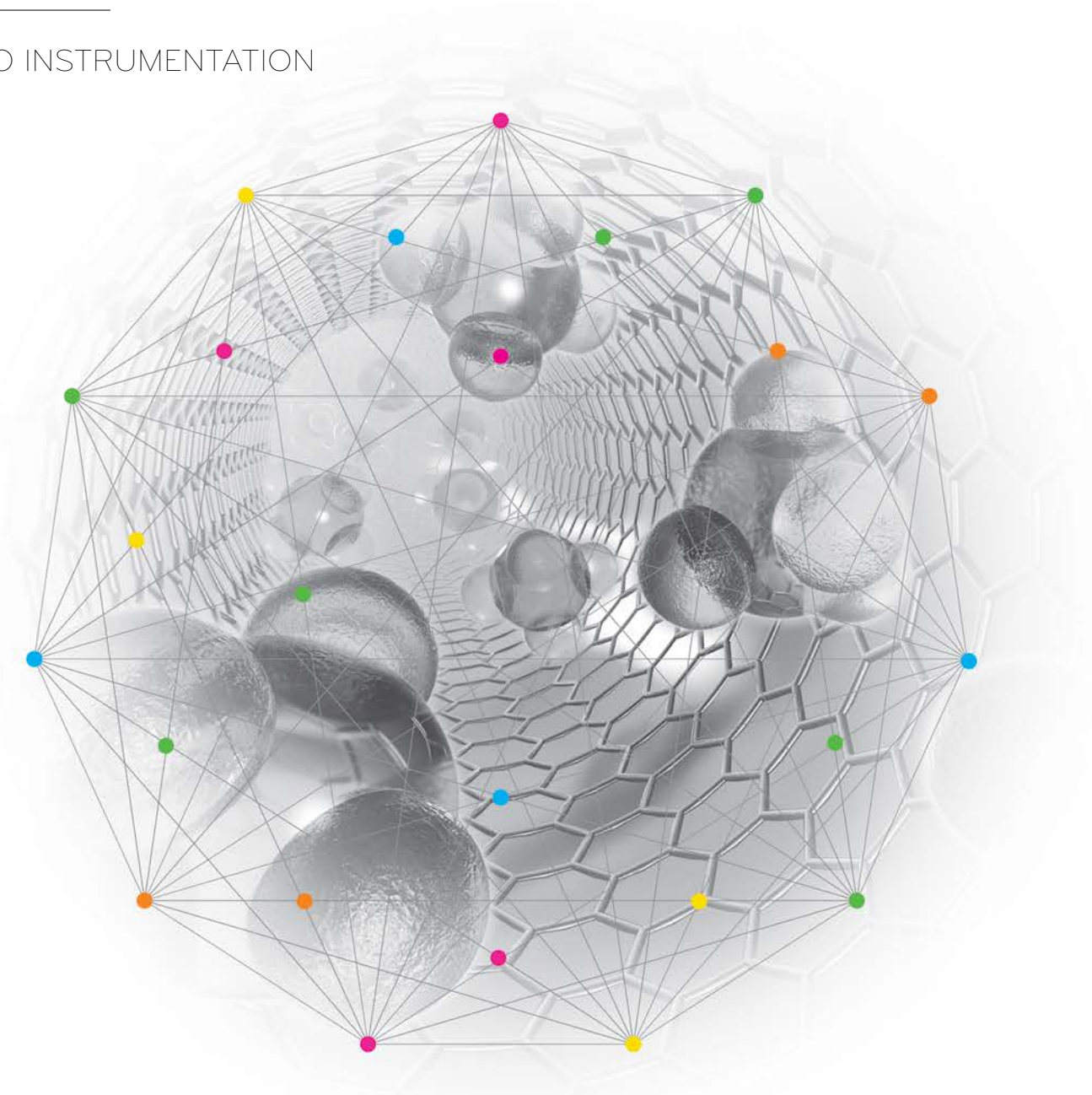


TSI KNOWS NANOPARTICLE MEASUREMENT

NANO INSTRUMENTATION



UNDERSTANDING, ACCELERATED

AEROSOL SCIENCE MEETS NANOTECHNOLOGY

TSI CAN HELP YOU NAVIGATE
THROUGH NANOTECHNOLOGY

Our Instruments are Used by Scientists Throughout a Nanoparticle's Life Cycle.



Research and Development

On-line characterization tools help researchers shorten R&D timelines. Precision nanoparticle generation instrumentation can produce higher quality products.



Manufacturing Process Monitoring

Nanoparticles are expensive. Don't wait for costly off line techniques to determine if your process is out of control.



Health Effects-Inhalation Toxicology

Researchers worldwide use TSI instrumentation to generate challenge aerosol for subjects, quantify dose, and determine inhaled portion of nanoparticles.



Nanoparticle Exposure and Risk

Assess the workplace for nanoparticle emissions and locate nanoparticle sources. Select and validate engineering controls and other corrective actions to reduce worker exposure and risk. Provide adequate worker protection.



What Is a Nanoparticle?

A nanoparticle is typically defined as a particle which has at least one dimension less than 100 nanometers (nm) in size.

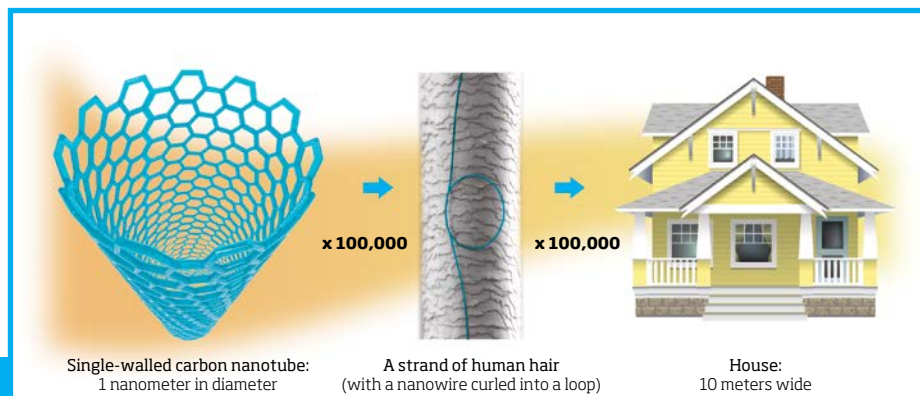
Why Nano?

