Visualisation of exposure to nanoparticles using PIMEX

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Abstract. In 2010 the Video Exposure Monitoring method PIMEX was applied to visualize exposure to nanoparticles for several tasks. Next to personal observations the video captured the working conditions and registered possible changes in operational conditions. Simultaneously and coupled with the video both the personal exposure (in the breathing zone) and the background exposure were monitored. In this way the personal exposure to synthetic particles can be corrected for the background exposure to natural occurring nanoparticles or confounding factors. The resulting videos can be edited and used for risk communication purposes. Overall, PIMEX can be of added value for the risk assessment of engineered nanoparticles.

1. Introduction
Nanotechnology is a rapidly growing business, whether it is for sunscreen applications, on car windows, in socks or as nano-chemotherapy. The possibilities seem almost unlimited for these new techniques whereby materials are being designed or manipulated on the nanoscale. The term 'nano' is usually used for materials with one or more dimensions between 1-100 nanometers (a nanometer is a millionth of a millimeter). This can be a single particle, but also a fiber or a plate.

The applications of nanotechnology are many because with these techniques it is possible to create materials with new properties. These properties may, however, differ substantially from the properties that these same materials have at a larger scale [1]. Due to these other properties, it is possible that the hazardous properties, compared to the parent material, are also different. For instance, decreasing particle size might lead to more reactive particles per unit mass and result in a larger surface specific area. As a result other health effects than the known human health effects of the parent material might occur. At the moment the possible hazardous properties of nanoparticles are not yet fully characterized.

Besides the uncertainty concerning the hazardous properties of the nanoparticles there is also discussion on the exposure potential of the so-called synthetic nanoparticles. How and when does exposure happen, via which exposure routes and how should exposure be measured and characterized? Typically, exposure to particles is expressed in terms of mass concentration (e.g. mg/m³). However, there is increasing evidence that exposure to (water insoluble) nanoparticles can be better expressed in terms of particle number (e.g. p/cm³), or surface area concentration [2]. At the moment there is no standardized measurement strategy for exposure assessment of nanoparticles in the workplace. In addition there is no (portable / personal air sample) measurement device available yet that is able to simultaneously measure all these different exposure parameters.

Because of the uncertainty related to the hazardous properties of nanoparticles and the possible health effects following exposure, in 2009 the Dutch government decided to apply the precautionary
principle [3]. This means that policies and implementation measures should focus on preventing or minimizing the exposure of workers to nanoparticles. It is up to the employers to apply the precautionary principle and to implement it in the risk inventory and the corresponding action plans. To help implement the precautionary principle good practices have been developed. In 2008 an investigation was carried out in the Netherlands to obtain an overview of the good uses of engineered nanoparticles in Dutch companies and research facilities [4]. Part of the deliverables was a best-practice guidance sheet (good-use-decision-tree) with a step-wise approach of risk characterization (figure 1).

![Diagram](image.png)

**Figure 1.** Steps of the good-use-decision-tree.

2. PIMEX

PIMEX (Picture Mix Exposure) is a visualization technique that can support employers in carrying out the exposure assessment and in complying with the precautionary principle. It is a video exposure monitoring method that had been broadly applied within occupational hygiene practice for over 20 years. PIMEX was originally developed in the eighties in Sweden by the National Institute for Working Life [5]. Similar developments took place around the same time in the USA (NIOSH) under the name Video Exposure Monitoring (VEM) [6]. In 2004 PIMEX was introduced in the Netherlands and applied for different purposes, with currently >100 movies freely available in Dutch. Movies cover broad topics such as chemicals, physical strain, vibration, noise, heat stress and ionizing radiation. These movies have been developed for various industries and private companies.

The PIMEX set is coupled with measurement equipment, a computer and a video camera. The work situation or action that is filmed and simultaneously real-time measurements are performed (e.g. with a DustTrak or PID). The devices are connected to a laptop with PIMEX software. The measurement data are being sent to the laptop via an analogue signal and integrated with the video so that both the work situation and measurement data are presented on the screen. In this way, activities where for instance exposure to hazardous substances are possible, and specific moments where exposure occurs, are visualized. With the latest version (PIMEX-2008) up to four different devices can be connected to simultaneously monitor and visualize exposure.

