

## CHAPTER 11

### OCCUPATIONAL TOXICOLOGY

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#### Abstract

Occupational toxicology addresses workplace chemical exposures that affect millions of workers across diverse industries, requiring specialized approaches to identification, management, and prevention. Workplace exposures occur through inhalation, dermal contact, and ingestion routes, with inhalation predominating in industrial settings where particulates, gases, vapors, and fumes present significant hazards. Industry-specific risks include silica and asbestos in construction, solvents and heavy metals in manufacturing, pesticides in agriculture, and chemotherapeutic agents in healthcare. Protection measures follow a hierarchical approach prioritizing elimination of the hazard, substitution with safer alternatives, engineering controls like ventilation systems, administrative controls including work rotation, and personal protective equipment as the final defense. Biological monitoring assesses internal dose through biomarkers in blood or urine, while environmental monitoring quantifies workplace contaminant levels using various sampling methods. Medical surveillance programs combine periodic examinations, function testing, and exposure records to detect adverse effects before clinically apparent disease develops. Regulatory frameworks establish permissible exposure limits, require hazard communication through standardized systems, mandate monitoring for certain substances, and establish medical removal provisions for workers showing early signs of toxicity. Occupational toxicologists must understand these complex interactions between workplace hazards, individual susceptibility factors, and regulatory requirements to effectively prevent, recognize, and manage work-related toxic exposures.

**Keywords:** Occupational Exposure, Industrial Hygiene, Biomonitoring, Permissible Exposure Limits, Hazard Communication, Respiratory Protection

## Learning Objectives

After completion of the chapter, the learners should be able to:

- Identify common toxicants associated with specific industries and occupations, including their exposure routes, mechanisms of toxicity, and target organs.
- Apply the hierarchy of controls framework to develop comprehensive protection strategies for workplace chemical hazards.
- Design appropriate biological and environmental monitoring programs for specific occupational exposures, including selection of appropriate biomarkers and sampling strategies.
- Interpret occupational exposure limits including Permissible Exposure Limits (PELs), Threshold Limit Values (TLVs), and Short-Term Exposure Limits (STELs) in relation to workplace assessment and regulatory compliance.
- Develop medical surveillance programs tailored to specific workplace hazards, including appropriate screening tests, examination frequency, and action levels for intervention.
- Evaluate the effectiveness of personal protective equipment including respirators, chemical-resistant clothing, and gloves for specific workplace exposures, addressing selection, fit, maintenance, and limitations.

## WORKPLACE EXPOSURES

Occupational environments present unique toxicological challenges through potential for prolonged, high-concentration exposure to diverse chemical, physical, and biological hazards.

### Industrial Chemicals

Solvents represent among the most ubiquitous chemical exposures in industrial settings, with applications spanning degreasing, cleaning, extraction, paint and coating formulation, adhesives, and chemical synthesis across numerous industries. These compounds typically share properties including volatility creating inhalation exposure potential, lipid solubility enhancing dermal absorption and nervous system effects, and capacity to dissolve or extract other substances. Aliphatic hydrocarbons including hexane, heptane, and mineral spirits demonstrate primary toxicity through central nervous system depression, with n-hexane additionally causing peripheral neuropathy

through its metabolite 2,5-hexanedione. Aromatic hydrocarbons including benzene, toluene, and xylene create more complex toxicity profiles: benzene demonstrates established hematopoietic toxicity including bone marrow depression and leukemogenicity through reactive metabolites; toluene produces both acute central nervous system effects and chronic manifestations including cognitive dysfunction and hearing loss; while xylene isomers create similar neurological effects with reduced hematological concerns. Chlorinated solvents including trichloroethylene, perchloroethylene, and methylene chloride produce hepatorenal toxicity alongside central nervous system depression, with additional specific concerns including cardiac sensitization to catecholamines, recognized carcinogenic potential for specific compounds, and carbon monoxide generation through metabolic pathways.

Work practices significantly influence exposure patterns, with particular high-risk scenarios including confined space operations where vapor accumulation creates both acute toxicity and oxygen displacement risks; spray applications generating respiratory-sized particles alongside vapor components; manual cleaning operations without local exhaust ventilation; and maintenance operations involving solvent-containing systems without adequate lockout/tagout and decontamination procedures. Exposure assessment employs industrial hygiene methodologies including air sampling with personal monitoring in the breathing zone, biological monitoring measuring either parent compounds or their metabolites in blood or urine, and dermal exposure assessment using specialized sampling techniques or fluorescent tracers with ultraviolet visualization. Multiple exposure routes necessitate comprehensive evaluation beyond air monitoring alone, as significant absorption may occur through dermal contact with both liquid and vapor forms of lipophilic solvents. Risk management approaches include substitution with less hazardous alternatives when feasible, engineering controls focusing on enclosure and ventilation, work practice modifications emphasizing closed transfer systems, and personal protective equipment including respiratory protection and chemical-resistant gloves selected based on specific solvent permeation characteristics.

