SIBYLLINE

REFINED INSIGHT

SPECIAL REPORT

Ukraine

19 July 2023

2020

NUCLEAR INCIDENT SCENARIOS AT THE ZAPORIZHZHIA NUCLEAR POWER PLANT

Key Takeaways

- Upticks in fighting and rhetoric around the Zaporizhzhia Nuclear Power Plant (ZNPP) have raised concerns over the likelihood of a nuclear incident, with Moscow and Kyiv accusing one another of endangering nuclear safety, preparing 'provocations' and risking a major incident.
- A major nuclear disaster at the ZNPP nevertheless remains highly unlikely, even in the event of an accidental or deliberate strike against the reactor. Containment measures and back-up cooling systems will likely mitigate the release of radiation during a meltdown, with the design of the plant providing a more robust 'defence in depth' system of defences than those at Chernobyl and even Fukushima.
- As such, the worst-case scenario would be more akin to the Fukushima nuclear accident as opposed to Chernobyl, though redundant and multiple independent systems make this highly unlikely. In this scenario, radiation released during a meltdown would most likely impact the surrounding area, rather than spreading high concentrations of radiation hundreds of kilometres across Europe.

Context

Over the last year, both the Russians and Ukrainians have accused one another of preparing so-called "provocations" at the Zaporizhzhia Nuclear Power Plant (ZNPP). Ukraine has recently accused Russia of mining the plant, including the cooling pond, and of setting devices that 'resemble explosives' on the roofs of a reactor building. Moscow, meanwhile, has alleged that Ukrainian forces stationed in Nikopol plan to fire at the plant, whereafter Kyiv will blame Russia for creating a "man-made disaster" at the site. Both sides have also accused one another of preparing a radiological 'dirty bomb' attack at the plant or elsewhere on the frontline. While we cannot confirm the validity of these claims, Russian false-flag operations have remained par for the course throughout this war. False-flag threats will remain high at the ZNPP going forward, particularly if Ukraine's counter-offensive builds momentum along the southern frontline in the coming weeks.

The Russian MoD has confirmed it has drawn up plans to evacuate the area in the event of an incident, while Ukraine’s Ministry of Interior reported on 29 June that authorities of Zaporizhzhia, Dnipropetrovsk and Kherson oblasts launched a large-scale exercise in preparation for a nuclear incident at the ZNPP. These are the latest indications that the situation at the plant continues to deteriorate, with both sides increasing preparedness for an incident.

Misinformation and sensationalist claims will remain an issue obscuring the situation at the ZNPP

Given broader fears around nuclear power and escalating rhetoric and accusations, misinformation around the status of the ZNPP will remain an omnipresent issue. A major uptick in fighting around the plant will likely obscure the picture on the ground and lead to sensationalist claims or deliberate misinformation campaigns in the immediate aftermath by both sides.

Ultimately, it remains highly unlikely that the Russians would actively attempt to trigger a catastrophic meltdown, given that the radiation released would threaten Russia as much as western Ukraine or Europe. Nevertheless, staging false-flag "provocations" likely serves Moscow's interests to accuse Kyiv of threatening a nuclear disaster – and may be designed to undermine Western support for Ukrainian counter-offensives which could ultimately endanger the plant if fighting were to reach it.

The Kremlin may seek to use merely the fear of a nuclear incident to achieve its strategic objectives

A key factor to consider for business contingency planning is that panic and speculation around a nuclear incident may ultimately serve the Kremlin's interests without the need to actually escalate. Russia may seek to weaponise the plant as a terror weapon in order to put pressure on Kyiv and its partners to freeze the frontline, if and when Ukraine's counter-offensive succeeds in breaking through in the south.