The answer is simple: better material properties. Nanomaterials have novel electrical, catalytic, magnetic, mechanical, thermal, and optical properties which are primarily attributed to the high fraction of molecules on the surface of a nanoparticle. Take a four nm CdS nanoparticle, a third of the 1500 atoms are on its surface! Surface molecules also have different bonding and quantum states than bulk materials, resulting in unique material properties. For instance, a 50 nm copper nanoparticle is extremely hard; and both zinc oxide and titanium oxide nanoparticles are clear rather than white.

Real-time Nanoparticle Measurements

Real-time aerosol measurements are a powerful tool in nanotechnology for many professionals, including researchers, process engineers, and industrial hygienists. Immediate feedback can detect exposure and process problems sooner, protecting workers and saving product. An added bonus: on-line measurements are often more cost-effective than expensive off-line surface imaging techniques.

Nanoparticles: The Scale of Things



Strand of human hair with nanowire curled into loop.
Image credit: Limin Tung, Harvard University. Image concept: National Nanotechnology Institute.

Types of Nanoparticles

Nanoparticles are made from a wide variety of materials and are routinely used in medicine, consumer products, electronics, fuels, power systems, and as catalysts. Below are a few examples of nanoparticle types and applied uses:

| | |
|------------------------|---|
| Carbon-based: | Buckeyballs (targeted antibiotics) Nanotubes (stronger tennis rackets) |
| Metal Oxides: | TiO ₂ (transparent sunscreens) ZnO (hydrogen sensors) |
| Metals: | Ag (plastic containers to keep food fresh longer) Au (breast cancer detection) Al (fast burning rocket fuels) |
| Metal Alloys: | Pd-Au (groundwater pollutant removal) Au-Pt (enhanced fuel cells) FeCo-Au (enhanced tumor imaging) |
| Semiconductors: | CdS (nanowires - smaller computer chips) GaAs (quantum dots -security inks) CdTe (efficient solar cells) |
| Polymers: | Nanofibers (stain resistant materials) Nanopolymers (cancer cell targeting) |

NANOPARTICLE GENERATION AND SIZE CLASSIFICATION



Nanoparticle Generator

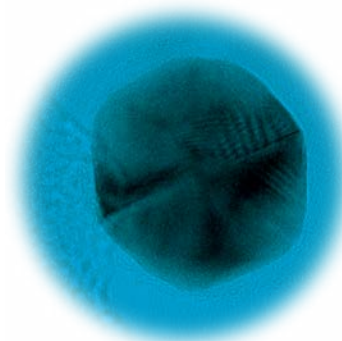
Electrospray Aerosol Generator Model 3482

High number concentrations of uniform nanoparticles in minutes.

The Electrospray Aerosol Generator Model 3482 outputs monodisperse particles as small as two nanometers. It can be used to generate catalysts and precursors or to aerosolize nanoparticle product from wet synthesis processes. Easy to set up and run, the Model 3482 eliminates the need for complex reactors or difficult-to-control furnaces.



- + 2 nm to 100 nm
- + Variety of particle types
- + Single-sized nanoparticles
- + Variety of particle sizes
- + Uniform size and shape
- + Non-radioactive neutralizer included



30 nm gold nanoparticle generated from electrospraying a gold colloid solution which is then sized using the SMPS™ spectrometer. Image provided by Professor Knut Depper, Head of the Nanocrystals and Epitaxy group at Lund University.



Single-walled carbon nanotubes generated by electrospray of aqueous suspensions. Provided by Dr. Bon-Ki Ku from CDC-NIOSH (Centers for Disease Control and Prevention; National Institute for Occupational Safety and Health). Provision of the image does not constitute or imply an endorsement by NIOSH or the federal government of the contents of this brochure.



Nanoparticle Size Selector

Electrostatic Classifier
Model 3082

Selects only the nanoparticle size of interest.



The Model 3082 is effectively a band pass filter for particle size - a wide distribution of aerosol goes in and only one particle size comes out resulting in more uniform nanoparticles as a final product or as a process precursor. Used by product researchers, inhalation toxicologists, and process engineers, the Model 3082 narrows the incoming size distribution to create a more controlled nanoparticle.

- + Narrow size distributions: $\sigma_g < 1.05$
- + Electronically select particle size
- + Size classify particles from 2 nm to 1,000 nm
- + Fully automated instrument controls

State-of-the-Art Flow Control

- + Precise flow measurement
- + Electronically adjustable flow rates
- + Recirculating flow scheme
- + Automatic Pressure and Temperature Correction



Nanometer Particle Sampler

Nanometer Aerosol Sampler (NAS) Model 3089

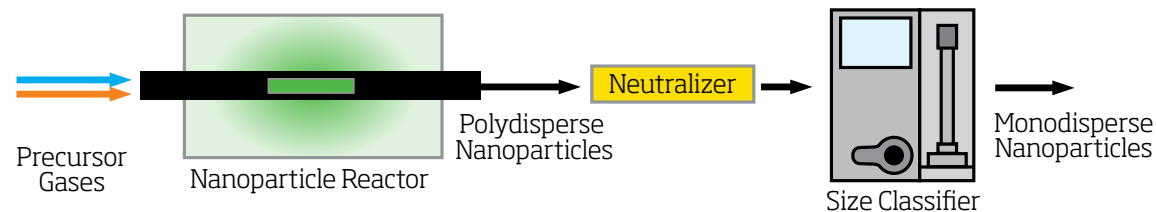
Collect nanoparticle samples for surface analysis techniques.



This electrostatic precipitator was designed to couple directly downstream of our 3082 Electrostatic Classifier to capture samples of 2 nm to 100 nm particles onto TEM grids, AFM substrates, or glass slides. The nanometer aerosol sampler allows easy and convenient nanoparticle collection for chemical analysis or off-line imaging.