Heavy metals continue creating significant occupational exposure concerns despite increasing regulation, with workers in mining, metallurgy, manufacturing, construction, electronics, and recycling industries demonstrating particular risk. Lead exposure occurs in battery manufacturing, radiator repair, metal recycling, construction involving older structures, and shooting range operations, with toxicity affecting hematopoietic, nervous, renal, reproductive, and cardiovascular systems. Contemporary understanding emphasizes

health effects at blood lead levels previously considered acceptable, driving progressively lower occupational exposure limits.

**Table 11.1: High-Risk Occupational Exposures by Industry**

Industry	Common Toxicants	Primary Health Effects	Exposure Routes
Construction	Silica, asbestos, lead, solvents, wood dust	Pneumoconiosis, mesothelioma, neurotoxicity, cancer	Inhalation, dermal, ingestion
Healthcare	Anesthetic gases, chemotherapy drugs, disinfectants, latex	Reproductive effects, asthma, dermatitis, liver toxicity	Inhalation, dermal, needlestick
Agriculture	Pesticides, fertilizers, diesel exhaust, grain dust	Cholinergic toxicity, respiratory disease, dermatitis	Inhalation, dermal, ingestion
Manufacturing	Solvents, metals, plastics, engineered nanoparticles	Neurotoxicity, cancer, respiratory disease, dermatitis	Inhalation, dermal
Mining	Silica, coal dust, diesel exhaust, metals	Pneumoconiosis, COPD, cancer, heavy metal toxicity	Inhalation, dermal
Welding	Metal fumes, gases (ozone, nitrogen oxides)	Metal fume fever, pneumonitis, chronic lung disease	Inhalation, ocular

Cadmium exposures in nickel-cadmium battery production, metal plating, pigment manufacturing, and electronic waste processing create nephrotoxicity and carcinogenic risk through mechanisms including metallothionein binding and oxidative stress. Mercury exposure in chloralkali production, artisanal gold mining, dental amalgam handling, and certain manufacturing processes produces neurobehavioral effects

through mechanisms targeting sulfhydryl-containing proteins and disrupting cellular redox status. Chromium compounds in metal plating, stainless steel welding, pigment production, and leather tanning create exposure risk primarily to hexavalent forms demonstrating respiratory irritation, sensitization potential, and carcinogenicity through DNA damage mechanisms.



### Remember

**Industry-specific hazards include pneumoconioses from mineral dusts in mining and construction, neurotoxicity from solvents in manufacturing, cholinergic toxicity from pesticides in agriculture, and diverse chemical exposures in healthcare settings.**

Exposure routes vary by specific process and material state, with inhalation predominating for fume, dust, and vapor forms while ingestion typically occurs through hand-to-mouth transfer from contaminated surfaces or inadequate hygiene practices. Secondary exposure affecting family

members through take-home contamination on work clothing and vehicles represents a recognized concern, particularly affecting children whose developing systems demonstrate enhanced vulnerability. Biological monitoring provides exposure assessment integrating all routes, with specific markers including blood lead levels, urinary cadmium, urinary mercury, and various chromium measurements in blood, urine, or exhaled breath condensate depending on the specific exposure scenario. Medical surveillance protocols incorporate both exposure biomarkers and early effect indicators potentially identifying subclinical toxicity before irreversible damage occurs, with specific programs tailored to particular metals and target organ concerns. Control strategies emphasize engineering approaches including enclosed systems, local exhaust ventilation, and wet methods reducing dust generation; work practices addressing hygiene, separate clean and dirty areas preventing cross-contamination, and proper cleaning procedures; and comprehensive personal protective equipment programs when other controls cannot achieve adequate exposure reduction.

