SUB MER GED

ANNEX B

SUBMERGED:
Study of the Destruction of the Kakhovka Dam and Its Impacts on Ecosystems, Agrarians, Other Civilians, and International Justice

Expert Research and Analysis of the Impacts of the Dam's Destruction on the Zaporizhzhia Nuclear Power Plant

TRUTH HOUNDS GREENPEACE

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Kakhovka Reservoir and Zaporizhzhia nuclear power plant, including the cooling pond, June 5, 2023. Source: Sentinel-2.

Introduction

The destruction of the Nova Kakhovka Hydroelectric Power Plant (HPP) and the consequent drainage of the Kakhovka Reservoir has had a direct impact on the safety hazards and risks at the Zaporizhzhia Nuclear Power Plant (ZNPP).[1] The ZNPP, which was attacked and occupied by Russian military forces on March 3–4, 2022, was a unique event in the history of atomic power.[2] The resulting safety and security implications for the ZNPP are without precedent. It is in this context that the destruction of the Nova Kakhovka HPP and the consequent rapid drainage of the Kakhovka Reservoir must be considered. The Kakhovka HPP and Reservoir were fundamental to the operational safety of the ZNPP. The license to operate the ZNPP is premised on the availability of the Kakhovka Reservoir to supply water to the plant and in the event of a nuclear emergency, function as a vital heat sink. This section will seek to explain the impact of its loss as a result of Russian military activity.

The Zaporizhzhia Nuclear Power Plant

The Zaporizhzhia Nuclear Power Plant (ZNPP) is located near the Ukrainian city of Enerhodar, on the left bank of the Kakhovka Reservoir in the Kamianka-Dniprovska District in the Zaporizhzhia Region. The nuclear plant consists of six pressurized water reactors, which are water-moderated and water-cooled or Water-Water Energetic Reactor or VVER. They were designed during the 1970s by Gidropress of the Soviet Union and are each rated at 1,000 MW. The construction of reactor unit 1 began in 1980, and it was connected to the electrical grid in December 1984.[3] The other five units at ZNPP

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[1] IAEA, Communication dated June 6, 2023 received from the Permanent Mission of Ukraine to the Agency, INFCIRC/ 1093, see www.iaea.org/sites/default/files/publications/documents/infcircs/2023/infcirc1093.pdf

[2] Greenpeace Germany, "New analysis on severe nuclear hazards at Zaporizhzhia plant in Ukraine" https://www.greenpeace.org/international/press-release/52459/nuclear-hazards-zaporizhzhia-plant-ukraine-military-invasion/

[3] International Atomic Energy Agency (IAEA), Power Reactor Information Service (PRIS) Ukraine, see https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=UA

began operation between 1985 and 1995. The ZNPP is one of four commercial nuclear power plants in Ukraine.[4] In terms of generating capacity, the ZNPP is the largest nuclear power plant in Europe. In 2021, the last full year of operation prior to Russia's full-scale invasion, the 15 nuclear reactors in Ukraine generated 81 terawatt hours of electricity or 55 percent of the nation's supply.[5] The ZNPP generated 34 terawatts of this output, or 41 percent.[6] As a result of the Russian attack, occupation, and shelling of the ZNPP and the resultant Loss of Off-Site Power (LOOP), all six reactors were shut down at different times during 2022, with the last operating reactor shutdown in September 2022. This is directly relevant to the issue of the impact of the loss of the Kakhovka Reservoir.

Access to large volumes of water is fundamental to all nuclear power plants operating in the world today. During routine power operations, water is required to absorb the residual waste heat from the reactor condensers, also to cool spent fuel, and also to cool vital safety related equipment. In the event of an accident, nuclear power plants need water to remove the decay heat produced by the reactor core fuel and also to cool the equipment and buildings used to provide the core's heat removal. The water demand for a nuclear plant during reactor operation is significantly greater than for reactors that have been in extended shutdown.

One day after the Russian attack on ZNPP, on March 5, 2022, the Ukrainian government issued an appeal letter to the United Nations Secretary-General which warned, "The cooling of nuclear fuel at Zaporizhzhia NPP power units is ensured by design systems in accordance with the requirements of safe operation procedures. Losing the possibility to cool nuclear fuel would lead to significant radioactive emissions into the environment. As a result, such a disaster may outweigh all the previous accidents at nuclear power plants ever

[4] The other power plants are Rivne, South Ukraine and Khmelnytskyi.

[5] World Nuclear Industry Status Report 2022, Ed. Mycle Schneider, Julie Hazemann, Antony Froggatt MV Ramana, et al, WNISR, see www.worldnuclearreport.org/IMG/pdf/wnisr2022-v3-lr.pdf

[6] IAEA, PRIS.

recorded, including the ones at Chernobyl and Fukushima Daiichi NPP..."[7]

Despite condemnation from UN member states, the Russian Armed Forces, the State Nuclear Corporation, Rosatom, and the Russian nuclear regulator, Rostechnadzor, continued their occupation of the ZNPP through 2022 and into 2024. The vulnerability of the nuclear reactors to major incidents, including the release of radioactivity, inevitably increased as a consequence of the Russian occupation.

Water Supply at ZNPP

As stated, access to very large volumes of water is fundamental for all commercial nuclear power plants. The Kakhovka Reservoir was the source of service water supply for the ZNPP. In the area of ZNPP, the Reservoir was 4-13 kilometers wide and had an average depth of 8 meters and a maximum depth of 14-16 meters (in the bed of the Konka River and Dnipro River). The hydraulic structures for water management of the ZNPP are a complex set of engineering structures. This complex also includes the use of the inlet, outlet water channels, and the condenser pumps of the Zaporizhzhia Thermal Power Plant (ZTPP) which is adjacent to the ZNPP site water complex. The other water-related infrastructure includes the ZNPP cooling pond dam with blowdown facilities, pumping stations for various purposes, spray ponds, cooling towers, access roads, and underground utility networks.[8] There are effectively two ZNPP service water systems: one for routine operation, the condensers, utilizing the inlet and outlet channels and cooling pond; and the second for safety systems, which relies on the operation of the spray ponds. The water entering the plant

