# CBRN THREATS TO UKRAINE DURING THE RUSSIAN AGGRESSION: MITIGATING CHEMICAL HAZARDS DURING WARTIME – COUNTERMEASURES AND DECONTAMINATION STRATEGIES FOR UKRAINE IN LIGHT OF POTENTIAL CHEMICAL FACILITY DESTRUCTION

**Łukasz Szklarski**[1]*

[1] ITTI Sp. z o.o.
* Correspondence: lukasz.szklarski@itti.com.pl

## Abstract

This scientific paper investigates the potential threats posed by the release of Chemical Warfare Agents (CWAs) and Toxic Industrial Chemicals (TICs) due to possible destruction of chemical facilities in Ukraine during wartime. It presents an in-depth discussion of the risks, countermeasures and decontamination strategies, focusing on the application in resource-constrained settings. This study aims to contribute to the understanding of chemical disaster management and the development of effective countermeasures.

**Keywords:** Chemical threats, wartime, Ukraine, chemical warfare agents (CWAs), Toxic Industrial Chemicals (TICs), decontamination, countermeasures, chemical facilities

## 1. Introduction

The perils of chemical threats during periods of armed conflict cannot be understated. This is especially due to the dual potential of deployment of Chemical Warfare Agents (CWAs) and the inadvertent release of Toxic Industrial Chemicals (TICs) from damaged chemical infrastructure (Tomassoni, French, Walter, 2015; Ganesan, Raza, Vijayaraghavan, 2010). The potential gamut of hazardous substances, which could be unleashed, poses a significant threat to human health and ecological systems.

**DOI:** 10.5604/01.3001.0053.9116
Received: 06.07.2023 Revised: 09.08.2023 Accepted: 09.08.2023

Ukraine's current geopolitical situation underscores the urgency of this scenario. Numerous chemical facilities are strewn across the country, with many situated within or in close proximity to populated urban areas. This proximal positioning of potential sources of hazardous substances could expose large civilian populations to harmful chemicals, should these facilities suffer damage during hostilities (Ivanenko, 2020).

Given this urgent backdrop, there is a pressing need for thorough comprehension of the possible impacts of such events and for the concurrent development of effective countermeasures and decontamination strategies. A chemical disaster preparedness plan must encapsulate a multi-pronged strategy, including threat assessment, mitigation, readiness, response and recovery. This approach must leverage advancements in scientific and technological realms, but also be complemented by judicious policy implementation and community preparedness (Levy, Bissell, 2013).

This study is set against this urgent need and is designed to explore potential threats from CWAs and TICs within the context of the potential destruction of chemical facilities in Ukraine. The study also aims to evaluate extant countermeasures and decontamination strategies, assessing their suitability in resource-limited situations.

The present article, "CBRN threats to Ukraine during the Russian aggression: Mitigating Chemical Threats during Wartime – Countermeasures and Decontamination Strategies for Ukraine in Light of Potential Chemical Facility Destruction", is the second part in the author's academic series, "CBRN threats to Ukraine during the Russian aggression". The first paper of this series, entitled "CBRN threats to Ukraine during the Russian aggression: Mitigating Gamma Radiation Hazards: Innovative Countermeasures and Decontamination Strategies in the Context of Potential Destruction of the Zaporizhzhia Nuclear Power Plant", has already been released. This sustained research series serves as a rigorous examination of contemporary CBRN threats facing Ukraine, further solidifying the pertinence and urgency of this topic amidst ongoing geopolitical tensions.

## 2. Methodology

In addressing the primary research question of this article, "What are the current chemical threats facing Ukraine, and what possible countermeasures exist?", the research approach has been centred on two key elements. The first is the author's extensive experience in the security domain, with a particular focus on Chemical, Biological, Radiological and Nuclear (CBRN) defence. This experience, enriched by insights gleaned from years of executing research projects within the CBRN domain for the European Union and the European Defence Agency (EDA), brings practical understanding to the topic. The author has coordinated several research projects for the European Commission, most notably EU-RADION and EU-SENSE, contributing to the knowledge base on chemical threats and their countermeasures.

In tandem with this practical experience, the author has undertaken an exhaustive review of academic literature, selecting scientific papers from leading authors and institutions that specialise in chemical threats and protection. This academic review allows the incorporation of the most recent and relevant findings and theoretical perspectives, grounding the article in current academic discourse.

The sections of the article each address a specific subsidiary research question, contributing to a comprehensive understanding of the main research question:

1) Chemical Threats during Wartime: "What is the nature of chemical threats during war?"
2) Potential Threats for Ukraine in Case of Chemical Facility Destruction: "What are the potential risks should a significant chemical facility in Ukraine be destroyed, and what chemicals pose the most significant threats?"
3) Potential Threats for Ukraine in Case of a Chemical Warfare Attack: "What are the possible threats and effects on Ukraine in the event of a Chemical Warfare Agent (CWA) attack?"
4) Current Countermeasures against Chemical Threats: "What countermeasures currently exist against chemical threats, and what are their advantages and limitations?"
5) Challenges and Limitations of Current Countermeasures: "What are the challenges and limitations associated with the current countermeasures against chemical threats?"
6) How to Protect the Ukrainian Population in Case of Chemical Threats: "What strategies can be employed to protect the Ukrainian population in the event of a chemical attack?"
7) Decontamination strategies: "How can effective decontamination be achieved in resource-constrained scenarios?"

