Good practices and responsible use of nanomaterials

Development of best practice guidelines for the handling of nanomaterials in research, training and technological development is becoming essential

Esperanza Guerra
Enrique Forero
Edgar González

© UniversoNano Media Design

Increasing implementation and use of nanomaterials in research, technological development and training, urgently require to meet the issues relating to the exposure of living beings and the incorporation into the environment of these entities, which by their size, composition and properties may compromise food safety, health, water quality, air and soil.

Advances resulting from the transition to nanometric technologies have positioned the nanomaterials as one of the most important allies for the construction of the new model of technological development. The novel properties exhibited by the matter at the nanoscale [1], offer many possibilities to face the problems of the energy, environmental and health, among others.

For a large part of the offer of nanomaterials produced, there is not enough information about the potential toxic effects and environmental impact [2]. As distinguishing aspects that make them candidates to take their use and handling within the context of the precautionary principle are: size, solubility, shape, composition, structure, concentration, specific surface area, Zeta carge/potential, and capability to generate free radicals among others.

Numerous studies show that exposure to levels above certain specific thresholds, the risk is enough to abide the recommendations and observations for use and handling. For example, the toxicity of carbon nanotubes is associated with the length/diameter ratio of the tubes, the type of functionalization and rigidity among other aspects [3]. In the list of classification IARC Monographs on the Evaluation of Carcinogenic Risks to Humans -International Agency for Research on Cancer-, multi-walled carbon nanotubes MWCNT-7 have been classified as IARC Group 2B carcinogens (possibly carcinogenic to humans). The single-walled carbon nanotubes are classified as IARC Group 3 (not classifiable as to its carcinogenecity to humans).
Nanomaterials of high utilization such as titanium dioxide can produce inflammation and genotoxicity. It has been classified as an IARC Group 2B carcinogen [4], although it should be noted that there are not enough studies to make a definitive classification.
Superparamagnetic iron oxide nanoparticles, are nanomaterials used in medicine for their remarkable benefits and advantages in imaging, drug delivery, and hyperthermia. However, some studies show potential DNA damage and oxidative stress [5]. All these results, although inconclusive, obligate to increase efforts in research on toxic effects of nanomaterials.

In some research or training institutions, handling and management of waste from nanomaterials are not properly protocolized, which poses a potential problem in terms of the safety of students, researches or workers exposed. Protection and waste management in research activities, technological and industrial development that make use of nanomaterials, are required. In some cases, protection elements used for handling conventional chemicals, are not sufficient.

One of the causes that provoke the omission of good practice in the use and handling of nanomaterials, is the insufficient availability of local guides and manuals on protection and waste management as well as properly structured documents and socialization on potential toxicological effects and environmental impact. It is also worth mentioning the lack of regulations and normativity on this issue.

Some countries have already developed guidelines on safe handling of nanomaterials, regulation and good practices.
In 2007 the Federal Institute for Occupational Safety and Health and the German Chemical Industry Association conducted a review of occupational health and safety methods currently applied in the chemical industry in activities involving nanomaterials, and provided specific orientations regarding measures in the production and use of nanomaterials in the workplace [6].

The United States is one of the most active countries in

Esperanza Guerra
Academia Colombiana de Ciencias Exactas Físicas y Naturales
E-mail: *leguerrag@unal.edu.co*
Enrique Forero Ph.D.
Academia Colombiana de Ciencias Exactas Físicas y Naturales
Consejo Nacional Asesor de Nanociencia y Nanotecnología
Red Nanocolombia
E-mail: *enriqueforero2003@yahoo.com*
Edgar E González Ph.D.
Instituto Geofísico, Facultad de Ingeniería, Pontificia Universidad Javeriana
Nanoscalar Science and Technology Center
Academia Colombiana de Ciencias Exactas Físicas y Naturales
Consejo Nacional Asesor de Nanociencia y Nanotecnología
Red Nanocolombia
E-mail: *egonzale@javeriana.edu.co*

The novel properties exibited by the matter at the nanoscale, offer many possibilities in order to address the problems of energy, health and environment

this matter as illustrated in Table 1. In 2004 the Draft Health Safety Guidelines for Nanotechnology research was published by the University of California. In 2008, the Massachusetts Institute of Technology elaborated the document: Best Practices for Handling Nanomaterials in Laboratories. This document highlights the following recommendations [7]:

- "**Know the existing toxicity information available for your nanomaterial.** Be aware that many MSDSs currently shipped with nanomaterials refer to the bulk material toxicity information, which is inappropriate for the nanomaterial. If no information is available for your materials or the toxicity information is limited or uncertain, handle the material as if it is toxic".