- + Uniform deposition on substrate
- + High collection efficiency
- + Adjustable flow and voltage
- + Built-in pump and flowmeter
- + Ability to use wide variety of substrates
- + Simple to operate

Application Focus: Product Research and Development



ON-LINE NANOPARTICLE SIZE CHARACTERIZATION



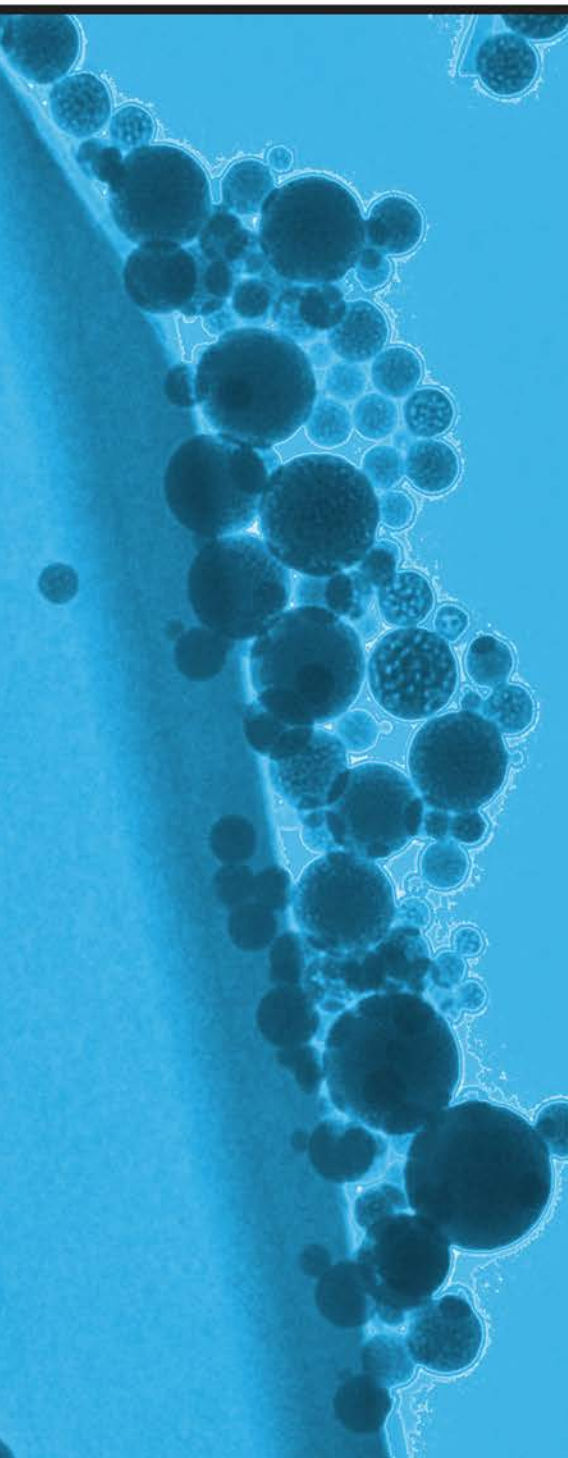
Nanoparticle Sizer

Scanning Mobility Particle Sizer™ (SMPS™) Spectrometer Series 3938

The gold standard for nanoparticle sizing. Don't wait for TEM or SEM - measure nanoparticles in real-time!

The SMPS™ spectrometer is a real-time, on-line nanoparticle sizer with high resolution and unparalleled accuracy. This measurement technique is used by the National Institute of Standards and Technology (NIST) to size 60 nm and 100 nm Standard Reference Method (SRM) and is also used successfully by scientists to size carbon nanotubes, catalysts, TiO_2 , SiO_2 , and virtually any aerosolized nanoparticle.

- + 2.5 nm - 1,000 nm
- + Up to 167 channels of resolution
- + Ultra-high accuracy
- + Ultra-high resolution
- + Concentrations up to 10^8 particles/cm³
- + Flexible set-up and application
- + Aerosol Instrument Manager® Software



Porous zinc sulfide particles made by spray pyrolysis captured on a filter fiber. Image provided by Professor Mark T. Swihart, Director of Integrated Nanostructured Systems at the University at Buffalo (SUNY).

SMPS™ Spectrometer Nanoparticle Applications



Research and Development

Faster, more reliable size measurement for immediate feedback. Significantly reduces research timeline.



Process Control

Expedite quality control processes and save money.



Health Effects - Inhalation Toxicology

Size the challenge aerosol just prior to subject introduction and quantify inhalation dose.

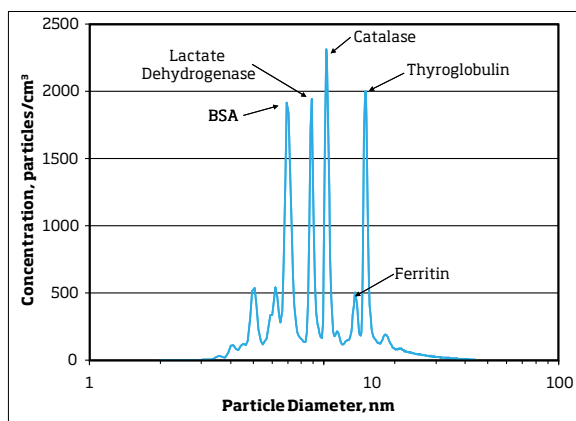


Nanoparticle Emission Control

Characterize fugitive nanoparticles and track sources.

Nanoparticle Size Resolution

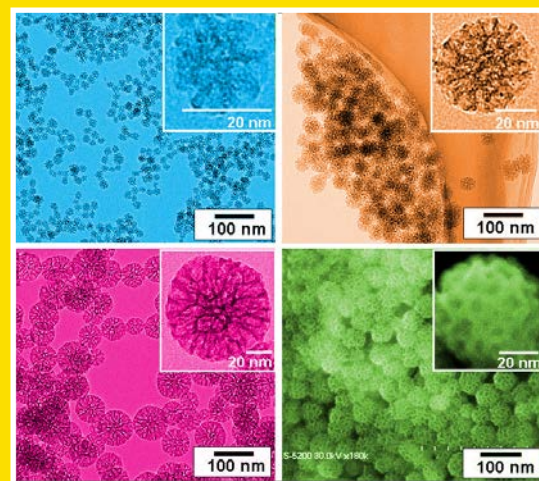
TSI's SMPS™ spectrometer has superior nanoparticle resolution. The example data depicted below is the size distribution from a sample of mixed molecular weight proteins that were aerosolized using the Electro Spray Aerosol Generator Model 3482. Since proteins have a fixed molecular weight (i.e., particle size) when they are aerosolized, they can be used as a type of size standard.