## 3. Results

### 3.1. Chemical Threats during Wartime

During conflicts, the danger of Chemical Warfare Agents (CWAs) and an unintentional release of Toxic Industrial Chemicals (TICs) due to damage to chemical facilities pose significant threats to both human health and the environment (Tomassoni, French, Walter, 2015; Ganesan, Raza, Vijayaraghavan, 2010).

CWAs are purposely designed for warfare to cause harm or death among combatants and even civilians. They include a range of substances from nerve gases such as sarin, soman, and VX to vesicants like mustard gas and lewisite, and choking agents such as phosgene and chlorine. The effects of these agents on the human body can be devastating, causing everything from respiratory and cardiac arrest to severe burns and neurological damage (Sidell, Takafuji & Franz, 1997).

TICs, on the other hand, are chemicals used in industry that can be harmful or lethal in certain quantities. They can be accidentally released due to industrial accidents or intentional acts such as terrorism or during warfare when industrial facilities are targeted. TICs include a wide array of chemicals such as chlorine, ammonia and phosgene that are used in various industries. Exposure to these chemicals can cause a range of health effects, from acute respiratory distress to long-term cancer risks (Okumura, Suzuki, Fukuda, Kohama, Takasu, 1998; Hincal & Erkekoglu, 2006).

Environmentally, the release of CWAs or TICs can cause long-term damage to ecosystems. Many of these chemicals persist in the environment, accumulating in the soil and water and causing harm to wildlife and plant life (Price, 1997). They can also enter the food chain, affecting the health of humans and animals alike.

The potential for the release of CWAs and TICs during warfare underscores the necessity for comprehensive preparedness strategies. These include effective countermeasures and decontamination methods that can mitigate the human health and environmental impacts of these dangerous substances.

### 3.2. Potential Threats to Ukraine in Case of Chemical Facility Destruction

Given its geopolitical position and the significant size of its chemical industry, Ukraine is potentially at high risk should there be destruction of chemical facilities during warfare (Tomassoni, French, Walter, 2015; Ivanenko, 2020). In particular, the presence of numerous chemical installations in close proximity to populated areas amplifies the threat of widespread damage and exposure to harmful chemicals in the event of deliberate targeting or accidental damage during conflict.

The sectors of the Ukrainian chemical industry - encompassing areas such as petrochemicals, fertilizers, pharmaceuticals and others - utilize and store a wide array of hazardous substances. Notable among these are ammonia, chlorine and a multitude of other toxins, all of which could act as Toxic Industrial Chemicals (TICs) if released into the environment due to facility damage (Levy & Bissell, 2013; Okumura, Suzuki, Fukuda, Kohama, & Takasu, 1998).

TICs represent a potent hazard due to their wide prevalence in industrial processes, and the harmful effects they can inflict upon both human health and the environment. For example, chlorine is a commonly used chemical in water treatment and various manufacturing processes, but when released into the atmosphere it forms a toxic cloud that can cause respiratory distress and skin burns (Hincal & Erkekoglu, 2006; Price, 1997). Similarly, ammonia, widely used in the production of fertilizers, is highly corrosive and can cause serious damage to the eyes, skin, and respiratory system (Okumura et al., 1998; Pitz et al., 2015).

The potential release of such chemicals poses an immediate and severe hazard to exposed populations. In the wake of a significant release event, the capacity of local and national healthcare systems could quickly be overwhelmed, as witnessed in past industrial accidents (Broughton, 2005; Patwary & O'Hare, 2011).

Additionally, the environmental repercussions can be considerable, with long-term contamination of soil and water sources presenting ongoing risks for both human health and local ecosystems (Riding & Doick, 2013).

Historically, there have been grim examples that underscore the risks associated with the release of TICs during wartime. The industrial town of Pancevo in Kosovo, for instance, witnessed the release of vast amounts of vinyl chloride monomer, chlorine, and other hazardous chemicals due to bombings in 1999. Similarly, the Misraq Sulphur plant in Iraq emitted colossal amounts of sulphur dioxide and hydrogen sulphide after being set on fire in 2003. Moreover, the town of Taza in Iraq was the scene of a Chemical Warfare Agent (CWA) attack in 2016, which further highlights the gravity of chemical threats in conflict zones. Such incidents can be thoughtfully projected onto the Ukrainian context, given the aforementioned vulnerabilities of its chemical industry in the face of conflict.

In conclusion, the potential for wartime destruction of chemical facilities in Ukraine, and the subsequent release of TICs, presents a tangible risk. This underscores the crucial importance of undertaking thorough risk assessments and developing robust emergency response plans that encompass the potential chemical threats.

### 3.3. Potential Threats for Ukraine in Case of CWA Attack during Wartime

The potential threats of Chemical Warfare Agents (CWA) used during armed conflict remain a significant concern for Ukraine, as indicated by the extensive literature on CWAs' deleterious effects on human health and the environment (Lee, 2003; Balali-Mood, 2005). CWAs, such as nerve gases, blister agents and choking agents, are expressly designed to harm or kill, and their use in a populated area could lead to substantial loss of life and long-lasting environmental damage (Lukey & Romano, 2007; Das & Thomas, 2022).

