RAPID DETERMINATION OF THORIUM IN URINE BY QUADRUPOLE ICP-MS
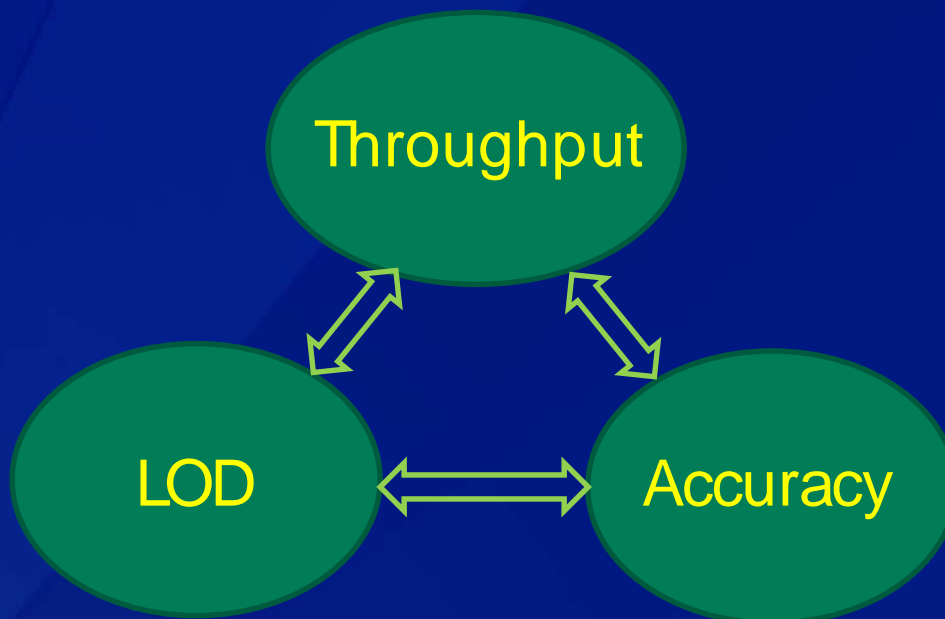
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CDC

Thorium-232 quantification by ICP-MS

Throughput

LOD

Accuracy

Goals of this study:

This method was developed to identify Thorium-232 in urine to provide data for quantitative assessment of Th-232 internal contamination.

Limit of Detection (LOD) , Throughput and Accuracy are three major factors considered in this study. They are interactive, and were optimized based on Radiological Emergency Response needs in the process of method development.

Introduction

- **Thorium occurrence**

  - Thorium is a naturally occurring primordial radioactive element that is ubiquitous in all rocks, soils, surface and groundwater, plants and animals at low concentrations (~10 µg/g).

Isotope	Half-life (year)	Specific Activity (Ci/g)	Natural Abundance (%)	Decay Mode
Th-232	1.41E+10	1.1E-7	> 99	α
Th-230	7.54E+4	2E-2	« 1	α
Th-229	7.34E+3	2.2E-1	« 1	α

Introduction (cont.)

- **Characteristics in the environment and the body**

    - Low solubility; exclusively as the tetra-positive aqua ion $[Th(H_2O)_9]^{4+}$

    - No biomagnification in terrestrial or aquatic food chains

    - Of the amount absorbed into the bloodstream, 70% deposits in bone.

    - Low concentration in urine, 50th percentile 0.85 ng/L; 95th percentile 3.09 ng/L (Ting et. al. 1999)

Introduction (cont.)

- **Risk and health effects**

- **Exposure from anthropogenic sources**
  Includes nuclear fuel production facilities, nuclear waste storage areas, and nuclear power plants.

- **Lifetime cancer mortality**
  The major means of contamination with Th are ingestion of food and water containing Th and inhalation of Th contaminated dust.
  The main health concern: bone cancer.

Thorium analytical technologies

■ **List of analytical techniques:**

Alpha spectrometry(AS); neutron activation analysis (NAA); thermal ionization mass spectrometry (TIMS); inductively coupled plasma mass spectrometry (ICP-MS)

■ **Limitations of the techniques**

- Large sample volume (AS)
- Expensive and relatively rare equipment (NAA)
- Long counting time (AS)
- Tedious chemical purification (AS, NAA, TIMS)

Thorium analytical technologies (cont.)

- **Detection: ICP-MS (Quadrupole ICP-MS/ Sector Field ICP-MS)**

  - Low limits of detection for long-lived radionuclides
  - short analytical time
  - multi-element analytical ability.