Powerful System Software

All TSI SMPS™ spectrometers come equipped with Aerosol Instrument Manager® software, a program designed for use with Windows® operating systems to control instrument operation, collect high-resolution data, and provide impressive file-management capabilities. Data can be weighted by any moment of number concentration, including diameter, surface area, volume, and mass while comprehensive statistical analysis is computed automatically for the entire distribution or specific size ranges defined. An export function allows easy transport of files to spreadsheets or other applications for customized data handling. Additional software capabilities include multiple-scan averaging, a buffer for comparing data sets, programmable start/stop times, and automatic file storage and printout options.

- + Automated data inversion
- + Advanced post-processing options
- + Comprehensive statistical analysis
- + Real-time data display
- + Play-back feature
- + Easy data export



Silica nanoparticles from wet synthesis (liquid) batch reactor. Aerosolized with Electro Spray Aerosol Generator 3482. On-line size classification using SMPS Model 3998N76.

ONE SECOND NANOPARTICLE SIZING



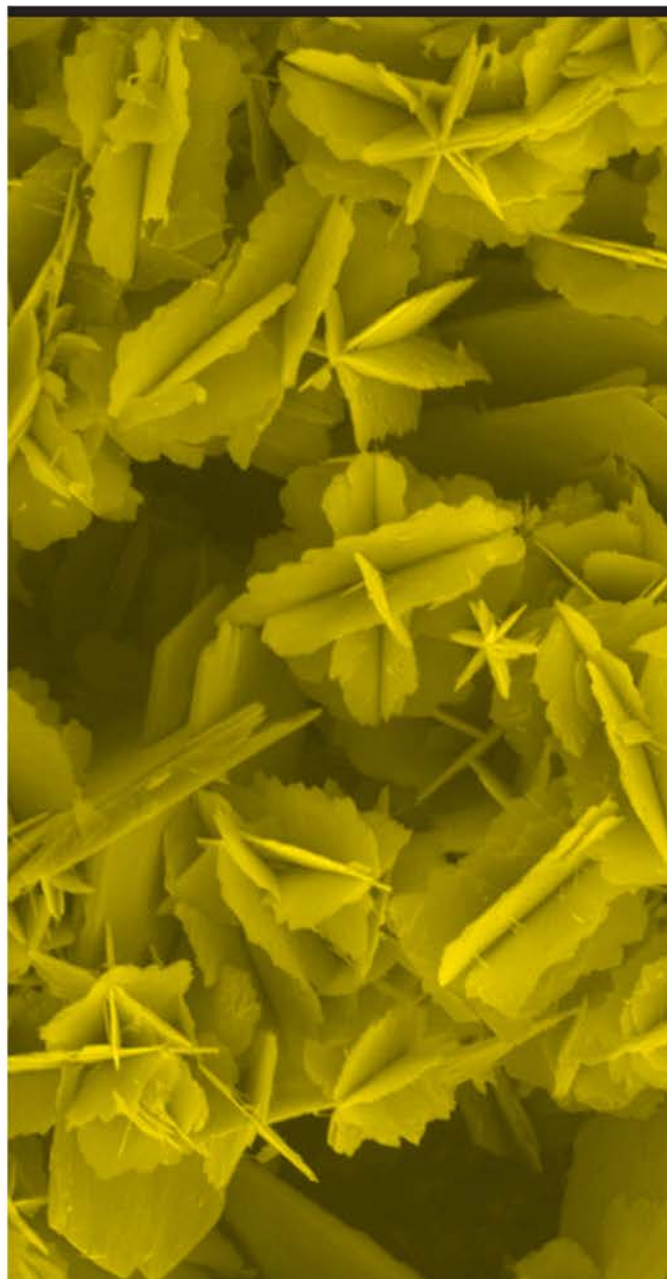
Fast Nanoparticle Sizer

Fast Mobility Particle Sizer™ (FMPS™) Spectrometer Model 3091

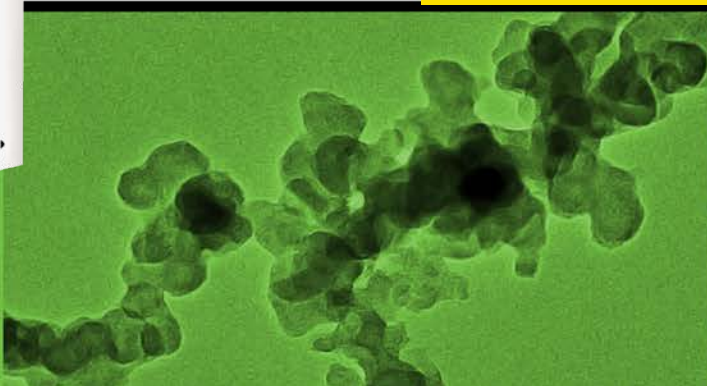
Close relation to the SMPS™ spectrometer with one second time resolution.

Capture nanoparticle nucleation events, characterize nanoparticle formation, and catch nanoparticle emission bursts with this ultra-fast, on-line sizer. The FMPS™ spectrometer is routinely used for research and development, manufacturing control, point source exposure research, and other applications where particle events occur too quickly to characterize with other analytical methods.

