APPLICATION NOTE

ICP - Mass Spectrometry

Authors

Chady Stephan, Ph.D.

Aaron Hineman

PerkinElmer, Inc.
Woodbridge, Ontario CAN

Analysis of NIST Gold Nanoparticles Reference Materials Using the NexION 350 ICP-MS in Single Particle Mode

Introduction

Engineered nanomaterials (ENs) refer to the process of producing and/or controlling materials that have at least one dimension in the size range of 1 to 100 nm. They often possess different properties compared to bulk materials of the same composition, making them of great interest to a broad spectrum of industrial and commercial applications.

Recent studies have shown that some nanoparticles may be harmful to humans. A 2009 study in the Journal of Nanoparticle Research showed that zinc oxide nanoparticles were toxic to human lung cells in lab tests even at low concentrations (Weisheng et al., 2009).[1] Other studies have shown that tiny silver particles (15 nanometers) killed liver and brain cells in laboratory rats. At the nano scale, particles are more chemically reactive and bioactive, allowing them to easily penetrate organs and cells (Braydich-Stolle *et. al.*, 2005).[2]

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To better understand the impact of nanoparticles, several key characteristics need to be assessed, such as concentration, composition, particle size, shape and other surface characteristics (Figure 1). Given these requirements, several analytical instruments must be used to characterize the material. Table 1 lists the key characteristics and many of the current analytical technologies that can be applied.

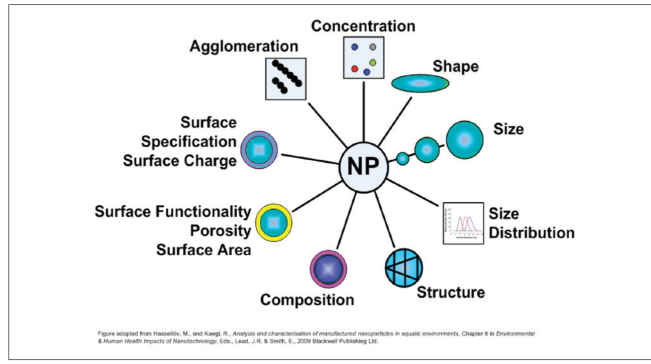


Figure 1. Key parameters to characterize nanomaterials (Hasselhov, 2009).[3]

Table 1. Nanomaterial characteristics and applicable analytical technologies.

Analytical Technique		Concentration	Particle Size	Particle Size Distribution	Surface Charge	Surface Area	Shape	Agglomeration	Structure	Composition
		Nanomaterial Characteristic								
Inductively Coupled Plasma-Mass Spectrometry	ICP-MS	●								●
Single Particle ICP-MS	SP-ICP-MS	●	●	●				●		●
Field Flow Fractionation + ICP-MS	FFF-ICP-MS	●	●				●	●		●
Liquid Chromatography/Mass Spectrometry	LC/MS	●								●
Optical Spectroscopy - UV/Vis	UV/Vis	●								●
Fluorescence Spectroscopy	FL	●	●					●		●
Turbidity			●	●				●		
Scanning Electron Microscopy	SEM		●	●			●	●	●	
Transmission Electron Microscopy (+EDX)	TEM		●	●		●	●	●	●	●
Atomic Force Microscopy	AFM		●	●	●	●	●	●		
Confocal Microscopy			●	●			●	●	●	
Field Flow Fractionation	FFF		●	●			●	●		
Dynamic Light Scattering	DLS		●	●			●	●		
Static Light Scattering	SLS		●				●	●		
Laser-Induced Plasma Spectroscopy	LIPS		●							
Dialysis			●	●						
Electrophoresis and Capillary Electrophoresis			●	●	●					
Ultrafiltration			●	●						
Centrifugation			●	●				●		
Filtration			●	●						
Nanoparticle Tracking Analysis	NTA		●	●				●		
Hydrodynamic Chromatography	HDC		●	●						
Laser-Induced Breakdown Detection	LIBD		●	●				●		
Size Exclusion Chromatography	SEC		●	●						
Selected Area Electron Diffraction	SAED		●	●					●	
Zeta Potential by DLS					●					
Molecular Gas Absorption (BET)					●	●				
X-ray Photoelectron Spectroscopy	XPS				●	●				●
X-ray Diffraction	XRD								●	
Thermogravimetric Analysis	TGA									●
Quartz Microbalances										●
Differential Scanning Calorimetry	DSC									●
Dynamic Mechanical Analysis	DMA									●
Fourier Transform-Infrared Spectroscopy	FT-IR									●
FT-IR Imaging									●	●
Raman Spectroscopy									●	●
TGA Coupled with Gas Chromatography/Mass Spectrometry	TGA-GC/MS									●
Electron Energy Loss Spectroscopy	EELS (+EDX)									●

Inductively coupled plasma mass spectrometry (ICP-MS) is one of the leading analytical techniques capable of measuring and assessing many of these key characteristics of metal-containing particles[4]. Low detection limits are critical in determining small concentrations of particles in a liquid sample as well as examining the characteristics of individual particles. Additionally, flexibility of instrumental parameters, such as dwell time and speed of the electronics, can influence the quality of data collected. This work explores the capability of the NexION® 350 ICP-MS to measure the key characteristics of manufactured metal nanoparticles.

