The vulnerability of nuclear plants during military conflict

Yuzhnoukrainsk (South Ukraine) Nuclear Power Plant

Safety and security risks - lessons from Fukushima Daiichi

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Briefing - Greenpeace International

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State Nuclear Regulatory Inspectorate, Ukraine, 2015[1][1]

[1] National Academy Of Science Of Ukraine, “Development Of The Materials For Assessment Of Environmental Impact In The Course Of South-Ukraine Npp Operation”, State Institution «Institute Of Environmental Geochemistry Report, 2015,

Preface

This is the second of Greenpeace's briefings on the vulnerability of Ukraine's nuclear power plants during the Russian military invasion. The first briefing, on the Zaporizhzhia nuclear plant, was published on 2 March 2022.[2] Two days later, the Russian military took control of the site in an assault that involved the firing of an unknown quantity of heavy weaponry including artillery and /or possible tank shells.[3] Three Ukrainian security personnel were killed during the incursion, and the Zaporizhzhia reactor unit 1 was damaged. The risks to the safety of the Zaporizhzhia reactors remain severe, including events off site that are already disrupting the electrical grid.

Prior to that potentially catastrophic assault, nuclear security analysts had rated an armoured military attack on a nuclear power plant as possible but with a low probability, albeit with potentially severe consequences, while national nuclear regulators globally excluded even the possibility. The International Atomic Energy Agency (IAEA)'s 2021 safety guidelines on external hazards to nuclear plants "specifically excluded from consideration" any possibility of the firing of a military projectile as a Beyond Design Basis External Event (BDBEE), saying: "In general, military projectiles have velocities higher than Mach 1, and are therefore usually beyond the range of applicability of the techniques described in this Safety Guide."[4] Less than a year after this IAEA conclusion, the world held its breath as artillery was fired at the Zaporizhzhia nuclear plant. The operator of the nuclear plant, Energoatom, reported that two artillery shells hit the area of the Dry Spent Fuel Storage Facility (DSFSF) where there are many hundreds of tons of spent fuel."[5]

The potential for military damage to nuclear power plants has always existed, even if remote. Over the decades, nuclear security specialists commissioned by Greenpeace have presented analysis to governments on the risks and consequences of the use of military

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[2] Greenpeace International, "Nuclear power plant vulnerability during military conflict – Ukraine technical briefing", 2 March 2022, see https://www.greenpeace.org/international/nuclear-power-plant-vulnerability-during-military-conflict-ukraine-technical-briefing/

[3] German Galushchenko, "Letter to António Guterres, Secretary-General of the United Nations", 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

[4] IAEA, "Design of Nuclear Installations Against External Events Excluding Earthquakes", Specific Safety Guide No. SSG-68, VIENNA, 2021, see https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1968_web.pdf

[5] Stefan Schultz, "We can't even see if there are any bodies there", der Spiegel 6 March 2021, see https://www.spiegel.de/wirtschaft/soziales/naftogaz-chef-juri-vitrenko-im-interview-zum-krieg-in-der-ukraine-a-2d5d0804-61f8-4b1f-8b91-8ed9af0f43e9
Energoatom, 4 March 2022, on Telegram, see https://t.me/energoatom_ua/1930; and Gary Peach/Stephanie Cooke, "Ukraine: Zaporozhye Nuclear Plant Staggers On After Attack", Energy Intelligence, 4 March 2022, see https://www.energyintel.com/0000017f-52de-dca3-a77f-f6ff74950000

grade weapons and tactics against vulnerable nuclear plants and materials.[6] [7] [8] Those warnings have generally been ignored by the IAEA and other agencies. To include such attacks as a factor into the design of a nuclear reactor would effectively exclude the possibility of ever building and operating commercial nuclear power plants.

