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Security of Critical Infrastructure Facilities in the Fuel and Energy Sector Under Martial Law

Keywords:

nuclear safety,
armed conflict,
physical protection,
international humanitarian law,
IAEA

The article presents a comprehensive study of the problem of physical protection of nuclear installations in the context of interstate armed conflict, taking into account modern military threats. The relevance of the topic is determined by the increasing involvement of military operations in the vicinity of nuclear facilities, which creates a new spectrum of risks that have not been systematically addressed within classical approaches to nuclear safety and international humanitarian law. The purpose of the study is to identify the key challenges related to the protection of nuclear facilities during armed conflict, to analyze existing international legal and institutional mechanisms, and to substantiate possible directions for their improvement. The research methodology is based on a systemic and structural analysis of international legal norms, the safety principles and standards developed by the International Atomic Energy Agency, as well as a comparative analysis of precedent cases involving the impact of armed hostilities on nuclear infrastructure. As a result of the study, critical gaps in the current system of physical protection of nuclear installations under conditions of armed conflict are identified, and a set of legal and policy-oriented recommendations aimed at the strengthening of international nuclear safety mechanisms is proposed. The scientific novelty of the research lies in the integration of legal, security, and technical perspectives to formulate a coherent approach to ensuring nuclear safety during military hostilities. The practical significance of the obtained results consists in the possibility of their application in the activities of national nuclear regulatory authorities, operators of nuclear power plants, and international organizations involved in the development and adaptation of physical protection standards to modern conflict-related threats. The proposed conceptual framework may contribute to enhancing international cooperation and improving the resilience of nuclear safety systems in crisis and wartime conditions.

Introduction

Armed conflicts are traditionally considered by international law and security systems as factors that create increased risks for the civilian population and critical infrastructure. At the same time, full-scale military actions against states with nuclear facilities on their territory cre-

ate a fundamentally new dimension of threats related to the possibility of nuclear and radiation safety breaches. Damage, occupation, or militarization of nuclear facilities can lead to consequences that extend beyond the conflict zone and have a transboundary and global nature.

The current international nuclear security system was developed mainly in peacetime and was focused on

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preventing man-made accidents and countering threats from non-state actors, such as terrorist groups, organized criminal networks, and other entities not acting on behalf of a state. At the same time, scenarios of high-intensity interstate armed conflicts, in which nuclear facilities could be used as elements of military strategy or political pressure, remained outside the focus of the practical application of most international mechanisms. This has resulted in significant gaps in the legal and institutional framework for the protection of nuclear facilities during military operations.

The International Atomic Energy Agency (IAEA) plays a special role in the global nuclear security architecture, promoting the peaceful use of nuclear technologies, developing safety standards, and providing technical assistance to states. However, the IAEA's mandate is limited mainly to advisory and monitoring functions and does not provide for instruments to enforce compliance with nuclear safety requirements in the context of armed conflict. The absence of an international body capable of ensuring the implementation of measures to protect nuclear facilities during wartime highlights the need to rethink the existing system of international regulation.

In this context, it is particularly important to analyze the impact of armed conflicts on nuclear safety and to assess the capacity of international humanitarian and international nuclear law to respond to new types of threats. The purpose of this article is to examine contemporary challenges in the field of nuclear security in the context of military operations, identify key legal and institutional gaps, and justify possible directions for improving international mechanisms for the protection of nuclear facilities.

Analysis of literature data and problem statement

The current array of publications and international documents emphasizes the multidimensional nature of nuclear safety issues: accident prevention and mitigation as well as prevention of unlawful acts, including terrorism and sabotage. The Treaty on the Non-Proliferation of Nuclear Weapons (NPT) forms a three-pronged basis (non-proliferation, disarmament, and peaceful use), while the practical instruments of the IAEA — safeguards, inspections, guidance documents — detail the requirements for physical integrity, operational safety systems, reliable off-site power supply, logistics, radiation monitoring, and communication with regulatory authorities.

At the same time, international humanitarian law (Article 56 of Additional Protocol I to the Geneva Conventions) prohibits attacks on facilities whose release of

dangerous forces could have large-scale consequences, but it contains exceptions and does not cover a number of elements of the fuel cycle [1]. The experience of combat operations, particularly around the Zaporizhzhia NPP, has revealed the vulnerability of external power supplies, the criticality of cooling systems, and the limitations of existing enforcement mechanisms and rapid international response.

Among the key gaps, the following can be highlighted:

- 1) limited IAEA mandate in the field of security (as opposed to safeguards): lack of legally binding decisions and rapid access tools during the active phase of the conflict;
- 2) massive strikes on energy facilities raise the question of integrating air defense and electronic warfare capabilities into the security system of nuclear facilities;
- 3) lack of universal, politically stable mechanisms for demilitarizing nuclear power plant sites and guarantees that they will not be used as military bases.

