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INSIGHT

Russian Military Actions at Ukraine's Nuclear Power Plants

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Russia's military occupation of Ukraine's six-reactor Zaporizhzhia nuclear power plant (ZNPP)—the largest in Europe—has raised widespread alarm about potential damage to the plant that could cause large radioactive releases to the environment. Russian forces captured the plant on March 4, 2022, with reported "heavy fighting and artillery shelling." Since September 2022, an International Atomic Energy Agency (IAEA) expert team at the plant has been assessing safety conditions. The United States has called on Russia to "withdraw its military and civilian personnel from the plant" and "return full control of the plant to the competent Ukrainian authorities."

Multiple drone strikes on the plant on April 7, 2024—including the containment dome roof of one of the reactors—constituted "a major escalation of the nuclear safety and security dangers," according to IAEA Director General Rafael Mariano Grossi. The IAEA team found no damage to the plant's critical safety systems. The IAEA Board of Governors held a special session on April 11 to discuss potential dangers, and the UN Security Council scheduled a similar meeting for April 15. IAEA experts at the ZNPP have not been given access to all areas of the site.

Since August 2022, military action in region has severed all off-site power to the Zaporizhzhia plant eight times, according to the IAEA. Whenever offsite power is lost, the plant's emergency diesel generators are activated to provide electricity for reactor cooling systems. The plant's six reactors have been shut down since September 2022. However, decay heat from the reactors' nuclear fuel must be continuously removed to prevent overheating and radioactive releases.

Military actions have affected the cooling water supply for the plant. Since Russian forces destroyed the Kakhovka Reservoir dam in 2023, replacement groundwater wells supply cooling water to the plant. Ukraine's top nuclear regulatory official said that lack of maintenance and repairs over two years of occupation has led to a "significant degradation of nuclear and radiation safety and lack of emergency response capability."

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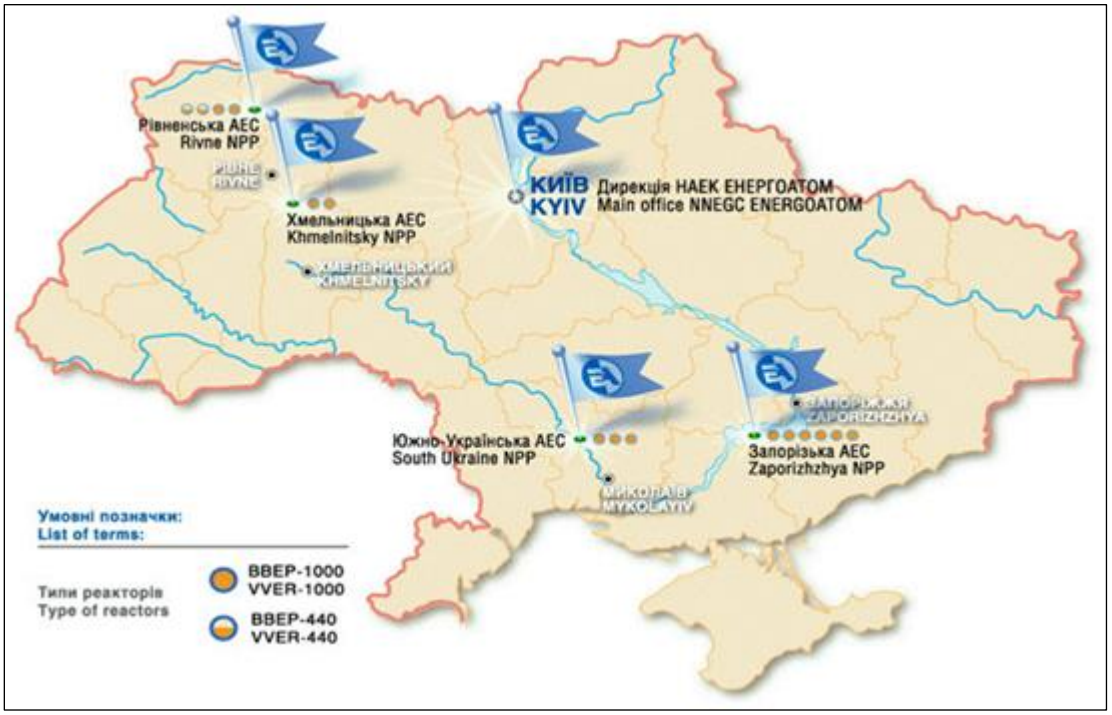
Nuclear Power Plants Operating in Ukraine