The consequences of the Russian military attack on Zaporizhzhia could have been catastrophic. Today the plant personnel are under direct military command. The risks to the safety of the reactors remain severe, including events off site that disrupt the electrical grid. As with the Zaporizhzhia attack, the aim is likely not to destroy the reactors but to secure them under Russian control. They are a strategic target for Russia. However, as this second Greenpeace briefing warns, the very act of seizing them could lead to their destruction and major environmental and human health consequences.

The safety and security of Ukraine's nuclear plant from military attack can only be assured with an immediate ceasefire and withdrawal of all Russian military forces.

Overview

The military assault and seizure of the Zaporizhzhia nuclear plant by the Russian military on 3-4 March 2022 was a unique event in the history of atomic power.[9] In an appeal letter to the United Nations Secretary General, the Ukrainian government on 5 March warned: **"The cooling of nuclear fuel at Zaporizhzhya 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 recorded, including the ones at Chornobyl and Fukushima Daiichi NPP - Russian shells fell in the area of the spent nuclear fuel storage facility, which is located on the Zaporizhzhya NPP site. In case this hazardous facility is damaged by strikes, this will also lead to major radioactive release."**[10]

If, as is feared, President Putin were to repeat this dangerous act, a nuclear target for the Russian military could be the Ukrainian nuclear power plant at Yuzhnoukrainsk (South

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[6] Oda Becker, "Terrorist attacks with armour-piercing weapons (AT-14 Kornet-E) on (older) German nuclear power plants" Report, public version, Greenpeace Germany e.V., Foreword by Heinz Smital, September 2010, see https://www.greenpeace.de/publikationen/KURZ_Panzerbrechende_Waffen_14092010_0.pdf

[7] Greenpeace International, "Potential Radiological Impact and Consequences arising from Incidents involving a Consignment of Plutonium from COGEMA/La Hague to Marcoule/Cadarache", Commissioned by Greenpeace, March 2004, see https://www.parliament.uk/globalassets/documents/post/postpr222.pdf

[8] Greenpeace France, "Report Summary, "Security of nuclear reactors and spent fuel pools in France and Belgium and related reinforcement measures", October 2017, see https://cdn.greenpeace.fr/site/uploads/2017/10/Summary-of-the-report.pdf

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

[10] German Galushchenko, "Letter to António Guterres, Secretary-General of the United Nations", 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

Ukraine Nuclear Power Plant - SUNPP), located at the Southern Bug River in Mykolaiv province and of strategic importance to electricity generation to the five million people in Nikolaev, Odessa, Kherson regions, part of the Kirovograd region, and in Crimea.

Ukraine's operating nuclear plants were designed in the 1970s-1980s and only partly meet modern design principles concerning redundancy, diversity and physical separation of redundant subsystems or the preference of passive safety systems. The Yuzhnoukrainsk nuclear plant site has three different versions of the Soviet design VVER-1000 reactor which were connected to the grid between 1982 and 1989. All three reactors have exceeded their original 30-year design lives, and should have been shut down between 2013 and 2020. Ignoring major safety issues with the reactors, in particular in relation to the ageing design structures, systems and components, Ukraine's regulator issued licence extensions for continued operation. These were issued prior to completion of Environmental Impact Assessments (EIAs), including trans-boundary radiological impacts, which are a legal obligation under the United Nations Espoo Convention, of which Ukraine is a signatory.[11]

An ongoing European environmental impact assessment process, received expert witness that concluded that, "Serious accidents with containment failure and containment bypass with significantly higher releases…cannot be ruled out for the NPP South Ukraine…with effects (that) can be far-reaching and long-lasting, even affecting countries that, like Austria, do not directly border Ukraine."[12]

The Yuzhnoukrainsk nuclear reactors, as with the Zaporizhzhia nuclear plant which was attacked and seized by Russian military forces on 4 March 2022, play a major role in electricity generation for south Ukraine. The Yuzhnoukrainsk reactors generate on average 10 percent of Ukraine's electricity – but importantly are part of the south Ukraine electric power producing complex (EPPC), and are operated in combination with pumped-hydroelectric storage facilities.[13]

An attack and seizure of the Yuzhnoukrainsk reactors, as with the attack and seizure of the Zaporizhzhia nuclear plant on 3-4 March 2022, is clearly a major strategic objective of the Russian military in terms of controlling the electricity supply of southern Ukraine and as leverage over the Ukrainian government.

