn	55	2	He	^{45}Sc
Mo	95	0.2	He	^{89}Y
Ni	60	0.5	He	^{89}Y
Pb	208	0.2	He	^{193}Ir
Pt	195	3	He	^{193}Ir
Sb	121	0.2	NoGas	^{103}Rh
Se	78	1	H_2	^{89}Y
Sn	118	1	He	^{103}Rh
Tl	205	0.1	NoGas	^{193}Ir
V	51	1	He	^{45}Sc
Zn	66	0.1	He	^{89}Y

■ Results and Discussion

Influence of Sample Matrix

The calibration was created by simple dilution of reference material. Thus, the matrix content is given in Cal5 but reduced for lower concentration levels (Cal 2 – Cal 4).

A complementary matrix-free calibration is analyzed for Mercury (Cal 6 – Cal 8) in a similar concentration range within the same method.

The results of both approaches are combined (Fig. 2, Hg) in one plot and show perfect alignment, which demonstrates the system and method parameters are well selected to compensate even different salt levels and give a further prove for the ability to allow for a precisely determination of mercury.

Reduction of Memory Effect and Carry-Over

Mercury is well known as being affected by stronger memory effects, possibly resulting in stronger carry-over contamination after overrange samples.

Using alkaline media reduces the memory effect and its negative consequences. For example, measuring a blank sample after measuring Cal5 sample (Hg 32.5ppb), the carry-over is below 0.1%.

In addition, the LabSolutions™ Extended Rinsing function allows to automatically run an additional rinsing steps after a specified threshold is exceeded. In this method, the threshold was selected to be 1.3 times the maximum upper concentration of calibration curve, to ensure low carry-over even for higher concentrated samples.

Sensitivity, Stability and QC-Recovery

In general, the method is developed to analyze the usual reference ranges (Table 5). The ICPMS-2050 LF sensitivity is determined by standard deviation of the calibration curve blank sample. Because samples and reference samples are treated in the same way, the dilution factor can be disregarded, allowing to use the given limit of quantification (LOQ) as approximation for the method quantification limit (MQL).

Table 5 ICPMS-2050 LF method sensitivity for undiluted urine and common reference ranges [µg/L]

Element	LOD (3s) ≈ MDL	LOQ (10s) ≈ MQL	Common Reference Range[4)]	ICPMS-2050 LF suitable?
Al	0.8	2.8	< 15.0	●
As	0.05	0.15	< 15.0	●
Ba	0.04	0.12	< 10.0	●
Be	0.001	0.003	< 0.05	●
Cd	0.008	0.026	< 0.8	●
Co	0.07	0.23	< 1.5	●
Cr	0.13	0.43	< 0.6	●
Cu	0.10	0.32	< 5-50	●
Fe	0.7	2.5	<100 µg/d	●
Hg	0.06	0.19	< 1.0	●
I	0.13	0.44	100-199 insufficiency <20-99	●
Mg	8	27	50-150 mg/d	●
Mn	0.04	0.14	< 1.9	●
Mo	0.09	0.29	< 7-94	●
Ni	0.06	0.19	< 3.0	●
Pb	0.03	0.11	< 3.8	●
Pt	0.002	0.006	< 0.20	●
Sb	0.007	0.024	< 0.2	●
Se	0.09	0.31	2-31	●
Sn	0.20	0.66	< 2.0	●
Tl	0.005	0.017	< 0.5	●
V	0.021	0.070	< 0.2	●
Zn	1.3	4.2	150-1200	●

The method was stable over the whole runtime (~70 samples) indicated by internal standard recovery (Fig. 4) and in addition by recovery of reference samples.

Urine control L1 and L2 (Recipe) as well as L2 (Seronorm) included to beginning and end of batch have been well traced back to given values within specified reference ranges. The reference values may be entered to the LabSolutions™ ICPMS method directly, allowing for quick assessment of the quality of the results obtained from each run, as outliers will be highlighted automatically.