- **ICP-MS Disadvantages**

  - Potential interferences from isobaric and /or polyatomic ions may require chemical or analytical separation.

Purpose of this method development

- Develop a rapid, reliable thorium analytical method.

- Use a new generation of quadrupole ICP-MS.

- Eliminate the memory effect without using hazardous hydrofluoric acid.

- Develop a method capable of determining the excretion of Th in human urine of populations

    - low, naturally occurring daily Th background levels, and

    - higher level Th from anthropogenic sources.

Experimental

Instrumentation

- PerkinElmer NexION 300 Quadrupole ICP-MS
- SC-4 DX autosampler

Sample preparation

- 0.5 mL urine sample diluted with 4.5 mL diluent (2% HNO_3 + 100 ng/L ^{233}U tracer/ internal standard)

- Rinse solution for autosampler and ICP-MS: 5% HNO_3 + 0.025 M oxalic acid

Experimental (cont.)

■ **Data processing and calculations**

● Calibration standards

- 5, 20, 80, 300, 1000 ng/L
- matrix matched: 10 X dilution of calibrators into base urine

● ^{233}U Internal standard

1) corrects for ICP-MS ion beam intensity fluctuations
2) compensates for potential loss of Th during sample introduction due to their similar chemical behaviors.

Experimental (cont.)

Instrumental conditions for thorium analysis by QICP-MS

NexION®300D Operation mode	Standard
RF power (KW)	1.6
Nebulizer gas flow (L/min)	0.89-1.0
Auxiliary gas flow (L/min)	1.2
Plasma gas flow (L/min)	18
Analog stage voltage (Kv)	-2.3
Pulse stage voltage (v)	1.2
Deflector voltage (v)	-6.25
Discriminator threshold	13
Quadrupole rod offset	0
Cell entrance/exit voltage	-4
Cell rod offset	-6
Detector mode	Pulse
Dwell time (ms)	200
Sweep (ms)	100
Sample flush & Wash (s)	35,60
Measured isotopes	^{232}Th, ^{233}U

Results and Discussion

- Memory effect and carryover

- Spectrometric interferences

- Linearity

- Method Limit of Detection (LOD)

- Accuracy and precision

Memory effect and carryover

■ Thorium carryover is observed in adjacent sample measurements, due to its chemical/physical behavior – "sticky" when in low concentrations of mineral acids.

Reported solution : 5% HNO3 + 5% HF

■ These measures were taken to reduce carryover:

- Use high concentration of nitric acid in rinse solution (>1%)

