COMMITTEE ON THE MEDICAL EFFECTS OF AIR POLLUTANTS

Statement on airborne nano- and microplastic particles and fibres

Summary

There is evidence of the ubiquitous presence of nano- and microplastic (NMP) particles and fibres in our environment, including within both indoor and outdoor air. This has led to growing concern regarding human exposure and potential long-term health effects. Consequently, NMP research has increased and has received significant attention. However, the NMP field has several methodological and data challenges that presently, significantly affect the quality, and interpretability of published studies. This raises the risk of overemphasising limited data that does not represent real-world exposure conditions, or adequately acknowledges the uncertainties around NMP identification, especially within human tissues.

There remains considerable uncertainty as to the nature and magnitude of health risks posed by the inhalation of NMPs in the context of the numerous other, more dominant components (both by mass and number) of ambient particulate air pollution. Apart from high exposures in occupational settings, there is insufficient, good quality data to assess whether inhalation of NMPs is harmful to health at this time. Therefore, high-quality studies are required to better understand the potential exposure to, and adverse effects from, environmentally relevant airborne NMPs, in order to evaluate any possible long-term health risks. This statement provides comment on the current ‘state of the science’ available to inform an assessment of the health risks from the inhalation of NMPs and the key considerations for future research.

Limitations in analytical techniques mean that it has been difficult to detect and quantify airborne NMPs within the size ranges that are most relevant to inhalation exposure. In addition, most studies that have investigated the potential toxicity of inhaled NMPs have used plastic beads, which are chemically and morphologically different to those in real-world exposures, at inappropriately high exposure concentrations, with inadequate characterisation of physical and chemical characteristics. Hence, the relevance of these studies towards a real-world population exposure to NMPs is unclear. There is also a lack of data on the fate of NMPs within the body after they have been inhaled. Emerging evidence of the presence of NMP in human tissue needs validating due to the limitations of current analytical techniques in detecting plastic particles of this size in biological samples, the risk of background contamination, and the potential for artefacts. The only epidemiological data available concerns workers in the plastics and textile industries.

These studies have indicated that short and long-term exposure, to concentrations of NMPs much higher than those to which the general population might be exposed, can affect lung function and cause lung disease.

Because of the lack of suitable data on exposure and adverse effects, COMEAP agrees with other authoritative bodies who have concluded that there is currently insufficient evidence to allow a comprehensive assessment of the potential health risks from NMP in air. In fact, we would advise against attempts at risk assessment based on the limited evidence that is currently available. To bridge this gap, as the field evolves, we would encourage best practice when designing experiments to provide robust and reliable data to allow an assessment of the plausibility of an adverse effect.

We highlight some research priorities to address data gaps in assessing NMP exposure and toxicity. Key areas include: developing standardised reference materials; the harmonisation of sampling and analytical methods and toxicological studies; harmonisation of, and improved, terminology; conducting experimental studies that represent real-world conditions; comparing the effects of NMPs with those of other types of particles in these studies; and researching the uptake, distribution, and persistence of inhaled NMPs.

Background

NMP particles and fibres have been detected widely in the environment, and their distribution is now considered to be ubiquitous. Their environmental presence is projected to increase with accelerated global production of plastic materials (Geyer and co-authors, 2017) and the continued degradation of plastic products and waste in the environment. Emerging evidence for the presence of NMPs in body fluids and their potential accumulation in internal organs, as reviewed in Wright and co-authors (2023), has led to a growing concern regarding human exposure to these particles/fibres and their potential impacts upon human health.

A plastic can be defined[1] as a synthetic or semi-synthetic material that contains, as an essential ingredient, a high relative molecular mass polymer and which, as part of its processing, can be shaped by flow. Polymeric materials can be classified according to their structure, source/origin, molecular forces and mode of polymerisation.

