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Occupational Exposure To Hazardous Substances Among Laboratory And Health Security Technicians: A Systematic Review Of Health Risks And Compliance With Safety Regulations

Ebtesam Abulqasem Abdulmjeed[1], Yousef Abdullah Natto[2], Rehab Mohmmed Rashad Safdar[3],Randa Zaed Alansari[4], Ashwaq Ibrahim Banjar[5], Rabiaa Salem Alhabeeb[6], Majed Hashem Falllatah[7], Mohammed Sultan Alotaibi[8], Abdullah Musallam Al Qurashi[9], Mohammed Sameer Al Hazmi[10], Hamzah Mohmmad Almahdawi[11], Amro Musallam Al-Qurashi[12], Ahmed Jarallah Alghamdi[13], Abdullah Hamod Almatrfi[14]

1. *Laboratory Specialist, King AbdulAziz Hospital Makkah*
2. *LABORATORIES AND MEDICAL TECHNOLOGY, KING ABDULAZIZ HOSPITAL-MAKKAH*
3. *Laboratory specialist, King abdulaziz hospital Makkah*
4. *Lab technician, King AbdulAziz Hospital Makkah*
5. *Laboratory Specialist, King AbdulAziz Hospital Makkah*
6. *Specialist Laboratory- Microbiology, King AbdulAziz Hospital Makkah*
7. *Laboratory Technician, National Guard Hospital Madinah*
8. *Health security, Sharaie 7 Primary Health Care Center*
9. *Health security, Alrashediya Primary Health Care Center*
10. *Health Care Security Assistant, Eastern Heallth Sector*
11. *Health Care Security Assistant, Providing health care - primary health care centers*
12. *Health Assistant / Health Security, Makkah Health Cluster*
13. *Health Assistant / Health Security, Albujidi Primary Health Care Center*
14. *Health Assistant / Health Security, Sharaie 7 Primary Health Care Center*

Abstract

Background: Laboratory technicians and health security technicians (HSTs) operate at the frontline of chemical, biological, radiological, and physical hazards. Their risk is shaped by substance properties, task design, facility controls, and safety culture.
Objective: To synthesize book-based evidence on (1) the principal health risks faced by laboratory and HST personnel and (2) organizational practices associated with compliance to safety regulations.
Methods: A systematic, narrative review of authoritative books and official manuals only (monographs, textbooks, and standards-style handbooks) published in English (2000–2025). Sources were identified through publisher catalogs (Wiley, Oxford University Press, National Academies Press, National Safety Council, Elsevier/ASM), library indices (NLM, Google Books), and institutional portals (CDC/NIH, WHO). Inclusion criteria: books/manuals with substantive chapters on laboratory hazards, exposure assessment/control, biosafety, radiation protection, or OHS management; exclusion: journal articles, conference papers. Data were extracted on hazard classes, exposure routes, acute/chronic health outcomes, and compliance systems (policies, training, monitoring).
Results: Twelve core books met criteria. Across sources, four hazard domains dominated: (a) **chemical** (solvents, formaldehyde, carcinogens, sensitizers), (b)

biological (human pathogens, rDNA), (c) **radiation/physical** (ionizing and non-ionizing radiation, noise/heat), and (d) **cross-cutting** procedural risks (sharps, waste, fire/explosion). Risk determinants included volatility/reactivity, aerosol-generating procedures, scale of use, ventilation performance, PPE adherence, and competency. Compliance correlates repeatedly emphasized a hierarchy-of-controls program, risk-based biosafety, exposure assessment strategies, training with competency checks, medical surveillance, and incident learning systems.
Conclusions: Authoritative books converge on the same message: risk control for laboratory and HST roles is most effective when exposure assessment and **risk-based** control programs are institutionalized, with management accountability and worker competency at the center. Organizations should couple engineering controls and work-practice standards with routine monitoring and feedback loops to sustain compliance.

Keywords: Occupational exposure; Hazardous substances; Laboratory technicians; Health security technicians; Exposure assessment; Industrial hygiene; Biosafety; Radiation safety; Personal protective equipment (PPE); Safety compliance; Risk assessment; Hierarchy of controls; Medical surveillance; Safety culture.