- Add oxalic acid to rinse solution

- Hand pipette with disposable tips instead of Digiflex automatic pipette

- Replace peristaltic pump tubing before sample run

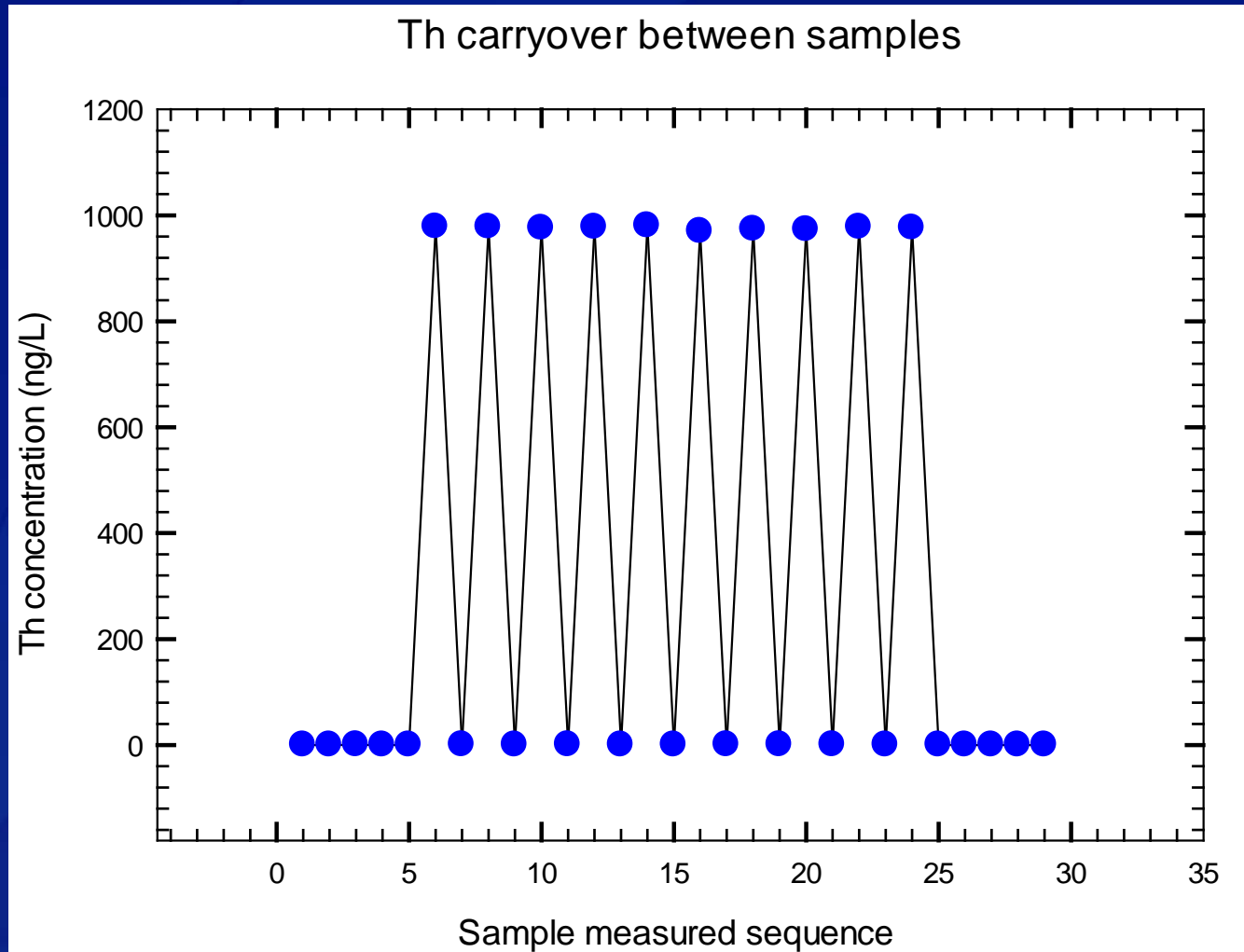# Memory effect and carryover (cont.)

Important findings:

a) Th memory effect is enhanced with increased urine sample Th concentration.

b) Higher concentrations of HNO_3 will reduce the Th memory effect.

c) Presence of oxalic acid will essentially eliminate the Th memory effect.