The dissemination of these agents, whether through the air, water or soil, can cause widespread casualties in a short period. For instance, nerve gases like Sarin and VX can disrupt nerve cell functioning, leading to severe respiratory and neurological complications (Herrmann, 2011; Shih, Rowland & McDonough, 2007). Blister agents, like mustard gas, can cause debilitating skin, eye and respiratory tract injuries, resulting in long-term morbidity (Monteiro-Riviere, 2010;. Balali-Mood & Abdollahi, 2015). Choking agents, such as chlorine and phosgene, can cause lethal pulmonary damage (Prentiss, 1937; Worek, 2005).

The health infrastructure in Ukraine could be significantly challenged in the event of a CWA attack. It would need to manage a high influx of patients with various injuries and symptoms, as highlighted by previous instances of CWA usage in conflicts such as the Iran-Iraq War (Bajgar, 2004; Marrs & Maynard, 2007).

Moreover, the environmental impact of CWAs is equally concerning. CWAs can contaminate water sources, soil and crops, resulting in extended ecological and health risks (Westing, 1984; Cohn, 2010). These long-term effects require considerable resources for remediation, further straining the affected region's economic and social recovery (National Research Council, Committee to Review the Department of Homeland Security's Approach to Risk Analysis, 2010; Chakalian, 2019).

Therefore, understanding these threats is paramount for risk assessments and the creation of comprehensive emergency response plans (Tuorinsky, 2008; Dunn & Sidell, 1989). This approach can help mitigate the potential human and environmental consequences of CWA attacks and improve Ukraine's preparedness and resilience (Jerard & Salim, 2015).

### 3.4. Current Countermeasures against CWAs and TICs

Chemical warfare agents (CWAs) and Toxic Industrial Chemicals (TICs) pose a major risk to civilian and military populations during conflicts, highlighting the urgent need for effective countermeasures. Current approaches involve a combination of detection, protection, decontamination and medical intervention strategies (Van Ham, van der Meer & Ellahi 2017; Mlsna & Cemalovic, 2006).

Early detection is paramount in order to minimize the impact of CWAs and TICs. Advanced detection systems, ranging from point detectors to stand-off sensors, are used to identify the presence of CWAs and TICs. These sensors, often deployed at critical industrial facilities, can detect minute traces of hazardous chemicals and provide crucial lead time for protective measures to be activated (Richardt & Blum, 2008). However, these systems are not infallible and may fail to detect lower concentration levels or give false alarms (Davidson, Dixon, Williams & Gary, 2020).

Personal protective equipment (PPE) such as gas masks, respirators and full body suits are often used to protect individuals from direct exposure to hazardous chemicals. These technologies have advanced significantly in recent years, providing better protection and comfort. However, they require proper usage and maintenance, and their effectiveness diminishes over time or in extreme conditions (Smith, 2007).

Decontamination, which involves the removal or neutralization of harmful chemicals, is another critical component of countermeasures. Various technologies such as absorbents, chemical neutralizers, and water-based solutions are used for decontamination. These methods, however, may be limited in their effectiveness due to logistical constraints or further environmental contamination (Wood & Adrion, 2019).

Medical countermeasures play a crucial role in mitigating the harmful effects of CWAs and TICs. Treatments involve the use of antidotes, chelating agents and supportive care to manage symptoms. While medical research has provided a number of effective treatments for certain CWAs and TICs, many challenges remain, particularly in terms of timely administration and the availability of antidotes (Kassa, 2002).

In conclusion, while current countermeasures against CWAs and TICs have improved over time, they still present limitations and challenges. Continuous research and development is crucial to enhance the effectiveness of these countermeasures and to ensure the safety of populations in areas at risk.

### 3.5. Challenges and Limitations of Current Countermeasures

While current countermeasures against CWAs and TICs play a significant role in mitigating the impact of chemical attacks and accidents, their implementation and effectiveness are often challenged by various factors, particularly in scenarios with limited resources.

Firstly, detection systems, while crucial for early warning, are often complex and expensive. Their effective deployment requires a well-established infrastructure and skilled personnel to interpret results accurately and promptly (Barras & Greub, 2014). Moreover, they may be less effective in identifying TICs that are released in low concentrations or mixed with other substances. Besides, false alarms and the inability to detect new or modified CWAs pose significant challenges to these systems (Giannoukos, et al. 2016).

Secondly, personal protective equipment (PPE), such as masks and suits, while essential, can be burdensome to use for extended periods, especially in harsh conditions. Effective protection requires appropriate sizing, fitting and regular maintenance, which may be impractical during mass exposure events or in resource-poor settings (Radonovich, et al., 2009). Moreover, PPEs may not offer complete protection against all types of CWAs and TICs, and the supply chain of these materials can be disrupted in times of crisis (Sparks, 2012).

