

"GLOBAL CHALLENGES EMERGED FROM THE ZAPORIZHZHIA NUCLEAR POWER PLANT IN THE FRONTLINE OF THE WAR OF UKRAINE"

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For the first time in history, a nuclear power plant has become a military objective in the frontline of a war. While previous military operations at the Iraqi Osirak reactor (1981), the Iranian Bushehr nuclear power plant (1987) and the Slovenian Krško nuclear power plant (1991) were somewhat *ad hoc*, the Zaporizhzhia nuclear power plant (ZNPP) continues to be disputed as a military target in the frontline of the tragic war in Ukraine, a new and unprecedented situation for which the international community was unprepared. The first military actions on nuclear facilities in that war also affected the exclusion zone of the accidented Chornobyl nuclear power plant and the nuclear research centres KINR in Kyiv and NSC-KIPT in Kharkiv. Although there has been no external radiological impact to date, it is imperative to prevent Zaporizhzhia and any nuclear facilities from becoming military targets.

The Zaporizhzhia nuclear power plant was seized militarily by Russia on 4 March 2022. Its six Russian-designed VVER-1000/320 reactors produced 27% of Ukrainian electricity before the war and its location would be crucial for the electricity supply to Crimea and the Donbas region. The UN Security Council agreed in August 2022 to send to ZNPP nuclear safety inspectors of the International Atomic Energy Agency (IAEA), which as an autonomous agency of the United Nations created in 1957 is the only international body coordinating technical assistance to Ukrainian nuclear facilities. The plant continues to be under the command of the Russian state-owned Rosatom and its six reactors are in shutdown condition without producing electricity and heat since September 2022. Russia decreed its ownership of ZNPP on 5 October 2022 and a new operating organization was implemented with part of previous Ukrainian Energoatom staff having signed contracts with Rosatom and lastly adopted Russian citizenship, together with additionally arrived Russian operators of Rosenergoatom. In this respect, a sectoral union organization was erected and a collective agreement was signed. No employees of Energoatom are anymore allowed to enter the site since February 2024, so that on that date the entrance of Ukrainian specialists (120 according to Russia and 360 according to Ukraine) to ZNPP was blocked with an uncertain operational impact as consequence.

The Zaporizhzhia nuclear power plant needs to be protected

With the takeover of the plant, many personnel with Ukrainian licenses -especially plant and unit shift supervisors- left the plant. The regulatory control is provided by the Russian regulator Rostekhnadzor through supervision of the plant and licensing of employees in accordance with Russian legislation. In February 2024, from the 120 operators, eighty had Russian Rostekhnadzor licences and other forty operators were in the process to transitioning from their Ukrainian SNRIU licences to authorisations issued by Rostekhnadzor. In May 2024, the plant had about 5,000 employees compared to about 11,500 employed before the war, with further eight hundred open positions to be covered. The maintenance staff was still reduced to 40% in November 2023. Russia continues the recruitment of new personnel claiming to have enough

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specialists under Russian training and licensing regulations. New training instructors were hired and Rosatom assures to have enough authorized operating staff to safely maintain the reactor units in their current shutdown states. IAEA inspectors visited the training centre and its simulators verifying the Russian requirements for new operators, but they were still not permitted to talk to the main control room personnel to assess their experience and expertise. The city of Enerhodar, located around five kilometres away, where the majority of ZNPP employees are living, underwent water and heating restrictions at the beginning of the war, as well as drone strikes in September and November 2023. Due to military strikes, various local and regional sub-stations were damaged in July 2024, producing power outages and affecting water supplies in Enerhodar, which since April 2024 has also suffered diverse drone attacks.



