Experimental Evaluation of the Effectiveness Offered by Different Types of Personal Protective Clothing Against Nanoaerosols

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Abstract. The rapid expansion of nanotechnology is outpacing health and safety recommendations for engineered nanomaterials. Thus, there is a lack of information about the effects that nanomaterials can induce in the human health. Nevertheless, workers in nanotechnology-related industries are potentially at risk of being exposed to nanomaterials. Therefore, there is a need of characterize the behaviour of personal protective equipment against penetration nanoparticles, in order to provide an adequate protection to the workers. In this study, the efficiency of several protective dermal equipment against water-based NaCl aerosol was evaluated. For this purpose, different protective clothing and gloves were selected to carry out the assays, simulating typical use conditions of protective equipment under occupational settings. Results obtained exposed that the level of protection offered by the distinct types of personal protective coveralls depended not only on the fabric, but also on their fitting to the body of the subject. On the other hand, the efficiency of the protective gloves was set in the range from 95% to 99%, depending on the thickness and the type of material.

1. Introduction

Nanotechnology is a term coined by Norio Taniguchi in 1974 [1], referring to the manipulation of matter on an atomic, molecular or supramolecular level. This discipline has experienced a tremendous growth during lasts years, promoting the development of a new generation of products in most major industry sectors [2–4]. Nevertheless, along with their benefits, engineered nanomaterials (ENMs) raise many questions and generate concerns about their potential effects on the human health owing to their physical, chemical and biological properties, which differ significantly from larger sized bulk materials, even when the basic material is the same [3,5,6]. This is as a consequence related to the increase of the surface area per unit of mass when size decreases, and the fact that the quantum effects play a greater role the smaller a particle becomes [1,7].

ENMs are defined as intentionally manufactured products having, at least, one dimension in the range 1-100 nm [8]. Nanoparticles (NPs) are a subset of ENM, described as single particles with a diameter or dimension below 100 nm [9]. However, apart from the intentionally-manufactured NPs, there are different sources of unintentionally-produced NPs which exist in some workplaces. A variety of airborne dust generating mechanisms can be presents in the occupational settings, including accidental spills, combustion, falling powders, agitation or transferring processes. Grinding and milling bulk materials also generates and suspends small particles as airborne dusts [10]. Consequently, workers in nanotechnology-related industries are potentially at risk of being exposed to ENMs [11,12].

Penetration of NPs into the human body can occur through respiration, dermal or oral routes [13]. Inhalation is the main exposure pathway for particulate matter and, consequently, the most critical for NP intake [14]. Nevertheless, the skin is the largest organ of the body, and it is also a potential route of exposure to ENMs. Oral exposure can also occur from incidental ingestion or unintentional hand-to-mouth transfer [15].

Regarding dermal exposure, the potential for NPs to penetrate the skin has been investigated in previous works found in the literature. Results show that the smaller the nanoparticle is, the easier is to penetrate the skin [16]. Furthermore, damaged or injured skin increases the NPs permeation [17]. However, no clear evidence has been found demonstrating that NPs are transported via the circulatory system through skin penetration to other body organs [16,18].

Although data from toxicological studies have suggested that nanoscale materials can pose new and unconventional risks, it should be noted that current available information about toxicity and hazard is limited, making difficult to carry out a quantitative risk assessment [8–10,19]. Therefore, given the limited amount of information about the health risks associated with occupational exposure to engineered nanomaterials, the precautionary principle suggests to take measures to minimize worker exposures [9,20].

The framework for occupational risk management applied to engineered nanomaterials takes into account the traditional industrial hygiene hierarchy to avoid or control the exposure of workers to these materials. Thus, these approaches comprises elimination or substitution, process enclosure, engineering control, procedural control, and personal protective equipment (PPE) [9,12]. Therefore, the use of PPE, such as protective clothing and gloves, supposes the last line of defence in the hierarchy of exposure control after all other available measures have been implemented [21,22]. Hence, the development and implementation of efficient PPE against NPs is needed in order to maintain the exposure as low as possible [6].

There are several types of protective clothing available in the market to protect workers who are exposed to a chemical risk. Protective clothing is classified using a scale ranged from 1 to 6 as a function of the level protection offered. Thus, the type 1 provides the highest level of protection and 6 the lowest. Suits type 1 are designed to be completely isolated from the environment, protecting the worker against chemicals and gases (UNE-EN 943-1,2); type 2 offers protection against chemicals, but not against gases (UNE-EN 943-1); type 3 is impermeable to liquids (UNE-EN 14605); type 4 is impermeable to aerosols (UNE-EN 14605); type 5 resist the penetration of solid particles suspended in the air (UNE-EN 13982-1); finally, type 6 offers a limited protection against liquid products (UNE-EN 13034) [23]. Although there are no standard regulations available describing the type of protective clothing needed to protect the worker against the exposition to NPs, some recommendations have been published which suggest the use of determined protective equipment. On the one hand, if the NM is used in form of dust, the use of disposable suits type 5 is proposed. In contrast, when the NM is used in a colloidal solution, the use of type 4 or 6 is suggested. It has to be said that there exists disposable protective clothing which is certified for several types simultaneously. Furthermore, the use of nonwoven materials is strongly recommended due it seems that offers better protection than woven fabrics [24].

