

# OCCUPATIONAL SAFETY RISKS AND BEST PRACTICE GUIDELINES IN THE ENVIRONMENTAL APPLICATION OF NANOTECHNOLOGY

**Boma Horsfall**

Department of Industrial Safety and Environmental Engineering Technology, Nigerian Army College of Environmental Science and Technology, Makurdi, Benue State.

Corresponding email: [horsfallboma510@gmail.com](mailto:horsfallboma510@gmail.com)

## **Abstract**

This study explores the advancements, applications, and occupational safety implications of nanotechnology in Nigeria, a field that integrates engineering, physics, chemistry, biology, and materials science. It highlights nanotechnology's transformative role in medicine, agriculture, environment, and industry through its nanoscale manipulation that enhances material properties and efficiency. The paper identifies the emerging adoption of nanotechnology in Nigeria, supported by institutions such as NISLT, SHESTCO, NASENI, and universities like OAU and UNN. Applications span across sectors, including nano-based fertilizers, antibacterial packaging, nanoparticle drug delivery systems, and nano-filtration technologies for water purification. Using a mixed-methods research design, the study combines quantitative and qualitative approaches to assess occupational safety risks and develop best practice guidelines. Findings reveal that while nanotechnology offers immense environmental and economic potential, it also presents occupational hazards from nanoparticle exposure through inhalation, dermal absorption, and ingestion. Commonly used nanomaterials such as AgNPs, TiO<sub>2</sub>, CNTs, ZnO, and AuNPs pose toxicity and environmental risks if unmanaged. Consequently, the paper emphasises the need for proactive risk management through standardised protocols, exposure control, personal protective equipment (PPE), and adherence to WHO, ISO, and NIOSH safety

guidelines. Recommendations focus on engineering and administrative controls, safety training, waste management, and sustainability-oriented nanomaterial development. The study concludes that achieving safe and sustainable nanotechnology in Nigeria requires harmonising innovation with occupational and environmental safety for responsible scientific advancement.

**Keywords:** Nanotechnology, Hazards, OSHA, NIOSH.

### **Introduction**

Nanotechnology is a naturally interdisciplinary field that incorporates concepts from engineering, physics, chemistry, biology, and materials science. Applications in electronics, medicine, energy, and environmental science are among the many fields in which it finds use. Nanotechnology is unique because it significantly increases the surface area to volume ratio of materials at the nanoscale, which results in novel characteristics and improved reactivity (Tarafdar et al., 2013). Nanotechnology, according to Phogat et al. (2018), is the manipulation and control of matter at the nanoscale, which is generally between 1 and 100 nanometers, where special phenomena allow for new applications. This area of research includes the development and use of materials, tools, and systems by manipulating matter at the nanoscale level and taking advantage of size-dependent characteristics that are different from those at higher sizes as an innovative approach to scientific advancement, nanotechnology deals with the handling of materials at the nanoscale, which is one billion times smaller than a meter (Mahmoud et al., 2019).

Nanotechnology is a rapidly developing field that has profound effects across various industries. According to Oyono et al. (2024), it reduces systemic toxicity, aids in targeted imaging, and in the early diagnosis of cancer. It also supports personalised therapy approaches and the use of nanoparticles as contrast agents in imaging, which can result in more accurate and clear diagnosis. Drugs can be delivered by nano-carriers

to certain locations in the body, increasing therapy efficacy and reducing adverse effects Sim and Wonk, (2021); Oladipo and Ajayi (2020). In order to guarantee safe implementation in medical applications, especially in the use of antibacterial and antiviral medicines, it also discusses possible safety and environmental issues related to nanomaterials, highlighting the necessity of thorough risk assessments (Ma et al., 2024). An overview of the ways that nanotechnology is transforming a number of industries, including food and agriculture, is given in this study. It addresses how nanomaterials might improve agricultural output and create cutting-edge food packaging options, both of which promote industry as a whole (Malik et al., 2023). According to a study by Zayed et al. (2024), nanomaterials are highly helpful in producing goods that are more ecologically friendly, efficient, and long-lasting, hence promoting sustainable development objectives. Nanotechnology applications in the food industry, such as food processing, packaging, and quality monitoring, allow for the creation of better packaging materials that increase shelf life and safety as well as Nano-sensors that can quickly identify impurities, guaranteeing the security and quality of food. Aigbogun et al. (2018) examined the risks to occupational safety posed by nanotechnology in order to assess existing safety procedures and legal framework.

### **Aim of the Study**

The study aims to assess occupational safety risks associated with the environmental application of nanotechnology and to develop comprehensive best practice guidelines that promote workers' safety, regulatory compliance, and sustainable nanotechnology use in environmental management processes.