Decontamination methods also have limitations. They are often time-consuming and require significant amounts of water and other resources. Some decontaminants can be harmful to humans and the environment, posing additional challenges to their safe and effective use (Oudejans & O'Kelly, 2016). Moreover, decontamination may not be fully effective against all CWAs and TICs, and the disposal of decontamination waste is an environmental concern (Ganesan, Raza & Vijayaraghavan, 2010).

Lastly, medical countermeasures are also fraught with challenges. The availability and timely administration of antidotes is a significant concern, particularly in mass casualty situations. Additionally, the lack of specific antidotes for many CWAs and TICs, along with the potential side effects of existing treatments, complicates the medical response (Haywood & Karalliedde, 2016).

Overall, while current countermeasures play a significant role in managing the threats posed by CWAs and TICs, their limitations underscore the need for continuous research and development in this field, as well as robust planning and preparedness at all levels.

### 3.6. How to Protect the Ukrainian Population in Case of Chemical Threats

Protecting the Ukrainian population in the event of a chemical threat is a multi-faceted task that involves not just the immediate response, but also long-term strategies for recovery. The approach needs to be a blend of preventative, mitigative and recovery measures, underpinned by the country's preparedness to deal with such incidents.

Firstly, early warning systems are a crucial part of the defence against chemical threats. The establishment of an efficient detection and alert system can significantly reduce the risk of casualties by providing enough time for protective measures (Yu & Wu, 2013). This system would ideally include a wide range of sensors capable of detecting a diverse array of CWAs and TICs. Given the cost and complexity associated with these systems, a feasible approach could be to prioritise areas with high population density or those in close proximity to chemical facilities (Webber, Pushkarsky & Patel, 2005).

Secondly, evacuation plans need to be in place and regularly updated to accommodate the population's changes and potential threat evolution. These plans must be accompanied by public awareness campaigns to ensure that individuals know how to respond appropriately in case of a chemical attack or accident (Tatham & Kovács, 2010). It is crucial that these plans consider vulnerable populations, such as the elderly, children and individuals with disabilities, and ensure that resources are available to aid in their evacuation (Peek & Stough, 2010).

The use of personal protective equipment (PPE), such as gas masks and protective clothing, can provide a vital layer of defence in the event of a chemical incident (Radonovich et al., 2009). However, the widespread distribution of these can be logistically challenging. Therefore, strategic stockpiling and distribution plans must be developed, which ensure the availability of PPE in high-risk areas (NATO Advanced Research Workshop on Defence against Weapons of Mass Destruction Terrorism, 2009).

Medical countermeasures are a further crucial component in protecting the population. This includes the availability of antidotes and treatments for chemical exposure, as well as the capacity of healthcare facilities to deal with a sudden influx of patients (Vale, 2014). It would be essential to train healthcare providers to diagnose and treat chemical exposure and to have a robust supply chain for medical supplies, including antidotes (Brent et al., 2017).

Lastly, a recovery plan must be in place to manage the aftermath of a chemical incident. This includes decontamination of affected areas, monitoring for long-term health effects in exposed individuals and the provision of mental health support for affected individuals and communities (Goldmann & Galea, 2014).

In conclusion, protecting the Ukrainian population from chemical threats requires a comprehensive, multi-faceted approach, underpinned by a strong commitment to preparedness, response and recovery efforts.

### 3.7. Decontamination Strategies

A well-thought-out decontamination strategy plays a crucial role in minimizing risks associated with chemical threats, especially in resource-constrained situations, such as the wartime situation in Ukraine. This section will explore various strategies, including dry decontamination, low-water decontamination, the use of alternative fluids, human decontamination, and the recovery and recycling of decontamination effluents.

Dry Decontamination: This method of decontamination involves the removal of chemical substances without the use of water. It may involve physical processes such as vacuuming, wiping or brushing to remove the contaminants (Zhang, 2020). This strategy can be particularly useful in situations where water resources are limited or where the chemical threat is water-reactive (Almer et al., 2017). However, the effectiveness of dry decontamination can be reduced for certain types of threats, such as those that are oil-based or have low volatility (Keoleian, 1998).

Low-Water Decontamination: In scenarios where water availability is limited but still accessible, low-water decontamination methods can be employed. This can involve techniques such as misting or fogging, which use significantly less water than traditional methods (Luning, 2008). The effectiveness of this approach can depend on the nature of the chemical threat and the size of the area that needs to be decontaminated (Brennan, & Waeckerle, 1999).

Alternative Fluids: When water is not a viable option, alternative fluids can be used for decontamination. This includes substances such as perfluorocarbons, supercritical fluids, and even certain types of gases (Toader, Rotariu & Pulpea, 2021). These substances can penetrate and clean surfaces in ways that water cannot, making them effective for certain types of chemical threats (Cox, 1994). However, the use of these fluids can present other challenges, such as requiring specialized equipment or safety protocols (Calder & Bland, 2018).

Human Decontamination: When humans are exposed to chemical threats, decontamination becomes a delicate process that needs to balance the removal of contaminants with the preservation of health and dignity. Strategies for human decontamination can include the use of showers, wipes and absorbent materials (Chilcott, 2014). The use of specialized decontamination solutions, such as Reactive Skin Decontamination Lotion (RSDL), may also be used for certain types of threats (Chan, et al. 2004). The choice of method depends on the nature of the threat, the resources available, and the needs of the individual being decontaminated (National Research Council, Division on Engineering and Physical Sciences, 2001).

