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Ensuring Nuclear Safety in Ukraine in Conditions of War

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ABSTRACT: The ongoing war in Ukraine has significantly raised concerns about the safety of nuclear power plants (NPPs), especially in the context of the Zaporizhzhia NPP. This precarious situation has revealed substantial weaknesses in the existing global nuclear safety framework, emphasizing the need for sweeping reforms in international law. While the International Atomic Energy Agency (IAEA) has played a commendable role in advocating for nuclear safety through various resolutions, missions, and safety principles, the effectiveness of these efforts is compromised by Russia's non-compliance and its ability to exercise veto power in the UN Security Council. Confronting these challenges requires a diverse and comprehensive approach from the international community. This includes revising international legal structures, conducting in-depth studies on nuclear safety in conflict zones, and considering diplomatic initiatives like establishing safety zones around nuclear facilities. Another possible strategy is the deployment of peacekeeping forces, though geopolitical factors currently limit its viability. Resolving the nuclear safety concerns intensified by the Russia-Ukrainian war demands robust legal and political actions, coupled with innovative solutions and global cooperation. Immediate and focused attention is crucial to avert any further escalation that risks a nuclear incident, posing dire threats not only to Ukraine but to the entire international community.

Keywords: nuclear safety, nuclear power plant, war in Ukraine, energy, IAEA standards.

1. INTRODUCTION

Over half a century of its development, nuclear energy has traversed a long, complicated, and controversial way: from ambitious plans to build a network of nuclear power plants (NPPs) to overcoming the consequences of the world's largest man-made environmental and humanitarian disasters. Along with this, until now, all accidents at NPPs have occurred in peaceful societies and have been caused by human error or natural disasters.

2022 will certainly go down in history as the year when the effectiveness of the existing international nuclear safety order has been unprecedentedly shaken after more than half a century of maintaining international safety, the global nuclear non-proliferation framework, and facilitating the expansion of peaceful applications of nuclear science and technology.

The war in Ukraine has marked the first time in history that nuclear power facilities have been the target of military attacks, and the Zaporizhzhia NPP, the largest NPP in Europe, has become the first civilian NPP to come under armed attack and is now at the center of major international concern.

The main goal of this study is to analyze the impact of the war in Ukraine on the safety of nuclear power plants, with particular focus on the Zaporizhzhia Nuclear Power Plant. It seeks to examine the vulnerabilities of nuclear infrastructure during armed conflict, assess the effectiveness of existing international legal frameworks and safety standards, and propose recommendations for strengthening global mechanisms to protect nuclear facilities in wartime conditions.

2. METHODOLOGY

The methodological basis of the research on the challenges of nuclear safety during the war, particularly in the case of the Zaporizhzhia Nuclear Power Plant of Ukraine, consists of a a set of general scientific and special legal methods of scientific cognition, including dialectical, analysis, historical and legal, comparative and legal, formal and legal, theoretical and legal forecasting. Thus, the dialectical method has been used to reveal the essence of nuclear safety as a dynamic concept that evolves under the influence of geopolitical, legal, and technological changes, especially in the context of war in Ukraine. The analytical method made it possible to study scientific literature, international reports, and expert assessments to identify key threats, contradictions, and shortcomings in the current nuclear safety frameworks. The historical and legal method was used to trace the evolution of international nuclear safety standards and the development of global legal regimes aimed at protecting civilian nuclear infrastructure. The formal and legal method has been employed to examine the legal obligations of states under international law, including the Geneva Conventions, the UN Charter, and IAEA conventions and safety standards, in relation to the protection of nuclear facilities during armed conflict. Finally, the method of theoretical and legal forecasting has been used to develop proposals and recommendations for improving the international legal framework and safety mechanisms to prevent and respond to nuclear threats arising from armed hostilities.

3. RESULTS AND DISCUSSION

The nuclear energy infrastructure of Ukraine

After the collapse of the Soviet Union, Ukraine inherited the world's third-largest arsenal of nuclear weapons. However, in its Declaration of State Sovereignty, Ukraine highlighted its intention to adhere to three non-nuclear principles: not to accept, not to produce, and not to acquire nuclear weapons [1]. The affirmation of these three non-nuclear principles led to the need to further resolve the fate of a powerful nuclear arsenal located on its territory.