- + Complete size distributions in 1 second
- + Front panel display to visualize events
- + Easy to use and maintain
- + 5.6 nm - 560 nm
- + High sample flow rate
- + No radioactive neutralizer or working fluids



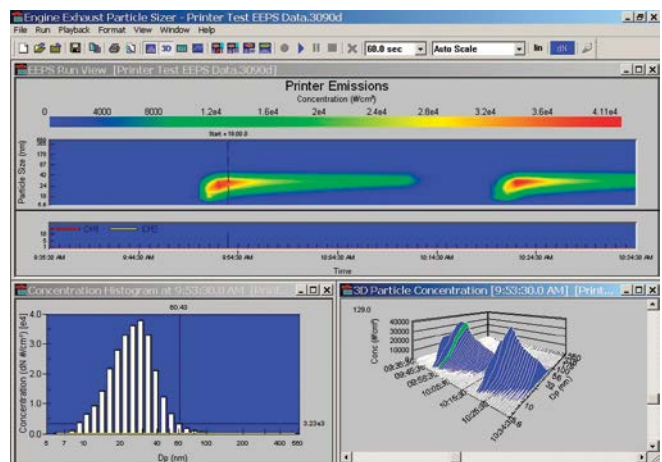
Nanostars of vanadium(IV) oxide.



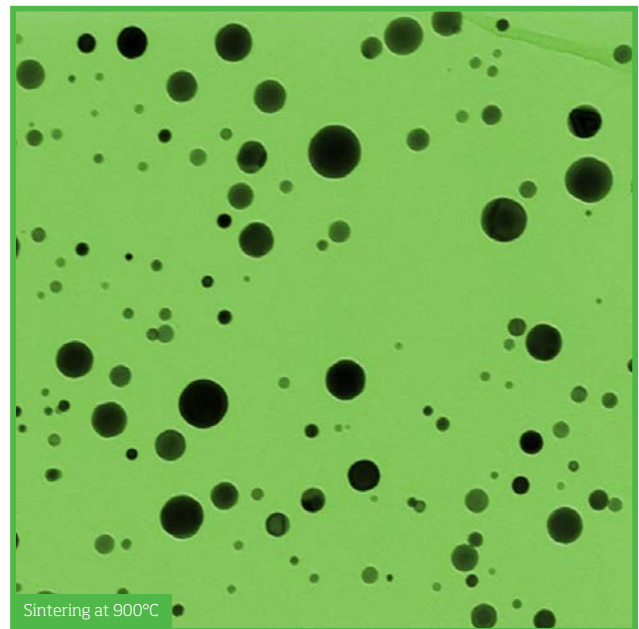
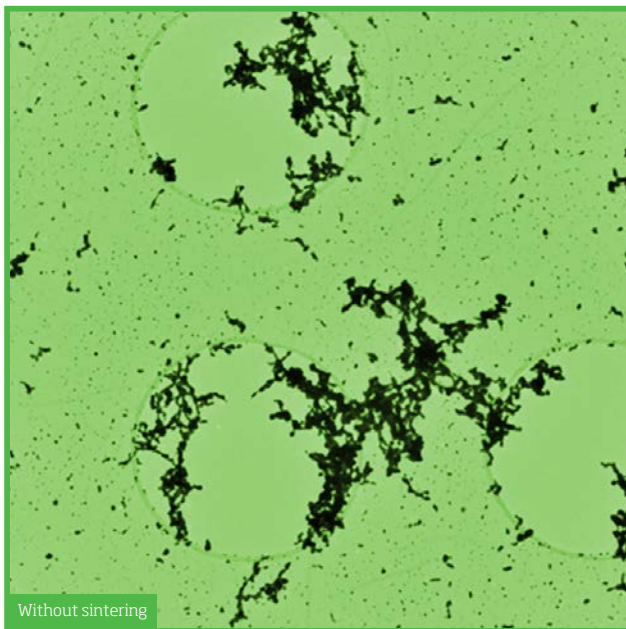
Silver nanoparticle aggregates generated by evaporation/condensation. Image provided by Dr. Seong Chan Kim and Professor David Pui, Distinguished McKnight University Professor at the University of Minnesota.

Application Focus: Nanoparticle Emissions from Laser Printers

1. Recent research has focused on nanoparticle emissions from certain types of laser printers. In 2007, a group from Australia found that nearly 30% of printers tested emitted high concentrations of nanoparticles; however, a full 60% of the printers did not emit any particles.
2. The size of particles released from printers is typically 30 nm to 100 nm.
3. Recent scientific publications reveal particle number emission rates from 10^9 to 10^{13} particles/hour.
4. NIOSH is currently investigating exposures from printer emissions.
5. International ecolabel "Blue Angel" requires laser printer particle emission testing.



FMPS™ spectrometer data of nanoparticle emissions from an office laser printer. Top: Contour graph of particle size/concentration over time. Bottom Left: 2D particle size histogram. Bottom Right: Particle size/concentration over time.



Application Focus: Fast Changing Aerosols

Morphology changes from sintering of silver nanoparticles generated by evaporation/condensation. Images above were provided by Dr. Bon Ki Ku of Centers for Disease Control, The National Institute for Occupational Safety and Health (CDC-NIOSH).