### **Objectives of the Study**

The objectives of this study are:

1. To identify and analyze the occupational safety risks associated with the handling, production, and environmental application of nanomaterials.

2. To evaluate existing safety policies, regulations, and workplace practices related to nanotechnology use in environmental industries.
3. To propose best practice guidelines for minimising occupational exposure and ensuring safe, sustainable nanotechnology applications in environmental management.

### **Nanotechnology Advancement in Nigeria**

In Nigeria, nanotechnology is still in its infancy when compared to more developed countries, although a number of organisations and corporations are beginning to investigate and fund applications connected to nanotechnology. Among the prominent sectors and entities in Nigeria where nanotechnology is having an effect are the Government-based Research Institute and the Academic Institution. A couple of these include the Nigerian Institute of Science Laboratory Technology (NISLT), which funds studies on nanomaterials and their uses. The Sheda Science and Technology Complex (SHESTCO), located in Abuja, is another; it has some of the most cutting-edge facilities for nanotech research. One organisation that helps finance and assist nanotech research and development is the National Agency for Science and Engineering Infrastructure (NASENI). Obafemi Awolowo University (OAU), the University of Nigeria, Nsukka (UNN), Covenant University, and the University of Lagos (UNILAG) are well known for nanotech and material science research, particularly in the areas presented in Table 1 below.

**Table 1: Nanotechnology Advancement in Nigeria**

S/N	Area of Application	Description
1.	Agriculture and Food Industries	Agriculture explores nanopesticides, nano-fertilizers, and nanomaterials like nano-silver to boost crop yields and improve environmentally friendly post-harvest preservation.
2.	Pharmaceuticals and Healthcare	Nanotechnology enhances drug delivery, enables rapid disease detection via nano-biosensors, and fosters collaborations to develop medicines for malaria and tuberculosis.
3.	Environment and Energy	Nanotechnology research focuses on efficient solar panels using nano-coatings and developing nano-filtration systems to provide clean water in rural areas.
4.	Industry and Startups	Few startups and companies in medicine, materials, and agriculture are adopting nanotechnology for diagnostics, coatings, and efficient, eco-friendly agrochemical formulations.

### Means of Data Collection

The study adopted a mixed-methods research design by combining both qualitative approaches and secondary data source to obtain comprehensive information on occupational safety risks and best practice guidelines in the environmental application of nanotechnology. These approaches allowed for the triangulation of findings, ensuring reliability, validity, and deeper contextual understanding of workplace safety issues, thereby combining the breadth of survey results with the depth of expert perspectives to produce robust, practice-oriented recommendations. Results from both the quantitative and qualitative components were integrated during the interpretation phase. Quantitative findings provided measurable evidence of occupational risks, while qualitative insights offered explanations and contextual depth to those findings. The integration enabled the formulation of comprehensive best practice guidelines and policy recommendations for enhancing occupational and environmental safety in nanotechnology operations.

### Common Nanomaterials and their Applications

Applications of nanotechnology are expanding in Nigeria, particularly in fields including water treatment, energy, agriculture, and health. Common nanomaterials and their applications in Nigeria include the following:

- **Silver Nanoparticles (AgNPs):** This substance is utilised in medicine and healthcare as antimicrobial coatings for hospital surfaces and wound dressings. It is also used in filters for water purification in order to eradicate bacteria and other contaminants.
- **Titanium Dioxide Nanoparticles (TiO<sub>2</sub>):** Due to its self-cleaning and UV-protective properties, titanium dioxide (TiO<sub>2</sub>) is widely utilised as an additive in the paint industry, as well as in the skincare and sunscreen segments of the cosmetics industry. Additionally, its photocatalytic capabilities are applied in environmental protection for the degradation of air and water pollutants.
- **Carbon Nanotubes (CNTs):** CNTs are utilised in electronics as sensors and batteries to improve functionality. They are employed in the construction sector to strengthen and extend the life of building materials and the membranes used in water treatment to filter impurities and heavy metals.
- **Zinc Oxide Nanoparticles (ZnO):** ZnO is beneficial in agriculture as nanofertilisers to increase crop productivity and used as cosmetics, which are found in lotions and sunscreens, and textiles, which are added to textiles for antimicrobial and UV protection.
- **Iron Oxide Nanoparticles (Fe<sub>3</sub>O<sub>4</sub>):** They are crucial for cleaning up oil spills and eliminating heavy metals from water in environmental remediation. Magnetic medication delivery systems, imaging, and water treatment to eliminate contaminants like lead and arsenic are examples of biomedical applications.
- **Gold Nanoparticles (AuNPs):** It is incorporated into HIV and malaria test kits and employed in photothermal therapy, as well as in targeted drug delivery for cancer treatment. Additionally, it is utilised as a biosensor in various laboratory applications and medical diagnostic procedures.