Ukraine has four operating nuclear power plant sites with a total of 15 reactors, which in recent years have provided about half of Ukraine's total electricity generation. All the operating Ukrainian reactors are light water reactors (cooled by ordinary water), using designs similar in concept to most of the world's commercial nuclear power reactors. Ukraine's operating nuclear plants are located throughout the country, as shown by the following IAEA map:



Source: IAEA, 2020

The operable Ukrainian reactors are fundamentally different from those at the Chernobyl plant, which suffered a major explosion in 1986. The four-unit Chernobyl nuclear plant, whose last operating reactor permanently closed in 2000, was occupied on the first day of the Russian invasion of Ukraine, on February 24, 2022. Russian troops left the plant by April 1 as part of a general withdrawal from northern Ukraine.

Reactor Safety Systems

The core of a light water reactor consists of about 100 tons of highly radioactive nuclear fuel producing tremendous heat through a nuclear chain reaction. Control rods in the reactor core slow or shut down the chain reaction. Although shutdown happens very quickly during an emergency, substantial amounts of heat continue to be produced from radioactive decay of the nuclear materials in the reactor core after the chain reaction stops. If water does not continue to circulate through the core, decay heat can build up enough to melt the nuclear fuel and breach the steel pressure vessel that holds the core. The heat and pressure could also eventually escape the concrete containment structure that surrounds the pressure vessel and associated pumps and piping.

Any reactors that were to continue operating at ZNPP would pose the highest risk of radioactive releases at the site, because of the heat produced by their nuclear chain reactions. The current shutdown of all the

plant's reactors has reduced that risk. When a reactor is shut down, the nuclear chain reaction stops and no longer generates heat, immediately reducing the reactor's total heat output by about 94%. The remaining 6% of the heat comes from the radioactive decay of nuclear materials in the reactor core. As the reactor core cools because of falling radioactivity (with heat output dropping by 99.5% after one day), there is less decay heat that must be removed by plant cooling systems. Reactor operators could further reduce the risk of overheating by transferring nuclear fuel from the plant's six reactors into adjoining storage pools, which would continue to cool the fuel.

Reactor Safety Risks from Russian Attacks

The ongoing Russian military action poses a range of potential threats to Ukrainian nuclear plant safety:

- *Direct military damage to one or more reactors*. Nuclear power plants are not designed to withstand military munitions, which could directly penetrate the concrete reactor containment and steel pressure vessel, allowing release of highly radioactive material.
- *Military damage to reactor safety systems*. Explosions and fires resulting from a military attack could disable safety systems vital to avoiding core overheating.
- *Station blackout: loss of electric power*. Nuclear plants rely on electricity to run cooling pumps and control systems. If power from the electric grid is lost, diesel generators produce backup power and are intended to operate long enough for grid power to be restored. Loss of power from both the grid and the diesel generators results in station blackout.
- *Disruption of plant personnel*. Plant safety could be at risk if military action hindered or blocked the hundreds of workers needed to operate, maintain, and manage a nuclear power plant.
- *Damage to spent fuel pool or cooling systems*. If damage to a spent fuel pool allowed its water to drain, or if the pool's cooling systems were disabled, the spent fuel could overheat and release large amounts of radioactive material to the environment.

Author Information

Mark Holt
Specialist in Energy Policy

Mary Beth D. Nikitin
Specialist in Nonproliferation

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