If the military or political situation deteriorates to such an extent that the Kremlin feels the need to escalate, it remains highly likely that Russia will ramp up nuclear rhetoric and distribute extremely disconcerting reports in an attempt to instil panic. This could include the dissemination of credible 'intelligence leaks' indicating preparations for a nuclear incident or a deteriorating situation at the ZNPP, even if the Kremlin has no intention of actually triggering a meltdown. This may ultimately aim at instilling panic in not only the Ukrainian but the wider European population to reduce Western support for Kyiv or apply pressure on Kyiv to de-escalate or accept some sort of ceasefire agreement. The IAEA's presence at the plant will provide a source of confirmation and assurance. However, they have been denied access to certain parts of the plant, and this would likely be the case during a particularly tense period or escalation.

Accusations that Kyiv is preparing to detonate a 'dirty bomb' are likely to play into this wider psychological warfare campaign. The Kremlin is likely to leverage the psychological impact of fears of a nuclear and/or radiological incident during a longer-term psychological terror campaign aimed at steadily eroding Western support for Ukraine and splitting NATO in the coming months. However, such reports do not necessarily mean Moscow will follow through with its effective threats.

Even if such panic and fear of a nuclear incident fails to change Kyiv's military policy, such panic could also serve Russian interests in undermining European and NATO cohesion. Merely the fear of a nuclear incident could trigger mass refugee flows from Ukraine into Europe. In this scenario, information vacuums are likely to increase pressure on corporate security teams to implement evacuation contingency planning and could cause panic among staff members in Ukraine and Eastern Europe. Security teams could mitigate the effects of such psyops on their staff by underscoring scenario plans and contingency planning to assuage employee concerns and support business continuity in locations perceived to be at risk by staff. This remains a key first-order impact that could impact business operations across a wide area in Europe, with refugee flows also likely to drive tensions in host countries during a crisis.

Scenarios

Scenario 1: Russian radiological 'dirty bomb' attack imitates a minor nuclear incident — **Most likely**

Key implications:

- Russia has already accused Kyiv of preparing a radiological 'dirty bomb' operation.
- The radiological impact of a dirty bomb will be limited to the immediate vicinity of the blast, and is extremely unlikely to result in large amounts of radiation travelling in the wind to other jurisdictions.

It remains a realistic possibility that Russian forces will use a radiological dirty bomb, in combination with a false-flag attack, to create the impression that Ukrainian shelling has triggered a radiation leak at the plant. On 23 October 2022, Russian Defence Minister Sergei Shoigu formally accused Kyiv of preparing to detonate a 'dirty bomb' in Ukraine in order to accuse Russia of using weapons of mass destruction. It should be noted that a 'dirty bomb' is a radiological weapon, and not a nuclear weapon. A radiological 'dirty bomb' uses conventional explosives to scatter radioactive material over a given area. Using conventional explosives, the blast radius of a dirty bomb would be equivalent to other conventional bombs and munitions. As a result, it remains highly unlikely that a dirty bomb would spread lethal quantities of radioactive material over a significant area, with the most lethal part of a dirty bomb attack most likely to be the conventional explosion itself. The most acute effect of a dirty bomb is its psychological impact as a terror weapon.

Scenario 2: Protective containments remain intact during a reactor meltdown — **More likely**

Key implications:

- If a meltdown occurs, but the containments hold, radiation would highly likely be contained to the immediate vicinity of the plant, most likely within an area of 1.6 miles (2.5km) from the plant.
- Only those working at the plant will face serious radiation risks and an evacuation would likely follow.

The most likely triggers for this scenario would be a total loss of power to the plant, or if the cooling systems were severely damaged – such as the cooling pond. Ukraine has alleged that Russian forces have mined the cooling pond, which remains the principal source of water to cool the last remaining 'hot shutdown' reactor. While the IAEA has found no evidence of such mines, it remains a realistic possibility in the coming months if Russia wishes to create a limited meltdown that triggers disproportionate panic across Ukraine and Europe.

This scenario would increase the risk of radioactive isotopes contaminating ground water supplies and the nearby Dnieper River, despite the destruction of the Kakhovka reservoir. Contaminated water could realistically flow down the Dnieper Estuary into the Black Sea, increasing the risk of small amounts of irradiated water washing up on Black Sea beaches. However, the amount of radiation is unlikely to be a serious threat to health in this limited meltdown scenario.

