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The sources and impacts of polystyrene nanoplastics (PSNPs)

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Polystyrene plastic products are widely used in everyday life and, through diverse processes, they may be broken down into nanoplastics with particles less than 1000 nm in diameter. Polystyrene nanoplastics (PSNPs) are difficult to degrade and can accumulate in the environment for many years, causing serious pollution to ecosystems and their organisms. This Environmental Brief summarises their main sources and major impacts.

Due to their high-quality properties, plastics have become an integral part of our lives and can be found in almost every field. The global annual production of plastics soared from 1.5 million tonnes in 1950 to just under 370 million tonnes in 2019[1]. However, most plastic wastes are difficult to recycle; more than 8 million tonnes of them enter the oceans globally each year[2] and spread by water and wind, causing serious pollution to the natural environment, including the atmosphere, water bodies and soil. In addition, the debris can easily enter animals and humans through air, food, and drinking water, posing a potential threat to the health of living organisms[3,4].

In 2019, the global production capacity of polystyrene was 15.6 million metric tonnes[1]. As one of the most widely used plastics, it is also one of the most important sources of nano-plastic wastes. Research conducted by Kik *et al.* (2020) has shown that PSNPs can penetrate into organisms through multiple pathways, including the skin, respiratory and digestive tracts, and can be enriched through the food chain[2]. Control of the sources and effects of PSNPs is an urgent priority.

Sources

Polystyrene (PS) has been widely used in food, toy and industrial packaging, building insulation, and medical equipment industries due to its abundant raw material sources, simple polymerisation process and properties (light, inexpensive, transparent, insulating, corrosion resistant and easy colouring)[3,5]. PS particles less than 1000 nm in diameter are categorised as polystyrene nanoplastics (PSNPs)[2,4]. Depending on the process from which they originate, they can be mainly divided into two groups: primary and secondary PSNPs. The former are derived from the release of PSNPs added directly to cosmetics, bioimaging and sensing, nano-pharmaceuticals and electronics and waterproof coatings[1]. They also serve as precursors for the synthesis of other polymer products, which escape during processing[3]. At present, most studies on the toxicity of PSNPs have focused on primary NPs.

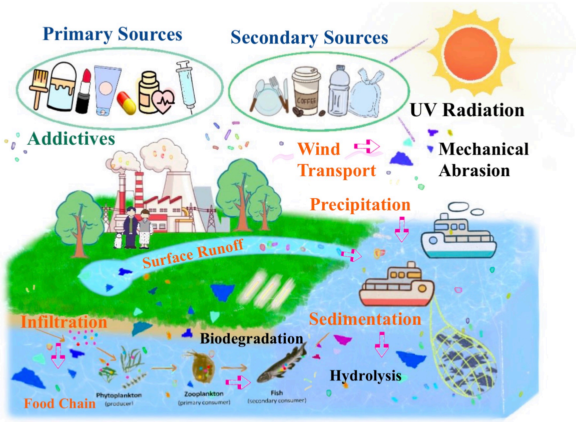

Figure 1. *Sources and transport of PSNPs.*

In contrast, after entering the environment, polystyrene plastic products break down into secondary microplastics (MPs) through continuous external processes like mechanical abrasion, hydrolysis, and biodegradation[4], and are further decomposed into plastic particles less than 1000 nm in diameter (secondary PSNPs). Prolonged sunlight exposure can lead to photodegradation of plastics, as the ultraviolet (UV) radiation in sunlight can break the C-H bonds in polystyrene molecules[6]. With the loss of integrity, these plastics are more likely to be broken due to wear, weathering and turbulence, which can lead to the gradual degradation of fragments into nanoscale particles[4,6].