- Under these conditions, no significant carryover was observed for consecutive measurements of blank and high concentration Th samples (> 5 µg/L).
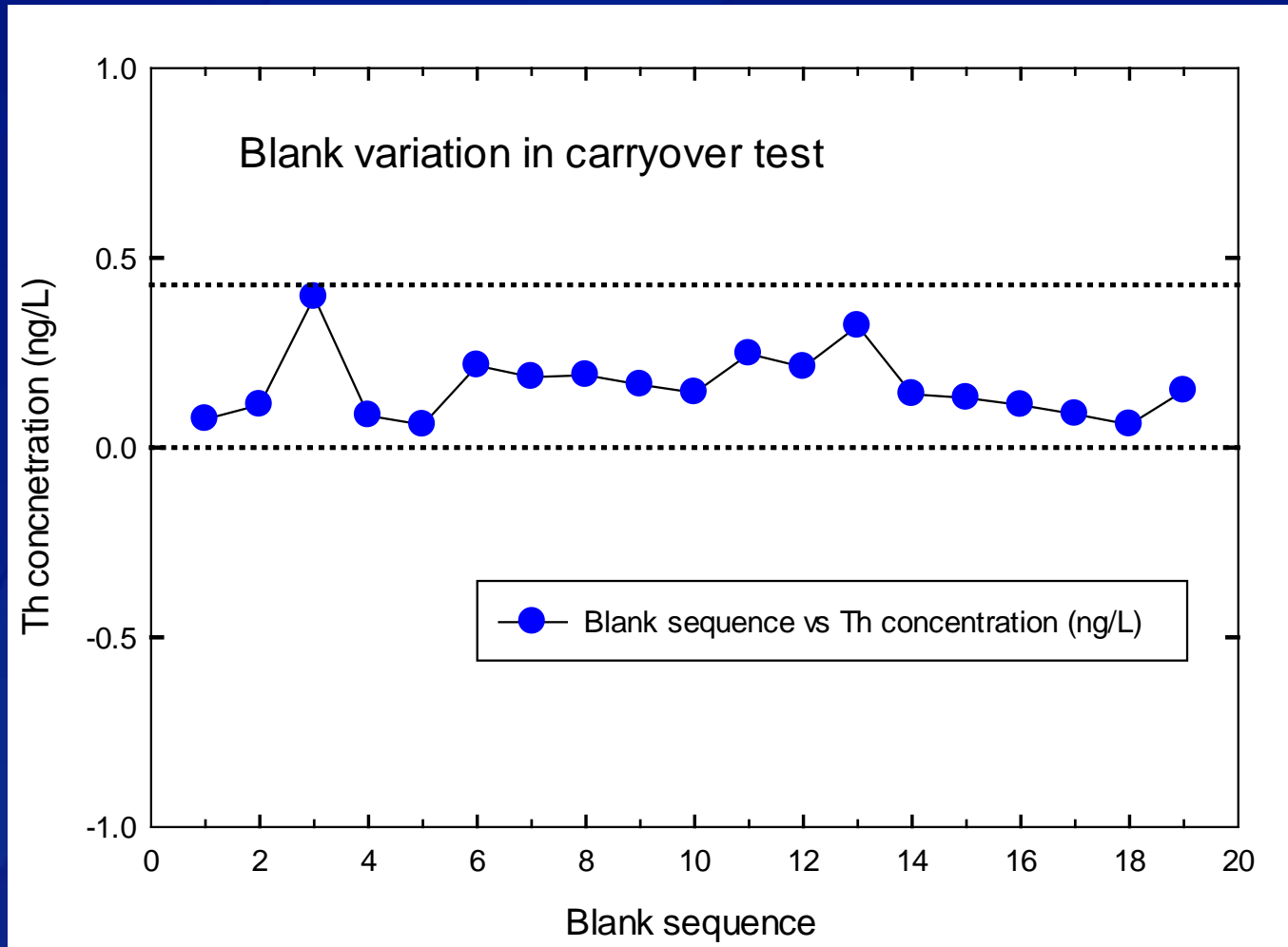
Memory effect and carryover (cont.)
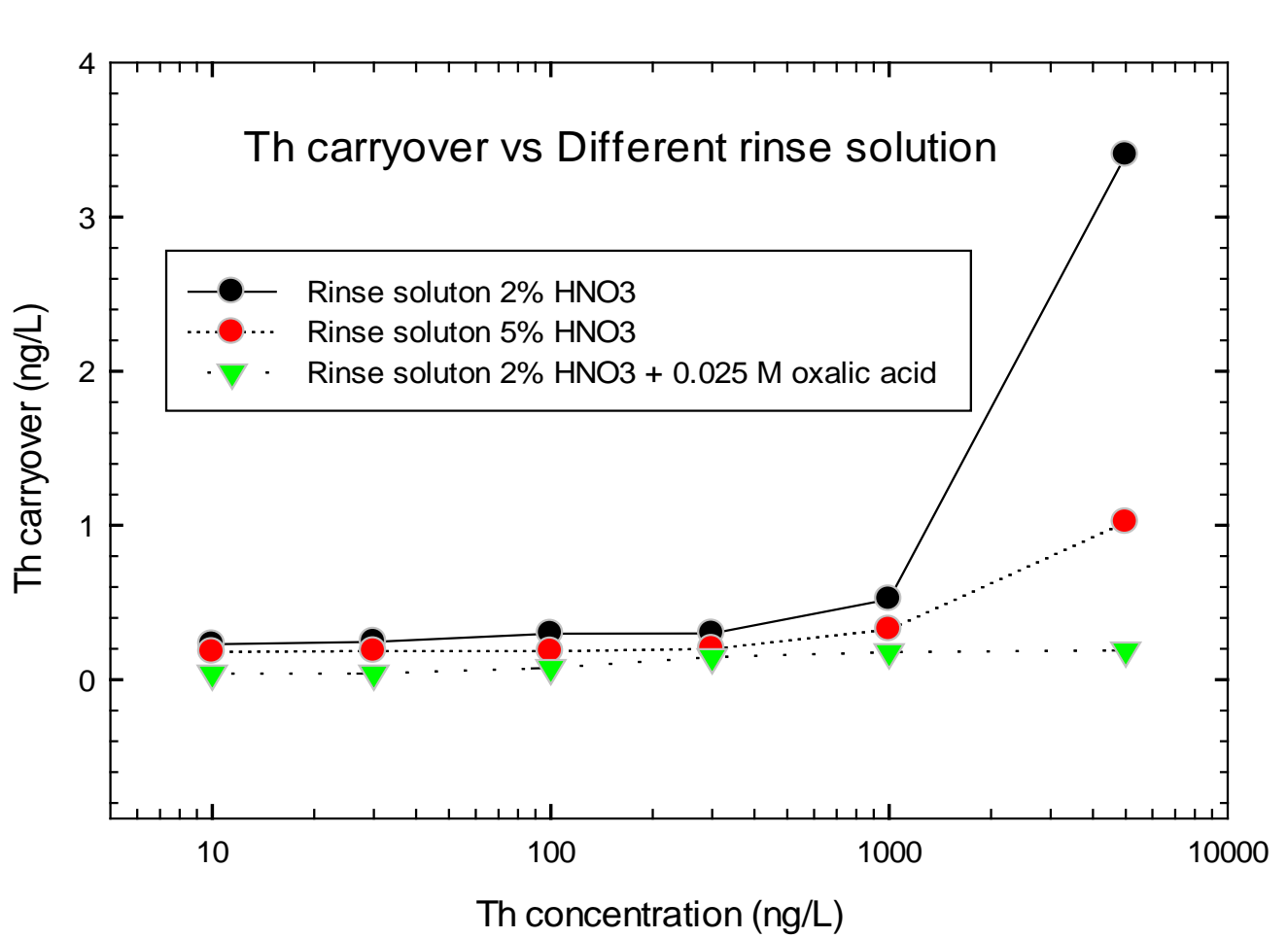
Selection of rinse solution to completely eliminate carryover of Th in the ICP-MS sample introduction system.