[7] "Letter to António Guterres, Secretary-General of the United Nations", *German Galushchenko,* Ukraine Minister of Energy, Petro Kotin, Acting President of SE NNEGC Energoatom, and Oleh Korikov, Acting Chairman of the Chief State Inspector of SNRIU, 5 March 2022, see https://snriu.gov.ua/storage/app/sites/1/uploaded-files/Letter_to_UN_05.03.22_FINAL.pdf

[8] V. Y. ULIANOV, V. V. BILYK, Research Results for the Earth Dam Condition of Cooling Pond of the Zaporizhzhia Nuclear Power Plant, 2022, http://stp.diit.edu.ua/article/view/267939/265995

cools equipment such as the chillers for air conditioning units, lubricating oil coolers for the main turbine, aftercoolers for air compressors, and heat exchangers for closed-loop cooling systems providing cooling water to other equipment like the spent fuel pool heat exchangers. After cooling these components, the service water system returns the warmed water to the nearby source, labeled "Ultimate Heat Sink" (UHS). The UHS is the system of cooling nuclear reactors and spent fuel pools and is defined under nuclear regulation. In the case of the ZNPP, the UHS is provided via the essential service water system (ESWS). The ESWS is designed for heat removal from the equipment important to safety, located in the reactor compartments and emergency diesel generator building, and for heat transfer to the ultimate heat sink. The ESWS performs the following functions: removes heat from the coolant through the Emergency Core Cooling System (ECCS) heat exchangers; removes heat from the equipment of safety systems; and removes heat from the equipment of normal operation systems important to safety.[9]

[9] SNRIU, 2011.

Ultimate Heat Sink

The UHS is defined as the complex water cooling-water sources necessary to safely shut down and cool a nuclear power plant. The US Nuclear Regulatory Commission (NRC) defines the UHS as the following: 1/The UHS must be able to dissipate the heat of a design basis accident, such as a loss of coolant accident for one reactor, together with being the heat sink for the safe shutdown and cooling of all other nuclear reactor units on the site; 2/ The UHS is required to provide a 30-day supply of cooling water at or below design basis temperature for all safety related equipment; and 3/ The system must be capable of performing under meteorologic conditions leading to the worst cooling performance and the conditions leading to the highest water loss.[10]

Within the cooling systems there are multiple Hydraulic Structures (HTS) for the managing of water. The (HTS) that are available for the UHS at ZNPP are identified in the image below and consist of:

- Spray ponds
- ZNPP cooling pond
- Zaporizhzhia Thermal Power Plant (ZTPP) cooling water channels

The ZNPP uses what in effect is a closed-cycle cooling system where the water used for cooling is pumped from the reactor steam condensers via the outlet channel to the cooling pond.[11] During the summer months when the water temperature is higher, water is circulated in both the twin cooling towers, the spray ponds adjacent to

[10] US NRC, Analysis of Ultimate Heat Sink Spray Ponds, Office of Nuclear Reactor Regulation, August 1981, see www.nrc.gov/docs/ML1214/ML12146A146.pdf

[11] E. V. Giusti and E. L. Meyer , Water Consumption by Nuclear Powerplants and Some Hydrological Implications, Geological Survey Circular 745, United States Department of the Interior, 1977, see https://pubs.usgs.gov/circ/1977/0745/report.pdf

the towers, and the spray modules in the cooling pond. These water losses are replaced by the flow of water from the Kakhovka Reservoir via the Zaporizhzhia Thermal Power Plant (ZTPP) inlet channel. The total throughput for the intake channel is 330 m^3/s.[12] Then the water enters the heat sink, along the supply channel to the reactor power units, then into the outlet channel, spray devices, cooling pond and two cooling towers. The average temperature of the cooled water in the pond during the hottest month of the year is 28.7°C. In the winter months, the water temperature is 17–18°C, as a result of which there is no ice cover on the cooling pond during winter. The process of operating this complex water management system, including the discharge of heated water from inside the reactor buildings and its resultant spray cooling, inevitably leads to water evaporation.

Cooling Pond

The cooling pond of ZNPP belongs to the lake-pond type. The cooling pond was constructed by cutting off the part of the Kakhovka Reservoir by an alluvial sandy dam and has the following parameters: the surface area is 8.2 km^2, the volume is 47.05 million m^3 with an average depth is 5.87 meters, the maximum depth is 13.5 meters, and the length of coastline of the pond is 11.2 kilometers.[13] The ZNPP cooling pond height is at a level of 22 meters, and therefore above the level of the Kakhovka Reservoir which on June 4, 2023, was 17.26 meters.[14]

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[12] P.S. Beiner, N.V. Beiner, O.D, Analysis Of The Influence Of Weather Conditions For Water Temperature In The Supply Channel Zaporizhzhia NPP, Chuzhikova-Proskurnina Sevastopol National nuclear energy university and industry Sevastopol, see https://msoe.ru/wp-content/uploads/2019/04/19-34.pdf (in Russian).

[13] Olena Fedonenko, Tamila Ananieva, Tetiana Sharamok, Oleh Marenkov Oles Honchar, "Environmental Characteristics by Eco-Sanitary and Toxic Criteria of the Cooling Pond of Zaporizhzhya Nuclear Power Plant (Ukraine)", Dnipro National University, Faculty of Biology and Ecology, Department of General Biology and Water Bioresources P.M.B. 49050, Dnipro, Ukraine, International Letters of Natural Sciences, 2018, see https://www.researchgate.net/figure/The-location-scheme-of-the-cooling-pond-of-Zaporizhzhya-NPP-ZNPP-Google-map_fig1_326922850

[14] Hydroweb, Lake Kakhovka, see https://hydroweb.theia-land.fr/collections/hydroweb/L_kakhovka?lang=en&

Russian Armed Forces Occupation of the Nova Kakhovka HPP

Prior to June 2023 and the Russian Armed Forces' destruction of the Nova Kakhovka Dam, there had been major concerns over the impact of the Russian occupation of the Dam and the effect on water levels in the Kakhovka Reservoir. Based on remote sensing satellite imagery compiled by Greenpeace, from October 4, 2022, the Russian military was observed to have opened sluice gates on the Nova Kakhovka HPP.