ON-LINE NANOPARTICLE NUMBER CONCENTRATION



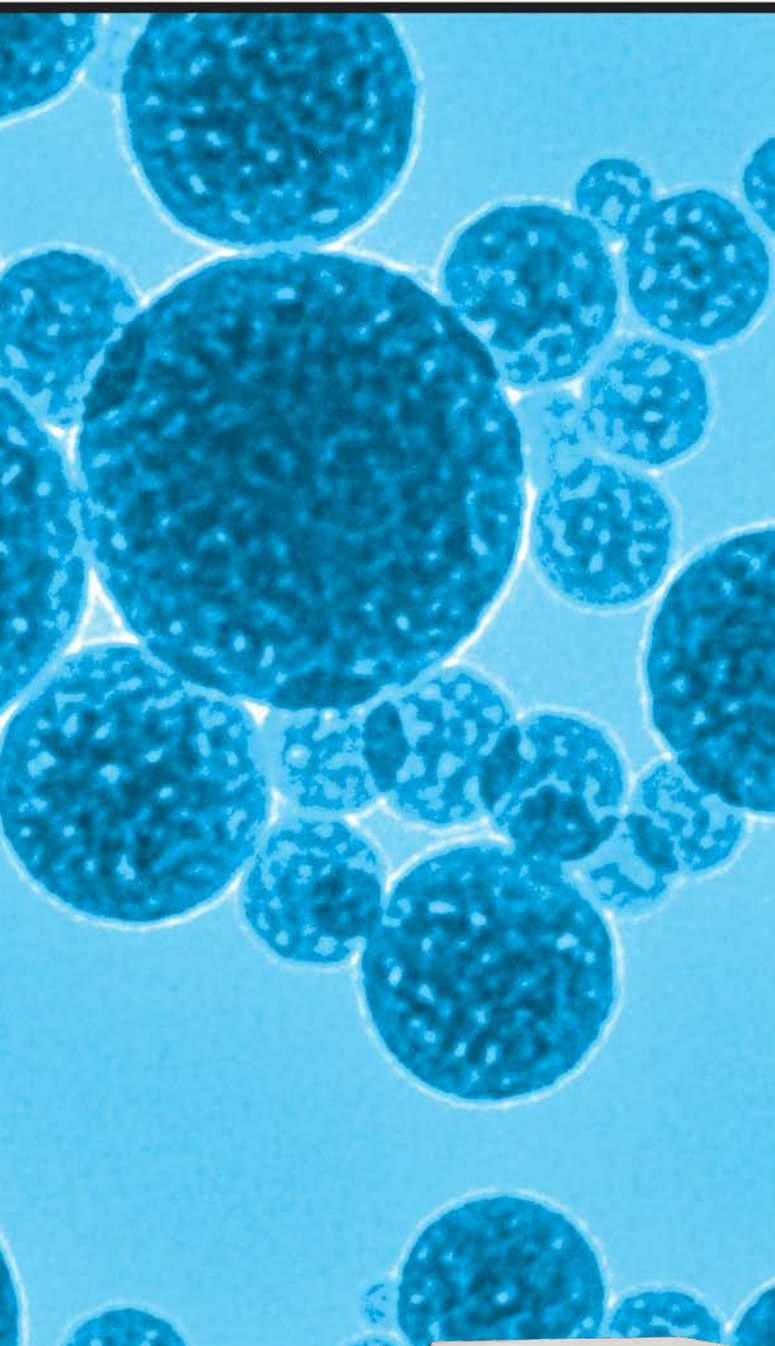
Nanoparticle Counter

TSI family of Condensation Particle Counters (CPC)

On-line single particle counting of nanoparticle concentrations down to 2.5 nm.

TSI CPC's provide accurate, real-time nanoparticle number concentration measurements in as little as 1/10th of a second. Nanoparticles do not scatter enough light to be detected by conventional optical particle counters. In order to achieve real time single particle counting, a condensation technique must be used; in this case, a working fluid is deposited on the nanoparticles in order to grow them to an optically detectable size. The particles are then passed through a laser and detector where every single particle in the sample stream is counted.

- + Fast response to rapid changes in concentration
- + Single particle counting to 4×10^5 particles/cm³
- + High accuracy
- + Built in data logging
- + Easy to use and maintain
- + Rugged enough for industrial use
- + A range of models to fit your application



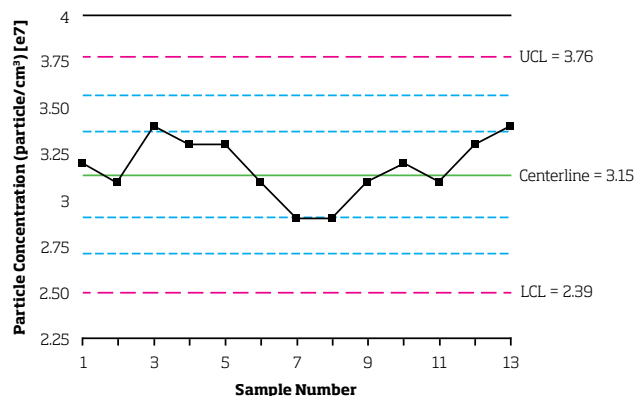
Porous zinc sulfide particles made by spray pyrolysis. Image provided by Professor Mark T. Swihart, Director of Integrated Nanostructured Systems, University at Buffalo (SUNY).



Application Focus: Manufacturing Process Control

In nanoparticle manufacturing, as in semiconductor manufacturing, “time is quite literally money” due to the extreme value of the finished product and the potentially hazardous precursors and products that must be carefully controlled during processing. As such, Statistical Process Control (SPC) is frequently applied to detect and quickly correct variations.

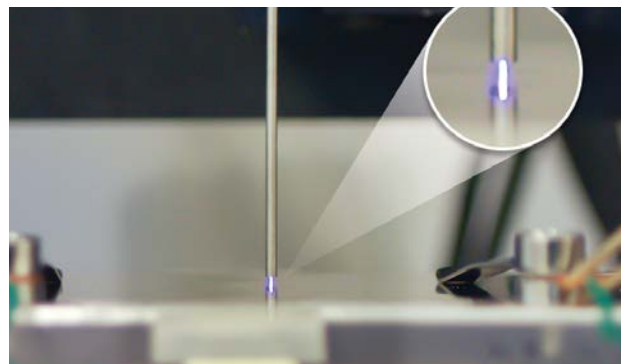
On-line measurements of particle concentration or count median diameter can be a powerful metric that immediately alerts process engineers when the nanoparticle synthesis process is out of control and is producing an inferior product. In fact, even small changes in concentration or particle size can be early warning signs that nanoparticle product quality is a concern, thus saving time and money.



Application Focus: Inhalation Toxicology

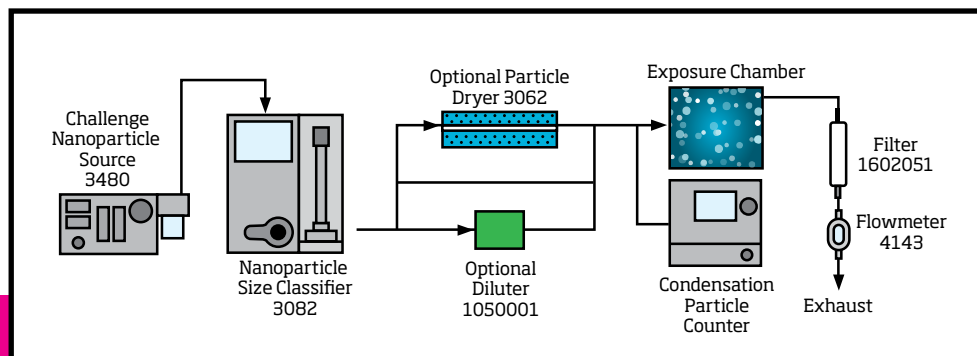
Inhalation toxicology of engineered nanoparticles is a growing area of research. Government agencies across the world are calling for more information on the toxicity of these new materials.