Moreover, different publications related to the efficiency that protective clothing offers against the exposure to NPs have been published. Golansky et al. [13], Park et al. [21], Gao et al. [25], Vinches et al. [20] and Ben Salah et al. [26] concluded that nonwoven clothes offered better protection than woven fabrics, which is in accordance with the recommendations exposed above.

In the case of protective gloves, recommendation suggest the use of chemical or biological protective gloves (UNE-EN 374). This equipment must be made with "impermeable" polymeric materials such as latex, nitrile, polyethylene or butyl. Nevertheless, although the word "impermeable" is used to define these kind of polymeric materials, they offer a limited resistance against the permeation of chemical products. Sooner or later the chemical can be adsorbed in the external surface of the glove and diffuse through it to reach the skin. Thus, in some cases, the use of double-glove is encouraged to increase the protection level offered. Furthermore, if the NM is used along with other chemical product such as an organic solvent, the effectiveness of the glove may be decreased [27].

As in the case of protective clothing, Vinches et al. [20], Gonlasky et al. [13,28] , Dolez et al. [29] and Park et al. [21], studied the protection offered by distinct protective gloves exposed to different types of NPs. The conclusions achieved in these works showed that protective gloves offers, in general, goods levels of protection against the NPs assayed.

The selection of PPE must be based on an adequate risk assessment, giving rise to a clear picture on the level of protection that is needed. However, penetration efficiencies of protective clothing against NPs have not been explored deeply yet and, in some cases, results obtained are conflictive [12,13,20,29]. Therefore, little is known about the effectiveness of protective clothing when is exposed to NPs and, consequently, the available data for the selection of protective dermal equipment is limited [21,29,30].

This paper reports results obtained related to the penetration of NPs through protective clothing and gloves. The assayed protective clothing consisted in four different non-woven tissues, while the materials of the gloves selected to perform the assays were latex, vinyl, nitrile, neoprene, polyvinyl chloride and butyl. Furthermore, different movements were carried out in order to simulate typical use conditions of protective equipment under occupational settings.

2. Materials and methods

Due to the lack of a standard to test the protective equipment against airborne NPs, ISO norms and standards were reviewed and adapted to the conditions necessary to generate and measure NPs.

2.1. The testing chamber

Experiments were carried out in a test room isolated from the environment, specifically designed and built for this purpose. Entrance to the exposure chamber was performed through a Safe Access System (SAS) room, an isolated room from the others and from the outside where the subjects could put on their PPE safely. This room was maintained at overpressure to avoid leakage or contamination from ENMs from the other testing rooms, which were maintained at negative pressure. Thus, the ENMs were always contained inside the testing room, avoiding the release to the outside or contamination of the testing room. Furthermore, the SAS entrance has a control dispositive which does not allow that the door is unlocked when testing rooms are opened, in order to avoid direct contact with the testing chambers to the outside.

The pilot test chamber was designed to simulate working environments. It has a big, rectangular shape with a total volume of 10 m^3 where industrial instrumentation or processes can be replicated. A well-controlled laminar flow and HEPA filtering at both ends of the room remove completely the background, allowing tests under clean environments.

The tests room is prepared for wet or powdered dispersions of ENMs, since it has a flow director to modify ventilation type and a drainage system. It is coupled to the pilot test chamber through a connection panel where tubes can be plugged. Therefore, it can be measured or nebulized from any of the sides without the necessity of being inside the chamber.

The space of the rooms was designed minimizing the elements that could lead to accumulation of contaminants in edges or ground, building it with round corners and antistatic walls. Likewise, the material of the walls and floor is easily cleanable. Clean air was taken in from above the cabinet and passed through several HEPA filters to remove contaminants. Temperature, pressure, humidity, inlet and exhaust flowrates were controlled by an electronic control panel placed at the entrance.

Initially, in order to select the most appropriate concentration of NaCl to generate the aerosol, solutions with different amounts of this compound, ranged from 0.0001% to 0.1%, were prepared and tested. Two main assumptions related to the number and size of the NPs have to be taken into account; firstly, the number of particles generated depend on the concentration of the solution, following a directly proportional relation. Secondly, the greater the concentration, the bigger the particle diameter.