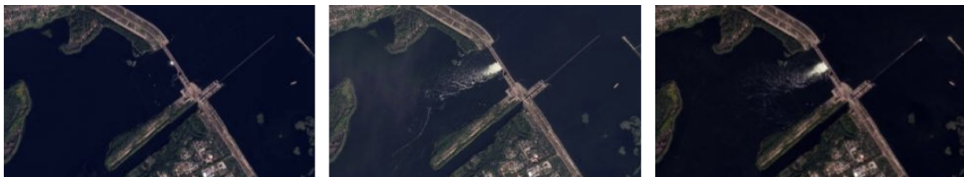
Source: Planet Lab 2022

According to Ukrhydroenerho experts, the Russian forces were deliberately discharging large volumes of water through the Kakhovka HPP by opening its gates.[15] The Russian objective appears to be to make it harder for Ukrainian military forces to cross the river, including in the area of Kherson. As a result of the Russian opening of sluice gates, there was a major decline in the water level of the Kakhovka Reservoir. The water volume decline of the Reservoir was significant and continued until early February 2022. On October 4, 2022, the water level in the Kakhovka Reservoir was measured at 16.53

[15] "Water level in Kakhovka Reservoir rapidly drops, threatens ZNPP operation", 7 February 2023, see https://en.lb.ua/news/2023/02/07/19189_water_level_kakhovka_reservoir.html

meters, and at its lowest point, on February 10, 2023, reached 14.06 meters.[16]

Planet Lab Images of Sluice Gates Opened from October 8, 2022, at Kakhovka HPP



October 7, 2022 October 8, 2022 October 11, 2022

Variation in water level in Kakhovka Reservoir
Source: Hydroweb

[16] Hydroweb, see https://hydroweb.theia-land.fr/collections/hydroweb/L_kakhovka?lang=en&

The Planet Lab. Satellite image of January 25, 2023, shows the decline in water level near the ZNPP inlet channel. Source: Planet Lab.

On February 6, 2023, an extraordinary meeting of the Ukraine State Commission on Technological and Environmental Safety and Emergency Situations was held under the chairmanship of the Prime Minister of Ukraine Denys Shmyhal. In connection with the uncontrolled discharge of water at the Kakhovka HPP, the water level in the Kakhovka Reservoir is rapidly decreasing as the volumes of the discharge exceed the volume of filling. The meeting noted that "A significant decrease in the water level in the Kakhovka Reservoir has a negative impact on the technical processes at the ZNPP. A level of 13.2 meters is the minimum for taking water into the cooling channel. If the water supply is stopped, there will be problems with the cooling of the reactors, and this will lead to a disaster" said Gennadiy Timchenko, first deputy head of the regional military administration, stated that.[17]

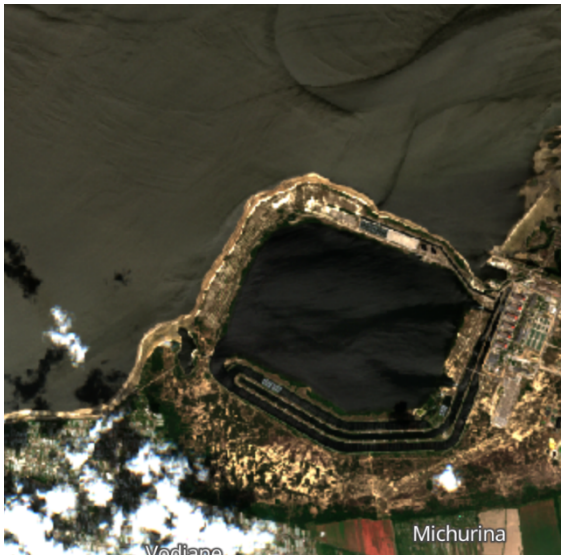
[17] "Water level in Kakhovka Reservoir rapidly drops, threatens ZNPP operation", 7 February 2023, see https://en.lb.ua/news/2023/02/07/19189_water_level_kakhovka_reservoir.html, and https://t.me/energoatom_ua/11841

The water levels in the Kakhovka Reservoir started to increase after mid-February 2023, due in large part to high water discharges from upstream in the Dnipro system.

Kakhovka Reservoir Water Levels and ZNPP Water Levels

Historically, the Kakhovka Reservoir has been the only source of water for the ZNPP. Water reaches the nuclear plant via the ZTPP water inlet channel and then through the condenser pumps to the outlet channel of the ZTPP. On the day of the destruction of Nova Kakhovka HPP, the first image below shows the level of water prior to drainage of the Reservoir. The water level in the Kakhovka Reservoir at the Ukraine HydroEnergo measuring station at Nikopol opposite ZNPP was 16.4 meters.

ZNPP water intake channel, June 6, 2023. Source: Planet



ZNPP cooling pond and Kakhovka Reservoir, June 8, 2023.
Source: Sentinel-2.

The decline in the reservoir water level resulting from the destruction of the Nova Kakhovka Dam can be seen in the image below.

ZNPP water intake channel, June 9, 2023
Source: Planet Lab

At 11 AM on June 8, 2023, the level of the Kakhovka Reservoir at Nikopol was 12.9 meters.[18] Less than 24 hours later, at 8:00 AM on June 9, 2023, the Ukraine Hydrometeorological Center reported the level at 11.33 meters at Nikopol.[19] The water level in the cooling pond as of June 8, 2023, was 16.66 meters.[20] It was during the period between June 9–10, 2023 that the water level of the Kakhovka Reservoir dropped below the level in the ZTPP intake channel. By 6:00 AM on June 10, 2023, the water level in the Kakhovka Reservoir was 10.55 meters at Nikopol,[21] while the intake channel was 11.08 meters.[22] On June 11, 2023, the cooling pond water level was 16.46 meters, a decline of 0.2 meters since June 8, 2023.[23]

Source: Energoatom, July 11, 2023.

[18] Energoatom, The water level in the ZNPP cooling pond is stable, June 8, 2023, see https://old.energoatom.com.ua/o-0806231.html

[19] Ukraine Hydrometeoreological Center, The State Emergency Service of Ukraine, June 9, 2023, see https://twitter.com/Ukrhydroenergo

[20] Energoatom, June 9, 2023.