In 1994, the Memorandum on Security Assurances in connection with Ukraine's Accession to the Treaty on the Non-Proliferation of Nuclear Weapons was signed by Ukraine, the Russian Federation, the United Kingdom of Great Britain and Northern Ireland, and the United States of America. According to this document, Ukraine needed to eliminate all nuclear weapons from its territory within a special period in exchange for the obligations of these three countries "to respect the independence and sovereignty and the existing borders of Ukraine...", "to refrain from the threat or use of force against the territorial integrity or political independence of Ukraine" [2].

Along with this, Ukraine has a highly developed nuclear energy infrastructure. Before the war, this developed nuclear energy infrastructure included four operating NPPs with 15 reactors of

a total installed capacity of 13,835 MW: Zaporizhzhia NPP (Energodar, Zaporizhzhia region), Rivne NPP (Varash, Rivne region), Khmelnytskyi NPP (Netishin, Khmelnytskyi region), South-Ukrainian NPP (Yuzhnoukrainsk, Mykolaiv region) (Fig.1). These four NPPs have provided more than 50% of the country's electricity and have been operated by the National Nuclear Energy Generating Company Energoatom [3]. The stopped Chornobyl NPP, where there is storage of spent nuclear fuel, and a nuclear installation "Neutron Source of the Kharkiv Institute of Physics and Technology", which by its nature is a unique innovative installation, the use of which contributes to the development of scientific and technical foundations of the latest safe nuclear systems, are also located on the territory of Ukraine [4; 5].

Fig 1. The nuclear energy infrastructure of Ukraine

Russia's full-scale invasion of Ukraine, seizure and occupation of Chornobyl and Zaporizhzhia NPPs, large-scale shelling of energy infrastructure, shelling of the nuclear installation "Neutron Source of the Kharkiv Institute of Physics and Technology", missile flights over the South Ukrainian NPP, and rocket attacks near this NPP, and the emergency shutdown of nuclear reactors at all NPPs in the state have led to the emergence of new threats to the nuclear safety of Ukraine, Europe, and the world. This situation has destabilized the entire world nuclear order and highlighted the need to rethink the fundamental issues of ensuring nuclear safety.

However paradoxical it may seem, ignoring its obligations at the international level, questioning the nuclear taboo between the nuclear powers of the world (China, France, Great Britain, USA), and violating its obligations to Ukraine to prevent any form of aggression, Russia, as one of the signatory countries of the Memorandum, annexed Crimea, parts of Donetsk and Luhansk regions in 2014, and in 2022 launched a full-scale invasion of Ukraine.

In such circumstances, Russia's war against Ukraine has threatened a consensus that prevented the use of nuclear weapons, proliferation, and nuclear terrorism. It also served as a reminder that giving up nuclear weapons may no longer provide the security that was once considered likely.

Nuclear safety of NPP in war conditions

The issues of nuclear safety and radiation protection for the population and the environment, undoubtedly, have always been relevant. In his research, Woo Ho Tae investigated 8 possible cases of terrorist attacks on NPPs during normal operation and specifically analysed two cases involving armed attacks: a frontal assault with small arms and an attack with rockets or medium artillery, providing guidelines for preparation [6]. However, this research was based on assumptions, and such scenarios seemed unrealistic at the time.

Nowadays, the issue of NPP safety in war contexts has become an almost entirely new area of research. The war in Ukraine and the subsequent crises around nuclear facilities have drawn significant attention from global scientists. Researchers have explored the impact of war on nuclear order and nuclear safety, as well as the future of nuclear energy in Ukraine, including works by Budjeryn [7], Bollfrass and Herzog [8], Boulton [9], Chepeliev, Diachuk, Podolets, Semeniuk [10], Duliba and Chudyk [11; 12].

This overall nuclear safety objective is supported by two additional safety objectives: radiation protection and technical safety. The purpose of radiation protection is to ensure that radiation exposure within an NPP during its operation is as low as reasonably achievable and does not exceed established standards. It also aims to ensure that any radiological consequences of an accident are mitigated. The purpose of technical safety is to take all reasonably feasible measures to prevent accidents at nuclear facilities and, in the event of an accident, to mitigate its consequences.

