International Labour Organization

SAFETY + HEALTH FOR ALL

Exposure to hazardous chemicals at work and resulting health impacts: A global review

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Executive Summary

Background

Workers around the world are facing a global health crisis due to occupational exposure to toxic chemicals. **Every year more than 1 billion workers are exposed to hazardous substances, including pollutants, dusts, vapours and fumes in their working environments.** Many of these workers lose their life following such exposures, succumbing to fatal diseases, cancers and poisonings, or from fatal injuries following fires or explosions. We must also consider the additional burden that workers and their families face from non-fatal injuries resulting in **disability, debilitating chronic diseases**, and other health sequela, that unfortunately in many cases remain invisible. **All of these deaths, injuries and illnesses are entirely preventable.**

The International Labour Organization (ILO) has long recognized that the protection of workers from hazardous chemicals is essential to ensuring healthy populations as well as sustainable environments. Nevertheless, **workers continue to be disproportionally exposed to chemicals across almost all workplace sectors.** Production of chemicals as well as the industries using them are expanding, which means a **high potential for increased occupational exposure**. Moreover, with new chemicals introduced every year, mechanisms for regulating exposure such as the implementation of occupational exposure limits, struggle to keep up. There is therefore an urgent need to take action and implement a range of effective measures to prevent harm to workers, their families, and wider communities.

In response to growing international concern over chemical safety, the **Strategic Approach to International Chemicals Management (SAICM)** was developed to serve as a policy framework to promote chemical safety. Occupational exposure considerations should be at the core of SAICM Beyond 2020 and **even stronger measures are needed in this new framework to protect workers from chemical exposures**.

This global review was undertaken in order to provide a sound evidence base towards policy efforts. As such, it represents a necessary and comprehensive analysis of recent trends and priorities when it comes to protecting the health and safety of workers from occupational chemical exposures.

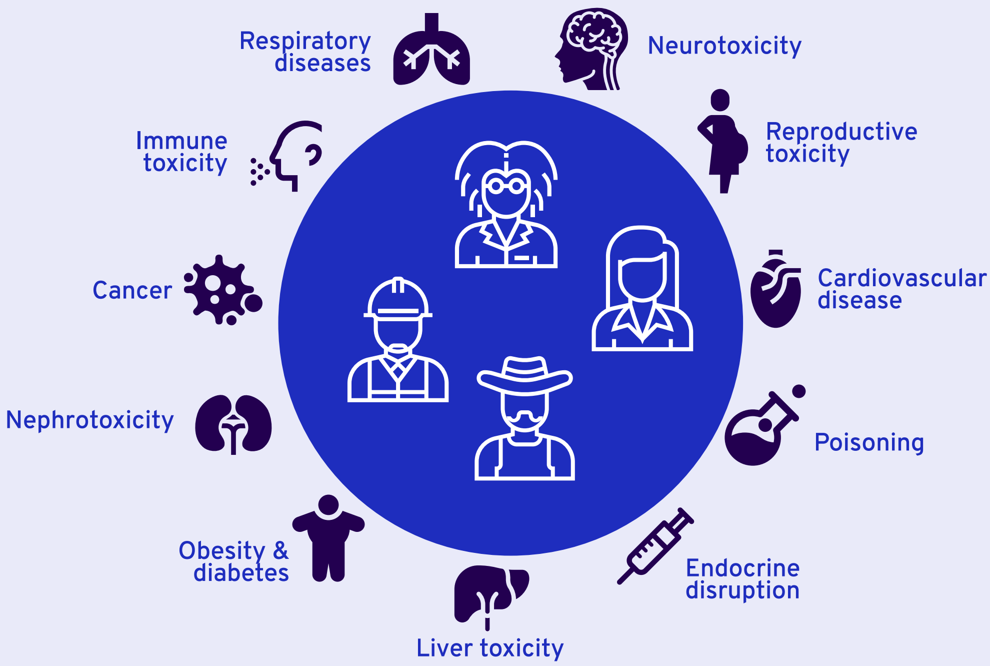
Main findings

The top chemical exposures identified as priorities include:

1. Asbestos
2. Silica
3. Heavy metals
4. Solvents
5. Dyes
6. Manufactured nanomaterials (MNMs)
7. Perfluorinated chemicals (PFAS)
8. Endocrine disrupting chemicals (EDCs)
9. Pesticides
10. Workplace air pollution

- For the great majority of chemical exposures, **data does not exist** for local, regional and global estimates and **the number of workers exposed cannot even be estimated**.

- Only a limited number of chemical occupational exposures are considered, monitored and regulated in workplaces. Because of the lack of comprehensive information on chemical exposure of workers and respective outcomes such as death, cancer, etc., global burden of disease calculations are often **missing or are severely underestimated.**
- Whilst some hazardous chemicals have been **phased out**, a number of toxic substances are still used globally, and **workers in low- and middle-income countries (LMIC) are particularly exposed**.
- **Cancer is the main cause of work-related death**, and more than 200 different substances have been identified as known or probable human carcinogens, with many of these exposures occurring in the workplace.
- Occupational chemical exposures have toxic effects on different body systems, including **reproductive, cardiovascular, respiratory and immune systems**, as well as **specific organs**, such as the liver and brain.



Priority Actions

This review clearly demonstrates the need for prompt action to protect workers across various economic sectors worldwide. Key actions to ensure worker protection and prevention efforts include strict and evidence-based occupational exposure limits, workplace measures following the hierarchy of control, and chemical phase outs and restrictions. Additional key points include:

- Policies for the sound management of chemicals should always follow a **systems approach**, as outlined in the **ILO Promotional Framework for Occupational Safety and Health Convention No. 187**.
- International labour standards are crucial in responding to the occupational health crisis posed by chemicals. Key ILO conventions pertaining to the safe management of chemicals, including **ILO**

Chemicals Convention No. 170 and the **Prevention of Major Industrial Accidents Convention No. 174**, should be ratified and implemented as a priority.

- A **preventative safety and health culture** should be established at national and workplace levels, with diverse stakeholders engaged at all levels.
- **Harmonised and evidence-based Occupational Exposure Limits (OELs)** must be established, updated, implemented and enforced for all major hazardous chemicals.
- At the workplace level, a programme approach for the sound management of chemicals is recommended, as well as a workplace strategy involving **chemical identification, comprehensive risk assessment and implementation of control measures**.
- Preventative measures should be implemented following the **Hierarchy of Controls**, as set forth in ILO guidance.
- There is an urgent need for **harmonized global data repositories** and databases of chemical exposure information and resulting health effects on workers.
- Further research on **non-communicable diseases** (NCDs) should be considered a priority, as well the **interlinkages with chemical exposures and infectious disease**. The COVID-19 pandemic highlighted the need to develop responsive policy efforts that take into consideration the multi-dimensional aspects of OSH.
- Efforts are needed to **generate gender disaggregated data** to identify and prevent exposures and impacts that are magnified by gender and biological factors.
- **Social dialogue is essential** for promoting transparent and active communication between stakeholders at all levels.
- There is a need for **increased engagement of world of work stakeholders in SAICM** and other international policy efforts dealing with chemicals, as well as the development of sound governance frameworks.

Although the health effects of some occupational chemical exposures are well established, it is likely that the long-term health impacts of certain chemicals will only become evident in years to come. What is clear however, is that the utilisation of hazardous chemicals in consumer products and industrial processes **will continue to increase in the coming years, leading to a higher burden of disease and adverse consequences for the environment**. We can no longer afford to be complacent in our global mismanagement of chemicals and a new approach is urgently needed to protect the billions of workers exposed on a daily basis. **Effective and evidence-based systems for the sound management of chemicals** must be implemented at both the national and workplace level as a matter of urgency.

Safe and healthy working conditions are fundamental to decent work.

▶ ILO Centenary Declaration for the Future of Work, 2019

Acronyms

ACGIH	American Conference of Governmental Industrial Hygienists
ASGM	Artisanal small-scale gold mining
BC	Black carbon
BMI	Body mass index
BPA	Bisphenol A
CCA	Chromated copper arsenate
CNT	Carbon nanotubes
COPD	Chronic obstructive pulmonary disease
DALY	Disability adjusted life year
DDT	Dichlorodiphenyltrichloroethane
DEP	Diethyl phthalate
DES	Diethylstilboestrol
ECHA	European Chemicals Agency
EDC	Endocrine-disrupting chemicals
EPA	Environmental protection agency
EU	European Union
GBD	Global burden of disease
GHS	Globally Harmonized System of Classification and Labelling of Chemicals
HHP	Highly hazardous pesticide
HIC	High-income countries
IARC	International Agency for Research on Cancer
ILO	International Labour Organization
IPCS	International Programme on Chemical Safety
IPEN	International Pollutants Elimination Network
LMIC	Low- and middle-income countries
MEHP	Mono-2-ethylhexyl phthalate
MMP	Monomethyl phthalate
MNMs	Manufactured nanomaterials
MWCNT	Multi-walled carbon nanotubes
NAFLD	Non-alcoholic fatty liver disease
NCD	Non-communicable disease
NHL	Non-Hodgkin Lymphoid
NIOSH	United States National Institute for Occupational Safety and Health
OEL	Occupational exposure limits
OSHA	United States Occupational Safety and Health administration
PCBs	Polychlorinated biphenyls
PCP	Pentachlorophenol
PD	Parkinson's disease
PEL	Permissible exposure limit
PFAS	Per- and polyfluoroalkyl substances
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonate
OPM	Particulate matter
PNC	Particle number concentration
POPs	Persistent organic pollutants
PPB	Parts per billion
PPE	Personal protective equipment
REL	Recommended exposure limit
RR	Risk ratio
SAICM	Strategic Approach to International Chemicals Management
SDG	Sustainable development goal
SMR	Standardized mortality ratio
SWCNT	Single walled carbon nanotubes
TWA	Time weighted average
UEEE	Used Electric and Electronic Equipment
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme

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Introduction

Purpose of the study

As the production and use of chemicals in workplaces around the world increases, workers are ever more at risk of hazardous chemical exposures which may be detrimental to their health. Aside from those employed by the chemical industry itself, workers from across almost all economic sectors are exposed to hazardous and toxic chemicals. Previous estimates published by the ILO have found that over 2,780,000 workers die globally each year due to their working conditions and that exposure to hazardous substances claim the lives of almost 1 million workers (Hämäläinen et al. 2017). This translates to at least one worker dying every 30 seconds due to occupational chemical exposure (UN 2018).

Due to scale of the problem, a comprehensive review of the evidence was needed to better understand the risks posed by hazardous chemicals and to identify measures to protect the health and safety of exposed workers. Chemical priorities in this study were identified based on the following criteria:

- Expected burden of exposure among workers (the higher the exposure and production trends, the higher the priority)
- Expected burden of disease and related mortality for workers (the higher the mortality, the higher the priority).
- Potential for improving and implementing protective and preventive measures for workers (i.e. chemical exposures for which occupational exposure limits are currently missing, chemical exposures where low to middle income countries could implement measures based on current practices from high income countries).

Why it is important to carry out a global review now?

The sound management of chemicals and waste is directly linked to the world of work. **While all populations may be exposed to chemicals, workers tend to face exposure to higher doses and over longer time periods, increasing their risk of significant health effects**. The ILO has highlighted the importance of chemical exposures as a top priority for advancing occupational safety and health (OSH) agendas worldwide and calls attention to significant interlinkages that exist between the world of work and other sectors, such as health, environment, agriculture and economic development.

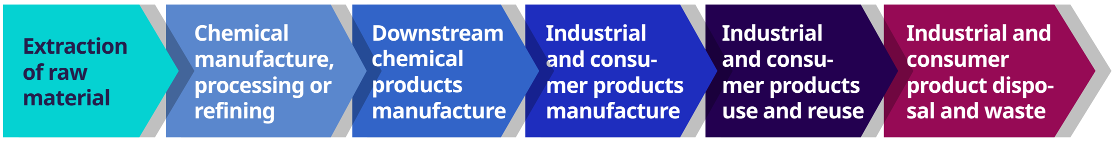
In response to growing international concern over chemical safety, the Strategic Approach to International Chemicals Management (SAICM) was developed with the overall objective of ensuring the sound management of chemicals throughout their life cycle. The ILO Governing Body endorsed SAICM in 2006, noting that this global policy framework is a remarkable tool to harmonise and integrate important elements needed for a universal approach to the sound management of chemicals worldwide.

An intersessional process is now underway to prepare recommendations regarding SAICM Beyond 2020. **Occupational exposure considerations should be at the core of SAICM Beyond 2020 and even stronger measures are needed in this new framework to protect workers from chemical exposures.** This global review aims to provide important considerations on exposure scenarios, the magnitude of worker exposure and health effects, as well as priorities for action during the intersessional process and beyond. The ILO also hopes that the publication of this global review will bring attention to the global health crisis workers are currently facing. It aims to promote the meaningful and active participation by world of work stakeholders, to ensure that the views of the labour sector are fully taken into account.

Trends in OSH and chemical safety

The chemical industry has a long history of steady growth of about 4 to 4.5 per cent per year, although some flattening has occurred over the past few years (UNEP 2019b). Global sales, including pharmaceuticals, were valued €3.47 trillion in 2017, making the chemicals industry the

▶ Figure 1. Value Chain of the Chemical Industry: from extraction to finished products



Source: (UNEP 2019a).

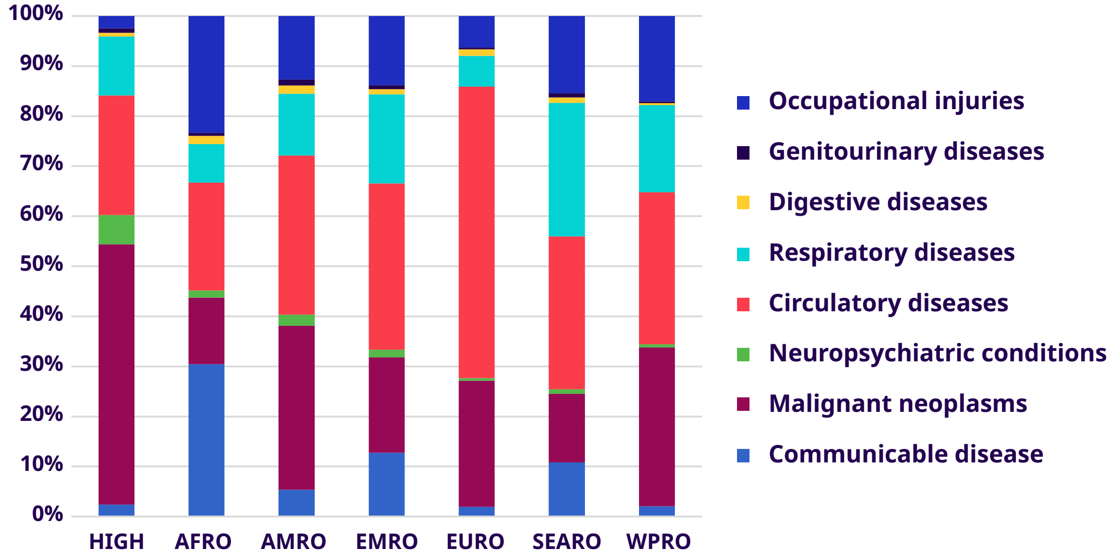
world's second largest production sector (ILO 2018). Asia is the region that currently produces and consumes the largest amount of chemicals. China has the largest chemical industry in the world, with 37 per cent of global sales. With a market share of around 16 per cent, the European Union (EU) ranks second, followed by the US with around 13 per cent. The global chemical industry's production capacity nearly doubled to around 2.3 billion tons between 2000 and 2017 (Cayuela and Hagan 2019), indicating potential future increases in the quantity of chemicals produced. Sales growth is expected to continue, though at a somewhat slower pace than in the past decade.

The global value chain of the chemical industry can be divided into key segments, as shown in **Figure 1** (UNEP 2019a). In a first step, feedstocks (e.g., natural gas and minerals) are processed into high-volume, low-value bulk chemicals. These are conventionally produced in high-capacity refineries and milling facilities. Intermediate chemicals are generally developed for further use in production or manufacturing processes, for example, dyes for paint production. Chemical processing and product manufacturing in downstream facilities are connected to innumerable product manufacturers in sectors such as agriculture, construction and electronics. The various segments may span a number of countries across the world. Industrial and consumer product use, re-use, disposal and waste can vary widely among different products and regions.

Workers face hazardous exposures at all stages of the global chemicals value chain. In addition, workers are exposed to a variety of chemicals across economic sectors, including but not limited to, agriculture, mining, construction, manufacturing, and services. Chemical hazards, both classic (such as asbestos), as well as emerging (manufactured nanomaterials), pose a direct threat to workers and can exacerbate existing health problems. Occupational chemical exposures can result in acute health effects, such as poisoning from pesticides, or in chronic disease, such as cancers. **Moreover, the production, use and storage of chemicals can result in fires and explosions, resulting in large scale fatal and non-fatal injuries. A recent example is the Beirut explosion (August 2020), when ammonium nitrate held in storage led to a series of explosions, claiming over 200 lives and resulting in more than 7,500 injuries.**

Non-communicable diseases (NCDs), such as cardiovascular disease, cancers and respiratory diseases, are another important consideration, as these may be triggered by exposure to hazardous substances. Indeed, **NCDs represent the vast majority of work-related diseases and an increased risk of NCDs is often associated with occupational chemical exposures** (Budnik et al. 2018). Recent estimates showed that occupational cancer accounted for 27 per cent of the 2.4 million deaths per year, as shown in **Figure 2** (Takala et al. 2014; Takala 2015). The estimated number of deaths attributable to occupational cancer annually increased from 666,000 deaths in 2011 to 742,000 deaths in 2015, an increase that could be explained by different variables, such as the evidence on new carcinogens, the methods of estimation, changes in the industry distribution of workers and a growing and ageing population. The ILO has released global data that also shows an increase in the number of fatal work-related cancers that occur every year (ILO 2018). In the EU alone, occupational cancer was responsible for 102,500 deaths in 2011 and 106,300 in 2015. Considering these data, it is clear that occupational cancer now represents one of the primary causes of work-related deaths globally and in many regions of the world, and that the numbers continue to grow (Iavicoli et al. 2019).

▶ **Figure 2. Global burden of global work-related diseases by regions. Total number of work-related fatalities was 2.4 million**



Source: Hämäläinen 2017

Figure based on WHO regional groupings: HIGH - High Income countries Low- and middle-income countries: AFRO - countries of the African Region AMRO - countries of the Americas EMRO - countries of the Eastern Mediterranean Region EURO - countries of the European Region SEARO - countries of the South-East Asia Region WPRO - countries of the Western Pacific Region

Exposure to chemicals in the world of work: a cross-cutting labour issue

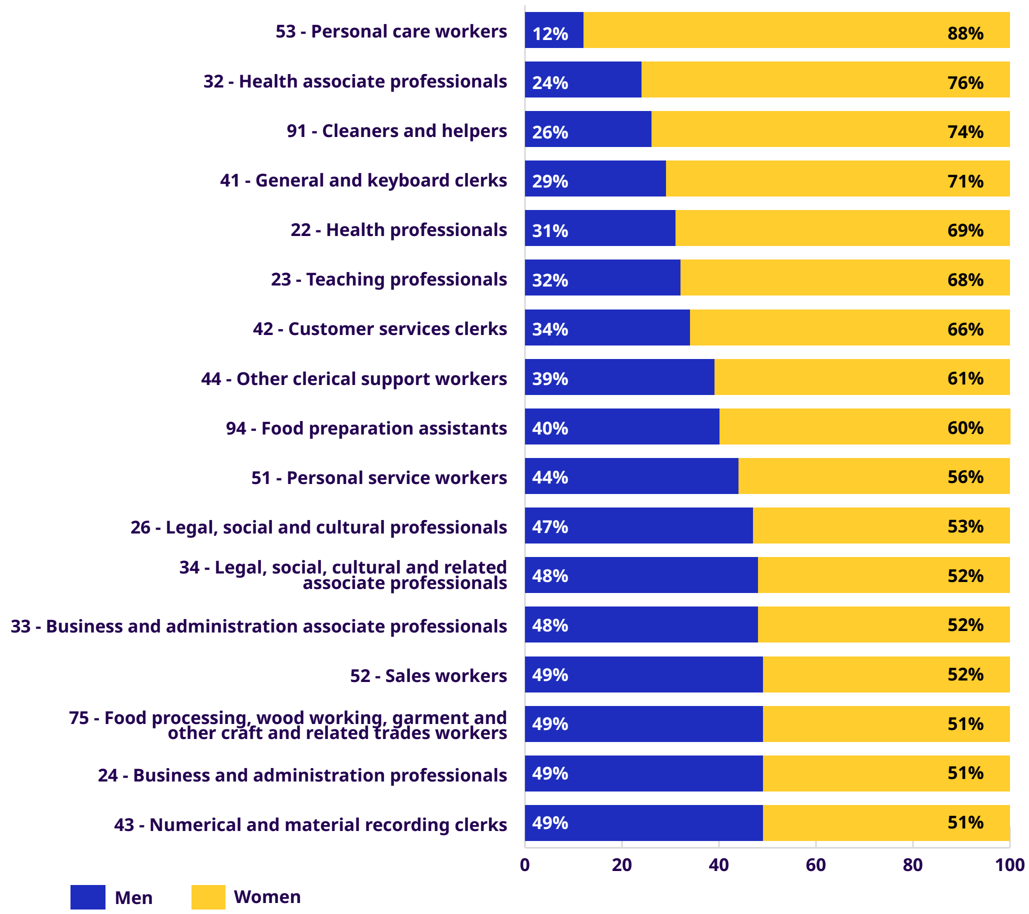
Changes in working practices, demographics, technology and the environment have resulted in new OSH concerns and in growing trends of occupational health inequalities among workers worldwide, particularly when it comes to exposure to toxic substances. Certain groups of workers, such as young workers, aging populations, migrant workers, women and workers in the informal sector, may face increased exposures to hazardous chemicals and suffer disproportionally from their health effects.

The protection of workers against exposure to chemicals is closely linked to the ILO's efforts to promote decent work and especially Fundamental Principles and Rights at Work (FPRWs). These include the elimination of child labour, forced labour and discrimination at work, as well as the right to freedom of association and collective bargaining. With regard to child labour, exposures to even low doses of chemicals, especially during critical periods of biological development, can cause devastating and lifelong functional impairments. Victims of forced labour and discrimination are also more likely to be affected by chemical exposure due to often unsafe working conditions. The same applies to workers who are not allowed to organise and bargain for their rights to be protected against hazardous substances.

The role of gender in occupational exposure to chemicals

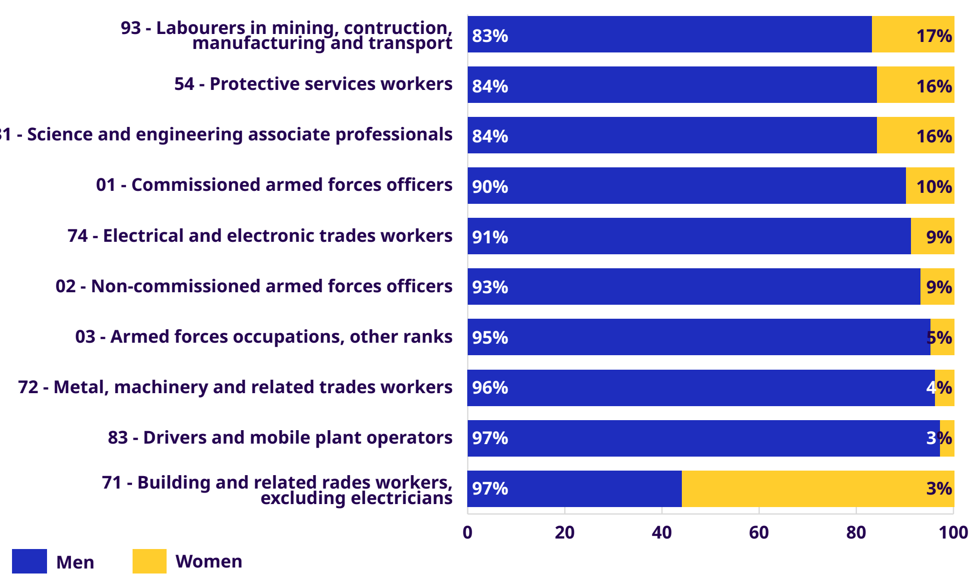
Working towards gender equality in the world of work is integral to the mission of the ILO, which adopted its Resolution on Equal Opportunities and Equal Treatment for Men and Women in Employment in 1985 (ILO 1985). Gender equality in the world of work refers to, amongst other criteria, equal access to safe and healthy working environments (ILO 1985).

▶ Figure 3a. Sectors with prevalent female workforce (based on data for 121 countries, representing 63% of global employment. (Data for China and India are not available)



Source: ILOSTAT 2020

▶ Figure 3b. Sectors with prevalent male workforce



Source: ILOSTAT 2020

Gender and biological sex are important aspects to consider in relation to occupational exposure to chemicals. Gender should be understood as the socially constructed differences between males and females, dependent on context and within societies and cultures (ILO 2007). Biological sex on the other hand refers to the biological differences between men and women, including differences in gonads and reproductive organs, hormonal cycles, fat distribution and immune response (IPEN 2020).[1]

Biological sex can lead to important differences in exposure and health effects when it comes to chemicals. For example, **the susceptibility of women to hazardous chemicals can vary based on their reproductive cycles and at different life stages such as pregnancy, lactation, and menopause, when their bodies undergo physiological changes that may affect their vulnerability to health damage from chemicals.** This is especially pronounced in pregnant women, for whom even low doses of chemicals might elicit dramatic effects in the developing foetus. This is particularly relevant for endocrine-disrupting chemicals (EDCs) that are able to induce hormonal effects at extremely low dosages, affecting fertility, fecundity and development (Vandenberg et al. 2012; Di Renzo et al. 2015). Also, as females are more likely to have more adipose tissue, this can lead to bioaccumulation of chemicals such as persistent organic pollutants (POPs) and heavy metals like mercury. These exposures can cause consequences to reproductive health, such as spontaneous abortion, birth defects and neurobehavioral consequences. A range of chemicals, including dichlorodiphenyltrichloroethane (DDT) and phtalates, have also been shown to impact male fertility and development, including development of the reproductive organs (Gore et al. 2014).