This statement refers to nano- and microplastics (NMPs), however, plastics of this size are also referred to as micro- and nanoplastics (MNPs or MNPLs) in the literature. NMPs can be categorised as either microplastics or nanoplastics, although, in reality, the component fraction within the air will be a mixture of both. There is no universally agreed definition of NMP. This statement uses the definition of NMPs, as stated by the World Health Organization (WHO, 2022), as artificial polymeric particles/fibres which can be up to 5 mm in diameter. The WHO defines nanoplastics (NPs) as artificial polymeric particles/fibres measuring less than 1 µm. This size definition is different from that often used for engineered nanomaterials (ENMs), as having at least one external dimension between 1 and 100 nm.

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[1] ISO 472:2023: Plastics - vocabulary. Geneva: International Organisation for Standardisation; 2013

The types of manufactured synthetic polymers that are regarded as NMPs have not been universally agreed. For example, there is a lack of consensus on the inclusion of elastomers, such as rubbers, or modified natural or semi-synthetic polymers, such as rayon and cellophane.

A specific source of synthetic polymeric airborne particles/fibres is non-exhaust vehicle emissions from the wear of tyres and non-metallic and metallic brake pads, as reviewed by Wright and Borm (2022). Tyre wear particles consist of a complex mixture of elastomers (for example, styrene-butadiene rubber) and non-plastic constituents such as natural rubber and metals and, therefore, their chemical composition is distinct from that of other NMPs. In addition, road wear and other particles deposited on the surface of roads, or other areas where vehicles are driven, are also incorporated in tyre wear particles. As such, they are considered to be significantly different from other plastic particles and outside the scope of this statement. We are aware of several on-going research studies on tyre wear. When the results become available, this evidence may supplement COMEAP's 2020 statement (COMEAP, 2020) on the evidence for health effects associated with exposure to non-exhaust particulate matter from road transport.

Plastics have a broad range of uses and applications and the sources of NMPs can vary widely. Some NMPs are deliberately manufactured for specific commercial use, for example, microbeads[2][3] used in personal care products, in paints and some cleaning products, which are called primary NMPs. However, the majority of NMPs are secondary NMPs produced from the fragmentation and breakdown of larger plastic debris (Koelmans and co-authors, 2022) by biological, physical and chemical processes in the environment. Indoor sources of exposure include household products and the abrasion of carpets, plastic/synthetic upholstery and synthetic fibres from clothing. Outdoor sources include, aerosolization from the air or water interface and sea spray, vented mechanical drying of synthetic material, dust from landfill and discarded plastic products (O'Brien and co-authors, 2023). Modelling of atmospheric NMPs has suggested marine and agricultural sources, and emissions from population centres, as being important (Brahney and co-authors, 2021).

Recent reports by authoritative bodies have reviewed the evidence for human health effects from the inhalation of plastic particles (WHO, 2022) (COT, 2024) and plastic-associated chemicals (UNEP, 2023). This statement draws on these reviews and aims to comment on the evidence for NMP inhalation exposure and the potential risks to health in the context of other air pollutants, highlighting the uncertainties and gaps in the evidence and the need for future research. A cross-disciplinary drafting group of COMEAP members and invited external experts working in the field of microplastics (Annex A) was established to advise on the content of the statement, evaluate and interpret the epidemiological and toxicological evidence, and draft the statement.

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[2] The UK Government placed a ban on the sale of products containing microbeads in 2018. [Press release: World leading microbeads ban comes into force]
[3] [The European Commission has adopted measures to restrict intentionally added microplastics.]