Polystyrene nanoplastics (PSNPs) can reach anywhere in the world by entering the atmosphere, hydrosphere, soil and even the biosphere through water and atmospheric cycles[1,4]. They can be found in drinking water, wastewater, sludge, compost and atmospheric sediments[2,5]. **Figure 1** depicts the main sources and transport processes of PSNPs. PSNPs in aquatic bodies mainly come from terrestrial inputs, fishing activities and ship discharges [6], and their mobility is largely dependent on their suspension capacity and particle size[6,7].

Sewage treatment plants are considered an important hub for plastic particles between human society and the natural environment[5]. In the atmosphere, PSNPs mainly originate from synthetic fibres in construction materials, waste incineration and landfills[8], and are transported by wind and natural deposition. Agricultural film residues, the use of sludge and organic fertilisers, surface water irrigation, atmospheric deposition, landfill and waste disposal are main sources of soil PSNPs [3]. In addition, environmental

PSNPs can enter food and drinking water in various ways, to then spread and accumulate through the food chain and food web, causing pollution and hazards [4].

Impacts

The toxicity of PSNPs is higher than that of ordinary plastics. Due to their size and high penetrating power, PSNPs can enter the organism through various channels (air, food, water, and skin) and accumulate in tissues[5]. PSNPs can pass through the food chain to consumers, causing deleterious effects[2]. PSNPs have a large specific surface area and may adsorb pollutants from the environment (*e.g*. heavy metals, polycyclic aromatic hydrocarbons, and antibiotics), causing combined toxicity[1,4]. Furthermore, PSNPs can act as carriers for some microorganisms, spreading globally by wind and hydrological processes such as ocean currents[3], leading to species invasion and spread of resistant bacteria and resistance genes[6].

Recent research by Wu *et al.* (2020) found that PSNPs can attach to the seed coat of soybean, reducing the rate of water and nutrient uptake thereby inhibiting seed vigour[8]. Experiments on lettuce showed that the toxicity of PSNPs is higher through foliar contact than root contact, probably due to the restriction of stomata that affects photosynthesis and respiration[3]. For animals, PSNPs can pass through the circulatory system, affecting the liver, kidneys and pancreas. They can even cross the blood-brain barrier into the brain, inducing oxidative stress, inflammatory responses, neurotoxicity, metabolic disorders and behavioural disturbances in tissues[1,2]. Studies in mice found exposure to high concentrations of PSNPs (200 mg/L for 48 h) reduced the viability of neuronal cells[3], 10 mg/L for 20 days developed tissue structural changes, lipid digestion problems, and blood frame damage; while aggregation was seen in the spleen, intestine, lungs, kidneys and brain[9].

Inhaled PSNPs tend to remain in the human respiratory system and gastrointestinal tract, which may cause DNA damage and contribute to cancer[2,5].

Conclusion

PSNPs are diverse in origin and widespread in various environmental media worldwide (**Figure 1**). Studies have shown that PSNPs are toxic to organisms and pose a threat to human health through the food web, inhalation and dermal exposure (**Figure 2**). However, animal studies are relatively narrow in subject, and the short duration and high concentrations of exposure make it hard to provide evidence of the risks of long-term daily exposure. In addition, the effects of PSNPs on humans are mainly based on human-derived cells and animal models, and there are no uniform criteria for determining their toxic effects. What is more, the research methods are relatively homogeneous.

In the future, it is imperative to develop new approaches to explore the effects of nano-plastic pollution and to further control plastic pollution and reduce its adverse effects through policy introduction, technological innovation and people's implementation.

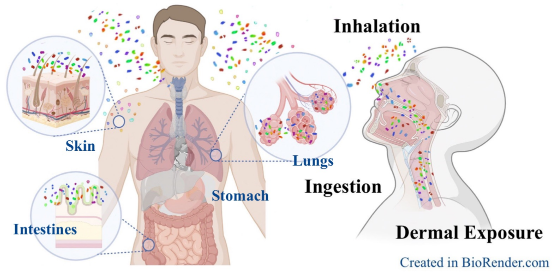

***Figure 2.** Main pathways of human exposure to PSNPs.*

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