A combination of decades old Soviet design, age related degradation, inadequate application of post Fukushima safety measures and weak nuclear regulation that authorised life extension to the reactors when they should have been shut-down, the Yuzhnoukrainsk reactors, like those at Zaporizhzhia, were at risk of a severe accident before the war against

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[11] UNECE, "Implementation Committee, Convention on Environmental Impact Assessment in a Transboundary Context", Letter to Ukraine Environment Minister, 2013, see https://www.ecoclubrivne.org/files/Espoo13.pdf

[12] Oda Becker Kurt Decker Gabriele Mraz, "NPP South Ukraine Lifetime Extension EIA, Expert Statement", Report REP-0774, translation and edit by Patricia Lorenz, Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology, Directorate VI/9 General Coordination of Nuclear Affairs Vienna 2021, see https://www.umweltbundesamt.at/fileadmin/site/publikationen/rep0774.pdf

[13] Energoatom, "SS "South-Ukraine NPP", 5 March 2022, see https://www.energoatom.com.ua/en/about-6/separated-59/npp_su-62

Ukraine. Those risks have been exponentially increased as a consequence of the unlawful actions of President Putin.

Background

There are three Russian VVER-1000 reactors (units 1-3) at the Yuzhnoukrainsk site, each with a generating capacity of 950 MWe. Unit 1 is V-302 design reactor, unit 2 V-338 and unit 3 V-320 reactor, with a total electrical power of 3000 MW. Yuzhnoukrainsk units 1 and 2 are designed to consist of two circuits with water-cooled water-moderated reactors VVER-1000 (respectively of the V-302 and 338 design) operating with pressurised water with an electrical power of 3000 MW.[14] The designs of units 1 and 2 are of identical design and have similar reactor facilities, layout and arrangements. Yuzhnoukrainsk unit 3 is developed according to WWER- 1000/V-320 standard design and is similar to the Zaporizhzhya units 1-6.

As of 2017, there were 946 assemblies weighing 409 tons Heavy Metal(tHM) of spent fuel in the pools of the Yuzhnoukrainsk reactors.[15]

The town of Yuzhnoukrainsk is located at a distance of 2.5 km from the Yuzhnoukrainsk reactors. The town of Voznesensk (at a distance of 30 km) and several urban-type settlements and villages are located within the 30-km area. The nearest major city situated beyond the borders of the 30 km area is the regional centre, Mykolayiv, located at a distance of 112 km from the Yuzhnoukrainsk site. The Yuzhnoukrainsk reactors are on the left bank of the Yuzhny Bug river, at a distance of approximately 159 km from its estuary. From south to north, the territory of the Yuzhnoukrainsk nuclear plant site is crossed by the Tashlyk water reservoir. From north-west to south-east the Yuzhny Bug river flows 60 km through the 30 km area. The nearest main building (unit 1) is 2.7 km from the river bank.