[21] Ukraine Hydrometeoreological Center, The State Emergency Service of Ukraine, June 10, 2023, see https://twitter.com/Ukrhydroenergo

[22] Energoatom, The water level in the ZNPP cooling pond is stable,July 11, 2023, see https://old.energoatom.com.ua/o-1107231.html

[23] Energoatom, July 11, 2023.

As the Reservoir continued to drain, structures related to the intake of water became visible. In the images below from July 13, 2023, multiple intake pipes for water to enter the ZNPP channel from the Reservoir are visible.

ZNPP water intake channel, July 13, 2023.
Source: Planet Lab

Below image from July 25, 2023, showing pipe structures for water intake.

ZNPP water intake channel showing pipelines in Kakhovka.
Reservoir, July 25, 2023 Source: Planet Lab

The Ukraine Hydrometeorological Center reported until June 12, 2023 that the water level at Nikopol was 9.04 meters as of 6:00 PM on June

11.[24] Water data at Nikopol was no longer available after June 13 due to the decline of the level below the sensors. While there has been some minor variation in the water levels of the Dnipro River channels since June 2023, as of 2024, the intake channel remains cut off from its historical water supply of the Kakhovka Reservoir.

ZNPP water intake channel, March 26, 2024.
Source: Planet Lab

Immediate Impact of the Destruction of Nova Kakhovka HPP on ZNPP

Due to the shutdown status of the ZNPP, there was a limited immediate impact on the plant with the destruction of the Nova Kakhovka Dam on June 6, 2023. The plant owner, Energoatom stated on the same day, "Since September 2022, the power units of the ZNPP have not been operating, therefore active evaporation of water from the cooling pond does not occur, and there has been no need to feed it yet. And even if there will be no water in the Kakhovka Reservoir at all, the project provides measures to replenish it. One of the latter is the use of underground water from wells at the ZNPP site."[25]

[24] Ukraine Hydrometeoreological Center, The State Emergency Service of Ukraine, June 12, 2023, see https://twitter.com/Ukrhydroenergo

[25] Energoatom, A drop in the water level in the Kakhovsky Reservoir does not directly affect the drop in the water level in the ZANP cooling pond, see https://old.energoatom.com.ua/o-0606232.html

Two days after the destruction of the Kakhovka HPP, the State Nuclear Regulatory Institute of Ukraine, (SNRIU) the nation's nuclear regulator, announced that an assessment of the impact of the loss of the Kakhovka Dam had been under preparation since 2022. This was in response to information that Russian armed forces had placed mines at the Kakhovka HPP in October 2022. The SNRIU had requested ZNPP owner, SE NNEGC Energoatom, to assess the impact of the decreasing water level in the Kakhovka Dam on the safe operation of the ZNPP and develop measures for such a case. Oleh Korikov, Acting Chairman of SNRIU, Chief State Inspector for Nuclear and Radiation Safety of Ukraine, during a meeting of the Parliamentary Committee on Environmental Policy and Nature Management, announced that Energoatom had prepared, "The Safety Analysis for Lowering the Water Level of the Kakhovka Dam" and developed "The Measures for Lowering the Water Level of the Kakhovka Dam. He stressed that the decrease in the water level of the Kakhovka Dam should not affect the nuclear and radiation safety of Zaporizhzhia NPP if these measures were implemented and all ZNPP units were in a state of "shutdown."[26]

At the same time, Oleh Korikov underlined that it is difficult to predict the state of nuclear and radiation safety in the conditions of occupation of ZNPP by terrorists with weapons in their hands, the presence of unauthorized personnel at the industrial site, as well as difficulty of predicting further goals and actions of the occupiers.[27]

Also, on June 8, 2023, the SNRIU issued an order for unit 5 at ZNPP to be immediately placed in a 'cold shutdown'.[28] The SNRIU based its

[26] SNRIU, Water level decreasing in the Kakhovka Dam will not have serious consequences for nuclear and radiation safety at ZNPP, if all necessary measures are taken - Oleh Korikov, June 8, 2023, see https://snriu.gov.ua/en/news/water-level-decreasing-in-the-kakhovka-dam-will-not-have-serious-consequences-for-nuclear-and-radiation-safety-at-znpp-if-all-necessary-measures-are-taken-oleh-korikov

[27] SNRIU, June 8, 2023.

[28] This was in accordance with Article 25 of the Law of Ukraine "On the Use of Nuclear Energy and Radiation Safety" and the Regulation on the State Nuclear Regulatory Inspectorate of Ukraine approved by Resolution No. 363 of the Cabinet of Ministers of Ukraine of August 20, 2014, the SNRIU issued an order to the State Enterprise NNEGC Energoatom to limit the operation of Zaporizhzhia NPP Unit 5

instruction on multiple factors, which included notification from Ukrhydroenergo of June 6, 2023, about the emptying of the Kakhovka Reservoir in a few days as a result of the Russian occupiers' blowing up of the Kakhovka HPP.[29] ZNPP reactor units 1, 2, 3, 4, 6, were at that time all in the cold shutdown in accordance with SNRIU orders of August 18, 2022 and February 10, 2023.[30] The "hot shutdown" status of a nuclear reactor means that the Reactor Coolant System (RCS) is maintained at a temperature above 260 centigrade; while in 'cold shutdown' the RCS is at less than 70 centigrade. In the hot shutdown mode, the temperature of the primary circuit is maintained by operating the main circulation pumps and regulating the degree of cooling through the heat exchangers of the cooling system.[31] As a former Zaporizhzhia reactor control engineer testified, hot shutdown is one of the intermediate modes between operation at minimum power and the cold state. In the hot shutdown mode, without proper cooling or de-energizing, in most cases, an accident will occur faster than in the cold state.[32]

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as an object of state supervision to the state of the reactor unit "cold shutdown". The order was issued to the operating organization due to the impossibility of eliminating the identified violations of nuclear and radiation safety requirements, namely: paragraph 4. of Chapter 1. of Section 4 of the Requirements for Emergency Nuclear Fuel Cooling and Heat Removal Systems to the Final Absorber, approved by SNRIU Order No. 233 dated 24.12.2015, registered with the Ministry of Justice of Ukraine on 16 January 2016 under No. 77/28207, see SNRIU, June 9, 2023. SNRIU Order restricts operation of ZNPP Unit 5 to cold shutdown condition, June 9, 2023, see https://snriu.gov.ua/en/news/snriu-order-restricts-operation-of-znpp-unit-5-to-cold-shutdown-condition

[29] SNRIU, June 9, 2023.