- "P**replan the experiments and determine equipment and procedures needed** to factor in all the items discussed below. These include equipment and procedures to prevent inhalation, skin or ingestion exposures, to prevent laboratory contamination, and to properly dispose of all nanomaterial waste. Have appropriate spill materials on hand before beginning your work. Equipment setup may require additional exhaust ventilation and installation or the use of respirators".

- "**Prevent Inhalation exposure during all handling of nanomaterials**. All free particulate nanomaterials should be worked with in exhausted enclosures which may include fume hoods, glove boxes, Class II Type A2, B1 or B2 biosafety cabinets, reactors and furnaces. Procedures involving manipulation of nanomaterials as free particles should be carefully conducted so that no release into the laboratory air occurs. Manipulation of free nanoparticulate on the lab bench should be avoided. Work with suspensions of nanoparticles that are subjected to processes that generate aerosols should

be performed in exhausted enclosures.

Fume Hoods when using a fume hood to contain dust or aerosols of nanomaterials, follow good fume hood use practices such as working 6" back from sash, working with sash below the chin, removing arms slowly from hoods to prevent dragging out contaminants, and not blocking the lower back slot with equipment.

Biosafety Cabinets. Only Class II type A2, B1 or B2 biosafety cabinets which are exhausted into the building ventilation system may be used for nanomaterialswork. BSCs that recirculate into the room may not be used. There is recirculation of air inside type A2 and B1 cabinets, so care should be taken not to perform extremely dusty processes in these cabinets as the internal fans of the BSC are not explosion proof. The air in the type B2 cabinet is 100% exhausted and standard amounts of nanomaterials and solvents may be used in this type of enclosure. The EHS Office should be consulted when considering a biosafety cabinet for control of nanomaterials.

Ventilation for furnaces and reactors should be provided to exhaust gasses generated by this equipment. If possible, the exhaust gasses should be run through a liquid filled bubbler to catch particulate before it enters the building ventilation system. Parts removed from reactors or furnaces for cleaning that may be contaminated with nanomaterial residue should be repaired or cleaned in a fume hood or other type of exhausted enclosure.

Ventilation for large equipment or engineering processes: Equipment that is too large to be enclosed in a fume hood can be set up such that specially designed local exhaust ventilation can capture contaminants at points where emission is possible. Also custom enclosures can also be designed by local vendors to contain potential emissions. Call the EHS Office for evaluation and design of specialized local exhaust ventilation systems.

Nanomaterial Transport in the Lab. Nanomaterials removed from furnaces, reactors, or other enclosures should be put in sealed containers for transport to other locations. If nanomaterial product from a reactor is bound or adhered to a substrate, the substrate may be removed and put in a transport container. If the nanomaterials product is unbound and easily dispersible (such as in CNT synthesis using aerosolized catalyst), the removal from a reactor should be done with supplementary exhaust ventilation or a glove bag connected to a HEPA vacuum".

- "**Prevent Dermal Exposure to Nanomaterials.** The ability of nanoparticles to penetrate the skin is uncertain at this point, so gloves should be worn when handling particulate and suspensions containing particulate. If working with dry particulate, a sturdy glove with good integrity should be used.

- "**Use Eye Protection**. Wear eye protection appropriate to the experimental conditions (for example, safety glasses, goggles, or face shields)".

In 2009 the Best Practices Guide to Synthetic Nanoparticle Risk Management, appeared in Canada. In it "the authors favour a preventive approach aimed at minimizing occupational exposure to NPs (nanoparticles) when their risk assessment cannot be established precisely" [8]. The guide includes, inter alia: identification of dangers, risk assessment, laws, regulations and obligations of the parties, working safely with nanoparticles. The exposition by inhalation of NPs of few nanometers causes that these entities will be deposited in the nose and thorat, and NPs of 15-20 nanometers will be deposited at the alveolar level [9], and later migrate to the lymphatic system and blood.

