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# CHEMICAL RISK ASSESSMENT METHODS: A COMPREHENSIVE REVIEW AND COMPARATIVE ANALYSIS

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**Abstract**
Chemical risk assessment is a process that aims to provides information on the probability of adverse effects following chemical exposures. This paper presents a review of the most widely used chemical risk assessment methods, including COSHH Essentials, Institut National de Recherche et de Sécurité (INRS), Chemical Risk Management (CHARM), Stoffenmanager, ECETOC TRA Targeted Risk Assessment, Advanced REACH Tool (ART), New Approach Methodologies (NAM), Critical Task Exposure Screening (CTES), SQCRA Method, Chem-SAM, UOW, and Chemical Health Risk Assessment (CHRA). A comparative analysis highlights their strengths, limitations, application cases, and use cases is also included. Finally are included some recent developments in Artificial Intelligence (AI) applications for chemical risk assessment.

**Keywords**: chemical risk, assessment methods, AI applications.

## Introduction

Chemical risk assessment is a critical process for safeguarding occupational, environmental, and public health against potential hazards posed by chemical substances. As chemical risks grow in complexity, the evolution of assessment methodologies and the incorporation of Artificial Intelligence (AI) advancements have become increasingly vital for ensuring effective and modernized safety practices. The methodologies employed for chemical risk assessment vary significantly in complexity, scope, and applicability. This review provides a detailed technical evaluation of the most widely used chemical risk assessment methods, including COSHH Essentials, Institut National de Recherche et de Sécurité (INRS), Chemical Risk Management (CHARM), Stoffenmanager, ECETOC TRA Targeted Risk Assessment, Advanced REACH Tool (ART), New Approach Methodologies (NAM), Critical Task Exposure Screening (CTES), SQCRA Method, Chem-SAM, UOW, and Chemical Health Risk Assessment (CHRA). A comparative analysis highlights their strengths, limitations, application cases, and use cases. Additionally, discuss recent developments in Artificial Intelligence (AI) applications for chemical risk assessment, emphasizing their transformative potential for modern practices, are discussed.

## Overview of Chemical Risk Assessment Methods

A description of the mainly used chemical risk assessment methods is presented next, comprehending each method strengths, limitations, application cases and use cases.
At the end of the chapter, a summary table is presented with the methods covered.

### *COSHH Essentials*

A The Control of Substances Hazardous to Health (COSHH) Essentials, developed by the UK Health and Safety Executive (HSE), is a qualitative and semi-quantitative tool designed to guide employers in managing chemical risks. It categorizes chemicals based on hazard banding and provides control guidance sheets (CGSs) with recommendations for workplace exposure controls.

- Strengths: Simple to use, focuses on practical control measures, low-cost implementation.
- Limitations: Limited to predefined scenarios and lacks precise quantitative exposure assessment.
- Application Cases: Widely used in manufacturing industries, healthcare facilities handling disinfectants, and laboratories with small-scale chemical use.

- Use Cases: Suitable for small to medium-sized enterprises (SMEs) with limited technical expertise. COSHH Essentials aligns well with workplaces requiring straightforward compliance solutions and minimal technical input.

***Institut National de Recherche et de Sécurité (INRS)***

INRS offers a suite of methodologies and tools for chemical risk assessment in the French occupational health framework. Tools like SEIRICH are aimed at evaluating workplace exposure and recommending controls.

- Strengths: Tailored for French regulatory requirements, provides detailed workplace-specific assessments.
- Limitations: May lack applicability outside French regulatory contexts, requires technical expertise.
- Application Cases: Industrial workshops, laboratories, and agricultural sectors in France.
- Use Cases: Comprehensive assessment within French industrial and regulatory settings. The INRS methodology is particularly valuable for organizations needing to align closely with French regulations while addressing complex workplace scenarios.

***Chemical Risk Management (CHARM)***

CHARM is widely used in offshore industries, particularly in assessing the environmental risks of chemicals discharged into marine environments.

- Strengths: Quantitative and focuses on environmental impact, robust database integration.
- Limitations: Industry-specific (offshore oil and gas), limited applicability to other domains.
- Application Cases: Offshore drilling operations, marine chemical discharge analysis, and environmental impact studies.
- Use Cases: Environmental risk assessment in offshore oil and gas industries. Its focus on marine environments makes CHARM indispensable for compliance and sustainability initiatives in this sector.

***Stoffenmanager***

Stoffenmanager is a web-based tool that assesses occupational exposure to hazardous substances and provides risk control advice.

- Strengths: User-friendly interface, incorporates quantitative exposure modeling, widely used across industries.
- Limitations: Relies on default values that may oversimplify complex scenarios.
- Application Cases: Factories handling solvents, automotive industries, and construction sites.
- Use Cases: Occupational exposure assessment in industries with diverse chemical use. Stoffenmanager's integration of AI-based modules enhances its accuracy and adaptability to dynamic workplace conditions.