Given the identified gaps, the scientific and practical problem lies in developing a comprehensive model for ensuring the nuclear and energy security of critical infrastructure facilities during armed conflicts, which:

- a) extends the protective regime to all links in the nuclear fuel cycle and critical elements of the energy system,
- b) ensures operational international monitoring and access for inspections with minimal dependence on political agreement between the parties,
- c) supports the demilitarization of nuclear power plant zones and creates legal safeguards against the use of nuclear sites for military purposes.

The novelty lies in combining engineering criteria for the stability of energy systems with legal mechanisms for international access and demilitarization, as well as in incorporating countermeasures against UAVs into the design of physical protection and emergency preparedness. The practical result is a set of parameterized requirements and procedures suitable for implementation by operators, regulators, and international institutions.

Research objectives and tasks

The purpose of the study is to analyze the threats currently facing critical infrastructure facilities — nuclear power grids in Ukraine. Finding ways to ensure nuclear safety in a state of martial law, as well as involving international institutions in the process of resolving such situations and developing ways to obtain safety guarantees, is a key issue today.

The scientific novelty of the study lies in a comprehensive analysis of nuclear and radiation safety issues in the context of interstate armed conflict, taking into account modern military threats, in particular the use of unmanned aerial vehicles and the militarization of nuclear facilities. The article substantiates the inadequacy of the current international physical protection regime to counter threats from the regular armed forces of states and identifies areas for its possible improvement, taking into account wartime conditions.

Global nuclear security and threats

Global nuclear security is shaped by a combination of international rules, institutional mechanisms, and technical practices designed to minimize the risks of nuclear incidents, limit the proliferation of nuclear materials, and reduce the likelihood of deliberate interference with nuclear facilities. In the “classical” model, this system works best when the basic prerequisites for controllability are in place: predictable access for inspectors, continuity of oversight bodies, a controlled operating environment, and the ability to implement standard safety procedures. It is under such conditions that international approaches to risk assessment have historically been designed, with an emphasis on technological failures, human factors, and countering non-state threats.

However, high-intensity armed conflicts dramatically change the risk structure: individual violations of regulations are no longer the key issue, but systemic failures of the operating environment — the destruction of critical infrastructure, restrictions on access to resources and personnel, pressure on operators, loss of stable power supply and communications, and the inability to conduct full-fledged international monitoring. In wartime, “security conditions” are critically important: the physical integrity of the facility, the operability of security systems, stable control, and the availability of a channel for decision-making without coercion. That is why the IAEA, in its crisis assessments, separately emphasizes a set of basic principles (the so-called “indispensable pillars”) that must be maintained even during hostilities — otherwise, the level of risk increases regardless of formal compliance with procedures [2].

At the same time, legal restrictions on the use of force against dangerous facilities in international humanitarian law, in particular the special protection regime for nuclear power plants as facilities containing dangerous forces, create an important benchmark, but do not provide an automatic mechanism for implementation in practice. Even

with prohibitions in place, real security requires prevention, control, and accountability tools that can act quickly, including in situations of limited access, information uncertainty, and political escalation [3]. This means that the gap between the regulatory model and operational capacity is becoming one of the main sources of vulnerability in the global nuclear security system during wartime.

An additional factor in contemporary threats is technological asymmetry: the widespread use of unmanned aerial vehicles and remote strike capabilities allows critical infrastructure elements to be targeted “below the threshold” of classic military scenarios. This is particularly dangerous for the nuclear sector due to the possibility of attacks not only on the facility itself, but also on its auxiliary systems (power supply, substations, communications, logistics, and support systems), which indirectly undermines the ability to maintain safe operating conditions. As a result, nuclear safety in a state of war takes on a systemic character: it depends not only on engineering barriers at the site, but also on the stability of the power system, the security of infrastructure nodes, and the availability of effective international control and response mechanisms.

Thus, contemporary challenges demonstrate the need to move from a “peaceful” logic of nuclear safety to an approach that directly takes into account military risks: infrastructure degradation, restrictions on international control, coercion of personnel, scenarios of prolonged failures, and new types of technological threats. This provides a basis for further analysis of specific incidents and the development of integrated solutions focused on the resilience and manageability of the security system, even in crisis conditions.

Key principles of nuclear safety

The key principles of nuclear safety are based on IAEA international standards and national regulatory documents. They are aimed at preventing accidents, minimizing the consequences of possible incidents, and protecting people and the environment. However, ensuring nuclear safety is multidimensional and covers not only the technical aspects of the safe operation of nuclear facilities, but also the global dimension of nuclear non-proliferation [4]. In the context of growing geopolitical instability, the combination of these tasks is of particular importance.

Under the NPT, participating states are obliged to use nuclear materials and technologies exclusively for peaceful purposes. The key role in this regard belongs to oper-

ating organizations, which ensure strict compliance with IAEA safety and safeguards requirements.

The culture of nuclear safety prioritizes transparency and accountability. Regular reporting to international bodies, inspections, and the exchange of information on the status of nuclear materials create an atmosphere of trust between states and minimize the risk of covert military activities.

The concept of defense in depth is aimed not only at preventing accidents, but also at preventing unauthorized access to nuclear materials. Security systems, access control, accounting, and transportation of nuclear fuel are important tools for countering possible theft or sabotage.