In some research or training institutions, handling and management of waste from nanomaterials are not properly protocolized, which poses a potential problem in terms of the safety of students, researches or workers exposed

In a document produced by Ministry of Health, Labour and Welfare of Japan in 2009, the preventive measures against exposure of nanomaterials were established [10]. It is emphasized that on the basis of the precautionary approach, it is important to increase the efficacy of exposure prevention practices and to understand the properties of nanomaterials. Aspects such as working environment management, installations, examinations of the concentration of nanomaterials in workplaces, cleanning of floors, use of protective equipment, dissemination of information on nanomaterials, among others, are considered.

The Departament of Science and Technology of the Indian Government published in 2011 the Guidelines and Best Practices for Safe Handling of Nanomaterials in Research Laboratories and Industries [11]. This guide contains the identification of hazards, pathways and common activities that could result in exposure, exposure control strategies,

best practices to be followed while handling nanoparticles, best practices and adequate approaches regarding making and handling nanopowders and use of products relating to food and healthcare, safety practices and product stewardship.

Spain has contributed with varius reports and guidelines on risk and good practice associated with nanomaterials. Between 2012 and 2013 the Tecnalia Foundation developed a practical manual of risks for health and safety in the work place arising from the manipulación of nanomaterials [12]. In the manual, the following issues are addressed:
Nano-objects and nanomaterials, toxicology, security and health aspects, use of nanomaterials and exposure scenarios, risk assessment, prevention and protection, regulations and standards.

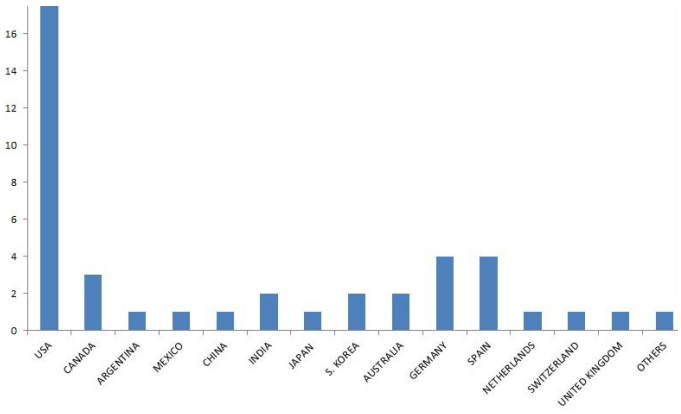

Figure 1 Number of guides of good practices associated with nanomaterials and recommendation documents by country.

One of the causes that provoke the omission of good practice in the use and handling of nanomaterials, is the insufficient availability of local guides and manuals on protection and waste management well as properly structured documents and socialization on potential toxicological effects and environmental impact. It is also worth mention the lack of regulations and normativity on this issue

in addition, the mini-guide on best practices for the safe handling and use of nanoparticles made by the Consorsio NanoSafe Pack should be mentioned.

In Latin America, some countries have advanced in the preparation of guides, although none has been yet published. In Colombia, the Network of Nanoscience and Nanotechnology (Red NanoColombia) [13] through its National Advisory Council is working on the elaboration of a guide to be submitted for evaluation and possible implementation in laboratories and universities.