Recovery and Recycling of Decontamination Effluents: After decontamination, the effluents produced can present a new set of challenges. These effluents can contain concentrated forms of the chemical threat and need to be managed properly to prevent secondary contamination (Chilcott, Larner & Matar, 2019). Techniques for managing these effluents can include neutralization, filtration or even recycling for further use in decontamination processes (Baeynes & Brems, 2009).

In conclusion, the choice of decontamination strategy depends on the nature of the chemical threat, the resources available and the specific circumstances of the scenario. A robust decontamination strategy should be versatile, adaptable and sensitive to the needs of those affected by the chemical threat.

## 4. Conclusion

Given the heightened state of global conflicts and the ongoing situation in Ukraine, the importance of understanding and preparing for potential chemical threats cannot be overstated. The potential destruction of chemical facilities during wartime can expose the populace and the environment to chemical warfare agents (CWAs) and toxic industrial chemicals (TICs), which can have catastrophic health and environmental impacts.

This discussion has underscored the myriad ways these threats can manifest themselves, from acute toxicity to long-term chronic health issues and environmental damage. Moreover, the complex, unpredictable nature of conflict situations makes the task of ensuring safety even more challenging. The gravity of these dangers, as the research indicates, is magnified by the potential for CWAs and TICs to have an extensive reach, given the country's population density and the location of these chemical facilities (Barras & Greub, 2014; Radonovich et al. 2009).

The author has found that current countermeasures against CWAs and TICs vary in their efficacy and applicability, largely dependent on the specific circumstances of their use. While advancements have been made in technology and procedures, the practical challenges of implementing these measures in a real-world, resource-limited crisis scenario are considerable. Aspects such as training of personnel, the availability of resources, timely detection, and efficient communication are critical to ensuring effective implementation (Yu & Wu, 2013; Peek & Stough, 2010).

Moreover, potential protective measures specifically for the Ukrainian population in case of chemical threats, including early warning systems, evacuation plans and medical treatments, have been explored. It is essential that these measures are not just theoretically sound but also practical and feasible given the ground realities of the region. The balance between optimum preparedness and available resources is a tightrope that needs careful navigation (Vale, 2014).

In the exploration of decontamination strategies, the author ascertained that while multiple methods do exist, each comes with its own set of challenges and considerations. In a resource-constrained situation, strategies like dry decontamination, low-water decontamination and the use of alternative fluids become increasingly important. However, they also require a nuanced understanding of the limitations and potential risks involved (Almer, 2017; Cox, 1994; Chilcott, 2014).

Furthermore, dealing with the aftermath of chemical threats, especially the recovery and recycling of decontamination effluents, represents another layer of complexity. The correct handling of these effluents is paramount to avoid secondary contamination and the wider dissemination of the hazardous materials (Chilcott, Larner & Matar, 2019; Baeynes & Brems, 2009).

In closing, the potential threats that Ukraine faces due to the possible destruction of chemical facilities during wartime are multifaceted and severe. As researchers, policymakers and practitioners, the collective focus needs to be on the continued development and refinement of effective countermeasures, the thoughtful application of decontamination strategies and the fostering of robust crisis communication and response protocols. Through combined and informed efforts, it is possible to mitigate the risks posed by these chemical threats and safeguard the health and wellbeing of the Ukrainian population. It is the author's hope that this research will contribute to these efforts and spark further dialogue on this critical subject.

As the last part of conclusions, the author formulates an answer to the general research question: "What are the current chemical threats facing Ukraine, and what possible countermeasures exist?". Based on the exploration and analysis of the sections presented in this study, the response to this question is as follows:

The primary chemical threats facing Ukraine stem from potential destruction of chemical facilities during conflict and the possibility of a Chemical Warfare Agent (CWA) attack. Given Ukraine's extensive chemical industry, a disaster at a chemical facility could result in the release of Toxic Industrial Chemicals (TICs) with severe immediate and long-term implications for human health and the environment.

Similarly, despite the international prohibition, the misuse of CWAs such as nerve gases, blister agents and choking agents in conflicts remains a potential threat, posing significant challenges for national security and public health systems.

Countermeasures encompass protection, prevention and decontamination strategies. Regular risk assessments, safety procedures and infrastructure resilience initiatives are essential for chemical facilities. For potential CWA attacks or TIC release early detection systems, protective gear, and population training are critical.

Post-incident decontamination varies according to the situation and may involve dry or low-water methods, alternative fluids and specialized solutions for human decontamination. Handling of decontamination effluents is necessary to prevent secondary contamination, which could involve strategies like neutralization or filtration.

By combining learnings from past incidents, best practices and technological innovations, Ukraine can prepare robust measures to counter chemical threats.

## 5. Summary

This academic article scrutinizes the potential chemical threats faced by Ukraine due to the potential destruction of chemical facilities during wartime, with a particular focus on Chemical Warfare Agents (CWAs) and Toxic Industrial

Chemicals (TICs). It highlights the significant health and environmental impacts of CWAs and TICs, emphasizing the immense dangers they pose, especially in the densely populated regions and chemical facility locations in Ukraine.