Below is a typical experimental set up for an inhalation “in-vivo” study. A condensation particle counter (CPC) sampling just upstream of the exposure chamber can improve the accuracy of the measured dose. An Electrostatic Classifier downstream of the challenge aerosol can tighten up the aerosol size distribution and lead to more firm conclusions about the effect of nanoparticle size on health.



Continuous flow microplasma reactor used to synthesize metal and semiconductor nanoparticles (single walled carbon nanotubes- SWCNT) which are sized online using the SMPS™ spectrometer Model 3936. Image provided by Professor Mohan Sankaran, Case Western University.

► Nanoparticle Toxicology: Measure Accurately, On-line, the Delivered Dose



NANOPARTICLE SURFACE AREA AND WORKER EXPOSURE



Nanoparticle Surface Area

Nanoparticle Surface Area Monitor (NSAM) Model 3550

Measure the dose of inhaled nanoparticles in the lung quickly and easily.

The Model 3550 provides a direct way to measure worker exposure. Many nanoparticle toxicology experts believe that the health effects of nanoparticles are better correlated to the surface area of the particles. The NSAM is a unique tool that quantifies the surface area of nanoparticle aerosols that deposit in the lung, corresponding to the International Commission on Radiological Protection (ICRP) lung deposition curves for the tracheobronchial (TB) and alveolar (A) regions of the human respiratory tract.

- + Measure lung deposited surface area of inhaled particles
- + Tracheobronchial or alveolar lung deposition
- + Comprehensive data collection software
- + Excellent sensitivity
- + Wide dynamic range
- + High time resolution
- + Custom calibration option for more flexible research options



Application Focus: Particle Deposition in the Lungs

It is important to understand how and where airborne particles will deposit in the lung because inhalation is the most common route of exposure for aerosols. Comprehensive lung deposition models are well developed for reference workers and model results show that deposition rates differ as a function of particle size and specific lung area (i.e., tracheobronchial or alveolar).



Respirator Fit Testers

PortaCount® Pro and Pro+ Model 8038

Protect your workers.

Test their Personal Protective Equipment (PPE).

A quantitative respirator fit test proves that the face piece of a respirator is sized appropriately and that the individual using it knows how to put it on correctly. Formal fit test records document efforts to protect workers.

- + OSHA compliant for all respirators, including N95, P1 and P2
- + Automated fit testing with FitPro™ Fit Test Software
- + Objective measurements
- + Fit test record database
- + Stand-alone operation
- + Fast fit times
- + Simple and easy to use

Nanoparticle Processing and Respirator Use

1. Respirators are recommended for nanoparticle manufacturing to safeguard against potentially harmful substances.
2. Although there is still limited information on the health effects of engineered nanoparticles, the US Environmental Protection Agency recently outlined a new research strategy to better understand how manufactured nanomaterials may harm human health and the environment.

*References: NIOSH Publication No. 2009-125: Approaches to Safe Nanotechnology, Managing the Health and Safety Concerns Associated with Engineered Nanomaterials.



NANOPARTICLE EXPOSURE AND PROTECTION



Hand-Held Nanoparticle Counter

Condensation Particle Counter
Model 3007



Portable hand-held CPC is ideal for quantitative nanoparticle emission surveys and work area assessments.

Track down point sources of nanoparticles with this battery powered CPC that can detect and count nanoparticles down to 10 nm. The Model 3007 is one of our smallest Condensation Particle Counters. At only 3.8 pounds, it provides versatility not common with larger particle counters. Active volumetric flow control increases data accuracy and provides a more quantitative measurement.

- + Battery powered operation
- + Particle size range of 10 nm to 1,000 nm
- + Built-in LCD display
- + Small and light weight; ergonomic design
- + +/- 10% particle concentration accuracy

TSI also offers the P-Trak® Ultrafine Particle Counter Model 8525. This base model can provide qualitative measurements and comes with a convenient telescoping sample probe. The Model 8525 is routinely used by industrial hygienists to qualitatively assess the workplace, check HVAC system filter efficiency, evaluate effectiveness of engineering controls, and track down point sources of ultrafine and nanoparticle generation.



Battery Powered Particle Sizer

Optical Particle Sizer
Model 3330



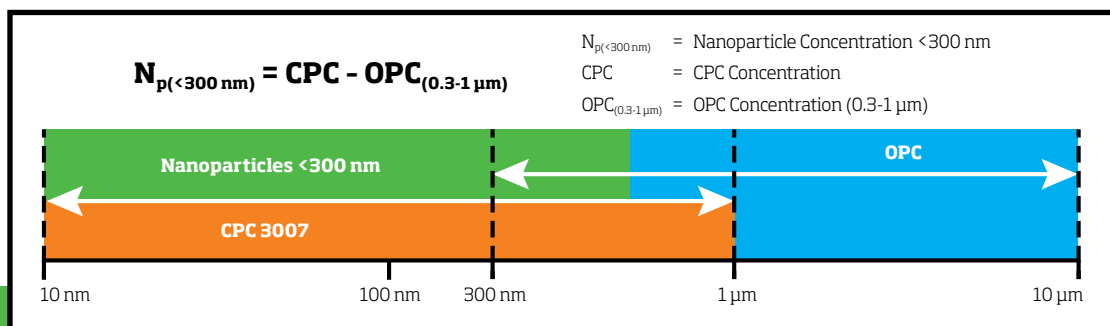
A 16-channel, adjustable binned Optical Particle Sizer to measure airborne particles from 0.3 to 10 µm.