Scenario 3: Spent fuel rods trigger localised fallout, fires spread radiation further afield — **Less likely**

Key implications:

- The used fuel pool is located inside the containment building at the ZNPP, which is a major advantage in contrast to Fukushima, where the pools were not as well protected.
- Main risk will be of overheating spent fuel rods causing a fire, which could spread radiation through smoke.

A comparatively less likely, but more impactful, incident would involve major damage to support systems outside the reactor containment structure, namely the pumps, heat exchangers or back-up diesel generators. All of these systems facilitate active cooling, which ensures that Zaporizhzhia's six reactors, even those that had been successfully shut down in March 2022, do not overheat. One of the plant's electric substations has already been damaged in shelling, but there are no indications that this has fundamentally threatened the resilience of the back-up systems.

A disruption to the pools of water used to cool spent fuel rods present another scenario, though this would likely be still less catastrophic than a meltdown. Nevertheless, if accidental or deliberate damage is caused to these pools, the spent fuel rods could overheat and cause a fire. This would most immediately pose a threat to the immediate vicinity of the plant, but it could also spread radioactive material further afield during a large fire, depending on the strength and direction of the wind. On 6 August 2022, a rocket appeared to explode in the vicinity of the spent fuel storage facility, but there has been no indication that the attack caused any damage to the pools or the spent fuel rods themselves. Nevertheless, if fighting approaches the plant or the Russians seek to sabotage or conduct a false-flag operation, attacking the spent fuel facilities remains a credible scenario.

Scenario 4: Containments are breached, triggering catastrophic meltdown, radiation leak

Remote chance

Key implications:

- If the protective shell that protects one the 'hot shutdown' reactors is breached, a meltdown would trigger a much more extensive release of radiation.
- Even in this worst-case scenario, the ZNPP cannot physically meltdown like the Chernobyl disaster.

The ZNPP has containments around its six reactors, and so even in the event of overheating or a meltdown, the risk of a catastrophic release of radiation remains highly unlikely. While containments are designed to resist an external impact, for example a terrorist attack, they are not designed to withstand a direct missile strike. Nevertheless, the pressurised steel containments at Zaporizhzhia remain extremely strong by design. Robust containment structures would therefore mitigate the risk of a catastrophic meltdown even in the event of a direct attack, as long as said attack was not purposefully trying to breach the containment structure.

If an actor was deliberately trying to compromise the containments and trigger a meltdown, the risk of a catastrophic nuclear disaster would be much higher, with release of radiation much more likely to impact countries outside of Ukraine, including potentially Georgia, Moldova, Poland, Romania and Russia, depending on the direction and strength of the wind. However, it remains extremely unlikely that Russian forces would actively try to trigger a meltdown of this scale given that a catastrophic release of radiation is much more likely to impact Russia than Central Europe.

In the extremely unlikely scenario that a catastrophic meltdown occurs at the ZNPP, and containment buildings fail to contain the most dangerous radiation, the impact on the wider region will depend heavily upon the direction and strength of the wind. If a strong westerly wind is blowing, radiation could travel hundreds of kilometres across Europe, though it will be impossible to predict precisely those areas most impacted due to the importance of the wind.

Nevertheless, the presence of containments in the Zaporizhzhia plant would likely limit the radiation released, and as such the incident would more likely resemble that of Fukushima, with comparatively limited radiation leakage – though this would nevertheless require a mass evacuation of the surrounding area. Even in this worst-case scenario, the ZNPP cannot physically meltdown in the same way as Chernobyl due to fundamentally different engineering, numerous back-up safety features and 'defence in depth', and the fact that it has remained in cold shutdown for months. See below for direct comparisons between the meltdowns at Fukushima and Chernobyl.

Given that the Khakovka Reservoir on the Dnieper River supplies the water-cooling system for the ZNPP, a meltdown could feasibly contaminate water with radioactive isotopes, which would likely flow south into the Black Sea and could thus risk contaminating the shores of the Black Sea with low-levels of radiation.