Airborne exposure to nano- and microplastics

The methods that have been used to measure and identify microplastic particles in air are different from those that are usually used to measure particulate air pollution. Most measurements of particles in air relate to the mass concentration (for example, μg/m^3) of particles within specific size ranges. The size ranges are defined according to aerodynamic diameter, which influences where the particles are likely to be deposited within the respiratory tract. Particles of up to at least 100 μm can be inhaled into the nose and mouth. The larger particles are trapped in the nose and mouth and can be swallowed. The smaller particles, up to approximately 10 μm (the thoracic fraction, PM_{10}) can enter the conducting airways. The respirable fraction (up to 4 μm, approximating PM_4) can penetrate to the lower region of the lung (respiratory region) where gas exchange takes place. In ambient air, the fraction of particles up to 2.5 μm ($PM_{2.5}$) is often measured and has been shown in epidemiological studies to be associated with health effects, particularly respiratory and cardiovascular effects, and mortality (USEPA, 2019). Ultrafine particles (UFPs), with an aerodynamic diameter of 0.1 μm (100 nm) or less, are also of interest as they contribute the greatest number of particles per unit volume relative to the total number of particles in the air. Their small size and large relative surface area may make them more biologically active and more likely to cross the alveolar membrane and enter the circulation, leading to systemic effects. Total suspended particulates (TSP) are also sometimes measured (TSP was the main particle metric measured in the US prior to 1987). The aerodynamic diameter of a particle refers to the size of a sphere of unit density with the same aerodynamic properties as the particle of interest. Microplastic particles, and especially fibres, are likely to deviate substantially from the spherical form and may have non-unit density. The physical dimensions of a microplastic particle are, therefore, likely to differ significantly from its aerodynamic diameter. Nonetheless, the aerodynamic diameter remains a good guide to the likely fate of microplastic particles in the human respiratory system, although less so for microplastic fibres. The conventional size ranges for particulate air pollutants do not easily transfer to the size definitions commonly used to define NMPs nor to the methods usually used to identify and characterise them (see definition in preceding section).

Accurately detecting and quantifying NMP particles/fibres smaller than 10 μm in diameter in environmental samples is challenging due to difficulties in extracting, isolating, avoiding contamination and verifying the chemical composition of particles of this size (Prata and co-authors, 2020). Reported concentrations of NMPs and size classifications are influenced by the detection limit of the analytical techniques used. As analytical techniques have evolved, and spatial limits of detection have decreased, it has been possible to detect and quantify increasingly smaller plastic particles in air. However, even the best imaging spectroscopic instruments can only assess particles as small as 1 μm. Consequently, most studies to date have used analytical methods that are able to detect and identify particles sizes >10 μm, outside the PM_{10} and $PM_{2.5}$ fractions relevant to exposure via inhalation (Gouin and co-authors, 2022) (Peñalver and co-authors, 2020). In addition, there is a lack of data on the potential contribution of nanoplastics to the ultrafine particle fraction (UFP) (≤ 0.1 μm in diameter).

Outdoor particle number concentrations of NMPs have been reported at between <1 and >1000 microplastics/m^3 within TSP in air, with reported concentrations being dependent on the location and analytical technique used (O'Brien and co-authors, 2023). There are only a limited number of studies reviewed by O'Brien and co-authors (2023) reporting mass-based quantification of microplastics in air.

There may be higher concentrations, and different compositions, of airborne microplastics indoors compared with outdoors. However, it is difficult to draw conclusions from the available literature. A recent review of the literature (O'Brien and co-authors, 2023) suggested that, based on the assumed sources of microplastic within the indoor environment (for example, clothing, carpets, and other synthetic fabrics), concentrations indoors would be expected to be higher than outdoors. Indoor concentrations would be dependent on ventilation and the use of air conditioners, which could act by filtering and trapping plastic particles but also as a source by releasing trapped microplastics if filters are not cleaned. It noted that the composition and concentrations of airborne microplastics indoors would be expected to vary between buildings, as they likely reflect differences in the characteristics and contents of the internal space, and occupant behaviour.

A potentially significant source of NMPs in air is fibres from the abrasion of synthetic textiles, including clothing. Many studies have reported detection of microplastic fibres in outdoor and indoor air, and in dust. Of the studies reviewed by O'Brien and co-authors (2023) that reported the shape of microplastics in outdoor air, 55% reported fibres as being the most abundant. However, this figure is biased by the inclusion of studies in which only fibres were counted. Similarly, in indoor air, fibres are the dominant shape reported in the literature (O'Brien and co-authors, 2023). However, comparisons of the numbers of particles of different shapes may be influenced by the analytical methods used and the geometry, as it is a common regulatory approach to group fibres according to their aspect ratio (the length divided by the width or diameter).