The fundamental concept of NPP safety is the so-called “in-depth protection”, which is a hierarchical deployment of different levels of equipment and procedures. This approach maintains the effectiveness of physical barriers placed between radioactive materials and workers, the public, or the environment in normal operation, anticipated operational occurrences, and, for some barriers, in accidents at the plant [13]. This concept is implemented through design and operation and is generally structured in five levels. These levels protect against a wide variety of transients, incidents, and accidents, including equipment failures and human errors within the plant, as well as events initiated outside the plant. If one level fails, the subsequent level comes into play.

During the design and construction of NPPs, measures are taken to ensure the safety of their operation. These measures relate to design features, including the strengthening of plants against external events such as aircraft accidents, redundancy through the provision of backup equipment, and safety and protection systems. These systems ensure the stability of the power plant against internal and external threats and the high reliability of its systems and equipment [13]. However, no NPP is designed to defend against military attacks, and it is unknown whether such a station has sufficient strength to withstand constant military bombing or artillery shelling [13].

The International Atomic Energy Agency (IAEA) was established as a response to global concerns about the dangers and consequences associated with the military application of nuclear technology. Its primary role is to set up and manage safeguards aimed at upholding nuclear safety. Within the framework of the IAEA’s safety standards, there are three key types of publications: Safety Fundamentals, Safety Requirements, and Safety Guides. These documents detail the essential principles, requisites, and guidelines necessary for ensuring

comprehensive nuclear safety. This includes aspects such as nuclear safety, radiation safety, transport safety, waste safety, and general safety practices.

Speaking about the NPPs, it is worth noting that various IAEA standards establish requirements applicable to the design of NPPs and exposure to NPPs, such as Specific Safety Requirements No SSR-2/1 (rev.1) "Safety of Nuclear Power Plants: design" [14], Specific Safety Guide No. SSG-64 “Protection against Internal Hazards in the Design Nuclear Power Plants” [15], Specific Safety Guide No. SSG-68 “Design of Nuclear Installations Against External Events Excluding Earthquakes” [16], Specific Safety Guide No. SSG-53 “Design of the Reactor Containment and Associated Systems of Nuclear Power Plants” [17] etc.

An analysis of these international standards reveals that the protection of NPPs from military missiles, such as bombs or rockets, has never been a consideration. At that time, standards were developed to design NPPs for protection from the effects of external events. These events include air crashes, external fires, explosions, electromagnetic interference, floods, extreme winds, volcanism, and biological phenomena. Specifically, in Safety Guide No. NS-G-1.5, titled “External Events Excluding Earthquakes in the Design of Nuclear Power Plants”, the term “missile” refers generally to a moving object. This includes the primary missile (the aircraft itself) and secondary missiles (such as engines and landing gear) [18]. This Safety Guide was later superseded by Specific Safety Guide No. SSG-68 “Design of Nuclear Installations Against External Events Excluding Earthquakes”. In this newer guide, the term “missile” is again used in a general sense, but it explicitly excludes military missiles, whether explosive or not, from consideration [16; 12].

Along with direct attacks, nuclear installations are also at risk of suffering unintentional damage during armed conflicts, which can potentially trigger a chain of events leading to a serious accident. Such unintended damage may include fighting near an NPP, potentially causing accidental fires that could destroy vital security systems or disrupt the external power supply.

The massive shelling of Ukraine’s energy sector by Russia has significantly damaged about half of Ukraine’s energy infrastructure, resulting in the largest blackouts in the country’s history. This led to a situation where all NPPs simultaneously lost offsite power, necessitating the activation of diesel generators at the stations.

An NPP requires a reliable electrical grid for its operation. The safety of the NPP and the reliability of the electrical grid system are mutually interdependent. A loss of offsite power can significantly impact an NPP’s ability to achieve and maintain safe shutdown conditions, as noted by Johnson and Ma [19]. The offsite electric grid system is crucial for several critical technological processes, including cooling. In the absence of an offsite grid system, the NPP’s integrity relies solely on emergency diesel generators. However, these diesel generators may not be as reliable as offsite power from the grid under normal conditions [20]. For instance, the Zaporizhzhia NPP currently depends on a single operational 750 kilovolt (kV) external power line for the electricity required for cooling the reactors and performing other essential nuclear safety and security functions. This is a significant reduction from the four lines it had access to before the armed conflict in Ukraine [21].