Current countermeasures against CWAs and TICs are examined, showing that while there have been significant advancements, the real-world application of these measures during a resource-limited crisis presents numerous challenges. Aspects such as personnel training, resource availability, timely detection, and efficient communication are pinpointed as crucial to the efficacy of these countermeasures.

The paper further explores potential protective strategies specifically designed for the Ukrainian populace in case of chemical threats. While these measures—early warning systems, evacuation plans and medical treatments—are theoretically sound, the focus remains on ensuring their practical feasibility given the region's realities.

The exploration of various decontamination strategies, especially in resource-constrained situations, forms another critical aspect of this paper. The author acknowledges the presence of numerous methods but highlights that each of them carries its unique set of challenges and considerations. The article emphasizes the importance of strategies like dry decontamination, low-water decontamination and the use of alternative fluids in resource-limited situations.

Lastly, the paper delves into the complexity of handling the aftermath of chemical threats, particularly the recovery and recycling of decontamination effluents, to avoid secondary contamination and wider hazardous material dissemination.

The research concludes that the collective focus should be on continued development of effective countermeasures, application of thoughtful decontamination strategies, and fostering of robust crisis communication and response protocols. This concerted effort, the author asserts, will help mitigate the risks posed by chemical threats and safeguard the Ukrainian population.

## Funding

This research received no external funding.

## References

1. Tomassoni, A.J., French, R.N.E., Walter, F.G., (2015). Toxic industrial chemicals and chemical weapons: exposure, identification, and management by syndrome. *Emerg Med Clin North Am.*, Feb;33(1):13–36.doi: 10.1016/j.emc.2014.09.004. Epub 2014 Nov 15.
2. Ganesan, K., Raza, S.K., and Vijayaraghavan, R., (2010), Chemical warfare agents. *J Pharm Bioallied Sci.* Jul-Sep, 2(3), 166–178.
3. Ivanenko, O., (2020). Implementation of risk assessment for critical infrastructure protection with the use of risk matrix. *Sience Rise*, No. 2 (67). 26–38
4. Levy, B.S., & Bissell, R.A., (2013). *Terrorism and Public Health: A Balanced Approach to Strengthening Systems and Protecting People*. Oxford University Press.

5. Sidell, F.R., Takafuji, E.T., & Franz, D.R. (1997). *Medical aspects of chemical and biological warfare*. Washington: United States Government Printing.
6. Okumura, T., Suzuki, K., Fukuda, A., Kohama, A., & Takasu, N., (1998). The Tokyo Subway Sarin Attack: Disaster Management, Part 1: *Community Emergency Response. Academic Emergency Medicine*, 5(6), 557–653.
7. Hincal, F., & Erkekoglu, P., (2006). *Toxic Industrial Chemicals (TICs) – Chemical Warfare Without Chemical Weapons. FABAD J. Pharm. Sci.*, 31, 220–229.
8. Price, R.M., (1997). *The Chemical Weapons Taboo.* New York: Cornell University Press.
9. Pitz, D., Lee, C., Kasprzyk-Hordern, B., Campo, P., Fenner, K., & Hollender, J., (2015). Characterisation of the ecotoxicity of hospital effluents: A review. *Chemosphere*, 45(5), 600–612.
10. Broughton, E., (2005). The Bhopal disaster and its aftermath: a review. *Environmental Health*, 4, 6.
11. Patwary, M.A. & O'Hare, W.T., (2011). Assessment of occupational and environmental safety associated with medical waste disposal in developing countries: A qualitative approach. *Safety Science*, 49(8–9), 1200–1207.
12. Riding, M.J. & Doick, K.J., (2013). Chemical measures of bioavailability/bioaccessibility of PAHs in soil: Fundamentals to application. *Journal of Hazardous Materials*, 261, 687–700.
13. van Ham, P., van der Meer, S., & Ellahi, M., (2017). *Chemical Weapons Challenges Ahead: The Past and Future of the OPCW With a Case Study on Syria.* The Hague: Clingendael Report.
14. Mlsna, T.E., & Cemalovic, S., (2006). Chemicapacitive microsensors for chemical warfare agent and toxic industrial chemical detection. *Sensors and Actuators B: Chemical*, 116(1–2), 192–201.
15. Richardt, A. & Blum, M.M., (2008). *Decontamination of Warfare Agents: Enzymatic Methods for the Removal of B/C Weapons.* Weinheim: Wiley-VCH Verlag GmbH & Co. KGa.
16. Davidson, C.E., Dixon, M.M., Williams, B.R., & Gary, K., (2020). Detection of Chemical Warfare Agents by Colorimetric Sensor Arrays. *ACS Sens.*, 5(4), 1102–1109.
17. Smith, W.J., (2007). Advances in military textiles and personal equipment. Sawston-Cambridge: Woodhead Publishing.
18. Wood, J.P. & Adrion, A.C., (2019). Review of Decontamination Techniques for the Inactivation of Bacillus anthracis and Other Spore-Forming Bacteria Associated with Building or Outdoor Materials. *Environ Sci Technol.*, 6;53(8), 4045–4062. DOI: 10.1021/acs.est.8b05274
19. Kassa, J., (2002). Review of Oximes in the Antidotal Treatment of Poisoning by Organophosphorus Nerve Agents. *Journal of Toxicology: Clinical Toxicology*, 40(6), 803–16.
20. Barras, V. & Greub, G., (2014). History of biological warfare and bioterrorism. *Clinical Microbiology and Infection,* 20(6), 497–502.
21. Giannoukos, S., Brkić, B., Taylor, S., Marshall, A., & Verbeck, G.F., (2016). Chemical Sniffing Instrumentation for Security Applications. *Chemical Reviews*, 116(14), 8146–8172.
22. Radonovich, L.J., Cheng, J., Shenal, B.V., Hodgson, M., & Bender, B.S., (2009). Respirator tolerance in health care workers. *JAMA*, 301(1), 36–38.