In addition to the inhalation and potential deposition of particles throughout the respiratory tract, an important exposure pathway for NMPs is the ingestion of larger particles and fibres (>4 µm) deposited in the upper respiratory tract, which tend to be swallowed and enter the gastrointestinal tract from where they can be absorbed (WHO, 2022) (COT, 2024). Deposition of plastic particles and fibres onto food, followed by ingestion, should also be considered as a potential source of exposure from airborne NMPs (COT, 2024). A study (Fang and co-authors, 2022) measured microplastics deposited from the atmosphere in dining and drinking venues and estimated that ingestion of atmospheric deposited microplastics through diet was of a similar magnitude to estimates of inhalation exposure (Zhang and co-authors, 2020) and 2 to 3 orders of magnitude greater than direct ingestion from microplastics within food sources (Cox and co-authors, 2019) (Zhang and co-authors, 2020).

Epidemiological evidence

The main challenge in conducting epidemiological research on airborne NMPs is the lack of standardised methods for assessing potential exposures. As a result, uncertainty surrounds the magnitude of health risks posed by inhalation of NMPs, which are breathed in the context of numerous other, more dominant components that comprise the majority of airborne PM_{10} and $PM_{2.5}$.

Occupational epidemiological studies can provide information on diseases associated with NMP exposure. However, these studies are based on workers exposed to extremely high concentrations that are much greater than ambient levels to which the general population might be exposed and do not represent the wider population in terms of other factors, such as age, sex, or pre-existing conditions. Most occupational studies focus on workers in the textile, and vinyl chloride/polyvinyl chloride industries involving exposures to fibrous and non-fibrous plastic particles over extended periods of time (WHO, 2022). The WHO (2022) reviewed the evidence for workers exposed to NMPs and concluded that there is some evidence of reduced pulmonary function and specific lung pathology, such as interstitial lung disease, in occupational settings. Currently, there is inadequate evidence to evaluate whether there is a carcinogenic risk from occupational exposure to NMPs.

Toxicological evidence

The uncertainty in the data for exposure to biologically relevant NMPs is a significant barrier to assessing the hazard to human health (WHO, 2022). The wide range of sources of NMPs is reflected in the diversity of their physical and chemical properties. The dose of particles needed to elicit an adverse effect and the corresponding toxicological end points will be dependent on a combination of these factors.

A recent WHO report (WHO, 2022) reviewed the literature and evaluated 19 *in-vivo* and 12 *in-vitro* studies according to their quality for risk assessment. Nearly all studies looked at a monodisperse (uniform in size, shape and chemical composition) group of plastic particles, with polystyrene nanoparticles being tested in the vast majority of *in-vitro* studies. It concluded that there is some limited evidence from toxicity studies to suggest that NMPs deposited in the lung induce oxidative stress, inflammation and cytotoxicity. The report stated that, based on this limited data, NMP ‘may have adverse effects similar to those of well-studied solid and insoluble particles through similar modes of action’. Most studies used inappropriately high exposure concentrations of NMPs with inadequate characterisation meaning that their relevance to real-world exposures is limited, preventing a meaningful consideration of relevant toxicological pathways and the potential human health impact.