Every unit of nuclear fuel is strictly accounted for. The IAEA applies a system of safeguards that makes it impossible for materials suitable for weapons to disappear. IAEA inspectors conduct independent inspections of facilities using modern monitoring technologies, from remote cameras and sensors to satellite surveillance systems. This ensures the objectivity of the assessment and reduces the risk of non-compliance.

Armed conflicts create a new dimension of risk for nuclear security. The seizure of nuclear power plants could lead to the use of their resources for military purposes or to nuclear terrorism. That is why the international community insists on the demilitarization of areas where nuclear facilities are located and on strengthening their protection.

International cooperation in the field of nuclear safety

Since the advent of nuclear technology, nuclear safety has become one of the key factors in shaping the international security system. It is viewed not only as a technical issue of safe operation of nuclear facilities, but also as a component of global policy that combines elements of deterrence, international control, and mutual responsibility of states. In this context, international cooperation is a fundamental tool for reducing the risks associated with the use of nuclear energy, as the potential consequences of nuclear incidents are transboundary in nature and cannot be limited to the territory of a single state.

The IAEA plays a central role in the system of international cooperation in the field of nuclear safety, whose activities are aimed at ensuring a balance between the development of the peaceful use of nuclear energy and preventing its use for military purposes. Through a system of safeguards, inspections, expert missions, and the development of guidance documents, the IAEA forms

the institutional basis for international trust and transparency in the nuclear field. At the same time, scientific research and analytical publications emphasize that the Agency's mandate in the field of nuclear security is mainly advisory in nature and largely depends on the political will of member states, which limits its ability to act in times of crisis and armed conflict [5].

Nuclear safety issues are also on the agenda of the United Nations and the UN Security Council, which, in accordance with the UN Charter, are empowered to maintain international peace and security. It is the Security Council that has the power to adopt decisions that are binding on all states, including sanctions or the deployment of peacekeeping missions. However, current practice shows that the application of these mechanisms in the field of nuclear security is significantly complicated in cases where a state possessing nuclear weapons is a party to an armed conflict, which reduces the effectiveness of collective response measures [6].

Multilateral treaties and conventions that form the legal basis of the global non-proliferation regime are an important element of international cooperation in the field of nuclear safety. The Treaty on the Non-Proliferation of Nuclear Weapons enshrines the fundamental principles of non-proliferation, disarmament, and the peaceful use of nuclear energy, creating a framework of obligations for participating states. It is supplemented by specialized international conventions aimed at the physical protection of nuclear materials and facilities, as well as technical assistance and experience-sharing programs that contribute to enhancing national security capabilities [7].

Recent events related to military influence on nuclear facilities, particularly in Ukraine, have demonstrated the limitations of traditional formats of international cooperation, which are primarily focused on stable political conditions. Scientific and expert publications emphasize that in conditions of armed conflict, there is a gap between formal international obligations and the actual ability of international institutions to ensure the protection of nuclear facilities, the safety of personnel, and continuous international monitoring. This highlights the need to develop new approaches to international cooperation that combine legal, political, and technical instruments for responding to nuclear risks in wartime [8].

Thus, international cooperation in the field of nuclear safety remains a key condition for reducing global nuclear risks, but modern armed conflicts require its adaptation to new realities. Strengthening coordination between international organizations, improving legal mechanisms of accountability, and expanding the capabilities for

rapid international response are necessary prerequisites for improving the effectiveness of the nuclear safety system in a state of war.

The challenges of today

The Russian Federation's armed aggression against Ukraine, which has been ongoing since 2014, has had a significant impact on the functioning of the international security system and has called into question the effectiveness of existing mechanisms for maintaining international law and order. The peculiarity of this aggression lies in the fact that it is being carried out by a state that is a permanent member of the United Nations Security Council and possesses significant nuclear potential. Under such conditions, nuclear weapons cease to be exclusively an element of strategic deterrence and are used as an instrument of political pressure, creating a fundamentally new range of risks for international security.

The full-scale invasion in 2022 led to a sharp escalation of threats in the field of nuclear and radiation safety. For the first time in modern history, military actions directly affected facilities related to the use of nuclear energy and the handling of radioactive materials. The seizure of the Chornobyl exclusion zone and spent nuclear fuel storage infrastructure, violations of physical protection regimes, the theft of ionizing radiation sources, the occupation of the Zaporizhzhia nuclear power plant (ZNPP) along with the satellite city of Enerhodar, as well as the shelling of the Neutron Source research facility demonstrated the vulnerability of the existing system of international control and response to crisis situations.

These events have not only regional but also global implications, as nuclear and radiation risks are by their nature not confined within national borders. They have demonstrated that existing international nuclear safety mechanisms are largely geared to peacetime conditions and do not take into account scenarios of high-intensity interstate armed conflict. In such conditions, formal compliance with international treaties and recommendations does not guarantee the actual safety of nuclear facilities and personnel.