In addition, gender-related differences in the occupational roles of men and women can influence level, frequency and source of exposure to chemicals. Overall, men tend to be more exposed to hazards caused by substances that are carcinogenic or may cause circulatory and respiratory disease (ILO 2010). In a recent study on 166,617 exposure measurements selected for 40 different carcinogens, exposed workers were 91 per cent men and 9 per cent women (Scarselli et al. 2018). In some sectors, male workers constitute the majority of the workforce and are more exposed to chemical hazards, as for example in construction, mining, agriculture and metal production (ILO 2010). However, **chemical exposures in female workers are dramatically increasing and are often underestimated, particularly in informal sectors and in Low and Middle Income Countries (LMICs)** (Hohenadel et al. 2015; IPEN 2020). Furthermore, in different sectors female workers constitute the majority of the workforce and are more exposed to chemical hazards, for example in health professions, textile production and in the cleaning sector (**Figure 3**). In the garment sector, female workers are disproportionately exposed to a number of hazardous dyes and solvents, some of which are proven carcinogens, as well as endocrine disrupting chemicals. In addition, work tools and personal protective equipment (PPE) has been traditionally designed for the Western male body and therefore may fit female workers poorly, leading to reduced protection and increased risk of chemical exposure.

The COVID-19 pandemic and its effect on workers' chemical exposures

The COVID-19 pandemic severely disrupted the chemical sector worldwide and increased the risk of different hazardous chemical exposures. Indeed, the overall burden of chemical exposure in workers did decline amid the COVID pandemic, particularly in highly industrialised areas. This effect was clearly demonstrated by the ubiquitous reduction in air pollution amid the COVID-19 epidemic in areas where lockdown measures were adopted and where a severe decline of chemical production was observed (Bauwens et al. 2020).

However, in all workplaces, especially in key essential services, such as health care, transportation, grocery stores, emergency personnel and other sectors of the workforce, workers may find themselves frequently working in the presence of chemicals and disinfectants (ILO 2020b). Due

1 The terms "gender" and "biological sex" are not interchangeable; gender identity may or may not correspond with the biological sex assigned. Gender identity exists on a spectrum and is not necessarily confined to an identity that is completely male or completely female (WHO 2016b).

to a likely global increase in demand for many of these disinfectants, people working in the chemical industry may also work with increasing volumes of these compounds (ILO 2020b). Some of the chemicals frequently used to disinfect against COVID-19 include quaternary ammonium, hydrogen peroxide, peroxyacetic acid, isopropanol, ethanol, sodium hypochlorite, octanoic acid, phenolic, triethylene glycol, L-lactic acid, glycolic acid, or dischloroisocynurate dehydrate (Fair, 2020). Quaternary ammonium and sodium hypochlorite, in particular, carry an increased risk of COPD (Dumas et al. 2019), may impact fertility (Melin et al. 2014) and can exacerbate asthma symptoms (Fair 2020).

Both shut down and start-up of industries require special attention to prevent the occurrence of chemical accidents. Two recent accident cases, that occurred when restarting a plant after shutdown due to the COVID-19 pandemic, exemplify these risks: in a polymer plant in India a leak of hazardous gas led to the death of at least 11 people and injuries to hundreds more; an explosion at a plastics factory in Italy killed one person and injured two others (EC-JRC 2020). The COVID-19 pandemic has also led to an increase in the production of disinfectants, chemicals and PPE. The rapid scale up of these productions may pose risks for industrial accidents and challenges for OSH.

Methodology

A scoping review was conducted to frame the most recent trends and priorities for chemical exposure and health effects for workers. Scoping reviews are useful for identifying and mapping available data and scientific literature and are particularly relevant for assessing emerging evidence. We searched the following databases (2010-present day): PubMed, Scopus and Web of Science. Additionally, we searched for relevant data and reports from the following agencies repositories (2010-present day): ILO, WHO, IARC, IPCS, UNEP, NIOSH, OSHA, EPA, ECHA and European Commission.

Reviews, reports and data published after 2010 in English served as key references. Based on the available evidence, the report identified priorities for chemical exposures. Due to the number of existing occupational chemicals, specific exposures were considered in this review if they were well-known or it was assumed that at least 1 million workers worldwide are currently exposed to the substance. Burden of disease and figures related to mortality were also considered. Occupational cancer data were prioritised, as cancer represents one of the primary causes of work-related deaths globally. Data on other significant health impacts associated with occupational chemical exposure, including pneumoconiosis, neurotoxic effects and endocrine disruption, were also included. **As this was a scoping review, it was not possible to include all occupational chemical exposures and all possible health impacts.**

Based on the priorities that emerged in the review, a number of actions were identified that can help promote safer chemicals management within the world of work. Actions were selected for both national and workplace levels, with research gaps and social dialogue also considered. The identified actions are proposed as a working foundation to stimulate future discussions and are not meant to be exhaustive.

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Summary of Findings

SUBSTANCE	PRIMARY HEALTH IMPACTS+	GLOBAL BURDEN OF OCCUPATIONAL EXPOSURE*	WORK-RELATED HEALTH IMPACT*	SELECTED PRIORITY ACTIONS AND PROGRESS
Asbestos	Cancer (mesothelioma, cancer of the lung, larynx, ovary) Asbestosis and pleural disease	>125,000,000 (WHO 2018)#	>233,000 deaths annually (GBD 2019)	Phase out of asbestos has proven effective and has already been implemented in over 50 countries. Continued use and exports to LMICs continues to pose a threat to workers. Effective and safe substitutes are needed.
Silica	Cancer (lung) Silicosis	>50,000,000 (Limited data covering 35 countries) (OSHA 2002; IOM 2011) #	>65,000 deaths annually (GBD 2019)	Sandblasting bans, regulation and OELs have proven effective and have been successfully implemented, in particular in high-income countries. Continued efforts are needed in selected sectors (textiles, masonry) as well as in LMICs.
Heavy metal: Lead	Cancer (stomach) Neurotoxicity Cardiovascular disease	>1,800,000 (UE-OSHA 2014; CAREX-Canada 2020)	Limited data (>900,000 due to environmental lead exposure (GBD 2019))	Phasing out lead from gasoline, paint and batteries has proven effective in reducing human exposure in selected regions. Further global efforts are needed, particularly in LMICs. Updated and harmonised OELs are needed.
Heavy metal: Mercury	Neurotoxicity Nephrotoxicity Immune toxicity Reproductive toxicity	>19,000,000 (Limited data for artisanal small-scale gold mining only) (Steckling et al. 2017)	Limited Data (>2,000,000 DALYs attributable to chronic metallic mercury vapour intoxication) (Steckling et al. 2017)	Stronger workplace prevention efforts are needed, as well as phase out across various economic sectors. The Minamata Convention has been implemented in over 120 countries. Nevertheless targeted strategies are needed at both the national and workplace level to protect workers' health, particularly in LMICs and in the informal economy.
Solvents	Cancer Neurotoxic effects including 'chronic solvent-induced encephalopathy' (CSE) Reproductive toxicity	Limited data	Limited data	The phasing out and ban of the most hazardous solvents has proven effective in selected countries and regions; however national laws and workplace regulations are still needed in the majority of workplace settings. Increased efforts are needed in LMICs and the informal economy.
Dyes	Cancer (bladder)	Limited data	Limited Data	The phasing out and ban of the most toxic azo dyes has been effective and successfully implemented, in particular in high-income countries. Evidence-based and harmonised OELs must be developed for all dyes.

Manufactured Nanomaterials (MNMs)	Limited data Suggestion of cancers (mesothelioma and lung cancer)	Limited data	Limited data	National regulations based on evidence from risk assessments should be developed for MNMs. Different OELs have been implemented, but evidence of the effectiveness of these OELs is still limited and harmonised OELs are missing.
Perfluorinated chemicals (PFAS)	Cancer (testicular, liver and kidney) Immune toxicity Liver toxicity Reproductive toxicity	Limited Data	Limited Data	PFOS and PFOA have been phased out in different countries, however, these substances can bioaccumulate and remain in tissue long after they are removed from use. There are currently thousands of PFAS still in use and the effectiveness of OELs and other protective measures to prevent risk in workers are still unclear.
Endocrine Disrupting Chemicals (EDCs)	Reproductive toxicity Obesity Diabetes Neurotoxicity Cancers (breast, prostate)	Limited Data	Limited Data (what we know: >20 million IQ points loss, >800,000 cases of male infertility in the US and Europe due to environmental exposure at normal levels) (Trasande et al. 2016; Attina et al. 2016)	The phasing out and ban of the most toxic EDCs has been successfully implemented, in particular in high-income countries. Increased efforts are needed to identify EDC exposure and to implement control strategies in LMICs. Gender considerations should be mainstreamed in OSH regulations.
Pesticides	Poisoning Cancer (various) Neurotoxicity Endocrine disruption Reproductive toxicity	Limited Data (although presumably a significant number of global agricultural workers may be exposed - approximately 883 million agricultural workers (ILO, 2019; Carvalho 2017)	Limited Data (>300,000 deaths annually due to unintentional acute pesticide poisoning alone) (Boedecker 2020)	The phasing out and ban of the most toxic HHPs has been successfully implemented, in particular in high-income countries. Increased action is needed for LMICs, particularly for regulation and practical workplace prevention efforts. OELs for HHPs should be implemented and enforced globally.
Workplace Air Pollution	Cancers (lung) Respiratory disease Cardiovascular disease	>1.2 billion (WHO 2018c)	>860,000 deaths annually (WHO 2018c)	Targeted pollution control strategies been successfully implemented, in particular in high-income countries. More efforts are needed to design and implement workplace prevention measures, with a focus on LMICs.

[+] *Indicated as main health impacts only; a number of additional health impacts may also be related to exposure to this substance.*

[*] *Figures presented should be interpreted as low-end estimates, thus indicated with a ">", given the lack of comprehensive reporting and data available, particularly from LMICs and informal sectors.*

[#] *Based on estimates from 2018. A new WHO/ILO joint estimate is under development*

Chemical exposures

Asbestos

- Asbestos describes a group of naturally occurring minerals that includes chrysotile, crocidolite, amosite, anthophyllite, tremolite and actinolite. Although chrysotile is the most commonly known form, all types of asbestos are occupational carcinogens.
- Occupational exposure to asbestos occurs through inhalation of fibres from air contaminated with asbestos, for example, during the handling of asbestos and asbestos-containing materials.
- Occupational exposure to asbestos causes an estimated 233,000 deaths each year worldwide and about 125 million people in the world are estimated to be exposed to asbestos at the workplace (Furuya et al. 2018, WHO 2018).
- Major producers of asbestos continue to export asbestos to countries around the world, especially to LMICs where use has increased, while use in other countries has decreased due to regulation.
- Since asbestos is predominately used in occupations with manual labor, such as construction, occupational exposure to asbestos predominately occurs in men, with the exception of the asbestos textile industry. Women run a higher risk of secondary exposure or exposure through contaminated consumer products.

Exposure

Occupational exposure through inhalation, and to a lesser extent ingestion, occurs in the mining and milling of asbestos (or other minerals contaminated with asbestos), the manufacturing or use of products containing asbestos, construction, automotive industry, and the asbestos-abatement industry (including the transport and disposal of asbestos-containing waste). At present, more than 50 countries have banned asbestos. Unfortunately, as the developed world was phasing out or restricting the use of asbestos, LMICs were greatly increasing use of this toxic material. The current world total production is still estimated to be 1,100,000 metric tons (Bernhardt and Reilly 2019). Peak world production was estimated to be 5,090,000 metric tons in 1975, with approximately 25 countries producing asbestos and 85 countries manufacturing asbestos products (Nishikawa et al. 2008).

Currently about 125 million people in the world are exposed to asbestos at the workplace (WHO 2018). The United States Occupational Safety and Health administration (OSHA) estimated in 2008 that 1.3 million employees in construction and general industry faced significant asbestos exposure on the job in the United States of America (OSHA, 2008). In Europe, estimates of the number of workers exposed to asbestos have been developed by the CAREX study. Based on occupational exposure to known and suspected carcinogens collected during 1990–93, the CAREX database estimates that a total of 1.2 million workers were exposed to asbestos in 41 industries in the 15 Member States of the EU (EU-OSHA 2014). CAREX Canada estimates that 152,000 Canadians are exposed to asbestos in their workplaces (CAREX-Canada 2020).

Health effects

Cancer

Asbestos is classified by the International Agency for Research on Cancer (IARC) as carcinogenic to humans (group 1), i.e. that there is sufficient evidence in humans for the carcinogenicity of all forms of asbestos. Asbestos causes mesothelioma and cancer of the lung, larynx, and ovaries. There are also observed associations between exposure to all forms of asbestos and cancer of the pharynx, stomach, and colorectum (IARC 2012). An increased risk of colorectal cancer had also been confirmed. A recent case-control study of over 5,000 cases of cholangiocarcinoma, or bile duct cancer, in Finland, Iceland, Norway and Sweden, showed a positive association between occupational exposure to asbestos and the risk of intrahepatic cholangiocarcinoma (Farioli et al. 2018).

Occupational exposure to asbestos causes an estimated 233,000 deaths each year worldwide due to a number of diseases: mesothelioma, lung cancer, larynx and ovary cancers, and asbestosis (Furuya et al. 2018). This estimate is much higher than the previous estimates by WHO of 105,000 deaths per year, that were based on a more limited number of diseases (lung cancer, mesothelioma and asbestosis) (Prüss-Ustün et al. 2011); (WHO 2014b); (Abubakar et al. 2015). However even the

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Occupational exposure to asbestos causes an estimated
233,000
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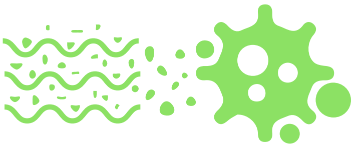
asbestos
at the workplace

most recent estimates might still be an underestimate, since they do not account for other forms of cancers that have been positively associated with asbestos (cancer of the pharynx, stomach, and colorectum) (IARC 2012). Furthermore, because asbestos is more likely to cause lung cancer than mesothelioma, the estimated total burden of asbestos related lung cancer might still be an underestimate. The WHO estimates a risk ratio of 6:1 for contracting lung cancer versus mesothelioma following chrysotile exposure (WHO 2014b).

Asbestosis and pleural disease

Asbestosis is a type of pneumoconiosis caused by the inhalation of asbestos fibres and occurs primarily as a result of occupational exposure. The WHO estimated that the number of deaths per year from asbestosis was 7,000 to 24,000 (Abubakar et al. 2015). The WHO/ILO are currently performing a series of systematic reviews that will inform the new estimates of the Global Burden of Disease (GBD) regarding asbestosis. Asbestos exposure can also cause pleural disease, a non-cancerous lung condition that causes changes in the membrane known as the pleura, that surrounds the lungs and chest cavity.

Even the most recent estimates might still be an underestimate, since they do not account



for other forms of cancers that have been positively associated with asbestos
(cancer of the pharynx, stomach, and colorectum)

Regional trends

In 2018, the major producers of asbestos were Russia (650,000 metric tons), Kazakhstan (220,000 metric tons), China (100,000 metric tons), and Brazil (100,000 metric tons) (Bernhardt and Reilly 2019). It has been estimated that half of the asbestos produced is used by China and India, followed by Brazil, Indonesia and Russia (Marsili et al. 2016).

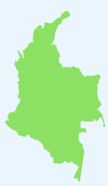
Major producers continue to produce and export asbestos to countries around the world, especially to LMICs. Over 2,030,000 tons of asbestos are consumed annually according to the latest available consumption data (Furuya et al. 2018). Considerable use of asbestos has continued in much of Asia, Africa, and in some countries in Latin America. China and India have been major consumers of asbestos. India produces little to no asbestos, however has become a major importer with exponential growth in the manufacture of asbestos cement and pipes (Frank 2014). The few epidemiological studies available show clear evidence of clusters of mesothelioma in municipalities with a history of asbestos consumption and a forecasted rise in its incidence in Argentina and Brazil for the next decade (Algranti et al. 2019).

The role of gender

There is a strong gender dimension in the exposure to asbestos. Occupations that are high risk for asbestos exposure generally involve physical labor such as construction, mining and demolition and are predominately held by men. The one notable exception is the textile industry, which has a large proportion of female workers, where asbestos is often used, for example, for protective clothing. A study from Southeast China looked at mesothelioma cases in workers in asbestos textile workshops, who also could perform hand-spinning at home in their spare time (Gao et al. 2015). Out of the 28 workers with a confirmed mesothelioma diagnosis, all were females.

Because of occupational gender differences, women have a higher risk of exposure from domestic products such as talc contaminated with asbestos, or secondary exposure to asbestos, for example from family members working with asbestos carrying residues home with them (Gordon et al. 2014).

▶ Case study: Multi-dimensional effects of an asbestos-cement factory in Sibaté, Colombia



The asbestos industry began operations in Colombia in 1942, with an asbestos-cement facility located in the municipality of Sibaté. In recent years, residents have been complaining about an unusually large number of people diagnosed with asbestos-related diseases. A study to analyse the situation of Sibaté started in 2015, to verify if the number of asbestos related diseases being diagnosed was higher than expected, and to identify potential asbestos exposure sources in the town. Using geographic information systems, landfilled zones in the urban area of Sibaté were identified, on top of which a school and different sports facilities were built. The analysis of four soil samples collected in landfilled zones, confirmed the existence of an underground layer of friable and non-friable asbestos. Not surprisingly, the estimated age-adjusted incidence rate of mesothelioma in Sibaté was higher those reported in other cities, regions and countries of the world (Ramos-Bonilla et al. 2019).

Major producers continue to produce and export asbestos

to countries around the world, especially to LMICs

MAIN SECTORS OF EXPOSURE	PRIMARY HEALTH IMPACTS	GLOBAL BURDEN OF OCCUPATIONAL EXPOSURES	WORK-RELATED HEALTH IMPACT
Mining Construction Agriculture; plantations; other rural sectors Automotive industry Protective textiles	Cancer (mesothelioma, cancer of the lung, larynx, ovary) Asbestosis and pleural disease	>125,000,000 (WHO 2018)*	>233,000 deaths annually (GBD 2019)

**Based on estimates from 2018. A new WHO/ILO joint estimate is under development*

▶ Selected Priority Actions: Asbestos

Examples of national policy measures

Ratify and implement the **ILO Asbestos Convention, 1986 (No. 162)**. This includes measures to be taken for the prevention and control of, and protection of workers against, health hazards due to occupational exposure to asbestos. Key provisions:

- Replace asbestos or products containing asbestos with materials evaluated as less harmful.
- Prohibit (totally or partially) the use of asbestos or products containing asbestos in certain work processes.
- Implement measures to prevent or control the release of asbestos dust into the air and ensure that exposure limits or criteria are complied with.
- Reduce exposure to as low a level as is reasonably possible.

Additional actions for policy makers

- Include measures in national OSH programmes to protect workers from exposure to asbestos.
- Eliminate the future use of asbestos.
- Develop national programmes for elimination of asbestos-related diseases.
- Establish regulatory controls and guidance on measures to prevent exposure to asbestos in place and during asbestos removal (abatement).
- Establish worker registries with past and/or current exposures to asbestos, organise medical surveillance of exposed workers and improve early diagnosis, treatment, and rehabilitation services for asbestos-related diseases.
- Promote prevention through safety by design to minimise occupational hazards for the future.

Occupational Exposure Limits (OELs)

- Update, implement and enforce OELs for various forms of asbestos and ensure global harmonisation of these OELs.
- Established OELs include: The European Union's single maximum limit value for airborne concentrations of asbestos is 0.1 fibers/cm3, as an 8-hour TWA (Currently under review by the European Chemicals Agency (ECHA)).

Examples of practical workplace interventions

- Replace chrysotile asbestos with safer substitutes and prevent potential exposure to any other type of asbestos already in place.
- Promote the elimination of the use of chrysotile asbestos among contractors and suppliers.
- Monitor the work environment for contamination with various forms of asbestos.
- Ensure compliance with exposure limits and technical standards for working with asbestos.
- Establish engineering measures for control of the exposure to asbestos at source.
- Provide special training for workers involved in activities with potential exposure to asbestos.
- Provide appropriate PPE, free of charge.
- Ensure registration and medical surveillance of workers exposed to asbestos.
- Promote the identification and proper management of all forms of asbestos currently in place.

Sources include: ILO 2007b, WHO 2014a

Silica

- Silica, or silicon dioxide (SiO2), is a natural compound of silicon and oxygen found mostly in sand. The most abundant form of silica is α-quartz, and the term quartz is often used in place of the general term crystalline silica (c-silica) (Uhrlandt 2006).
- Inhalation leads to a range of lung-related diseases and IARC has concluded that there is sufficient evidence that c-silica causes cancer of the lung. Exposure also can cause silicosis, a long-term progressive lung disease, caused by the deposition of fine particulate silica dust.
- It has been estimated that over 65,000 deaths occurred worldwide in 2019 due to occupational silica exposure and prevention of exposure to silica is the most effective way to limit silica-associated morbidity and mortality (GBD 2019).
- WHO and ILO have recommended life-long health surveillance for workers exposed to respirable silica.
- While gender disaggregated data is mostly lacking, it is likely that silica exposure is most extensive in occupations involving manual labour, that typically are predominately male.

Exposure

Occupational exposure to respirable c-silica most frequently occurs at a wide range of processing and construction sites, such as metal, nonmetal, and coal mines and mills; granite quarrying and processing sites; hydraulic fracturing operations; crushed-stone industries; foundries; ceramics; and sandblasting operations (NTP 2016). Silica can also contaminate other ore or materials being mined, or a mining environment, thus inadvertently exposing workers. For example, substantial exposure to respirable c-silica occurs amongst coal miners in the central Appalachian coal mines in the United States, where thin seams of coal lie sandwiched between silica-rich sandstone.

The major component of sand and gravel is c-silica. The quartz/c-silica content of crushed stone varies from region to region. Heavy industry uses quartz sand to produce high-temperature or refractory silica brick, foundry moulds, and cores for the production of metal castings (IARC 2012). The oil and gas industry uses a water-sand mixture to fracture rock and silica sand to prop open fractures, which promotes hydrocarbon flow and extraction. C-silica is used as an asphalt filler and in bricks, mortar, plaster, caulk, roofing granules, wallboard, concrete, engineered/artificial stone and dimension stone in building materials (IARC 2012).

It has been estimated that approximately 2.3 million workers in the United States (OSHA 2020), 3-5 million workers in Europe (Matteis et al. 2017), 0.5 million workers in Japan, more than 23 million workers in China, 11 million workers in India, and over 6 million workers in South America (Brazil, Columbia, Chile, Peru) are occupationally exposed to silica.

Health effects

Cancers

Crystalline silica (c-silica) is classified by IARC as carcinogenic to humans (Group 1). According to IARC there is sufficient evidence that c-silica causes cancer of the lung (IARC 2012). Effects of inhaled c-silica are strictly associated with occupational exposure to particles that are of respirable size (<10 µm) (ATSDR 2019). Recent results of cohort studies and meta-analyses confirmed that exposure to c-silica is associated with lung cancer, even in the absence of silicosis (Liu et al. 2013; Poinen-Rughooputh et al. 2016). The risk of lung cancer increased also for long-term exposure below 100 $\mu g/m^3$ (Liu et al. 2017). In fact, recent estimates on pooled data from 10 cohorts with over 66,000 workers showed that a limit as low as 10 $\mu g/m^3$ would significantly prevent the number of deaths associated to lung cancer and other diseases caused by silica exposure (Keil et al. 2018). High levels of exposure to c-silica have been also associated to an increased risk of larynx cancer (Hall et al. 2019).

Silicosis

Silicosis is a type of pneumoconiosis, or pulmonary fibrosis, caused by inhalation and pulmonary deposition of respirable dust containing c-silica, primarily as a result of occupational exposure. It is a permanent disease with no treatment or cure and can become worse even after exposure to respirable dust ceases (Dumavibhat et al. 2013;

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It has been estimated that over

65,000 deaths

occurred worldwide in 2019

due to occupational silica **exposure**

Prevention of exposure to silica is the **most effective way to limit silica-associated morbidity and mortality**

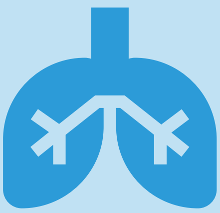
(GBD 2019)

Silicosis

a type of pneumoconiosis

is an incurable disease

with no available treatment



Hnizdo & Sluis-Cremer, 1993). The Global Burden of Disease Study (GBD 2019) estimated that all-cause mortality from occupational silica exposure resulted in 65,870 global deaths in 2019. Of this total, 12,886 deaths were specifically due to silicosis. Other significant causes of death included tracheal, bronchial and lung cancer. The WHO/ILO are currently performing systematic reviews that will inform new estimates of the GBD of silicosis. Silicosis, a type of pneumoconiosis, is an incurable disease with no available treatment.

Regional trends

Workers in LMICs are the most exposed to silica. However exposed workers within all countries are more likely to be migrant or racial/ethnic minorities. In 2016, an estimated 179,000,000 metric tons of silica in the form of industrial sand and gravel were produced throughout the world (USGS 2016). The top producers included The United States (77,700,000 metric tons), Italy (13,900,000 metric tons), France (8,700,000 metric tons), Turkey (8,000,000 metric tons), and Germany (7,500,000 metric tons) (USGS 2016).

The role of gender

Many of the occupations that have high silica exposure include heavy manual labour, which typically means that the majority of workers are male. For example, a study from Italy concluded that men were more likely to suffer from occupational silica exposure than women (Scarselli 2018). However, monitoring and health data that make gender clearly distinguishable is lacking on a global scale and the women working in these sectors should not be overlooked, as gender may influence severity of pulmonary diseases (Brass et al. 2010).

▶ Case study: Artificial stone workers in Australia

Occupational lung disease after inhalation of respirable silica is variable and potentially life-threatening. As the artificial stone industry has grown over the last two decades, clinicians have described unique manifestations of silicosis with signs and symptoms different from classic chronic silicosis. For example, a number of masons working with artificial stone have been forced to undergo lung transplantation due to silicosis. These patients have both fibrotic/nodular silicosis and conspicuous alveolar proteinosis within the same lung parenchyma. Radiological and histopathological correlates of disease has been shown clearly in the literature (Levin et al. 2019).