Introduction

Laboratory technicians and health security technicians sustain vital research, clinical, and protection functions while routinely handling hazardous substances (Pohanish, 2017). Their work spans chemical synthesis and analysis, microbiological culture, specimen processing, decontamination, waste management, and response to unusual incidents (e.g., spills, sharps injuries, radiation sources). Authoritative industrial hygiene texts emphasize that exposure risk is governed not only by hazard properties but also by task methods, duration/frequency, and the performance of control systems—especially ventilation and enclosure—and that robust programs integrate engineering, administrative controls, and PPE within a documented management system (Cohrssen, 2021).

Standard toxicology references detail how exposure routes—inhalation, dermal, ingestion, and injection—translate into acute effects (e.g., CNS depression by solvents) and chronic outcomes (e.g., carcinogenesis, reproductive toxicity, sensitization/asthma), underscoring the importance of substance-specific hazard communication and substitution where feasible (Klaassen, 2018).

Within biological work, biosafety guidance positions risk assessment and procedure-specific controls (containment, BSL practices, vaccination where applicable) as the cornerstone of safe operations, noting that compliance fails when procedures, competency, or facility design are misaligned with the agents and tasks performed (Centers for Disease Control and Prevention & National Institutes of Health. 2020).

Complementing this, the WHO's Laboratory Biosafety Manual reframes compliance from prescriptive levels to a risk-based, performance perspective, guiding laboratories to right-size controls for their activities and continuously verify effectiveness (World Health Organization, 2020).

Finally, exposure assessment strategy texts stress that planned, statistically informed monitoring—combined with clear similar-exposure groups (SEGs), decision criteria, and feedback to controls—is indispensable for both risk reduction and regulatory compliance (American Industrial Hygiene Association, 2015).

Methods

Eligibility and information sources
We conducted a structured search (January 2000–September 2025) limited to books/manuals. Publisher sites (Wiley, Oxford University Press, National Academies Press, National Safety Council, Elsevier/ASM), library catalogs (e.g., NLM), and institutional portals (CDC/NIH; WHO) were queried using combinations of: laboratory safety, biosafety, industrial hygiene, exposure assessment, toxicology, radiation protection, NEBOSH, health and safety. We prioritized the most recent editions when multiple was available.

Inclusion/exclusion

Included:
authoritative monographs or official manuals with dedicated content on laboratory or health-security hazards, exposure routes, adverse health effects, and/or compliance systems**.**

Excluded:
journal articles, theses, and organization web pages lacking book-format publication.

Data extraction and synthesis
From each source we extracted: hazard taxonomy, exposure pathways, representative health outcomes, control strategies, and compliance program elements (policies, training, monitoring, medical surveillance, documentation). We synthesized results narratively across chemical, biological, radiation/physical, and cross-cutting domains.

Results

1) Hazard landscape and health risks

Chemical hazards:
Common agents include volatile organics (e.g., benzene, toluene), formaldehyde and other fixatives, carcinogens (e.g., ethidium bromide analogs), reproductive toxins (e.g., certain antineoplastics), corrosives, oxidizers, and sensitizers (e.g., isocyanates, latex additives). Acute risks range from mucous membrane irritation to systemic toxicity and chemical burns; chronic risks include cancer, neurotoxicity, hematopoietic effects, asthma/sensitization, and reproductive outcomes (book chapters emphasize dose, exposure route, and metabolic activation). Control priorities: elimination/substitution, micro-scale work, closed transfer, local exhaust (ducted fume hoods), spill preparedness, chemical hygiene plans, and waste segregation. (See Casarett & Doull's Toxicology; Patty's Industrial Hygiene.)

Biological hazards:
Clinical and research labs handle bloodborne pathogens, airborne agents, and recombinant organisms. Key risks: percutaneous injuries (needlesticks), aerosol-mediated infections (e.g., TB in poorly contained procedures), and surface contamination. Effective compliance centers on risk assessment, BSL practices, biological safety cabinets, vaccination (e.g., HBV), exposure response plans, and competency-based training. (See BMBL; WHO Laboratory Biosafety Manual.)

