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# NSAM-derived total surface area versus SMPS-derived "mobility equivalent" surface area for different environmentally relevant aerosols

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ABSTRACT

The surface area of inhaled particles deposited in the alveolar region, as reported by the TSI nanoparticle surface area monitor (NSAM), was compared with the corresponding value estimated by a TSI scanning mobility particle sizer (SMPS) for a range of environmentally relevant aerosols, including petrol emissions, ETS, laser printer emissions, cooking emissions and ambient aerosols. The SMPS values were based on a mobility size distribution assuming spherical particles using the appropriate size-dependent alveolar-deposition factors provided by the ICRP. In most cases, the two instruments showed good linear agreement. With petrol emissions and ETS, the linearity extended to over $10^3$ $\mu m^2$ $cm^{-3}$. With printer emissions, there was good linearity up to about 300 $\mu m^2$ $cm^{-3}$ while the NSAM increasingly overestimated the surface area at higher concentrations. The presence of a nucleation event in ambient air caused the NSAM to over-estimate the surface area by a factor of 2. We summarize these results and conclude that the maximum number concentration up to which the NSAM is accurate clearly depends on the type of aerosol being sampled and provide guidance for the use of the instrument.



## 1. Introduction

Lung deposition is the main pathway of airborne particles into the human body with the potential to cause adverse health effects. Airborne particulate matter (PM) has been associated with many adverse health effects such as asthma, respiratory and cardiovascular diseases (Russell & Brunekreef, 2009). Epidemiological studies have shown a direct link between particle number concentration and ill health (Oberdorster et al., 2005; Sioutas et al., 2005). Particle size is an important parameter because the surface area of a given mass of small particles is much greater than that of the same mass of larger particles. Since the amount of toxins that a particle can carry is directly proportional to its surface area, it is likely that smaller particles, in particular those smaller than 100 nm – the so called ultrafine particles, will play a more important

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role in causing severe health effects (Stoeger et al., 2006). Smaller particles have a higher specific surface area (area per unit mass) than coarser particles. Therefore, estimating exposures to a certain level of particles by their mass concentration, may grossly underestimate their associated health risks. For that reason, total particle surface area is considered to be an important parameter in health effects requiring more investigation (Giechaskiel et al., 2009).

Presently, there is no exposure standard for aerosol surface area. This is partly because of the lack of information on the importance of this parameter and the interpretation of the measurement itself. Surface area is a purely operational term since the actual parameter that is measured by each device depends on the physical principle of operation. For example, instruments based on diffusion charging assume that the charge acquired by the particle is proportional to the 'surface area' or to be more specific – the 'ion accessible surface area' of a particle. For this reason, some workers prefer the term 'equivalent surface area', similar to 'equivalent diameter'. No aerosol measuring device measures geometrical area directly.

A convenient technique has been the derivation of surface area from particle number size distribution measurements obtained with a Scanning Mobility Particle Sizer (SMPS). However, this method has many limitations. Firstly, the SMPS measures the mobility diameter of the particles and not the geometrical diameter. The surface area is related to the geometrical diameter and not to the mobility diameter. More importantly, airborne particles, particularly vehicle emission particles such as soot, are not spherical in shape and are often found in the form of long chain like structures (Maynard & Aitken, 2007; Park et al., 2003, 2004). This makes it very difficult to calculate their surface areas from their effective mobility equivalent diameters without knowledge of the particle morphology. In order to overcome this problem, a number of studies have utilized a combination of TEM and size distribution data to obtain a more accurate surface area estimate (Ku & Maynard, 2005; Ku & Kulkarni, 2012; Lall & Friedlander, 2006; Park et al., 2003, 2004).

The nanoparticle surface area monitor (NSAM) monitors particles in the air and uses an algorithm to estimate the total surface area of particles that are deposited either in the alveolar or the tracheobronchial region of the human lung in real time (Asbach et al., 2009; Fissan et al., 2006). The instrument has been used in many applications to compare its response with other instruments and to investigate the structure of ultrafine particle agglomerates (Bau et al., 2012; Ku & Kulkarni, 2012; Wang et al., 2010) and to estimate exposure to nanoparticles in various environments such as in pizzerias (Buonanno et al., 2010) and in automotive plants (Buonanno et al., 2011).

While the NSAM is the most widely used instrument for the determination of the surface area of particles deposited in the lungs, the SMPS is the instrument that is most commonly used for size distribution measurements. Therefore, the aim of this study was to assess the performance of the two instruments by comparing the "NSAM-derived surface area" with "SMPS-derived mobility equivalent surface area" with the specific objectives of investigating their response to different types of aerosols, their size and number concentration. The novelty of this study is the large number of aerosols that have been investigated. Comparing the varied response of the two instruments to the different aerosols emphasizes the importance of taking the morphology and structure of the aerosols into account. The findings are of importance in assessing the exposure and deposition of aerosols in the human respiratory system and illustrate the limitations of the two methods.

## 2. Methods

In this study, we used an SMPS and an NSAM, operating side by side, sampling from the same ultrafine particle source at the same time. The instruments sampled through two identical conductive rubber tubes, each of internal diameter 4 mm and length 900 mm. In previous experiments we have determined that the particle losses for various aerosols in the ultrafine particle size range through similar tubes were less than 1%.

The NSAM was used to determine the deposition in the alveolar region of the lung, as it has been shown that, during inhalation, ultrafine particles are much more likely to be deposited in the alveolar region than in the tracheobronchial region (Asbach et al., 2009). The alveolar-deposited surface area of the particles in unit volume of inhaled air, as reported by the NSAM, was compared with the corresponding factor estimated from the SMPS size distributions weighted by the alveolar-deposition factors provided by the International Commission on Radiological Protection (ICRP, 1994). Various size ranges of the SMPS distributions were investigated in order to estimate the optimum response size range of the NSAM. Recognizing the possibility that the NSAM response would be affected by the type of particles used, we repeated the experiments with ultrafine particles derived from several different sources such as petrol emissions, environmental tobacco smoke (ETS), indoor cooking emissions, laser printer emissions and ambient air.

### 2.1. Instrumentation

#### 2.1.1. The NSAM

The TSI model 3550 NSAM is designed to measure the total surface area of particles deposited in the human lung of a reference worker (Fissan et al., 2006). It should be noted that the NSAM does not report the total surface area of particles suspended in the air but, rather, the total surface area of the particles that are deposited in the lung in units of $\mu m^2\ cm^{-3}$. Its principal of operation is based on diffusion charging of sampled particles, followed by detection of the aerosol using an electrometer. The sampled air enters the instrument at a flow rate of 2.5 L $min^{-1}$ through an inlet cyclone that removes all particles larger than 1 μm. The flow is split, with 1 L $min^{-1}$ passing through a particle filter and an ionizer, and the balance 1.5 L $min^{-1}$ being measured as aerosol flow. The flows are recombined in a mixing chamber where aerosol particles are made to undergo positive unipolar charging by diffusion. The charged aerosol passes through a trap to remove excess ions