MAIN SECTORS OF EXPOSURE	PRIMARY HEALTH IMPACTS	GLOBAL BURDEN OF OCCUPATIONAL EXPOSURES	WORK-RELATED HEALTH IMPACT
Mining **Construction** **Agriculture; plantations; other rural sectors** **Oil and gas** **Manufacturing** (manufacturing of non-metallic/ mineral products (e.g. pottery, ceramics, bricks) and stone cutting, shaping and finishing) **Niche industries using abrasive sandblasting** (e.g. textiles/garments, restoration)	Cancer (cancer of the lung); Silicosis	>50,000,000 (Limited data covering 35 countries) (OSHA 2002; IOM 2011)*	>65,000 deaths annually (GBD 2019)

**Based on estimates from 2018. A new WHO/ILO joint estimate is under development*

▶ Selected Priority Actions: Silica

Examples of national policy measures

- Phase out the practice of sandblasting. Sandblasting has been banned in several countries (mostly high-income) for decades. Many LMICs have yet to ban sandblasting and enforcement of the ban has proven to be challenging, especially in informal settings.

Additional actions for policy makers

- Reinforce regulations and promote workplace inspections to ensure effective implementation of the sandblasting ban and other measures to reduce workers' exposures to silica.

Occupational Exposure Limits (OELs)

- Update, implement and enforce OELs for silica and ensure global harmonisation of these OELs.
- Established OELs vary depending on the country and sector. The table below includes a sample of established OELs.

Examples of practical workplace interventions

- Apply the Hierarchy of Controls, following national recommendations as relevant. Primary prevention through physically removing the hazard or substitution through replacing the hazard with a less hazardous option is the most effective way to limit silica-associated morbidity and mortality. For example, when conducting abrasive blasting, substituting the silica-containing abrasive with steel grit or steel shot is a substitution that eliminates exposure to silica.
- Carry out regular workplace sampling for respirable dust using best practice methods.
- Implement engineering controls to remove respirable c-silica from the environment such as ensuring drilling, mining, and tunneling equipment are using water suppression systems to improve dust capture at the source. Water spraying systems can also be used to capture dust at the impact site when cutting and finishing manufactured stone countertops containing c-silica Using a tiered approach and applying multiple engineering controls to limit respirable dust at the source, through the transmission path, and at the level of the worker can ensure that the chain of exposure is interrupted.
- Use administrative controls and PPE as a last resort. They are the least effective control methods and require increased costs, as well as a great deal of effort from the worker to ensure adequate and sustained protection.
- Perform periodic screening and health surveillance of workers exposed to respirable c-silica. WHO and ILO have recommended life-long health surveillance for workers exposed to respirable c-silica, including:
  1. Chest radiography at baseline, after 2–3 years of exposure, and every following 2–5 years. This should be systematically interpreted according to the 2011 ILO Guidelines for the use of the ILO International Classification of Radiographs of Pneumoconioses.
  2. Annual pulmonary function testing (spirometry) with respiratory symptom assessment.
  3. Conduct tuberculosis testing as needed based on local rates. This will enable identification of sentinel cases of disease and allow early interventions to prevent progression.

Sources include: NIOSH 2002 and 2015, NIOSH & OSHA 2015, Colinet et al. 2010, Organiscak et al. 2009, ILO &WHO 2006, ILO & WHO 2007, ILO 2011, Wagner 1996

▶ Example of the range of Respirable Silica OELs from various countries and organizations (Aug 2020)

Country/Organization	Occupational Exposure Limit
American Conference of Governmental Industrial Hygienists (ACGIH)[1]	0.025 mg/m^3
Australia (SafeWork)[2]	0.05 mg/m^3
Canada[3]*	0.025 mg/m^3
European Commission Scientific Committee on Occupational Exposure Limits (SCOEL)[4]	0.05 mg/m^3
South Africa[5]	0.1 mg/m^3
U.S. Non-regulatory (NIOSH)[6]	0.05 mg/m^3
U.S. Regulatory (OSHA: General Industry/Maritime)[7]	0.05 mg/m^3
U.S. Regulatory (MSHA: Mining)[8]	0.1 mg/m^3

**Most, but not all, Canadian Jurisdictions follow ACGIH TLV OEL of 0.025 mg/m3*
1- ACGIH TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. 2012; Cincinnati, Ohio.
2-https://www.safeworkaustralia.gov.au/doc/workplace-exposure-standards-airborne-contaminants
3-https://laws.justice.gc.ca/eng/regulations/SOR-86-304/index.html; https://www.ccohs.ca/oshanswers/chemicals/chem_profiles/quartz_silica.html
4- SCOEL 2003. Recommendation from the Scientific Committee on Occupational Exposure Limits for Silica, Crystalline (respirable dust) SUM 94. http://ec.europa.eu/social/BlobServlet?docId=3858&langId=en Accessed August 4, 2020.
5- South Africa Department of Labour (2004) National Programme for the Elimination of Silicosis. https://www.ilo.org/wcmsp5/groups/public/---ed_protect/---protrav/---safework/documents/policy/wcms_118112.pdf Accessed August 4, 2020.
6- NIOSH (1974). Criteria for a recommended standard: occupational exposure to crystalline silica. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health, HEW Publication No. (NIOSH) 75-120, pp.54-55, 60-61.
7-https://www.federalregister.gov/documents/2016/03/25/2016-04800/occupational-exposure-to-respirable-crystalline-silica
8-30 CFR 70.101, 71.101, and 90.101 https://www.msha.gov/regulations/standards-regulations

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Heavy metals

- Heavy metals are metals with a high density that in many cases are hazardous, such as arsenic, cadmium, lead, mercury and hexavalent chromium.
- Occupational exposure to heavy metals and their compounds occurs in a wide range of sectors such as construction, mining, electronics and the textiles industry.
- Arsenic, cadmium and hexavalent chromium are classified as carcinogenic to humans whereas lead is classified as probably carcinogenic to humans, in addition to other health impacts associated with exposure to heavy metals. WHO has identified arsenic, cadmium, lead and mercury as four of the top ten chemicals of major public health concern.
- Occupational limits and restrictions of these substances are in place in several countries, although there is still lack of international harmonisation.
- Some heavy metals, such as lead and mercury, can impact pregnancy outcomes and cause developmental impacts in children, which makes protecting women from occupational exposure of utmost importance.

Exposure

Arsenic is mostly used in industrial processes to produce antifungal wood preservatives, which can lead to soil contamination, in particular chromated copper arsenate (CCA). The production and use of CCA has been prohibited in the certain countries, however the presence of wood treated with CCA is still ubiquitous (Chen and Olsen 2016). Arsenic is also used in the pharmaceutical and glass industries, in the manufacture of alloys, sheep dips, leather preservatives, arsenic-containing pigments, antifouling paints and poison baits and, to a diminishing extent, in the production of agrochemicals (especially for use in orchards and vineyards). Arsenic compounds are also employed in smaller amounts in the microelectronics and optical industries. In 2019, the world production of arsenic trioxide from mining was 33,000 metric tons, with China (24,000 metric tons) and Morocco (6,000 metric tons) being the leading global producers, accounting for about 90 per cent of estimated world production (USGS 2020). Inorganic arsenic is naturally present at high levels in the groundwater of a number of

Globally
14-19 million workers
are employed as **artisanal small-scale gold miners**
▶ **25%** and **33%** of these **miners**
suffer from **chronic metallic mercury vapour intoxication**

LMICs
carry the
largest burden of
exposure for
all heavy metals

countries, including Argentina, Bangladesh, Chile, China, India, Mexico, and the United States (WHO 2019a). There is no global estimate of occupational exposure to arsenic. NIOSH estimates that 70,000 workers, including approximately 16,000 female workers, were potentially exposed to arsenic and arsenic compounds in the workplace from 1981 to 1983 (NIOSH 1990). The CAREX database estimates that 147,569 workers were exposed to arsenic and arsenic compounds in the EU between 1990– 1993 (EU-OSHA 2014). CAREX Canada estimates that 25,000 Canadians are currently exposed to arsenic in their workplaces (CAREX-Canada 2020).

The highest potential occupational exposures to **cadmium** occur in production and refining of cadmium, nickel-cadmium battery manufacture, cadmium pigment manufacture and formulation, cadmium alloy production, mechanical plating, zinc smelting, brazing with silver-cadmium-silver alloy solder and polyvinylchloride compounding. In 2019, the world production of cadmium from refineries was 25,000 metric tons and the leading global producers were China (8,200 metric tons), the Republic of Korea (5,000 metric tons), and Japan (1,900 metric tons) (USGS 2020). The main anthropogenic sources of cadmium in the atmosphere are smelting of non-ferrous metal ores, fossil fuel combustion, ferrous metal production, municipal waste incineration and cement production (WHO 2019b). There is no global estimate of occupational exposure to cadmium. The CAREX database estimates that between 1990-93, 207,350 workers were exposed to cadmium and cadmium compounds in the EU (EU-OSHA 2014). CAREX Canada estimates that 35,000 Canadians are exposed to cadmium in their workplaces (CAREX-Canada 2020).

Hexavalent chromium compounds are used widely in applications including: pigment for textile dyes, paints, inks, and plastics; corrosion inhibitors; wood preservatives; metal finishing and chrome plating; and leather tanning. In 2019 the world production of chromium from mining was 44,000,000 metric tons and the leading global producers were South Africa (17,000,000 metric tons), Turkey (10,000,000 metric tons), and Kazakhstan (6,700,000 metric tons) (USGS 2020). Exposure to chromium occurs in: production, use and welding of chromium-containing metals and alloys; electroplating; production and use of chromium-containing compounds, such as pigments, paints, catalysts, chromic acid, tanning agents, and pesticides (IARC 2012). The CAREX database estimates that between 1990-93, 785,692 workers were exposed to hexavalent chromium compounds in the EU (EU-OSHA 2014). CAREX Canada (2011) estimates that 83,000 Canadians are occupationally exposed to hexavalent chromium compounds (CAREX-Canada 2020).

Lead is used mainly in the production of lead-acid batteries, plumbing materials and alloys, as well as in cable sheathing, paints, glazes and ammunition (WHO 2017a). Lead is also still used in some countries as a stabiliser in polyvinyl chloride (PVC) (ECHA 2016) and lead chromates as pigments in yellow plastics (Stenmarck et al. 2017). In 2019, the world production of lead from mining was 4,500,000 metric tons and the leading global producer was China (2,100,000 metric tons) (USGS 2020). The manufacture of these lead-containing products can result in widespread occupational exposure. Occupational exposure can also occur during the application and removal of lead-containing paints; during the grinding, welding and cutting of materials coated with lead-containing paints such as in shipbuilding, construction and demolition industries; when recycling PVC and other plastics (Stenmarck et al. 2017); and in the fabrication and carving of lead crystal glassware (WHO 2019c). Mining, smelting, and formal and informal processing and recycling of electric and electronic waste can also be significant sources of exposure. Lead was used widely in the form of tetraethyl and tetramethyl lead as antiknock and lubricating agents in petrol, emitting inorganic lead particles from vehicles. This use has been phased out in almost all countries, which has resulted in a significant reduction of human exposure and mean blood lead concentrations (UNEP 2020b). The CAREX database estimates that between 1990-93, 1,500,000 workers were exposed to lead and inorganic lead compounds in the EU (EU-OSHA 2014). CAREX Canada estimates that 277,000 Canadians are presently occupationally exposed to lead (CAREX-Canada 2020).

Occupational exposure to **mercury** occurs in mining, e.g. in mercury mining, gold mining where mercury is used in amalgamation, and mining of other metals such as copper, zinc and silver. In 2019, the world production of mercury from mining was 4,000 metric tons and the leading global producer was China (3,500 metric tons) (USGS 2020). Approximately 15 million people participate in artisanal small-scale gold mining (ASGM) in developing countries (Gibb and O'Leary 2014). Mercury is also used as a catalyst in chlor-alkali production, vinyl chloride monomer production and other manufacturing processes, posing a risk for occupational exposure. Mercury occurs naturally in the earth´s crust, which leads to coal and crude oil being contaminated by mercury and potential for occupational exposure in coal-fired power plants and the oil sector (IPEN 2014). Phenyl mercury acetate is sometimes added to pulp in the paper-making process as a fungicide or slimicide, which can lead to occupational exposure. In addition, mercury is a component of dental amalgam and a source of occupational exposure in dental care (Bjørklund et al. 2019). Finally, mercury can be used in gold plating in a process called "mercury gilding" or "fire gilding", practiced in the manufacturing of gilded crafts and religious idols. This involves mixing metallic mercury and gold particles to form a paste which is applied to the idols. The mercury is then burned off, leaving a gold coating and exposing the workers to the mercury vapours (IPEN 2014).

Health effects

Cancer

IARC (2012) has classified arsenic, cadmium and hexavalent chromium as carcinogenic to humans (Group 1), noting that there is sufficient evidence to conclude that:

- **Arsenic** and inorganic arsenic compounds cause cancer of the lung, skin, urinary bladder. Also, positive associations have been observed between exposure to arsenic and inorganic arsenic compounds and cancer of the prostate, kidney, liver and bile duct.
- **Cadmium** and cadmium compounds cause cancer of the lung and positive associations have been observed between exposure to cadmium and cadmium compounds and cancer of the prostate and kidney.
- **Hexavalent chromium** compounds cause cancer of the lung. Positive associations have been observed between exposure to hexavalent chromium compounds and cancer of the nasal cavity and paranasal sinus (IARC 2012). An increased risk of stomach cancer was also observed in workers exposed to hexavalent chromium (Welling et al. 2015). However, according to IARC there is limited evidence that hexavalent chromium compounds cause cancer of the stomach (IARC 2012).
- Inorganic **lead** compounds have been classified as probably carcinogenic for humans (Group 2A) IARC (2006). This is supported by a recent study that analysed data on two cohorts of almost 30,000 lead-exposed workers with past blood lead data (Finland: n=20,752, Great Britain: n=9,122), which showed increased incidence trends for lung and brain cancer with increasing blood lead level (Steenland et al. 2019).

Other health outcomes

Long-term occupational exposure to high levels of inorganic **arsenic** often affect the skin, with hyperpigmentation as the most common dermal

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effect (Baker et al. 2018), and hyperkeratosis with bilateral thickening of the palms and soles may also occur. Other effects of exposure to high levels of inorganic arsenic include peripheral neuropathy, gastrointestinal symptoms, conjunctivitis, diabetes, renal system effects, enlarged liver, bone marrow depression, high blood pressure and cardiovascular disease (Baker et al. 2018). Most cases of acute arsenic poisoning occur in occupational settings from accidental ingestion of insecticides or pesticides (Ratnaike 2003). The clinical features initially invariably relate to the gastrointestinal system and include nausea, vomiting, abdominal pain, and diarrhoea (Ratnaike 2003).

The kidney is the main target of **cadmium** and cadmium accumulates primarily in the kidneys with a biological half-life in humans of 10–35 years (WHO 2019b). Osteomalacia (softening of the bones) and osteoporosis may occur in those exposed through living or working in cadmium-contaminated areas. Long-term, high-level occupational exposure is associated with lung changes, primarily characterised by chronic obstructive pulmonary disease (WHO 2019b).

Exposure to **hexavalent chromium** exposure can induce asthma, irritation, kidney damage, liver damage, pulmonary congestion and oedema. Some workers can also develop an allergic skin reaction, called allergic contact dermatitis (OSHA 2006). A recent study in women working in hexavalent chromium industries showed that exposure induced developmental toxicity of the placenta (Banu et al. 2017).

Chronic occupational exposures resulting in blood **lead** levels as low as 10 µg/dL in adults are associated with impaired kidney function, high blood pressure, nervous system and neurobehavioral effects, cognitive dysfunction later in life, and subtle cognitive effects attributed to prenatal exposure (Banu et al. 2017). Occupational lead exposure was recently shown to be associated with increased risk of Amyotrophic Lateral Sclerosis (Meng et al. 2020). It is estimated that lead exposure accounts for 1.06 million deaths and 24.4 million disability-adjusted life years (DALYs) due to long-term effects on health (IHME 2020). In the United States, environmental exposures to lead have been estimated to be responsible for 256,000 deaths a year from cardiovascular disease and 185,000 deaths a year from ischaemic heart disease (Lanphear et al. 2018).

Mercury and methylmercury are toxic to the central and peripheral nervous system. The inhalation of mercury vapour can produce harmful effects on the nervous, digestive and immune systems, lungs and kidneys, and may be fatal (Bernhoft 2012). The inorganic salts of mercury are corrosive to the skin, eyes and gastrointestinal tract, and may induce kidney toxicity if ingested (Bernhoft 2012). One study showed that mercury exposure in mining populations in Brazil lead to autoimmune dysfunction and systemic inflammation (Gardner et al. 2010). A recent systematic review reported a significant association between mercury and hypertension (Hu et al. 2018). Globally, 14-19 million workers are employed as artisanal small-scale gold miners and between 25 per cent and 33 per cent of these miners (3.3-6.5 million miners globally) suffer from chronic metallic mercury vapour intoxication. The resulting global burden of disease is estimated to range from 1.22 to 2.39 million DALYs (Steckling et al. 2017).

Regional trends

LMICs carry the largest burden of exposure for all heavy metals. Arsenic occupational exposure is often higher in LMICs and its effects are of particular concern where inorganic arsenic is already naturally present at high levels like India and Bangladesh (Rahman et al. 2018). Cadmium exposure is commonly higher in cottage industries in LMICs (Sethi and Khandelwal 2006) as well as exposure to hexavalent chromium in tannery workers, where protection measures are often inadequate (Were et al. 2014). Also, many formal and informal occupational activities are associated with lead exposure in LMICs, including battery manufacture, demolition work, welding, and small businesses repairing automobile radiators (Kordas et al. 2018). ASGM largely occurs in LMICs, accounting for the great majority of the burden of occupational exposure to mercury (UNEP 2019a).

The role of gender

Both genders are subject to occupational exposure to heavy metals, but gender related variances in work tasks have an impact on the exposure sources and levels. Occupational exposure to lead from paint comes from work in paint factories, construction and demolition, painters and in automotive repair shops. These are all generally male-dominated occupations, especially in very traditional societies. In contrast, women are more likely to be exposed to lead from paint through lead contaminated dust generated by deteriorating decorative lead paint. This is typically found at homes, pre- and primary schools and other indoor environments common for typically female dominated occupations. Mercury is used extensively in ASGM which includes an estimated 10 to 15 million miners, including 4 to 5 million women and children (UNEP, 2019a). Women are often involved in the amalgamation process, often in home environments with children nearby (Ismawati 2014).

All the five heavy metals described in this chapter can impact the reproductive system. In addition, some of the metals accumulate in the human body and many heavy metals are deposited in the bones (Chang et al. 2018). This also includes lead. When blood levels decrease through lowered exposure, lead in the bones can still be released, which keeps the blood concentration elevated. Both lead and mercury are transferred to the fetus in pregnancy and the child during breastfeeding, causing developmental harm to brain and nervous systems.

▶ Case study: Mercury exposures in ASGM

There are more than 850 ASGM hotspots identified in 27 provinces of Indonesia, most of which use mercury to extract gold (Yuyun Ismawati 2014). These provide livelihood to more than 1 million people. In 2015, a study was conducted in a small village (Pangkal Jaya) where all inhabitants either worked in the gold mining industry or were engaged in some way. Ore processing took place close to homes within residential areas. Samples were taken to assess mercury vapour in the air as well as within rice collected in the area. The average concentration of mercury vapour in the air was 4.154 nanogram/m3, notably higher than recommended levels. The average mercury content in the rice samples was 143 ppb, almost three times higher than the safe level recommended by the government of Indonesia. Several community members and children showed severe symptoms of mercury poisoning such as mental retardation, cerebral palsy, muscular dystrophy and seizures.

▶ Case study: Mercury exposures and symptoms in smelting workers of artisanal mercury mines in China

Mercury exposures to smelting workers of artisanal mercury mines in Wuchuan, China were evaluated by urine and hair mercury levels. The mean urinary mercury (U-Hg), hair total mercury (T-Hg), and hair methyl mercury (Me-Hg) for smelting workers was 1060 µg/g creatinine (µg/g Cr), 69.3 and 2.32 µg/g, respectively. The results were significantly higher than that of control group, which is 1.30 µg/g Cr, 0.78 and 0.65 µg/g, correspondingly. The average urinary beta2-microglobulin (beta2-MG) was 248 µg/g Cr for the exposed group, compared to 73.5 µg/g Cr for the control group. The results showed a serious adverse effect on the renal system for the smelting workers. The workers were exposed to mercury vapour through inhalation and the exposure route of Me-Hg may be through intake of polluted diet. Clinical symptoms including finger and eyelid tremor, gingivitis, and typical dark-line on gums were observed in six workers. This study revealed that smelting workers in Wuchuan had higher levels of mercury in their urine and hair, and also exhibited higher levels of preliminary health impacts, evidenced by increased beta2-MG and clinical symptoms (P. Li et al. 2008).

MAIN SECTORS OF EXPOSURE	SUBSTANCE	PRIMARY HEALTH IMPACTS	GLOBAL BURDEN OF OCCUPATIONAL EXPOSURES	WORK-RELATED HEALTH IMPACT
Mining Construction Agriculture, plantations, other rural sectors Manufacturing Basic metal production Shipping, ports, fisheries, inland waterways Utilities (water, gas, electricity) Textiles, clothing, leather, footwear Mechanical and electrical engineering sector	Overview	Various	>25,000,000	Limited data
	Lead	Cancer (stomach) Neurotoxicity Cardiovascular Disease	>1,800,000 (EU-OSHA 2014; CAREX-Canada 2020)	Limited data (>900,000 due to environmental lead exposure (GBD 2019))
	Mercury	Neurotoxicity Nephrotoxicity Immune Toxicity Reproductive toxicity	>19,000,000 (Limited data for artisanal small-scale gold mining only) (Steckling et al. 2017)	Limited Data (>2,000,000 DALYs attributable to chronic metallic mercury vapour intoxication) (Steckling et al. 2017)
	Arsenic	Cancer (lung, skin, urinary and bladder) Skin toxicity Neurotoxicity Nephrotoxicity	>3,000,000 (GBD 2019)	Limited data
	Cadmium	Cancer (lung) Nephrotoxicity Bone toxicity	>500,000 (GBD 2019)	Limited data
	Hexavalent Chromium	Cancer (lung) Nephrotoxicity Lung toxicity Skin toxicity Liver toxicity	>1,000,000 (GBD 2019)	Limited data

▶ Selected Priority Actions: Mercury

Examples of national policy measures

Refer to, ratify and implement the following conventions, as appropriate:

- **ILO Safety and Health in Mines Convention, 1995 (No. 176).** The main provision in Convention No.176 addressing chemicals is Art. 9, which mandates that employers must inform workers of existing chemical hazards and all relevant preventative and protective measures for these hazards; take appropriate measures to eliminate or minimise those hazards; provide free protective equipment in the event that safety cannot otherwise be ensured; and ensure provision of first aid, transportation and appropriate access to medical facilities for workers suffering from injury or illness due to chemical hazards.
- **ILO Employment Injury Benefits Convention, 1964 (No. 121).** Workers should have access to a remedy to the exposure to mercury (schedule I).
- **ILO List of Occupational Diseases (revised 2010) in the annex of ILO Recommendation No. 194.** The List of Occupational Diseases and the Recording and Notification of Occupational Accidents and Diseases [List of Occupational Diseases Recommendation, 2002], includes diseases caused by mercury or its compounds (para. 1.1.7).
- **Minamata Convention.** A global UN treaty with 128 signatories adopted to protect health and the environment from releases of mercury and mercury compounds. The Convention obliges governments to take a range of actions, including to address mercury emissions to air and to phase-out certain mercury-containing products. Reducing mercury exposure from ASGM is one of the Minamata Convention's most important aims.

Additional actions for policy makers

- Eliminate the use of mercury in gold mining, especially in the ASGM sector where workers are especially highly exposed. Prohibit the processing of mercury/gold amalgam in residential areas.
- Phase out of intentional mercury use in other sectors should also be implemented to prevent occupational exposure.
- Stop the generation and extraction of new mercury as well as trade of mercury.

Occupational Exposure Limits (OELs)

- Update, implement and enforce OELs for mercury and ensure global harmonisation of these OELs. Strict occupational exposure limits for mercury in all sectors, including sectors where mercury is present as a contaminant, should be adopted and implemented.

Examples of practical workplace interventions

- Use mercury exposure reduction methods to more effectively concentrate gold (so as to reduce the quantity of mercury used in the amalgamation process).
- Avoid open air burning of amalgam.
- Operate mercury capture devices such as retorts or fume hoods to capture mercury vapour emitted when the mercury/gold amalgam is burned.
- Utilise mercury-free processes in ASGM, for example, gravity-only concentration methods, such as panning, sluicing, centrifuges, spiral concentrators, vortex concentrators and shaking tables. Other concentration methods include magnets and flotation.
- Provide effective PPE for all occupations using mercury. This should be designed to effectively protect people of all body types, including physiological differences between genders.

Sources include: UNEP 2012 and 2019a, WHO 2016c, ILO 2017

▶ ILO Convention No. 176 and the Minamata Convention

A highlight of Convention No. 176 (C176) is its synergies with the Minamata Convention on Mercury. Use of mercury in mining, especially in gold mining, continues to constitute a major health and environmental hazard. While C176 does not mention mercury directly, the open provisions on chemicals in Art. 9 cover this substance and therefore mandate the elimination or at least minimization of hazards relating to mercury as well as other hazardous chemicals used in gold mining. Mercury in mining is also addressed by the Minamata Convention, which contains provisions on the dangers relating to ASGM. C176 and the Minamata Convention therefore complement each other, as C176 closes the gaps when it comes to chemical exposures, for example regarding other hazardous chemicals used in mines such as cyanide and solvents.

▶ Selected Priority Actions: Lead

Examples of national policy measures

- Refer to policy actions and examples set forth by the Global Alliance to Eliminate Lead Paint. Lead Paint is identified as an Emerging Issue of Concern under SAICM with the target of global elimination. To support this goal, the Global Alliance was formed in 2009, which also aims to prevent workers' exposure.
- Ratify and implement the **ILO Safety and Health in Construction Convention, 1988 (No. 167)**. Provisions provided for protecting the health of workers from chemical hazards through the implementation of appropriate preventive measures in the construction sector. Whilst lead exposure may occur in a number of sectors, there is a need to focus on the construction industry, where lead exposure frequently occurs during tasks that generate fumes and respirable dust containing lead, or when painting with leaded paint.