[30] SNRIU, June 9, 2023.

[31] NRC, Standard Technical Specifications Westinghouse Plants Revision 5.0 Volume 1, Specifications, see www.nrc.gov/docs/ML2125/ML21259A155.pdf

[32] See interview of Timur Valieiev who worked as a leading reactor control engineer at the ZNPP Unit 6 reactor. In 2023, when the Russians began to force the plant's specialists to sign contracts with its own nuclear energy agency, Rosatom, and obtain Russian passports, Valieiev escaped to Germany. As reported in, Yulia Valova, Hot and cold: The risks posed by mines at Zaporizhzhia nuclear power plant, June 24, 2023, see https://emerging-europe.com/news/hot-and-cold-the-risks-posed-by-mines-at-zaporizhzhia-nuclear-power-

Rosatom continued to defy SNRIU and maintained one of the ZNPP reactors in "hot shutdown" mode until April 2024.[33] SNRIU chair stated, "The cold state of power units is safer than the hot state. If the power units are in a cold state, we can talk about reducing water consumption, as water resources are limited after the destruction of the Kakhovka Reservoir, and reducing electricity supply from the Ukrainian power system. From the point of view of nuclear and radiation safety, in case of a complete blackout of the plant, the time margin increases before the possible destruction of safety barriers to the spread of radiation into the environment".[34]

In response to the loss of access to the Kakhovka Reservoir, the Rosatom management at the ZNPP in summer 2023 set about the construction of underground wells on the site. By September 2023, a total of 11 wells provided water to the ZNPP spray ponds at an average of 250 m^3 per hour.[35] As of April 2024, the ZNPP cooling pond was being supplied with approximately 400 m^3/h of water from the sprinkler ponds as well as from the discharge channel of the nearby ZTPP.[36] The water supplied from the 11 underground wells is providing enough cooling water for the six units in shutdown, but still not enough to maintain the water inventory in the ZNPP cooling pond.

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plant/#:~:text=It%20can%20be%20in%20this,than%20from%20the%20cold%20state.%E2%80%9D

[33] SNRIU, Oleh Korikov: All ZNPP power units are in a cold state, but the main threats to nuclear and radiation safety are the occupation and militarization of the plant, April 15, 2024, see https://snriu.gov.ua/en/news/oleh-korikov-all-znpp-power-units-are-in-a-cold-state-but-the-main-threats-to-nuclear-and-radiation-safety-are-the-occupation-and-militarization-of-the-plant

[34] SNRIU April 15, 2024.

[35] IAEA, Update 185 - IAEA Director General Statement on Situation in Ukraine 103/2023, September 29, 2023, see https://www.iaea.org/newscenter/pressreleases/update-185-iaea-director-general-statement-on-situation-in-ukraine

[36] IAEA, Update 219 – IAEA Director General Statement on Situation in Ukraine, April 4, 2024, see https://www.iaea.org/newscenter/pressreleases/update-219-iaea-director-general-statement-on-situation-in-ukraine?utm_source=miragenews&utm_medium=miragenews&utm_campaign=news

ZNPP Status – Reactor Restart and Cooling Water

As stated, there are multiple risks of a major nuclear event at the ZNPP due to the occupation of the site by Rosatom, the Russian nuclear regulator Rostekhnadzor, and the Russian armed forces. Unique in the history of nuclear power, a commercial nuclear plant site is located on the frontline of a major war, and has been converted by Russian armed forces into an active military base and launch site for conducting military operations against Ukraine.[37] In the existing conditions, there is sufficient water capacity on the ZNPP to meet the water-cooling requirements of the site. The destruction of the Kakhovka HPP and the drainage of the Kakhovka Reservoir take on a far greater significance in terms of the impact on nuclear plant safety at Zaporizhzhia if Rosatom proceeds with its plans to restart one or more nuclear reactors. The prospect of a major radiological release is significantly increased if one or more reactors are restarted by Rosatom.

Under the current conditions where the six reactors are in shutdown mode, there is, however, still the potential for a nuclear event that would lead to the release of radioactivity from the site. A cliff edge event, where the failure of one part of the system cascades to the point of a major incident is today ever-present. Of particular concern is the fragility of the electrical supply to the ZNPP which remains the most serious in terms of potential consequences. Repeatedly, since 2022, the main electrical supply lines to the ZNPP have been disconnected.[38] Whereas before the Russian full-scale invasion, the ZNPP site had

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[37] Greenpeace Germany, A Nuclear Power Plant as Launch Pad - Analysis of the occupation of Zaporizhzhia NPP by Russian armed forces and Rosatom and the role of the IAEA, September 28, 2023, see www.greenpeace.de/publikationen/McKenzie_Report_Zaporizhzhia.pdf and www.greenpeace.de/publikationen/Greenpeace_Assessment%20_IAEA_Zaporizhzhia.pdf

[38] IAEA, Communication from the Permanent Mission of Ukraine to the Agency, INFCIRC/1190, March 22, 2024, see www.iaea.org/sites/default/files/publications/documents/infcircs/2024/infcirc1190.pdf

access to four 750 kilovolt main lines and six 330 kilovolt emergency backup lines, due to Russian shelling and the ongoing conflict, the ZNPP has only access to one 750 kilovolt line and one 330 kilovolt line. Frequently, one of these lines is not available due to Russian military activity. Most seriously, on eight occasions since March 2022, the ZNPP has suffered a Loss of Offsite Power (LOOP), where all external electricity supply is lost.[39] The ZNPP during these periods is dependent upon its emergency diesel generators which operate the safety systems of the reactors and spent fuel pools, including cooling water pumps. The diesel generators also require cooling water to function.