***ECETOC TRA Targeted Risk Assessment***

Developed by the European Centre for Ecotoxicology and Toxicology of Chemicals (ECETOC), this tool provides tiered exposure and risk assessment for industrial chemicals.

- Strengths: Tiered approach allows for scalability, well-suited for regulatory compliance under REACH.
- Limitations: Conservative estimates may lead to over-control measures, requires input data accuracy.
- Application Cases: Chemical manufacturing, formulation, and downstream user applications in the EU.
- Use Cases: Risk assessment for regulatory compliance under the European Union's REACH framework. The tool's adaptability makes it ideal for varying levels of regulatory complexity.

***Advanced REACH Tool (ART)***

ART is an advanced exposure modeling tool designed to estimate worker exposure to chemicals based on task-specific scenarios.

- Strengths: High accuracy in quantitative exposure estimation, incorporates multiple exposure determinants.
- Limitations: Requires extensive input data, may not be suitable for SMEs.

- Application Cases: Pharmaceutical manufacturing, chemical synthesis facilities, and industrial painting processes.
- Use Cases: Detailed occupational exposure assessment for large-scale industries. ART's precision supports high-stakes environments where exact exposure quantification is critical.

***New Approach Methodologies (NAM)***

New Approach Methodologies (NAM) focus on integrating non-animal testing methods and computational modeling to evaluate chemical hazards and exposure scenarios.

- Strengths: Promotes ethical considerations by avoiding animal testing, innovative computational approaches.
- Limitations: Limited validation and adoption, requires specialized knowledge.
- Application Cases: Toxicological risk evaluations in cosmetics, biopharmaceuticals, and agrochemical industries.
- Use Cases: Cutting-edge research and regulatory scenarios requiring alternative approaches. NAM exemplifies the ethical and technological shift in risk assessment paradigms.

***Critical Task Exposure Screening (CTES)***

Critical Task Exposure Screening (CTES) is designed to identify and evaluate specific tasks or processes that pose significant chemical exposure risks in workplaces.

- Strengths: Focuses on high-priority tasks, incorporates observational and task-specific data.
- Limitations: Task-specific focus may not cover broader workplace risks, requires detailed task analysis.
- Application Cases: Industrial processes involving volatile solvents, spray painting, and chemical mixing.
- Use Cases: Targeted interventions for high-risk tasks in manufacturing and construction industries. CTES provides actionable insights to mitigate exposure in critical operations.

***SQCRA Method***

The Semi-Quantitative Chemical Risk Assessment (SQCRA) method combines qualitative and quantitative elements to evaluate chemical risks in workplaces.

- Strengths: Balances simplicity and detail, applicable to diverse industries.
- Limitations: Limited by the quality of input data, may oversimplify complex risks.
- Application Cases: Small manufacturing units, warehouses storing hazardous materials, and logistics hubs.
- Use Cases: General workplace risk assessment. Its balance of simplicity and detail makes it accessible for varied industrial applications.

***Chem-SAM***

Chem-SAM is a comprehensive risk assessment tool that integrates chemical hazard data with exposure scenarios to evaluate workplace safety.

- Strengths: Detailed exposure assessment, customizable for various industries.
- Limitations: Complex implementation, requires substantial data.
- Application Cases: Chemical plants, mining industries, and specialized R&D laboratories.
- Use Cases: High-detail risk assessments for complex workplaces. Chem-SAM excels in environments demanding high precision and flexibility.

***UOW Risk Assessment Method***

Developed by the University of Wollongong, this method incorporates both qualitative and quantitative techniques for assessing chemical hazards in academic and research environments.

- Strengths: Specific to academic settings, emphasizes training and awareness.
- Limitations: Limited scalability to industrial applications.
- Application Cases: University laboratories, pilot research facilities, and teaching environments.

- Use Cases: Risk assessment in academic and research laboratories. The UOW method highlights the importance of education and tailored safety practices in research settings.

***Chemical Health Risk Assessment (CHRA)***

CHRA is a structured approach used primarily in Malaysia for assessing chemical health risks in workplaces.

- Strengths: Highly structured, focuses on compliance with Malaysian occupational health regulations.
- Limitations: Region-specific applicability, limited adoption outside Malaysia.
- Application Cases: Electronics manufacturing plants, oil palm processing facilities, and construction sites.
- Use Cases: Occupational risk assessment in Malaysian industries. CHRA ensures robust compliance with regional regulations, offering a reliable framework for workplace safety.

Table 1 presents a comparison (strengths, limitation and best uses cases) for the above discussed assessment methods.