Isocyanates, reactive chemicals containing the functional group  $\text{N}=\text{C}=\text{O}$ , create distinctive occupational health challenges through their widespread industrial use and significant sensitization potential. Major applications include polyurethane production for foams, elastomers, adhesives, and coatings, with common compounds including toluene diisocyanate (TDI), methylene diphenyl diisocyanate (MDI), and hexamethylene diisocyanate (HDI). Primary health effects involve respiratory sensitization potentially resulting in occupational asthma, with additional concerns including irritant effects on respiratory tract,

skin, and mucous membranes; allergic contact dermatitis; and hypersensitivity pneumonitis with certain exposure patterns. The immunological mechanism involves isocyanate reactivity with biological proteins creating hapten-carrier complexes capable of triggering immune responses, with both IgE-mediated and non-IgE pathways implicated in respiratory sensitization. Particularly concerning work scenarios include spray application creating respirable aerosols with potential for both pulmonary deposition and skin exposure; heated processes volatilizing isocyanates from supposedly "safe" prepolymers; and grinding or cutting of cured polyurethane potentially liberating unreacted isocyanates.

Exposure assessment presents significant challenges due to isocyanates' high reactivity, tendency to polymerize, occurrence in multiple physical forms, and sensitizing potential at concentrations below many analytical method detection limits. Current approaches employ specialized sampling techniques including derivatization to stabilize the isocyanate group for analysis, with methodologies tailored to specific isocyanate species and exposure scenarios. Medical surveillance focuses on respiratory symptoms and function, with periodic questionnaires, spirometry, and occasionally specific inhalation challenge testing in specialized centers. Management strategies emphasize rigorous exposure control due to sensitization risk even at low concentrations, with approaches including closed systems where feasible, highly efficient local exhaust ventilation, respiratory protection programs with supplied air systems for higher-risk operations, comprehensive skin protection preventing dermal sensitization, and worker education regarding the irreversible nature of sensitization necessitating stringent exposure prevention.

Pesticides in occupational settings create complex toxicological challenges due to their intentional biocidal activity, diverse chemical classes with varying mechanisms, and multiple exposure routes. Agricultural workers experience exposure during mixing, loading, and application operations; reentry into treated areas; and harvesting activities. Additional occupational scenarios include pest control operations in structural, landscape, and public health applications; manufacturing and formulation facilities; and transportation and retail handling. Major chemical classes include organophosphates and carbamates inhibiting cholinesterase with resulting cholinergic effects; pyrethroids affecting sodium channels with predominantly neurological and dermal manifestations; neonicotinoids targeting nicotinic acetylcholine receptors; phenoxy herbicides with concerns regarding contaminants like dioxins in older formulations; and various fungicides with class-specific effects ranging from irritant properties to specific organ system toxicity.

Exposure assessment employs both environmental monitoring techniques including air sampling, surface wipe sampling, and patch or whole-body dosimetry for dermal exposure quantification; and biological monitoring measuring either parent compounds, specific metabolites, or effect biomarkers like cholinesterase activity for certain classes. Exposure determinants include application method, with backpack spraying typically creating higher exposure than mechanized systems; environmental conditions, particularly temperature and humidity affecting both dermal absorption and respiratory exposure patterns; use of personal protective equipment, with effectiveness highly dependent on proper selection, fit, condition, and decontamination practices; and work practices including hygiene behaviors, storage and handling procedures, and adherence to restricted entry intervals. Management approaches incorporate integrated pest management reducing overall pesticide use; engineering controls including closed mixing and loading systems; administrative controls focusing on training, supervision, and work scheduling to minimize exposure; and comprehensive personal protective equipment programs addressing the multiple exposure routes associated with pesticide handling.

Nanomaterials represent an emerging occupational exposure category with distinctive toxicological considerations resulting from their extremely small size (at least one dimension less than 100 nanometers) creating unique physical and chemical properties compared to their bulk material counterparts. Occupational exposures occur in research and development facilities, manufacturing operations producing raw nanomaterials, downstream incorporation into products, and increasingly in processing or disposal of nano-enabled products. Health concerns derive from nanomaterials' ability to deposit in the deep lung with limited clearance mechanisms, potential translocation across biological barriers including lung epithelium and blood-brain barrier, enhanced reactivity due to high surface area to mass ratio, and capacity to generate reactive oxygen species. Specific materials of concern include carbon nanotubes with asbestos-like morphology raising fibrogenic and carcinogenic potential; metal and metal oxide nanoparticles demonstrating various organ system effects; and quantum dots containing toxic metal components in highly bioavailable forms.

Exposure assessment employs specialized methodologies addressing the limitations of conventional industrial hygiene approaches when applied to nanoscale materials. Direct-reading instruments measure particle number concentrations and size distributions, though with limited capacity to distinguish engineered nanomaterials from background ultrafine particles. Electron microscopy provides definitive characterization but with significant analytical complexity and cost limitations for routine monitoring. Control banding

**END OF PREVIEW**

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