Additional actions for policy makers

- Promote the phase out of lead from remaining sources of exposure, such as lead paint
- Strictly control lead exposure in industries such as the production and recycling of lead acid batteries
- Establish legal requirements for training and PPE for workers conducting lead paint abatement on legacy paint.
- Adopt, implement and enforce strict OELs for lead acid battery recycling

Additional actions for policy makers

- Promote the phase out of lead from remaining sources of exposure, such as lead paint and other industrial products.
- Strictly control lead exposure in industries such as the production and recycling of lead acid batteries.
- Integrate lead into national OSH programme considerations, specifically when it comes to requirements for training and PPE for workers conducting lead paint abatement on legacy paint.

Occupational Exposure Limits (OELs)

- Update, implement and enforce OELs for lead and ensure global harmonisation of these OEL. OELs specifically for lead acid battery recycling are especially needed.
- Established OELs include:
  - EU Directive 98/24/EC: 0.15 mg/m3 per 8 hour TWA and 70 µg lead/100 ml blood. Apply these for all workers and indicate when suspension from lead work is required.
  - Lower limits may be recommended and used at a national level, with still lower limits for young persons and women. For example, the ACGIH recommends a limit of 30 µg/100 ml, which is the same limit used for women of reproductive age in the UK.

Examples of practical workplace interventions

- Eliminate the use of lead where possible.
- Substitute lead for a less hazardous material, for example apply non-leaded paint rather than a coating containing lead.
- Use engineering controls, such as totally enclosed process and handling systems, processes which keep production of dust, fumes and vapours to a minimum and ventilation systems.
- Utilise administrative controls, such as reducing worker hours and durations of exposure.
- Employ other safe work practices, such as regular cleaning of surfaces, safe storage of lead and lead waste, prohibition of eating, drinking and smoking in contaminated areas and hygiene measures, for example, washing contaminated clothing.
- Provide effective PPE designed to effectively protect people of all body types. For example, impermeable protective clothing is essential for work with lead alkyls if there is the risk of skin contact.

Sources include: WHO 2017 and 2019c, OSHA n.d., HSE 2002

▶ The Global Alliance to Eliminate Lead Paint

The Global Alliance to Eliminate Lead Paint (Lead Paint Alliance) is a voluntary partnership formed by the United Nations Environment Programme (UNEP) and the World Health Organization (WHO) to prevent exposure to lead through promoting the phase-out of paints containing lead. The ILO has joined the Alliance and leverages its unique tripartite structure to promote social dialogue towards the phase out of the manufacture and sale of lead paint. More information on tools to promote the phase out of lead in paint can be found here.

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Spotlight on e-waste: Hazardous substances within the life cycle of high tech electrical and electronic products

- The lifecycle of electronic products includes extraction, production, transport, use, recycling and waste management, all of which can lead to exposure to various chemicals.
- More than 60 chemical elements can be found in electronics, including aluminum, gallium, arsenic, lead, cadmium, chromium, mercury, copper, manganese, nickel, iron, and zinc, many of which are potentially, or known to be, hazardous. Additional chemicals may also be present, such as brominated flame retardants and polychlorinated biphenyls (PCBs).
- Health risks may result both in workers as well as in the community from direct contact with heavy metals, from inhalation of toxic fumes and particulate matter, hand to mouth transfer, as well as from accumulation of chemicals in soil, water and food.
- Exposure to the various chemicals, compounds and biproducts present in e-waste have been identified as carcinogenic to humans (group 1) by IARC. Other health effects include neurotoxicity and impacts to the reproductive system.
- The majority of the workforce in the electronics industry are young women and case studies have shown increased rates of leukaemia and adverse pregnancy outcomes as a consequence of occupational exposure.

More than **60 chemical elements** can be found in **electronics**

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▶ Figure 4. Chemical classification of e-waste components and sources and routes of exposure

	Component of electrical and electronic equipment	Component of electrical and electronic equipment	Route of exposure
Persistent organic pollutants			
Brominated flame retardants Polybrominated diphenyl ethers	Fire retardants for electronic equipment	Air, dust, food, water, and soil	Ingestion, inhalation, and transplacental
Polychlorinated biphenyls	Dielectric fluids, lubricants and coolants in generators, capacitors and transformers, fluorescent lighting, ceiling fans, dishwashers, and electric motors	Air, dust, soil, and food (bioaccumulative in fish and seafood)	Ingestion, inhalation or dermal contact, and transplacental
Dioxins			
Polychlorinated dibenzodioxins and dibenzofurans	Released as combustion byproduct	Air, dust, soil, food, water, and vapour	Ingestion, inhalation, dermal contact, and transplacental
Dioxin-like polychlorinated biphenyls	Released as a combustion byproduct but also found in dielectric fluids, lubricants and coolants in generators, capacitors and transformers, fluorescent lighting, ceiling fans, dishwashers, and electric motors	Released as combustion byproduct, air, dust, soil, and food (bioaccumulative in fish and seafood)	Ingestion, inhalation, and dermal absorption
Perfluroalkyls	Fluoropolymers in electronics	Water, food, soil, dust, and air	Ingestion, dermal contact, inhalation, and transplacental
Polyaromatic hydrocarbons			
Acenaphthene, acenaphthylene, anthracene, benz[a]anthracene, benzo[a]pyrene, benzo[e]pyrene, benzo[b]fluoranthene, benzo[g,h,i]perylene, benzo[j]fluoranthene, benzo[k]fluoranthene, chrysene, dibenz[a,h]anthracene, fluoranthene, fluorene, indeno[1,2,3-c,d]pyrene, phenanthrene, and pyrene	Released as combustion byproduct	Released as combustion byproduct, air, dust, soil, and food	Ingestion, inhalation, and dermal contact
Elements			
Lead	Printed circuit boards, cathode ray tubes, light bulbs, televisions (1·5–2·0 kg per monitor), and batteries	Air, dust, water, and soil	Inhalation, ingestion, and dermal contact
Chromium or hexavalent chromium	Anticorrosion coatings, data tapes, and floppy disks	Air, dust, water, and soil	Inhalation and ingestion
Cadmium	Switches, springs, connectors, printed circuit boards, batteries, infrared detectors, semi-conductor chips, ink or toner photocopying machines, cathode ray tubes, and mobile phones	Air, dust, soil, water, and food (especially rice and vegetables)	Ingestion and inhalation
Mercury	Thermostats, sensors, monitors, cells, printed circuit boards, and cold cathode fluorescent lamps (1–2 g per device)	Air, vapour, water, soil, and food (bioaccumulative in fish)	Inhalation, ingestion, and dermal contact
Zinc	Cathode ray tubes, and metal coatings	Air, water, and soil	Ingestion and inhalation
Nickel	Batteries	Air, soil, water, and food (plants)	Inhalation, ingestion, dermal contact, and transplacental
Lithium	Batteries	Air, soil, water, and food (plants)	Inhalation, ingestion, and dermal contact
Barium	Cathode ray tubes, and fluorescent lamps	Air, water, soil, and food	Ingestion, inhalation and dermal contact
Beryllium	Power supply boxes, computers, x-ray machines, ceramic components of electronics	Air, food, and water	Inhalation, ingestion, and transplacental

Source: (Grant et al. 2013).

DEFINITION: Electronic and electrical waste (e-waste) is defined as any end-of-life "equipment which is dependent on electrical currents or electromagnetic fields in order to work properly" (UNEP 2007; ILO 2019a, 2019c, 2019d), including: small and large household appliances; information technology and telecommunications equipment; lighting equipment; electrical and electronic tools, toys, and leisure and sports equipment; medical devices; monitoring and control instruments; and automatic dispensers, components and parts of electrical and electronic equipment (batteries, circuit boards, plastic casings, cathode-ray tubes, activated glass, lead capacitors, etc.).

Exposure

Production and use of electronics is rapidly expanding. As a consequence, the amount of e-waste is expected to increase to 52.2 million metric tonnes by 2021 and grow up to 111 million tonnes by 2050 (Parajuly et al. 2019). High-volume informal recycling of e-waste has been reported in many countries, including China, Ghana, India, Nigeria, the Philippines, Thailand, and Vietnam (Orisakwe et al. 2019). One case study in Nigeria showed that in 2015/2016, EU member states were the origin of around 77 per cent of Used Electric and Electronic Equipment (UEEE) imported into Nigeria. Since LMICs generally have less e-waste management infrastructure than higher income economies, there are alarming exposure trends that require urgent attention (Baldé et al. 2017). It has been estimated that solid waste management and recycling provide employment for 19 to 24 million women and men worldwide, of which four million work in the formal waste and recycling sector (ILO 2013). However, the lack of data and issues of defining used electrical and electronic equipment have rendered it impossible to provide a global figure for employment in the e-waste subsector (ILO 2019a). It has been estimated that informal and formal e-waste workers are over 690,000 in China (Wang et al. 2013), 500,000 in India (Joon 2017), 100,0000 in Nigeria (Ogungbuyi et al. 2012), 34,000 in Argentina (ILO 2020a).

Health effects

Cancer

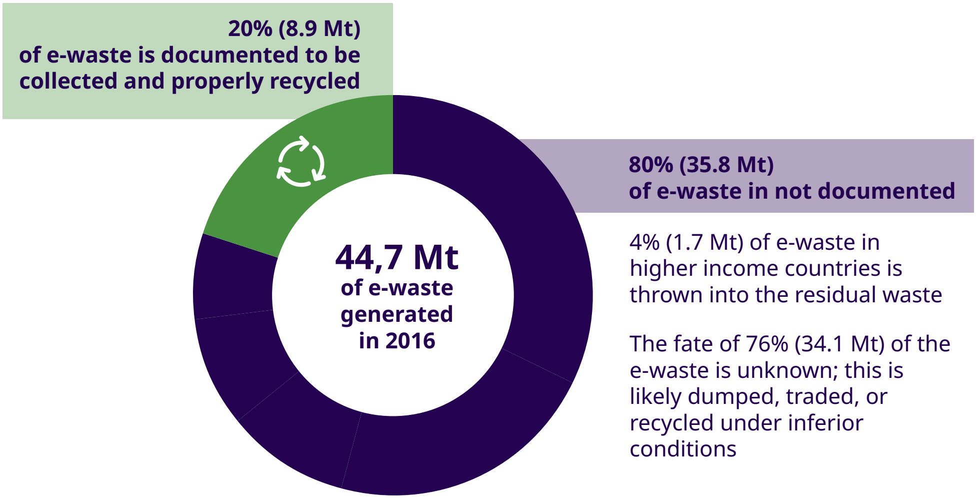
There is mounting evidence of an association between occupational exposure to hazardous substances during manufacture of electronics and cancer. An investigation of 32,000 worker deaths in one large electronics manufacturer between 1969 and 2001 found that overall proportional mortality ratios were elevated in male and female workers. Proportional cancer mortality ratios for brain, kidney, and pancreatic cancers were significantly higher in male workers, while female workers experienced significantly elevated numbers of deaths from kidney cancer, lymphoma, and leukaemia (Clapp 2006). In the semiconductor industry, a number of reports of leukaemia and non-Hodgkin lymphoma (NHL), cancers known to have a similar pathophysiology, have generated public concern. One study from the Republic of Korea assessed leukaemia and NHL cases from a semiconductor plant, finding that 17 workers suffered from the illnesses, with 11 of them young women. The relatively young age (mean=28.5 years) at the time of diagnosis raises particular concerns for the severity of the problem and requires further research into the exposure-outcome causal relationship (Kim et al. 2012).

Several compounds and biproducts present in e-waste have been identified as carcinogenic to humans (group 1) by IARC, including PCBs, TCDD (2,3,7,8-tetrachlorodibenzo-p-dioxin), cadmium, nickel, hexavalent chromium, and beryllium (Grant et al. 2013). A number of studies identified increased cancer risks in adults (lung cancer) and children (lymphoma) working in e-waste dismantling and burn sites (Wang et al. 2012; Huang et al. 2016; Zheng et al. 2015; Davis and Garb 2019). Workers in e-waste sites are often exposed to very complex mixtures that vary over time, which makes the exact dose–response relations of the carcinogenic effects of chemical mixtures in e-waste sites difficult to assess (Grant et al. 2013). Informal working conditions, lack of adequate personal protective equipment and the frequent turnover of workers in e-waste sites further complicate accurate risk assessments for long term carcinogenic effects that often occur decades after the exposures.

Other health outcomes

In the Republic of Korea, an analysis of epidemiological data found evidence suggesting reproductive risks to women from semiconductor fabrication jobs including spontaneous abortion, congenital malformation, and reduced fertility (Kim 2014). A subsequent examination of reproductive risks among female microelectronics workers aged 20 – 39 years old found a significantly higher risk for spontaneous abortion and menstrual aberration (Kim 2015).

▶ **Figure 5. Collection methods of e-waste**



Source: Baldé et al. 2017

In addition to its hazardous components, the processing or dismantling of electronic products can also give rise to additional toxic by-products likely to affect human health, and not assessed in original product manufacture (Heacock et al. 2016). A systematic review showed that several known neurotoxicants are found in e-waste, such as lead, mercury, cadmium, and brominated flame retardants. Exposure to these substances can lead to irreversible cognitive deficits in adults and children and behavioral and motor skill dysfunction across their lifespan (Grant et al. 2013). In particular, workers may directly encounter hazardous substances in fumes or dust through inhalation, skin contact, or oral intake via dismantling activities they perform themselves or that are performed by others nearby (Grant et al. 2013). Alarmingly, children and adolescents are commonly employed in e-waste recycling, posing a significant risk to neurodevelopment (Heacock et al. 2016). A cohort of children and adolescents exposed to lead through burning cable activities were assessed in Uruguay and showed an average blood level of 9.19 µg/dL, almost double when compared to the level of concern (5 µg/dL) (Pascale et al. 2016).

Regional trends

In 2016, Asia was the region that generated by far the largest amount of e-waste (18.2 million tonnes - Mt), followed by Europe (12.3 Mt), the Americas (11.3 Mt), Africa (2.2 Mt), and Oceania (0.7 Mt). Although e-waste is not generated exclusively by wealthy countries, such countries contribute substantially to e-waste problems in LMICs because of regulatory ambiguities that allow e-waste export for re-use, regardless of actual product functionality (Heacock et al. 2016). The decommissioning of solar photovoltaic panels, a specific form of e-waste, also presents a considerable challenge. With an average life of 30 years, many solar photovoltaic panels in the United States, Japan and Europe will soon reach the end of useful life and will need to be recycled appropriately (Invernizzi at al. 2020).

One of the largest e-waste sites in the world is Agbogbloshie, an area in Ghana's capital city Accra that is also home to up to 80,000 people (Oteng-Ababio and Grant 2019). The people working in this area have typically no mechanisms in place to protect against exposure to the hazardous chemicals in the e-waste they are handling, or protection against dust and the smoke at the site that is contaminated with hazardous substances. Numerous studies have provided evidence of occupational exposure to chemicals and their health impacts at this site. Specifically, exposures to persistent organic pollutants such as PCBs and dioxins, toxic metals and arsenic have been documented, as well as health impacts including cancer, lung diseases, and cardiovascular disease. Due to the extent of chemical contamination at the site, Agbogbloshie has been named one of the world's ten worst toxic threats (Blacksmith Institute 2013).

▶ Case study: Contamination levels in the breast milk of Ghanaian women from an e-waste recycling site

A recent study assessed the levels of polycyclic aromatic hydrocarbons (PAHs) in breast milk samples from 128 Ghanaian women. PAHs have carcinogenic and mutagenic properties and therefore have the potential to adversely impact the health on infants. These chemicals can be produced unintentionally as a result of pyrolysis or incomplete combustion, for example when burning plastic casings of e-waste. Samples were collected from a group of working women from Agbogbloshie and one control group from non-working women living in a nearby residential area. Alarmingly, a total of 18 PAHs were detected in the samples from women in both groups. The most carcinogenic of all the PAHs, benzo[a]pyrene (Kato et al. 2011), was detected in 92 per cent of the milk samples from the working women in Agbogbloshie, but were below the limit of detection in all the samples from women in the residential area. Overall, the mean concentration levels of 13 of the 18 PAHs in the breast milk samples from working women in the Agbogbloshie e-waste site were higher than the respective mean concentrations from residential non-working women (Asamoah et al. 2019).

The role of gender

As described in the evidence above, many women work along the life cycle of the electronics sector and suffer from adverse health effects as a result. In many cases these are young women. For example, the electronics industry in Vietnam employed 634,440 people in 2016, where around 70 per cent of the workforce was female. Over 85 per cent of those workers were under the age of 35 (UNIDO 2019).

In many countries, women and children play dominant occupational roles in e-waste, increasing their risk for potential exposures from chemicals released from the burning and disassembling of various electronic products. In some countries, the work tasks included are segregated by gender, where the men collect the waste and women and children conduct the manual processing and therefore are more exposed to the hazardous chemicals (UNEP 2020c). A systematic review showed that pregnancy outcomes were negatively affected in workers exposed to e-waste, including increases in spontaneous abortions, stillbirths, premature births and reduced birth weights (Grant et al. 2013).

Nevertheless, it is important to note that evidence from this sector have shown that exposure and resulting health impacts occur in both women and men due to the wide variety of hazardous chemicals used. As many of these chemicals may affect the reproductive system, it is important to conduct additional epidemiological studies to understand the gender dimensions of OSH in this continually expanding sector.

▶ Spotlight on e-waste priority actions

Priority measures to prevent hazardous occupational exposure to e-waste includes restrictions and phasing out the use of these substances, in addition to adopting and implementing strict OELs. However, the informal nature of many of these workplaces makes implementation of regulations a challenge. Actions to reduce occupational exposure and protect worker health must be locally tailored and take into consideration the large differences in the scale of e-waste sites, which range from vast facilities to tiny family operations. Additional actions that can be taken include:

- ▶ Share good practices from already existing regulations, such as the EU Directive on Restriction of Hazardous Substances.
- ▶ Address the early life-cycle stages of e-waste, e.g., by taking proactive approaches such as adopting applicable fiscal policies and design guidelines to foster development of electronics made with minimal use of hazardous substances and by green manufacturing processes (UNEP 2020a).
- ▶ Properly address the situation of informal workers who handle e-waste through comprehensive OSH training that focuses on hazard reduction and best practices, including the provision of PPE as a last resort option.
- ▶ Reduce dependence on open burning techniques by the provision and use of electric-powered, automated wire-stripping machines (Caravanos 2015).
- ▶ Implement extended producer responsibility measures to ensure safe handling for e-waste. Bulk purchaser and retailers should include requirement of safe production in their procurement, including listing prohibited substances in the manufacturing process and proof of protection from occupational exposure (Caravanos 2015).

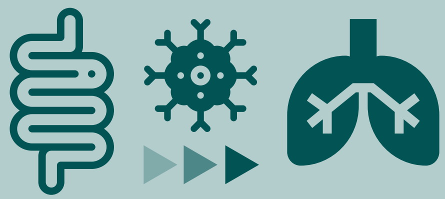
▶ Solvents

- Solvents are hazardous substances used in large quantities globally and in a wide range of occupations. They are found in many products, including cleaning materials, paints, adhesives, inks and toiletries. Common examples are isopropanol, benzene, toluene, xylene and solvent mixtures, such as white spirits.
- High solvent exposure occupations include painters, lacquerers, printers, dry cleaners, footwear manufacturers, occupations in graphics and plastic product works.
- Inhalation of solvent vapours is the most common method of occupational exposure, although dermal contact may be high in industries such as painting.
- Acute, high-level exposures can lead to delirium, respiratory depression and death. Chronic, low-level exposures are solvent specific and have been associated with cancer, reproductive concerns and neurotoxic effects.
- Solvents should be considered an occupational health and safety priority, as large numbers of workers are exposed to them globally and serious health impacts have been identified by robust scientific evidence.

Exposure

The term 'solvent' is generic and may include hundreds of different chemical compounds. Solvents are used to dissolve or dilute other substances and are found in cleaning agents, fossil fuels, paints, adhesives and varnishes and are used in the production of dyes, plastics, textiles, printing inks, agricultural products and pharmaceuticals. Solvents are volatile agents and occupational exposure generally occurs by inhalation of vapours. Dermal exposure is also prevalent in some industries, such as painting and industrial degreasing (Dick 2006). Certain tasks, such as spraying, can produce very high exposure levels.

Blood absorption occurs quickly after exposure, with blood levels dependent on environmental factors, such as solvent concentration in the air, room ventilation and duration of exposure (Hurley and Taber 2015). Solvents may also be retained in organs with high lipid content, such as the brain, with potentially adverse health impacts.



▲ Increased risks of **gastrointestinal cancers** have been suggested following exposure to **toluene**

and occupation as a painter has consistently been associated with a

▲ **40%** increased risk of **lung cancer**

Health effects

Whilst acute health impacts are fairly consistent across solvent type, the effects of chronic solvent exposure are usually solvent-specific and should therefore be considered on an individual basis. This is a complex area of research due to the intrinsic differences between solvent types, individual susceptibility and the impact of variables, such as dose and duration of chemical exposure.

Cancer

IARC has classified benzene and trichloroethylene (TCE) as carcinogenic to humans (group 1), and some solvents, for example, methylene chloride and tetrachloroethylene, as probably carcinogenic (group 2A). Benzene has been specifically linked with leukaemia (WHO 2019e) and chlorinated hydrocarbons to renal cancer (Brüning et al. 2003). Increased risks of various gastrointestinal cancers have been suggested following exposure to toluene, and occupation as a painter has consistently been associated with a 40 per cent increased risk of lung cancer. There is evidence for increased risks of liver cancer and non-Hodgkin's lymphoma following trichloroethylene exposure, oesophagus and cervical cancer for tetrachloroethylene exposure and lymphohematopoietic malignancies after carbon tetrachloride. An excess risk of liver and biliary tract cancers was suggested in the cohort with the high exposure to methylene chloride (Lynge et al. 1997).

Other health outcomes

Aside from cancer, the principal health effects most typically associated with organic solvent exposure include nervous system damage, kidney and liver damage, skin lesions and adverse reproductive effects, such as sperm changes and infertility. Virtually all solvents can cause adverse effects to reproductive health. Specifically, they have been associated with cleft palates, miscarriage, newborn infection and childhood cancer (Rim 2017). Acute health impacts include skin, eye and lung irritation, headache, nausea, dizziness and light-headedness (ILO 2004). Very high levels can lead to unconsciousness, seizures and even death, for example in unventilated spaces (Dick 2006).

Chronic exposure in the work environment can produce a range of adverse neurotoxic effects, including headache, fatigue, memory and concentration impairment, irritability, depression and personality changes (White and Proctor 1997). A meta-analysis of 46 cross-sectional studies showed that occupational solvent exposure was associated with deficits in cognitive function, particularly for attention and procedural speed (Meyer-Baron et al. 2008). There is strong evidence that some solvents may cause peripheral neuropathy, which causes altered sensation, loss of vibration perception and impaired proprioception. The solvent n-hexane has been associated with outbreaks of peripheral neuropathy in furniture manufacturers, printers and shoemakers and methyl n-butyl ketone with an outbreak in an Ohio textile printing plant (Dick 2006).

Chronic solvent induced encephalopathy (CSE) can occur after long-term exposure to solvents, for example, in chronically exposed workers. This syndrome is characterised by symptoms of fatigue, irritability and forgetfulness, as well as neurobehavioural deficits, such as decreased motor performance and information processing (Van Valen et al. 2012). A recent study of a cohort of CSE patients found that 37 per cent were on permanent work disability pensions (Van Valen et al. 2018). When taking into account the potential number of workers impacted by CSE globally, the public health implications may therefore be considerable.

Virtually **all solvents can cause**

adverse effects to **reproductive health**

Benzene

Exposure to benzene continues to be a major occupational health concern. The presence of benzene in petrol and as a common industrial solvent can result in significant occupational exposure and a range of acute and long-term health effects. Although benzene concentration in petroleum is now limited in many regions and solvent use is also restricted, exposure to benzene remains high in some industries, including shoemaking, painting, printing and rubber manufacturing (Loomis et al. 2017). Acute effects include headache, dizziness, confusion, tremors and eye, skin and respiratory irritation. Chronic exposure can lead to cancers such as leukaemia, aplastic anaemia, DNA damage and immunosuppressive effects (WHO 2019e).

Regional trends

Solvent exposure is one of the most common chemical exposures in the workplace, following gases and dusts (Benke et al. 2017). As awareness of the dangers of solvent exposure have become more evident, legislation and advances in technology have resulted in decreased use of the more hazardous solvents in Europe and the US. For example, the 1987 Montreal Protocol led to the restriction or phase out of many ozone-depleting solvents and water-based paints have replaced traditional, solvent-based coatings (Dick 2006). In some industries, for example dry cleaning, improvements to equipment and processes have lessened solvent use. In LMICs however, standardised regulations are minimal and solvent use is most likely inadequately controlled.

▶ Case study: The association between occupational solvent exposure and cognitive performance

The French CONSTANCES study evaluated the association between occupational solvent exposure and cognitive performance in a cohort of over 40,000 participants, aged 45-69 years old. Cognitive function, episodic verbal memory, language ability and executive function were evaluated using a standardised battery of cognitive tests. Results showed that men occupationally exposed to gasoline, white spirits or cellulosic thinner were at greater risk of cognitive impairment, whilst women exposed to white spirits or exposed for more than 20 years had poorer cognitive performance, with an exposure-effect relationship found for the number of solvents used and cumulative exposure time. Specifically, cognitive performance decreased with the number of solvents to which individuals were occupationally exposed and with the cumulative exposure time (Letellier et al 2020).

