Mgr. ***Eva Stýblová***
Faculty of Biomedical Engineering, CTU in Prague, Nám. Sítná 3105, 27201 Kladno, Czech Republic
Email: styblova.eva@gmail.com

Coll. PhDr. ***Štěpán Kavan***
Ph.D. Faculty of Health and Social Sciences, University of South Bohemia in České Budějovice
Email: stepan.kavan@email.cz

DOI: https://doi.org/10.37458/ssj.5.3.6
Research Paper
Received: November 3
Accepted: December 14

RESILIENCE AND RISKS TO RADIOLOGICAL EVENTS IN TIMES OF WAR

Abstract: *In the context of nuclear and radiological accidents, strengthening preparedness and response capabilities is essential, especially under the complex and unstable conditions of armed conflicts. While existing nuclear safety research generally assumes peaceful environments, it fails to account for the unique challenges posed by wartime scenarios, where access to affected sites, infrastructure stability, and responder safety are compromised. Armed conflicts increase risks not only for civilian populations but also for emergency response teams who may face logistical and safety barriers. This study seeks to address these gaps by developing tailored methodological and technological approaches to enhance resilience in nuclear emergency preparedness, response, and recovery systems. Using scenario-based planning, it emphasizes resilience assessments and ethical considerations to adapt existing frameworks to the specific risks of conflict zones. The outcome will be actionable guidelines, tools, and educational resources designed to improve nuclear safety protocols, ensuring better protection for both responders and affected populations in future conflict-related radiological incidents.*

Key Words: *Nuclear Safety Risk, Resilience, Radiological Emergency, War*

Introduction

Current research in the field of nuclear safety and security mostly focuses on peaceful environments, but this does not take into account the specific challenges that armed conflicts bring. These situations increase the risks both for the affected population and for the responding units. The project RRADEW ("Resilience to RADiological Events in Wartime") aims to increase the resilience of systems for preparation, response and recovery after nuclear and radiological accidents in the context of wartime conflicts. The RRADEW project connects 14 institutions from different areas and, using the scenario methodology, develops innovative technological and methodological solutions aimed at strengthening resilience in the event of radiological accidents as a result of war conflicts.

In connection with nuclear and radiological accidents, it is crucial to strengthen preparedness and the ability to respond in the complex and unstable conditions of armed conflicts. Research to date shows that this area has not been sufficiently explored, especially in the specific contexts of war zones. Baum and Barrett (2018) mention that nuclear weapons and their potential use in armed conflict pose global catastrophic risks. In their literature review, they also address the issue of accidents in nuclear facilities and recommend strengthening global mechanisms to minimize these risks.

Internationally, various measures have been taken to improve preparedness and response to nuclear and radiological accidents. According to Linsley (2002), the international response includes a variety of cooperation mechanisms, but issues specific to armed conflict still remain insufficiently covered. Similarly, in its manual for first responders, the IAEA emphasizes the need for specific accident protocols in crisis and military situations where radiological hazards are significantly compounded by conflict (IAEA, 2006).

Historical examples, such as the Chornobyl accident, show how a nuclear accident can have devastating effects on public health, especially in the context of political instability or armed conflict. In this context, Tobias and Shrader-Frechette (1999) analyze how the population and workers of the nuclear sector were exposed to physical and psychological consequences during the crisis. It is also important to perceive the social and ethical dimensions of crisis

management in nuclear accidents. Oughton and Howard (2012) emphasize that managing radiological risks is not only a technical issue but also involves social and ethical challenges that are further complicated in the context of armed conflict. Ethical aspects of interventions in crises where the social structure is disrupted may include, for example, inequalities in the protection of different populations or questions of equity in access to rescue.

In their work on the Sendai Framework, Koerner and Sterrett (2017) discuss an approach to disaster resilience. This framework includes preventive planning, resilience and disaster recovery capability, which is also key to preparedness for radiological incidents that may result from military attacks on nuclear facilities. In terms of specific threats, Lilienfeld and Binder (2015) emphasize preparedness for radiological terrorist attacks, which also have implications for military scenarios. They draw attention to the need to strengthen the security of nuclear facilities, which can be misused as strategic targets during armed conflicts.

Results And Discussion

The overall objective of RRADEW is to enhance nuclear emergency preparedness, response, and recovery (EPR&R) systems by developing methodological and technological approaches to strengthen resilience in the context of war or armed conflict disasters.