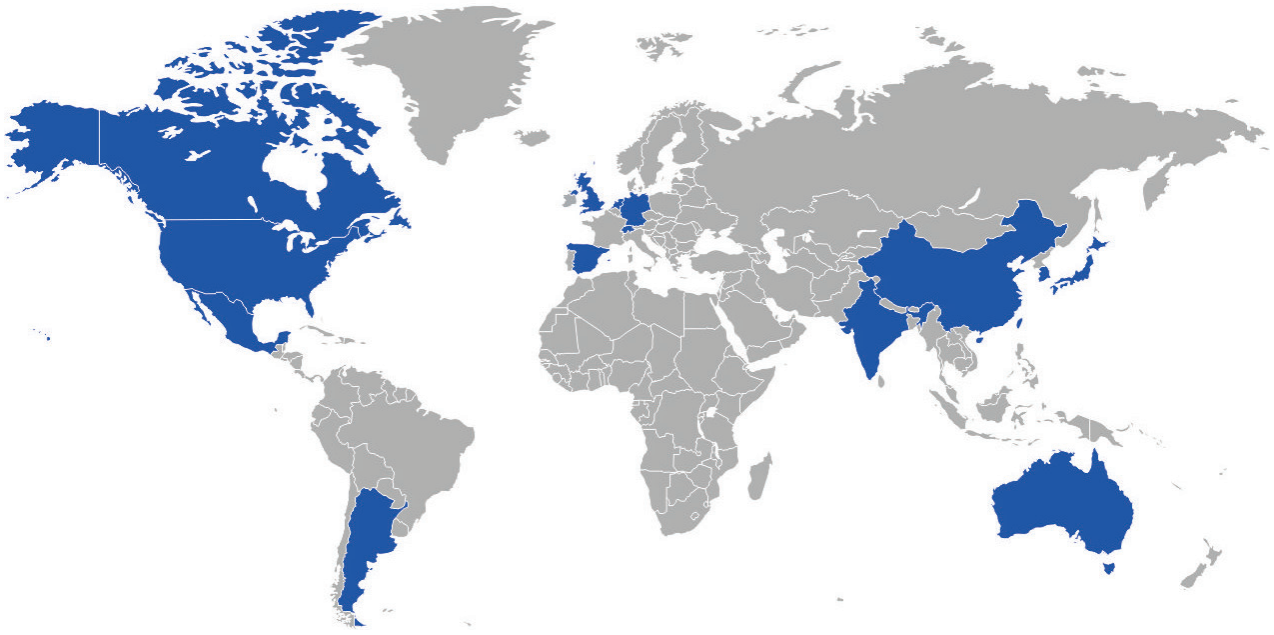

Figure 2 Map of countries that have developed good practices guidelines associated with nanomaterials.

On the basis of the precautionary approach, it is important to increase the efficacy of expusure prevention practices and to understand the properties of nanomaterials

CONCLUSION

There is no doubt about the importance and the crucial role that nanoscience and nanotechnology will play in seeking solutions to the main problems faced by the society of the XXI century. However there is an urgent need to produce guidelines for the responsable use of these emerging technologies, particularly regarding the handling and waste management related to nanomaterials..

This implies increasing efforts to find enough information on their toxic effects on living organisms, lifecycle and potential impacts on the environment.

This will prevent the inappropiate use of nanomaterials in consumer products and industry, from becoming a problem that later we need to remedy.

References

[1] González, E. *J. Nano Sci. Tech.,* **1**, 48 (2013).
[2]Liu, Y., Zhao, Y., Sun, B., & Chen, C. *Acc. Chem. Res.* **46** (3), 702-713 (2013).
[3] Kostarelos, K. *Nature Nanotechnology*, **26,** 774- 776 (2008).
[4] International Agency for Research on Cancer (IARC). List of classifications in: http://monographs.iarc.fr/ENG/Classification/latest_classif.php
[5] Singh, N., et al., *Nano Rev.*, **1**, 5358 (2010).
[6] http://www.baua.de/en/Topics-from-A-to-Z/Hazardous-Substances/Nanotechnology/pdf/guidance.pdf?__blob=publicationFile
[7]https://ehs.mit.edu/site/sites/default/files/files/University_Best_Practices.pdf
[8] Ostituy, C., et al. Best Practices Guide to Synthetic Nanoparticle Risk Management. IRSST -Communications Division (2009).
[9] Ostiguy, C., et al. Nanoparticles: Current Knowledge about Occupational Health and Safety Risks and Prevention Measures, Studies and Research, IRSST, Report R-470 (2006).
[10]http://www.jniosh.go.jp/oldsite/joho/nano/files/mhlw/Notification_0331013_en.pdf.
[11] CKMNT. Guidelines and Best Practices for Safe Handling of Nanomaterials in Research Laboratories and Industries. Report. http://nanomission.gov.in/What_new/Draft_Guidelines_and_Best_Practices.pdf
[11] http://energy.gov/ (Office of Energy Efficiency and Renewable Energy)
[12] http://www.osalan.euskadi.eus/contenidos/informacion/presentacion_proyectos_investi/es_jt120903/adjuntos/proyecto_tecnalia.pdf
[13] www.rednanocolombia.org

Table 1. Information by country on recomendations and good practice guidelines related with nanomaterials.