MAIN SECTORS OF EXPOSURE	PRIMARY HEALTH IMPACTS	GLOBAL BURDEN OF OCCUPATIONAL EXPOSURES	WORK-RELATED HEALTH IMPACT
Food; drink; tobacco Mechanical and electrical engineering Construction Chemical industries Printing Plastics Rubber Textiles; clothing; leather; footwear Manufacturing Dry cleaning	Cancer Neurotoxic effects including 'chronic solvent-induced encephalopathy' (CSE) Reproductive toxicity	Limited data	Limited data

Selected priority actions: Solvents

Examples of national policy measures
▶ Develop national laws or regulations that prescribe the measures to be taken for the prevention and control of, and protection against, occupational hazards due to solvents. ▶ Phase out the use of toxic solvents in certain work processes where alternative practices exist and replace solvents with less harmful substitute products when available. For most of the hazardous solvents it is possible to find a substitute with the same characteristics, but less drastic effects on health. ▶ Refer to other national examples, such as the EU, who has banned or restricted a number of hazardous solvents, such as dichloromethane-based paint strippers and N-Methyl-2-pyrrolidone, a solvent widely used in coatings and cleaning agents.
Additional actions for policy makers
▶ Develop targeted research programs to identify and prioritize preventative actions in order to reduce worker exposure to solvents.
Occupational Exposure Limits (OELs)
▶ Update, implement and enforce OELs for various forms of solvents and ensure global harmonisation of these OELs. ▶ Refer to individual OELs that have been assigned by selected countries and agencies, such as the EU and the ACGIH.
Examples of practical workplace interventions
▶ Eliminate and substitute the use of hazardous solvents at the workplace level where possible. ▶ Open doors and windows to increase ventilation, however mechanical ventilation may be necessary in some places. Encapsulation systems can also help reduce exposure. Ventilation is important, as solvents quickly create high concentrations of vapours in confined spaces. ▶ Store solvents in properly labelled suitable containers, using dispensers where possible to keep evaporation to a minimum and reduce spillage. ▶ Dispose of solvent-soaked rags in closed containers. ▶ Train workers in specific handling and use of solvents. Training should include but not be limited to – physical properties, health effects, routes of exposure, how to minimize exposure, PPE, first aid, spillages, and disposal. ▶ Apply good practices in measuring exposure to solvent vapours in order to understand whether the controls in place are sufficient to protect workers' health. ▶ Provide appropriate safety equipment, including fire extinguishers and absorbent material, for situations such as spillage or emergency. ▶ Prohibit eating, smoking or drinking when hazardous solvents are handled. ▶ Make PPE available free of charge, such as protective overalls, gloves and masks with filters, which should be used according to the recommendations. Store all PPE in a clean place away from possible contact with solvent vapours.

Sources include: ILO 2004 and 2014, ESIG 2018

Spotlight on Benzene Priority Actions

As a solvent, benzene can be substituted with a variety of less hazardous ones. A number of solvents have similar characteristics to benzene, however with less hazardous effects.

- Engineering controls using enclosed or exhaust ventilation can be effective, and isolation of operations can also reduce exposure.
- Benzene should be stored in tightly closed containers in a cool well-ventilated area.
- Metal containers need to be grounded to avoid ignition from sparks caused by static electricity. Benzene reacts violently with oxidizing agents, such as permanganates, nitrates, peroxides, chlorates and perchlorates.
- Labels on bottles or containers should carry symbols indicating the health risk, following the GHS.
- PPE, for example breathing protection, is a last resort but may be necessary in some situations. It is essential to use the correct equipment, i.e., mask and filter type A and viton or polyvinyl alcohol (PVA) gloves, although even these have limited resistance to benzene.

Source: ILO 2004

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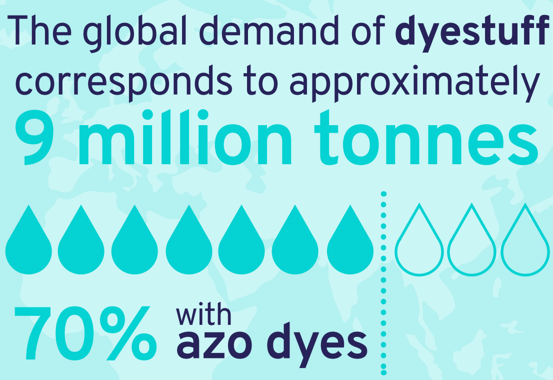
▶ Dyes

- Synthetic dyes are used in different industries, such as textiles, leather, pharmaceuticals, food and cosmetics.
- Azo dyes, the most commonly used dye, are aromatic hydrocarbon derivatives of benzene, toluene, naphthalene, phenol and aniline.
- Azo dyes and their by-products, aromatic amines, have been linked to various cancers and allergic reactions.
- Women are more likely to be exposed to dyes in the workplace and are therefore at a higher likelihood of adverse health outcomes, especially in relation to pregnancies. Furthermore, they experience gender-related disadvantages, such as lower pay and limited career advancement, as well as being at risk of sexual harassment and gender-based violence.

Exposure

Dyes are chemical substances that bond to a substrate and are classified according to their chemical properties and solubility. They are used to modify the colour of different substrates, such as textiles, paper and leather. Occupational exposures to dyes occur during their production and use. There are an estimated 800 dyes



currently in use, including azo dyes (Licina et al. 2019). Although originally from natural sources, modern dyes are synthetic substances which can be hazardous to health and polluting to the environment.

The global demand of dyestuff corresponds to approximately 9 million tonnes (Rawat et al. 2016), with azo dyes making up greater than 70 per cent of this figure (Benkhaya et al. 2020). The textile industry consumes two-thirds of production worldwide, however dyes are also commonly used in pharmaceuticals, food and cosmetics (Ventura-camargo, Marin-morales 2013). Some azo dyes degrade under certain conditions, leading to the release of carcinogenic aromatic amines, such as aniline, benzidine and 2-naphthylamine (Licina et al. 2019).

Health effects

Cancer

Although many azo dyes are non-toxic, some have been identified as having mutagenic or carcinogenic effects. Carcinogenic aromatic amines are of particular concern for workers. Bezidine, for example, has been found to be carcinogenic to humans and has been specifically linked to bladder cancer (IARC 2010b). Analysis of 86 textile products in Japan detected carcinogenic aromatic amines in low concentrations on a variety of clothing items (Kawakami et al. 2010). Other chemicals identified as carcinogenic to humans (IARC group 1) include 4-Aminobiphenyl, a dye intermediate, and those used in the production of auramine and magenta dyes (IARC 2010b). Numerous dyes contain the chemical ortho-toluidine, which has also been linked to bladder cancer (IARC 2010b).

Hairdressers exposed to hazardous dyes

Hairdressers are frequently exposed to dyes during the course of their work. The major pathway for exposure is via skin contact, followed by dermal absorption. The IARC has identified occupational dye exposures as a hairdresser are probably carcinogenic to humans (IARC 2010b). In particular, the risk of bladder cancer was considered to be increased, particularly for men. In 2007, the EU banned the use of 135 individual ingredients in hair dyes.

Dyes can also cause respiratory problems due to inhalation of dye particles and also may cause skin irritation and other allergic symptoms (Hassan and Nemr 2017). For example, p-phenylenediamine, another azo dye component, is a known contact allergen (Chung 2016).

Regional trends

The manufacturing of benzidine is specifically prohibited in the EU, Japan, the Republic of Korea, Canada and Switzerland. From November 2020, the EU has restricted the use of azo dyes in the textile/garment sector (EU-Commission 2018). Textiles make up a significant proportion of dye use globally, with China, Bangladesh and Vietnam being three of the world's top five garment exporters (ILO 2019f). The textile industry generates large amounts of industrial effluents each year causing water pollution which is not only harmful for aquatic life, but also mutagenic to humans. The safe disposal of industrial waste containing potentially carcinogenic dye effluents is therefore especially concerning in these regions (Hassaan and Nemr 2017). Alternative colouring processes, for example, using pigments or digital printing, are examples of more sustainable fabric colouring processes, with less of a reliance on toxic chemicals.

MAIN SECTORS OF EXPOSURE	PRIMARY HEALTH IMPACTS	GLOBAL BURDEN OF OCCUPATIONAL EXPOSURES	WORK-RELATED HEALTH IMPACT
Textiles; clothing; leather; footwear Chemical industries Food; drink Pharmaceuticals Cosmetics	Cancer (bladder)	Limited data	Limited data

▶ Selected priority actions: Dyes

Examples of national policy measures

- Develop national laws or regulations that prescribe the measures to be taken for the prevention and control of, and protection against, occupational hazards in the working environment due to hazardous dyes.
- Refer to existing national regulations, for example, azo dyes releasing one of the 22 known carcinogenic aromatic amines are banned from clothing textiles in the European Union (Annex XVII of the REACH regulation; No, 1907/2006). The regulation can be found here

Additional actions for policy makers

- Approve the use of less hazardous dyes as much as possible. For example in textiles, benzidine-based dyes should be replaced with safer substitutes.

Occupational Exposure Limits (OELs)

- Develop evidence-based OELs for hazardous dyes and methods to implement and enforce them. Ensure global harmonisation of these OELs.

Examples of practical workplace interventions

- Consider if there are less hazardous forms of the dyestuffs available. Choosing low-dusting dyes such as those in granular, dust-suppressed or liquid form can be a very important factor in reducing exposure.
- Prevent secondary exposure to dust from powdered dyes from settled deposit by using appropriate storage methods, ventilation methods and cleaning.
- Train workers about sensitisation, how to handle dyes safely and how to report health symptoms.
- Make appropriate PPE available free of charge, as well as training on how it should be used.
- Carry out health surveillance for workers at risk of being exposed to reactive dyes.

Sources include: EC 2009, HSE n.d.

Spotlight on textiles:
One of the largest employers worldwide

The Asia-Pacific region accounts for 60 per cent of the world's total apparel exports – a fact that has led it to be labeled the "clothing factory of the world" (ILO, 2020c). The region employed an estimated 65 million garment sector workers in 2019, accounting for 75 per cent of all garment workers, bringing the global total to 80 million (ILO 2020c). Three of the world's top five garment exporters are China, Bangladesh and Vietnam (ILO 2019f). Despite some progress in occupational standards, concerns about working conditions in LMIC persist and exposures to hazardous substances remain high (Barua and Ansary 2017; Ahsan et al. 2019).

Thousands of dyes and solvents are used in textile production, many of which have mutagenic and carcinogenic properties (Singh and Chadha 2016). Commonly used chemicals include:

- Crease-resistant agents: Used in finishing processes, they may contain formaldehyde, known for its toxicity and regulated in many countries.

- Flame retardant chemicals: These include organophosphorus and organobromine compounds, which have been associated with adverse health outcomes.
- Azo dyes: Constitute 60-70% per cent of all dyestuff used in textile production (Rawat et al. 2016), however are known to release carcinogenic aromatic amines, many of which are banned from clothing textiles in the EU.

Increased incidence of bladder cancer and lung cancer have been consistently reported in textile industry workers exposed to carcinogens (Singh and Chadha 2016). In addition, increased incidence of dermatitis has been reported in textile workers (Chen et al. 2017). Higher frequency of chronic bronchitis and COPD have also been observed among textile workers (Nafees et al. 2016) as well as increased mortality for diabetes and ischaemic heart disease (Zanardi et al. 2011).

Women constitute more than 80 per cent of the workforce in the textiles, clothing, leather and footwear industry (ILO 2019). Within the Asia-Pacific region, the majority of garment workers are women (35 million), with the garment sector employing 5.2 per cent of all working women in the region (ILO 2020c). Many of these are young women and therefore concerns exist regarding the potential impact on current and future pregnancies (ILO 2019e). For example, trichloroethylene, a solvent used to scour cotton, wool, and other fabrics has been shown to cross the placenta and can cause congenital heart defects in the developing fetus (ATSDR 2019).

Phasing out the most hazardous chemicals is considered a priority action for the textile industry. The EU has provided a good example by restricting the use of 33 substances classified as carcinogenic, mutagenic or toxic for reproduction (CMR) in the textile/garment sector, starting from November 2020 (EU-Commission 2018). Extending this ban globally could prevent exposure to chemicals known to be carcinogenic, mutagenic or toxic for reproduction. The EU restriction covers polar aprotic solvents and azo-dyes and acrylamines, as well as a number of others.

▶ Case study: A disease burden analysis of garment factory workers in Bangladesh proposal for annual health screening

Health status of garment and textile factory workers in Bangladesh was characterized in a retrospective review of worker health information using 1906 medical records. The mean age of the workers was 27.9±7.3 y, with 60 per cent female and 40 per cent male. One-fifth of all workers were found to be anaemic. Elevated blood pressure was also present among 12 per cent of workers, and elevated fasting blood glucose among 8 per cent. A majority of these health conditions had not been previously diagnosed. Despite the relatively young mean age, significant percentages of workers were identified as having undiagnosed health conditions which required urgent medical attention. The findings suggest that provision for annual health screening, either by mobile on-site clinics or by training the existing in-house medicals staff, will help improve health of garment workers (Solinap et al. 2019).

Reminder

The Global Alliance to Eliminate Lead Paint (Lead Paint Alliance) is a voluntary partnership formed by the United Nations Environment Programme (UNEP) and the World Health Organization (WHO) to prevent exposure to lead through promoting the phase-out of paints containing lead. The ILO has joined the Alliance and leverages its unique tripartite structure to promote social dialogue towards the phase out of the manufacture and sale of lead paint. More information on tools to promote the phase out of lead in paint can be found here.

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Manufactured nanomaterials (MNMs)

- Manufactured nanomaterials (MNMs) do not belong to any specific group of chemicals, but are defined as materials that have at least one dimension (height, width or length) that is smaller than 100 nanometers. However, they can be grouped further according to composition.
- The recent increase in production and use of MNMs in a wide variety of industries and products highlights the need to comprehensively assess OSH impacts.
- Health hazards can result from inhalation, ingestion or skin absorption of MNMs.
- Multi-walled carbon nanotubes and titanium dioxide have been classified by IARC as possible carcinogens (group 2B). Other health impacts for a range of MNMs include specific organ toxicity after chronic exposure.
- The field of nanotechnology is expanding rapidly, which means that much is still unknown about additional health effects and gender related impacts.

Humans have long been exposed to unintentionally produced nanoparticles

such as those from combustion processes, but the recent increase in MNM production represents a **novel exposure risk for workers**

Exposure

In the workplace, health hazards can result from inhalation, ingestion or skin absorption of MNMs. The human lungs represent an excellent entry portal for MNMs due to their high surface area, thin epithelial barriers and extensive vasculature. While dermal and oral exposure may occur, inhalation is more likely to result in a larger systemic dose of MNMs (WHO 2017b).

The global nanotechnology market is expected to grow by a compound annual growth rate of 18 per cent from US$39.2 billion in 2016 to US$90.5 billion by 2021 (BCC Research 2017). This includes the market for nanoparticle-based sunscreen products and nano-catalyst thin films for catalytic converters, thin film solar cells, nanolithographic tools and nanoscale electronic memories and many other applications (BCC Research 2017). Nanosilver, due to its antibacterial and antimicrobial properties, is widely used in the manufacture of consumer products, with most uses in electronics, information technology, health care, textiles and personal care products. Titanium dioxide and silicon dioxide nanoparticles are also widely used and constitute, together with nanosilver, 25 per cent of the nanoproducts introduced on the market (Inshakova and Inshakov 2017). MNMs are also increasingly used for pest control (Athanassiou et al. 2018).

Health effects

The physicochemical properties and the associated health effects of MNMs depend on their characteristics, such as size, shape, composition, surface characteristics, charge and extent of their solubility. Humans have long been exposed to unintentionally produced nanoparticles, such as those from combustion processes, but the recent increase in MNM production represents a novel exposure risk for workers.

Cancer

Epidemiological evidence of occupationally-related tumours typically emerge only after decades of latency. Since MNMs were introduced quite recently on the market, this means that such evidence is currently not available. As a comparison, the peak of asbestos-related mesothelioma occurs only after 65 years of age. However, there are different long-term cancer bioassays that are the most predictive toxicological assays for carcinogens (Bucher 2002), and these have been performed on MNMs. In vitro assays for relevant key characteristics of carcinogens (Guyton et al. 2018) have also been performed on different MNMs.

One type (Mitsui-7) of Multi-Walled Carbon NanoTubes (MWCNT) have been classified by IARC as possible carcinogens (group 2B) (IARC 2018). This type of MWCNT was found to induce malignant mesothelioma when administered by intrascrotal or intraperitoneal injection in rodents, and an inhalation study demonstrated that rats exposed to respirable MWCNT developed lung tumours (Sakamoto et al. 2009; Kasai et al. 2015). MWCNT were shown to induce both lung tumours and malignant mesothelioma in rats, when administered by trans-tracheal intrapulmonary spraying (Numano et al. 2019). Progress has been made in understanding carbon nanotube (CNT)-induced pathologic conditions in recent years, demonstrating a close interconnection with inflammation, fibrosis and cancer. The key factors seem to be that MWCNT are long, rigid and biopersistent fibres that are small enough to reach the peripheral lungs, similar to asbestos fibres (Poland et al. 2008). Mechanistically, a number of mediators, signaling pathways, and cellular processes are identified as major mechanisms that underlie the interplay between inflammation, fibrosis, and malignancy, and serve as pathogenic bases for these disease conditions in CNT-exposed animals. These studies indicate that CNT-induced pathological effects, in particular, inflammation, fibrosis, and cancer, are mechanistically, and in some cases, causatively, interrelated (Dong and Ma 2019).

Titanium dioxide or TiO2 (not size-specific) was classified by IARC as possibly carcinogenic (group 2B) (IARC 2010b) and as a suspected carcinogen by the European Chemicals Agency (ECHA) (Canu et al. 2019). The US NIOSH has classified inhaled ultrafine TiO2 as a potential occupational carcinogen. These evaluations were based on studies that found an increased risk of lung cancer in studies on rats. In particular, an inhalation study showed a statistically significant increase in lung cancer in rats exposed to ultrafine TiO2 at an average concentration of 10 mg/m3 (Heinrich et al. 1995). More recently, chronic exposure to food grade TiO2 (E171, a white coloring agent with up to 36 per cent of MNMs) was able to initiate and promote the expansion of preneoplastic lesions in the colon of rats, which parallels the development of an inflammatory microenvironment in

▶ Case study: Carbon nanotube and nanofiber exposure and sputum and blood biomarkers of early effect among U.S. workers

An industry wide cross-sectional epidemiological study of 108 workers from 12 US worksites was conducted to evaluate associations between occupational carbon nanotube and nanofiber (CNT/F) exposure and sputum and blood biomarkers of early health effect. CNT/F exposure was assessed via personal breathing zone, filter-based air sampling. A number of biomarkers of early health effect were associated with CNT/F exposure. Inhalable rather than respirable CNT/F was more consistently associated with fibrosis, inflammation, oxidative stress, and cardiovascular biomarkers (Beard et al. 2018).

the mucosa, and the selection of preneoplastic cells in vitro (Bettini et al. 2017).

Other health outcomes

Apart from carcinogenic effects, many other non-cancer effects have emerged from toxicological studies. For single-walled carbon nanotubes (SWCNT) there is evidence of a hazard for germ cell mutagenicity and specific organ toxicity after repeated exposure. For MWCNT, there is evidence of a hazard for eye damage, germ cell mutagenicity and specific organ toxicity after repeated exposure. For silver nanoparticles, there is evidence of a hazard for respiratory/skin sensitisation and specific target organ toxicity after repeated exposure. For gold nanoparticles, there is evidence for specific target organ toxicity after repeated exposure. For silicon dioxide, there is evidence for specific target organ toxicity after repeated exposure. For titanium dioxide, there is evidence for reproductive toxicity and specific organ toxicity after repeated exposure. For cerium dioxide, there is evidence of specific target organ toxicity after repeated exposure. For zinc oxide, there is evidence for specific organ toxicity after repeated exposure (WHO 2017b).

Regional trends

The United States, South Korea, China, and Japan are the largest producer of nanoproducts and hold the largest proportions of those nanotechnology patents (StatNano 2019). Middle-income countries such as Brazil and South Africa produce MNMs and have research laboratories that produce CNTs. LMICs produce nanosilver that is incorporated in milk packs, fabrics and clothes and MNMs are also produced for use by the pharmaceutical industry. The implementation of OSH regulations is usually less effective in LMICs, which means that workers in these countries are at greater risk of the potential negative health effects than their counterparts in high-income countries (WHO 2017b).

The role of gender

There are still many unknowns about the diverse group of MNMs and their impact on human health, including gender impacts. Due to the wide use of MNMs, the gender balance of the workforce is hard to assess. While most studies of health impacts of nanomaterials have been conducted on animals such as rodents, there are some indication of health impacts especially relevant for the female workforce. Preliminary evidence has indicated that carbon nanotubes may harm the female reproductive system, cross the placenta and cause embryo lethality, early miscarriages and fetal malformations in female mice (Hansen and Lennquist 2020). Titanium dioxide nanoparticles can cause ovarian dysfunction, affect genes regulating immune response, disrupt the normal balance of sex hormones and decrease fertility (Sun et al. 2013). In addition, many MNMs can cross the placenta where they can cause altered development of internal organs and morphology as well as defects in the reproductive and nervous systems of the offspring (Sun et al. 2013).

Reminder

ILO Chemicals Convention No.170 has an all-encompassing scope and covers all chemicals and all mixtures including novel and emerging chemical hazards. As such, C170 represents a legislative gap filler and ratifying and implementing the convention can be seen as a priority for MNMs. More information can be found here.

MAIN SECTORS OF EXPOSURE	SUBSTANCE	PRIMARY HEALTH IMPACTS	GLOBAL BURDEN OF OCCUPATIONAL EXPOSURES	WORK-RELATED HEALTH IMPACT
Chemical industries Food; drink; tobacco Health services Mechanical and electrical engineering Textiles; clothing; leather; footwear	Carbon Nanotubes (MWCNT)	Cancer (mesothelioma and lung cancer)	Limited data	Limited data
	Titanium Dioxide	Cancer (lung cancer)	Limited data	Limited data

▶ Selected priority actions: Manufactured Nanomaterials

Examples of national policy measures

- Develop national laws or regulations that focus on enhanced risk assessment and reduce occupational exposure to MNMs in the workplace.

Additional actions for policy makers

- Gather and make publicly available information about MNM health hazards. An example includes Nanodatabase, produced by the Danish Ecological Council and Danish Consumer Council. This database now includes more than 5,000 products containing MNMs.
- Make resources available for increased workplace research on MNMs and their occupational health impacts, including gender- and sex-differentiated studies of impact.
- Establish regulatory data requirements on MNMs in the workplace, taking into account their properties and life cycles, to inform future hazard and risk assessments.
- Strengthen social dialogue and promote concerted actions at the international level to work towards common definitions and toxicological grouping strategies for MNMs.
- Ensure legislation for harmonised labelling for MNMs, particularly in light of the increasing evidence concerning the workplace hazards related to MNMs exposure.

Occupational Exposure Limits (OELs)

- Develop evidence-based OELs for MNMs and methods to implement and enforce them, as comprehensive regulatory OEL values for MNMs in workplaces do not currently exist. Ensure global harmonisation of these OELs.
- Assess if workplace exposures exceed the proposed OEL values in annex 1 of the WHO Guidelines on Protecting Workers From Potential Risks Of Manufactured Nanomaterials. Workplace exposure studies indicate that in many situations, exposure can rapidly exceed the proposed OELs. The chosen OEL should be at least as protective as a legally mandated OEL for the bulk form of the same material.
  - NIOSH recently proposed a quantitative framework to group nanoscale and microscale particles by hazard potency to derive OELs. This demonstrated that the development of OELs for MNMs remains a priority. The EU also emphasises the creation of a robust evidence-base and practical approaches for regulating MNMs in the workplace.

Practical workplace interventions

- Consider, as a first control measure, changing the process in such a way that no MNMs will be released into the air.
- Use engineering controls when there is a high level of inhalation exposure or when there is no, or very little, toxicological information available.
- Prevent dermal exposure by occupational hygiene measures such as surface cleaning and the use of appropriate gloves.
- Conduct worker exposure assessments using comprehensive exposure assessment using evidence-based methods.
- Educate potentially exposed workers on the risks of MNMs and how best to protect themselves. Topics should include which hazards are specific to MNMs and different from the bulk material; which hazard classes are assigned to MNMs; which routes of exposure are important; which workplace exposures have been measured and which tasks put workers most at risk; how proposed OELs can be interpreted; when and how control banding, specific controls and PPE for MNMs can be used.
- Use PPE in the absence of appropriate engineering controls, especially respiratory protection, as part of a respiratory protection programme that includes fit-testing.

Sources include: WHO 2017b, UNEP 2020a, Drew et al. 2017, Hodson et al. 2019, EU-Commission 2020b, EU-Commission 2020b.

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Perfluorinated chemicals (PFAS)

- First created in the 1930s, perfluorinated chemicals (PFAS) include over 4,730 man-made chemicals that contain fluorine atoms bonded to a carbon chain. Perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) have been manufactured the longest, are the most widespread in the environment and are the most studied PFAS to date.

- The chemical composition of PFAS makes them oil and water repellent, stabile at high and low temperatures, and effective for friction reduction, marking them as important additives for many consumer products.

- PFAS have been used in a wide range of products, including textiles, paper products, food contact materials, semiconductors, automotive and aerospace components, cookware, food packaging, stain repellant clothing and firefighting foams.

- PFAS have been linked to a variety of cancers and are known to interfere with immune function, endocrine function and breast development.

- Biological sex can influence effects resulting from exposure to PFAS as well as bioaccumulation and clearance. Since PFAS are so widely used, it is difficult to assess gender implications for exposure and health impacts. Studies have shown elevated levels of PFAS in the blood of both male and female firefighters.

Perfluorinated chemicals (PFAS) include over

4,730 man-made chemicals

that contain fluorine atoms bonded to a **carbon chain**

Exposure

Human exposures to PFAS are extremely widespread and particularly high levels are often found in workers in chemical industries. The US National Health and Nutrition Examination Survey (NHANES) reported detectable PFAS blood serum concentrations in virtually all individuals in the United States (97 percent). Workers in the chemical industries have the highest potential exposure to PFAS, followed by highly-exposed residents and then the general population. In one study of workers at the Washington Works facility in West Virginia, the average serum PFOA level in 2001–2004 was 1,000 ng/mL (Sakr et al. 2007); the mean PFOA level in highly-exposed residents (without occupational exposure) near this facility was 423 ng/mL in 2004–2005 (Emmett et al. 2006). By comparison, the geometric mean concentration of PFOA in the US population was 3.92 ng/mL in 2005–2006 (K. Kato et al. 2011).