The plans of Rosatom to restart one or more reactors have only emerged since early 2024 and remain vague.[40] There are multiple obstacles to restarting reactors at ZNPP, which include the physical condition of the reactors and safety systems after nearly two years of Russian occupation; inadequate vital inspection and maintenance by a dramatically reduced workforce, including underqualified Rosatom appointed staff. Evidence of the degradation of the plant has been raised repeatedly by the SNRIU. In November 2023, the Head of the SNRIU – Chief State Inspector for Nuclear and Radiation Safety of Ukraine Oleh Korikov warned, "The Russian occupation of ZNPP has led to a total degradation of emergency preparedness and response system, the destruction of the physical protection system, logistics, the lack of spare parts and materials, and serious degradation of equipment. Noting in January 2024 that "the lack of proper maintenance and repairs led to the degradation of nuclear and radiation safety at ZNPP. In particular, this has already manifested itself in two

[39] IAEA, Update 214 – IAEA Director General Statement on Situation in Ukraine, March 1, 2024, see https://www.iaea.org/newscenter/pressreleases/update-214-iaea-director-general-statement-on-situation-in-ukraine

[40] Greenpeace calls on IAEA Director General to warn Rosatom: No restart of Zaporizhzhia nuclear plant!, February 3, 2024, see https://www.greenreconstruction.com/news/greenpeace-calls-on-iaea-director-general-to-warn-rosatom-no-restart-of-zaporizhzhia-nuclear-plant; and Dan Sabbagh, Greenpeace accuses Russia of 'unprecedented escalation' if it restarts Zaporizhzhia reactors, March 7, 2024, see https://www.theguardian.com/world/2024/mar/07/greenpeace-accuses-russia-of-unprecedented-escalation-if-it-restarts-zaporizhzhia-reactors,

of last year's operational events with the leakage of potentially radioactive water from the primary to the secondary circuit."[41]

Commercial nuclear plants in Ukraine and globally have not been designed to operate under war conditions, and this includes the licensing of reactors to operate. It is therefore clear that the current conditions of the reactors in cold shutdown, pre-operational measures, and the actual start-up of a reactor at Zaporizhzhia would be a violation of Ukraine's nuclear safety and security regulations. The statutory body solely and legally responsible for nuclear regulation at Zaporizhzhia, the SNRIU, has had no access to the Zaporizhzhia nuclear plant since March 2022. Rosatom has no legitimate license for operating Zaporizhzhia and the Russian regulator, Rostekhnadzor, has no legal authority to conduct inspections or issue an operating license for the Zaporozhzhia nuclear plant.[42]

In assessing the potential for severe radiological events at the ZNPP, it must be considered that the range of scenarios is very large. The active presence of Russian armed forces Rosatom and Rostekhnadzor means that a deliberate act of sabotage leading to major damage to vital components, including safety systems, must be considered. The destruction of the Nova Kakhovka HPP by Russian armed forces on June 6, 2023, demonstrates intent and opportunity, both of which exist at the ZNPP under current circumstances. These are factors that have never been included in formal regulatory reviews of nuclear power plant safety assessments.

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[41] SNRIU, Russian invaders do not provide access to IAEA experts to important areas of the Zaporizhzhya NPP industrial site, January 4, 2024, see https://snriu.gov.ua/en/news/russian-invaders-do-not-provide-access-to-iaea-experts-to-important-areas-of-the-zaporizhzhya-npp-industrial-site

[42] In November 2023, the IAEA was informed that Rostekhnadzor, the Russian regulatory body for nuclear and radiation safety, is establishing, "a more permanent presence at the ZNPP with the arrival at the site of the Head of ZNPP Nuclear and Radiation Safety Inspections.", IAEA, Update 193 - IAEA Director General Statement on Situation in Ukraine, November 13, 2023, see https://www.iaea.org/newscenter/pressreleases/update-193-iaea-director-general-statement-on-situation-in-ukraine

Operating one or more reactors at Zaporizhzhia under these conditions is outside any regulatory conditions. As such no legitimate regulatory assessment exists that would permit the operation of ZNPP reactors. The operational license granted by SNRIU for the ZNPP is based on the physical conditions of the site and its environment prior to the Russian occupation of the plant. As a result of the destruction of the Kakhovka HPP and drainage of the Kakhovka Reservoir, the physical conditions of the ZNPP have fundamentally changed. While it is accepted that there is sufficient water on the ZNPP to meet current demands while all reactors are in shutdown mode, operational reactors require active cooling with far larger volumes of water. The Kakhovka Reservoir was an integral part of the water management system for the ZNPP, as the principal source of water for the cooling pond. All design basis accident (DB) and beyond-design-basis accident assessments by Ukraine's regulator were premised on the existence of the UHS and sufficient water supply, including make-up supply from the Kakhovka Reservoir.

The margin of safety is significantly reduced at the ZNPP if the reactor or reactors restart operation. For the ZNPP, when the stress tests were conducted it was concluded that in the event of a Loss of Off-Site Power (LOOP) followed by a Station Blackout (SBO) and loss of UHS cooling function the minimum time until reactor core damage in the absence of intervention by the operator would be 3.5-4 hours.[43] Under current conditions at the ZNPP there is no assurance that operator intervention would take place. The drainage of the Kakhovka Reservoir is not the initiating event that would likely cause a severe nuclear radiological event at the ZNPP, but the fact that it no longer exists would potentially contribute to any future disaster being more significant and consequential.

[43] ENSREG, Ukraine: Peer review country report Stress tests performed on European nuclear power plants, European Nuclear Safety Regulators Group, Stress Test Peer Review Board, April 26, 2012, see www.ensreg.eu/sites/default/files/Country%20Report%20UA%20Final.pdf

Image of Kakhovka Reservoir and ZNPP with cooling pond, June 6, 2023.
Source Planet

Vulnerability of ZNPP Cooling Pond

The potential weakening of the ZNPP cooling pond dam as a result of the drainage of the Kakhovka Reservoir following the destruction of the Nova Kakhovka HPP is an additional factor for consideration. The post-Fukushima stress tests that were conducted by Ukraine's nuclear regulator of the ZNPP included an assessment of the loss of water at the ZNPP cooling pond in the event of the failure of the Kakhovka HPP. The initiating scenario was a result of a seismic event, not deliberate Russian detonation of the Dam structure. The assessment concluded that due to the width of the cooling pond levee, the cooling pond dam will not be broken; and that, "water losses because of filtering will remain actually unchanged in comparison with the design-basis conditions." (The NHL of the pond is 16.5 meters, minimum volume level in the Kakhovka Reservoir is 12.7 meters.)

