Risk of unprecedented nuclear disaster if Russia's attacks on Ukraine's electricity system continue

Executive Summary

As a result of Russia's deliberate attacks on Ukraine's energy system, Ukraine is on the edge of a nuclear crisis, unprecedented in the history of nuclear power. If Russian attacks continue on the electricity system, there is a very real prospect of simultaneous and multiple emergency failures at Ukraine's nuclear reactors with the release of catastrophic levels of radioactivity from the reactor cores and spent fuel pools. The most vulnerable reactors are those at the three power plants currently generating electricity. The immediate impact would be on the people and the environment of Ukraine, but there is the potential for much of Europe and beyond to be severely impacted by radioactive contamination.

In the worst-case scenario each of the existing thirty large sources of radioactivity in Ukraine could lead to radiological consequences beyond the total release from Fukushima Daiichi and even the disaster in Chornobyl and its radiological impact.

Since the start of Russia's full scale invasion of Ukraine, Russia's military strikes have been targeting Ukraine's electricity system, including its generation capacity and electricity substations. As a direct consequence, Ukraine's national grid is now severely damaged and the largest part of its generation capacity has been incapacitated.

Not a single national nuclear power program in the world has been designed to cope with the scale of disruption the full-scale Russian war has inflicted on the territory of Ukraine. There is currently no existing safety analysis available for nuclear regulators worldwide that considers such a scale of a crisis Russia's deliberate attacks have caused in the national electricity system of Ukraine and its consequences for nuclear power plant safety.

What is the current state of energy infrastructure in Ukraine?

Due to Russian's deliberate attacks on Ukraine's energy infrastructure since 2022, Ukraine's electricity system is now severely weakened and fragile. By summer 2024, Russia had destroyed as much as 90-95 percent of thermal power plants and 40 percent of hydroelectric power plants that functioned in Ukraine.[1]

Ukraine is currently generating electricity (operating at power) from three nuclear power plants with a total of nine nuclear reactors. Four at Rivne, near Varash, Rivne Oblast; two at Khmelnytskyi, Khmelnytskyi Oblast; and three at South Ukraine Nuclear Plant in Mykolaiv Oblast.

[1] Forbes Ukraine, The IAEA will monitor key Ukrainian substations for the first time, Anastasia Dayna, 13 September 2024, see https://forbes.ua/company/magate-vpershe-bude-monitoriti-ukrainski-klyuchovi-pidstantsii-chi-zakhistit-tse-ikh-vid-obstriliv-rf-a-krainu-vid-totalnogo-blekautu-13092024-23608

These three nuclear power plants currently generate the majority of the electricity of Ukraine.[2] The six reactors at Zaporizhzhia, which remain under illegal Russian military and Rosatom (Russian State Nuclear Corporation) occupation, have been shut-down since September 2022.

What is causing unprecedented risk now in Ukraine's energy system?

Recent reports from the President and Foreign Minister of Ukraine have raised the spectre of further escalation of Russian strikes against Ukraine's electricity infrastructure, and in particular the electrical sub stations and nuclear reactor switchyards.[3]

Sub stations serve as transmitters of electricity and are vital to maintain the functioning of Ukraine's energy network. In addition, they are also vital to maintain the operation of Ukraine's nuclear reactors.

Attacks on Ukraine's electric power grid pose major safety challenges to operating nuclear power plants due to the rapid transients they cause in the offsite power supply. These transients are characterised by sudden and severe fluctuations in power supply, requiring immediate and accurate response from reactor operators.

The potential loss of the substations, in particular those directly associated with Ukraine's nuclear plants, can cause emergency shutdowns of multiple reactors. If, due to Russian military strikes, the electrical grid collapses, the electrical supply cannot be maintained for cooling of reactors and spent fuel pools, as well as for running the vital safety systems. This can dramatically increase the risk of reactors' core damage, resulting in nuclear fuel meltdown and multiple failures across Ukraine's reactor fleet, including multiple and cascading reactor unit failures. For the nine reactors currently generating electricity, the time frame from first loss of electric power and cooling function of the reactor core fuel to fast progression to severe fuel core damage is measured in hours.