The operation of an NPP during a war hinges on the functionality of all its systems and the efficiency of its staff. NPP safety systems, such as emergency cooling systems and reactor

containment, are designed to counteract design errors, prevent more severe accidents, and minimize their radiological consequences. A case in point is the destruction of the Nova Kakhovka dam and hydroelectric power plant, which served as a source of cooling water for the Zaporizhzhia NPP's nuclear reactors. This event removed a critical level of protection for the NPP, significantly complicating the task of refilling the cooling pond. The cooling pond is essential for the continuous cooling of the Zaporizhzhia NPP and for preventing overheating of the reactors.

The safe operation of an NPP during wartime is critically dependent on the staff currently serving at the facility. They possess the necessary knowledge of the requirements for stable NPP functioning, can ensure the safety of different parts of the NPP, and are capable of assessing the consequences of various actions. However, factors such as continuous working days without rotation, stress from the presence of armed military personnel, and concerns for loved ones can impair the performance of workers, increasing the risk of human error. The effectiveness of handling potential accidents and the swift, professional resolution of problems or implementation of necessary procedures using technical resources largely depend on the actions of the NPP staff [22]. Nevertheless, under these conditions, there are risks of losing control over power units, obstruction in using additional safety equipment, extinguishing fires, and responding to other potential accidents.

The safe operation of the Zaporizhzhia NPP during its occupation depends not only on the Ukrainian personnel, who continue to operate the plant and manage emergencies, but also on the Russian military, which may obstruct the Ukrainian staff in utilizing additional safety equipment, extinguishing fires, and responding to other potential accidents. The substantial reduction of maintenance personnel by approximately one-third since the beginning of the war further exacerbates concerns regarding the facility's ability to adequately maintain systems, structures, and components crucial for the NPP's nuclear safety and security.

The situation at the Zaporizhzhia NPP is uniquely troubling. Firstly, Russia has been utilizing the plant as a shield against attacks, as a weapons warehouse, and as a cover for launching attacks. According to the Second Summary Report by the Director General of the IAEA titled 'Nuclear safety, security and safeguards in Ukraine,' an IAEA team observed the presence of Russian military personnel, vehicles, and equipment in various locations at the ZNPP. This included several military trucks on the ground floor of the Unit 1 and Unit 2 turbine halls, and military vehicles stationed under the overpass connecting the reactor units [23].

Secondly, the situation at the Zaporizhzhia NPP has raised critical questions about which country bears responsibility for the safety of the NPP. According to the UN Convention on Nuclear Safety "responsibility for nuclear safety rests with the State having jurisdiction over a nuclear installation" [24]. The Zaporizhzhia NPP falls under Ukraine's jurisdiction and operates based on a license issued by the State Nuclear Regulatory Inspectorate of Ukraine. In light of the potential consequences of an accident at the Zaporizhzhia NPP, particularly considering the occupation of the plant and the loss of water resources from the Kakhovka reservoir (a primary source for the plant's cooling system), the State Nuclear Regulatory Inspectorate of Ukraine opted to operate the nuclear units of the Zaporizhzhia NPP in "shutdown for repair" and "cold shutdown" modes [25]. These measures were implemented by the Ukrainian staff.

Since March 2022, the Zaporizhzhia NPP has been occupied by Russia, which has declared it as its "federal property". Russia established a state-owned enterprise to oversee the plant's activities and deployed its own expert group at the facility. This situation raises a critical issue: who is responsible for ensuring the safety and management of the station under these circumstances? While Ukraine is committed to fulfilling its international obligations, its ability to take effective actions is significantly limited due to the occupation. Conversely, there is scepticism about Russia's willingness to undertake meaningful safety measures. In this context, the pressing question arises: what short-term solutions exist for this complex and unprecedented situation?