The issue of physical protection of nuclear facilities requires special attention. Traditionally, physical protection systems are designed to address threats from non-state actors and are aimed at preventing, detecting, and responding to unauthorized actions. However, military actions by a state's regular armed forces go beyond these scenarios and create a situation in which existing approaches to physical protection prove insufficient. This creates a need to rethink

the role and tasks of physical protection of nuclear facilities in the context of armed conflicts.

In addition, attacks on nuclear facilities and related infrastructure can be considered violations of international humanitarian law and the principles of international nuclear law aimed at preventing the release of dangerous forces and protecting the civilian population. However, the lack of effective mechanisms to enforce compliance with these norms in wartime significantly limits their practical effectiveness.

Thus, the current challenges in the field of nuclear security lie not only in the growing number of threats, but also in the mismatch between the nature of these threats and the capabilities of the existing international response system. The military impact on nuclear facilities requires a review of approaches to ensuring nuclear and radiation safety, taking into account the realities of armed conflicts, which determines the relevance of further scientific analysis of this issue.

Nuclear facilities in the combat zone

The targeting of nuclear facilities in the context of military operations is not an unprecedented development. Historical practice demonstrates that nuclear infrastructure has repeatedly been perceived as possessing strategic value, both in situations of declared armed conflict and in periods formally characterized as peace. These incidents reveal a persistent tension between military considerations and the emerging norm of special protection for nuclear installations.

During the Second World War, Allied operations against the Norsk Hydro heavy water plant in Norway were aimed at disrupting Germany's nuclear research program, reflecting the strategic importance attributed to nuclear-related industrial facilities. Subsequent conflicts further illustrated this pattern. In 1980, the Iranian Air Force struck the Osirak research reactor in Iraq, while in 1981 the Israeli Air Force conducted a separate operation that destroyed the same reactor prior to its commissioning. During the Iran–Iraq War, the Bushehr nuclear power plant, then under construction, was subjected to multiple Iraqi air strikes, resulting in significant damage and long-term delays, though not complete destruction.

Similarly, during the 1991 Gulf War, coalition forces targeted elements of Iraq's nuclear program, including facilities associated with research and uranium enrichment. Later incidents, such as the 2007 air strike against a suspected undeclared nuclear facility in Syria, further demonstrate that nuclear installations have been regarded

as legitimate strategic objectives under certain security rationales.

Taken together, these cases indicate that the use of force against nuclear infrastructure has historical precedent. However, they also underscore the absence of a fully coherent and operationalized international legal regime capable of reconciling military necessity with the imperative of preventing radiological catastrophe. This historical experience highlights structural ambiguities in the protection framework applicable to nuclear facilities during armed conflict.

The full-scale invasion of Ukraine by the Russian Federation in 2022 differs fundamentally from previous precedents in terms of its scale, duration, and the systematic nature of its military impact on nuclear facilities. On the first day of the aggression, February 24, 2022, Russian troops seized the industrial site of the Chornobyl Nuclear Power Plant, which was subsequently used as a military base. The occupation was accompanied by damage to equipment, mining of the territory, fires, and a complete loss of control by regulatory authorities over nuclear and radiation safety, as well as the accounting of nuclear materials in the exclusion zone. The active military presence in the radioactively contaminated territory created additional risks of repeated radiation contamination with potentially catastrophic consequences.

Since March 4, 2022, the ZNPP, the largest in Europe and one of the largest in the world in terms of installed capacity, has been under the control of Russian troops. During the occupation, the ZNPP industrial site was converted into a military facility housing equipment, ammunition, and personnel. Constant shelling and damage to energy infrastructure elements have led to repeated losses of external power supply, directly threatening the ability to maintain reactor cooling systems and remove residual heat. The prolonged operation of equipment in non-standard conditions, the degradation of safety systems, and limited access for personnel increased the risks of nuclear and radiation hazards.

In March 2022, the Neutron Source research facility, located at the Kharkiv Institute of Physics and Technology, was also shelled. Damage to this facility, which is not designed for operation in combat conditions, posed a threat of serious radiation and environmental consequences.

A new and particularly dangerous stage of escalation was the use of unmanned aerial vehicles against nuclear infrastructure facilities. On February 14, 2025, a strike drone with a high-explosive warhead hit the New Safe Confinement (NSC) over the destroyed fourth power unit of the Chornobyl Nuclear Power Plant. The attack dam-

aged elements of the outer and inner cladding of the protective arch, as well as crane system equipment. Although no increase in radiation levels was recorded, the very fact that the operating conditions of the NSC were violated requires further assessment from the point of view of the long-term safety of the facility.

The massive nature of the attacks on Ukraine's energy infrastructure significantly increased nuclear risks. The loss of external power supply and disruption of power lines created the threat of so-called station blackout scenarios, in which even shut-down nuclear power plants require significant amounts of electricity and water to remove residual heat from nuclear fuel. The events of 2022, in particular the automatic shutdowns of the Rivne, South Ukraine, and Khmelnytskyi nuclear power plants as a result of missile strikes on the power grid, clearly demonstrated the interdependence of nuclear and energy security.