Why does Ukraine's damaged electricity grid mean a high risk for a potential nuclear disaster?

For the safety of nuclear power plants (NPP), stability of the electricity supply needs to be guaranteed. The offsite grid plays a key role. The NPPs are connected to the grid through several electricity lines. When there is an imbalance between electricity generation and load, grid frequency tends to become lower caused by the trip of a major generator or a fault in a substation. When the frequency is too low, the grid operator would first call for more generation to start up. However, this is highly challenging in the current Ukrainian context.

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[2] Kateryna Hodunova, Russia has destroyed all thermal power plants, nearly all hydroelectric capacity in Ukraine ahead of winter, Zelensky says, Kyiv Independen, 25 September 2024, see https://kyivindependent.com/russia-destroys-all-thermal-power-plants-nearly-all-hydroelectric-capacity-in-ukraine-ahead-of-winter-zelensky-says/#:~:text=According%20to%20the%20Energy%20Ministry%2C%20nuclear%20generation%20currently%20accounts%20for,Russian%20occupation%20since%20March%202022

[3] Office of the President of Ukraine, There Can Be No Just Peace Without Ukraine - Speech of the President at the UN General Assembly, 25 September 2024, see https://www.president.gov.ua/en/news/ne-mozhe-buti-spravedlivogo-miru-bez-ukrayini-vistup-prezide-93493l; and, UKRINFORM, Russia preparing strikes on Ukraine's critical nuclear energy facilities – MFA, 23 September 2024, see https://www.ukrinform.net/rubric-ato/3908093-russia-preparing-strikes-on-ukraines-critical-nuclear-energy-facilities-mfa.html

As a next step, load-shedding would take place. This means parts of the grid are switched off in order to lower the demand. A first problem with a degraded grid, even without a Loss of Offsite Power (LOOP) is that the pumps that circulate the cooling water in a nuclear reactor rely on stable electric power. A degraded grid cannot provide that stability. If the grid voltage and frequency are not sufficient, motors cannot develop sufficient motor torque to continue operation or start, and the electric system shuts them down.[4]

If one or several NPPs trip, and/or key substations have been damaged or destroyed by Russian military strikes, this could push voltage and frequency beyond the margins, with no additional generation capacity available. This can then lead to other generation capacity to trip, leading to a cascade and a system-wide blackout. This could result in all four nuclear plants in Ukraine losing their offsite power from the grid, a so-called Loss of Offsite Power (LOOP) situation.

The risks of a Station Black-Out (SBO)

When nuclear power plants (NPP) loses theirs offsite power from the grid, a Loss of Offsite Power (LOOP) event occurs. The power plant falls back to three main power sources to maintain its critical safety systems: batteries, back-up diesel generators, and the possibility to trip one reactor at the plant to house load.

If even onsite power generation fails, the plant enters Station Blackout (SBO). In the case of an operational nuclear power plant, this can lead to the boiling of the cooling water in the reactor vessel in a matter of hours, which can result in core damage and release of radiation within the reactor containment building, and further into the environment due to overpressure within the containment.

Major difficulties to recover from a black-out (Black Start)

A black start (or black-out recovery) is the complex process to restart the electric power system from a black-out. This process is to be coordinated by the TSO (Ukrenergo) in Ukraine and requires a sufficient number of power plants with black start capability, such as Battery Energy Storage Systems (BESS), diesel generators, hydro-electric plants and thermal plants. BESS can be combined with variable renewable sources such as wind and solar.

Nuclear power plants are not capable of a black start and are thus dependent on those other sources[5]. This is particularly problematic in the Ukrainian context of today, because most of the hydro and fossil generation capacity has been incapacitated by the Russian aggression, and Ukraine does not have (yet) a significant BESS capacity.

What are the potential consequences of a Station Black-Out in Ukraine?