INSTITUTION	COUNTRY	FUNCTION	GUIDE
DOE (Department of Energy) Nanoscale Science Research Centers	USA	Advice and recomendation	Approach to Nanomaterial ES&H
Georgia Institute of Technology	USA	Research	Nanotechnology Safety Resources
Iowa State University	USA	Research	Laboratory Safety Manual
MIT (Massachusetts Institute of Technology)	USA	Research	Best Practices for Handling Nanomaterials in Laboratories
NASA (National Aeronautics and Space Administration)	USA	Research	Nanomaterials Safety and Health Guideline for Carbon-based nanomaterials
NSF (National Science Foundation)	USA	Research	Environmental, Health and Safety guidelines for NSF Nanoscale Science and Engineering Research Centers
University of Oklahoma Health Science Center	USA	Research	Nanoparticle Handling Guidelines
EHRS (Environmental Health and Radiation Safety), University of Pennsylvania	USA	Research	Nanoparticle Handling Fact Sheet
University of California (published as ISO TC 229 WG 3)	USA	Research	Laboratory Management - Draft Health Safety Guidelines for Nanotechnology research
UCSB (University of California Santa Barbara)	USA	Research	Laboratory Safety Fact Sheet 32# - Engineered Nanomaterials: Guidelines for Safe Research Practices
University of Dayton	USA	Research	Nano Technology - Health & Safety
VCU (Virginia Commonwealth University)	USA	Research	Nanotechnology and Nanoparticles
CHS (Center for High-Rate Nanomanufacturing) Northeastern University. Boston	USA	Research & production	Interim Best Practices for Working with Nanoparticles
U.S. National Institute for Occupational Safety and Health	USA	Advice and recomendation	Approaches to Safe Nanotechnology: Managing the Health and Safety Concerns
Hallock et al. Massachusetts Institute of Technology. Environment, Health and Safety Office,	USA	Advice and recomendation	Potential risks of nanomaterials and how to safely handle materials of uncertain toxicity
Hoyt and Mason, Journal of Chemical Health & Safety	USA	Research	Nanotechnology - Emerging health issues
Schulte et al., Scand J Work Environ Health. National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention	USA	Research & Production	Sharpening the focus on occupational safety and health in nanotechnology
Department of Health and Human Services	USA	Advice and recomendation	General Safe Practices for Working with Engineered Nanomaterials in Research Laboratories
University of British Columbia	Canada	Research	AMPEL Nanofabrication Facility Members' Laboratory guide
Institut de recherche Robert-Sauvé en santé et en sécurité du travail.	Canada	Research	Best Practices Guide to Synthetic Nanoparticle Risk Management
Concordia University	Canada	Research	Nanomaterials Safety Guidelines
CENAM + HLRCC (United States-Mexico High-Level Regulatory Cooperation Council) Working Group	México	Advice and recomendation	Lineamientos para regulaciones sobre nanotecnologías para impulsar la competitividad y proteger al medio ambiente, la salud y la seguridad de los consumidores