Thus, it was chosen a concentration of 0.05% of NaCl to carry out the experiments. The geometric mean diameter for the particle count distribution was about 40 nm, and the particle concentration was maintained in about 3,5 to 5,0 x 10^4 particles/cm^3. This concentration was maintained with less than

10% of variability between the beginning and the end of the tests (generally below 5%). The distribution of the aerosol obtained for this level of concentration is shown in Figure 3.
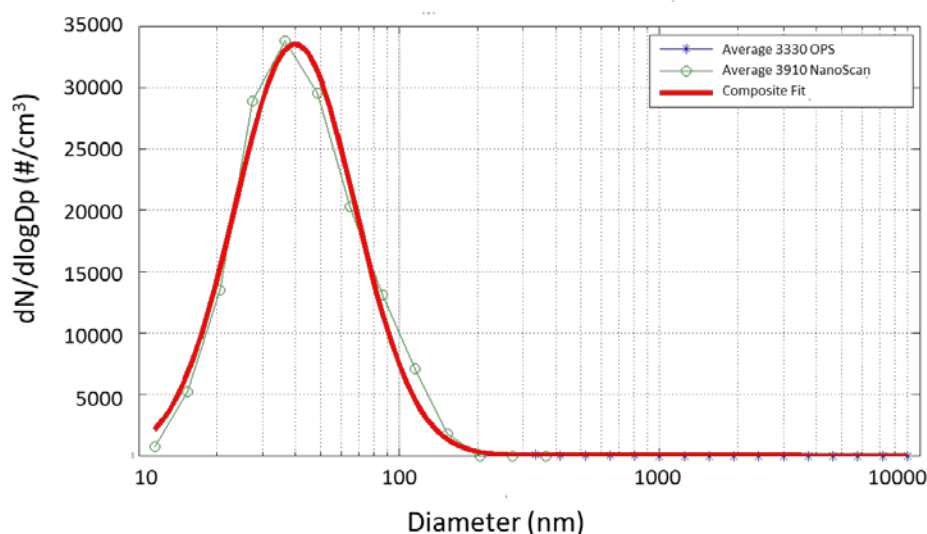

Figure 1: Particle number concentration as a function of size.

2.2. Equipment

Tests were performed generating a NaCl solid aerosol inside a test chamber isolated from the environment [26,31,32]. In order to produce the atmosphere of NPs, 0.5 g of NaCl purchased from Sharlau (Spain) were weighted and dissolved in 1 liter of ultrapure water obtained using a Milli-Q® Integral Water Purification System (Merk, USA). A bottle with the NaCl solution was placed on a magnetic stirrer to avoid deposition and connected to the Constant Output Atomizer (TSI 3076, USA). Flow was adjusted to 4 L/min and the pressure was set in 2.4 bar. The nebulized material was passed through a Diffusion Dryer (TSI 3062, USA), a silica gel desiccant aimed to remove the water droplets and the remaining humidity, in order to avoid agglomeration or aggregation effects. Afterwards, a neutralizer is placed to remove most of the charge of the generated particles and reduce electrostatic effects. Finally, when the concentration of NaCl NPs in the chamber was stabilized, experiments were carried out.

The specific instrumentation used to measure the airborne NPs characteristics were the Optical Particle Sizer (TSI 3330, USA) and Nanoscan SMPS (Scanning Mobility Particle Sizer, TSI 3910, USA), used for size distribution measurements. Two parallel CPCs (Condensation Particle Counter, TSI 3007, USA) were employed to quantify the particle number concentration at different locations, and to monitor the temperature and humidity in the chamber, a Testo 435 Multifunction Measuring Instrument (Testo, Germany) was employed.

2.3. Protective equipment assays

With the purpose of evaluate the effectiveness of the dermal protective equipment against NPs, several types of protective gloves and clothing were selected to carry out the experiments. The selection of the representative PPEs to be studied was carried out distributing questionnaires amongst industrial companies working with ENMs to compile information on the most widely used suits on each case. Samples of the same characteristics as the ones indicated in the answers were selected, trying to cover a wide range of standard levels of protection.

2.3.1. Setup for protective gloves assay. Following the recommendations which suggest the use of gloves against chemical and biological risks to protect workers against NPs, different types of common protective gloves made with impermeable polymeric materials (including reusable and single-use

gloves) were selected and tested. Thus, the single-use protective gloves selected were latex (without powder), vinyl (with and without powder) and nitrile (two different thickness). On the other hand, reusable gloves chosen were made of neoprene, polyvinyl chloride or butyl. Before starting the experiment, a previous visual examination was performed with the aim to discard gloves which presented any defect or gash.

Assays were carried out employing a specific device designed for this purpose, consisting in a steel cylinder (35 mm length, 20 mm diameter) opened by the front side. The back and the side were perforated in three points (Ø 5 mm) in order to insert three metal tubes (two in the back and one in the side). Finally, a circular mark (Ø 50 mm) was adapted in the front side.