Despite extensive research on planning and response for radiological and nuclear emergencies, existing studies and guidelines have not yet considered the context of armed conflict situations, which present unique challenges that can compromise the safety and well-being of both affected populations and responders. RRADEW research adopts a scenario approach that allows key actors to envision, anticipate and solve problems that can arise during disasters. This recognizes that contingency planning is an important part of EPR&R and follows the United Nation's Sendai Framework on Disaster Risk Reduction definition of resilience as the “ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner”. In the context of nuclear emergency preparedness, this requires a critical reflection on how an armed conflict situation may impact the feasibility and adequacy of current planning, response and recovery strategies.

RRADEW will assess and prioritize plausible scenarios for the deployment of hostilities at nuclear facilities and consider their possible radiological consequences. The resilience of the emergency management system will be analyzed through case studies, the development and application of a resilience analysis platform, and the assessment of legal, ethical, and social issues. The final output of the project will be guidance and recommendations for improving radiological protection and strengthening resilience in situations of armed conflict, as well as education and training materials for better preparation of stakeholders.

RRADEW covers a significant part of the scope of the PIANOFORTE Call#1 Topic#3, focusing on the analysis of "existing radiological or nuclear emergency preparedness and response systems and their resilience to accident scenarios in the context of war or armed conflict", "development of event scenarios", "societal resilience, stakeholder involvement and ethical and legal considerations". Studying the resilience of nuclear emergency response in armed conflict situations is crucial to ensure effective preparedness and response measures, and to understand and address the unique challenges and vulnerabilities arising in these complex and hostile environments.

Furthermore, the safety and well-being of affected populations may be compromised by the ongoing hostilities, making it difficult to identify and prioritize radiation protection countermeasures. There is a strong need to better understand the robustness of principles that govern radiation protection, and Emergency Preparedness, Response, and Recovery (EPR&R) strategies in a context of armed conflict, and to identify needed amendments in guidance to enhance resilience.

To be better prepared, the first step is to consider scenarios and assess their potential impacts. Such analyses have been performed in many studies from a technical, social, environmental, and economic point of view. However, there have been hardly any studies of military actions, characterized by specific accidents or malevolent acts on nuclear facilities that can occur. For example, a nuclear facility may be taken over and used as a military base or instrument of terror, with the potential to lead to a radionuclide release to the environment and put psychological pressure on the community: both situations that qualify as a nuclear incident.

The disregard by the aggressor for any protection conventions for civilian infrastructure during the war in Ukraine is a current and pressing cause for concern. There is a need to develop comprehensive scenarios for a wide range of facilities with radiological risks (all types of nuclear power reactors, research reactors, nuclear vessels and floating reactors, fuel reprocessing plants, radioactive waste facilities, industrial or medical facilities, etc.), and for a wide range of threats (e.g. incidents or accidents, cyber-attacks, lost radioactive sources).

Despite this focus on nuclear emergency management and, in parallel, disaster resilience theories and practice, there are scarcely any studies investigating in a comprehensive way the resilience of societies in nuclear emergencies and mitigation plans in the context of armed conflicts. There is also little cross-fertilization at a conceptual level between the nuclear and non-nuclear fields. There is a need to develop a holistic framework and gather empirical evidence to characterize, assess and enhance resilience in nuclear emergencies in armed conflict situations. This should take stock of insights from different relevant fields, e.g. disaster management in armed conflicts, and nuclear emergency preparedness and response.

The RRADEW project is organized into 6 work packages (numbered WP #0 to #5), described below. The activities are scheduled to last 30 months, from 1 February 2024 to 31 July 2026. Its key objectives are:

- to assess, evaluate, and prioritize the most likely scenarios for the deployment of hostilities at nuclear facilities and consider possible radiological consequences of such attacks (WP1);
- to gain a better understanding of the factors influencing the capacities of people, communities, regions and countries to prepare and respond to nuclear emergency situations in the context of war or armed conflicts (WP2);
- to study the resilience of the emergency management system at the different phases of an event, i.e. emergency preparedness, response, and recovery (WP2);
- to analyze the ability of organizations and communities to effectively respond to and recover from the impact of armed conflicts that may generate nuclear or radiological incidents, by utilizing four case studies (WP3);
- to evaluate the impact of possible countermeasures in the different scenarios and, using multi-criteria methods, deduce the strategic actions to be taken as a priority (WP4).

- to address the ethical issues of radiological disaster preparedness and management in armed conflict situations (WP5);
- to conduct a critical reflection on how an armed conflict situation may impact the feasibility and adequacy of current nuclear emergency planning and response arrangements and strategies, considering legal, social, ethical, technical, human, and economic issues (WP2, WP4, WP5);
- to develop guidance and recommendations for improving radiological protection and strengthening resilience in armed conflict situations (WP4).