LINK	ORIGEN	DATE	ONLINE AVAILABILITY LANGUAGE
http://science.energy.gov/~/media/bes/pdf/doe_nsrc_approach_to_nanomaterial_esh.pdf	Governmental	2008	✓ English
http://www.ehs.gatech.edu/sites/default/files/nanotechnology.pdf	Academic	2009	✓ English
http://publications.ehs.iastate.edu/labsm/#1/z	Academic	Reviewed 2016	✓ English
https://ehs.mit.edu/site/sites/default/files/files/University_Best_Practices.pdf	Academic	2008	✓ English
http://procure.arc.nasa.gov/assets/docs/APR1700.1-R/APR1700.1TOC.html	Gubernamental	2007	✓ English
_____	Governmental	2009	_____
http://compliance.ouhsc.edu/ibc/Home/Resources.aspx	Academic	2009	✓ English
http://www.ehrs.upenn.edu/media_files/docs/pdf/chp_sop_nanoparticles.pdf	Academic	2008	✓ English
_____	Academic	2004	_____
http://www.ehs.ucsb.edu/labsafety/fact-sheets	Academic	2009	✓ English
https://www.udayton.edu/facilities/ehsrm/programs_folder/environmental_safety_folder/nano_safety_page.php	Academic	2006	✓ English
http://oehs.vcu.edu/chemical/nanotech.pdf	Academic	2007	✓ English
http://eprints.internano.org/34/1/Best_Practices_for_Working_with_Nanoparticles_Version_1.pdf	Academic	2008	✓ English
https://www.cdc.gov/niosh/docs/2009-125/pdfs/2009-125.pdf	Governmental	2009	✓ English
http://www.sciencedirect.com/science/article/pii/S1871553208000492	Academic	2009	✓ English
http://www.sciencedirect.com/science/article/pii/S1871553207000722	Academic	Artículo (Propuesta). 2008	✓ English
http://www.ncbi.nlm.nih.gov/pubmed/19137209	Academic	Artículo, 2008	✓ English
http://www.cdc.gov/niosh/docs/2012-147/pdfs/2012-147.pdf	Governmental	DHHS (NIOSH) Publication No. 2012–147	✓ English
http://www.phas.ubc.ca/~ampel/nanofab/sop/NanofabFacilityGuide.pdf	Academic	2004	✓ English
https://www.irsst.qc.ca/media/documents/PubIRSST/R-599.pdf	Independient	2009	✓ English
https://www.concordia.ca/content/dam/concordia/services/safety/docs/EHS-DOC-035_NanomaterialsSafetyGuidelines.pdf	Academic	____	✓ English
http://www.revistas.unam.mx/index.php/nano/article/view/45193/40731	Governmental	2012	✓ Spanish

Gabriela Trupia, FAN, 2015	Argentina	Research	Nanotecnología y elaboración de nuevos marcos regulatorios en Argentina: estrategias, acciones y desafíos
Standardization Administration of China	China	Advice and recomendation	Notice on Standard Draft Planning on 17 National Standards including "the Standard on the Health and Safety Practices in Occupational Settings Relevant to Nanotechnologies (ISO/TR 12885:2008)
Nano Mission, DST, Govt of India. Centre for Knowledge Management of Nanoscience & Technology	India	Advice and recomendation	Guidelines and Best Practices for Safe Handling of Nanomaterials in Research Laboratories and Industries
National Institute of Advanced Industrial Science and Technology	Japan	Research	Guideline for Prevention against Exposure to Nanomaterials
Ministry of Health, Labour and Welfare	Japan	Advice and recomendation	Measures for Prevention of Exposure to Nanomaterials at Workplaces
Korean Agency for Technology and Standards	South Korea	Advice and recomendation	Guidance on the Safe Handling of Nanomaterials to be provided
NanoSafe Australia Network (RMIT University)	Australia	Advice and recomendation	Current OHS Best Practices for the Australian Nanotechnology Industry
Safe Work Australia	Australia	Advice and recomendation	Engineered nanomaterials: evidence on the effectiveness of workplace controls to prevent exposure
Federal Institute for Occupational Safety and Health (BAuA) German Chemical Industry Association (VCI)	Germany	Advice and recomendation	Guidance for Handling and Use of Nanomaterials at the Workplace
Ministry for Economics, Transportation and State Development for the State of Hessen	Germany	Advice and recomendation	Innovationsfördernde Good-Practice-Ansätze zum verantwortlichen Umgang mit Nanomaterialien
Federal ministry for labour and social affairs, GMBl Nr.15 S.295-314 (02.04.2008)	Germany	Advice and recomendation	TRGS (technical rule for hazardous substances) 526 - laboratories
Statutory employment accident insurance fund for the Chemical Industry (BG Chemie) / German Social Accident Insurance (DGUV), Jedermann-Verlag, Heidelberg	Germany	Advice and recomendation	BGI/GUV-I 850-0 Sicheres Arbeiten in Laboratorien
NanoSafePack Consortium	España		Buenas prácticas para el manejo y uso seguro de nanopartículas en industrias del envase y embalaje
Instituto Nacional de Seguridad e Higiene en el Trabajo	España	Advice and recomendation	Seguridad y Salud en el Trabajo con Nanomateriales
Instituto Nacional de Seguridad e Higiene en el Trabajo	España	Advice and recomendation	Riesgos asociados a la nanotecnología
De Ipiña ET AL. Fundación Tecnalia Research and Innovation	España	Advice and recomendation	Manual Práctico para la Integración en la Pyme de la Gestion de Riesgos Derivados de la Nanotecnología y los Nanomateriales (NanoBook 2)
Delft University of Technology	Netherlands	Research	TNW Nanosafety Guidelines
EPFL (École polytechnique fédérale de Lausanne)	Switzerland	Research	Nanoparticles: a security guide
HSE (Health and Safety Executive)	United Kingdom	Advice and recomendation	Nanotechnology
ORC (Organization Resources Councelors)	Organization	Advice and recomendation	Guidelines for Safe Handling of Nanoparticles in Laboratories