A circular piece of the glove was fixed in the aforementioned device sealed with a clamp and placed into the chamber described in section 2.1, so that the glove was exposed to the NPs aerosol only by one side. The concentration of NPs in the chamber was measured using a CPC. Another CPC was connected in the back side of the device to measure the concentration of NPs capable of permeate the glove material. At the same time, a sheath flow of clean dry air was supplied inside the glove at the same flow rate as the measuring devices were suctioning, in order to avoid the creation of a depression. Furthermore, a HEPA filter was connected in the third tube to act as a scape/entrance valve: in the case of overpressure, air was allowed to escape from inside the system; on the other hand, if the pressure inside the system was lower than outside, air entered in the system through the HEPA filter. A schematic representation of the montage is illustrated in **Figure 2**.
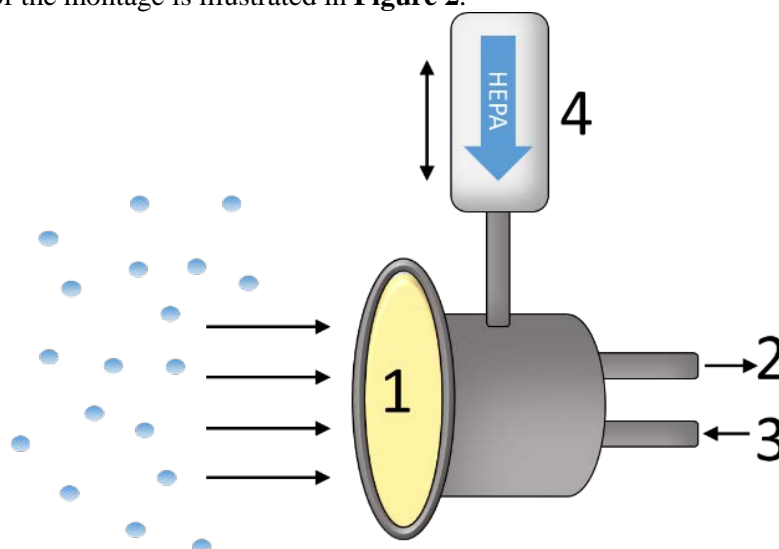

Figure 2: Schematic representation of the device employed to test the penetration of NPs in different gloves. 1: Test samples, 2: Input measurement device, 3: Clean dry air flow, 4: HEPA filter.

2.3.2.   Setup for protective suits assay. To study the efficiency of protective clothing against NPs, five types of non-woven protective suits were selected to perform the tests, according to the criteria which encourages the use of this type of fabrics (Table 1): The first suit (PS1), classified as Cat III type 3B, 4B, 5B and 6B, consisted on a material with a high barrier protection against chemicals which offers protection against many concentrated inorganic acids and bases, and against a wide range of organic chemicals. The second one (PS2) was a coverall formed by million fine and continuous fibers made of high density polyethylene, classified as type 5B and 6B. The third coverall (PS3) was made with double-side PVD coated Nylon and classified as type 4 Cat III. Finally, the fourth suit (PS4), made with polypropylene, was classified as type 6, Cat I. The last suit (PS5) was a self-ventilated protective suit for radioactive protection (type 1). All suits were available in sizes ranging from M to XXL in order to cover the different body shapes of the test subjects.

Table 1: Protective suits selected for testing along with their code name and their standard classification.

Code	Material	Cat./Type	Reuse/Disposable
PS1	High barrier protection against chemicals (Tyvek type)	Cat III Types 3B, 4B, 5B and 6B	D*
PS2	Million fine and continuous fibers made of high density polyethylene (Tychem type)	Types 5B and 6B	D*
PS3	Double-side PVD coated Nylon	Cat III Type 4	R
PS4	Polypropylene	Cat I Type 6	D
PS5	Self ventilated radioactive suit	Cat III Type 1	R

* According to manufacturers' instructions, it could be reused provided that is in good conditions.

The protocol followed to calculate the inward leakage of NPs into protective clothing was adapted from the international standard UNE-EN ISO 13982-2 2005 "Protective clothing for use against solid particulates – Part 2: Test method of determination of inward leakage of aerosols of fine particles into suits" (ISO 13982-2: 2004). The main variation was the use of NPss to carry out the test, which required different ambient conditions and the use of specific devices to generate and detect them.

Firstly, a visual inspection was carried out to detect any malformation or defect. If so, the garment was discard. At least 10 human subjects with different features and good health were dressed with the suit following the manufacturer's instructions. Besides, in order to protect the subjects during the assays but also simulate the real operative conditions, they were equipped with protective respiratory equipment, gloves and security shoes.

The suit had connexions for silicone tubing in three different points at different heights: chest, waist and knee, and a CPC was connected to the point selected to perform the sampling. The concentration inside the chamber was measured with a second CPC. A pump was connected to supply a flow of dry, clean air inside the suit in the same range as the measuring devices suction rate, with the purpose of equal the drift inside, while, the third point remained closed. The sequence of connexions can be seen in Table 2.

Table 2: Sampling scheme and positions to perform the test of suits and coveralls against NPs.