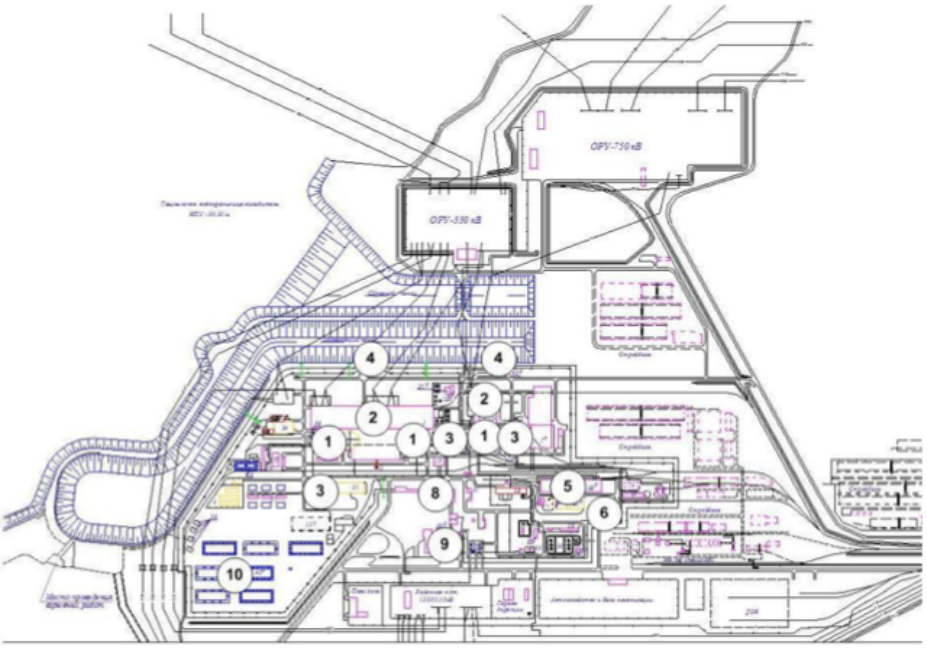
The Yuzhnoukrainsk nuclear plant is owned by the State Enterprise “National Nuclear Energy Generating Company Energoatom” (SE NNEGC), or Energoatom. SE South Ukraine Nuclear Power Plant or SUNPP is a separate entity of Energoatom.

Yuzhnoukrainsk (South Ukraine) Nuclear Power Plant

[14] State Nuclear Regulatory Inspectorate, “Ukraine National Report On Stress Test Results”, 2011, https://www.ensreg.eu/sites/default/files/National%20Report%20of%20Ukraine.pdf

[15] IAEA, “Ukraine National Report: On Compliance with Obligations under the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management”, 2017, see https://www.iaea.org/sites/default/files/national_report_of_ukraine_for_the_6th_review_meeting_-_english.pdf

SUNPP	Reactor type	Start of construction	Start of commissioning	End of design lifetime
Unit 1	VVER-1000/302	01/03/1977	22/12/1982	02/12/2013
Unit 2	VVER-1000/338	01/10/1979	06/01/1985	12/05/2015
Unit 3	VVER-1000/320	01/02/1985	20/09/1989	10/02/2020



1 – RPV
2 – Turbine hall
3 - DG
4 – unit pump station
5 – radwaste treatment building
6 – solid radwaste storage facility
7 – annexe buildings
8 – lab and services buildings
9 – office buildings and check point
10 – spray cooling pond

Yuzhnoukrainsk nuclear power plant site, Energoatom, 2015.[16]

Strategic importance of Ukraine's nuclear plants

In Russia's war on Ukraine, nuclear power plants and other large electricity generating plants, are both military and strategic targets.

[16] Energoatom, "Safety Justification South Ukraine NPP Power Units, Operational Lifetime Extension, Over the Design Period", Non Technical Summary, 2015, Energoatom, see https://www.umweltbundesamt.at/fileadmin/site/themen/energie/kernenergie/verfahren/ukraine/uvp_zaporoshe_suedukr/rnkh_ovns_juuaes_2015_eng.pdf