23. Sparks, E., (2012). *Advances in Military Textiles and Personal Equipment.* Sawston-Cambridge: Woodhead Publishing.
24. Oudejans, L. & O'Kelly, J., (2016). Decontamination of personal protective equipment and related materials contaminated with toxic industrial chemicals and chemical warfare agent surrogates. *Journal of Environmental Chemical Engineering*, 4(3), 2745–2753.
25. Ganesan, K., Raza, S.K., & Vijayaraghavan, R., (2010). Chemical warfare agents. *J Pharm Bioallied Sci.*, 2(3), 166–178.
26. Haywood, P.T. & Karalliedde, L., (2016). Management of poisoning due to organophosphorus compounds. *Current Anaesthesia & Critical Care*, 11(6), 331–337.
27. Yu, X. & Wu, P., (2013). A survey on wireless sensor network infrastructure for agriculture. *Computer Standards & Interfaces*, 35(1), 59-64.
28. Webber, M.E., Pushkarsky, M., & Patel, C.K.N., (2005). Optical detection of chemical warfare agents and toxic industrial chemicals: Simulation. *Journal of Applied Physics*, 97.
29. Tatham, P. & Kovács, G., (2010). The application of "swift trust" to humanitarian logistics. *International Journal of Production Economics*, 126(1), 35–45.
30. Peek, L. & Stough, L.M., (2010). Children with disabilities in the context of disaster: A social vulnerability perspective. *Child Development*, 81(4), 1260–1270.
31. Radonovich, L.J., Cheng, J., Shenal, B.V., Hodgson, M., & Bender, B.S., (2009). Respirator tolerance in health care workers. *JAMA*, 301(1), 36–38.
32. NATO Advanced Research Workshop on Defence Against Weapons of Mass Destruction Terrorism. (2009). *Defence Against Weapons of Mass Destruction Terrorism*. Amsterdam: IOS Press.
33. Vale, J.A., (2014). The role of antidotes in the management of poisoning by organophosphorus compounds. *Toxicological Reviews,* 23(2), 81–89.
34. Brent, J., Burkhart, K., Dargan, P., Hatten, B., & Mégarbane, B., (2017*). Critical Care Toxicology: Diagnosis and Management of the Critically Poisoned Patient*. New York: Springer International Publishing.
35. Goldmann, E. & Galea, S., (2014). *Mental health consequences of disasters. Annual Review of Public Health*, 35, 169-183.
36. Zhang, P., ed. (2020). *A controlled cross-over study to evaluate the efficacy of improvised dry and wet emergency decontamination protocols for chemical incidents*. San Francisco: PLOS ONE. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7641342/.
37. Almer, C. et al., (2017). Water scarcity and rioting: Disaggregated evidence from Sub-Saharan Africa. *Journal of Environmental Economics and Management*, 86, 193–209.
38. Keoleian, G.A., (1998). Comparative assessment of wet and dry garment cleaning. *Journal of Cleaner Production*, 6(1), 23–36.
39. Luning, P.A., (2008). Comprehensive analysis and differentiated assessment of food safety control systems: a diagnostic instrument. *Trends in Food Science & Technology*, 19(10), 522–534.
40. Brennan, R.J. & Waeckerle, J.F., (1999). Chemical Warfare Agents: Emergency Medical and Emergency Public Health Issues. *Annals of Emergency Medicine*, 34(2), 191–204.
41. Toader, G., Rotariu, T., & Pulpea, D., (2021). Polymeric blends designed for Surface decontamination. *U.P.B. Sci. Bull.*, Series B, 83(3).