Memory effect and carryover (cont.)

Th carryover between samples

Variation of Th concentrations for a consecutive measurement of blank and 1000 ng/L Th samples.

Memory effect and carryover (cont.)

Variation of Th concentrations in consecutive blank sample measurements made during the 1000 ng/L Th carryover test.

Spectrometric interferences

- Potential spectrometric interferences to Th are the polyatomic ions: shown below.

  Pooled base urine spiked with NHANES 95th percentile or maximum potential concentration for the impurities was used for interference testing.

  $$^{197}Au^{35}Cl \rightarrow \text{Spike Impurity Au} \rightarrow 5 \ \mu g/L$$
  $$^{192}Os^{40}Ar \rightarrow \text{Spike Impurity Os} \rightarrow 1 \ \mu g/L$$
  $$^{198}Hg^{34}S, {}^{201}Hg^{31}P \rightarrow \text{Spike Impurity Hg} \rightarrow 5 \ \mu g/L \ (95^{th})$$
  $$^{192}Pt^{40}Ar, {}^{194}Pt^{38}Ar, {}^{196}Pt^{36}Ar \rightarrow \text{Spike Impurity Pt} \rightarrow 1 \ \mu g/L$$

- No significant polyatomic ion was detected in this study.

Linearity

- The method's linearity for analysis of Th was determined by analysis of samples with Th concentration target values that covered the desired measurement range.

- Five samples with target values of 5, 20, 80, 300, and 1,000 ng/L of Th were used for the linearity determination.