- **Silica Nanoparticles (SiO<sub>2</sub>):** It is utilised in the food industry as an additive to enhance flow properties and extend shelf life. In the pharmaceutical sector, it plays a vital role in drug delivery systems for efficient medication distribution. Additionally, it is incorporated into the construction industry as a cement additive to improve strength and durability.

#### **Potential Occupational Hazards of Nanomaterials**

Uncontrolled nanomaterial releases have the potential to pollute the workplace and cause hazards. This is because certain manufactured nanoparticles might have harmful properties that are not present in their bulk counterparts. Risks include interactions with biological systems like DNA and mitochondria, bioaccumulation, and long-term health impacts. Similar in behaviour to asbestos, carbon nanotubes (CNTs) have the potential to cause cancer. Oxidative stress and pulmonary inflammation may be brought on by titanium dioxide nanoparticles. Human cells may potentially be cytotoxically affected by silver nanoparticles. Because zinc oxide nanoparticles are known to cause inflammation and oxidative stress, they can build up in ecosystems and have an impact on both soil and aquatic life.

#### **Routes of Exposure of Nanoparticles**

Routes of exposure to nanoparticles determine how these materials enter the human body and potentially cause harm. Common exposure pathways include inhalation, dermal contact, and ingestion, each influencing absorption, distribution, and toxicological effects within occupational and environmental settings. Figure 1 shows these exposure routes.

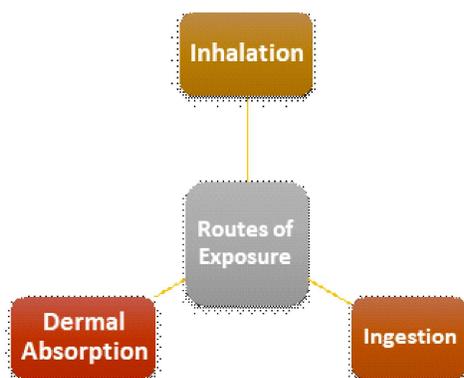


Figure 1: Represents Routes of Exposure of Nanoparticles

**Inhalation:** The most prevalent and worrisome method of occupational exposure is inhalation. Consequently, depending on the type of nanoparticle, they may cause oxidative stress, pulmonary fibrosis, inflammation, and even cancer. They can also enter the bloodstream and penetrate deeply into the lungs.

**Dermal Absorption:** In certain situations, nanoparticles may cause systemic absorption in addition to localised skin irritation or allergic reactions, oxidative stress and cellular damage; which carry long-term hazards including neurological consequences and the possibility of cancer.

**Ingestion:** Food and drink contamination or unintentional hand-to-mouth transmission could be the cause of this. Many nanoparticles are unknown, but if swallowed, some could have negative effects on the gastrointestinal tract or overall health.

### Best Practice Guidelines

Best practice guidelines on occupational safety in nanotechnology aim to protect workers from potential hazards associated with nanomaterials. They emphasise risk assessment, exposure control, safe handling, and proper waste management. Implementing standardised protocols, continuous training, and regulatory compliance ensures a safe working environment and promotes responsible innovation in

nanotechnology applications (McCornick et al., 2021). Additionally, assigning hazard classes in line with the globally harmonised system, assessing worker's exposure, preventing inhalation of manufactured nanomaterial, assess if exposure exceeds occupational exposure limits, and training workers are some of the best practices by WHO (2017), NIOSH (2013), and ISO guidelines.

### **Conclusion**

Nanotechnology has become a potent instrument for solving environmental problems, providing creative answers for waste management, water purification, pollution removal, and sustainable energy. It has enormous potential to improve environmental protection, but because of the innovative features of nanomaterials, it also poses special risks to occupational safety. Employees engaged in the manufacturing, handling, and disposal of nanomaterials may be exposed to dangers such as inhalation, skin contact, and unknown long-term health impacts. Implementing thorough safety measures is essential to ensuring the proper development and implementation of nanotechnology in environmental domains. Adopting best practices including engineering controls, effective training programmes, personal protective equipment (PPE), and regulatory compliance are all part of this. Nanotechnology has the potential to revolutionise environmental sustainability, but its development must not be allowed to tamper with human health and safety needs. The realisation of nanotechnology's full potential in a way that is both socially and environmentally responsible will depend on proactive risk management, ongoing innovation, and regulatory monitoring.