Health effects

Cancer

IARC has classified PFOA as possibly carcinogenic to humans (Group 2B) (IARC 2017) and the US Environmental Protection Agency (EPA) (2016e, 2016f) concluded that there was suggestive evidence of the carcinogenic potential of PFOA and PFOS in humans. The US National Toxicology Program (US NTP) recently showed that there was clear evidence of carcinogenic activity following PFOA exposure in rats (NTP 2019). **Increases in testicular, liver and kidney cancer have been observed in workers and communities chronically exposed to high levels of PFAS** (Barry et al. 2013; Steenland and Woskie 2012; Vieira et al. 2013; Girardi and Merler 2019).

Other health outcomes

A review of epidemiological studies reported potential associations between perfluoroalkyl exposure and several health outcomes related to the liver, including liver damage, as shown by increases in serum enzymes and decreases in serum bilirubin levels (specifically for PFOA, PFOS, PFHxS), and increases in serum lipids, particularly total cholesterol and low-density lipoprotein (LDL) cholesterol (specifically for PFOA, PFOS, PFNA, PFDeA) (ATSDR 2018). Another systematic review concluded that PFOA and PFOS are presumed to be a hazard to immune system functioning in humans (NTP 2016). This conclusion is based on evidence that PFOA and PFOS suppressed the antibody response in animal studies and that these chemicals affect multiple aspects of the immune system in humans, including decreases in antibody production (Kielsen et al. 2016). Furthermore PFOA and PFOS cause developmental toxicity in animals and human epidemiology studies also show associations between some PFAS and developmental effects (Butenhoff et al. 2009; Koustas et al. 2014; Valvi et al. 2017). A systematic review and meta-analysis of the data estimated that a 1ng/mL increase in serum or plasma PFOA was associated with a -18.9 gram difference in birth weight in humans (Johnson et al. 2014). PFAS also present endocrine disrupting properties, specifically human and animal studies showed an association of PFAS exposures with thyroid hormones imbalances and decreased fertility (Donat-Vargas et al. 2019; Hines et al. 2009; Preston et al. 2018; Bach et al. 2016).

Regional trends

PFAS contamination is ubiquitous in humans and in the environment (Hu et al. 2016). However the highest levels of exposure tend to be observed near PFAS producing facilities or disposal sites, both in developed and developing countries (Guelfo et al. 2018). While different developed countries are starting to phase out PFAS and are imposing more restrictive limits (OECD 2015), in LMICs this is not occurring and the production of PFAS have been largely moved from the US and Europe to Asia, with China being the main producer (Song et al. 2018). In 2009, PFOS was listed under the Stockholm Convention for global elimination and in 2019, the Conference of the Parties of the Stockholm Convention listed PFOA for global elimination.

▶ Case study: Male workers exposed to polyfluoroalkyl acids with high internal dose of perfluorooctanoic acid

The association between exposure to PFASs and mortality in a cohort of 462 male employees in a factory that had been producing PFOA and PFOS was investigated. Measurements of workers´ PFOA serum concentration were used to predict a cumulative serum PFOA concentration of each cohort member. Mortality rates were compared to the regional population using the standardised mortality ratio (SMR) and to workers of a nearby metalworking plant in terms of risk ratio (RR), across categories of probability of PFASs exposure and tertiles of cumulative serum PFOA concentrations. Internal PFOA serum concentration among 120 PFAS workers was classified as very high (Geometric mean: 4048 ng/mL; range 19-91,900 ng/mL). Overall mortality in the PFAS worker cohort was increased for liver cancer and malignant neoplasm of lymphatic and haematopoietic tissue. In comparison with metalworking plant workers, the RRs for mortality were increased in PFAS workers for overall mortality, diabetes, liver cancer and liver cirrhosis. Mortality for these causes increased in association with probability of PFASs exposure and with cumulative PFOA serum concentrations. The cohort showed increased mortality for all causes and subjects in the highest cumulative internal dose of PFOA had a statistically significant increase for mortality of liver cancer, liver cirrhosis, diabetes, malignant neoplasms of lymphatic and haematopoietic tissue in both comparisons (Girardi and Merler 2019).

The role of gender

Biological sex has implications for health effects resulting from PFAS exposure, such as impact on hormones, fertility and pregnancy. Also, physiological differences can impact bioaccumulation and clearance. For example, one study showed that female workers below 50 years of age in a fluorochemical plant in China had a lower half-life of perfluoroalkyl acids in the body compared to the male workers (Fu et al. 2016).

While workers in PFAS manufacturing are especially exposed, exposure to PFAS can occur in a wide variety of occupational settings since they are used in numerous products. It is therefore difficult to draw any general conclusions on gender-related differences of exposure. However, several studies have shown that **firefighters have higher blood levels of PFAS compared to the general population due to exposure from PFAS-containing firefighting foam, as well as PFAS treated protective gear**. Firefighting is generally a male-dominated occupation and most studies have been focussed on male worker cohorts. However, a recent study of an all-female cohort of firefighters showed that all of the 86

MAIN SECTORS OF EXPOSURE	PRIMARY HEALTH IMPACTS	GLOBAL BURDEN OF OCCUPATIONAL EXPOSURES	WORK-RELATED HEALTH IMPACT
Chemical industries Food, drink, tobacco Textiles, clothing, leather, footwear Construction Electronics manufacturing Aerospace Automotive Emergency response	Cancer (testicular, liver and kidney) Immune toxicity Liver Toxicity Reproductive Toxicity	Limited data	Limited data

▶ Selected priority actions: Perfluorinated chemicals

Examples of national policy measures

- Develop regulations to address PFAS use at the workplace, focused on eliminating and substituting with safer alternatives.
- Refer to the 2020 EU Commission's new set of comprehensive actions to address the use of and contamination with PFAS due to "a full spectrum of illnesses and the related societal and economic costs". The actions aim to ensure that the use of PFAS is phased out in the EU unless it is proven essential for society. Due to the ubiquitous nature of PFAS exposure across workplaces and proven health impacts, the phase out of PFAS for safer alternatives marks a priority initiative that should be replicated globally.
- Refer to and implement the Stockholm Convention and other related policies for PFAS:
  - Since 2009, perfluorooctane sulfonic acid (PFOS) and its derivatives have been included to eliminate their use. In 2019, governments agreed to a global ban on perfluorooctanoic acid (PFOA), its salts and PFOA-related products.
  - PFOS and PFOA have also been phased out in the EU under the POPs Regulation.

Additional actions for policy makers

- Consider listing additional types of PFAS under the Stockholm Convention for global elimination, using a grouping approach for increased effectiveness.
- Implement or prioritise the use of safer non-persistent alternatives for all PFAS uses that cannot be contained. This includes firefighting foams, a major source of PFAS contamination, for which fully effective alternatives are now available, such as non-persistent fluorine-free foams. Any operational differences between persistent and non-persistent foams can now either be engineered out or dealt with by appropriate training.
- Harmonise classification and labelling, applying the GHS as relevant.

Occupational Exposure Limits (OELs)

- Develop evidence-based OELs for PFAS. The US EPA plans to develop cancer and noncancer toxicity values for PFAS, where sufficient health effects data currently exist, are publicly available and adequately support human health toxicity value derivation.

Examples of practical workplace interventions

- Provide targeted preventative measures to occupations especially exposed to PFAS, such as firefighters and workers in the chemicals industries and products manufacturing
- Ensure that appropriate training is given when non-persistent alternatives are used.
- Supply effective PPE designed to effectively protect people of all body types, including physiological differences between genders.
- Ensure medical surveillance of exposed workers, using new approaches to biomonitoring, such as general suspect screen (GSS). GSS integrates exposure knowledge and serum suspect screening and has proven to be an effective technique in female firefighters.

Sources include: IPEN 2019, EU-Commission 2020a, Grashow et al. 2020

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Endocrine-disrupting chemicals

- Endocrine disrupting chemicals (EDCs) are substances that can act at very low doses to impact the functioning of the endocrine system. This can lead to adverse health effects in an organism, its offspring or populations, such as changes in the morphology, physiology, growth, development, reproduction or life span.
- EDCs belong to many different chemical groups, which means that exposure can occur in a wide range of occupations.
- EDCs have been implicated in multiple reproductive disorders in men and women, as well as cancers, neurodevelopmental disorders and obesity.
- Scientific studies have estimated significant costs due to health effects of EDCs: US$217 billion per year in the EU and US$340 billion per year in the United States.
- Endocrine-disrupting chemicals impact both sexes, but exposure to the same chemicals may cause different effects in men and women.

Scientific studies have estimated significant costs due to **health effects of EDC**

US$340 billion per year

US$217 billion per year

Exposure to EDCs can occur in a very **wide range of occupations**

▶ Figure 6. List of EDCs (part 1)

Chemical Name	CAS Number(s)	Completed assessments as the basis for inclusion *	Other completed assessments	Ongoing and planned assessments
BENZOPHENONES				
Benzophenone-1; 2,4-Dihydroxybenzophenone; Resbenzophenone	131-56-6	SIN, Danish Criteria (Cat. 2a)	EU Priority List Category 1	
Benzophenone-2; 2,2',4,4'-tetrahydroxybenzophenone	131-55-5	SIN, Danish Criteria (Cat. 1)	EU Priority List Category 1	
Benzophenone-3; Oxybenzone	131-57-7	SIN, Danish Criteria (Cat. 2a)	EU Impact Assessment	EU CoRAP
4,4'-dihydroxybenzophenone	611-99-4	SIN, Danish Criteria (Cat. 2a)	EU Priority List Category 1	
3-BC, MBC, EHMC				
3-Benzylidene camphor (3-BC); 1,7,7-trimethyl-3- (phenylmethylene) bicyclo[2.2.1]heptan-2-one	15087-24-8	SIN, Danish Criteria (Cat. 1)	EU Impact Assessment, EU Priority List Category 1	
3-(4-Methylbenzylidene) camphor; 1,7,7-trimethyl-3-[(4- methylphenyl) methylene]bicyclo[2.2.1] heptan-2-one	36861-47-9	SIN, Danish Criteria (Cat. 1)	EU Priority List Category 1	
2-ethylhexyl 4-methoxycinnamate	5466-77-3 /			
83834-59-7	SIN, Danish Criteria (Cat. 1)	EU Impact Assessment, EU Priority List Category 1	EU CoRAP	
BISPHENOLS F AND S				
Bisphenol F	620-92-8	SIN		
Bisphenol S	80-09-1	SIN	EU Impact Assessment	EU CoRAP
PARABENS				
Methylparaben	99-76-3	Danish Criteria (Cat. 2a)	EU Impact Assessment, EU Priority List Category 1	EU CoRAP
Ethylparaben	120-47-8	Danish Criteria (Cat. 2a)	EU Priority List Category 1	EU CoRAP
Propylparaben; propyl 4-hydroxybenzoate	94-13-3	SIN, Danish Criteria (Cat. 2a)	EU Impact Assessment, EU Priority List Category 1	EU CoRAP
Butylparaben; butyl 4-hydroxybenzoate	94-26-8	SIN, Danish Criteria (Cat. 1)	EU Priority List Category 1	
PHTHALATES (NON-EU REACH SVHCs)				
Diethyl phthalate (DEP)	84-66-2	SIN, Danish Criteria (Cat. 2a)	EU Impact Assessment, EU Priority List Category 1	US EDSP, Japan EXTEND
Dihexyl phthalate (DHP)	84-75-3	SIN, Danish Criteria (Cat. 1)	EU Impact Assessment, EU REACH SVHC **	Japan EXTEND
Dicyclohexyl phthalate (DCHP)	84-61-7	SIN, Danish Criteria (Cat. 1)	EU Priority List Category 1	EU CoRAP, Japan EXTEND
Dioctyl phthalate	117-84-0	SIN		
Diisodecyl phthalate (DiDP)	68515-49-1 / 26761-40-0	SIN		
Diundecyl phthalate (DuDP), branched and linear	3648-20-2	SIN		
OTHER PHENOL DERIVATIVES				
4-nitrophenol	100-02-7	SIN, Danish Criteria (Cat. 2a)		
2,4,6-tribromophenol	118-79-6	SIN		
Resorcinol	108-46-3	SIN, Danish Criteria (Cat. 1)	EU Impact Assessment, EU Priority List Category 1	EU CoRAP
BHT AND BHA				
Butylated hydroxytoluene (BHT)	128-37-0	SIN		EU CoRAP
Tert.-Butylhydroxyanisole (BHA); tert-butyl-4-methoxyphenol	25013-16-5	SIN, Danish Criteria (Cat. 1)	EU Impact Assessment, EU Priority List Category 1	EU CoRAP, US EDSP
DITHIOCARBAMATES				
Metam-sodium	137-42-8	SIN, Danish Criteria (Cat. 1)	EU Priority List Category 1	
Zineb	12122-67-7	SIN, Danish Criteria (Cat. 1)	EU Impact Assessment, EU Priority List Category 1	Japan EXTEND
Ziram	137-30-4	SIN	EU Impact Assessment	EU CoRAP, US EDSP,
Japan EXTEND				

Thiram	137-26-8	SIN, Danish Criteria (Cat. 1)	EU Impact Assessment, EU Priority List Category 1	
PCP, TEBUCONAZOLE, AND TRICLOSAN				
Pentachlorophenol (PCP)	87-86-5	SIN, Danish Criteria (Cat. 1)	EU Priority List Category 1	US EDSP, Japan EXTEND
Tebuconazole	107534-96-3	Danish Criteria (Cat. 1)	EU Impact Assessment	US EDSP
Triclosan	3380-34-5	Danish Criteria (Cat. 1)	EU Impact Assessment	EU CoRAP
MISCELLANEOUS				
Tert-butyl methyl ether; MTBE; 2-methoxy-2-methylpropane	1634-04-4	SIN, Danish Criteria (Cat. 1)	EU Impact Assessment, EU Priority List Category 1	EU CoRAP, US EDSP
Quadrosilan; 2,6-cis-Diphenylhexamethylcyclotetrasiloxane	33204-76-1	SIN, Danish Criteria (Cat. 1)	EU Priority List Category 1	
Carbon disulphide	75-15-0	SIN	EU Impact Assessment	EU CoRAP
Triphenyl phosphate	115-86-6	SIN	EU Impact Assessment	EU CoRAP

Source: UNEP
The chemicals which appear in this table have not been identified as known or suspected EDCs as part of a regulatory review which considers and weighs all available evidence, engages external peer review and is open and responsive to public review and comment.
** Specific categorization from the Danish criteria results is provided. Cat. 1 = Category 1 (endocrine disruptor), Cat. 2a = Category 2a (suspected endocrine disruptor).*
*** This initiative has chemicals included specifically due to their endocrine disrupting potentials, however, these chemicals were included in the initiative for other reasons.*

▶ Figure 7. List of EDCs (part 2)

Chemical Name	CAS Number(s)	Completed assessments as the basis for inclusion	Other completed assessments	Ongoing and planned assessments
Bis(2-ethylhexyl) phthalate; DEHP	117-81-7	EU REACH SVHC	EU Impact Assessment, EU Priority List Category 1	US EDSP, Japan EXTEND
Diisobutyl phthalate; DIBP	84-69-5	EU REACH SVHC	EU Impact Assessment	
	131-55-5	SIN, Danish Criteria (Cat. 1)	EU Priority List Category 1	
Dibutyl phthalate; DBP	84-74-2	EU REACH SVHC	EU Impact Assessment, EU Priority List Category 1	US EDSP, Japan EXTEND
Benzyl butyl phthalate; BBP	85-68-7	EU REACH SVHC	EU Impact Assessment, EU Priority List Category 1	US EDSP, Japan EXTEND
4-(1,1,3,3-tetramethylbutyl) phenol	140-66-9	EU REACH SVHC	EU Impact Assessment, EU Priority List Category 1	
4-(1,1,3,3-tetramethylbutyl) phenol, ethoxylated	2315-67-5/ 2315-61-9/ 9002-93-1/ 2497-59-8/ Others not specified	EU REACH SVHC		
4-Nonylphenol, branched and linear	84852-15-3/ 26543-97-5/ 104-40-5/ 17404-66-9/ 30784-30- 6/ 52427-13-1/ 186825-36-5/ 142731-63-3/ 90481-04-2**/ 25154-52-3**/ Others not specified	EU REACH SVHC	EU Priority List Category 1	EU CoRAP*
4-Nonylphenol, branched and linear, ethoxylated	104-35-8/7311-27-5/ 14409-72-4/ 20427-84-3/ 26027-38-3/ 27942-27-4/ 34166-38-6/ 37205-87-1/ 127087-87-0/ 156609-10-8/ 68412-54-4**/ 9016-45-9**/ Others not specified	EU REACH SVHC	EU Priority List Category 1	EU CoRAP
4-Heptylphenol, branched and linear	6465-71-0/ 6465-74-3/ 6863-24-7/ 1987-50-4/72624-02-3/ 1824346-00-0/ 1139800-98-8/ 911371-07-8 / 911371-06-7 /911370-98-4/ 861011-60-1/ 861010-65-3/ 857629-71-1/ 854904-93-1/ 854904-92-0/ 102570-52-5/ 100532-36-3/ 72861-06-4/ 71945-81-8/ 37872-24-5/ 33104-11-9/ 30784- 32-8/ 30784-31-7/ 30784-27-1	EU REACH SVHC		
p-(1,1-dimethylpropyl) phenol	80-46-6	EU REACH SVHC	EU Impact Assessment	EU CoRAP

Source: UNEP
** This initiative has chemicals included specifically due to their endocrine disrupting potentials, however, these chemicals were included in the initiative for other reasons.*

*** Identified as additional CAS numbers by ChemSec for these compounds on the SIN List and are not originally on the EU REACH SVHC list.*

Exposure

Exposure to EDCs varies widely within and among countries. It has been estimated that the majority of the health related costs caused by EDCs in the United States are related to flame retardants, while in Europe they are related to organophosphate pesticides (Trasande et al. 2016; Attina et al. 2016).The costs estimated for the health effects of exposure to 10 EDCs was US$217 billion per year in the EU (Trasande et al. 2016) and US$340 billion USD per year in the United States (Attina et al. 2016). An additional important conclusion to draw from these studies is the limited availability of data on the burden of EDCs worldwide. Furthermore, these studies considered a limited number of EDCs effects (only 10 EDCs were included in the analysis), suggesting a possible underestimation of the costs. The life cycles of EDCs are of particular concern, since many of them can contaminate workers even decades after their use has been discontinued. This is the case for PCBs: even though their production was banned worldwide in the 1970s, they are still present and continue to contaminate workers due to their biopersistence (Ma et al. 2018; Gioia et al. 2014). The life cycle of plastics containing EDCs represents, in particular, a global challenge, in light of the increasing production volumes and ubiquitous environmental contamination with microplastics (Chen et al. 2019). However specific data on prevalence of exposure to EDCs in workers and related health effects, especially associated with fertility, are missing.

The construction and plastics industries employ millions of workers globally, which use large quantities of chemicals that are known or suspected EDCs. Current health surveillance of these workers gives very limited insight into the health risks associated with exposure to EDCs (Butchko and Stargel 2001). A recent systematic review on biomonitoring of occupational exposure to phthalates highlighted the lack of recent occupational studies on both old and new phthalate exposure in the EU and the need for a harmonised approach (Fréry et al. 2020).

The definition of EDCs proposed by the WHO and International Programme on Chemical Safety (IPCS) in 2002 is now widely accepted (WHO 2002): "an endocrine disrupter is an exogenous substance or mixture that alters function(s) of the endocrine system and consequently causes adverse health effects in an intact organism, or its progeny or populations." An adverse effect is defined as: "a change in the morphology, physiology, growth, development, reproduction or life span of an organism, system or population (Tanakaya et al. 2015) that results in an impairment of functional capacity, an impairment of the capacity to compensate for additional stress or an increase in susceptibility to other influences."

Health effects

While EDCs belong to different chemical groups and have a wide range of different chemical-physical properties, they all share the capacity of altering the endocrine system. Hormones are secreted into the blood or within organs and act on target tissues throughout the body at extremely low concentrations (typically in the part per trillion to part per billion range). Similarly, endocrine disruptors can act at very low doses, acting as exogenous hormones or altering the endogenous hormone balance. UNEP has recently produced three overview reports on EDCs (UNEP 2017a, 2017b, 2017c) and produced a list of 45 substances identified as EDCs or potential EDCs belonging to 18 chemical groups.

Cancer

Strong evidence has accumulated since the 1970s for an implication of oestrogens in the incidence of different types of cancers. Synthetic oestrogen diethylstilboestrol (DES) has been shown to increase the risk of breast and vaginal cancer following intra-uterine exposure (Newbold 2008; Schrager and Potter 2004). Another example is a drug against breast cancer, Tamoxifen, which inhibits oestrogen-stimulated growth of breast cancer cells, but is associated with potent oestrogen activity in the uterus. Consequently, tamoxifen has been classified by IARC as a known carcinogen for the endometrium (Yang et al. 2013). Bisphenol A (BPA), a common chemical in plastics, also interacts with the oestrogen receptors and is a possible risk factor for breast cancer (Seachrist et al. 2016). Additionally, experimental evidence

▶ Case study: Phthalate exposure in sales clerks

High levels of phthalates in cosmetic products have raised concerns about phthalate exposure and the associated risk for cosmetics sales clerks in southern Taiwan. The exposure and risk of phthalates was analysed in 23 cosmetics, 4 perfume, and 9 clothing department store sales clerks. The urinary levels of the phthalates mono-2-ethylhexyl phthalate (MEHP) and monomethyl phthalate (MMP) were significantly higher after their shift than the corresponding pre-shift levels in cosmetics group, and the post-shift levels of urinary MMP was significantly higher than the corresponding pre-shift levels in the perfume group. Over half of the cosmetics (70 per cent) and perfume sale clerks had exceeded cumulative risk of phthalate exposure for anti-androgenic effect. Cosmetic and perfume workers had increased risks of reproductive or hepatic effects for diethyl phthalate (DEP) and DEHP exposure. The study also noted that dermal exposure represents an important route of phthalate exposure for cosmetics and perfume workers (Huang et al. 2018).

indicates that BPA exposure can lead to increased susceptibility to prostate cancer (Seachrist et al. 2016). Epidemiological case-control studies documented that the xeno-oestrogenic burden, which corresponds to the overall oestrogen-like activity from molecules stemming from outside the body, can be a predictor of breast cancer incidence (Pastor-Barriuso et al. 2016). Increased incidence of papillary thyroid cancer has also been linked by epidemiology and experimental evidence to EDCs, including flame-retardants and pesticides (Perdichizzi et al. 2014; Hoffman 2017).

Other health outcomes

A range of EDCs have been implicated in multiple reproductive disorders in men and women, from reduced fertility, fecundity (Trasande et al. 2016; Skakkebaek et al. 2019) and testicular dysgenesis syndrome (Skakkebaek et al. 2016). One of the EDCs most clearly linked to male reproductive disorders are phthalates (such as DEHP), which have been linked to cryptorchidism, hypospadias, reduced anogenital distance (Toppari et al. 2010; Lioy et al. 2015). In females, phthalates, benzophenones and dioxins have been linked to endometriosis (Smarr, Kannan, and Louis 2016; Bruner-Tran et al. 2017). Experimental studies have shown that maternal exposure to different EDCs (DES, vinclozolin, BPA and PCBs) adversely affect mating, reproduction and exert multigenerational effects (Walker and Gore 2011; Krishnan et al. 2018). Results from a meta-analysis on a large population-based birth cohort design (almost 134,000 mother–child pairs) indicate that employment during pregnancy in occupations classified as possibly or probably exposed to EDCs, was associated with an increased risk of low birth weight. Further, the risk increased with the increasing number of EDCs groups that women were exposed to (Birks et al. 2016).

Both epidemiological and experimental studies have shown that prenatal exposure to multiple EDCs can diminish IQ or increase risk of neurodevelopmental disorders and obesity (Braun 2017; Mughal et al. 2018; Ghassabian and Trasande 2018). Some of the best studied EDCs adversely affecting neurodevelopment include PCBs, where reductions in cognitive function were observed already decades ago for the highest maternal PCBs exposures (Jacobson and Jacobson 1996). Other known or suspected EDCs that can affect brain development include phosphorylated and brominated flame retardants, some phenols, phthalates and perchlorate (Demeneix 2019). Furthermore, exposures to different EDCs have been associated with type-2 diabetes and obesity, including BPA, phthalates, triclosan and benzo(a)pyrene (Le Magueresse-Battistoni et al. 2018).

The **construction and plastics industries** employ

millions of workers

globally

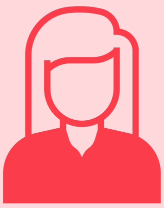
which use large quantities of chemicals that are **known or suspected EDCs**

Regional trends

It has been estimated that environmental exposure to EDCs induce a loss of over 20 million IQ points and over 800,000 cases of cases of male infertility in the US and Europe every year (Trasande et al. 2016; Attina et al. 2016). A recent review explored in the general population if diabetogenic exposure to EDCs was associated with racial, ethnic, and socioeconomic exposure disparities in the US. Among Latinos, African Americans, and low-income individuals, numerous studies have reported significantly higher exposures to diabetogenic EDCs, including polychlorinated biphenyls, organochlorine pesticides, multiple chemical constituents of air pollution, BPA and phthalates (Ruiz et al. 2018). Comparison of occupational exposure to EDCs and related effects among developing and developed countries are currently missing, however disparities might likely play a role in occupational settings as well. Only a few studies exist that are related to burden of disease and exposure for EDCs in LMICs (Bedoya-Ríos et al. 2018), however they are widely recognised as a sensitive target in light of the waste cycles and the lack of regulation (UNEP 2017c; Gioia et al. 2014; Ma et al. 2018).

The role of gender

Women and men share the same hormones, but the levels of different hormones can vary and affect the body differently. As such, exposure to the same EDCs may cause different effects in men and women. Endocrine-disrupting chemicals may for example have adverse effects on regulation of female reproductive hormones and tissues. This in turn can lead to reproductive disorders such as early puberty, infertility, abnormal cyclicity, premature ovarian failure/menopause, endometriosis, fibroids, and adverse pregnancy outcomes. Impacts on male reproductive health have been suggested to include birth defects of male reproductive organs, increased incidence of testicular germ cell carcinoma and poor semen quality (Gore et al. 2015).