Thus, the Russian Federation's armed aggression against Ukraine and systematic attacks on nuclear facilities have created unprecedented challenges in the areas of nuclear safety, physical protection, and personnel safety guarantees [9]. These events are likely to have a long-term impact on the further development of the international physical protection regime and require a thorough rethinking, taking into account military threats and the interconnection between nuclear safety and other components of global security.

Use of unmanned systems to attack energy infrastructure

Since the start of the full-scale invasion, the terrorist state has been systematically using unmanned aerial vehicles (UAVs) to attack critical infrastructure in Ukraine. The greatest pressure is being exerted on the energy sector, which is of strategic importance for the economy, defense, and the lives of the civilian population. The goal of these strikes is to weaken not only the Ukrainian economy but also the morale of its population.

Drone attacks are a complex and growing threat to the internal security of the state and international stability. UAV strikes can target any number of targets, including military facilities, government buildings, power plants, airports, and the civilian population. The wide range of UAVs available, from small and modified commercial drones to military ones equipped with weapons and powerful surveillance systems, enables individuals, non-state actors, and states to carry out remote attacks.

When it comes to conducting precision strikes against specific targets, including infrastructure and personnel,

the military often uses armed UAVs. Drone attacks carried out by terrorists and insurgents may be accompanied by the use of improvised explosive devices, adding another layer of complexity to security challenges. A significant number of recent UAV strikes have targeted energy infrastructure, raising concerns about the vulnerability of such systems. Protecting critical infrastructure from the threat of drone attacks will require coordinated action by government agencies and critical infrastructure operators.

Drone strikes on energy infrastructure can disrupt the supply of electricity, heat, and fuel to homes and businesses. Power plants, electrical grids, oil and gas facilities, energy transportation infrastructure, fuel storage facilities, control centers, and communications infrastructure are all vulnerable to drone attacks. UAV strikes can cause significant damage to all types of power plants, whether thermal, nuclear, hydroelectric, or renewable energy facilities. Disruption of energy facilities can cause large-scale power outages, which in turn will affect residential, industrial, and commercial consumers and critical infrastructure. Power line towers, substations, and transmission lines that make up the power grid are critical components that, if attacked, can lead to power outages, equipment damage, and potential safety issues.

Oil refineries, natural gas processing plants, pipelines, and storage terminals are other potential targets for attacks. Sabotage of oil and gas infrastructure can cause supply shortages, fires, explosions, and environmental damage. Drone attacks can disrupt coal transportation, natural gas and oil at ports, airports, railways, and highways, which would affect energy supply chains and disrupt economic activity. If a UAV strike damages a critical facility such as a control center, substation, fuel depot, or emergency response center, it could pose a threat to safety and operational integrity. Potential targets for drone attacks include telecommunications towers, satellite facilities, and data centers that support the operation of energy infrastructure. Disruptions to communication networks can hinder emergency response and stakeholder coordination.

When drones target energy infrastructure, many moral and legal questions arise regarding the safety of energy infrastructure and the people who depend on it: civilian safety, humanitarian crises, environmental impacts, disruption of key services, and more. Addressing these issues requires a comprehensive approach that upholds justice, accountability, and human rights while protecting the critical infrastructure necessary for sustainable growth and prosperity.

Attacks by unmanned systems on energy infrastructure will continue to be a tactic, especially in times of war and confrontation. Government and local authorities, as well as public and private owners and operators of critical energy facilities, must take steps to protect vital infrastructure from such attacks. Protecting the resilience of the power system and improving the security of energy supply are two of the most important issues during massive UAV strikes.

Nuclear security risks as a consequence of nuclear terrorism

More than three years have passed since the world was shocked by Russia's occupation of the ZNPP in Ukraine. Fighting near the plant is causing serious concern among experts and increasing risks. Currently, the ZNPP is powered by only one external power line, which poses serious risks. All six reactors are in cold shutdown mode, and none of them can be safely restarted. In addition, the water level in the cooling pond has dropped to 13.4 meters, close to the critical threshold of 12 meters, beyond which the cooling systems will fail. Despite the passage of time, the harsh reality remains: a terrorist state retains control of the plant, and this situation is a constant reminder of the serious threats to current nuclear safety standards.

In these new conditions, effective nuclear safety requires a reassessment of priorities, as the occupation has revealed a completely new type of risk: a state possessing nuclear weapons continues to attack, shell, mine, and operate a Ukrainian nuclear facility as part of its so-called "special military operation."

Traditionally, nuclear safety has been centered on the physical protection of facilities against diverse threat vectors. Currently, the main threat remains the same: deliberate hostile actions by state actors against facilities where nuclear materials are stored, such as nuclear reactors, which could lead to radiation leaks.

Nuclear reactors seized by state authorities may be intentionally operated in breach of applicable international nuclear safety standards and binding regulatory requirements. The potential consequences are serious: from melting the core to compromising containment, leading to death and disease, contamination of agricultural land and water supplies, and disruption of transport and communication networks, not to mention undermining confidence in nuclear energy. And this is not purely a theoretical scenario.