### **Recommendations**

The following recommendations were made:

- i. Safety regulations should prioritise engineering controls such as the use of fume hoods, containment systems, and local exhaust ventilation to effectively mitigate the aforementioned risks.

- ii. Administrative controls should focus on establishing exposure duration limits, enforcing standard operating procedures, mandating safety training, ensuring proper material labeling, and implementing exposure monitoring and concentration assessment of nanoparticles.
- iii. Personal Protective Equipment (PPE) including protective coats, respirators, helmets, safety goggles, and gloves should be properly utilised at all times.
- iv. Safe work practices should incorporate effective waste management, standardised cleaning procedures, adherence to precautionary principles, and prompt spill response measures.
- v. Risk assessment should be integrated throughout the design and development stages of nanotechnology-enabled products, ensuring comprehensive life-cycle analysis that evaluates potential risks from manufacturing to disposal, while promoting transparency in consumer communication and product labeling.
- vi. A sustainability-focused approach should also be adopted to support the development of eco-friendly and safe nanomaterials.

### References

- Aigbogun, I. E., Mohammed, S.S. D., Orukotan, A. A. and Tanko, J. D. (2018). The Role of Nanotechnology in Food Industries- A Review. 7(4):1-9.
- Current Intelligence Bulletin 65: Occupational Exposure to Carbon Nanotubes and Nanofibers. A Publication of National Institute of Occupational Safety and Health (NIOSH). Publication Number 2013 - 145.
- Ma, X., Tian, Y., Yang, R., Wang, H., Allahou, L. W., Chang, J., Williams, G., Knowles, J. C. and Poma, A. (2025). Nanotechnology in Healthcare, and its Safety and Environmental Risks. *Journal of Nanobiotechnology*. 22,715. <https://doi.org/10.1186/>

- s12951-024-02901-x
- McCormick, S., Niang, M. and Dahm, M. M. (2021). Occupational Exposures to Engineered Nanomaterials: A Review of Workplace Exposure Assessment Methods. *Current Environmental Health Rep.* 8(3):223-234. doi: 10.1007/s40572-021-00316-6.
- Mahmoud, N., Mohammad, S., Mohaddeseh, S. and Zahra, I. (2019). An Introduction to Nanotechnology. *Interface Science and Technology, Elsevier.* 28, 1-27. ISSN 1573-4285.
- Malik, S., Muhammad, K., and Waheed, Y. (2023). Nanotechnology: A Revolution in Modern Industry. *Molecules*, 28(2), 661. <https://doi.org/10.3390/molecules28020661>
- NIOSH Current Intelligence Bulletin: Occupational Exposure to Carbon Nanotubes and Nanofibers.
- Oladipo, I. C. and Ajayi, V. A. (2020). Relevance of Nanotechnology in Drug Delivery: An Overview. *World Journal of Pharmacy and Pharmaceutical Sciences.* 9(12):92 - 120.
- Overview of ISO Guidance and the Control-banding Approach (ISO/TS 12901-2) and Standards Development under ISO/TC 229.
- Oyono, J. L., Dakeyo, M. N. and Tatah, L. (2024). Impact of Nanotechnology in Cancer Treatment: Understanding its Potential Benefits and Applications in Improving Therapeutic Outcomes. *American Journal of Technology*, 3(1), 17-32.
- Phogat, N., Kohl, M., Uddin, I. and Jahan, A. (2018). Interaction of Nanoparticles with Biomolecules, Protein, Enzymes, and Its Applications. *Precision Medicine Tools and Quantitative Approaches*, Academic Press. Pp 253-276.
- Ramos, D. and Almeida, L. (2022). Overview of Standards Related to the Occupational Risk and Safety of Nanotechnologies. *Standards*, 2(1), 83-89. <https://doi.org/10.3390/standards2010007>
- Sim, S. and Wong, N. K. (2021). Nanotechnology and its use in Imaging and Drug Delivery (Review). *Biomed Rep.*14(5):42. DOI: 10.3892/br.2021.1418.

- Tarafdar, J. C., Sharma, S. and Raliya, R. (2013). Nanotechnology: Interdisciplinary Science of Applications. *African Journal of Biotechnology*. 12(3):219-226. DOI:10.5897/AJB12.2481
- WHO (2017) Guidelines on Protecting Workers from Potential Risks of Manufactured Nanomaterials
- Zayed, A., Herbid, S. and Fahmy, S. (2024). Nanotechnology and its Role in Product Sustainability. *International Design Journal*. 14(4):157 - 170.