Some steps for ensuring Ukraine's nuclear safety

In international humanitarian law, specifically the law of war, attacks on nuclear installations are expressly prohibited to protect victims of armed conflicts, as stated in Article 56 of the Additional Protocol I of June 8, 1977, to the Geneva Conventions of August 12, 1949.

To ensure nuclear safety in Ukraine, certain measures must be implemented at the international level. The war in Ukraine highlights the ongoing necessity for the global community to "achieve a high level of nuclear safety worldwide, based on strengthening national measures and international cooperation" [24].

In light of escalating geopolitical tensions, it is imperative for the international community to rethink and remodel the global architecture of nuclear safety. This process begins with a comprehensive understanding of potential threats, their targets, and the necessary countermeasures.

The war in Ukraine has underscored the vulnerability of nuclear facilities to military attacks. Given that there are currently 431 nuclear reactors operating worldwide, with additional reactors being constructed in countries like China, Egypt, and Turkey [26], it's imperative to develop an effective global nuclear safety architecture. This architecture should encompass standards and best practices, foster confidence-building, and prioritize the minimization and eventual elimination of risks.

Ukraine's experiences have shown that nuclear safety is a global concern, necessitating international legal agreements and voluntary initiatives as the foundation of a robust and effective global security architecture. Particularly, the situation surrounding the Zaporizhzhia NPP highlights the gap in international legal frameworks regarding the operation of NPPs in war conditions.

Considering the ever-changing global landscape, international legal acts must evolve accordingly. Future regulations should not only acknowledge the possibility of NPPs becoming targets in military conflicts but also clearly define responsibility for these facilities in cases of seizure and occupation.

The UN Security Council, vested with the "primary responsibility for the maintenance of international peace and security" [27], has faced challenges in leading the response to the conflict in Ukraine. This is primarily due to Russia, a permanent member of the Security Council, vetoing a resolution condemning the attack on Ukraine. In response, the Security Council convened an emergency special session of the General Assembly to address the issue. The UN Charter allows the General Assembly to consider matters of international peace and

security when the Security Council is unable to act due to a lack of unanimity among its five permanent members: China, France, Russia, Great Britain, and the United States.

In its resolution ES-11/1 dated March 2, 2022, the UN General Assembly strongly deplored Russia's aggression against Ukraine. It demanded the withdrawal of all Russian military forces from Ukrainian territory and the reversal of decisions recognizing the status of certain areas in the Donetsk and Luhansk regions of Ukraine [28]. While the UN General Assembly adopted several resolutions subsequently, none specifically addressed the nuclear safety of Ukraine and Europe or Russia's responsibility in this context.

In contrast, the IAEA has taken significant steps since the outbreak of the Russian-Ukrainian war to ensure the safety of Ukraine's nuclear facilities. The IAEA's governing bodies, the Board of Governors and the General Conference adopted various resolutions addressing the nuclear safety situation in Ukraine. These include resolutions GOV/2022/17 (dated 03.03.2022), GOV/2022/58 (dated 15.09.2022), and GOV/2022/71 (dated 17.11.2022), all entitled "The safety, security and safeguards implications of the situation in Ukraine" [29; 30; 31].

The IAEA Director General has identified "seven indispensable foundations of nuclear safety": maintaining the physical integrity of NPPs, including reactors, fuel ponds, and radioactive waste storage; ensuring the complete serviceability of all systems and equipment at all times; enabling the operational staff to perform their safety duties and make decisions without undue pressure; having a reliable external power supply for all nuclear facilities; ensuring uninterrupted logistic chains for resources and transportation to and from the sites; having effective radiation monitoring systems both onsite and in the surrounding areas, along with emergency preparedness and response measures; and maintaining communication with the regulator and other relevant entities [32].

The IAEA's efforts extend beyond the issuance of resolutions. During the war, it has conducted over 12 missions to Ukraine, including deploying a permanent monitoring mission at the occupied Zaporizhzhia NPP to ensure its nuclear safety and security and carry out crucial safeguards activities [21]. Similar monitoring missions have also commenced at other Ukrainian NPPs. These missions provide the international community with reliable information about the state of safety and security at each of these facilities.

