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INSIGHT

Russian Military Actions at Ukraine's Nuclear Power Plants

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Russia's ongoing military occupation of Ukraine's six-reactor Zaporizhzhia nuclear power plant (ZNPP)—the largest in Europe—has raised widespread alarm about the potential for damage to the plant that could cause large radioactive releases to the environment. Russian forces attacked and captured the plant on March 4, 2022, with reported "heavy fighting and artillery shelling."

Shelling around the plant resumed on August 5, 2022, prompting the International Atomic Energy Agency (IAEA) to warn, "Any military firepower directed at or from the facility would amount to playing with fire, with potentially catastrophic consequences." Continued shelling during August and September 2022 repeatedly disabled the plant's connections to the surrounding power grid. The loss of offsite power forced the two reactors that had been operating since the initial Russian takeover to shut down and then restart when power lines were repaired. According to IAEA's September 7 status report, the plant is currently disconnected from the grid, and one reactor is operating to provide on-site power.

After months of negotiation, an IAEA expert team arrived at ZNPP on September 1, 2022, to assess the conditions at the plant. IAEA's report on the mission, issued September 5, 2022, described extensive damage to plant facilities and surrounding infrastructure from repeated shelling. The report warned that continued military action "represented a constant threat to nuclear safety and security because critical safety functions (containment of the radioactivity and cooling in particular) could be impacted." The report called for "establishment of a nuclear safety and security protection zone around the ZNPP." It also noted that the plant's operating staff is "subject to constant high stress and pressure" which "could lead to increased human error with implications on nuclear safety." Russian forces have seized control of ZNPP and its management, but the plant's operational personnel have remained on duty. IAEA experts will remain at the plant to monitor safety conditions.

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 from the Soviet Union similar in concept to

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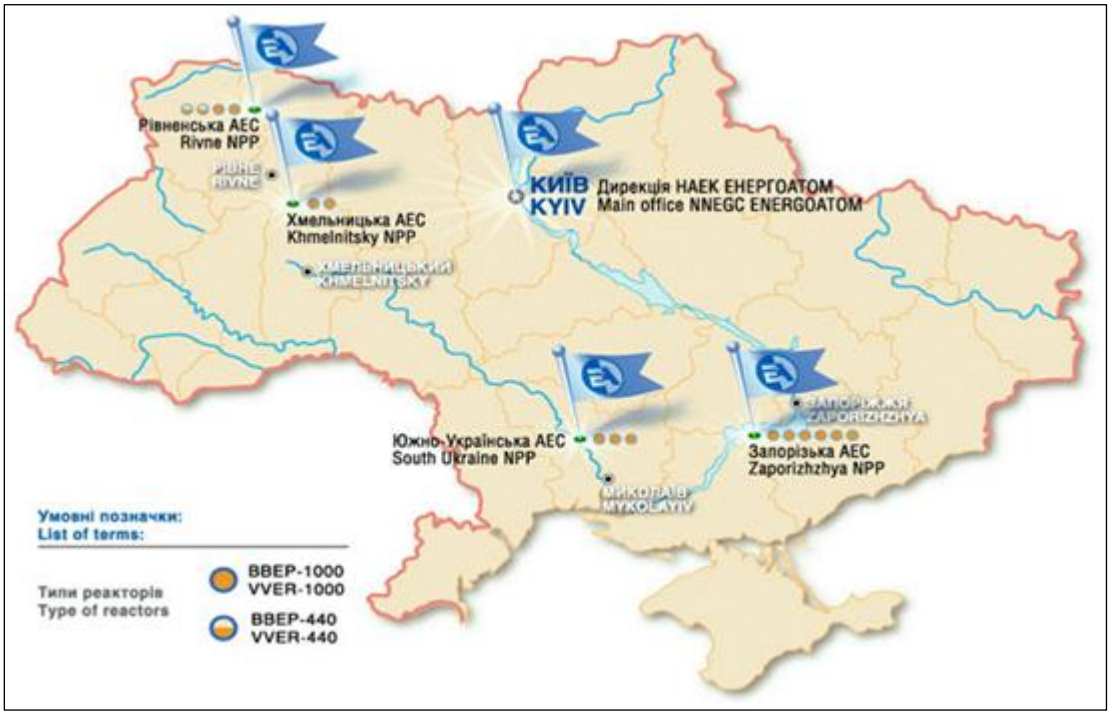
most of the world's commercial power reactors. Ukraine's operating nuclear plants are located throughout the country, as shown by the following IAEA map:



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. To slow or shut down the chain reaction, control rods are inserted into the reactor core. 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. This occurred during the Fukushima Daiichi accident in Japan at reactors built with a different type of containment from those in Ukraine.

Any reactors continuing to operate at ZNPP are said to pose the highest risk of radioactive releases at the site, because the nuclear chain reaction in the reactor core produces heat, pressure, and radioactive materials. Shutting down all the reactors at the plant—by halting the chain reactions—would reduce that risk. When a reactor is shut down, its heat output immediately drops by about 94%, with the remaining heat continuing to be produced by the radioactive decay of nuclear materials in the reactor core. As the

reactor core cools while radioactivity decreases, it becomes less vulnerable to disruptions in plant cooling systems. Decay heat, even at reduced levels, must be constantly removed from the reactor core to prevent the nuclear fuel from melting. Such risks could be further reduced by transferring nuclear fuel from the plant's six reactors into adjoining storage pools, although they still must be constantly cooled, such as by adding water.

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*. Even if a military attack did not damage the reactor containment, explosions and fires 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, the condition that caused the radioactive releases at Fukushima, even though the reactors there had shut down.
- *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 its cooling systems were disabled, the spent fuel could overheat and release large amounts of radioactive material to the environment.

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