The invasion of Ukraine and the seizure of the Zaporizhzhia NPP create a risk that could lead to the leakage of

radioactive materials outside the country. Moreover, the threat of such actions turns the plant into an instrument of coercion that can be used as leverage to secure military and political advantages.

Thus, the occupation of the ZNPP since March 2022 reveals an unprecedented gap in nuclear safety. However, it is difficult to assess the nature, likelihood, and potential consequences of the risks arising in this situation. There is no single agreed terminology to describe this situation, and it has been framed in different ways in legal and security discourse.

International law and nuclear safety during military operations

Armed conflict significantly increases risks to nuclear and radiation safety, as damage to, seizure, or militarization of nuclear facilities can have large-scale humanitarian and environmental consequences. In such situations, the conduct of states is governed by international humanitarian law in conjunction with international nuclear law, which establishes special protection regimes for facilities related to the use of nuclear energy.

The basic rules of warfare regarding civilian facilities, including nuclear installations, are enshrined in the 1949 Geneva Conventions and the 1977 Additional Protocols. In particular, international humanitarian law prohibits attacks on civilian objects if such actions could cause excessive loss of civilian life or release dangerous forces. Nuclear facilities are subject to a special protection regime precisely because of the potential scale of the consequences of their damage.

Certain provisions of international humanitarian law regulate the defense and occupation of nuclear facilities. Parties to an armed conflict are required to exercise extreme caution when conducting military operations in close proximity to nuclear power plants and other nuclear facilities. The permissibility of deploying military units near such facilities is limited solely to the purposes of their protection and does not give the nuclear facility the status of a legitimate military target, as directly follows from interpretations of the norms of international humanitarian law [10].

According to the official comments of the International Committee of the Red Cross on Article 56 of Additional Protocol I, the parties to the conflict may in certain cases be obliged to refrain even from actively defending a nuclear power plant if there is a real threat of the release of dangerous forces. In the event of the occupation of a nuclear facility, responsibility for ensuring its safety rests

with the occupying party, which is obliged to take all possible measures to prevent incidents that could harm the civilian population or the environment.

The shelling and occupation of nuclear facilities and sites where radioactive materials and sources of ionizing radiation are used by the Russian Federation violate both international humanitarian law and the basic principles of international nuclear law. Such actions not only pose a direct threat to nuclear and radiation safety, but also effectively make it impossible for Ukraine to fulfill its international obligations under the Convention on Nuclear Safety, the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, and the Agreement with the IAEA on the Application of Safeguards.

The key role of the IAEA in addressing the nuclear threat

The Russian Federation's full-scale armed aggression against Ukraine has created unprecedented risks to global nuclear security that extend far beyond the national context. The seizure and militarization of nuclear facilities, in particular the Chornobyl and Zaporizhzhia nuclear power plants, have caused serious concern among the international community, given that these facilities are intended exclusively for the peaceful use of nuclear energy. Military influence on such facilities significantly increases the likelihood of nuclear or radiation accidents, the consequences of which can be transboundary and global in nature.

The attacks on nuclear facilities and their subsequent capture on the territory of Ukraine indicate a violation by the Russian Federation of a set of international legal norms. This refers, in particular, to the provisions of Additional Protocols I and II to the 1949 Geneva Conventions, The International Convention for the Suppression of Acts of Nuclear Terrorism, the Convention on the Physical Protection of Nuclear Material and Nuclear Facilities, and the Amendment to this Convention. Together, these documents form a legal regime that prohibits the use of force against nuclear facilities and obliges states to ensure their protection even in conditions of armed conflict.

In accordance with international law and IAEA requirements, nuclear power plants and other nuclear facilities have the status of facilities for the peaceful use of nuclear energy and cannot be considered legitimate military targets. The actions of the Russian Federation contradict not only the Geneva Conventions and their additional protocols, but also the Charter and basic prin-

ciples of the United Nations, as well as the fundamental principles of nuclear safety developed and enshrined in IAEA documents. This indicates a systematic nature of violations of international obligations in the field of nuclear and radiation safety.

In March 2022, during a meeting of the IAEA Board of Governors, the Agency's Director General Rafael Grossi formulated the concept of the "Seven Indispensable Pillars of Nuclear Safety", which became the basis for an international approach to protecting nuclear facilities in crisis situations. These principles cover the physical integrity of nuclear facilities, the uninterrupted operation of safety and security systems, the professional independence of personnel, a stable external power supply, reliable logistics chains, effective radiation monitoring and emergency preparedness, and robust communication between operators, the national regulator, and the IAEA. Together, they represent the minimum conditions without which the safe operation of nuclear facilities is impossible.

The practical implementation of these principles has taken on particular significance in connection with the situation at the ZNPP. On September 1, 2022, the IAEA Director General personally crossed the line of combat operations to ensure the Agency's permanent presence at the ZNPP site. Since then, dozens of IAEA staff have been sent to the plant on rotational missions, an unprecedented step in the organization's history that underscores its key role in efforts to reduce nuclear risks in wartime.