	Sampling	Sheath Air	Closed
Position 1	Knee	Chest	Waist
Position 2	Waist	Knee	Chest
Position 3	Chest	Waist	Knee

The subject was placed inside the test chamber and asked to perform a series of exercises in the following order: (I) Standing still, (II) walking at 5 km/h, (III) continuous squatting at a frequency of 5 squats/minute. The time for each exercise in each sampling position was 3 minutes, and 1 minute of stabilization was left between exercises. A schematic representation of the assay performed to study the efficiency of protective suits is shown in **Figure 3**.
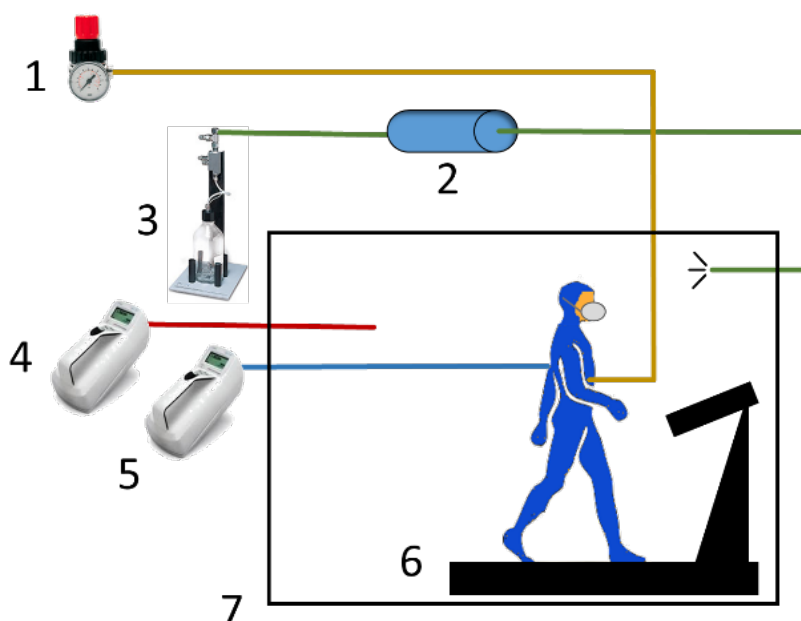
Figure 3: Scheme of the assay carried out to study the efficiency of protective suits. 1: Supply of clean air, 2: Diffusion dryer, 3: Constant output atomizer, 4: CPC measuring outside the suit, 5: CPC measuring inside the suit, 6: Treadmill, 7: Isolated chamber.

Furthermore, in order to evaluate the efficiency offered by the fabric itself, a piece of the protective clothing was placed in the device developed to analyse the leakage in gloves. The protocol followed was the same than the explained in section 2.3.1.

3. Results and discussion

Distinct values of efficiency against NPs were obtained depending on the personal protective equipment tested. Results achieved are described and discussed in the following sections.

3.1. Protective gloves

According to the standards, chemical protective gloves have to be made with impermeable polymeric materials. Although the term "impermeable" is used, impermeable materials offer a limited resistance against chemicals due to, sooner or later, chemicals will permeate them. The standard UNE-EN 374:2004 stablishes some considerations about the characteristics which protective gloves against chemicals and microorganisms have to satisfy. Nevertheless, the classification and protection offered by these gloves, according to this standard, does not take into account the airborne NPs.

The efficiency of several commercial protective gloves made with different materials was evaluated. The percentage of NPs capable to cross the barrier of the glove was determined calculating the percentage of inward leakage (IL%), comparing concentrations at both sides of the glove:

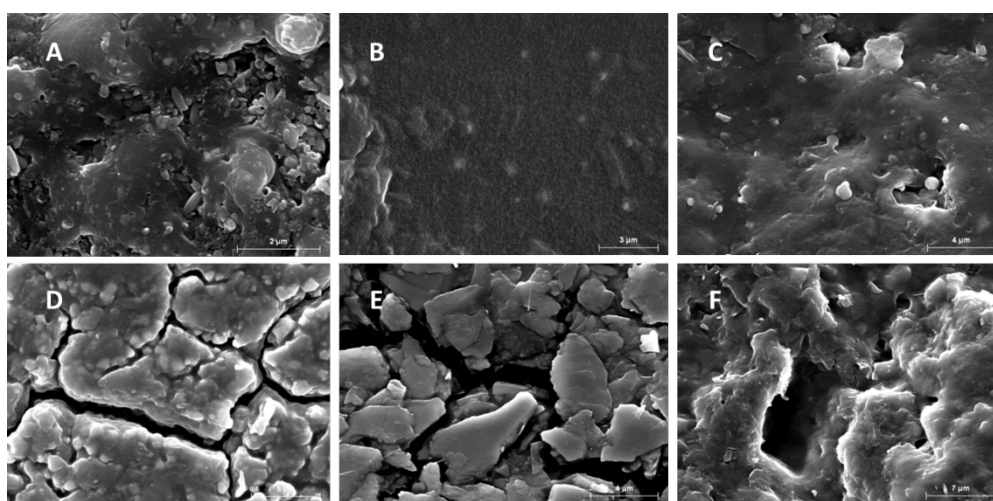$$IL\% = \frac{C_1}{C_2} \cdot 100$$

Where C_2 represents the concentration of aerosol in the side of the glove exposed to the atmosphere and C_1 is the concentration of NPs found at the other side.