Similarly, a recent statement from the Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment (COT, 2024) considered the potential toxicological risk of exposure to microplastics via inhalation and noted that the data on the fate of inhaled microplastics in mammalian species, and their retention in the lung, are unclear. It also noted that there are few studies comparing the toxicity of synthetic fibres with natural fibres. However, it is known that fibre rigidity is one of the characteristics, in addition to length and diameter, that determines the pathogenicity of asbestos fibres (Mossman and Churg, 1998). In general, NMPs are engineered not to exhibit these physical characteristics (Csernica and Brown, 1999) (Omnexus). There is a lack of clarity and understanding of the actual physical (and chemical) characteristics of NMPs to which humans could become exposed. Therefore, any consideration of how the toxicity of fibrous NMPs in the lung compares to the established effects of asbestos and other pathogenic fibres should be evaluated in the context of the fibre paradigm (Donaldson and co-authors, 2010), where the degree of toxicity is related to the dose, rigidity, dimensions (diameter and length) and biopersistence of the fibre.

Most studies investigating NMP toxicity to date have used pristine, polystyrene spheres (Wright and co-authors, 2024). However, there are significant physiochemical differences between polystyrene nano and microspheres made for biological and analytical purposes compared to environmentally generated NMPs. Real-world NMPs are a complex mix, diverse in size, shape, chemical composition, aging and surface contaminants. Therefore, depending on the research question being addressed, pristine polystyrene spheres may not represent suitable model particles and would be unsuitable for assessing the health risks associated with exposure to polystyrene NMPs in the environment (Gouin and co-authors, 2024). Empirical data on the influence of shape, polymer type, weathered state, crystallinity, hydrophobicity, surface chemistry and charge are needed to characterise the hazard from exposure to environmentally relevant NMPs. Obtaining this data will require innovations in sample preparation and careful characterisation of NMPs used in these types of study (Wright and co-authors, 2024).

It has been suggested that once NMPs enter the body they have the potential to accumulate in internal organs and tissues due to their biological persistence. This raises the possibility that acute exposure to high concentrations commonly used in toxicity studies will fail to capture these slow exposure dynamics. There is also the potential for a fraction of small particles (≤1 µm), deposited following inhalation in the alveoli of the lung, to cross the alveolar wall, translocating into the bloodstream and able to then be transported to other parts of the body (Nakane, 2012). The extent to which particles found in ambient air cross from the lung into the blood is unclear (COMEAP, 2022). There are a limited number of studies reporting NMP particles (Amato-Lourenço and co-authors, 2021) (COT, 2024) and fibres in human lung tissue (Chen and co-authors, 2022). Several recent studies have suggested the potential for translocation and accumulation in the body, with NMPs being reported in human organs, tissues and bodily fluids including heart (Yang and co-authors, 2023), liver (Horvatits and co-authors, 2022), brain (Nihart and co-authors, 2025), placenta (Garcia and co-authors, 2024), breast milk (Ragusa and co-authors, 2022), blood (Brits and co-authors, 2024) and arterial plaques (Marfella and co-authors, 2024). However, many existing studies are based on small sample sizes and often poorly report controls. In addition, modern laboratories are significant sources of NMPs and current detection methods make it difficult to eliminate the risk of contamination or to conclusively demonstrate the presence of NMPs in a sample. For example, it can be difficult to distinguish between fatty acids and polyethylene when using pyrolysis gas chromatography mass spectrometry (Py-GCMS) to identify and quantify plastics in blood and tissue samples. Therefore, if biological material is not completely removed from the sample, it could be potentially misidentified as polyethylene. Also, many findings are not biologically plausible, with large NMPs of a size significantly greater than 5 µm in tissues and biological samples being reported in many studies, which is contrary to the current understanding of how particles are transported within the body. For the majority of studies, it is unclear whether translocation of the NMPs detected would have occurred in the lung following inhalation. Translocation across the gastrointestinal tract following ingestion might be more likely. Hence, there is a need for quality assured experiments to prevent the potential misidentification of NMPs in biological samples (Wright and co-authors, 2023) (Xu and co-authors, 2025).

