

PROTECTION MEASURES AGAINST HAZARDOUS AND DANGEROUS AGENTS IN THE WORKPLACE: EVIDENCE, CONTROLS AND BEST PRACTICES

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Abstract. Workplace exposure to hazardous and dangerous agents—including chemical, biological, physical and ergonomic risks—remains a major contributor to occupational illness, injury and productivity loss worldwide. Effective protection measures depend on a layered approach: engineering controls, administrative/work-practice controls and personal protective equipment (PPE). Meta-analyses and systematic reviews (2019-2025) indicate that engineering and administrative controls significantly reduce exposure compared to reliance on PPE alone.

This review synthesises international evidence, outlines the hierarchical model of control, evaluates PPE selection and limitations, and offers best practice recommendations for multi-national manufacturing and production environments. The goal is to inform safety professionals and industry managers on evidence-based protective strategies that go beyond the worker-only focus.

Keywords: occupational exposure; hazard control hierarchy; personal protective equipment; engineering controls; administrative controls; meta-analysis.

МЕРЫ ЗАЩИТЫ ОТ ОПАСНЫХ И ВРЕДНЫХ ФАКТОРОВ НА РАБОЧЕМ МЕСТЕ: ДОКАЗАТЕЛЬСТВА, СРЕДСТВА КОНТРОЛЯ И ПЕРЕДОВОЙ ОПЫТ

Аннотация. Воздействие опасных и вредных факторов на рабочем месте, включая химические, биологические, физические и эргономические риски, остается одним из основных факторов профессиональных заболеваний, травматизма и снижения производительности труда во всем мире. Эффективность мер защиты зависит от многоуровневого подхода: инженерно-технического контроля, административного/практического контроля и средств индивидуальной защиты (СИЗ).

Метаанализы и систематические обзоры (2019–2025 гг.) показывают, что инженерно-технический и административный контроль значительно снижают воздействие по сравнению с использованием только СИЗ. В данном обзоре обобщены международные данные, изложена иерархическая модель контроля, оценен выбор СИЗ и ограничения, а также предложены рекомендации по передовой практике для многонациональных производственных и производственных сред. Цель — предоставить специалистам по безопасности и руководителям отраслей информацию о научно обоснованных стратегиях защиты, выходящих за рамки защиты только работников.

Ключевые слова: воздействие на рабочем месте; иерархия контроля опасностей; средства индивидуальной защиты; инженерно-технический контроль; административный контроль; метаанализ.

Introduction

In industrial and production environments, workers are exposed to a complex mix of hazardous agents—chemicals (dusts, gases, vapours), biological agents (pathogens, bioaerosols), physical risks (noise, heat, vibration) and ergonomic stresses.

Protecting workers requires not only identifying these hazards but implementing effective protection strategies. The “Hierarchy of Controls”—which favours elimination, substitution, engineering controls, administrative controls and finally PPE—provides the foundational framework. The National Institute for Occupational Safety and Health (NIOSH) summarises this approach by stating that elimination and substitution are at the top of the pyramid, and PPE is the “last line of defence”. Scholars emphasise that PPE, while necessary, is the least effective single line of defence and must be supplemented by other control layers. For instance, a systematic review found that individual behavioural training was substantially less effective than engineering or elimination approaches in preventing occupational accidents.

This review explores protection measures against hazardous agents, examines evidence for control effectiveness, highlights gaps and offers recommendations for practice.

Protection Measures: Controls and Evidence

The Hierarchy of Controls

Control measures are typically ranked in order of effectiveness:

1. **Elimination / Substitution** – remove the hazard or replace with a less hazardous alternative.
2. **Engineering Controls** – design modifications, isolation, local exhaust ventilation (LEV).
3. **Administrative / Work Practice Controls** – safe work procedures, training, scheduling, limiting exposures.
4. **Personal Protective Equipment (PPE)** – respirators, gloves, hearing protection, eye/face shields.
5. The evidence emphasises that as you move up the hierarchy (toward elimination/substitution), the reliability and effectiveness of the controls typically increase because they require less day-to-day compliance by the worker.