As can be seen in **Table 3**, the efficiency of the gloves increases with the thickness. The surprisingly high penetration of the latex gloves can be due to a deformation or breakage of this specific set of gloves or due to a greater size of the pore of the glove material in comparison with the nanoparticle. In the case of Butyl, results were so unalike each other that were discarded.

Table 3: Efficiency of distinct protective gloves against NaCl nanoparticles.

Type	Material	Thickness (mm)	IL (%)
Disposable	Nitrile Thin	0.07-0.09	0.040
	Nitrile Thick	0.11-0.15	0.006
	Vinyl	0.08	0.103
	Vinyl (without powder)	0.08	0.013
	Latex (without powder)	0.15	4.64
Reusable	Neoprene	0.7	1.63
	PVC	1.30	3.17
	Butyl	0.36	-

In order to understand whether previous results depend on the pore size or material of the glove, a close SEM image of the surface of some gloves was taken (*Figure 4*). Performance depends strongly on the material of the glove. Although, generally, there are no pores in their surface, some small defects or gaps can be enough to offer a way to penetrate inside the glove. Nevertheless, materials such as neoprene or butyl seem to be composed with cracks big enough in comparison with NM size. Thus, worst performance is expected with them.

Figure 4: SEM images of the surface of protective gloves. A) Latex, B) PVC, C) Nitrile thick, D) Neoprene, E) Butyl, F) Nitrile thin.

The proposed assay assumes a high concentration of NPs in the environment close to the glove, thus it can be considered as a worst case scenario. However, the conditions of this specific test may be unrealistic, since in a real case scenario not only the NPs are important, but also the solvent or any other chemical manipulated along the live cycle of the NM. Although some of the gloves tested are specifically or recommended for liquid handling, the high penetration shown for airborne NPs brings to recommend to wear a disposable glove under the reusable one to avoid the dermal contact.

3.2. Personal protective suits

Several protective suits can be found in the market depending on the risk that we want to control. The standard UNE-EN 13982:2005 stablishes the requirements and characteristics that protective clothing must offer against solid particles. As happened with the gloves, this standard does not include the efficiency offered against NPs.

The efficiency of five distinct commercial protective clothing made of different materials was tested. The inward leakage was calculated as follows:

$$IL\% = \frac{C_1}{C_2} \cdot 100$$

Where C_2 represents the concentration of aerosol in the atmosphere and C_1 is the concentration of NPs found inside the suit (particles/cm^3). It was performed, at least, 3 replicates of each positioning. Then, the arithmetic mean of the total inward leakage was calculated for the whole exercise program and for all test subjects. This result is reported to classify the performance of the protective suit, given by the Nominal Protection Factor (NPF). The NPF is the concentration ratio of contaminant in the ambient atmosphere to the concentration of the contaminant inside the suit, giving an idea of how many times is protected the wearer (i.e. a NPF of 20 means that the clothing protects 20 times more versus wearing nothing). In Table 4 can be seen a summary of this classification, along with the assigned class for each PS.

Table 4: Classification of non-ventilated protective suits.