It should be emphasised that there is no scenario where the Zaporizhzhia plant, or any other nuclear power plant, could be made to explode like a nuclear weapon.

Comparisons between Zaporizhzhia, Fukushima and Chernobyl

It is important to stress that a nuclear disaster at the ZNPP of major severity remains highly unlikely, even in the event of an accidental (or deliberate) strike against the reactor. Many commentators have raised concerns of a Chernobyl-style nuclear disaster if fighting intensifies around the plant, but this is erroneous and highly misleading.

The Zaporizhzhia plant is of a modern design, and so a Chernobyl-style radiation leak is highly improbable due to fundamentally different engineering. The Chernobyl plant's reactors did not have a containment building – a structure inside the concrete outer building that protects the reactors, which is also designed to protect against terrorist attacks. This meant that Chernobyl had much weaker 'defence in depth' radiation mitigation than modern plants, which allowed extremely radioactive material to escape the reactor. By contrast, for example, the Fukushima nuclear plant in Japan had containments, which successfully limited the amount of radioactive material released during the disaster in 2011. In short, the Fukushima plant's containments prevented a disaster on the scale of Chernobyl.

Below is a table comparing the relative safety of numerous features of the three nuclear power plants, with safer and more modern systems highlighted in **blue**, and less safe and more dangerous features highlighted in **orange**. As you can see, the Zaporizhzhia Nuclear Power Plant is significantly safer than Chernobyl, and has numerous advantages compared to Fukushima Daiichi.

Feature	Zaporizhzhia (ZNPP)	Fukushima Daiichi	Chernobyl (ChNPP)
Back-up generator	Yes	Yes	Yes
Safety of reactor type	Pressurised water-water energetic reactors (VVER)	Boiling water reactor (BWR)	Graphite-moderated reactor (RBMK)
Control rod type	Non-graphite tips on control rods	Non-graphite tips on control rods	Graphite tips on control rods
Containment structure	Yes	Yes	No
Spent fuel rod storage	Within primary containment structure	Outside primary containment, but inside reactor building (secondary containment)	Outside all containment structures
Operational status	Cold shutdown	Fully operational	Fully operation
Reliability of external back-up power	Poor, subject to shelling	Good, did not fail	Did not fail, but took too long before meltdown
Reliability of water-cooling systems	Moderate but vulnerable; integrity of cooling pond intact, but Kakhovka dam breach has reduced available water sources	Good	Good

The ZNPP has been in cold shutdown for months, significantly reducing radiation risks in contrast to both Fukushima and Chernobyl

Five of the plant's six reactors have remained in 'cold shutdown' for months, with unit 5 currently under 'hot shutdown', which provides residual power to the plant's site and the town of Enerhodar. However, the IAEA reported on 12 July that unit 5 will be placed in cold shutdown, while unit 4 will move from cold shutdown to hot shutdown. Ukraine's Energoatom stated on 10 June that unit 5 must be put into 'cold shutdown' following the blowing of the Kakhovka dam as a safety precaution. However, the adviser to the director general of Rosenergoatom has since said that Ukrainian demands to place the final reactor in cold shutdown 'cannot be justified'. Other Russian and Ukrainian sources indicate that the Russian authorities are refusing to do so. If reactor four is placed in hot shutdown, which remains likely, this will remain the most vulnerable to an escalation and could generate limited radiation in the event of a major safety incident or deliberate attempt to trigger a meltdown.

While reactor five remains under hot shutdown currently, the fact that the remaining reactors have been in cold shutdown is one of the key distinctions between ZNPP and Fukushima. The latter's reactors were in full operation right up until the earthquake which triggered the radiation leak. Whereas, with the exception of unit 5, Zaporizhzhia's reactors have had months to cool and for pressure to reduce, significantly reducing the presence of numerous radioactive isotopes.

Due to key distinctions with the Chernobyl disaster, the health risks of a radiation leak will be limited

Iodine-131 is amongst the most dangerous radioactive material that could be released during an incident at a nuclear power plant. However, because Zaporizhzhia's reactors have been in cold shutdown for months, the vast majority of the Iodine-131 has completely decayed, and as such poses a significantly lower risk. Iodine-131 has a half life of just eight days, meaning it decays by half every eight days. After around 80 days, the Iodine-131 has completely decayed, posing no significant health risk.