Linearity (cont.)
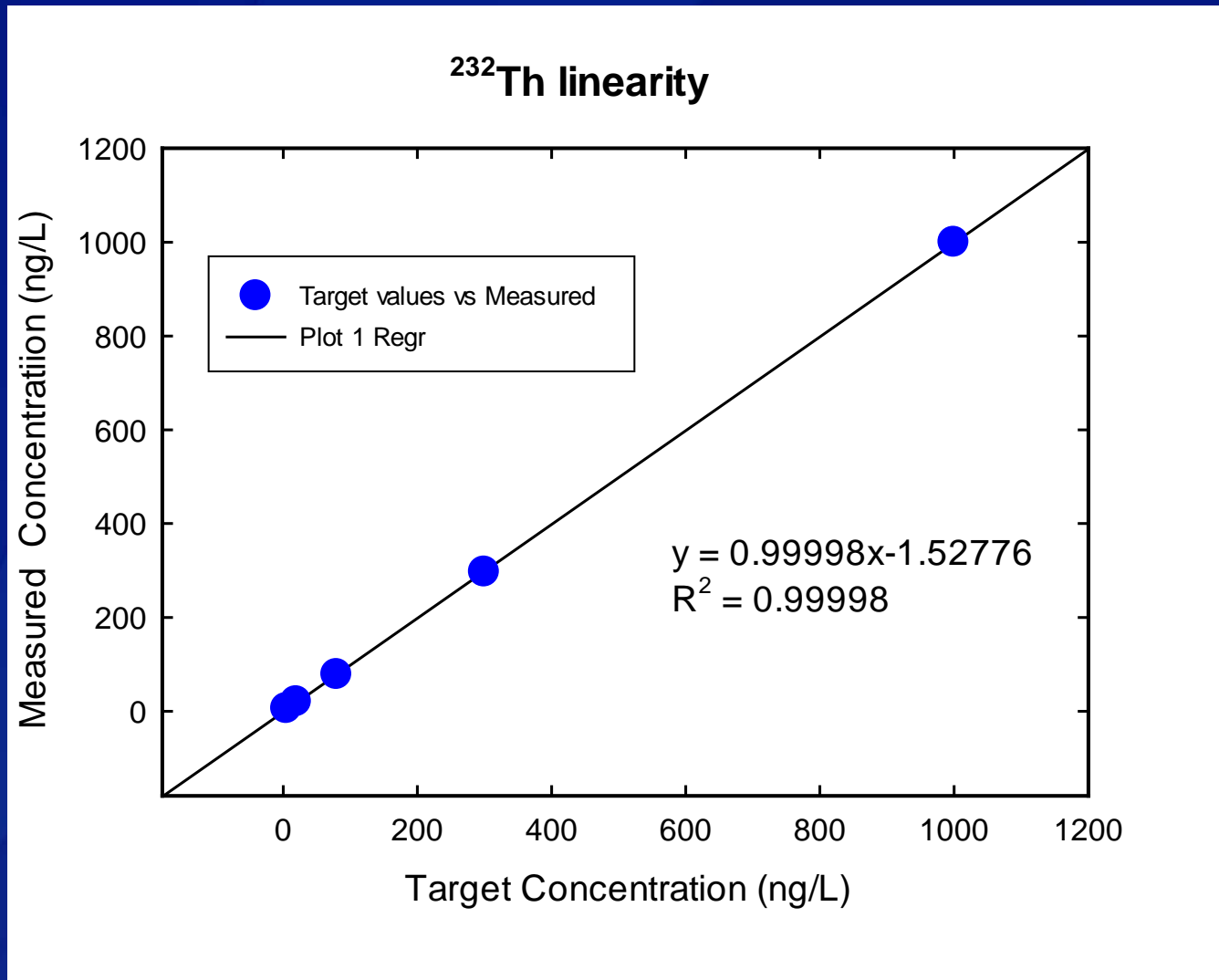
Method [232]Th linearity over the range of 5-1000 ng/L

Method Limit of Detection (LOD)

- The method's LOD was determined based on the standard deviation of measured blank and samples that had low Th concentrations.

- It was calculated using Taylor's method:

$$\text{Conc}_{\text{LOD}} = [\text{mean}_b + 1.645(S_b + \text{int})]/[1 - 1.645(\text{slope})]$$