IL (%)	Cat.	NPF
20	I	2
2	II	50
0.2	III	500

As can be seen in Figure 5, best results were achieved in PS1 and PS2. In both PS, mean values of %IL sampling in the knee were below 5%. Similar results were also obtained sampling in the waist, but in PS1 the dispersion of the results was higher. However, results of %IL obtained sampling in the chest were higher and more disperse. Furthermore, in general terms, greater inward leakage was observed when subjects were asked to do squats, probably because this movement caused a compression or deformation in the suit, allowing the apparition of gaps between the suit and the skin by which the NPs could enter inside.
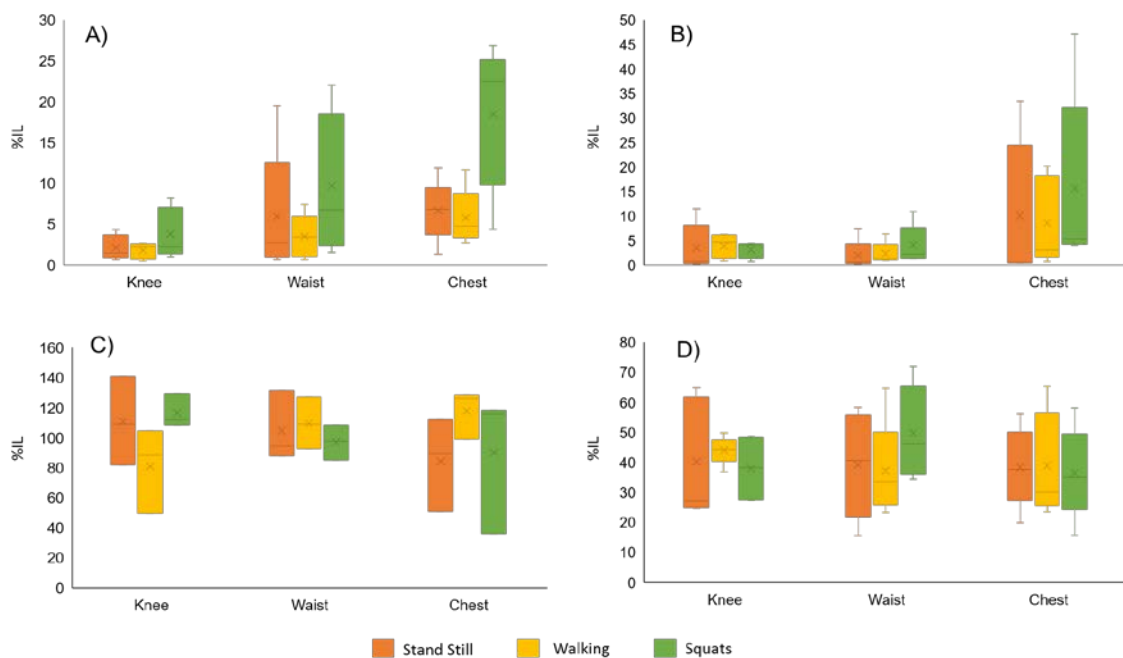
Figure 5: Values of % inward leakage obtained in the different protective suits assayed. A) Protective suit #1, B) Protective suit #2, C) Protective suit #3, D) Protective suit #4.

The PS3 offered the worst protection against NPs, due the mean values of %IL obtained in all the sampling points were practically about 100%. Moreover, the dispersion of the results achieved was high, obtaining great differences between each subject. These results might be explained because, although this coverall is classified as Cat III type 4, both the sleeves and the legs of this PS did not adjusted the body of the user, leaving spaces between the body and the suit by which the NPs could enter inside.

Results obtained for PS4 were similar in the three sampling points and for each action, with a mean value inward leakage of about 40%. This suit, although theoretically was the one which had to offer the worst protection due it was classified as Cat I type 6, improved the results offered by PS3 because, in this case, the sleeves and the legs were adjusted to the user, avoiding the penetration of the NPs by the gaps generated between the body and the suit. These results shown that the efficiency offered by the protective clothing not only depended on the type or material of suit, but also the fitting achieved with the body. Thus, the adjust between the protective clothing and the body of the user is a critical parameter to take into account at the time of choosing a PS to protect the worker against the exposition to NPs. The PS5 was not represented since the %IL was below 0.001% in every occasion, even 10 times lower, thus offering the highest protection of all.

In Figure 6 can be seen the variations of both concentrations recorded at the same time. It can be observed how the squats modified abruptly the air inside the suit, promoting the entrance of NPs by the gaps of the suit, although, immediately after stopping, the concentration decreased to lowest levels. Contrarily, concentration remained mainly constant when the subject was walking, but, during the pause for stabilization, there was an increase of NPs inside the suit due to the recovery of the shape while standing still.
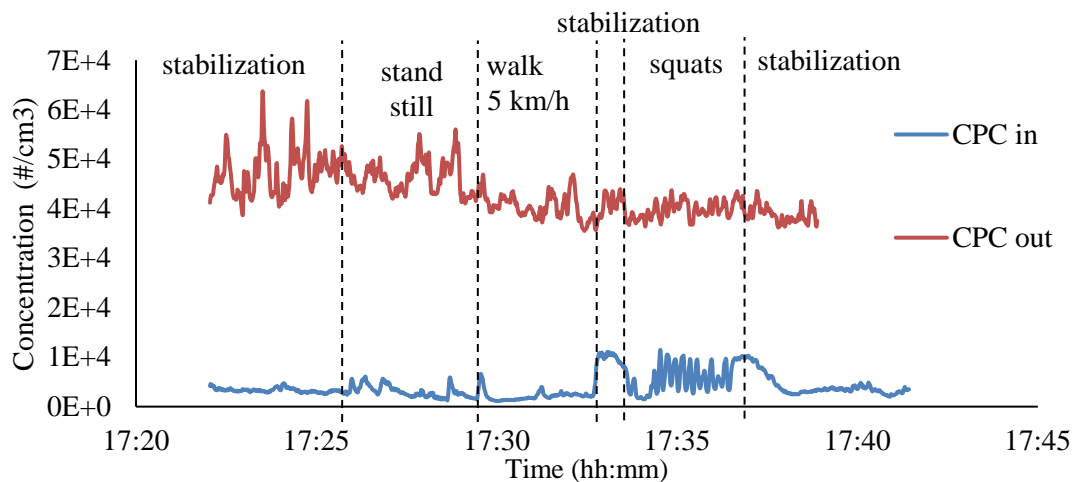

Figure 6: Concentrations in the test chamber (upper line) versus inside the suit during a series of exercises (lower line).