On the other side, the Ukrainian regulator SNRIU, without formal communication lines to the plant, still demands the IAEA to check the compliance with the Ukrainian regulations of the operational staff and was also issuing regulatory orders against the hot shutdown condition of specific reactor units aimed to produce heating for the district of Enerhodar during winters and steam to process radioactive resins and liquid waste. Despite the professionalism of the operators, all these uncertainties have a negative impact on the safety culture concept of the plant, which also suffers lack of external contractors and specific spare parts to ensure adequate in-service inspection and maintenance programmes. It is announced that Russian products have replaced previous Ukrainian purchases covering about 90% of the ZNPP's needs, but the supply chain seems still fragile. In this regard, the ZNPP management reported that a new software system makes it possible to publish tenders for the procurement of new spare parts and equipment from Russian suppliers. The maintenance plan for 2024 is modest focusing just to safety systems, diesel generators, unit transformers and the 750 kV electrical switchyard. It is also essential to have proper emergency preparedness and effective response arrangements in place. Two specific emergency exercises were performed at the end of 2023 and on 15 May 2024 another emergency drill was performed, in this case on a scenario of damage to a pipe connected to one of the water sprinkler ponds providing cooling water to reactor unit 1. Moreover, a revised on-site emergency plan is expected to be issued in September 2024 with two exercises scheduled for the coming months.

Continuous attacks to the energy infrastructures make the Ukrainian electricity grid very fragile and unstable. Such growing vulnerability in the Ukrainian electricity network affects the safety of ZNPP, even with its six reactors in shutdown condition, since the plant depends on the external power supply to feed safety systems and to cool irradiated fuel. Presently only the 750 kV 'Dniprovská' power line out of four pre-war lines and just the 330 kV 'Ferosplavna' back-up power line out of six pre-war lines from the nearby DRES thermal power plant are operational. For four months, between March and July 2023, no support line was operational, and this was

again the situation between 20 February and 14 March 2024 for which all scheduled preventative maintenance activities on safety-related equipment were suspended due to the “general situation in the plant’s surroundings”. Even though maintenance work on part of safety systems were resumed at the end of May, it negatively affected the implementation of the ZNPP’s preventive maintenance plan for 2024, having also long-term impact for nuclear safety due to degradation of components and systems. Moreover, the loss of that unique back-up power line occurred again on 22 August and 2 September 2024. In the event of a complete external power outage, the so-called loss of off-site power, the plant must rely on emergency diesel generators as a last line of defence. That emergency scenario occurred in October 2022 for the first time in the plant’s 37-year history at that moment, and meanwhile has already occurred eight times (!), the last one on 2 December 2023, representing a huge loss of redundancy in the electricity supply to the plant. The loss of connection to the sole remaining 750 kV off-site power line occurred diverse times, but the operation of the unique 330 kV back-up line made not necessary the intervention of emergency diesel generators. Therefore, the power supply continues to be extremely vulnerable to power disruptions and, in this regard, also the Dnipro hydroelectric power plant, upstream in the Dnieper River and feeding electricity to ZNPP, lost one third of its production capacity due to explosions occurred on 23 March 2024.

Furthermore, the destruction of the Kakhovka dam on 6 June 2023 represents a gigantic decrease in the available water reservoir used to cool the plant, so that it is no longer possible from the reservoir to refill the cooling pond of the plant, which is presently fed by the discharge channel of a nearby thermal power plant close to the plant. The cooling pond level in September 2024 decreased about two metres below the level of mid-2023. In this context, the eleven groundwater wells, which were drilled and insulated within the perimeter of the site after the destruction of the dam, are assuring the 250 cubic meter per hour necessary for the water sprinklers to cool the six shutdown units for months, with that cooling pond representing the primary water resource in case the wells would become unavailable. However, that cooling situation with dwindling water levels cannot be a sustainable solution on medium term. Additionally, one of the two cooling towers available for normal operation of the plant was affected by a recent explosion on 11 August and is not anymore operable.



In this respect, it is noteworthy that Ukraine participated in the nuclear stress tests supervised by the European Nuclear Safety Regulators Group (ENSREG) after the Fukushima accident. As result of that exercise a Ukrainian National Action Plan was developed in 2013 with different updates till 2020. Its Art.5 deals with a long-term cooling without power supply, so that emergency procedures were expanded with new equipment such as mobile vehicles, pumping boats or submersible pumps. Presently, further measures are being assessed to ensure sufficient

cooling in the long term, as the recharge to the cooling pond directly from the Dnieper River. That possibility would require to build a robust infrastructure and in the discussed case that one of the reactors should turn into operation it would be really challenging (notwithstanding that proper condition of equipment with poor maintenance is not assured) since the circulation water for only one of the reactors in normal operation would require an estimated recirculation water flow of about 140.000 cubic meter per hour.