Impacts of EDCs on **female reproductive health** include **early puberty, infertility, abnormal cyclicity, premature ovarian failure/menopause, endometriosis, fibroids, and adverse pregnancy outcomes**

Adverse reproductive effects for **men** include **birth defects of male reproductive organs, increased incidence of testicular germ cell carcinoma and poor semen quality**

MAIN SECTORS OF EXPOSURE	SUBSTANCE	PRIMARY HEALTH IMPACTS	GLOBAL BURDEN OF OCCUPATIONAL EXPOSURES	WORK-RELATED HEALTH IMPACT
Chemical industries Food; drink; tobacco Health services Mechanical and electrical engineering Textiles; clothing; leather; footwear Oil and gas production; oil refining Agriculture; plantations; other rural sectors Construction	Overview	Various	Limited data	800,000 cases of male infertility in the US and Europe
	Phthalates	Reproductive toxicity Obesity Diabetes	Limited data	Limited data
	Pesticides (Organophosphates, Triclosan)	Neurotoxicity	Limited data	Limited data
	Parabens	Reproductive toxicity	Limited data	Limited data
	Bisphenols	Cancer (breast, prostate) Obesity Reproductive toxicity	Limited data	Limited data
	Flame retardants	Neurotoxicity Reproductive toxicity	Limited data	Limited data

▶ Selected priority actions: Endocrine-disrupting chemicals

Examples of national policy measures

- Develop national laws or regulations that prescribe measures to be taken for the prevention and control of, and protection against, occupational hazards in the working environment due to EDCs.
- Harmonize international policies on the labelling and regulation of EDCs. UNEP has produced a list of 45 substances identified as EDCs, or potential EDCs, belonging to 18 chemical groups and has also produced overview reports on EDCs. These could be a starting point to build on for harmonised global labelling and regulation of EDCs. Other more extensive lists building on scientific evidence are already available and could be integrated into the UNEP list, such as the EU priority list of EDC chemicals, developed within the EU-Strategy for Endocrine Disruptors.

Additional actions for policy makers

- Create a list of EDCs with a priority of phasing out the ones that are most potent and used most extensively, with the highest risk of exposure.
- Gather, update and make publicly available information about use of EDCs, their health hazards and regulatory measures taken in certain countries
- Use existing measures from industries such as agriculture, manufacturing and waste management to prevent exposures to EDCs.
- Regularly synthesise and disseminate relevant scientific evidence in a policy-ready format to bring governments and world of work stakeholders to the same level of awareness.
- Strengthen dialogues and concerted actions at all levels to enable an effective and efficient way forward, including advancement and implementation of, for example, standard data requirements and testing methods, mutual acceptance of data and existing assessments, joint assessments and joint strategies for addressing EDCs.
- Carry out research on gender-specific endpoints and mainstream gender considerations in OSH regulations for EDCs.

Occupational Exposure Limits (OELs)

- Develop evidence-based OELs for EDCs and methods to implement and enforce them. Ensure global harmonisation of these OELs.
- Evaluate exposures to EDCs to ensure that decision-makers know how chemicals are being used, can access robust biomonitoring data so that exposures can be characterised, and can implement OELs and other exposure mitigation programmes as needed.

Examples of practical workplace interventions

- Ensure EDCs in the workplace are identified, properly classified and labelled so workers and employers understand they are working with EDCs. Prevention measures will differ based on the type of EDC workers are using.
- Apply the hierarchy of controls as relevant to ensure workers are protected from the harmful effects of EDCs.

Sources include: UNEP 2017a, 2017b and 2017c, EU 2020, Kassiotis et al. 2020

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▶ Pesticides

- Pesticides are chemicals with biologically active ingredients used widely by large numbers of agricultural workers and those engaged in vector control. Occupational exposure occurs during handling, dilution, mixing, application and disposal of pesticides, as well as during cleaning of containers and handling of crops.
- Exposure occurs primarily through dermal and inhalation routes. Ingestion might occur through consumption of contaminated food or through oral contact with contaminated hands. Contaminated clothing is a significant source of exposure.
- A range of different pesticides have been classified by IARC as carcinogenic to humans (group 1) and probably carcinogenic to humans (group 2A). Other health impacts include poisonings, neurotoxic effects and endocrine disruption.
- Pesticide poisoning represents a major occupational health crisis with estimates indicating that up to 44 per cent of farmers are poisoned every year.
- While both women and men face risk of exposure to pesticides in the agricultural sector, the magnitude will depend on country-specific contexts for which tasks men and women perform. Health outcomes can also differ between men and women.

The International Code of Conduct on Pesticide Management is a voluntary framework that defines Highly Hazardous Pesticides (HHPs) as pesticides that present particularly high levels of acute or chronic hazards to health or the environment according to internationally accepted classification systems– such as from WHO or the Globally Harmonized System of Classification and Labelling of Chemicals (GHS) – or their listing in relevant binding international agreements or conventions (WHO/FAO 2014). Some older pesticides are listed under the Stockholm Convention for global elimination or restriction, since they are persistent, bioaccumulative, cause adverse effects and are transported over a long range (e.g. lindane, mirex and DDT).

The introduction of regulations to **phase out the use of HHPs** has **saved innumerous lives**

▶ **HHPs Criteria Table**

1	Pesticide formulations that meet the criteria of **Classes Ia or Ib** of the **WHO Recommended Classification** of Pesticides by Hazard
2	Pesticide active ingredients and their formulations that meet the criteria of **carcinogenicity Categories 1A and 1B** of the Globally Harmonized System of Classification and Labelling of Chemicals (GHS)
3	Pesticide active ingredients and their formulations that meet the criteria of **mutagenicity Categories 1A and 1B** of the **GHS**
4	Pesticide active ingredients and their formulations that meet the criteria of **reproductive toxicity Categories 1A and 1B** of the **GHS**
5	Pesticide active ingredients listed by the **Stockholm Convention** in its **Annexes A and B**, and those meeting all the criteria in paragraph 1 of **annex D** of the Convention
6	Pesticide active ingredients and formulations listed by the **Rotterdam Convention** in its **Annex III**
7	Pesticides listed under the **Montreal Protocol**
8	Pesticide active ingredients and formulations that have shown a **high incidence of severe or irreversible adverse effects** on human health or the environment.

In addition, pesticides that appear to cause severe or irreversible harm to health or the environment may be considered to be highly hazardous (see HHPs Criteria table). However, to date there is no harmonised, internationally agreed list of HHPs. While some pesticides are classified as HHPs and banned in specific countries, in other countries they are approved for use. For example, phorate, which is classified as extremely hazardous (Class 1a) by WHO has been banned in the EU, Brazil and China, while it remains approved for use in the United States (Donley 2019). WHO considers HHPs as a major public health concern (WHO 2019d) and the introduction of regulations to phase out the use of HHPs has saved innumerous lives (WHO/FAO 2019).

Exposure

It is estimated that approximately 1.8 billion people are engaged in agricultural activities worldwide, and most use pesticides to protect food and commercial products that they produce (Carvalho 2017). During increased attention from global policy makers in the last two decades, global pesticide use has continued to grow steadily to 4.1 million tonnes per year in 2017, an increase of nearly 81% from 1990 (FAOSTAT 2019). The greatest exposure to pesticides is for agricultural workers during handling, dilution, mixing and application. Exposure is mainly by the dermal route for preparation of sprays and by the dermal and inhalation routes during application. Ingestion might occur through consumption of contaminated food during or following work or through oral contact with contaminated hands. Contaminated clothing is a significant source of exposure. Stocks of obsolete pesticides still represent an exposure hazard in many countries, in particular if storage or disposal is inappropriate (WHO 2019d).

Health effects

Cancer

A range of different pesticides have been classified by IARC as carcinogenic to humans (group 1):

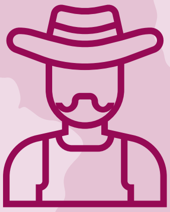
- arsenic and arsenical compounds
- pentachlorophenol (PCP)
- lindane
- ethylene oxide

Several pesticides have been also classified by IARC as probably carcinogenic to humans (group 2A):

- dichlorodiphenyltrichloroethane (DDT)
- organophosphates (malathion, diazinon, glyphosate)
- aldrin and dieldrin
- captafol
- ethylene dibromide
- formaldehyde

it is estimated that **385 million cases** of **unintentional, acute pesticide poisoning (UAPP)** occur **annually** world-wide

44% of **farmers are poisoned by pesticides** every year



In the Agricultural Health Study, a prospective cohort study of over 89,000 farmers, cancer excesses were observed for prostate cancer, lip cancer, lymphomas, leukemia, thyroid cancer, testicular cancer and peritoneal cancer among farmers exposed to pesticides (Lerro et al. 2019). A pooled analysis of non-Hodgkin Lymphoid (NHL) malignancies by the AGRICOH Consortium that included more than 316,270 farmers, showed elevated hazard ratios for NHL and use of terbufos; chronic lymphocytic leukaemia/small lymphocytic lymphoma and deltamethrin; and diffuse large B-cell lymphoma and glyphosate (Leon et al. 2019). A meta-analysis reported that the overall risk of NHL in individuals exposed to glyphosate-based herbicides was increased by 41 per cent. Animal studies also showed an association between pure glyphosate and malignant lymphoma (Zhang et al. 2019). Another systematic review showed that herbicide exposure and agricultural exposure to pesticides was associated with an increased risk of thyroid cancer (Han, Kim, and Song 2019).

Other health outcomes

The incidence of pesticide poisonings among agricultural workers varies in accordance with spraying circumstances. However, various global estimates on incidence of pesticide poisonings have been made, and the most often cited numbers are 3,000,000 hospitalised acute poisonings, 25,000,000 less severe poisonings (not requiring hospitalisation), and around 300,000 deaths from all types of poisoning per year (Jørs et al. 2018). In terms of fatal self-poisonings, a systematic review showed that 110,000 to 168,000 deaths occur globally every year due to pesticides, representing up to 20 per cent of global suicides (Mew et al. 2017).

A systematic review of data published between 2006 and 2018, supplemented by mortality data from WHO, found that there were approximately 740,000 annual cases of unintentional, acute pesticide poisoning (UAPP), with 7,446 fatalities and 733,921 non-fatal cases. On this basis, it is estimated that 385 million cases of UAPP occur annually world-wide including 11,000 fatalities. These figures indicate that around 44 per cent of farmers are poisoned by pesticides every year (Boedeker 2020). As such, acute pesticide poisoning represents a major current global health crisis. There is an urgent need to recognize the high burden of non-fatal acute pesticide poisoning, as the current focus only on fatalities hampers international efforts in risk assessment and prevention of poisoning.

Acute and chronic neurotoxic effects have also been increasingly associated with pesticides exposure. A meta-analysis of 104 studies showed that exposure to paraquat (herbicide) or maneb/mancozeb (fungicide) was associated with about a 2-fold increase in risk of Parkinson Disease (Pezzoli and Cereda 2013). A systematic review and meta-analysis showed a positive association between pesticide exposure and Alzheimer's disease (Yan et al. 2016). Organophosphates (insecticides or herbicides) exposure have been associated with acute and chronic neurotoxicity, cognitive impairment and depression (Freire and Koifman 2013; Muñoz-Quezada et al. 2016). As described in previous chapters, pesticides can also act as endocrine disruptors, in particular organophosphate pesticides (Trasande et al. 2016; Attina et al. 2016).

Regional trends

It is estimated that LMICs account for about 70 per cent of worldwide HHP use, i.e. over 1.2 million tonnes in 2017 (Public Eye 2020). The greatest number of unintentional acute pesticide poisoning cases is in southern Asia, followed by

▶ Case study: Occupational exposure to pesticides and resultant health problems among cotton farmers of Punjab, Pakistan

Cotton is an important cash crop for Pakistan, but the amount of pesticides used in crop production in Pakistan has increased rapidly in the recent years. At the same time, farmers are unaware of the hazard and how to prevent exposure. A study including 318 randomly selected male cotton farmers was conducted in 2008, assessing exposure to pesticides and self-reported health problems. A quarter of the participants did not know how to read and write. Based on WHO´s classification, 23 per cent of the amount of pesticides used (assessed as kg of active ingredient) belonged to the category 'highly hazardous', and 55 per cent to the category of 'moderately hazardous'. Common high exposure risks included: pesticide spills in the stage of spray solution preparation (76 per cent), the use of low-technology and faulty sprayers (68 per cent) and spraying in inappropriate weather (47 per cent). More than a third of the farmers reported multiple symptoms caused by pesticide use, where the most common were irritation of skin and eyes, headache and dizziness. It is worth noting that most farmers thought these symptoms were nothing out of the ordinary and that few reported visiting the doctor (Khan and Damalas 2015).

south-eastern Asia and east Africa with regards to non-fatal UAPP (Boedeker 2020). The proportion of pesticide self-poisoning varies considerably between regions, from 0.9 per cent in LMICs in the European region to 48.3 per cent in LMICs in the Western Pacific region (Mew et al. 2017). **Since the 1960s, when pesticides were introduced into small-scale farming, an estimated 14 million premature deaths have resulted from pesticide self-poisoning and over 95 per cent of these deaths have occurred in LMICs (WHO/FAO 2019).**

The role of gender

The gender balance of agricultural work force varies between regions. One estimate is that women on average make up 40 per cent of agricultural workers in LMICs, ranging from about 20 per cent in Latin America to 50 per cent in Africa, East and Southeast Asia (FAO 2011). Data related to gender aspects of pesticide use is incomplete and results inconsistent, partly because of country differences due to cultural and social norms, educational levels and awareness. For example, it was noted that South African women farmers were on average as responsible for spraying on their farms as men, and that women carry out the bulk of spraying on oil palm plantations in Indonesia, but that male farmers were much more likely to use pesticides in smallholder rice production in northern Ghana (UNEP 2018). There are also gender differences in exposures to pesticides other than during application in tasks typically carried out by women, such as during cotton picking, weeding and thinning sprayed crops, picking tea leaves, washing out pesticide containers or washing pesticide-contaminated clothing (Memon et al. 2019; Tsimbiri et al. 2015).

SECTORS OF EXPOSURE	PRIMARY HEALTH IMPACTS	GLOBAL BURDEN OF OCCUPATIONAL EXPOSURES	WORK-RELATED HEALTH IMPACT
Agriculture, plantations, other rural sectors Chemical industries	Poisoning Cancer Neurotoxicity Endocrine disruption	Limited Data (although presumably a majority of global agricultural workers (1.8 billion) exposed) (Carvalho 2017)	Limited Data (>300,000 deaths annually due to unintentional cute pesticide poisoning alone) (Boedecker 2020)

Phasing out HHPs has reduced mortality rates

There is an urgent need to phase out all HHPs, starting from the most toxic ones, in order to prevent deaths caused by exposure. The introduction of regulations to control the use of HHPs in high-income countries has saved innumerous lives, and mortality rates for acute poisoning are dramatically lower than in LMICs (WHO/FAO 2019).

▶ Selected priority actions: Pesticides

Examples of national policy measures

Refer to, and ratify/implement the following conventions/codes:

- **ILO Safety and Health in Agriculture Convention, 2001 (No. 184).** This Convention prescribes standards on the safe use of chemicals used in agriculture, including pesticides.
- **Stockholm Convention on Persistent Organic Pollutants.** The Convention aims to eliminate or restrict the production and use of persistent organic pollutants (POPs)
- **Rotterdam Convention on the Prior Informed Consent** Procedure for Certain Hazardous Chemicals and Pesticides in International Trade. The Rotterdam Convention is a multilateral treaty to promote shared responsibilities in relation to the importation of hazardous chemicals.
- **FAO and WHO International Code of Conduct on Pesticide Management.** Key provisions:
  - Avoid using pesticides whose handling and application require the use of PPE that is uncomfortable, expensive or not readily available.
  - Collect reliable data and maintain statistics on health effects of pesticides and pesticide poisoning incidents
  - Introduce the necessary policy and legislation for the regulation of pesticides, their marketing and use throughout their life-cycle, and make provisions for its effective coordination and enforcement.
  - Consider prohibiting the importation, distribution, sale and purchase of HHPs, if risk mitigation measures or good marketing practices are insufficient to ensure that the product can be handled without unacceptable risk to humans and the environment.

Additional actions for policy makers

- Finalize the harmonized list of HHPs from the already advanced drafts in existence.
- Strengthen international support for LMICs to develop, adopt and implement legally binding instruments to control HHPs in order to prevent worker exposure.
- Combat illegal trafficking of illicit pesticides.
- Enhance resources and capacities for treatment of existing HHP stockpiles at the workplace and HHP contaminated sites.
- Implement GHS to classify and label HHPs and effectively communicate hazards, without requiring workers to read warning text. Train workers on GHS interpretation.
- Promote integrated pest management (IPM) and integrated vector management (IVM) through investment in training, communication and further research, and monitoring of their effectiveness.
- Improve the availability and distribution of low-risk biological alternatives.
- Use good agricultural practice schemes and other non-regulatory options to promote substitution of HHPs by pest management approaches and products that pose less risk.
- Consider using financial incentives (e.g. subsidy or taxation instruments) to favour low risk products, such as biological control agents and most biopesticides, over high risk products.

Occupational Exposure Limits (OELs)

- Update, implement and enforce OELs for HHPs and ensure global harmonization of these OELs.

Examples of practical workplace interventions

- Start with elimination, which involves using biological controls and plant-based fertilisers and also techniques such as crop covering. Also prioritise substitution using less toxic pesticides.
- Apply engineering controls where possible, specifically for less toxic pesticides. These include nozzle placement, droplet size, equipment calibration, baffles, deflectors, air induction nozzles and tree-sensing technology.
- Introduce preventive occupational measures, including farmer training on IPM with good agricultural practices and greater use of ecologic alternatives. These have proven effective not only at reducing the number of poisonings but, in some cases, also in increasing profits.
- Promote communication and awareness-raising efforts to train workers in contact with HHPs about the health hazard. This should include how to safely handle both HHPs and contaminated equipment, the risk of spray drift to nearby waterways and communities, and the risk of exposure when handling crops sprayed with pesticides.
- Introduce procedures to limit environmental exposure, for example, managing the timing of application and introducing buffer zone.
- Ensure availability of appropriate PPE and application equipment.

Sources include: FAO and WHO 2016, Weinberg et al. 2009

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▶ Workplace air pollution

- Although not often considered an occupational exposure, pollution of air at the workplace, either indoors in the work premises or during work outdoors, can cause a range of acute and chronic health impacts, and can be prevented.

- The most common pollutants considered in air pollution estimates include fine (PM2.5) and course (PM10) particulate matter, ozone, nitrogen dioxide (NO2), and sulfur dioxide (SO2). Other air pollutants that can be important for specific health issues and that are less frequently considered in air pollution estimates include benzene, formaldehyde or carbon monoxide.

- Air pollution, particulate matter and diesel exhaust have been classified by IARC as carcinogenic to humans (Group 1). Air pollution has also been linked to to a wide range of diseases in several organ systems such as cardiovascular and pulmonary disease.

- **Globally, over 1.2 billion workers spend most of their working hours outdoors, at risk for exposure to outdoor air pollution. The WHO estimates that 860,000 deaths a year can be attributed to occupational exposure to air pollutants, although the real magnitude of the health impacts on workplace air pollution is likely to be much higher.**

- Health impacts caused by air pollution may differ between women and men, most likely due to an interplay between biological and gender-related factors.

Air pollution, particulate matter and **diesel exhaust**
have been classified by IARC as
carcinogenic
to humans

Exposure

Workers across all economic sectors and throughout the supply chain are constantly exposed to air pollution, from when they commute to work to their workplaces. Worldwide at least 1.2 billion workers work outdoors for a majority of their work time (WHO 2018c). Higher exposures are observed for outdoor workers in areas with high levels of air pollution generated by heavy traffic or industries. Level of exposures are in general higher in LMIC megacities and industrial areas (Chen 2020). Dramatic air pollution reductions observed in China and in other countries following COVID-19 related lockdowns clearly show how industrial operations and commuting affect air pollution and related deaths (Chen 2020).

Occupational exposure to indoor air pollution is also a major risk for workers. Indoor air pollution can be caused by chemicals, gases, fumes, aerosols, particles and other substances. It is particularly common in sectors that include processes such as burning, cleaning or internal combustion. In the absence of good ventilation, indoor air pollutants can be more concentrated, putting workers at higher risk for harmful levels of exposure (WHO 2018).

In 2016, 91 per cent of the world's population was living and working in places where the WHO standards for air quality were not met (WHO 2016a). Considering there are over 3.3 billion workers in the world (ILO 2020d), it is possible that as many as 3 billion workers were living and working in places where the air quality was below WHO standards.

Health effects

Cancer

Air pollution has been classified by IARC as carcinogenic to humans (Group 1). According to IARC there is sufficient evidence that air pollution can cause cancer of the lung (IARC 2013b). Particulate matter, a major component of outdoor air pollution, has also been classified by IARC as carcinogenic to humans (Group 1) (IARC 2013b). **For lung cancer alone, air pollution causes 223,000 deaths/year worldwide** (IARC 2013a, 2015). In addition, diesel exhaust has been classified by IARC as carcinogenic to humans (Group 1) (IARC 2013c). Exposure-response estimates for workers in the trucking industry and in miners show that approximately 6 per cent of annual lung cancer deaths in these workers may be due to diesel exhaust exposure (Vermeulen et al. 2014). Smaller particles (PM0.1) have also been associated with a higher incidence of cancers, including in organs other than lungs, such as brain and breast (Weichenthal et al. 2020) (Goldberg et al. 2018).

Other health outcomes

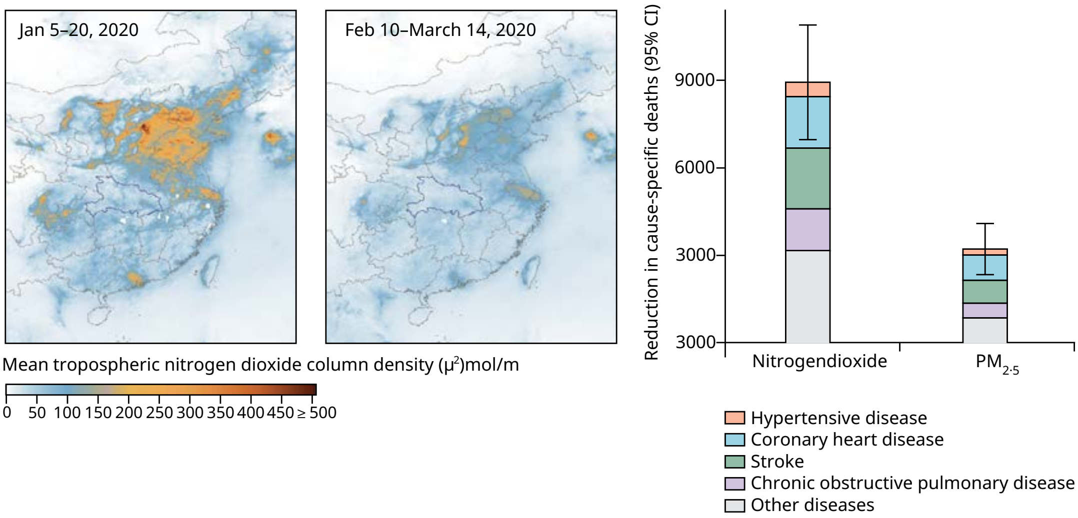
PM2.5 is the best studied form of air pollution and is linked to a wide range of diseases in several organ systems. The strongest causal associations are seen between PM2.5 pollution and cardiovascular and pulmonary disease. A cohort study on 176,309 construction workers showed that occupational exposure to particulate air pollution, especially diesel exhaust, increases the risk for ischaemic heart disease (Torén et al. 2007). Increased risk of COPD was also observed in diesel exhaust exposed workers (Doney et al. 2019). When compared to larger particles, smaller particulate matter (PM0.1) tends to have more detrimental effects, and exposure has been proposed to play an important role in cardiovascular health (Downward et al. 2018). Global Burden of Disease estimates performed by the Lancet Commission on Pollution and Health attributes 4,200,000 deaths per year due to outdoor air pollution alone (Landrigan et al. 2018).

WHO estimates that health effects of occupational exposure to selected air pollutants at the workplace can cause more than 860,000 deaths a year (WHO 2018c), although the real magnitude of the health impacts on workplace air pollution is likely to be much higher. It is difficult to quantify the GBD given the potential for concomitant exposures, as well as the diversity of air pollutants and occupational exposure scenarios across workplaces, tasks and sectors (WHO 2018).

Regional trends

LMICs are the most affected by air pollution. In fact, 89 per cent of deaths due to ambient air pollution occurred in LMICs (Landrigan et al. 2018). Several cities in India and China record average annual concentrations of PM2.5 pollution of greater than 100 µg/m^3, and more than 50 per cent of global deaths due to ambient air pollution in 2015 occurred in India and China. According to WHO, 98 per cent of urban areas in developing countries with populations of more than 100,000 people fail to meet the WHO global air quality

▶ **Figure 8. Air pollution levels and avoided cause-specific deaths during the COVID-19 outbreak in China**



Source (Chen 2020).

guideline for PM2.5 pollution of 10 µg/m^3 of ambient air annually (WHO 2020).

The role of gender

The role of gender in air pollution and respiratory health is emerging through growing epidemiologic evidence that exposure and health impacts may differ between women and men (Clougherty 2010). Whether this is due to biological differences such as hormonal status, lung volume and body size or gender differences in exposure such as activity patterns, smoking behaviours and occupational roles is unknown, but an interplay between the two is likely. While results of studies vary, more studies on adults indicate stronger effects among women and studies of children suggest stronger effects among boys in early life and among girls in later childhood.

▶ Case study: Workers' exposure to air pollutants during commuting in London - Are there inequalities among different socio-economic groups?

Low income workers often experience higher exposures to air pollutants. Exposure to particulate matter (PM1, PM2.5 and PM10), black carbon (BC) and ultrafine particles (PNCs; 0.02–1 µm) for typical commutes by car, bus and underground from four London areas with different levels of income deprivation was compared (G1 to G4, from most to least deprived). The highest BC and PM concentrations were found in G1while the highest PNC was in G3. Workers from less income-deprived areas have a predominant use of cars, receiving the lowest doses during commute, but generating the largest emissions per commuter. Conversely, workers from high income-deprived areas have a major reliance on the bus, receiving higher exposures, while generating less emission per person. These findings suggest an aspect of environmental injustice and a need to incorporate the socioeconomic dimension in air pollution exposure assessments.