In order to confirm the importance of the fitting between the PS and the body, the protection offered by the fabric material was evaluated following the protocol used to study the material of the gloves. In this assay, only the efficiency of the fabric was evaluated, avoiding problems related to the formation of gaps by which the NPs could enter inside. As can be observed in Figure 7, the protection efficiency against NPs achieved by the fabrics of the PS1, PS2, PS3 and PS5 was higher than 99%. Moreover, as could be expected, fabric of the PS4 offered the lowest level of protection, although it was upper than the 95%. These results confirm that, although the fabrics offer a good level of protection against NPs, the formation of gaps between the body and the PS is a critical parameter which determines the global efficiency of the suit against NPs.
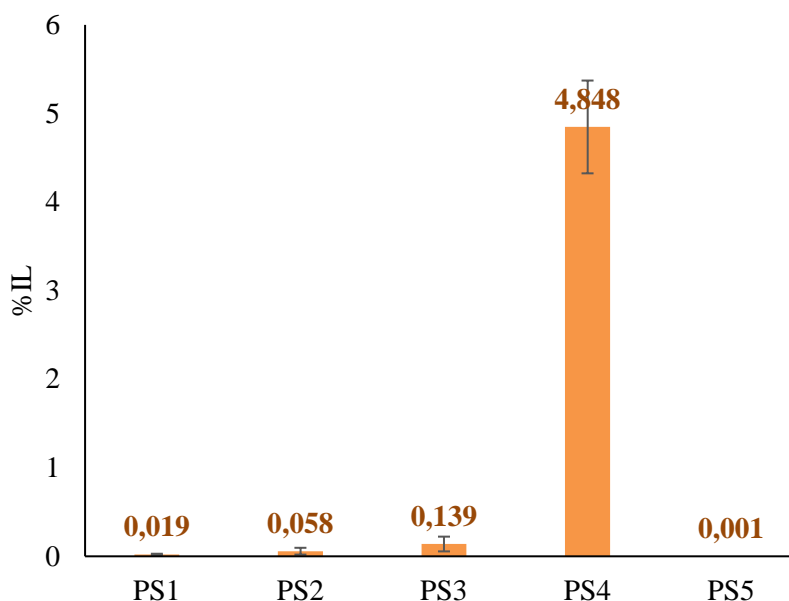
Figure 7: Results of inward leakage obtained in the different fabrics of the protective suits assayed.

4 Conclusions

In this work, the efficiency of different types of personal protective equipment against NPs has been tested and compared. Results obtained can contribute a very useful information to select the most appropriate PPE to protect workers in nanotechnology-based industries from the exposition to ENMs, offering a clear picture of the level of protection achieved by different types of personal protective clothing available in the market.

With the purpose of evaluating the efficiency of distinct types of protective clothing available in the market, different subjects were asked to do several exercises in order to simulate working conditions. Results showed that PS1 PS2 and PS5 offered the best level of protection against NPs, being upper than the 90% in most cases, close to 100% in the case of the PS5, since isolates efficiently from the exterior. The worst level of efficiency was registered by PS3 due the %IL obtained was about 100%. This result could be explained because PS3, although theoretically had to offer a good protection, the suit did not adjust the body of the subject, allowing the apparition of gaps between the suit and the skin by which the NPs might enter inside. PS4 offered a protection lower than PS1 and PS2, and higher than PS3.

On the other hand, the level of protection offered only taking into account the different fabrics was quantified. The level of efficiency obtained by the different fabrics was upper to 99% for PS1, PS2, PS3 and PS5. In any case, the lowest level of protection was still upper than 95%, achieved by the PS4. These results confirm that, although the fabrics reached a good efficiency against NPs, the fitting between the PS and the body of the user determined the global efficiency of the PS, and the small gaps between the body and the suit propitiate the leakage of NPs to the interior due to the movements of the wearer. Therefore, in order to improve the level of protection, protective suits should be sealed to the body of the user, avoiding the apparition of gaps by which the NPs can enter inside.

The efficiency of protective gloves was a function of the material, reaching values from 95% to 99% depending on the type of glove. For the same material, the ones with greater thickness achieved better results. Additionally, images about the surface of the gloves were taken by SEM, showing that some materials presented imperfections or gaps in their surface which could offer a way to the NPs to penetrate inside the glove. Thus, with the aim to achieve a better protection, the use of a double glove is recommended due it is difficult that both gloves have the imperfections in the same place.

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