The dispute over the plant on the frontline of the war, anti-personnel mines placed within the site's external perimeter, firing of rockets close to the plant, and even sabotage or terrorist actions, clearly increase the risk of accident. Military activity near ZNPP became a daily reality. Indeed, drone strikes, frequent blasts and fire can affect installations with a subsequent potential radioactive impact, such as irradiated nuclear fuel pools with cooling pumps, radioactive waste storage facilities, electrical lines and equipment feeding electricity to safety systems, the structure of the cooling pond and the discharge channel, or the water sprinkler equipment, which are now essential to ensure the cooling of irradiated fuels. The plant can render unusable in diverse ways, also through damaged conventional non-nuclear equipment placed for instance in turbine halls. In that respect, in August 2022 the fresh nuclear fuel storage suffered a direct shelling and just on last 11 August a fire caused significant damage to one of its two cooling towers.



Long-term operating plans are not announced. Despite speculations on bringing into operation one unit in the fall of 2024, all the mentioned elements make the situation of ZNPP precarious and unsustainable in the medium term. The Zaporizhzhia nuclear power plant needs to be protected since there is a real and permanent risk of a nuclear accident. The gradual reduction in significant safety levels and margins in Zaporizhzhia, together with chances of human errors or military mistakes, may be brewing a potential accident to the frustration of the international community. Although in the current state of the plant, a Chernobyl-type accident cannot occur for physical and technological reasons, if specific essential systems were to be affected, there would be the risk of not being able to ensure safe cooling of the residual heat from the irradiated fuels. In such a case, fuel meltdowns could occur with release of radioactive products, i.e. level 4 or higher on the international nuclear event scale (INES) corresponding to reactor damage and radioactive release. Such a potential accident would have a phenomenology like a Fukushima-type scenario (level 7 on the INES scale), but with less impact since all six ZNPP reactors are shutdown since September 2022, so that the residual heat of irradiated fuels to be cooled would be quite low. Additionally, some radioisotopes of high concern as Xenon-133, Iodine-131 and Iodine-133 would not contribute to the impact because of their short half-life values. However, a complete and definitive lack of coolant causing a fuel meltdown accident with a release of radioactive products could have, depending on its magnitude, a transboundary and indiscriminate impact affecting public health and environment in various countries.

Nonetheless, a radioactivity release from ZNPP would, irrespective of its magnitude, have a great psychological and political impact. The world's reaction would have to be seen, but such a scenario could alter the course of the conflict, leading to possible outside humanitarian interventions and escalating the dimension of the war.

Need of a ratified global treaty on non-aggression to nuclear facilities

The implications of the actual situation in Zaporizhzhia exceed safety and security aspects addressing issues of global concern. Indeed, it reflects the lack of a ratified global agreement to protect nuclear infrastructures with significant potential impact on the population. In this respect, diverse legal frameworks can link nuclear facilities and armed conflicts. The 1949 Geneva Conventions were extended by the 1977 Additional Protocol I referring to international armed conflicts. Its article 56 addresses restrictions on the protection of facilities with potential impact to population, but it does not explicitly address nuclear installations. Furthermore, the Russian Federation revoked in 2019 its previous ratification in 1989 of that Protocol, and among other countries, the United States never ratified that Protocol and explicitly rejects that Article 56 in its Law of War Manual of the US Department of Defence. Also, the 1979 IAEA Convention on the Physical Protection of Nuclear Material and Nuclear Facilities, which criminalises illicit trafficking and sabotage of nuclear materials or nuclear facilities, does not cover military attacks to such facilities.

These rules are insufficient and ambiguous conferring certain legal vacuum, which can formally mean that attacking a nuclear facility may not be illegal. Therefore, there is an urgent need for a specific ratified global convention or treaty on non-aggression against nuclear facilities to prevent such facilities (as well as dams, chemical facilities, etc.) from being used as military targets. Such agreement could include different rules in wartime, for instance concerning attack warnings, establishment of security zones around nuclear facilities, placing reactors under international control, IAEA involvement to assist in controlling reactors and spent fuel facilities, among others. Even if in the madness of a war some country did not abide by such norms, the very existence of internationally ratified rules should prevent the normalization of other potential attacks and delegitimize the possibility of justifying warlike actions against nuclear facilities in other crisis and regions of the world. The recent approach of the war frontline to the Russian nuclear power plant in Kursk with four units (two of them Chernobyl-type RBMK reactors) increases the risk of normalising the involvement of nuclear installations in armed conflicts and makes more necessary than ever a global agreement. In relation with that new situation, IAEA DG Grossi visited the Kursk plant on 27 August 2024.