Nevertheless, Caesium-137 remains a highly dangerous radioactive isotope which has been released during other nuclear incidents, including Fukushima, but with a much longer half-life (30 years). Given its half life, it is more likely that airborne Caesium-137 reaches areas outside of Ukraine after a major incident. However, even during the Chernobyl disaster, where large amounts of Caesium-137 were released, there was limited evidence to indicate that it caused widespread health problems across Europe. A release of Caesium-137 would therefore most likely pose the most acute threat to individuals in the immediate vicinity of the plant.

The most serious health risk in the event of a major radiation leak will be thyroid cancer in young people. However, this will depend on the quantity and length of exposure to radioactive isotopes and is ultimately highly unlikely to seriously impact individuals far from the ZNPP site, even in scenario 4.

Evidence following the Chernobyl disaster indicates that exposure to high quantities of shorter-lived Iodine isotopes resulted in a higher likelihood of thyroid cancer developing in young people. However, as discussed above, the vast majority of short-lived isotopes, including Iodine-131, have already decayed in the ZNPP. According to Professor Geraldine Thomas, Professor of Molecular Pathology at Imperial College London, there is also no evidence that longer-lasting Caesium-137 has played a role in individuals developing thyroid cancer, though high doses of Caesium-137 likely increase the risk of pancreatic tumours and cancers. Nevertheless, the overall quantities of the radiation released are likely to be limited, and only seriously impacting those in the immediate vicinity of the plant, with much reduced risks for those further afield.

Mitigation measures

In the event of a major nuclear incident or escalation, there is little individual organisations can do to mitigate the risk or respond during a nation- or region-wide civil emergency. Nevertheless, there are various steps organisations can take to mitigate the risk to their staff:

- Iodine or Potassium Iodide (KI) tablets help protect the thyroid from radioactive iodine if taken in advance of any radiation exposure following a nuclear incident. This is known as Iodine Thyroid Blocking (ITB). Generally, only those under the age of 40 are encouraged to take an iodine pill, due to the higher risk of developing thyroid cancer. In April 2022 the EU set up a joint reserve of 20 million iodine pills for the EU population and partner countries, including Ukraine. An uptick in iodine sales has been reported in numerous European countries since Russia's full-scale invasion of Ukraine, but despite some likely stockpiling and distribution campaigns across Europe since 2022, iodine shortages will be extremely likely in the run-up to and immediate after a nuclear escalation.

- While potassium iodide provides a special kind of protection in the event of a nuclear accident, the United States Nuclear Regulatory Commission (USNRC) stresses that evacuation is the most protective measure in case of a radiological or nuclear emergency. Successful evacuation protects the entire body from all radionuclides and exposure pathways. Administering iodine is considered a supplement to and not replacement for sheltering and evacuation. However, even if a major incident was to occur at the ZNPP, the need to administer KI tablets to staff operating outside of Ukraine will likely be very low, as the radiation levels that reach other jurisdictions will likely be low.
- Nevertheless, in the immediate aftermath of a major nuclear incident in Ukraine, working from home and/or a shelter remains something to consider, depending on proximity to the fallout zone, level of radiation released and wind direction. Staff operating inside Ukraine or nearer the site will likely be under government directed advice to remain in place or relocate. The Ukrainian government has already developed large-scale evacuation plans for the oblasts nearest to the ZNPP.
- Given that the radiation released during an incident will likely be limited, amongst the most serious risks to business continuity elsewhere in Europe will be second-order impacts triggered by panic and mis/disinformation campaigns. Pre-emptively preparing staff for mis/disinformation campaigning and educational workshops and transparent emergency planning could be used to assuage staff concerns. Panic could result in staff requests for evacuation of regions bordering ZNPP and Ukraine, even if the risk of radiation exposure is very low in those areas, such as in the event of a dirty bomb attack.