Experimental

All work was performed using a NexION 350 ICP-MS (PerkinElmer, Shelton, CT, U.S.) operated in single particle mode using the Syngistix™ Nano Application Module. Single particle mode analysis (SP-ICP-MS) allows the differentiation between the dissolved and nanoparticle analyte, measuring nanoparticle size, size distribution and assessing agglomeration. Coupled to a size-separation technique (i.e. field flow fractionation [FFF] or liquid chromatography [LC]), ICP-MS is capable of addressing size, size distribution, surface charge and surface functionality.

The NexION 350 ICP-MS is capable of data acquisition speeds of 100,000 points/sec using dwell times as short as 10 µs and eliminating electronic settling time. Combined with a unique ion path design (Triple Cone Interface [TCI] and Quadrupole Ion Deflector [QID]), the NexION 350 ICP-MS, in SP-ICP-MS mode is crucial in assessing nanoparticle fate, transformation and transportation in different matrices (i.e. environmental, biological, food, etc.).

Gold nanoparticle standard reference materials (NIST 8011, 8012 and 8013 – NIST®, Gaithersburg, MD, U.S.) were used for all analyses.

The gold particles were suspended in a solution of deionized (DI) water at a concentration of 250,000 particles/mL. In order to avoid dissolution of the gold nanoparticles, acid was not added.

Table 2. NexION 350 ICP-MS operational conditions.

Parameter	Value
Instrument	NexION 350D ICP-MS
Nebulizer	Concentric
Spray Chamber	Baffled Cyclonic
Torch and Injector	Glass Torch and Glass Injector
Power (W)	1600
Plasma Gas (L/min)	17
Aux Gas (L/min)	1
Neb Gas (L/min)	1.03
Sample Uptake Rate (mL/min)	0.3
Sample Tubing (Standard)	Orange/Green
Dwell Time (µs)	100

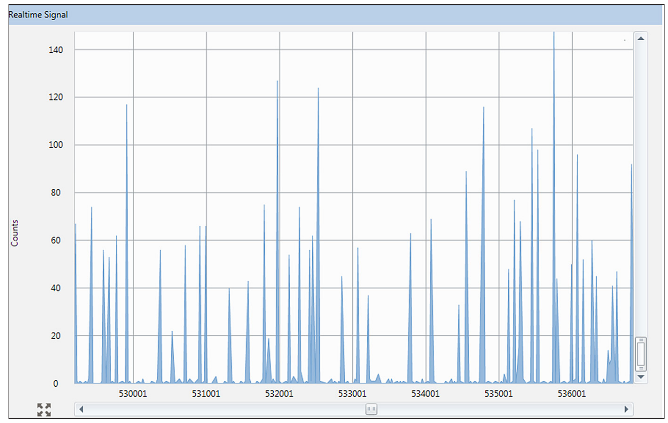


Figure 2. Generic signal when measuring nanoparticles in single particle ICP-MS mode. Each peak results from the ionization of a single nanoparticle.

All data was collected and processed using the Syngistix Nano Application Module. Gold was measured at m/z 197 (its only isotope) using a 100 µs dwell time with no settling time.

Results

Figure 2 shows part of the acquisition of 60 nm gold nanoparticles (NIST 8013), where each peak represents the instrumental response for an individual particle.

Particle size can be validated two ways with the Syngistix Nano Application Module: using calibrations from particle standards and calibrations with dissolved standards, the latter requiring the transport efficiency of the system be determined. Figure 3 shows the intensity distribution for three different size gold nanoparticles: 10, 30, and 60 nm (NIST 8011, 8012, 8013, respectively). These distributions demonstrate the NexION's ability to accurately detect, count, and measure nanoparticles of various sizes.

The intensity of the pulses generated by a single nano-particle is a function of the number of atoms in the nanoparticle, and hence its size. Figure 4 shows the plot of the mean intensity versus the mass of the nanoparticle for the different NIST SRMs (10, 30, 60 nm gold nanoparticles).