WP1 - Identification, evaluation, and selection of relevant war scenarios, leading to radiological consequences

WP1 will assess and evaluate the most likely scenarios for the deployment of hostilities at nuclear facilities and consider possible radiological consequences of such attacks. Facilities considered include nuclear power reactors, research reactors, SMRs and floating reactors, radioactive waste facilities, reprocessing plants, medical facilities and (high activity) radioactive sources. The types of situations will include offensive actions aimed at seizing a nuclear facility; actions that might be taken as a part of the defense campaign; frontline location close to the territory of a nuclear facility; artillery, and airstrikes near the territory of the nuclear facility; holding nuclear facility workers and their families as hostages. The aim is to focus specifically on the ways in which existing EPR&R scenarios may change because of military activities.

Based on existing sources and protocols, WP1 will assess vulnerabilities of facilities, in terms of both mechanical and technical aspects, as well as personnel vulnerability. For selected scenarios, an evaluation of nuclear safety and security, as well as modeling the potential radioactive contamination will be carried out. Results will be used to produce a matrix-based assessment of potential risks to facilities, based on scenario, likelihood, and potential consequences. The scenarios and matrix will be evaluated together with expert stakeholders consisting of national decision-makers, facility operators, RP specialists, military experts, and other first-line responders.

WP2 - Framework to characterize resilience at different levels in the context of nuclear emergencies in armed conflict situations

WP 2 has two major objectives: 1) Develop a methodological framework to identify dimensions, attributes, and indicators to characterize and assess the resilience of EPR&R systems in case of nuclear/radiological emergencies under an armed conflict situation. 2) Develop a platform for concrete resilience assessment for e.g. regulators, and communities.

WP 2 will develop a structured and comprehensive analysis to assess the resilience of EPR&R in armed conflict situations at different levels: individual, community, region, country, and EU levels. To achieve this objective, EPR&R management will be considered as a system of closely linked social, organizational, and technical elements. The resilience - according to its UNDRR definition - of this system can be characterized by its capacity to resist, absorb, accommodate, adapt to, transform, and recover from the effects of a radiation emergency in a timely and efficient manner.

WP 2 brings conceptual and technological innovation providing the ability to characterize, assess, and enhance resilience for EPR&R systems, for the first time in the context of armed conflicts in an integrated way. The results of the WP2 are i) a methodology, and ii) a platform, that can be applied for resilience assessment in view of example scenarios and countries in Europe. WP2 supports a better understanding of the factors influencing the capacities of people, communities, regions, and countries to prepare and respond to nuclear emergency situations in the context of war or armed conflicts.

WP3 - Case Studies on resilience

Objective: By examining and analyzing past or ongoing experiences, lessons can be learned, and strategies can be developed to enhance the resilience of various stakeholders: WP3 refers to the ability of organizations and communities to effectively respond to, and recover from the impact of armed conflicts with radiological threats/incidents/accidents.

WP4 - Strategies for building resilience

The aim of WP4 is to consolidate the results of the other Work Packages into a set of recommendations for improving global resilience to future nuclear or radiological (N/R) emergencies in the context of disasters related to war and armed conflict or disaster. Scenario-based methods will be used to help identify different resilience-building strategies, which will be

assessed through a multi-criteria decision analysis (MCDA) exercise. In parallel, WP4 also aims to adapt existing EPR&R training courses to situations of armed conflict or disaster.

WP5 - Ethical challenges

Ethical challenges will be addressed as a cross-cutting issue throughout the project. Key questions addressed include:

- whether the same ethical principles apply in an armed conflict situation as in an otherwise peaceful situation;
- whether, if the same principles apply, their relative importance is the same in a society at war or in peace, or different principles take precedence in each situation;
- whether potentially affected populations and members of the civil protection agencies or integrated rescue services are aware of/in agreement with such considerations;
- whether the perception of ethics differs in societies currently in an armed conflict, in those considering themselves close to being drawn into such a situation, or those at a distance.

Ethical challenges in disaster management in general is a relatively new field, although there is an increasing awareness that issues need to be addressed, and that there is a need for specific guidelines. Some work has also been done on ethical issues related to EPR&R, but studies focusing on such issues during an armed conflict situation are lacking. The recent experience of Russian aggression in Ukraine has shown that many unpredictable actions were taken by the aggressor, in particular threatening or attacking nuclear sites and radiological facilities.