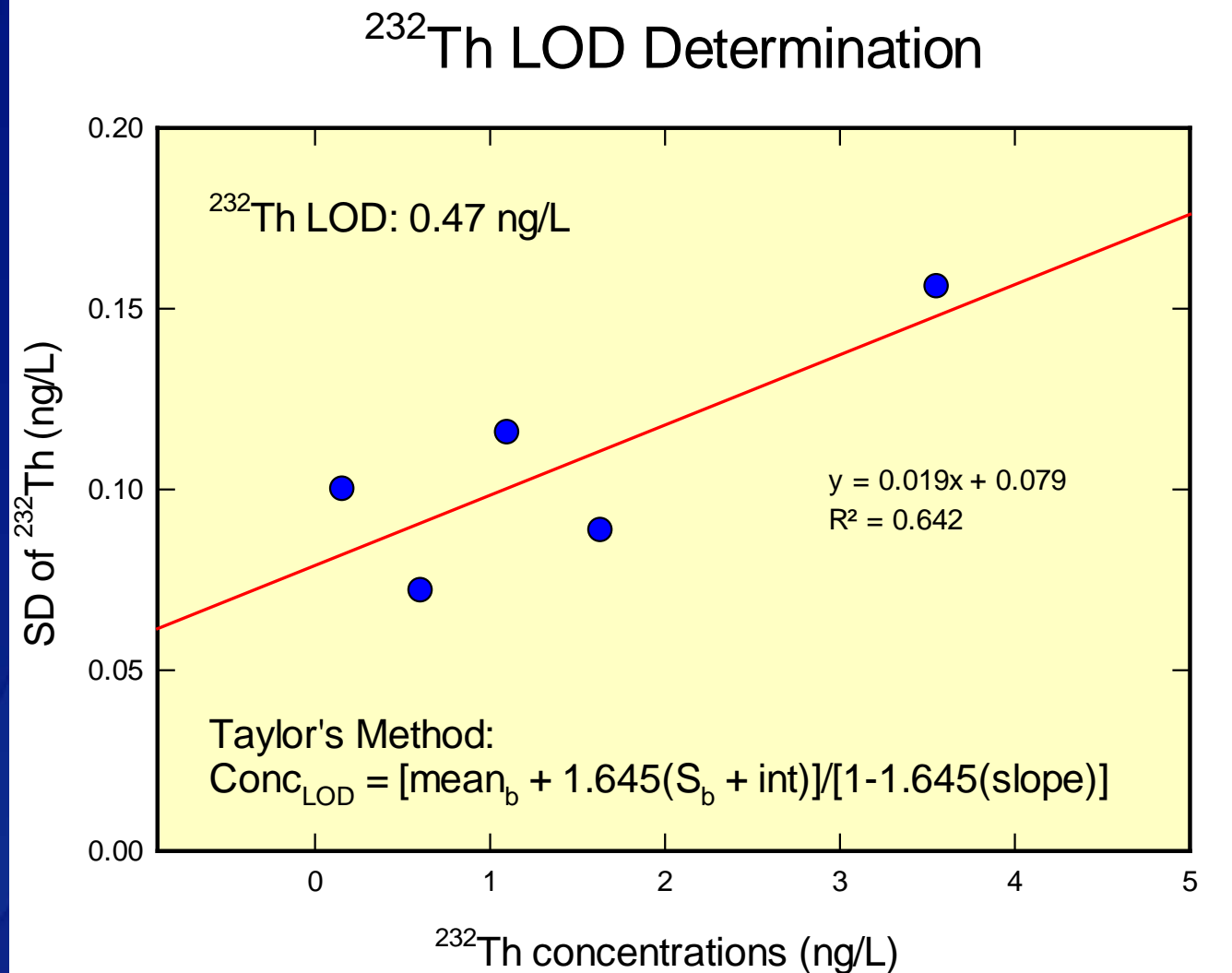- One blank and four low concentration Th samples (0.5, 1.0, 1.6, 3.5 ng/L) were used.

$$\text{LOD} = 0.47 \text{ ng/L}$$

LOD (cont.)

Results for measurement of urine samples with low concentrations of Th for LOD determination (N=20)

Sample	^{232}Th (ng/L) (N=20)	SD (ng/L)
Urine blank	0.160	0.100
L1: 0.5 ng/L	0.608	0.072
L2: 1.0 ng/L	1.101	0.116
L3: 1.5 ng/L	1.635	0.089
L4: 3.5 ng/L	3.558	0.156

LOD(cont.)

^{232}Th LOD Determination

^{232}Th LOD: 0.47 ng/L

y = 0.019x + 0.079
R² = 0.642

Taylor's Method:
$Conc_{LOD}$ = [$mean_b$ + 1.645(S_b + int)]/[1-1.645(slope)]

SD of ^{232}Th (ng/L)

^{232}Th concentrations (ng/L)

Method limit of detection (LOD) determination based on Taylor's method

Accuracy and precision

- Accuracy of this Th method was evaluated based on the measured Th concentrations of INSPQ QMEQAS reference materials. Results were in agreement with the target values to within 2SD.

- Precision of this method was estimated based on data generated from replicate determinations using the INSPQ QMEQAS reference materials. The RSD of six sample measurements on eight different days was 2% or less.

Accuracy and precision (cont.)