In the framework of the 2019 IAEA General Conference, the need to prohibit armed attacks on nuclear facilities was already addressed. More recently, there have been unsuccessful attempts to advance in this direction, such as at the Nuclear Non-Proliferation Treaty Review Conference of August 2022 aiming among others to prohibit nuclear facilities from becoming military targets, including scenarios with change of control of disputed territories. Furthermore, a resolution voted at the 2022 IAEA General Conference concerning the risk of fighting in Ukrainian nuclear power plants including Zaporizhzhia, was rejected by Russia considering Zaporizhzhia nuclear power plant as already located in a Russian province.

The last IAEA General Conference adopted a resolution in September 2023 calling for "the urgent withdrawal of all unauthorized military and other unauthorized personnel from Ukraine's ZNPP and for the plant to be immediately returned to the full control of the competent Ukrainian

authorities”, which was supported by 69 countries with 32 abstaining and six voting against. Ukraine, that was also elected in that conference as one of the eleven new countries to serve on the 35-member IAEA Board of Governors for the 2023–2024 period, announced it as an opportunity to speed up the de-occupation of the Zaporizhzhia plant. In this line, also a statement of the European Union plus other ten countries of 23 November 2023 called Russia to withdrawal troops of Zaporizhzhia and to heed the resolutions of the IAEA General Conference. Most recently, the UN General Assembly endorsed on 11 July 2024 a resolution on the safety and security of Ukraine’s nuclear facilities with special emphasis on ZNPP, which was adopted by a significant consensus, i.e. ninety-nine member states voting in favour, nine against and sixty abstentions.

Nevertheless, there are also positive agreements from which specific elements can be taken as reference. The 1988 India-Pakistan ‘Non-nuclear Aggression Agreement Treaty’ refrained each party from "undertaking, encouraging, or participating in, directly or indirectly, any action aimed at causing destruction or damage to any nuclear installation or facility in each country”. The 1991 ‘Brazilian-Argentine Agency for Accounting and Control of nuclear materials (ABACC)’, being the unique binational organisation for nuclear safeguards, is another example in the good direction. If conventional nuclear fission power should continue to produce electricity for the world, the challenge for the international community is to ensure that nuclear facilities remain strictly outside any armed conflict and maintain in that way the gained credibility of nuclear power.



➔ Ilyá Repin (1844-1930) - “Zaporizhian Cossacks writing a letter to the Turkish sultan” (203 x 358 cm) - ‘State Russian Museum’ - Saint Petersburg.

(Ilyá Repin was a Russian painter born in Ukraine in the XIX century, who described in that painting the Zaporizhian Cossacks writing a letter in 1676 in response to the Turkish Sultan Mahmud IV proposal to voluntarily surrender without resistance. It is noteworthy that Russians and Soviets were always proud of the Zaporizhians’ bravery).

Extension of IAEA nuclear safety and security standards for armed conflicts

Beyond the need of legal treaties or agreements prohibiting and trying to prevent attacks on nuclear facilities, the present crisis is also the opportunity to develop and adapt its current nuclear safety and security standards and guides to manage the safety and security of nuclear facilities in armed conflicts, and even to consider a possible extension of the IAEA mandate for that adaption. The 1991 technical assessments at the Slovenian Krško nuclear power plant

already addressed various technical aspects related to subcriticality, fuel cooling, containment integrity and radiological inventory. However, that work was not used to develop IAEA guidance and standards for war contexts, since as mentioned above the present IAEA's mandate does not include dealing with armed conflicts and military facilities.

In the same way that the Chernobyl catastrophe accelerated further developments of IAEA nuclear safety standards, and the Fukushima accident triggered diverse nuclear safety action plans under IAEA and Euratom, this war should legitimise the IAEA to monitor and support nuclear facilities in armed conflicts. In this respect, the IAEA already established after the outbreak of the war the following seven pillars of nuclear safety and security to assess risks in wartime contexts: physical integrity of all facilities; full functioning of all safety and security systems; working conditions and ability of operators to perform their duties and make decisions without undue pressure; ensuring external power supply; ensuring logistical supply and transportation to the site; effective radiological monitoring and emergency preparedness; and reliable communication with the nuclear regulator.