When discussing the framework to characterize resilience at different levels (WP2), particular focus will be given to ethical aspects associated with security, safety, and privacy, as well as vulnerability, and potential discrimination of affected populations.

The case studies planned in different countries (WP3) will include assessing the ethical awareness, the understanding of key issues, and the basis of the value referred to by first-line responders, non-governmental organizations, local communities, as well as nuclear facility operators and workers.

Linked to communication, the project will also address the degree to which ethical challenges are considered in education and training, including awareness of the ethical principles

and their possible adaptation to different situations among civil protection agencies/rescue services (paramedics, firefighters, police).

Resilience of Populations and Civilian Protection in Radiological Emergencies

Resilience in the face of radiological emergencies is crucial, especially given the potential for long-lasting environmental and health impacts. Defined broadly as the capacity to withstand, adapt to, and recover from hazards, resilience in populations requires a multifaceted approach that addresses technical safety, community readiness, and individual psychological preparedness (Paton & Johnston, 2017). Civilian resilience plays a vital role in radiological incident outcomes by empowering communities to minimize exposure, effectively respond to protective instructions, and maintain cohesion and order throughout the emergency and recovery phases (Dufty, 2020).

In recent studies, resilience is often broken down into "adaptive capacities," which encompass physical, social, economic, and environmental resources that communities leverage to recover from disruptions. These capacities are underpinned by education, clear communication channels, and reliable access to resources, which collectively contribute to a more robust and proactive response to radiological threats (Aitsi-Selmi et al., 2016). Building resilience involves not only structural and procedural safeguards but also efforts to increase public awareness of radiological risks and appropriate response strategies. Community-based resilience training programs have been shown to increase local preparedness, as citizens are better equipped to understand the nature of radiological hazards and effectively utilize protective measures such as shelter-in-place orders and iodine prophylaxis (Finn & Jakobsson, 2015).

Civilian Protection Strategies and Health Implications

To ensure civilian protection during radiological emergencies, immediate actions focus on minimizing exposure through protective measures and clear, timely communication from authorities. According to the World Health Organization (WHO), one of the most effective strategies is public education on radiological risks and response protocols, which fosters a culture

of readiness and informed action (WHO, 2018). The WHO further emphasizes that the pre-emptive distribution of potassium iodide and the establishment of safe evacuation routes are critical for protecting vulnerable populations from radiological exposure (Walsh et al., 2019). Such preventive measures are particularly relevant in high-density areas, where infrastructure and logistics can complicate emergency responses.

In high-risk areas, resilience-building strategies for radiological emergencies also include enhanced infrastructure protections and training for emergency responders. For instance, establishing secure shelters and investing in contamination-resistant facilities around nuclear power plants and other critical infrastructures can mitigate the risk to nearby communities. These facilities are built to provide secure locations where civilians can gather safely during a radiological incident, minimizing direct exposure while allowing authorities to manage evacuations in a controlled manner (Jacobs & De Smet, 2021).

Psychological Resilience and Public Communication

Psychological resilience, or the capacity to manage stress and maintain mental stability during crises, is a vital factor in effective radiological emergency response. Research suggests that clear, continuous communication from authorities supports psychological resilience by helping individuals understand the risks, available resources, and appropriate actions to take (Becker, 2019). Frequent updates and consistent messaging build trust, which is essential for maintaining public order during the high-stress conditions that accompany radiological emergencies (Hasegawa et al., 2016).

Moreover, mental health support following radiological incidents is integral to long-term resilience. Populations affected by radiological exposure may experience heightened anxiety and trauma, which necessitates coordinated mental health interventions to aid recovery. This psychological support is especially important in communities with previous exposure to conflict or disaster, where underlying vulnerabilities can amplify the psychological impact of a radiological emergency (Nakao & Takeuchi, 2018). Studies from the Fukushima disaster illustrate that structured mental health programs can significantly improve recovery outcomes,

highlighting the importance of integrating mental health into radiological emergency preparedness and response plans (Neria et al., 2018).

Integrative Frameworks for Radiological Emergency Resilience

To achieve effective resilience and civilian protection in radiological emergencies, many governments and organizations apply frameworks like the Sendai Framework for Disaster Risk Reduction. This international standard emphasizes risk reduction through proactive planning, preparedness, and resource mobilization at all community levels (Aitsi-Selmi et al., 2016). The framework has been instrumental in guiding nations to establish clear communication strategies, support resilient infrastructure, and create educational initiatives that enhance civilian knowledge of radiological hazards (Paton & Johnston, 2017).