***Table 1.*** *Comparative Analysis of Chemical Risk Assessment Methods.*

| Method | Strengths | Limitations | Best Use Cases |
|---|---|---|---|
| COSHH Essentials | Simple, practical guidance | Limited quantitative capability | SMEs with limited resources |
| INRS | Detailed, workplace-specific | Region-specific to France | French industrial settings |
| CHARM | Quantitative, environmental focus | Industry-specific | Offshore oil and gas |
| Stoffenmanager | User-friendly, quantitative modeling | Oversimplification of scenarios | General industrial use |
| ECETOC TRA | Scalable tiered approach | Conservative estimates | REACH compliance |
| ART | High accuracy, task-specific modeling | Data-intensive | Large-scale industries |
| NAM | Ethical, innovative computational methods | Limited validation | Research and regulatory innovation |
| CTES | Task-specific focus, actionable insights | Limited broader applicability | High-risk task interventions |
| SQCRA | Balances simplicity and detail | Dependent on input data quality | General workplace assessments |
| Chem-SAM | Comprehensive exposure assessment | Complex implementation | High-detail workplace assessments |
| UOW | Academic focus, tailored training | Limited industrial scalability | Academic and research labs |
| CHRA | Structured, regulatory compliance (Malaysia) | Region-specific | Malaysian workplace settings |

**Recent Developments in AI for Chemical Risk Assessment Methods**

The integration of Artificial Intelligence (AI) into chemical risk assessment has emerged as a transformative approach to enhance accuracy, efficiency, and scalability. AI-driven models leverage large datasets such as those from regulatory databases (e.g., REACH, OSHA) and toxicological repositories (e.g., ToxCast) alongside advanced algorithms, including random forests, neural networks, and support vector machines, to predict chemical hazards, exposure levels, and control measures with unprecedented precision. Key developments include:

- Machine Learning for Exposure Prediction: Algorithms trained on historical exposure data can predict potential exposure scenarios based on task, substance, and workplace conditions. AI-based tools such as advanced Stoffenmanager modules now incorporate machine learning to refine exposure modeling.
- Natural Language Processing (NLP) for Data Mining: NLP algorithms extract relevant hazard and exposure data from regulatory documents, research papers, and safety data sheets, automating data input and reducing manual errors.
- AI-Powered Risk Ranking Systems: Tools like ChemAI integrate risk ranking algorithms to prioritize high-risk substances, enabling targeted control interventions.
- Digital Twins for Scenario Testing: Digital twin technology, paired with AI, allows the creation of virtual workplace models to simulate chemical exposure under varying conditions, offering real-time feedback for risk mitigation strategies. For instance, simulations in large-scale manufacturing plants demonstrate reduced implementation costs and improved safety outcomes.
- AI in Toxicology: Predictive toxicology models powered by AI evaluate potential health risks of new chemicals, reducing reliance on animal testing and expediting regulatory approval processes.
- Cloud-Based AI Platforms: Platforms like RAMP (Risk Assessment Modeling Platform) use cloud computing and AI to centralize chemical risk assessment, enabling collaborative and remote evaluations across global sites.

***Examples of AI Applications in Chemical Risk Assessment***

- Stoffenmanager AI Modules: Recent updates in Stoffenmanager leverage AI to predict workplace exposure with greater accuracy, integrating historical data and real-time inputs to model risk scenarios dynamically.
- ChemAI: This tool uses AI algorithms for prioritizing chemical risks, combining hazard data, exposure potential, and workplace practices to rank substances by risk level.
- ToxCast and Tox21 Programs: These U.S. Environmental Protection Agency (EPA) initiatives employ machine learning to predict toxicological endpoints based on chemical structure and activity data.
- AI-Driven Digital Twins: In collaboration with industrial partners, digital twin models simulate complex environments, such as large-scale manufacturing plants, to test chemical exposure mitigation strategies before implementation.
- RiskMap AI: A cloud-based tool that integrates AI for real-time monitoring of chemical hazards and provides actionable recommendations for workplace safety improvements.

***Application Cases for AI in Chemical Risk Assessment***

- Healthcare: AI models are used to predict exposure to disinfectants and develop optimized ventilation strategies in hospitals.
- Manufacturing: Automated assessment of solvent risks in production lines, identifying areas for improved containment.
- Construction: AI-driven analysis of silica dust exposure to implement real-time monitoring and control.
- Regulatory Compliance: AI tools assist in generating tailored compliance reports for REACH, OSHA, and other frameworks.

**Conclusion**

The choice of a chemical risk assessment method depends on the specific context, regulatory requirements, and available resources. While COSHH Essentials and Stoffenmanager offer accessible solutions for general workplaces, advanced tools like ART and Chem-SAM are better suited for detailed quantitative assessments. Regional tools such as INRS and CHRA provide tailored solutions within their regulatory frameworks, whereas innovative approaches like NAM and CTES represent the future of chemical risk assessment by integrating ethical and computational advancements. Moreover, the advent of AI-driven tools is revolutionizing the field,

enabling more precise, efficient, and adaptable risk assessments. Understanding the strengths and limitations of each method is crucial for selecting the most appropriate approach for effective chemical risk management.

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