Calculating both for shut down and operational reactors, below are some of the potential radiological consequences that can occur in the case of a Station Black-Out in Ukraine:.[6]

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[4] http://large.stanford.edu/courses/2016/ph241/yang2/docs/bickel.pdf

[5] IAEA, Electric Grid Reliability and Interface with Nuclear Power Plants, 2012: https://www-pub.iaea.org/MTCD/publications/PDF/Pub1542_web.pdf

[6] Greenpeace International, The vulnerability of nuclear plants during military conflict Lessons from Fukushima Daiichi Focus on Zaporizhzhia, Ukraine, 2 March 2022, see

- Each reactor building has both a reactor core and a spent fuel pool.[7] This means that for a total of fifteen reactors apart from other installations, there are 30 large sources of highly radioactive nuclear fuel.
- In the case of one nuclear reactor event, atmospheric modelling simulations show that the highest risk for high level of contamination (>1000kBq/m2 of Cs-137, requiring relocation of populations to reduce radiation exposure) would be within a radius of a few hundred kms, thus mostly in Ukraine itself but also in neighbouring countries. A lower level of contamination, still requiring protective measures (between 128-1000 kBq/m2 of Cs-137), would affect the entire European territory. These are models for single reactor events, not for the cascading effects of multiple reactor events which are possible under current conditions.
- There are no public models that show the radiological releases and dispersal from multiple nuclear reactor units at multiple nuclear power plants.

With a long-duration grid blackout, there would be a risk of core damage at multiple power plants. At each power plant, there could be cascading consequences, when one large-scale release of one reactor could lead to loss of control at adjacent reactors leading to further releases.

Possible sequence of events leading to core damage:

Phase 1: collapse of the grid

- Damage to one or several main substations.
- Critical disturbance in the grid, beyond the criteria for frequency or voltage.
- Loss of Offsite Power (LOOP) for one or several NPPs.
- Reactor scram; electricity at the plant required for safety systems is provided by onsite diesel generators, batteries and/or trip to house load by 1 reactor at minimal power.
- Due to loss of generation capacity of one or several nuclear power plants, the limited remaining generation capacity in the grid cannot compensate causing a general black-out.

Phase 2: not possible to re-start the grid (black start)

- It is impossible to black start the grid, because most hydro and fossil plants are damaged and nuclear power plants do not have a black-start capability. This leads to a prolonged black-out.
- Diesel generators run out of fuel or malfunction, houseload production at the NPP fails.
- Nuclear power plant Station Black-Out (SBO), all safety functions at the NPP stop.
- Reactor core damage and large-scale release of radioactivity.

What is the state of nuclear safety in Ukraine now?

www.greenpeace.org/static/planet4-international-stateless/2022/03/6805cdd2-nuclear-power-plant-vulnerability-during-military-conflict-ukraine-technical-briefi

[7] The VVER 1000 reactor spent fuel pools are inside the reactor building containment; the two VVER-440 reactors in Ukraine have their spent fuel pools in the reactor building but outside the containment.

The entire nuclear safety analysis for Ukraine (and all nations) is designed and planned with some redundancy in the electric grid taken into account the so called 'N-1 standard', which ensures that the system is secure against any one single event[8].

However, not a single national nuclear power program in the world has been designed to cope with the scale of disruption the full-scale Russian war has inflicted on the territory of Ukraine. There is currently no existing safety analysis available for nuclear regulators worldwide that considers such a scale of a crisis Russia's deliberate attacks have caused in the national electricity system of Ukraine and its consequences for nuclear power plant safety.

Although the precise vulnerabilities and status of the Ukrainian grid caused by Russian military strikes is confidential, it is known that the reliability criteria that should apply to the operation of nuclear power plants are not met, such as the N-1 criteria. A further major disturbance in an already fragile grid could lead to a cascading black-out of the entire system, and thus put all four Ukrainian nuclear power plants in a LOOP (including the Zaporyzhzia NPP which is already shutdown but still connected to the Ukraine grid).

What are the social impacts of Russia's attack on Ukraine's energy system?