Image of Kakhovka Reservoir and ZNPP with cooling pond June 17, 2023. Source Planet

The stress test did however conclude that "a failure of the Kakhovka Hydroelectric Plant Dam after an earthquake may lead to loss of water in the Zaporizhzhya NPP cooling pond and, consequently, loss of make-up of the essential service water spray ponds."[44]

The stress test report from the SNRIU recommended that to prevent the impact of accident consequences on ZNPP hydraulic engineering structures, which includes the cooling pond, the following actions are planned:

- A detailed analysis of the potential water loss of Zaporizhzhia NPP cooling pond due to the break of the Kakhovka Hydroelectric Plant Dam resulting from an earthquake;
- Development of additional measures to provide for the makeup of the spray pond of the essential service water system (ESSW).[45]

[44] SNRIU, State Nuclear Regulatory Inspectorate Of Ukraine National Report On Stress Test Results, 2011, see www.ensreg.eu/sites/default/files/attachments/national_report_of_ukraine.pdf

[45] SNRIU, 2011.

It has not been possible to determine whether a detailed analysis has been completed.

In the immediate aftermath of the destruction of the KHPP and the drainage of the Kakhovka Reservoir, there were warnings of the impact on the physical integrity of the cooling pond dam. The French Government's Institute for Radiation Protection and Nuclear Safety (IRSN) stated, "A drop in the Dnieper's [Dnipro River] water level could lead to basin leakage, or even to the collapse of the surrounding dike, due to the pressure exerted by the water contained in the basin. As part of the post-Fukushima stress tests, the Ukrainian operator has estimated that the dike can withstand a Dnieper [Dnipro] level of 10 meters in the vicinity of the power plant. The stabilized level is determined by the position of the damage on the Dam. This water level and the water-tightness of the retention basin will be closely monitored over the coming days."[46]

The levels of the Kakhovka Reservoir at the ZNPP cooling pond continued to decline rapidly dropping more than 8 meters after the explosion.[47] While two channels of the Dnipro River run up against the ZNPP cooling pond dam wall, nothing remains of the Kakhovka Reservoir on the north and west sides of the ZNPP pond. The cooling pond was built on the engineering assessment that there would be external hydrological pressure from the larger Kakhovka Reservoir. As a consequence of the Russian armed forces' destruction of the Kakhovka HPP on June 6, 2024, the physical condition of the cooling pond dramatically changed. This raises significant questions about the stability of the ZNPP cooling pond dam.

[46] IRSN, Information Report Consequences of the damage to the Kakhovka Dam on the Zaporizhzhya nuclear power plant, June 7, 2023, see https://en.irsn.fr/sites/en/files/2023-09/IRSN_NI_Ukraine-Barrage-Kakhovka_07062023_EN_VF.pdf

[47] Energoatom July 11, 2023.

Vulnerability of the Cooling Pond to Physical Damage Resulting from Drainage of the Kakhovka Reservoir

"The dam of the cooling pond is located on the outer perimeter of the NPP industrial site. The outer perimeter is subject to the maximum influence during any natural and technogenic changes in the Kakhovka Reservoir surface." V. Y. Ulianov, V. V. Bilyk, June 2022.[48]

For any nuclear plant, the precise geological structure at the site is a fundamental safety parameter when assessing the suitability of the site prior to construction of the nuclear plant. The geological and hydrogeological conditions directly relate to the stability of large weight-bearing structures. In the case of the ZNPP, evidence of geodetic observations, analysis of the main buildings and structures conditions on the power units of ZNPP, as well as the results of engineering and geological surveys, have identified many factors that affect the bearing properties of sandy foundations. A recent paper by V. Y. Ulianov and V. V. Bilyk at the Prydniprovska State Academy of Civil Engineering and Architecture raises important questions about the potential impact on the structural stability of the ZNPP cooling pond.[49] Their analysis was published one year before the Russian destruction of the Nova Kakhovka Dam which raises further questions on the impact the loss of the Kakhovka Reservoir has had on the structural stability of the ZNPP cooling pond dam.

As detailed by V. Y. Ulianov and V. V. Bilyk, the cooling pond of the ZNPP was formed by blocking off part of the water area of the Kakhovka Reservoir by the method of filling a sand dam. From the

[48] V. Y. Ulianov, V. V. Bilyk, Research Results for the Earth Dam Condition of Cooling Pond of the Zaporizhzhia Nuclear Power Plant, Science and Transport Progress Bulletin of Dnipropetrovsk National University of Railway Transport, June 2022, see https://www.researchgate.net/publication/366664567_Research_Results_of_the_Earth_Dam_Condition_of_Cooling_Pond_of_the_Zaporizhzhia_Nuclear_Power_Plant

[49] V. Y. Ulianov, V. V. Bilyk, June 2022.

south and east, the earth dam adjoins the shore. From the north and west, it is washed by the waters of the Kakhovka Reservoir. The normal retaining level (NRL) of the Kakhovka Reservoir is +16.0 meters, and the dead volume level (DVL) is +12.0 meters. The type of dam is soil-filled without anti-filter systems (devices). It is homogeneous with freely formed slopes and a wide profile (spread profile), and the material is fine and medium Quaternary eolian alluvial sands of the valley of the rivers Dnipro and Konka. It was prepared by mainly alluvium by means of hydro-mechanization underwater to a depth of 8 meters, and partially by dry digging. The original concept for the construction of the Zaporizhzhia cooling pond was to form a stone banquet based on 1.7 million m^3 of rock. Following discussions in the Soviet Ministry of Energy, the cheaper option of sand-based construction was chosen to the reported saving of USD $30 million.[50]

One of the significant indicators is the morphological features of the sands of eolian-alluvial genesis. Mostly, the change in the properties of sandy soils affected the on-ground artificial structures of the site. This also applies to hydraulic structures. The main one is the cooling pond dam. This is one of the key facilities for the safe operation of nuclear power plants. There is a high necessity to monitor the earth dam of the cooling pond regularly. This is clearly not taking place while the ZNPP is under occupation by Rosatom.