MAIN SECTORS OF EXPOSURE	PRIMARY HEALTH IMPACTS	GLOBAL BURDEN OF OCCUPATIONAL EXPOSURES	WORK-RELATED HEALTH IMPACT
All sectors	Cancer (lung) Respiratory disease Cardiovascular disease	>1.2 billion (WHO 2018c)	>860,000 deaths annually (WHO 2018c)

▶ Occupational exposure to outdoor air pollution

Occupational exposure to outdoor air pollution is a particular concern, because the exposed population is large and conventional measures for engineering controls of workplace hazards, such as hazard elimination, encapsulation and ventilation are not always applicable to the outdoor environment. Employers and workers themselves may have little or no control over the sources of outdoor air pollution. Air pollution control in the world of work would enhance employment, decent work for all and social protection (SDG 8) and slow the pace of climate change (SDG 13) by transitioning to a sustainable, circular economy that relies on efficient industrial processes.

▶ Selected priority actions: Workplace air pollution

Examples of national policy measures

- Develop national laws or regulations that prescribe that measures to be taken for the prevention and control of, and protection against, occupational hazards in the working environment due to air pollution. Air pollution regulation to eliminate the source of pollutant release represents a priority and requires coordinated international and national regulation.
- Ratify and implement the **ILO Protection of Workers against Occupational Hazards in the Working Environment Due to Air Pollution, Noise and Vibration Convention, 1977 (No. 148)**. Key provisions:
  - Establish criteria for determining the hazards of exposure to workplace air pollution and specify exposure limits on the basis of these criteria
  - Eliminate any hazards due to air pollution in the working environment, by technical measures applied to new plant or processes in design or installation, or added to existing plant or processes; or, where this is not possible, by supplementary organisational measures.

Additional actions for policy makers

- Promote the creation of green jobs, reduce the use of solid fuels in work processes and the move to cleaner and more sustainable energy sources and processes.
- Implement guidelines at the national and local level to release warnings that reduce or stop work outdoors in periods of severe air pollution.
- Raise awareness of employers and workers about ambient air pollution and their responsibility for occupational health and safety.
- Recognise exposure to ambient air pollution while working outdoors as an OSH issue and use OSH regulations and standards to provide protection of workers.
- Provide toolkits and programmes for engaging businesses and workplaces in prevention and control of air pollution, for example by avoiding open air incineration and controlling other sources of air pollution at the workplace.
- Engage with private sector, businesses and workplace undertakings for preventing emissions of air pollution and improving their overall environmental performance.
- Stimulate initiatives combing occupational safety and health, environmental protection and green workplaces and technological transfer and innovations to prevent ambient and workplace air pollution.

Occupational Exposure Limits (OELs)

- Update, implement and enforce OELs for air pollution and ensure global harmonisation of these OELs.
- Air quality standards and OELs have been established for a large number of workplace air pollutants by organizations and national committees. The international chemical safety data cards (ICSCs), developed by WHO and ILO, contain references to the available standards for occupational exposure to more than 1700 substances.

Examples of practical workplace interventions

- Reduce the exposure, through spending less working time outdoors, rotating workers and restricting work during episodes of severe air pollution, including dust storms.
- Provide respiratory protection programmes, including appropriate respirators, fit testing and training of workers.
- Implement medical surveillance of workers, which should include medical check-ups for underlying health conditions that can worsen with exposure to air pollution, for example asthma, COPD and cardiovascular diseases, such as heart attack and stroke.
- Carry out health surveillance of the working environment and record levels of air pollution from the municipal sources.
- Report cases of occupational diseases that can be caused by ambient air pollution among exposed workers (asthma, chronic obstructive pulmonary disease, lung cancer) and follow up with the employment injury scheme.
- Design programs for effective medical surveillance of workers, including medical check-ups for underlying health conditions that can with exposure to air pollution.

Sources include: WHO 2018c

▶ Priority action areas

Based on the priorities that emerged in the review, a number of actions have been identified that can help promote safer chemicals management within the world of work and beyond. Priority areas have been divided into:

- National level action
- Workplace level action
- Research priorities
- Social dialogue

The actions are proposed as a working foundation to stimulate future discussions and are not meant to be exhaustive or apply to every situation.

National level action

Implement a national OSH system for the sound management of chemicals

A strong national OSH system is critical for the effective implementation of policies and programmes on OSH and the sound management of chemicals, both at the national and workplace level. ILO instruments on OSH and chemical safety (described below) provide a legal framework for managing risks posed by chemicals in the world of work and should be ratified and implemented as a priority action. A coherent and effective method is to use a management systems approach, based on the general ILO principles of these OSH instruments, as well as the ILO Guidelines on occupational safety and health management systems (ILO–OSH 2001), in promoting the sound management of chemicals throughout their life cycle.

Such a national policy framework should aim at the continuous harmonisation, integration and improvement of preventive and protective OSH measures, management systems and tools and capacity building, encompassing both the workplace and the environment. This includes effective labour inspection services provided with the means, qualifications and training to fulfil their duties.

As per the ILO Promotional Framework for Occupational Safety and Health Convention, 2006 (No. 187) and its accompanying recommendation (No. 197), **a national system for OSH**:

Should include:	Should also include, where appropriate:
▶ Laws and regulation, collective agreements where appropriate and any other relevant instruments on OSH pertaining to the sound management of chemicals. ▶ An authority or body, or authorities or bodies, responsible for OSH of chemicals, designated in accordance with national law and practice. ▶ Mechanisms for ensuring compliance with national laws and regulations regarding chemical management, including systems of inspection. ▶ Arrangements to promote, at the level of undertaking, cooperation between management, workers and their representatives, as an essential element of workplace-related prevention measures for the sound management of chemicals.	▶ A national tripartite advisory body, or bodies, addressing OSH issues related to chemicals. ▶ Information and advisory services on OSH measures regarding chemicals. ▶ The provision of OSH training regarding the sound management of chemicals. ▶ Occupational health services for workers exposed to chemicals, in accordance with national law and practice. ▶ Research on OSH for chemicals exposures. ▶ A mechanism for the collection and analysis of data on occupational injuries and diseases related to chemical exposures, taking into account relevant ILO instruments. ▶ Provisions for collaboration with relevant insurance or social security schemes covering occupational injuries and diseases from chemical exposures. ▶ Support mechanisms for a progressive improvement of occupational safety and health conditions for enterprises using chemicals, including micro-enterprises, small and medium-sized enterprises and the informal economy.

▶ Promoting a national preventative safety and health culture

Building, implementing and continuously strengthening a preventative safety and health culture is essential for improving safety in the workplace and minimizing any adverse impacts of chemical exposure. Actions taken at the national level to develop a preventative culture must also be applied at the workplace level.

Ratify and implement International Labour Standards on OSH

States have the duty to ensure that the fundamental principles and rights at work and ratified international labour standards protect and are applied to all workers. The ILO conventions as well as their accompanying recommendations have their own unique range of application in the field of OSH, which is not covered by any other international instruments on chemicals. These standards can allow countries to develop their own legislative and regulatory framework on chemical safety in the world of work. In the last 100 years, the ILO has adopted more than 50 legal instruments on the protection of workers, as well as the public and the environment, from chemical hazards.

Main ILO Conventions on chemicals in the world of work
▶ Chemicals Convention, 1990 (No. 170)
▶ Prevention of Major Industrial Accidents Convention, 1993 (No. 174)
Risk specific Conventions
▶ Benzene Convention, 1971 (No. 136)*
▶ Occupational Cancer Convention, 1974 (No. 139)
▶ Working Environment Convention, 1977 (No. 148)
▶ Asbestos Convention, 1986 (No. 162)
Instruments dealing with the fundamental OSH principles that provide a framework for risk management, including chemical risks
▶ Occupational Safety and Health Convention, 1981 (No. 155)
▶ Promotional Framework for Occupational Safety and Health Convention, 2006 (No. 187)
▶ Occupational Health Services Convention, 1985 (No. 161)
▶ List of Occupational Diseases Recommendation, 2002 (No. 194)

** Requiring further action to ensure continued and future relevance, as determined by the Governing Body upon recommendation of the SRM TWG in 2017*

Tackling Carcinogenic Chemicals: The Occupational Cancer Convention, 1974 (No. 139), provides for the measures to be taken for the control and prevention of occupational hazards caused by carcinogenic substances and agents. Key provisions include:

- periodically determining the carcinogenic substances and agents to which occupational exposure shall be prohibited or made subject to authorisation or control;
- making every effort to have carcinogenic substances and agents to which workers may be exposed in the course of their work replaced by non-carcinogenic substances or agents or by less harmful substances or agents;
- reducing the number of workers exposed to carcinogenic substances or agents and the duration and degree of such exposure to the minimum.

Improve recognition of occupational diseases caused by chemicals

The absence of reliable information about the incidence of occupational accidents and disease related to chemical exposures is a major obstacle towards the design of effective policy responses. One mechanism that can ameliorate the collection of data and statistics on occupational exposures and resulting disease is the implementation of a national Occupational Disease List. The ILO List of Occupational Diseases (revised 2010) represents the latest worldwide consensus on diseases which are internationally accepted as caused by work. It was designed to assist stakeholders in the identification and recognition of occupational diseases, including those caused by chemical substances. Section No. 1.1 of the Annex lists 40 different chemical substances and groups of substances, of which exposure to can cause disease.

Implement the Globally Harmonized System of Classification and Labelling of Chemicals (GHS)

The GHS is an internationally-agreed upon system to standardise hazard information of chemicals through labels and safety data sheets. Correct classification and labelling, as well as comprehensive worker training, can help improve OSH and workplace safety systems. Appropriate handling, use and storage of hazardous substances can in turn contribute to preventing hazardous exposures, as well as major industrial accidents. Social partners have supported global implementation of GHS as a way to share safety and health information to prevent workers' exposures to hazardous substances.

Develop, update and harmonise evidence-based Occupational Exposure Limits (OELs)

Chemical safety at the workplace can no longer afford Occupational exposure limits (OELs) are regulatory values which indicate levels of exposure that are considered safe for a chemical substance in a workplace. Unfortunately, OELs do not exist for many chemicals and those that do exist are often outdated. There is also a lack of harmonised data between different countries and safety bodies. Whilst databases of OELs provide valuable information on numerous chemical exposures, keeping these lists updated and relevant is a huge task. Suggested actions include:

- Create a priority system for OELs, to focus on those that do not exist or need to be updated
- Ensure that OELs are easily understandable and accessible
- Consider all potential health hazards, rather than only acknowledging single health effects
- Develop an approach covering all chemicals in the workplace, rather than focusing on individual chemicals only
- Produce and implement harmonised international guidelines for OELs
- Promote OELs on an international level with policy makers and industry representatives to ensure that OELs are enforced
- Update key OELs on a systematic basis to reflect advancements in science and technology

Mainstream gender into OSH policy and practice

Chemical safety in the workplace can no longer afford to be gender-blind, and it is essential that inclusive and responsive gender-sensitive OSH policies are developed. The ILO Maternity Protection Convention (No. 183) and accompanying Recommendation (No.191) set out that pregnant women should not be obliged to carry out work that is a risk to her or her child and provides for specific risk assessment concerning pregnant women, including chemical agents which represent a reproductive hazard. The ILO has also developed Guidelines for Gender Mainstreaming in Occupational Safety and Health to assist policy-makers and practitioners in taking a gender-sensitive approach for the development and implementation of OSH policy and practice.

Workplace level action

Implement a workplace programme for the sound management of chemicals

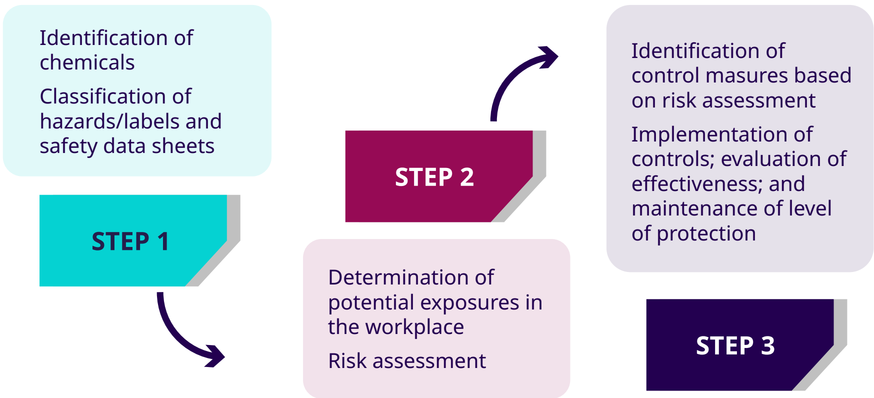
The ILO recommends that the following components are used as a general blueprint for the sound management of chemicals in the workplace. As always, national guidelines should be considered in the first instance.

Elements of the programme	Components
General obligations, responsibilities and duties	▶ Role of the competent authority; responsibilities and duties of employers, workers, and suppliers ▶ Rights of workers
Classification and Labelling following the GHS	▶ Criteria for classification of hazards ▶ Methods for classification ▶ Type of labelling on containers of hazardous chemicals
Chemical Safety Data Sheets	▶ Provision of information and training ▶ Content of safety data sheet
Operational Control Measures	▶ Assessment of control needs and elimination of hazards ▶ Control measures for: health hazards; flammable, dangerously reactive or explosive chemicals; disposal and treatment of chemicals, and so forth as appropriate

Design and Installation	▶ Enclosed systems where feasible ▶ Separate areas for hazardous processes to limit exposures ▶ Practices and equipment that minimize releases ▶ Local exhaust ventilation and general ventilation, as appropriate
Work Systems and Practices	▶ Administrative controls ▶ Cleaning and maintenance of control equipment ▶ Provision of safe storage for hazardous chemicals
Personal Protection	▶ Personal protective equipment ▶ Welfare facilities and personal hygiene ▶ Practices to maintain equipment and clothing as necessary ▶ Training on personal protection
Information and Training	▶ Workers should be provided information (labels and safety data sheets), and be trained how to handle them safely, what to do in an emergency, and how to obtain additional information
Maintenance of Engineering Controls	▶ Practices and procedures to keep engineering controls in good working order
Exposure Monitoring	▶ Measuring methods ▶ Monitoring strategy and appropriate recordkeeping ▶ Interpretation and application of data
Medical and Health Surveillance	▶ Medical exams as necessary and appropriate recordkeeping ▶ Use of results to evaluate program
Emergency Procedures and First Aid	▶ Planning should be done to anticipate possible emergencies, and have procedures to deal with them ▶ First aid should be available on-site
Investigation and Reporting of Accidents, Occupational Diseases and Other Incidents	▶ All incidents should be investigated to determine why they occurred, what failed in the workplace or in the emergency plan ▶ Authorities should be notified as required by national laws

Implement a workplace level strategy

The overall strategy to achieve the sound management of chemicals in the workplace and in protecting the general environment can be simply described in three steps:



1. The **first step** is to identify what chemicals are present; classify them as to their health, physical, and environmental hazards; and prepare labels and safety data sheets to convey the hazards and associated protective measures. Without such information on chemicals in the workplace, or released to the environment, it is not possible to go farther in terms of an evaluation of impact, and determination of appropriate preventive measures and controls. Information provides the underlying structure needed to achieve the sound management of chemicals.

2. The **second step** is to evaluate how the identified and classified chemicals are used in the workplace, and what exposures can result from this use. This may be accomplished through exposure monitoring, or through application of tools that allow for estimation of exposures based on factors regarding the quantity used, the potential for release given the conditions in the workplace or facility, and physical characteristics of the chemical.

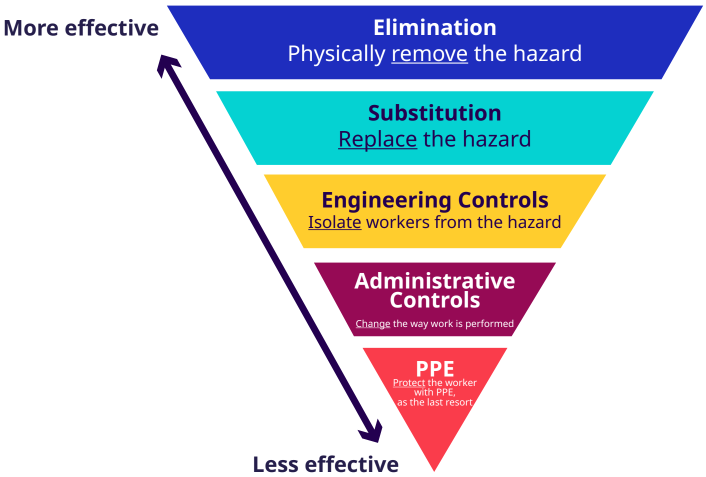
3. Once the hazards have been identified, classified, communicated, and their risk has been assessed, the **third step** is to use this information to design an appropriate preventive and protective programme for the workplace, using the Hierarchy of Controls (below). Other provisions of a thorough program that support and enhance these controls are exposure monitoring; information and training for exposed workers; recordkeeping; medical surveillance; emergency planning; and disposal procedures.

▶ Simple and accessible OSH strategies for MSMEs

The industrial fabric across the globe is mainly made of micro-, small, and medium-sized enterprises (MSMEs). There is a need to support MSMEs to conduct chemical risks assessments and to implement prevention measures in a practical way. This relies on data sharing and the emergence of an open source information on chemicals (e.g. GHS). More information on improving OSH in MSMEs can be found here.

Apply the Hierarchy of Controls

The Hierarchy of Controls is a system used to eliminate or minimise exposure to occupational hazards, such as chemicals. There are five categories in the hierarchy, with control methods at the top of the hierarchy potentially more effective than those at the bottom:



Most effective ↔ Least effective			
Most effective	**Elimination**	Physically remove the chemical	e.g. Eliminate the use of mercury in artisanal and small-scale gold mining. Consider alternative methods such as panning, sluicing or spiral concentrators
	Substitution	Replace the chemical	e.g. Substitute toxic pesticides such as paraquat and neonicotinoids for less toxic versions, such as biopesticides
	Engineering Controls	Isolate workers from the chemical	e.g. Use a suitable local exhaust ventilation (LEV) to remove chemical fumes at source and ensure there is adequate room ventilation
	Administrative Controls	Change the way work is performed	e.g. Adjust work tasks or schedules to limit the time workers are exposed to chemicals and create written operating procedures on handling hazardous substances
Least effective	**Personal Protective Equipment (PPE)**	Protect the worker with PPE, as the last resort	e.g. Workers should wear appropriate PPE, depending on the chemical and the work tasks. These may include gloves, overalls, masks with filters, and safety glasses, as deemed relevant by risk assessment

Elimination and substitution should be considered priority actions where possible. PPE should be only be used as a last resort. When necessary, employers should make available, free of charge, a range of appropriate PPE that is designed to effectively protect workers of all body types, including physiological differences between genders. When clothing is contaminated it should be changed promptly to avoid absorption through the skin.

▶ Workplace monitoring for chemical hazards

Only selected chemical occupational exposures are considered, monitored and regulated in workplaces. It is of paramount importance that monitoring and epidemiological surveillance in workplaces for hazardous substances is extended, starting from the over 200 substances classified as known or probable carcinogens by IARC, that are mostly occupational carcinogens.

Research priorities

Increase research and harmonise global OSH data, specifically for LMICs and informal sector

For the great majority of chemical exposures, data is not available and the number of workers exposed cannot be even estimated because of the lack of such data (both locally and globally). As such, there is an urgent need for increased research and harmonised global data repositories of chemical exposure information and related health effects amongst workers. Moreover, whilst some evidence does exist for HICs, there is a there is a general lack of data from LMICs. This includes studies about informal economy workers, who are at high risk of hazardous chemical exposures. Due to the nature of the work, workplace protections are often limited and there is minimal adherence to OSH regulations and general safety culture.

Strengthen Global Burden of Disease (GBD) estimates for occupational exposures and outcomes

Due to the lack of information on chemical exposure of workers and relative outcomes (death, cancer, etc.), GBD calculations are mainly missing or are severely underestimated. Enhanced data on economic costs to society would promote stronger policy responses. When sufficient data are available, initiatives such as the WHO-ILO Joint Methodology to produce systematic reviews on occupational exposures and risk factors are necessary to provide the evidence-base to produce reliable estimates of the GBD.

Increase research on Non-Communicable Diseases (NCDs)

Cancer is still the main cause of work-related death, however more efforts should be made to retrieve additional data on other NCDs that might be caused by occupational chemical exposures. Debilitating lung diseases, neurological disabilities and reproductive impairments, such as infertility, are among various other health impacts that continue to affect workers and their families.

Examine interlinkages with chemicals and infectious disease

Chemical exposures in workers are not only capable of causing NCDs, but also of increasing the incidence and risks related to infectious diseases. At the same time, infectious diseases can qualitatively and quantitatively affect occupational chemical exposures, particularly in chemical industries, together with the implementation of safety procedures and protections for workers. The COVID-19 pandemic highlighted the importance of this interplay, as exemplified by the increased COVID-19 mortality associated with air pollution. Further research is required to explore how chemical exposures may affect the onset and progress of infectious diseases.

Enhance the science-policy interface for OSH

Increased evidence is needed to support the implementation of regulations that take into account multiple occupational exposures, non-linear responses (particularly for endocrine disrupting chemicals) and windows of increased susceptibility, such as pregnancy and development periods in childhood. Further research is needed to integrate and translate toxicological evidence for workers' protection and prevention and in general to strengthen the science-policy interface in this respect. Developing a robust, two-way science-policy interface as part of the global efforts for the sound management of chemicals represents a priority for the work of world.

Raise awareness of gender inequalities and impacts on reproductive health

Efforts are also needed on a global level to generate gender disaggregated data to identify and prevent exposures that are magnified by gender factors, as well as impacts that are increased due to biological factors. Gender disaggregated data can provide the critical foundation for evidence-based policy efforts at both the national and workplace level. Raising awareness of the impact to women of reproductive age, pregnant and lactating women, as populations specifically sensitive to the health effects of chemical exposures, can create important opportunities for training and sharing of good practices (IPEN 2020).

Collect model policies, best practices and lessons learned

It is important to remember that some countries and stakeholders have already successfully implemented best practices for the sound management of chemicals in the workplace. Given the global inequalities that exist when it comes to OSH systems and safe chemicals management, it would be essential to collect examples of model policies and apply the lessons learned in sectors and geographical areas which would benefit from them. Conducting this type of policy research, and increased social dialogue (discussed below) among stakeholders to share model policies, best practices and lessons learned marks a priority action for the future.

Social dialogue

Promote social dialogue at all levels

Social dialogue includes all types of negotiation and consultation between, or among, representatives of governments, employers and workers, on issues of common interest. The main goal of social dialogue itself is to promote consensus building and democratic involvement among the main stakeholders in the world of work. Successful social dialogue structures and processes have the potential to resolve important economic and social issues, encourage good governance, advance social and industrial stability, and boost economic progress.

The extent of national-level social dialogue within the chemicals industries and throughout sectors using chemicals varies from country to country. Nevertheless, employers and workers in the chemical industries, and governments, have recognized the importance of social dialogue to help create an enabling environment to ensure safe, healthy, decent and productive work (ILO, 2013). Social dialogue in the chemicals sector can increase profits by leading to greater productivity and enhanced worker satisfaction (ILO, 2006). While examples and case studies of social dialogue in the chemicals industries have previously been reported there is a need to expand the scope of social dialogue to additional sectors using chemicals and to further promote the exchange of information at levels.

Enhance sound governance frameworks

The sound management of chemicals requires effective governance through transparency, public participation, and accountability among the world of work stakeholders and specifically governments, employers' organisations and workers' organisations. Making better use of social dialogue is important in order to improve legislation and its implementation. This includes effective labour inspection provided for with adequate means and conducted by suitably qualified and trained inspectors. The active participation of employers’ and workers’ organisations is essential for the development of national policies and programmes for the management of chemicals as well as its governance.

- Employers have a duty to take preventive and protective measures, through assessment and control of the risks at work, including to those related to chemical exposures. They also can promote sound governance frameworks at the national and workplace levels.
- Workers and their organisations have a right to be involved at all levels in formulating, supervising and implementing prevention policies and workplace programmes. They have a right to be protected from workplace risks and to take an active role in governance both at the national and workplace level.
- Policy makers, managers, supervisors, OSH professionals, and workers all have important roles to play, through effective social dialogue and participation in risk-management systems as well as the promotion of sound governance frameworks at all levels.

▶ Promoting the business case for OSH and chemical safety

Ensuring a safe and healthy work environment is a strategic goal for the global chemical industry. Employers believe that excellence in operations, preventing accidents and occupational diseases, is critical for operations in all countries. Responsible Care®, the global chemical industry's initiative to drive continuous improvement is an important element towards reaching the goal of sound chemicals management.

Increase engagement of world of work stakeholders in international policy efforts

There are a number of international policies, agreements and conventions in the field of chemical safety. SAICM in particular represents a global policy framework that can harmonise and integrate important elements needed for a universal approach to the sound management of chemicals worldwide. One of the key objectives of a revitalized strategy for SAICM Beyond 2020 is increased multi-sectoral and multi-stakeholder engagement in order to ensure that the new platform will be of interest to, and useful for, the work of the different ministries as well as a variety of stakeholders.

While social partners, including employers from the chemical industries and workers organisations, have demonstrated their commitment to SAICM and its processes, there is a continued need for enhanced participation and engagement of key world of work stakeholders in ongoing policy negotiations. Occupational exposure considerations should be at the core of SAICM Beyond 2020 and even stronger measures are needed in this new framework to protect workers from chemical exposures. As such, enhanced social dialogue will be critical during the intersessional process leading up to Fifth session of the International Conference for Chemicals Management (ICCM5), and beyond.

▶ The ILO and social dialogue in the chemicals sector

Many sectors using chemicals are of strategic importance to the sustainable development of national economies. The ILO has noted the importance of the chemical sector since the early stages of the Organization's activities and has actively promoted social dialogue in the sector for many years. Sustainable industrial policies underpinned by meaningful and effective social dialogue are key to managing the opportunities and challenges arising from digitalization and other technological advances in the chemical and pharmaceutical industries. In 2018, the ILO Global Dialogue Forum adopted Points of Consensus to guide governments, employers and workers in shaping a future that works for all in the chemical and pharmaceutical industries.

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