3. PIMEX and Nano

In 2009 a survey was carried out by Arbo Unie and funded by the Ministry of Social Affairs and Employment to identify different types of nano measuring equipment presently available and to examine if these devices can be coupled with PIMEX. In order to be useful for workplace (personal) sampling and for coupling with the PIMEX set several technical requirements were composed. The technical requirements are a) analogue output, b) direct readable, c) portable and d) useful for personal air sampling. Two measurement devices were selected that were available and met two or more of the technical requirements. These were connected with the PIMEX set and test-movies were made for situations were exposure to nanoparticles occurred.
The practical tests were successful and have shown that it is possible to connect nano-measuring equipment with PIMEX and thus visualize exposure to nanoparticles. This offers a number of practical features and benefits that can assist companies with the implementation of the precautionary principle and with some steps of the good-use-decision tree (figure 1). These steps are mentioned below.

3.1. Identify all tasks and activities with potential exposure
PIMEX can assist in detecting and visualizing possible sources of exposure to nanoparticles. In monitoring exposure to nanoparticles the observation and recording of workplace conditions is a very important aspect of the risk assessment, which increasingly becomes a standard procedure. With video recording a thorough observation and interpretation of the intended processes and the surrounding work conditions are possible and simplified. One of the advantages of video monitoring is that all visible details of the work situation are captured and stored (more than with only written registration), and can be viewed and analyzed afterwards. In this way these situations or specific processes are identified where exposure to nanoparticles occurs. This information can be further used for the implementation of risk management measures.

3.2. Personal air sampling to determine exposure
Besides the detection of sources related to process emissions, it is possible to assess exposure to nanoparticles in the breathing zone of the employee. This can be accomplished with portable measurement equipment. At the moment there are a few devices on the market that are portable and useful for personal air sampling. In this way it is clear which tasks result in exposure of the employee to nanoparticles. Based on this information risk management measures can be implemented if necessary.

3.3. Determination of and correction for the background concentration
There are numerous sources of nanoparticles. In the natural environment and in the ambient air outside the workplace nanoparticles occur manifold, ranging from traffic emissions to emission from the climate system or devices used for housekeeping. The contribution of a task or process compared with this background concentration may be relatively small, thus making it more difficult to correctly interpret the measurement data. The PIMEX set can be coupled to multiple devices, enabling the simultaneously assessment and recording of the process emission as well as the background concentration. In this way it is possible to correct exposure to manufactured nanoparticles for the background concentration. When doing this it is important to select good reference locations for background measurements (e.g. measuring incoming air in the breathing zone, in the same industrial setting, but located further away or a measurement in another room, e.g. an office).

3.4. Identification of confounding factors
The background concentration of nanoparticles can fluctuate considerably, e.g. due to opening / closing of doors or switching on of other equipment (e.g. a forklift). These additional sources of nanoparticles can strongly affect the exposure measurements of synthetic particles, especially when the expected exposure concentrations are low. When the contextual information during the measurements is not recorded it is impossible to determine whether increased concentrations are due to release of synthetic particles or due to a change in background levels. With PIMEX the work situation is recorded and possible confounding factors that might influence the exposure measurements are identified.

3.5. Validation of risk management measures
PIMEX can be used to determine the effect of risk management measures in reducing exposure to nanoparticles. Situations with and without control measures can be assessed and recorded (e.g. with/without local exhaust ventilation). During the recording the video and graphic images can be viewed on the screen. Immediately after the recording the images can be displayed again, so that those
involved (operator, manager or technical assistant and occupational hygienist) can see and discuss the effect of the control measure. If the effect of the measure is insufficient the situation can directly be adjusted and again recorded with PIMEX. In this way PIMEX can be used as an intervention method.

3.6. Education and training of employees
The recordings can be viewed on the spot. In addition they can also be edited for education and training purposes and viewed with a simple movie player. PIMEX has proven itself as an ideal tool for education and training of employees, because workers can see for themselves the effect of their actions on exposure. Seeing is believing!

4. Conclusion
In the Netherlands employers are required to implement the precautionary principle when synthetic nanoparticles are used or manufactured. The good use decision tree gives occupational hygiene professionals directions to get started with the risk assessment. An occupational hygiene background with knowledge of characterization of exposure specific to nanoparticles is essential. PIMEX is a valuable contribution in carrying out a number of steps of the good use decision tree. The PIMEX recordings can be used for different purposes or and be edited into films for education or training purposes.

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