This approach was further developed on May 30, 2023, at a meeting of the UN Security Council, where five specific principles were presented aimed at preventing a nuclear accident and preserving the integrity of the Zaporizhzhia Nuclear Power Plant. These principles include prohibiting any attacks on the plant or from its territory, preventing the use of the nuclear power plant as a military base, ensuring a stable power supply, protecting all systems and components necessary for safe operation, and refraining from actions that undermine the implementation of these requirements.

Despite the principles formulated and the constant presence of international observers, the situation at the ZNPP remains unstable. The militarization of the site, shelling of infrastructure facilities that ensure the operation of the plant, mining of the territory, restriction of personnel access, and disruption of radiation monitoring systems indicate a systematic disregard for the approaches established by the IAEA. Under these conditions, the Agency's activities are objectively limited by its mandate, which focuses primarily on technical assistance and mon-

itoring rather than on enforcing compliance with international standards.

Thus, the role of the IAEA in addressing nuclear threats in the context of military operations is decisive, but at the same time structurally limited. Ukraine's experience has shown that even the existence of clearly formulated principles of nuclear safety and international presence does not guarantee the elimination of risks in the absence of a cessation of hostilities. This highlights the need for further development of international nuclear security mechanisms, taking into account scenarios of armed conflict and strengthening the role of international institutions in the protection of nuclear facilities.

Shortcomings of the existing nuclear safety system

The above-mentioned international instruments constitute an important system aimed at protecting the status of nuclear facilities during armed conflict, but they have some shortcomings. The scope of Article 56 is limited to nuclear power plants, leaving research reactors, the transport of nuclear materials, uranium processing and enrichment facilities, and spent fuel pools outside the scope of the Protocol. In addition, paragraph 2 provides for an exception, terminating special protection from attack on nuclear facilities if they provide electricity on a regular, substantial, and direct basis in support of military operations.

Furthermore, customary international humanitarian law does not prohibit attacks on nuclear power plants, but calls on states to exercise "special caution" when attacking them as legitimate military targets.

It should also be noted that the IAEA has limited powers with regard to nuclear safety, unlike nuclear safeguards, as responsibility for nuclear safety rests entirely with each member state. The IAEA General Conference does not have the legal authority to adopt legally binding resolutions, as this authority rests solely with the UN Security Council, acting under Chapter VII of the Charter. Similarly, the "Seven Pillars of Nuclear Safety and Security" are complementary framework that builds on existing IAEA nuclear safety standards and nuclear security guidelines and does not impose legally binding obligations on member states.

A clear lesson to be learned from the current Russian-Ukrainian war, especially for the rapid potential expansion of peaceful uses of nuclear technology, including new modular reactors, to new nuclear states located in regions prone to armed conflict, military action, civil war, or insurgency, is that the international community needs

a mechanism for international safeguards to prevent and protect against the loss of international oversight of nuclear safeguards and to prevent the impact of armed action occurring at or near nuclear facilities.

This will help the IAEA overcome the difficulty of obtaining the consent of warring states or states experiencing civil conflict to send a technical mission at the very beginning of military action. Under this new Protocol, the IAEA will only need to inform the parties to the conflict, rather than obtain their permission, before visiting nuclear facilities under UN military protection. This Protocol will allow the IAEA to fulfill its role in promoting the peaceful use of nuclear technology without infringing on the sovereign rights of member states.

Possible ways to eliminate political gaps in nuclear security during armed conflicts

Recent events in the field of international nuclear security have revealed significant political and legal gaps in the mechanisms for protecting nuclear facilities in armed conflicts. Eliminating these gaps requires not only technical solutions, but above all the coordinated political will of states and the development of international legal instruments adapted to modern military threats.

One possible way to improve the international nuclear security regime is to conclude a special international agreement that would explicitly prohibit armed attacks on nuclear facilities and nuclear fuel cycle installations. Such an agreement could cover not only nuclear power plants, but also research reactors, small and advanced modular reactors (SMR, AMR), nuclear material enrichment and reprocessing facilities, as well as related activities, including the transport and management of radioactive waste. Formalizing such prohibitions in a treaty would create a clear legal basis for classifying attacks on nuclear facilities as international offenses and would contribute to increasing the level of international responsibility of states [11].

Another possible approach is to grant nuclear power plants and key nuclear facilities the status of demilitarized zones during armed conflicts. Although the physical protection systems of nuclear facilities are designed to take into account increased threats, such facilities remain, by their nature, civilian structures intended for the peaceful use of nuclear energy. The introduction of a demilitarized zone regime could reduce the risks of military impact on nuclear infrastructure, while affirming the right of states to the peaceful use of nuclear energy and strengthening the protection of the civilian population from potential radiation effects.

A limited United Nations peacekeeping presence in areas where nuclear facilities are located could play a special role in reducing risks. Such a presence could take the form of intervention at the invitation of a state whose nuclear facilities are threatened by armed conflict, provided that the principles of impartiality are observed and force is used exclusively within the limits of a defensive mandate. At the same time, the practical implementation of this mechanism is significantly limited by the UN Security Council's decision-making procedure, in particular the veto power of permanent members, which reduces the effectiveness of peacekeeping instruments in situations where one of these members is a party to the conflict [12].

