On the Way to Routine Analysis of Nanoparticles Using spICP-MS

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Overview

Purpose: Highlight the potential of spICP-MS for the analysis of samples containing nanoparticles.

Methods: Samples containing different nanoparticles were analyzed directly using a Thermo Scientific™ iCAP Q™ ICP-MS. Data evaluation was accomplished using a suitable software solution.

Results: Different types of nanomaterials have been analyzed and the result show good agreement with the expected values.

Introduction

The analysis of Nanoparticles (NPs) has become one of the hot topics in analytical chemistry. Although many everyday products contain such material, detailed knowledge about potential risks or hazards is still unavailable. In order to leverage the potential of ICP-MS for the analysis of NPs, two approaches have been developed in recent years: 1. Hyphenation of an appropriate separation technique like Field-Flow-Fractionation (FFF), or, 2. direct analysis of nanoparticles using spICP-MS.
Whereas the first technique is mostly used to fractionate a sample containing different nanoparticle sizes, the latter technique is a means to directly characterize nanoparticles in terms of size and particle number. Additionally, no peripheral devices are required as nanoparticle solutions can be aspired directly. Evaluation of the data is typically done using mathematical treatment of the measured signals obtained for signal particle events[1].

Methods

Sample Preparation

All measurements were conducted with NIST reference materials 8011, 8012 and 8013 (stabilized Au Nanoparticles of 10, 30 and 60 nm nominal diameter. All samples were sonicated before dilution in ultrapure water to an appropriate particle number concentration range (approx. 2-5 x 10^4 particles per mL).

Single Particle Data Acquisition

Operation of the instrument in the single particle mode was accomplished straightforward. As no peripheral device was required, samples were introduced directly to a self aspirating nebulizer. Data was acquired using a transient signal data evaluation module.

Mass Spectrometry

A Thermo Scientific iCAP Qc ICP-MS was used for all experiments. All experimental parameters are summarized in table 1:

FIGURE 1. The Thermo Scientific iCAP Q ICP-MS.

TABLE 1. Instrument Operation Parameters.

Parameter	Value
Nebulizer	PFA-100
Nebulizer Gas Flow	1.06 L· min^{-1}
RF Power	1550 W
Interface Set-up	Ni Cones, High Sensitivity Skimmer Cone Insert

The attainable detection limit for the nanoparticle size is mostly dependent on the detection sensitivity of the instrument. For AuNP´s, the use of the CCT mode using He can be an alternative (typical improvement of detection sensitivity up to a factor of three).

Data Analysis

Thermo Scientific Qtegra™ Intelligent Scientific Data Solution™ was used to operate the iCAP Q ICP-MS. All data handling to calculate particle size distributions and particle number concentration was carried out in a dedicated software solution.

Background Information

spICP-MS for Nanoparticle Detection

In contrast to conventional ICP-MS measurements, the evaluation of spICP-MS data is based on the individual treatment of discrete signals caused by the introduction and complete decomposition of particles in the plasma. Figure 2 shows a typical data set obtained in spICP-MS.

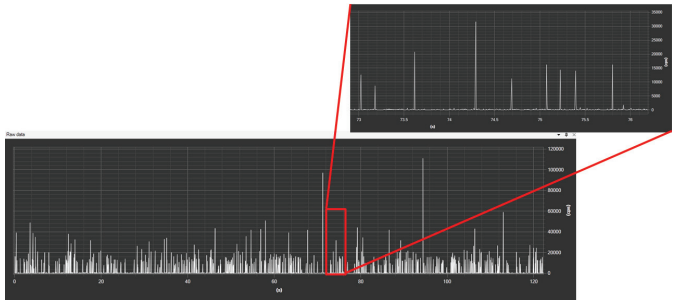


FIGURE 2. Typical data set acquired in the spICP-MS mode (Au nanoparticles, 30 nm nominal diameter).

The selection of an appropriate dwell time is crucial for spICP-MS data acquisition. Ideally, only one particle event is observed during one dwell time of the instrument (**A** in figure 3). Otherwise, artefacts can be observed that affect the result of the particle size determination:

- **Split Particle Events (B):** A nanoparticle signal is observed in two adjacent measurement slots. The extent of split particle events depends on the nanoparticle pulse duration and the applied dwell time, and can be reduced by using longer dwell times.
- **Double or Multiple Particle Events (C):** Two or more particles are observed in one measurement slot, leading to an overestimation of the particle size. The occurrence of such events can be estimated using Poisson statistics and can be reduced by sample dilution.

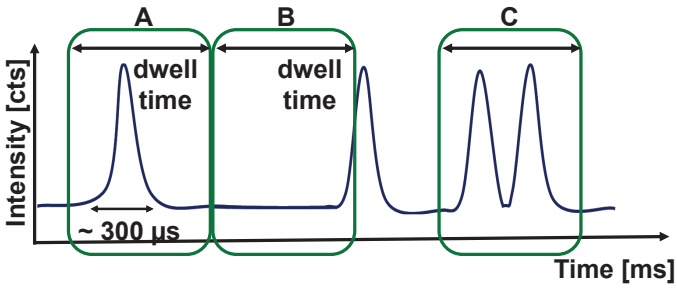


FIGURE 3. Relation between single particle events and applied dwell time.