Regrettably, Russia has not shown any signs of adhering to the resolutions passed by the IAEA Board of Governors in 2022, nor the earlier consensus resolutions of the IAEA General Conference. These resolutions assert that "any armed attack and threat against nuclear facilities dedicated to peaceful purposes constitute a violation of the principles of the UN Charter, international law, and the Agency's Statute". Furthermore, each of the IAEA's "seven indispensable pillars" for ensuring nuclear safety during armed conflict has been compromised at the Zaporizhzhia NPP, including the physical integrity of nuclear facilities; the operation of safety and protection systems; personnel working conditions; the reliability of supply chains and communication channels, radiation monitoring and emergency management; and the critically important off-site power supply.

The IAEA General Director has outlined five key principles to help ensure the safety and security of the Zaporizhzhia NPP, aimed at preventing a nuclear accident and ensuring the integrity of the plant: principle 1 - the absence of attacks from or against the plant, aimed at

reactors, storage of nuclear fuel, other important infrastructure or personnel; principle 2 - non-use of the station as a storage or base for heavy weapons or military personnel, which can be used for attacks by the station; principle 3 - absence of risks for external power supply of NPP, availability and safety of electricity at all times; principle 4 - protection against attacks or acts of sabotage of all structures, systems and components necessary for the safe and reliable operation of stations; principle 5 - the failure to take any action that would undermine the first 4 principles [21].

Additionally, the IAEA has urged Russia and Ukraine to establish a "safety and security zone" around the station. However, initiating such negotiations during a war between the two countries is completely unprecedented and vastly different from peacetime discussions.

Another approach to ensuring the nuclear safety of Ukraine, particularly at the Zaporizhzhia NPP, could involve the deployment of a peacekeeping force to demilitarize and protect the area. However, the feasibility of this option hinges on the decision of the UN Security Council. As previously mentioned, Russia, being a permanent member of the Council, possesses veto power. This reality presents a significant barrier, as Russia can effectively block any action it opposes, potentially preventing the activation of this mechanism.

The current situation underscores the need for revisions to global international law, particularly the UN Charter, which was established in 1950. We believe it is imperative to amend Article 27 of the Charter. The proposed amendment would stipulate that if a permanent member of the Security Council is involved in a dispute, decisions should be considered adopted with the affirmative votes of eight members of the Council. This count would include all permanent members, except for the one participating in the dispute, who would be required to abstain from voting. Such a change could ensure a more equitable and effective decision-making process in situations where permanent members are directly involved in conflicts.

In addition to political measures by the international community aimed at minimizing the risk of military attacks on nuclear facilities, there is a pressing need to initiate comprehensive studies. These studies should cover various aspects of nuclear safety during wartime and be integrated into the emergency plans of each NPP.

In current situation around nuclear power facilities in Ukraine, being both unprecedented and unstable, underscores the urgency of these measures. It is only through active and pragmatic international diplomacy that a lasting and effective solution to this complex problem can be achieved.

4. CONCLUSIONS

The war in Ukraine has brought to the forefront critical issues regarding the safety and security of nuclear power plants, particularly under the unique and precarious circumstances at the Zaporizhzhia NPP. This situation has exposed vulnerabilities in the current global framework for nuclear safety and highlighted the necessity for comprehensive revisions in international law and the UN Charter. The IAEA's active role in ensuring nuclear safety through its resolutions, missions, and proposed safety principles is commendable, yet the challenges posed by Russia's non-compliance and veto power in the UN Security Council underscore the complexities of enforcing and implementing these measures.

To address these challenges, it is crucial for the international community to adopt a multifaceted approach that includes the amendment of international legal frameworks, the development of detailed studies on nuclear safety in wartime, and the exploration of diplomatic solutions such as establishing safety zones around nuclear facilities. The deployment of peacekeeping forces is another potential avenue, although its feasibility is currently hampered by geopolitical realities. Ultimately, achieving a lasting and effective resolution to the nuclear safety issues exacerbated by the conflict in Ukraine will require not only robust legal and political measures but also innovative thinking and steadfast international cooperation. The situation demands urgent attention to prevent any escalation that could lead to a nuclear incident, with potentially catastrophic consequences not just for Ukraine but for the global community.

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