An additional area for improving the international nuclear security system could be the development of recommendations for the conclusion of temporary bilateral or multilateral agreements between the parties to the conflict under the auspices of the UN and the IAEA. Such agreements could define algorithms for operational actions to minimize the risks associated with military impact on nuclear facilities and contribute to maintaining basic nuclear and radiation safety conditions [13].

In the long term, the growth in the number of nuclear facilities in regions prone to armed conflict, particularly in connection with the spread of SMR and AMR technologies, reinforces the need to develop a more robust and flexible international nuclear safety system. Such a system should combine preventive mechanisms, crisis response tools, and political and legal guarantees capable of functioning even in conditions of military action [14].

Conclusions

The analysis presented in this article shows that the use of nuclear energy and the operation of nuclear facilities in the current context of armed conflicts go beyond traditional notions of nuclear safety as an exclusively technical or regulatory category. Military actions against nuclear facilities demonstrate the possibility of transforming nuclear infrastructure into an instrument of political and military pressure, which significantly increases the level of nuclear and radiation risks.

The article shows that the existing norms of international humanitarian and international nuclear law, although they contain important prohibitions and restrictions on the protection of nuclear installations, are insufficiently adapted to scenarios of high-intensity interstate armed conflicts. The full-scale invasion of the Russian Federation into Ukraine for the first time demonstrated the practice of using nuclear power plants

as elements of a military strategy, in particular through their occupation and militarization, which creates fundamentally new challenges for the international nuclear security system.

The results obtained indicate that the international regime for the physical protection of nuclear facilities, which has been developed over decades, is primarily focused on countering threats from non-state actors and does not provide for effective mechanisms to respond to actions by regular armed forces of states. Revising this approach would require a comprehensive transformation of the international physical protection system, which is unlikely in the short term given political and institutional constraints.

The article also argues that responsibility for ensuring nuclear safety lies primarily with the state on whose territory nuclear facilities are located, while the international nuclear safety regime plays a supporting and coordinating role. At the same time, in the event of an armed conflict, the consequences of a breach of nuclear and radiation safety are transboundary in nature, which necessitates increased international attention to this issue and the development of collective response mechanisms.

Overall, the findings of the study confirm the urgent need to improve international legal and political instruments for the protection of nuclear facilities in wartime, as well as to intensify international cooperation in the field of nuclear security. The lack of timely and decisive action by key international actors creates the risk of further normalization of military influence on nuclear infrastructure, which could have long-term negative consequences for global security. That is why clarifying the procedures for competent authorities and nuclear facility operators in crisis situations should be considered a priority area for further scientific and practical research.

The practical value of the results obtained lies in the possibility of their use in the development and improvement of physical protection systems for nuclear facilities, the preparation of decisions by regulatory authorities in the field of nuclear and radiation safety, as well as in the activities of nuclear power plant operators in conditions of crisis and military threats. The research materials can be used in scientific and analytical work and in the educational process.

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Безпека об'єктів критичної інфраструктури паливно-енергетичного сектору в умовах воєнного стану

У статті проведено комплексне дослідження проблеми фізичного захисту ядерних установок в умовах міждержавного збройного конфлікту з урахуванням сучасних військових загроз. Актуальність теми полягає у зростаючій ролі військових дій безпосередньо щодо ядерних об'єктів, що створює новий спектр ризиків, які не були предметом системного аналізу у класичних підходах до ядерної безпеки та міжнародного гуманітарного права. Метою дослідження є встановлення сутності сучасних викликів у сфері захисту ядерних об'єктів під час війни, аналіз існуючих міжнародно-правових механізмів, а також фор-

мулювання рекомендацій щодо їхнього удосконалення.

Методологія дослідження базується на системно-структурному аналізі міжнародних правових норм, стандартизованих принципів Міжнародного агентства з атомної енергії (МАГАТЕ), а також на порівняльному аналізі прецедентних ситуацій впливу збройних дій на ядерну інфраструктуру. У результаті роботи ідентифіковано ключові прогалини чинних механізмів фізичного захисту ядерних установок у контексті воєнних конфліктів та запропоновано напрями юридичних і політичних удосконалень міжнародної системи безпеки.

Наукова новизна дослідження полягає в інтеграції правового, безпекового й технічного вимірів для формулювання узгодженого підходу до забезпечення ядерної безпеки в умовах бойових дій. Практичне значення результатів полягає в можливості застосування висновків і рекомендацій при розробленні політик національних регуляторів ядерної безпеки, регламентів операційної діяльності атомних електростанцій та міжнародних стандартів фізичного захисту. Отже, представлена концептуальна модель може сприяти підвищенню ефективності міжнародного співробітництва та адаптації процедур захисту ядерних об'єктів до сучасних викликів.

Ключові слова: ядерна безпека, збройний конфлікт, фізичний захист, міжнародне гуманітарне право, МАГАТЕ.

Надійшла / Received 06.02.2025

Рекомендована до друку / Accepted 11.02.2026