Measured Th concentrations of INSPQ QMEQAS reference materials

	QM-U-Q1413	QM-U-Q1414	QM-U-Q1503	QM-U-Q1504	QM-U-Q1509	QM-U-Q1510
Average (N=8) (ng/L)	210.8	89.9	87.8	314.4	400.5	29.9
SD	2.8	1.5	1.4	5.8	6.9	0.6
RSD (%)	1.3	1.6	1.6	1.8	1.7	2.0
Target value	218.6	94.7	91.7	310.9	417.7	36.4
SD	10.2	4.5	4.2	8.9	34.1	3.3

Accuracy and precision (cont.)
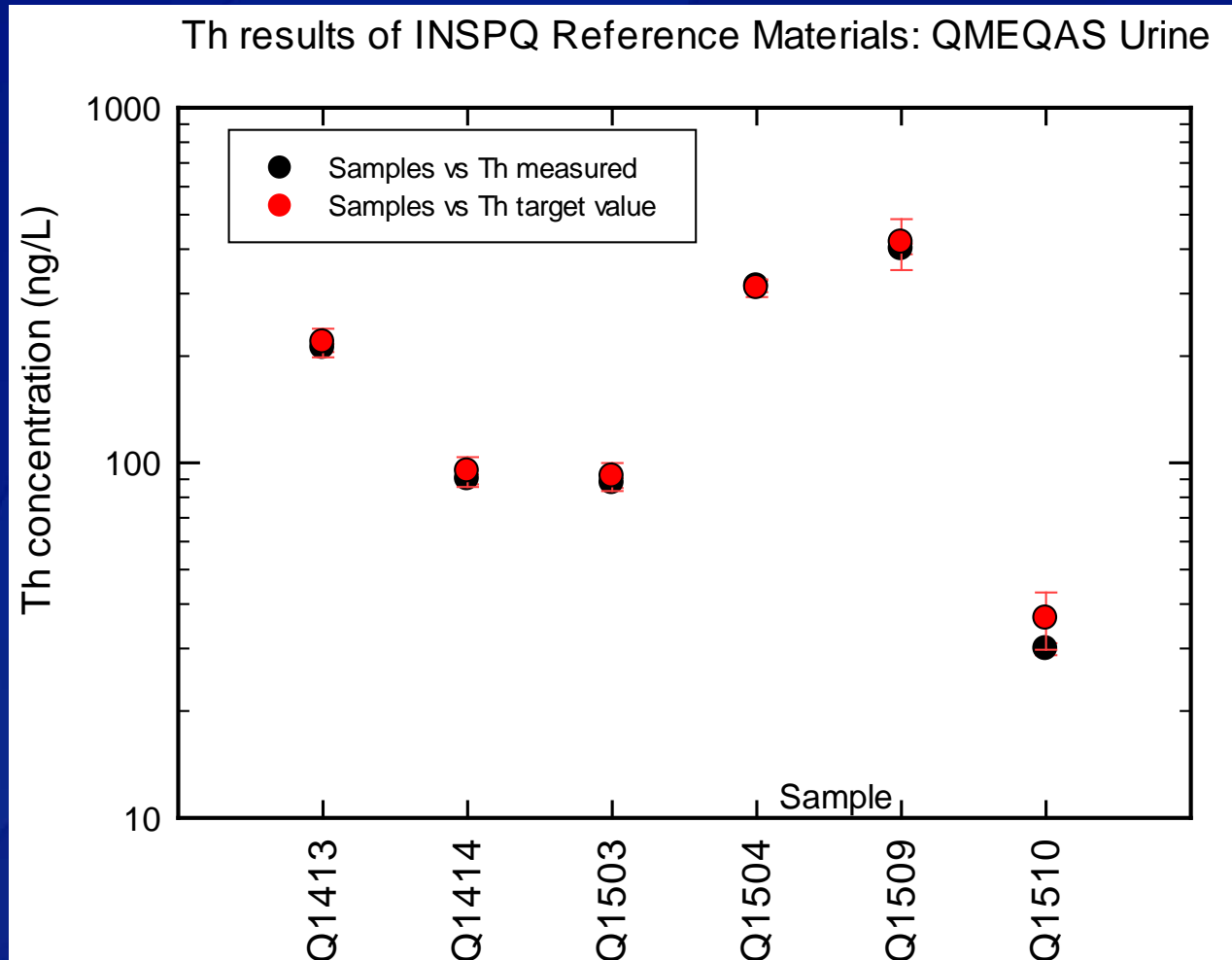
Comparison of measured results to target values of INSPQ reference materials QMEQAS

Summary

- A new method for analyses of trace Th in urine using a next generation quadrupole ICP-MS produced significant improvements in LOD and good accuracy and precision.

- This method avoids use of hazardous hydrofluoric acid in diluent and rinse solutions for washout of Th contamination, while still eliminating carryover and cross contamination.

- It requires only 0.5 ml of urine, minimal sample preparation, and is "dilute and shoot" analytical method.

- Samples throughput is ~ 200 per instrument in an 20 hour day.

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THANK YOU

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