http://www.unitar.org/cwm/nanosafety-regional-workshop-latin-american-and-caribbean-region-colombia	FAN + Government	2015 (Proposal)	✓ Spanish
_____	Governmental	2011	_____
http://nanomission.gov.in/What_new/Draft_Guidelines_and_Best_Practices.pdf	Governmental	2011	✓ English
_____	Independient	2009	_____
http://www.jniosh.go.jp/oldsite/joho/nano/files/mhlw/Notification_0331013_en.pdf	Governmental	2009	✓ English
http://www.kssn.net/eng/webstore/ksinfo.asp?idx=70679	Governmental	2012	✓ English
http://mams.rmit.edu.au/72nuxiavskpg.pdf	Academic	2007	✓ English
http://www.safeworkaustralia.gov.au/sites/SWA/about/Publications/Documents/312/EngineeredNanomaterials_Evidence_Effectiveness_WorkplaceControlsToPreventExposure_2009_PDF.pdf	Independient	2009	✓ English
http://www.baua.de/en/Topics-from-A-to-Z/Hazardous-Substances/Nanotechnology/pdf/guidance.pdf?__blob=publicationFile	Governmental	2007	✓ English
https://www.hessen-nanotech.de/mm/Suppl-NanoKomm_final_Web.pdf	Governmental	2008	✓ Germany
_____	Governmental	2008	_____
http://bgi850-0.vur.jedermann.de/index.jsp	Governmental	2008	✓ Germany
http://www.fan.org.ar/wp-content/uploads/2014/05/NanoSafePack-Mini-Guide-Spanish-Version-final.pdf	Company	2014	✓ Spanish
http://www.insht.es/InshtWeb/Contenidos/Documentacion/FICHAS%20DE%20PUBLICACIONES/EN%20CATALOGO/Higiene/2015%20Seguridad%20y%20salud%20en%20el%20trabajo%20con%20nanomateriales/SST%20con%20nanomateriales.pdf	Governmental	2015	✓ Spanish
http://www.insht.es/InshtWeb/Contenidos/Documentacion/FichasTecnicas/NTP/Ficheros/786a820/797%20web.pdf	Governmental	2008	✓ Spanish
http://www.osalan.euskadi.eus/contenidos/informacion/presentacion_proyectos_investi/es_jt120903/adjuntos/proyecto_tecnalia.pdf	Independient	2013	✓ Spanish
	Academic	2008	✓ English
http://ltp.epfl.ch/files/content/sites/ltp/files/groups/LTP-unit/public/securite/guide_securite_nanoparticules.pdf	Academic	2007	✓ English
http://www.hse.gov.uk/nanotechnology/	Governmental	2004	✓ English
http://www.orc-dc.com/files/2007/307/Safe_Practices_Labs.pdf	Independient	2005	✓ English