Results

Determination of Particle Size Distribution and Number Concentration

To determine the particle size distribution and concentration from the acquired raw data, the following calculation steps and assumptions have to be made.

1. **Filter sp events from underground**
→ Signals above certain intensity threshold

2. **Calculate mass of element observed in every event**
→ ([CPS] x dwell time) / detection sensitivity x sample flow

3. **Calculate particle diameter**
→ spherical particles, density equal to solid material

4. **Evaluate size distribution and number of particles**
→ Sort individual particles in bins, evaluate abundance

In order to accurately calculate the size and the particle number concentration in a sample, the following experimental parameters have to be known in advance:

Sample Flow: Flow rate of sample to the plasma, can be determined using a flow meter or gravimetrically

Detection Sensitivity: Instrument response to the analyte of interest

Nebulization or **Transport efficiency**: Fraction of total sample material reaching the plasma

Automated Determination of Measurement Parameters

For routine analysis, simple and reliable determination of crucial measurement parameters is mandatory. Whereas the determination of the detection sensitivity of the instrument is straightforward, the determination of the Transport Efficiency can be accomplished using a standard solution containing nanoparticles with known size and/or particle number distribution following reference 2.

Transport efficiency evaluation

Sample Identifier	Standard Identifier	Expected particle per volume [particle/ml]	Measured particle per volume [particle/ml]	Transport efficiency by particle per volume [%]
Transport Efficiency 1	NIST 8013	23788	2162.13	9.09
Transport Efficiency 2	NIST 8013	23788	1955.61	8.22

FIGURE 4. Automated determination of the transport efficiency using a particle standard.

Determination of Particle Derived Signals for Evaluation

Transforming the obtained data set from the time domain (CPS vs. measurement time) to the intensity domain (# of occurrences of signals vs. signal intensity) leads to a chart that allows to determine:

- Signals derived from background (Instrumental or dissolved ionic species) with low signal intensity but high number of occurrence
- Particle derived signals with high signal intensity but lower number of occurrence

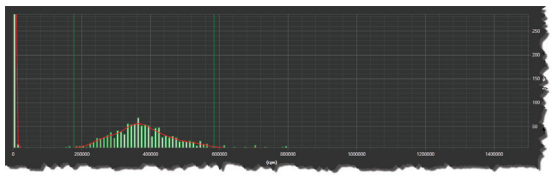
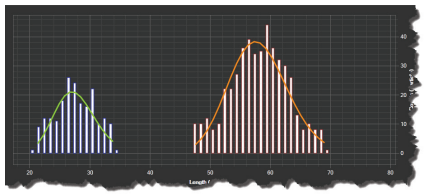


FIGURE 5. Signal distribution and selection of particle signals for evaluation.

Determination of Particle Size and Number

For every signal within the defined intensity window (figure 5) for a given particle fraction, the corresponding particle size is calculated and the particle size distribution is generated.



Sample	Nominal Diamter	Determined
NIST 8011	10 nm	9.2 ± 3
NIST 8012	30 nm	27.6 ± 3
NIST 8013	60 nm	58.1 ± 5

FIGURE 6. Particle Distribution and calculated particle size for NIST reference materials (Au nanoparticles).

Different particle fractions in a sample can be evaluated independently using dedicated intensity threshold values for each fraction.

Recognition and Elimination of Artefacts

Intelligent software for spICP-MS data evaluation can help to recognize and minimize both types of artefacts typically observed in spICP-MS, as highlighted in figure 7.

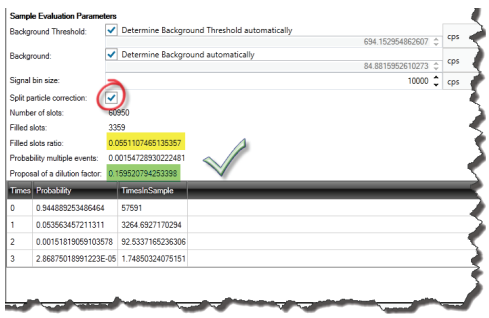


FIGURE 7. Tools for recognition and elimination of artefacts in spICP-MS.

Split Particle Correction: Sums up adjacent signals with intensities above background but below lower particle threshold (similar to reference 3).

Multiple Particle Events: Based on the number of filled slots, the probability for double and higher multiple particle events is calculated and a dilution factor is proposed according to a user definable filled slots ratio (e.g. 10%).

Conclusion

- The analysis of nanoparticles is more and more developing into an routine application since legislation is moving forward.
- Intelligent software solutions can support the user through automated determination of key parameters for particle size- and number evaluation.
- Potential artefacts can be avoided based on statistical evaluation of the acquired raw data and help to assure data quality.

References

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2. Pace *et al.*, Anal. Chem. **83** (2011), 9361-9369
3. Liu *et al.*, Anal. Chem. **86** (2014), 3405-3414