Optical particle counters (OPCs) are frequently used to measure worker air quality. Comparisons of outdoor versus indoor particle concentration levels can provide an excellent baseline assessment. The Optical Particle Sizer Model 3330 is a cut above the field of standard OPCs providing a higher quality measurement paired with a state-of-the-art user interface.

- + Size range: 0.3 to 10 µm
- + 16 size channels with user adjustable size binning
- + Built-in data logging capability for up to 30,000 samples
- + Portable, battery powered
- + Modern GUI with intuitive user interface
- + Filter-based sample collection for later gravimetric or chemical analysis

Application Focus: Emission Assessment

For nanoparticle emission assessment, the National Institute for Occupational Safety and Health (NIOSH) uses the Nanotechnology Emission Assessment Technique (NEAT). Outlined below, the approach is to measure the environment using both a CPC and an OPC, like the OPS Model 3330, to determine the concentration of airborne particles which are less than 100 nm.





Portable Nanoparticle Sizer using SMPS Technology

NanoScan SMPS Model 3910

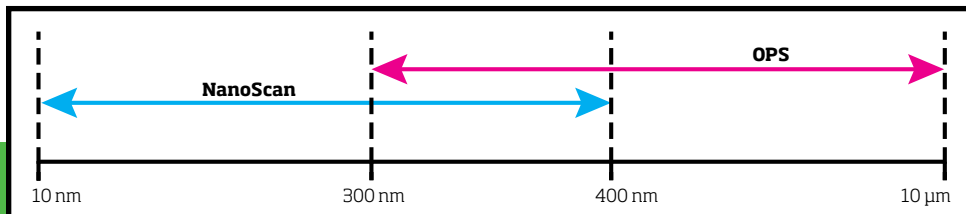
Easy to use, lightweight and battery-powered, NanoScan SMPS enables investigators to collect valuable nanoparticle size data from more sites. Derived from TSI core technologies, the NanoScan SMPS is an innovative, cost effective solution for real-time nanoparticle size measurements.

- + Size range from 10 to 400 nm
- + Two measurement modes:
 - SCAN - real-time size distributions
 - SINGLE - single size concentration monitoring
- + 1 minute size distributions; 1 second single size data
- + Built-in data logging
- + Small and portable
- + Concentrations up to 1,000,000 particle/cm³
- + Multi-Instrument Management Software for use with the Optical Particle Sizer Model 3910

Application Focus

The process of nanoparticle production and handling can create specific worker exposure risks that are not captured by general background monitoring equipment. Using portable tools like NanoScan allows measurement in the “breathing zone” during various production steps to see what activities and which steps are the source of particle in the air.

The new Model 3914 combines the NanoScan SMPS and the Optical Particle Sizer to measure particle size distributions over three orders of magnitude using affordable, portable, real-time instruments. Multi-Instrument Manager (MIM) software package can be used to simultaneously collect and merge data from both instruments into a single, continuous size distribution from 10 nm to 10 μ m.



NANO APPLICATION CHART

THE CHART BELOW IS A GUIDE FOR SELECTING AN INSTRUMENT THAT BEST FITS YOUR MEASUREMENT NEEDS

| Model | Research and Development | Manufacturing and Process Monitoring | Health Effects Inhalation Toxicology | Nanoparticle Exposure and Risk |
|--|------------------------------|--------------------------------------|--------------------------------------|--------------------------------|
| Nanoparticle Generation | | | | |
| Electrospray Nanoparticle Generator | 3482 | + | + | + |
| Electrostatic Particle Classifier | 3082N | + | + | + |
| On-line Concentration Measurement | | | | |
| Nanoparticle Condensation Particle Counters | 3772, 3775, 3776, 3787, 3788 | + | + | + |
| On-line Size Characterization | | | | |
| Scanning Mobility Particle Sizer™ Spectrometer | 3938 | + | + | + |
| Fast Mobility Particle Sizer™ | 3091 | + | + | + |
| Nanoparticle Exposure and Risk | | | | |
| Nanoparticle Surface Area Monitor* | 3550 | + | + | + |
| AeroTrak™ 9000 Nanoparticle Aerosol Monitor* | 9000 | | + | + |
| Hand-held Condensation Particle Counter | 3007 | | | + |
| P-Trak® Ultrafine Particle Counter | 8525 | | | + |
| PortaCount® Pro+ Respirator Fit Tester | 8038 | | | + |
| Optical Particle Sizer | 3330 | + | | + |
| NanoScan | 3910 | + | | + |
| Accessories | | | | |
| Nano Aerosol Sampler | 3089 | + | + | + |

* U.S. Patents 6,544,484 and 7,812,306

TSI Service, Service Agreements and Extended Warranties

Protect Your Investment...Protect your Data Accuracy.

TSI's Particle Instruments are the most reliable and accurate measurement instruments in the industry. Ensure your instruments are properly calibrated and at peak performance with routine annual service or a TSI QualityGuard™ Service Agreement.

Value

TSI has a vested interest in having an installed base of well serviced and calibrated instrumentation. We've priced our service agreements to provide an incentive for routine maintenance and calibration.

Upfront Fixed Costs

Budgeting made simple. No need to procure additional money for annual calibration or repairs. A QualityGuard™ service agreement guarantees your costs are fixed no matter what happens to parts or labor prices in the future.

Quality

TSI strives to meet or exceed our customers' needs and expectations through continual improvement of our processes, products and services. Our Quality System is registered to ISO 9001:2000 and TSI uses NIST traceable analytical tools and NIST traceable standard reference materials to check out and calibrate instruments.

Technical Expertise

No one knows more about a product than the manufacturer. TSI has invested in sophisticated instrumentation to allow our experienced repair technicians to checkout, test, calibrate and repair our instruments with unparalleled precision. Aerosol Instrument Manager, AeroTrak, P-Trak, PortaCount, TSI and the TSI logo are registered trademarks, and Fast Mobility Particle Sizer, FitPro, FMPS, QualityGuard, Scanning Mobility Particle Sizer, SMPS and TrakPro are trademarks of TSI Incorporated.

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UNDERSTANDING, ACCELERATED

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 Germany Tel: +49 241 523030