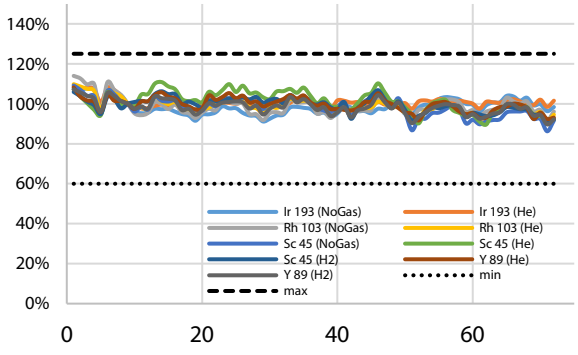

Fig. 3 Internal Standard Stability Plot, standardized to the calibration curve matrix sample (CAL5 = 100 %)

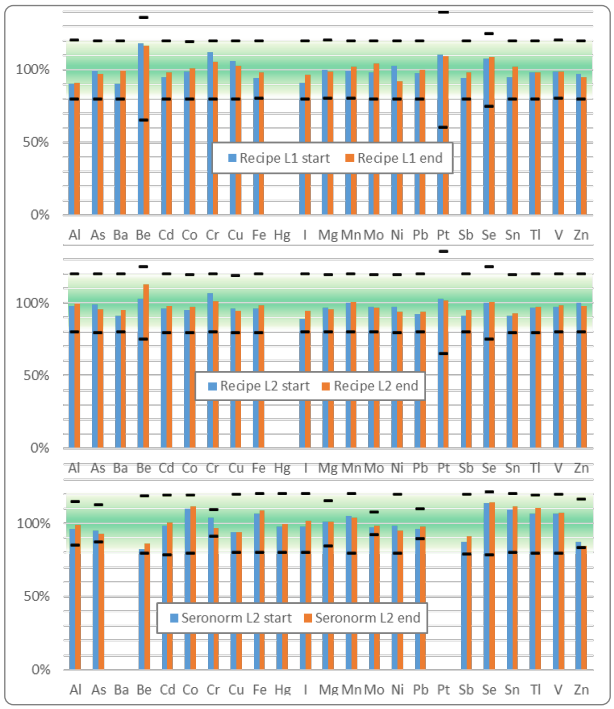

Fig. 4 Recovery of Reference Samples

■ Conclusion

Sample cycle times (including rinse) of below 3 minutes can be achieved without using complex sample injection techniques.

This short time can be achieved by the collision/reaction cell's extreme low gas switching times (<5 sec.) and features like ProActive Rinsing, which allows to already start rinsing before the actual measurement is finished. This is possible because the remaining sample in the capillary is further injected (measured), before rinse solution reaches the nebulizer.

For routine use, the ICPMS-2050 LF running alkaline media is highly suitable for analyzing nutritional, essential, and toxic elements in urine samples, even including iodine.

<References>

1) Rose C, Parker A, Jefferson B, Cartmell E. The Characterization of Feces and Urine: A Review of the Literature to Inform Advanced Treatment Technology. Crit Rev Environ Sci Technol (2015)
2) Putnam, D.F. Composition and concentrative properties of human urine. NASA Contractor Reports (1971)
3) Nelms, S., ICP Mass Spectrometry Handbook, CRC Press (2005)
4) Medical laboratory Bremen, https://www.mlhb.de/analysen (last access date 21.05.2025)

<Related Applications>

1. Determination of 20 Nutritional, Essential and Toxic Elements in Blood Serum by ICP-MS using Alkaline Dilution, Application News 05-SCA-116-010-EN
2. Determination of Essential and Toxic Elements in Urine by ICPMS-2050 using Acidic Dilution, Application News 04-AD-0312-EN

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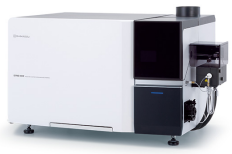

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