Emergency response assessment

- The Ukrainian Health Ministry has issued recommendations in the case of a nuclear incident at ZNPP. The recommendations offer practical guidelines to follow in case of a major radiation release.
- On 29 June, Ukraine's Ministry of Interior reported that authorities of Zaporizhzhia, Dnipropetrovsk and Kherson oblasts launched a large-scale exercise in preparation for a nuclear incident at the ZNPP. Involving 8,000 people, including local authorities, law enforcement, volunteers and medical staff, the exercises simulated evacuations with 350 vehicles and 400 evacuation buses and involved training with radiation measuring equipment. Simulation exercises also took place in Kyiv and other major urban centres.
- In August 2022, the EU donated 5 million potassium iodide tablets to protect Ukrainians from potential radiation exposure. In October 2022, Kyiv municipality distributed potassium pills to evacuation centres in preparation for a potential Russian nuclear strike on Ukraine. In June 2023, KI tablets were distributed to residents living near the ZNPP, with the Ministry of Health also reportedly preparing nationwide stockpiles of these tablets.
- Air Alert is a smartphone application supported by the Ukrainian Ministry of Digital Transformation. The application generates a loud, critical alert warning of an airstrike, chemical attack, radiation hazards, or other civil defence alerts. The application receives information from regional administrations and instantly informs residents at the beginning and end of an alert. Such an alert will likely sound in the event of a nuclear incident at the ZNPP.
- Shelters have been constructed across Ukraine. However, a government-led inspection in June found that around a quarter of Kyiv's 4,800 shelters were unavailable or unfit to protect civilians. The investigation was initiated after a Russian strike killed people after unsuccessfully trying to enter a shelter in a medical facility. Shortages and availability of shelters remains a nationwide problem, and in the immediate aftermath of a major incident, panic will likely exacerbate these issues.

Second order impacts of a nuclear incident at the ZNPP

- **Infrastructure**: The direct impact on Ukrainian energy infrastructure will likely remain very limited given that the ZNPP has been disconnected from the Ukrainian electricity grid for many months. It is in cold shutdown and has not produced electricity for the grid since 2022, meaning that in the event of a nuclear incident, Ukraine's overall power production capability will remain unchanged.
- **Borders and travel**: Even a small-scale nuclear incident is highly likely to disrupt travel across the wider region, with border closures a distinct possibility if panic sets in and Ukrainian refugees begin leaving the country en masse. Airspace closures also remain likely in the event of a major incident. Panic will likely mean demand for flights, trains and other forms of public transport in and out of the region will skyrocket, leading to serious disruptions for any evacuation plans.
- **Security and conflict risks**: Given that our most likely scenarios remain focused on a limited radiological release, it is unlikely to trigger a major deterioration in the overall security, civil unrest, civil conflict and terrorism landscape. However, in the event of a Russian deliberately triggering a catastrophic meltdown that irradiates large areas of Ukraine, threatening Europe (not to mention Russia itself), the risk of NATO intervention in the Russo-Ukrainian war will increase. NATO is understood to have made it clear to Moscow that any use of nuclear weapons would risk triggered an overwhelming conventional military response from a US-led coalition of the willing, likely aimed at destroying Russia's conventional military capability inside Ukraine and destroying the Black Sea Fleet. While none of the scenarios above involve the use of a nuclear weapon, the weaponisation of the ZNPP would likely test this red line, particularly if radiation leaks threaten eastern Europe. Such an intervention would risk a catastrophic escalation trap that neither side could be confident of being able to control, increasing the risk of miscalculation or desperation triggering a nuclear exchange. However, this is a remote chance and would be contingent upon myriad other factors and triggers, making this extremely unlikely.

Remote chance	Highly unlikely	Unlikely	Realistic possibility	Likely or probable	Highly likely	Almost certain
0-5%	10-20%	25-35%	40-50%	55-75%	80-90%	95-100%

Email: info@sibylline.co.uk
Tel: +44 203 411 0697

SIBYLLINE