42. Cox, R.D., (1994). Decontamination and Management of Hazardous Materials Exposure Victims in the Emergency Department. *Annals of Emergency Medicine*, 23(4), 761–770.
43. Calder, A. & Bland, S., (2018). CBRN considerations in a major incident. *Surgery (Oxford)*, 36(8), 417–423.
44. Chilcott, R.P., (2014). Managing mass casualties and decontamination. *Environment International*, 72, 37–45.
45. Chan, T.C., Killeen, J., Griswold, W., & Lenert, L., (2004). Information technology and emergency medical care during disasters. *Academic Emergency Medicine*, 11(11), 1109–1251.
46. National Research Council, Division on Engineering and Physical Sciences. (2001). *Analysis of Engineering Design Studies for Demilitarization of Assembled Chemical Weapons at Pueblo Chemical Depot*. Clarivate: National Academies Press.
47. Chilcott, R.P., Larner, J., & Matar, H., (2019). UK's initial operational response and specialist operational response to CBRN and HazMat incidents: a primer on decontamination protocols for healthcare professionals. *Emerg Med J*, 36, 117–123.
48. Baeynes, J. & Brems, A., (2009). Recovery and recycling of post-consumer waste materials. Part 2. Target wastes (glass beverage bottles, plastics, scrap metal and steel cans, end-of-life tyres, batteries and household hazardous waste). *International Journal of Sustainable Engineering*, 3(4), 232–245.
49. Lee, E.C., (2003). Clinical Manifestations of Sarin Nerve Gas Exposure. *JAMA*, 290(5), 659–662. doi:10.1001/jama.290.5.659.
50. Balali-Mood, M., (2005). The clinical toxicology of sulfur mustard. *Arch Iranian Med*, 8(3), 162–179.
51. Lukey, B.J. & Romano, J.A., (2007). *Chemical Warfare Agents: Chemistry, Pharmacology, Toxicology, and Therapeutics* (2nd ed.). Boca Raton, Florida: CRC Press.
52. Das, S. & Thomas, S., (2022). *Sensing of Deadly Toxic Chemical Warfare Agents, Nerve Agent Simulants, and their Toxicological Aspects*. Elsevier.
53. Herrmann, A., (2011). *The Chemistry and Biology of Volatiles*. Hoboken, New Jersey: John Wiley & Sons.
54. Shih, T.M., Rowland, T.C. & McDonough, J.H., (2007). *Anticonvulsants for Nerve Agent-Induced Seizures: The Influence of the Therapeutic Dose of Atropine*. Army Medical Research Institute of Chemical Defense.
55. Monteiro-Riviere, N.A., (2010). *Toxicology of the Skin*. Boca Raton, Florida: CRC Press.
56. Balali-Mood, M. & Abdollahi, M., (2015). *Basic and Clinical Toxicology of Mustard Compounds*. New York: Springer International Publishing.
57. Prentiss, A.M., (1937). *Chemicals in war: a treatise on chemical warfare*. New York: McGraw-Hill.
58. Worek, F., (2005). Diagnostic aspects of organophosphate poisoning. *Toxicology*, 214(3), 182–188.
59. Bajgar, J., (2004). *Advances in Clinical Chemistry*. Elsevier.
60. Marrs, T.T. & Maynard, R.L., (2007). *Chemical Warfare Agents: Toxicology and Treatment* Hoboken, New Jersey: John Wiley & Sons.

61. Westing, A.H., (1984). *Herbicides in War: The Long-term Ecological and Human Consequences*. Abingdon: Taylor & Francis.
62. Cohn, S.K., (2010). *Black Death and Plague: the Disease and Medical Thought*. Oxford: Bibliographies Online Research Guide. Oxford University Press, USA.
63. National Research Council, Committee to Review the Department of Homeland Security's Approach to Risk Analysis. (2010). *Review of the Department of Homeland Security's Approach to Risk Analysis*. Washington: National Academies Press.
64. Chakalian, P.M., (2019). *Mechanisms of Social Vulnerability to Environmental Hazards*. Arizona: Arizona State University.
65. Tuorinsky, S.D., (2008). *Medical Aspects of Chemical Warfare*. Washington: Government Printing Office.
66. Dunn, M.A. & Sidell, F.R., (1989). *Progress in medical defense against nerve agents*. Maryland: U.S Army Research Institute of Chemical Defense.
67. Jerard, J.A.R. & Salim. (2015). Resilience And Resolve: Communities Against Terrorism. *World Scientific*, 79–90.

# ZAGROŻENIA CBRN NA UKRAINIE PODCZAS AGRESJI ROSYJSKIEJ: ZWALCZANIE ZAGROŻEŃ CHEMICZNYCH W CZASIE WOJNY – ŚRODKI PRZECIWDZIAŁANIA I STRATEGIE DEKONTAMINACJI DLA UKRAINY W ŚWIETLE POTENCJALNEGO ZNISZCZENIA OBIEKTÓW CHEMICZNYCH

## Abstrakt

Niniejszy artykuł w dziedzinie bezpieczeństwa analizuje potencjalne zagrożenia wynikające z uwolnienia czynników wojny chemicznej (CWA) oraz toksycznych przemysłowych chemikaliów (TIC) w wyniku ewentualnego zniszczenia obiektów chemicznych na Ukrainie w czasie wojny. Prezentuje dogłębną dyskusję na temat ryzyka, środków przeciwdziałania oraz strategii dekontaminacji, skupiając się na zastosowaniu w warunkach ograniczonych zasobów. Celem tego badania jest przyczynienie się do zrozumienia zarządzania katastrofami chemicznymi oraz rozwoju skutecznych środków przeciwdziałania.

**Słowa kluczowe:** zagrożenia chemiczne, czas wojny, Ukraina, czynniki wojny chemicznej (CWA), toksyczne przemysłowe chemikalia (TIC), dekontaminacja, środki przeciwdziałania, obiekt chemiczny