Risk assessment

An assessment of the health risks from inhaling air pollutants, such as PM, involves integrating environmental, toxicological, and epidemiological data (WHO, 2016). Firstly, air quality modelling and monitoring data is used to identify and quantify the types and concentrations of pollutants to which the population is exposed. Epidemiological data describing the exposure-response relationship between air pollution exposure and health outcomes is then used to derive a concentration-response function (CRF), which can inform an estimate of the health risks to the population. Toxicological data is also important for health risk assessment as it provides insights into biological plausibility and helps strengthen the interpretation of the epidemiology. There is evidence from epidemiological and toxicological studies that some substances, for example asbestos, present a greater risk following inhalation than other airborne particles and fibres, because of their specific physical and/or chemical characteristics (Wieland and co-authors, 2022).

There is currently a lack of monitoring or modelled data on the concentrations and characteristics of airborne NMP, in the size fractions that are relevant for inhalation exposure, to accurately measure and assess exposure. In addition, there is insufficient epidemiological and toxicological data on the potential of NMPs to cause harm to human health, particularly in comparison with other particles. Without the necessary exposure, epidemiological and toxicological data it is not possible to describe a concentration-response relationship and, consequently, quantify the potential risk to health from NMPs in the air.

The literature includes some suggested approaches to risk assessment of inhaled NMP (Wright and Borm, 2022) (Koelmans and co-authors, 2022). For example, the mass proportion of NMPs in the PM_{10} and $PM_{2.5}$ fractions could be used to estimate the proportion of the risk from PM as a whole that is attributable to NMP (Wright and Borm, 2022). However, this approach relies on the assumption, for which evidence is lacking, that NMP contribute the same risk, on a mass/mass basis, as the rest of the ambient PM load. COMEAP would discourage using this approach to risk assessment as it will be uninformative until there is sufficient data on the hazard of NMP relative to other components of PM.

An alternative approach to risk assessment would be to integrate traditional toxicology methods with high-throughput molecular biology, bioinformatics and computational modelling to provide a mechanistic understanding of how inhalation of NMP affect the human body. However, this does not eliminate the need for exposure and hazard data and has challenges related to complexity, data interpretation and uncertainty in human relevance. Risk assessment frameworks (Koelmans and co-authors, 2022) requiring such an approach have been suggested but remain theoretical at present.

Consideration of the geometry of inhaled NMPs will be important in their risk assessment. Notably, environmental NMPs have been reported to have a large fibrous fraction (O'Brien and co-authors, 2023). Thus, similar to the already established methods to assess particle toxicology (Wright and Borm, 2022), evaluation of the hazard of fibre-shaped NMPs should be conducted in alignment with the principles of the fibre paradigm (Donaldson and co-authors, 2010) and compared to the hazard of known, pathogenic fibres (such as vitreous fibres or asbestos).

Discussion

Currently, a comprehensive risk assessment of the potential health effects from the inhalation of NMP is not possible due to significant evidence gaps, which have been described elsewhere (COT, 2024) (WHO, 2022).

Important areas for research include developing robust, quality-assured methods for sampling and analysing airborne NMP within respirable size ranges, to provide data on the concentration, size, shape and composition of these particles in the environment. At present, there are very few studies describing mass concentrations of NMP within the PM_{10} and $PM_{2.5}$ size fractions (Costa-Gómez and co-authors, 2023) (Chen and co-authors, 2024) and, those available, report a wide range of concentrations and proportions.

In addition, there is a need to evaluate and rank the relative hazard of NMPs from different sources and compare these with other components of PM. This will require well conducted toxicology studies, using well characterised, toxicologically relevant NMPs at environmentally relevant concentrations, so that effects observed experimentally can be reasonably extrapolated to those that could occur at real-world exposure levels. Experiments using high concentrations can result in dose-transitions due to non-linearity in toxicokinetics and/or toxicodynamics, making extrapolation very difficult if not impossible. Hence, to undertake such extrapolation, evidence of concentration/dose-proportionality over an appropriate concentration/dose-range is necessary. More information on how NMP properties in general cause adverse effects may provide a greater understanding of NMP toxicity and support future risk assessment (Wieland and co-authors, 2022). Although NMPs have a wide range of properties, many are shared with other particles. Therefore, it may be possible to infer possible adverse outcome pathways from previous research on other particle and fibre types.