As the United Nations Human Rights Monitoring Mission in Ukraine (HRMMU), recently reported, " Russian attacks on Ukraine's electric power system, damaging or destroying numerous power generation, transmission, and distribution facilities have had reverberating effects causing harm to the civilian population and the country's electricity supply, water distribution, sewage and sanitation systems, heating and hot water, public health, education, and the economy."[9] The United Nations Independent International Commission of Inquiry on Ukraine has also already concluded that Russian attacks on electricity infrastructure in 2022-2023 were widespread, systematic, and disproportionate, constituting the war crime of excessive incidental civilian harm and potentially a crime against humanity.[10]

Even without a nuclear disaster, people of Ukraine this winter would face extremely severe conditions with expected prolonged power cuts and lack of access to heating. Under war conditions, Ukrainian government authorities, energy companies, and humanitarian and recovery agencies are engaged in immense mitigation efforts to avert a humanitarian crisis this winter.[11]

Further Russian attacks could lead to the further loss of grid capacity and nation-wide blackout, a potential cascading crisis at multi reactor units and at multiple nuclear plants, and, finally, to major radiological releases. The terrible consequences the Ukrainian population would have to face are impossible to comprehend.

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[8] IAEA, Electric Grid Reliability and Interface with Nuclear Power Plants, 2012: https://www-pub.iaea.org/MTCD/publications/PDF/Pub1542_web.pdf

[9] OHCHR, Attacks on Ukraine's Energy Infrastructure: Harm to the Civilian Population UN Human Rights Monitoring Mission in Ukraine, September 2024, see https://ukraine.ohchr.org/sites/default/files/2024-09/ENG%20Attacks%20on%20Ukraine's%20Energy%20Infrastructure-%20%20Harm%20to%20the%20Civilian%20Population.pdf

[10] Report of the Independent International Commission of Inquiry on Ukraine, A/HRC/52/62 (hereinafter: A/HRC/52/62), 16 March 2023, available at: https:// www.ohchr.org/en/hr-bodies/hrc/iicihr-ukraine/index.

[11] OHCHR, 2024.

What Greenpeace sees as a solution to prevent a nuclear disaster?

In order to reduce the risk of an unprecedented nuclear disaster, Russia must immediately stop all attacks on the fragile electricity system of Ukraine, not only on the most critical substations, but also its remaining operational generation capacity.

The international community, including the International Atomic Energy Agency (IAEA), must put pressure on Russia to stop its irresponsible war crimes against the people, the environment and Ukraine's energy infrastructure.

In addition, the IAEA needs to play a particularly crucial role. According to the State Nuclear Regulatory Inspectorate of Ukraine (SNRIU), the International Atomic Energy Agency (IAEA) had agreed to a request to expand its permanent monitoring mission in Ukraine to cover electrical substations.[12] This expanded mission would mean IAEA inspectors are assigned to Ukraine's substations specific to all nuclear power plants. However, if this mission is to be effective in protecting critical energy infrastructure and to prevent Russian attacks, it must be undertaken immediately and comprehensively. Greenpeace International is urging the IAEA Director General in its letter sent on 30 September 2024 to do this.

Recommended actions

- Russia must immediately stop further attacks on the electricity system of Ukraine, and not only the nuclear plants and the most critical substations;
- The international community needs to apply all possible pressure on Russia to stop the attacks;
- The IAEA, with the full support of member states, must immediately implement its expanded mission in Ukraine to deploy inspectors to critical electricity infrastructure, specifically substations essential for nuclear power plant operation, and thus act as a deterrent to further Russian military attacks;
- Extend and apply faster international support to rebuild Ukraine's damaged energy infrastructure and to protect it;
- Increase further the import capacity through the ENTSO-E grid interconnections to Ukraine;
- On electricity demand side – expand energy efficiency measures and smart metres and extend and apply demand-side management;
- On electricity generation – further decentralisation, industrial-scale Battery Energy Storage Systems to be combined with solar PV and wind power to make Ukraine less vulnerable to attacks

[12] SNRIU, Oleh Korikov: IAEA will expand its presence in Ukraine - substations important for NPP safety will be monitored by permanent missions, 6 September 2024, see https://snriu.gov.ua/en/news/oleh-korikov-iaea-will-expand-its-presence-in-ukraine-substations-important-for-npp-safety-will-be-monitored-by-permanent-missions