One of the unique features of the Syngistix Nano Application Module is its ability to investigate nanoparticle size distribution and precisely quantify each distribution, thus providing accurate particle counting. To evaluate this function, nanoparticle solutions were prepared at different nanoparticle concentrations in DI water by mixing various concentrations of nanoparticles from both NIST 8012 and 8013 (i.e. 30 and 60 nm particles). Figure 5 displays the size distributions as shown in the Syngistix Nano Application Module. The reason that the intensities of the peaks are different is that the particles were present at different concentrations in the mixture: the 30 nm particles (NIST 8012) were at a concentration of 250,000 particles/mL, while the 60 nm particles (NIST 8013) were at 100,000 particles/mL.

To further test the power of the NexION 350 ICP-MS coupled with Syngistix Nano Application Module, four solutions containing different relative amounts of 30 and 60 nm gold nanoparticles (NIST 8012 and 8013) were prepared and measured. Figure 6 compares the actual particle concentrations (i.e. the particle concentrations used to prepare the standards) with the measured particle concentrations for both the 30 and 60 nm particles in all four solutions. The strong agreement between the actual and the measured concentrations demonstrates the accuracy of the measurements.

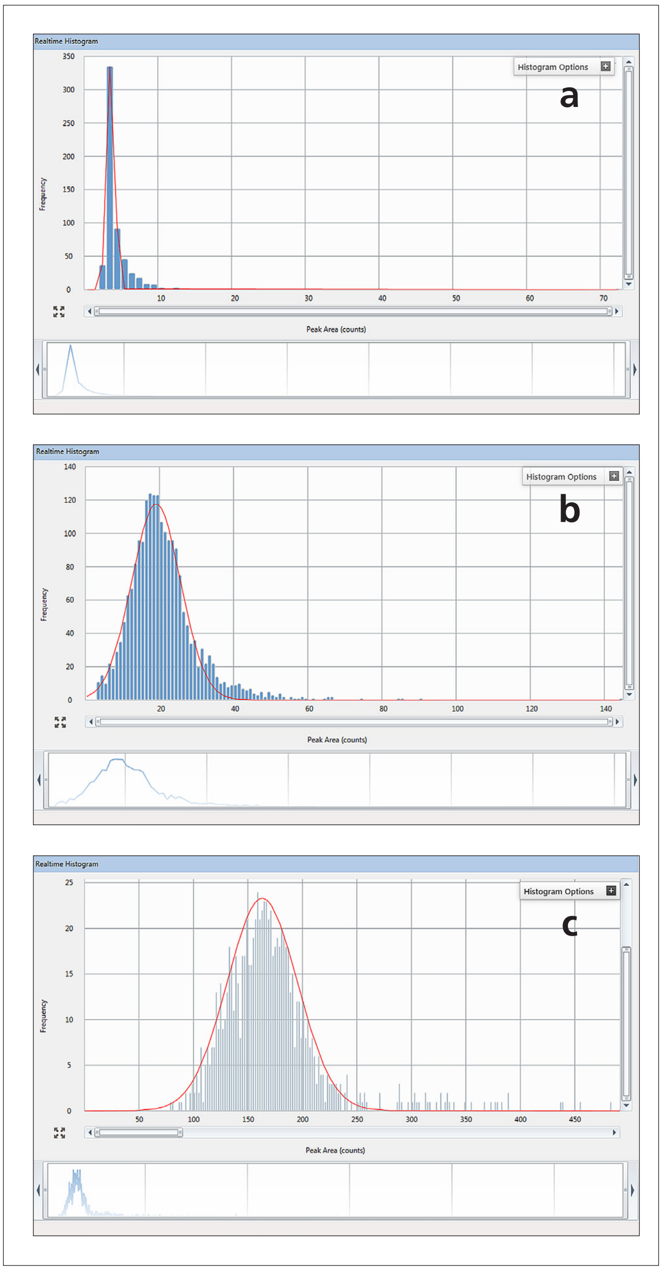


Figure 3. Intensity distributions of three different size gold nanoparticles: (a) 10 nm (NIST 8011); (b) 30 nm (NIST 8012); (c) 60 nm (NIST 8013).