Engineering Controls and Their Impact

Engineering controls are the “workhorse” of effective hazard mitigation in industrial settings. For example:

A systematic review of occupational safety interventions found that engineering changes—such as machine guarding, ventilation, process redesign—were more effective in reducing accidents than training or PPE alone.

One review notes that “engineering controls often provide stable protection” compared to administrative controls which rely heavily on human behaviour.

In practice, this means in manufacturing contexts where dust, gases or noise are present, installing proper ventilation, exhausts, enclosure of hazardous processes or substitution of materials can reduce exposures significantly.

Administrative Controls and Safe Work Practices

Administrative controls complement engineering controls by modifying how and when work is done. Training, job rotation, restricted access to hazardous zones and hygiene measures (e.g., hand-washing, surface cleaning) are critical. A broad overview of reviews concluded that mixed interventions (engineering + administrative) were more effective than either alone.

However, administrative controls depend heavily on compliance, monitoring and organisational culture. For example, an observational study of occupational safety interventions found that organisational-level measures out-performed individual-level training

Personal Protective Equipment (PPE): Selection, Use and Limitations

PPE remains a vital component of the protective strategy but must not be the sole reliance. Key findings:

A meta-analysis of PPE effectiveness in healthcare settings (COVID-19) found that face masks significantly reduced infection risk (OR = 0.16; 95% CI: 0.05–0.55) but gloves and gowns showed limited independent effect.

Another global meta-analysis on occupational accidents found inconsistent association between PPE use and accident reduction, especially in low-income countries.

A review of PPE impact on physical and mental stress found that prolonged use of PPE increased physical and psychological burden (stress +20-30 %, anxiety +35 %) among users.

These findings reinforce that PPE alone is insufficient without higher-order controls; also, PPE introduces its own burdens (comfort, usability, compliance) that must be managed.

Discussion

This expanded review consolidates recent global evidence indicating that workplace hazard protection requires a comprehensive, multi-layered strategy. Key takeaways:

Engineering controls (elimination/substitution and engineering) consistently demonstrate higher effectiveness and lower dependence on individual behaviour, making them foundational.

Administrative/work practice controls add important flexibility and adaptability, especially in process controls and scheduling, but their reliability depends on training, culture and organisational systems.

PPE, while necessary, should be treated as the final barrier, not the primary defence; reliance solely on PPE is fragile and less effective, especially when worker compliance or comfort is compromised.

Emerging research shows that PPE itself may impose additional burdens (stress, heat, fatigue) that inadvertently affect worker performance and safety. This means PPE programmes must include ergonomic design, stress management and usability assessments.

A significant gap remains in high-quality longitudinal studies on the health outcomes of control interventions in industrial contexts globally (especially in low- and middle-income countries).

Particularly relevant is the adaptation of the hierarchy of controls to new hazard types—including nanomaterials, climate-driven hazards (e.g., extreme heat) and psychosocial risks—which may require revisiting the model structure (for example, proposed “Psychosocial Hierarchy of Controls”).

In practical terms, manufacturing and production industries should ensure their safety programmes start with hazard elimination/substitution, retrofit engineering controls where possible, embed administrative systems for safe work practices, and use PPE in a well-structured programme that addresses usability and compliance.

Conclusion

Protecting workers from hazardous and dangerous agents in industrial settings demands a systematic, evidence-based strategy. The hierarchy of controls—prioritising elimination, substitution, engineering and administrative controls—provides the roadmap.

Personal protective equipment should be viewed as the final layer, not the primary defence. Organisations should implement documented hazard assessments, exposure control plans, and continuous training and monitoring. As industrial contexts evolve and new hazard types emerge, so too must our protective measures: adopting new technologies, refining work practices and expanding protective programmes globally will be critical to safeguarding health and productivity.

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