The analysis of Ulianov and Bilyk, which was published after the start of the Russian full-scale invasion in 2022 and the occupation of the ZNPP, recommends the continued monitoring of the dam of the cooling pond of ZNPP. The authors base their recommendations on the following:

- The result of work on the assessment of the technical condition of the structure;
- Repeated appeals of the relevant services due to erosion in certain sections of the cooling pond dam from the side of the Kakhovka Reservoir;

[50] As cited in V. Y. Ulianov, V. V. Bilyk, June 2022.

- Subsidence of the structure 2-8 millimeters/year and more, which exceeds the limit according to the requirements of regulatory documents, indicating the absence of soil stabilization in the dam body;
- Vibration-dynamic impact on the soils of the dam at the time of military events in the spring and autumn of 2022. The consequences of these events for the entire industrial site of the nuclear power plant must be studied; and
- Non-compliance of the current situation with regulatory most of the requirements of individual clauses of the document SOU-N MEV 40.1-00013741-79:2012.

The important issues raised by Ulianov and Bilyk take on greater urgency under the present conditions of the occupation of the ZNPP by Rosatom and the Russian armed forces, including the possible impact of the drainage of the Kakhovka Reservoir.

Conclusion

As detailed, due to the reactor shutdown status of the Zaporizhzhia nuclear reactors, the immediate impact on nuclear power plant safety of the loss of the Kakhovka Reservoir was limited. However, the safety implications of the destruction of the Kakhovka HPP for the reactors at Zaporizhzhia are profound, and depending on developments at the site, potentially severe. There are multiple factors that compromise the safety of the ZNPP while under Russian occupation and during the current war conditions. It is the combination of these factors that makes the nuclear hazards at the plant so dangerous.[51] The nuclear crisis at ZNPP was already critical prior to the destruction of the Kakhovka HPP in June 2023. The loss of the Kakhovka Reservoir has significantly contributed to the further reduction in safety margins at the plant. This applies to the current condition of reactors which remain in cold shutdown mode. Without professional and qualified inspections of the site, the vulnerability of key structures and components vital to the safety of the plant cannot be assured. The potential impact of the drainage of the Kakhovka Reservoir on the structural integrity of the ZNPP cooling pond dam is one such important issue for which there can be no credible assessment under Russian occupation and under war conditions. The destruction of the Kakhovka Reservoir by Russian forces takes on an even greater significance for the safety of the ZNPP if one or more reactors at Zaporizhzhia were to restart operations. As of February 2024, it is understood that Rosatom was considering the restart of one or more reactors at Zaporizhzhia.[52] It was confirmed in April 2024 that there are plans for restart.[53]

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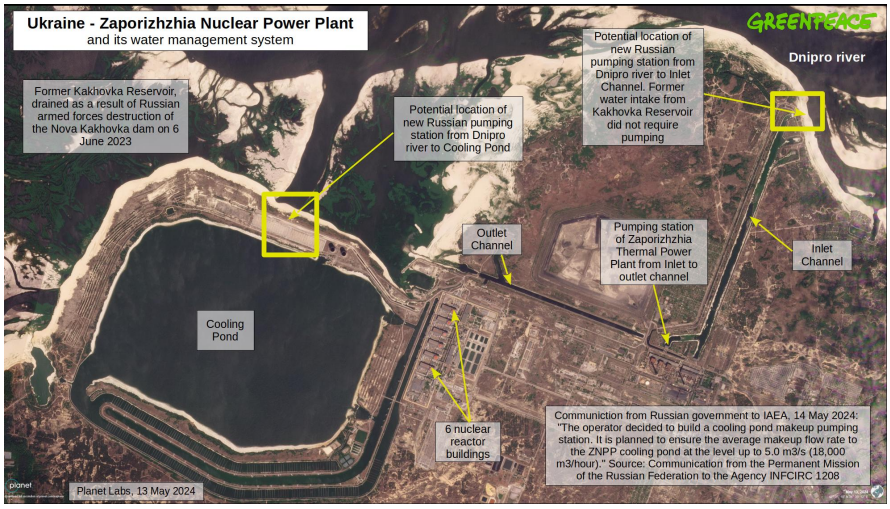
[51] SNRIU, The risks of an accident at the ZNPP are very high - Oleh Korikov, 28 July 2023, see https://snriu.gov.ua/en/news/the-risks-of-an-accident-at-the-znpp-are-very-high-oleh-korikov

[52] Greenpeace calls on IAEA Director General to warn Rosatom: No restart of Zaporizhzhia nuclear plant!, February 3, 2024, see https://www.greenreconstruction.com/news/greenpeace-calls-on-iaea-director-general-to-warn-rosatom-no-restart-of-zaporizhzhia-nuclear-plant

[53] Wall St Journal, Putin Told IAEA Russia Plans to Restart Zaporizhzhia Nuclear Plant, April 12, 2024, see https://www.wsj.com/world/europe/putin-told-iaea-russia-plans-to-restart-zaporizhzhia-nuclear-plant-f2045f50

In mid-May 2024, and for the first time, details of how Rosatom intends to supply additional water to the ZNPP were disclosed. In a submission to the IAEA, the Russian government stated that "Due to the destruction of the Kakhovka HPP Dam by the AFU, the design layout for the makeup of the cooling pond of the ZNPP was disrupted."[54] Consequently, "The operator decided to build a cooling pond makeup pumping station. It is planned to ensure the average makeup flow rate to the ZNPP cooling pond at the level up to 5.0 m^3/s (18,000 m3/hour)."[55] As of May 21, 2024, there is no physical evidence of the commencement of construction of a pumping station at the ZNPP. Greenpeace analysis concludes there are two potential sites for the station.[56] See the diagram below.



[54] IAEA, Communication from the Permanent Mission of the Russian Federation to the Agency, INFCIRC/1208, 15 May 2024, see www.iaea.org/sites/default/files/publications/documents/infcircs/2024/infcirc1208.pdf

[55] IAEA, May 17, 2024.

[56] Greenpeace CEE, Russian government publishes first detailed plans for restart of Zaporizhzhia nuclear plant – Greenpeace condemns nuclear blackmail, May 17, 2024, see https://www.greenreconstruction.com/news/russian-government-publishes-first-detailed-plans-for-restart-of-zaporizhzhia-nuclear-plant---greenpeace-condemns-nuclear-blackmail