After the first IAEA mission to ZNPP in September 2022, it was concluded that all those pillars were compromised, specific actions together with the establishment of a safety protection zone around the plant without military equipment were recommended and shifts of nuclear safety inspectors were established. In view that the demilitarised safety protection zone was not achieved, the UN Security Council further endorsed in May 2023 the following five concrete principles established by the IAEA, essential for averting a catastrophic incident at the Zaporizhzhia plant: no attacks of any kind from or against the plant, in particular directed to reactors, irradiated fuel storage, critical infrastructure or personnel; the plant cannot be used as storage or seating for heavy weaponry or military personnel that could be used for an attack from the plant; the external power supply cannot be placed at risk and must be secured at all times; all structures, systems and components essential to safety must be protected from attack or sabotage; and no action that undermines these principles must be taken.

The IAEA nuclear inspectors' presence and supervision in the site is trying to protect ZNPP in the war environment, in which the degraded safety is brought to its limits and may be able to produce uncontrolled risks. The shifts of IAEA inspectors also help to stabilize the nuclear safety and security at ZNPP bringing clarity of its situation to the world, especially at a time of unverified mutual allegations. In September 2024, the 23rd shift of IAEA inspectors crossed the frontline arriving to ZNPP and a total of fifty-nine deliveries of in-kind equipment for the Ukrainian electrical network and nuclear power plants, contributed by thirty countries plus the EU, were made through the IAEA aimed to reduce the possibility of accidents.

Even though the series of drone attacks to ZNPP in April 2024 did not damage safety or essential systems, they represented a first clear violation of the referred essential principles and increase the risk of severe accident. Moreover, full and unrestricted access of inspectors to all equipment and systems is not granted limiting the ability of IAEA to confirm the compliance of those five essential principles, being one of them that ZNPP cannot be used as storage or seating for heavy weaponry or military personnel. In that respect, access is not granted to western sides of turbine halls and to some reactor halls.

It is suggested that the mandate of the IAEA granted by the United Nations could be rethought and adapted, so that the IAEA could fully develop safety and security standards and guidelines for armed conflict environments. In this regard, the seven pillars of nuclear safety and security together with the five principles of protection for Zaporizhzhia are also a basis for developing standards and guidance in armed conflicts. The IAEA Safety Standards Commission (CSS) launched already in July 2022 a working group focussed on broad topical areas impacted given

the continually evolving nature of the armed conflict and aimed at addressing the practical applicability of current IAEA standards and security guidelines, shortcomings or challenges in their application, as well as lessons learned from the IAEA missions to Zaporizhzhia. The last CSS meeting held at the end of May 2024 continued assessing the outcome of that working group that is preparing an interim technical document, called TECDOC and planned to be published within 2024. Such an exercise has broad dimensions and long-term implications, also considering that the IAEA safeguards barely cover few military facilities. Furthermore, while the war continues it seems premature to start validation of existing or new IAEA standards for war scenarios. It is also expected that the TECDOC would have a positive multiplier effect on those countries having own regulatory agencies and able to develop own national standards.

The IAEA continues seeking greater engagement and commitment from the international community. In this regard, DG Grossi presented the actual situation to U.N. Security Council, his eighth last time on 13 August 2024, and negotiates at the highest level between the parties, being his last meetings with presidents of the parties in Sochi on 6 March and in Kyiv on 3 September 2024. It is imperative that the referred seven pillars of nuclear safety and the five concrete principles should be respected. In theory, nobody wants a nuclear accident, but a nuclear power plant is being disputed as a military target on a war frontline, with both sides accusing each other of misinformation and of preparing sabotage or terrorist actions at the power plant, which would break any of the five protection principles agreed at the UN Security Council. With various safety margins decreasing, DG Grossi called for maximum military restraint and stated that Zaporizhzhia is in a kind of grace period that is not infinite, and that there is no place for complacency or to believe that everything at ZNPP is stabilized. Time is playing against nuclear safety, so that a possible slow-motion accident cannot be ignored and the international community must be able to act before it happens.