Other frameworks, such as the WHO's Health Emergency and Disaster Risk Management (Health EDRM) framework, prioritize community-level engagement and capacity building for radiological resilience. Health EDRM encourages partnerships across sectors to ensure that health systems, local governments, and community organizations work together in radiological preparedness, further emphasizing the importance of resilience in high-risk populations (WHO, 2018).

CONCLUSION

The RRADEW project represents a key initiative that not only addresses the gap in preparedness for radiological accidents in armed conflicts but also contributes to the development of new standards of protection and response in these extreme conditions. Through research, scenario analysis and cooperation with experts at national and international levels, the project will provide valuable recommendations for improving the resilience of nuclear security. These findings will strengthen the ability of companies to respond to nuclear incidents, improve the protection of the population and ensure a higher level of preparedness for future challenges in the context of armed conflicts.

Overall, it is clear that the issue of resistance and preparedness for nuclear and radiological accidents during armed conflicts requires an interdisciplinary approach. It covers both the technical aspects of protecting nuclear facilities and the social, ethical and organizational issues that affect society's ability to respond to these complex and serious threats.

In summary, resilience in civilian populations is a critical factor in effectively managing radiological emergencies. It involves a combination of structural protections, community preparedness initiatives, and psychological support mechanisms. By leveraging frameworks such as the Sendai Framework and Health EDRM, authorities can build robust, adaptable, and resourceful communities prepared to face the unique challenges posed by radiological hazards.

References

1. Aitsi-Selmi, A., et al. (2016). The Sendai Framework for Disaster Risk Reduction: Renewing the global commitment to people's resilience, health, and well-being. International Journal of Disaster Risk Science, 7(2), 148–158.
2. Baum, S. D., & Barrett, A. M. (2018). Global catastrophic risks from nuclear weapons: A review of the literature. Risk Analysis, 38(3), 460-474.
3. Becker, J. S. (2019). Communicating risk to support community resilience to natural hazards. International Journal of Disaster Risk Reduction, 35, 101-112.
4. Dufty, N. (2020). Disasters and community resilience: Urban resilience planning in the context of disaster risk reduction. Australian Journal of Emergency Management, 35(4), 25–29.
5. Finn, T., & Jakobsson, E. (2015). Enhancing public health resilience to nuclear incidents: Lessons from recent radiological disasters. Public Health Preparedness and Response, 10(1), 60-66.
6. Hasegawa, A., et al. (2016). Effects of the Fukushima nuclear disaster on mental health in the general public through the five-year follow-up. Journal of Radiological Protection, 36(1), 65-76.
7. IAEA (2006). Manual for First Responders to a Radiological Emergency. IAEA.
8. Jacobs, K., & De Smet, H. (2021). Protective infrastructure for radiological hazards: Planning and implementation. Disaster Prevention and Management, 30(1), 23-37.
9. Koerner, J. M., & Sterrett, D. J. (2017). Resilience and disaster risk reduction: Revisiting the Sendai framework. Environmental Hazards, 16(2), 73-80.
10. Lilienfeld, A. M., & Binder, S. (2015). Public health preparedness and response to radiological terrorism. Journal of Homeland Security and Emergency Management, 12(2), 411-426.
11. Linsley, G. S. (2002). International response to nuclear emergencies: Preparedness and assistance. IAEA Bulletin, 44(1), 15-19.
12. Nakao, M., & Takeuchi, T. (2018). Mental health crisis management during and after radiation disasters: A literature review. Psychiatry and Clinical Neurosciences, 72(3), 180–193.

13. Neria, Y., et al. (2018). Long-term psychological consequences of nuclear disaster: A systematic review. Psychiatric Quarterly, 89(2), 351-365.
14. Oughton, D. H., & Howard, B. J. (2012). The social, ethical and communication aspects of radiation risk management. Journal of Environmental Radioactivity, 101(12), 706-710.
15. Paton, D., & Johnston, D. (2017). Disaster resilience: An integrated approach. Springer.
16. Tobias, A. M., & Shrader-Frechette, K. (1999). Nuclear Power and Public Health: Lessons from Chernobyl. The Lancet, 354(9188), 1757-1761.
17. Walsh, L., et al. (2019). Public health preparedness and response capacity and capability for nuclear and radiological emergencies. Health Security, 17(3), 210-217.
18. WHO (2018). Health Emergency and Disaster Risk Management Framework.