Further studies are also required to clarify the uptake, distribution, persistence and elimination of inhaled NMP, so that better estimates of accumulated tissue dose can be derived. To understand this, NMPs should be compared to other particles that are known to accumulate and persist in the body. There will be a need to consider the release of chemicals associated with NMPs into the tissue and the dynamic interaction of NMPs with biomolecules within the tissue environment. However, chemical additives and chemicals absorbed or adsorbed in the environment will not be unique to NMPs and it is unlikely that they will make a large contribution to the overall exposure to these chemicals (COT, 2021). The identification of NMP particles and fibres within tissues, which remains challenging and contentious, also needs to be aligned more fully with histopathological features associated with biologically persistent materials, such as tissue remodelling, granuloma formation, fibrosis and chronic inflammatory profiles.

Increasing efforts to reduce plastic pollution (UN, 2022) will reduce the concentration of NMP in the environment and airborne exposure over time. However, more data on the characteristics and size fractions of NMPs in air are needed to provide a better understanding of human exposure and their sources. Caution is needed when considering approaches to managing the possible risks from NMPs, as products used as plastic substitutes might also pose risks. For example, there is potential concern about the degassing of formaldehyde and melamine from bamboo composite cups (COT, 2024). A greater understanding of the risks posed by plastics and NMPs, and possible plastic substitutes, will help to prevent unintended consequences, such as the substitution of plastic materials with alternative substances that are equally or more harmful to health or the environment. Nonetheless, while the human health implications of NMP remain under investigation, there is good evidence of their adverse effects on different environmental systems (Thompson and co-authors, 2024). Hence, international and local efforts aimed at reducing plastic pollution are important to help reduce human exposures.

Conclusions

Detecting and quantifying airborne NMPs is difficult due to limitations in current analytical methods. There is, therefore, limited data on the concentrations of, and characteristics of, NMPs in the size fractions that are relevant for inhalation exposure and deposition in the lung.

There is some evidence from occupational studies that exposure to high concentrations of NMPs, much greater than levels experienced by the general population, can have effects on lung function. However, due to the lack of data on the concentration of NMPs in ambient air, and their toxicity, the magnitude of the health risks to the general population remains uncertain.

Most studies investigating the inhalation toxicity of NMPs use pristine (i.e. fresh, un-aged), polystyrene spheres, and many use inappropriately high exposure concentrations with inadequate physicochemical characterisation. More data is needed on the effects of size, shape, chemical composition and other factors from exposure to real-world NMPs, at environmentally relevant concentrations, and in comparison, with other types of particles and fibres with similar properties.

There is insufficient data on the fate of inhaled NMPs within the human body, including their potential to accumulate in organs and tissues. The quantification of NMPs in biological tissues remains challenging due to potential sample contamination and artefacts related to indirect chemical identification.

Overall, COMEAP agrees with the conclusions reached by other authoritative bodies (WHO, 2022) (COT, 2024) that there are insufficient data quantifying exposure to NMPs and their potential human health effects to carry out an informative assessment of the risk posed via inhalation exposure at this time. In fact, we strongly believe that any attempt at risk assessment based on the limited evidence currently available should be discouraged until the evidence base has matured. Improved quantification methods and continued research is necessary to fill these research gaps and provide more robust data on exposure and health effects.

Considerations for research

Research priorities for addressing the data gaps in the exposure assessment of NMPs in air and their potential toxicity and risk to human health have been stated previously (WHO, 2022) (COT, 2024).

The reproducibility of research, and more meaningful comparison of data, would be improved by using consistent terms and definitions describing NMPs. Common definitions of NMPs include size ranges that do not align with other air pollutants, which introduces difficulties for assessing inhalation health risks. An important source of information is epidemiological evidence from workers exposed to various NMPs in the plastics and textiles industries. A systematic review summarising this evidence might benefit the field.

