Federal Ministry
Republic of Austria
Climate Action, Environment,
Energy, Mobility,
Innovation and Technology

Nuclear Power and War

No civil nuclear power plant in the world has been designed to operate during a war. Nuclear safety and security depend on compliance with a complex set of rules and regulations, continuous inspections and maintenance, as well as a skilled workforce to carry out these tasks. None of this is guaranteed in Ukraine since Russia unleashed full-scale war on a country with 15 power reactors.

Vulnerabilities of Reactors and Spent Fuel Pools

Operation of each nuclear power must always ensure control of criticality, sufficient cooling and containment integrity for all radioactive material.

Nuclear reactors operate on the principle of controlled nuclear fission. When a reactor starts up, it “goes critical” and fission reactions start generating heat. Criticality must be always under control, either by so-called control rods that can be inserted into the reactor core or by chemical means, e.g. borated water that absorbs neutrons and can slow down the fission process. The process is taking place in most reactor types in a pressure vessel. As the nuclear reactions create a very high level of radioactivity, it is of utmost importance that the biosphere is always protected from any leaks. The first barrier is the form of fuel in stable pellets, the second barrier to environmental release is the fuel cladding, the third is the pressure vessel and the pipes of the primary cooling circuit, and the forth a steel-reinforced concrete containment.

The safety of a nuclear power plant is heavily depending on continuously functioning cooling systems to remove decay heat from reactor core and spent fuel (SF) pool, even when the reactor is shut down. Immediately after shutdown, a reactor core still generates about seven percent of the nominal thermal power. Decay heat decreases with time, first rapidly, then slowly. After one day residual heat is at about 0.5 percent (considerable 15 megawatt thermal (MWth) in the case of a typical 1,000 megawatt electric (MWe) reactor corresponding to 3,000 MWth) and still half of that after ten days.

The cooling requirement is not limited to the fuel in the core. Once the fuel is spent, it is unloaded from the reactor core and placed in a pool filled with water. Spent fuel transfer has to be performed continuously covered with cooling water for the first three years after removal from an operated reactor core to avoid immediate melting due to residual heat. As is the case when the fuel is in the reactor pressure vessel, the residual heat must be permanently removed from the pool in order to prevent the fuel from overheating. Failure to cool the fuel in the core can lead to a meltdown accident within about an hour. Spent fuel pool cooling-failure can lead to the evaporation of the cooling water. Spent fuel uncovered by water overheats which can cause the fuel to melt and to the release of radioisotopes. In addition, the possible chemical interaction of hot fuel cladding with steam can lead to hydrogen explosions within the spent fuel pool building causing its destruction entailing large releases of radioactivity into the environment. The grace time prior to fuel damage depends on the cooling period prior to the event, the fuel burn-up, water reservoir in SF-pool and population with SF elements and can reach from days to months.

Thus, effective cooling chains must be maintained *at all times* to remove residual heat from the reactor core and from the spent fuel pool.

In addition to the immediate technical challenges for nuclear safety in heavily armed conflicts, legal and organisational problems are created due to the enforcement of martial law which limits the capacity and authority of regulators and operators, including due to the lack of human resources.

Power Supply and Collateral Damage in War Times

Some countries heavily rely on nuclear power. In 2023, nine countries generated over one third of their electricity from nuclear plants[1], all of them in Europe. Two countries, France and Slovakia, generated more than half of their power from nuclear fission. The higher the nuclear share, the more difficult it becomes to shut down all reactors as a precautionary measure in case of war.

[1] This includes Ukraine. Ukrainian authorities have not released production data since 2021 when the nuclear share was 55 percent. However, it is likely that the share exceeded one third in 2023.

The attacker might want to disrupt the power supply of the attacked country in the short term but might also wish to maintain power supply in the longer term in case the objective is the occupation of attacked territories. The attacker could also use the threat of destruction as blackmail since the country hosting the nuclear facilities has an obvious interest in preserving public health and the environment.

Regardless of whether there is a military rationale to occupy, recapture, or destroy a nuclear power plant site, there can be multiple unintended causes of impact on nuclear safety and security:

- Accidental hits due to limited accuracy of weapon systems.
- Collateral damage during a military campaign.
- Limited knowledge of combatants of safety relevance of parts of a nuclear plant.
- Nuclear safety will likely not be a priority in a life-or-death combat situation.
- The power plant site can be used as a shield and turned into an impregnable fortress.

Specific Vulnerabilities of Nuclear Power Plants

Nuclear power plants are complex industrial facilities. Their safe operation depends on a stable technical, human, regulatory, political, and economic environment. Previous research on nuclear safety has taken these stable conditions for granted. However, war conditions expose vulnerabilities in a very different manner:

- Many important safety systems are located in traditional, non-bunkered industrial buildings including parts of the vital cooling chains, large parts of the power supply, transformers, diesel generators for emergency power, generator fuel, switchgear, and the control room.
- A stable connection to the power grid is the most important requirement for electricity supply. That is not currently guaranteed in Ukraine. The Zaporizhzhya nuclear power plant site with six reactors, occupied by the Russian military since March 2022, has been cut off from external power supply multiple times.
- In the case of grid loss, emergency generators can supply the minimum power required to maintain the cooling systems operational for a short time (e.g. a few days), but they are not designed for to operate for longer periods of time.

- As a shutdown nuclear power reactor cannot be restarted by diesel generators, it needs the grid connection to resume operation.[2]
- Electronic warfare, e.g. GPS signal jamming, is very frequent in armed conflicts. Electronic interference can impact crucial safety and security functions of control-command systems.

Safety Relevant Infrastructure

An operational cooling capacity is as vital for nuclear safety as a reliable power supply.

Interruption of pipelines, destruction of the links to the final heat sink, or pump inlets blocked by debris would jeopardize the cooling capacity. Many other conditions can significantly impact nuclear safety and security including the following:

- Free road access is essential for rotating shifts, delivery of spare parts, outside personnel, and emergency services like fire departments.
- Reactor operators trained for a specific individual plant cannot be simply replaced by operators from other plants, including those from an attacker country.
- Under war conditions, staff may be unsure whether they can leave the plant at the end of their shift and, if yes, whether they find family and friends alive when they get back home – uncertainties that heighten their stress level.
- Operating a nuclear facility at gun point could easily lead to considering even standard safety procedures as secondary, e.g. if electricity is highly needed because of destruction of conventional power plants.
- Staff will likely be deprived of their usual communication tools like their cell phones, restricting their ability to exchange and coordinate with colleagues, supervisors, and regulators.
- Regular maintenance is indispensable, including the delivery and installation of replacement parts, some of which might have to be ordered from foreign suppliers.
- Annual outages usually involve a large number of subcontractors. These companies might not want or be able to send their employees into a war zone or into an occupied nuclear power plant.

---

[2] Mycle Schneider et al., "The World Nuclear Industry Status Report 2022", October 2022, p.29, see worldnuclearreport.org/-World-Nuclear-Industry-Status-Report-2022-.html.

- Inspections by the state regulator or other third parties are an integral part of the safety approach. They will likely not be carried out under warlike conditions.
- International organizations like the IAEA have certain inspection rights under international law. These will likely not be implemented, at least not under usual conditions. Ukraine is a current example.

Last update: 2024