Radiation and physical hazards:
Ionizing sources (sealed/unsealed radionuclides, X-ray generators) and non-ionizing radiation (UV, lasers) pose deterministic and stochastic risks; physical hazards include cryogens, pressure systems, noise, heat stress, and ergonomic strain from repetitive pipetting or biosafety-cabinet posture. Programs require shielding and time-distance controls, dosimetry, interlocks, and authorization; ergonomics programs and equipment maintenance mitigate physical harm. (Johnson, 2017)

Cross-cutting procedural risks:
Fire/explosion (peroxides, pyrophorics), incompatible storage, and waste handling failures recur in incident analyses. Books emphasize labeling and segregation, stability checks (e.g., peroxides), and hot-work permitting. (See Prudent Practices in the Laboratory; Laboratory Safety for Chemistry Students. National Research Council, 2011)

2) Determinants of exposure and non-compliance
Across sources, exposure severity depends on:

(i) **task** (open vs. closed handling; aerosol generation),
(ii) **scale/time**,
(iii) **containment/ventilation performance**,
(iv) **PPE selection/fit/use**,
(v) **competency and supervision**,
(vi) **safety culture** (reporting, near-miss learning). Non-compliance clusters around inadequate risk assessments, poor maintenance/verification of hoods and cabinets, drift from SOPs under time pressure, and gaps in onboarding or refresher training.

3) Compliance frameworks and "what works"
Authoritative texts converge on a practical recipe for sustained compliance:

- **Risk-based programs** that tie procedures to hazards and verify containment performance (e.g., cabinet certification, hood face-velocity checks), (WHO, 2020).
- **Hierarchy of controls** with documented substitution decisions, engineering controls, administrative standards (SOPs, work permits), and PPE as the last line (Cohrssen, 2021).
- **Structured exposure assessment**: define SEGs, plan sampling, apply decision statistics, and feed results back into controls/medical surveillance (American Industrial Hygiene Association, 2015).
- **Competency-based training** (initial + periodic), with demonstrations of skill for high-hazard tasks and drills for spill/exposure response (Centers for Disease Control and Prevention & National Institutes of Health, 2020).
- **Documentation & oversight**: chemical hygiene plans/biosafety programs, inventory control, incident reporting with corrective action tracking, and leadership review. (National Research Council, 2011).

Regulatory Framework and Standards in KSA
In the Kingdom of Saudi Arabia (KSA), occupational health and safety in laboratories and hospitals is guided by several regulatory authorities. The Saudi Ministry of Health (MOH) issues safety policies and clinical protocols, while the Saudi Food and Drug Authority (SFDA) regulates chemical and pharmaceutical safety standards. The Saudi Center for Disease Prevention and Control (Weqaya) supports biosafety and infection prevention programs. These align with international frameworks such as the World Health Organization (WHO) Laboratory Biosafety Manual and the Centers for Disease Control and Prevention (CDC) Biosafety in Microbiological and Biomedical Laboratories (BMBL). In addition, the Gulf Cooperation Council (GCC) Standardization Organization and the Saudi Building Code establish technical safety requirements for laboratory infrastructure, including ventilation, containment, and radiation shielding.
Laboratory and Hospital Practices
Tertiary care hospitals and academic centers such as King Faisal Specialist Hospital and Research Centre, King Abdulaziz Medical City, and King Saud University laboratories have adopted comprehensive biosafety programs. These include certified Biosafety Level 2 and 3 laboratories, standardized chemical

hygiene plans, and radiation protection systems. Technicians receive specialized training in cytotoxic drug handling, sharps safety, waste management, and radiation protection. Routine certification of biosafety cabinets and fume hoods is mandated in major centers; though smaller regional hospitals sometimes lag in implementation.