COMEAP recommends the following research needs (see Figure 1) for understanding the exposure and health effects associated with inhaled NMPs and informing future health risk assessment.

- **Reference materials.** Most toxicity studies have been performed using pristine particles, mainly polystyrene. These pristine particles do not represent plastic particles in the environment that will have undergone degradation, absorbed contaminants, or have contaminants attached to their surface. Similarly, pristine polystyrene spheres used in studies are obtained from different suppliers and distributers and may not have identical properties. Therefore, a set of standard reference materials that are representative of the range of inhaled NMPs should be made available. Achieving this will be dependent on better characterisation of the types of NMPs that can be inhaled. Methods are also required to quantify the amount entering the body. The establishment of NMP databases that reflect their complex characteristics, similar to those developed for nanomaterials, would assist with future risk assessment.
- **Harmonisation of sampling and analytical methods.** Sampling and analysis are needed to quantify the exposure to NMPs in air and characterise their distribution in size, shape, and chemical composition. The methods used will need to be reproducible and accurate with any inherent biases identified and quantified. Enhanced techniques to accurately detect and quantify NMPs within respirable size ranges, particularly those with an aerodynamic diameter smaller than 4 µm, are needed. This data will inform the preparation of reference standards and determine appropriate doses for use in environmentally relevant toxicity testing.
- **Harmonisation of toxicity testing and reporting.** Currently, there is a lack of good quality toxicological studies in the literature using well characterised NMP particles, validated reproducible methods, and using other particles with similar physicochemical properties as a comparison. The use of reproducible methods will allow for meaningful comparison between different studies and reduce uncertainty in the data. There is need to draw on experience from research into other particles and apply this to improve the quality of the data on NMPs. We

recommend that experimental studies of NMPs should follow existing validated methods and best practice, where possible. Ensuring the reproducibility of studies will require standardised reporting of methodology and published studies should meet appropriate quality assurance and quality control standards.

- **Comparative toxicology studies using environmentally relevant doses**. Conducting well-designed toxicological studies using NMPs that accurately represent real-world conditions is a priority. Establishing the types of NMPs to which humans are most exposed and developing environmentally relevant reference materials will enable comparisons to be made between NMPs and other particles and fibres. Aligning toxicological studies with established methods for assessing particle and fibre toxicity will help contextualise the health risks of NMPs. Studies comparing the toxicological effects of NMPs with other types of particles and fibres will be necessary to inform their potential hazard and risk to the population.
- **Uptake, distribution and persistence.** It is uncertain whether, following exposure, NMPs are cleared by normal biological pathways or if they persist and accumulate within the body, presenting a persistent adverse challenge. Research on the fate of inhaled NMPs and their dosimetry within the human body is needed. This includes studies on their uptake, distribution, persistence, and elimination. Understanding how NMPs interact with and accumulate in different tissues, and whether they can cross biological barriers such as the alveolar walls into the bloodstream, will be important for evaluating long-term health risks. The continued development of methods for identifying NMPs in biological tissues is needed. Studies investigating NMP concentrations in human tissue should aim to identify associated histopathology and evidence of biological effects (such as persistent inflammation, and fibrosis).
- **Epidemiological evidence.** Epidemiological data will be important to provide a comprehensive understanding of the health risks of inhaled NMP. Epidemiological study would be aided by better information on the concentration of NMPs in $PM_{2.5}$ and PM_{10}, to allow meaningful exposure and dosimetry assessment for integration into studies examining short- and long-term health effects.

Figure 1. Areas of research for generating data on exposure and hazard to inform future health risk assessments of NMPs. This highlights important evidence gaps but does not represent the sequence or priorities for future research. Harmonised methods are needed to understand exposure and to develop relevant reference materials for hazard evaluation.

COMEAP
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Annex A

Committee on the Medical Effects of Air Pollutants (COMEAP) Airborne nano- and microplastics drafting group membership

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