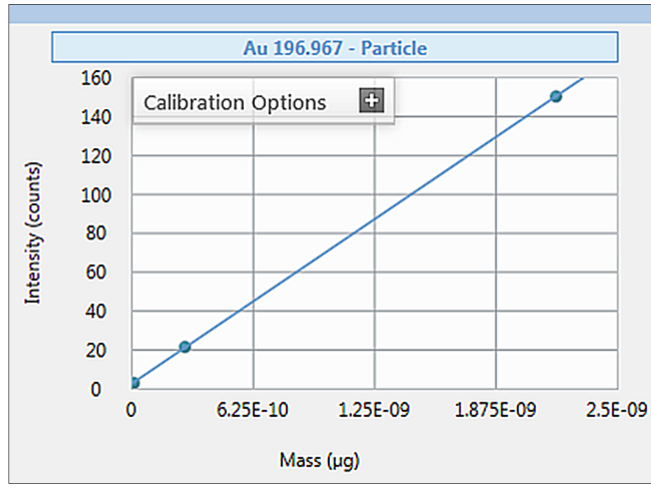


Figure 4. Plot of intensity vs. mass of gold nanoparticles (10, 30, 60 nm) as determined with the Nano Application Module in Syngistix for ICP-MS Software.

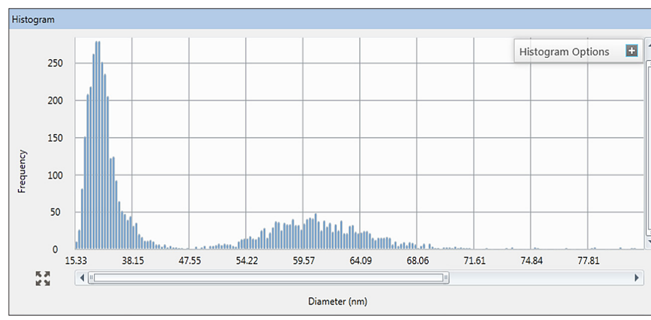
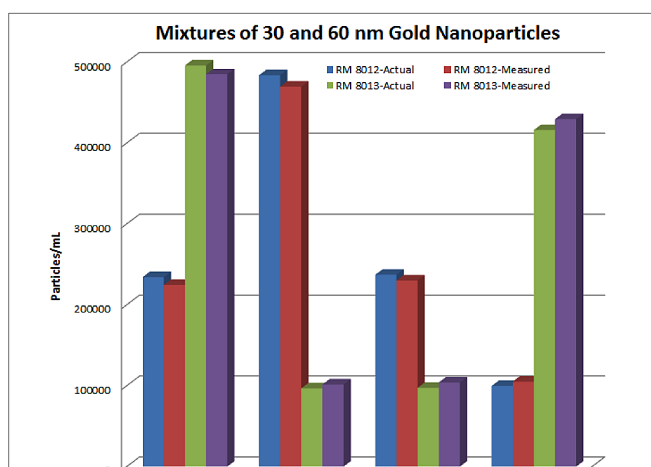


Figure 5. Size distribution as displayed in the Syngistix Nano Application Module for a mixture of 30 and 60 nm gold nanoparticles. The difference in the size of the peaks is due to the different concentrations of each nanoparticle in the mixture.



NIST 8012	Mixture 1	Mixture 2	Mixture 3	Mixture 4
Actual	234178	483541	236996	99571
Measured	224494	469468	229987	105025
Relative Difference (%)	4.2	3.0	3.0	5.3
NIST 8013	*Mixture 1*	*Mixture 2*	*Mixture 3*	*Mixture 4*
Actual	495720	96646	97255	415865
Measured	484826	101425	103890	429362
Relative Difference (%)	2.2	4.8	6.6	3.2

Figure 6. Analysis of four gold nanoparticle solutions comparing the actual and measured concentrations of both 30 and 60 nm particles. The blue (30 nm) and green (60 nm) bars represent the actual particle concentrations. The red (30 nm) and purple (60 nm) bars represent the measured particle concentrations.

Conclusion

ICP-MS is rapidly becoming the elemental measurement technique of choice for assessing the manufacturing accuracy and environmental lifecycle of engineered nanoparticles. When measuring dissolved elements, an ICP-MS system provides accurate composition and concentration measurements. Modern instruments, with ultra-fast electronics that enable the fastest data rates to capture nanoscale events, can provide advantages in the collection of more data per unit of time with greater precision.

The PerkinElmer NexION 350 ICP-MS, with Syngistix Nano Application Module operating in single particle mode, combines fast, accurate data acquisition with powerful data analysis capabilities, allowing metal and metal-containing nanoparticles to be characterized. Nanoparticle properties, which can be determined with this combination of hardware and software, include differentiation between dissolved and particulate signals, measurement of particle size and size distribution as well as exploration of agglomeration. This capability allows the characterization of nanoparticles used in food and consumer products, as well as the ability to explore the fate, transformation and effects of manufactured nanomaterials in the environment[5].

References

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PerkinElmer, Inc.
940 Winter Street
Waltham, MA 02451 USA
P: (800) 762-4000 or
(+1) 203-925-4602
www.perkinelmer.com

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