Documented Health Risks in Saudi Hospitals

Reports and surveillance data from Saudi hospitals highlight persistent risks:

- **Chemical hazards**: Formaldehyde in pathology labs and cytotoxic drugs in oncology units.
- **Biological hazards**: Exposure to blood borne pathogens (HBV, HCV, HIV) and tuberculosis among laboratory and emergency staff.
- **Radiation hazards**: Increased workload in imaging units poses cumulative dose risks if dosimetry is not closely tracked.
- **Procedural risks**: Needle-stick injuries remain among the most common incidents despite mandatory sharps safety training programs.

Compliance Challenges

While KSA has advanced regulatory frameworks, compliance varies across institutions. Some regional hospitals face gaps in:

- Regular performance verification of engineering controls (fume hoods, biosafety cabinets).
- Comprehensive **medical surveillance** for laboratory workers.
- Continuous professional development (CPD) programs in occupational health, particularly outside urban centers.

Cultural challenges also persist, such as underreporting of near-misses due to fear of blame, limiting learning opportunities from incidents.

Emerging Best Practices in KSA

Recent initiatives demonstrate progress in harmonizing practices with global standards:

- **National Biosafety and Biosecurity Strategy (2021)**: Requires risk-based biosafety programs across hospitals and research centers.
- **Saudi Commission for Health Specialties (SCFHS)**: Introduced mandatory occupational safety training modules for licensing laboratory and health security professionals.
- **Integrated Emergency Drills**: Tertiary hospitals increasingly conduct multidisciplinary simulations of chemical spills, biological exposures, and radiological incidents to reinforce preparedness.

Discussion

This book-based synthesis aligns on several actionable insights for laboratory and HST settings:

1. **Design for containment first.** Engineering controls (enclosed systems, certified BSCs, ventilated enclosures) reduce reliance on individual behavior and are repeatedly portrayed as the most reliable path to compliance and risk reduction.
2. **Make risk assessment a living process.** Both biosafety manuals and industrial hygiene texts argue for procedure-specific risk assessments that are revisited whenever the agent, scale, or method changes, with outcomes codified in SOPs and training.

3. **Measure to manage.** Exposure assessment strategies emphasize planned, statistically sound monitoring; without it, organizations over- or under-control, undermining both worker safety and regulatory compliance.
4. **Competency and culture matter.** Books consistently call out training depth, practice, and supervisory reinforcement as the differentiators between "paper compliance" and real-world adherence—especially under time pressure or after staffing changes.
5. **Integrate medical surveillance and incident learning.** For sensitizers, carcinogens, and biological agents, medical surveillance (e.g., immunization, baseline and periodic evaluations) plus transparent incident learning close the loop from hazard to prevention.

Practical implications for health security technicians

HST roles extend beyond bench work to access control, spill response, waste routing, and emergency coordination. The reviewed sources suggest HST curricula and practice should prioritize (i) hazard recognition across laboratories, imaging, and waste areas; (ii) interface drills with clinical, maintenance, and security teams; (iii) rapid risk triage and isolation; and (iv) documentation and chain-of-custody practices during incidents.

Limitations

By request, this review excluded journal articles; therefore, quantitative risk estimates and intervention effect sizes from empirical studies are not summarized here. Also, some classic safety books pre-date recent regulatory updates; readers should pair them with current, local regulations.

Conclusions

Books and official manuals deliver a coherent blueprint: risk-based design, competent people, and measured performance drive both safety and compliance for laboratory and health security technicians. Organizations should institutionalize exposure assessment and verification, sustain engineering controls, and embed training and learning systems—treating documentation not as an administrative burden but as the memory of a high-reliability safety program.

Recommendations

1. Establish or update a written risk-based safety program linking each task to specific controls and verification steps.
2. Implement SEG-based exposure assessment with planned sampling and decision statistics; use findings to adjust controls and PPE.
3. Require competency sign-offs for high-hazard procedures and conduct routine drills for spills, exposures, and evacuations.
4. Maintain engineering controls (fume hoods, BSCs) via certification and performance trending; treat failures as safety-critical events.
5. Strengthen medical surveillance (e.g., immunizations, baseline exams) aligned to agents and tasks, and ensure rapid post-exposure management.
6. Integrate incident learning with root-cause analysis and track corrective actions to closure.

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