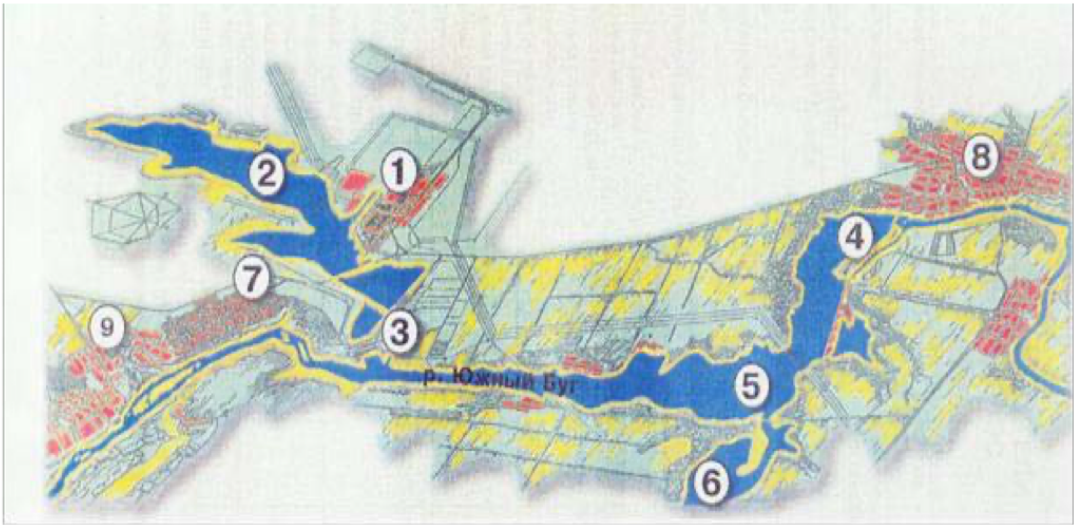


Fig. 2.3. – the South-Ukraine Power and Hydro Complex.
1 – South-Ukraine NPP; 2 – Tashlyk cooling pond; 3 - Tashlyk PSP;
4 – Olexandrivka hydrosystem; 5 – Olexandrivka water storage reservoir; 6 – Prybuzhzhia water storage reservoir;
7 – Yuzhnoukrainsk town, 8 – Olexandrivka village; 9 – Kostyantynivka village

Energoatom, 2015.[17]

Together the Yuzhnoukrainsk reactors, the Alexandrovka hydroelectric power plant (HPP), and the Tashlyc storage plant (SP) are the core of the South-Ukraine Electric Power Producing Complex (EPCC). It is the only facility in Ukraine with multi-purpose use of nuclear power as baseload combined with pump-storage capacities for electricity generation. Annually the EPPC at the river Yuzhnyi Bug produces 17-20 billion kWh of electric power, which is about 10% of total electric power production in the country and about 20% of Ukraine's nuclear generating capacity. The electric power produced by the Yuzhnoukrainsk reactors, Alexandrovka HPP and Tashlyc SP is sufficient to provide electricity for the Mykolaiv Region, Odessa Region, Kherson region, and the Crimea.

The Yuzhnoukrainsk reactors at the EPCC, as with those at Zaporizhzhia, clearly are of national strategic significance. "The Russians understand that energy is a massive tool of power," said R. Scott Kemp, a professor of nuclear science at M.I.T. "It's a point of tremendous leverage."[18] Intentional changes in the power output of the Zaporizhzhia complex, he said, "can essentially cause the whole country to lose its clean water, the pumping of gas, the refrigeration of food and electrical power needed for the communications of the military and the government. It's a serious vulnerability."[19]

Ukraine is currently disconnected from the Russian, Belarusian and EU electricity grids.[20] Ukraine in recent years has been seeking to improve its energy security, including

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[17] Op.Cit. Energoatom, 2015.
[18] Valerie Hopkins and William J. Broad, "Combat at Ukraine Nuclear Plant Adds Radioactive Dangers to Russian Invasion" 4 March, 2022, New York Times, see https://www.nytimes.com/2022/03/04/science/ukraine-nuclear-power-plant.html
[19] Ibidem.
[20] Suriya Jayanti, "Ukraine's Electrical Grid Shows How Hard It Is to Escape from Russia's Grasp", TIME, 1 March 2022, see https://time.com/6153039/ukraines-electricity-grid-escape-russia/

synchronisation with the European Union's electricity grid.[21] This would end its dependence on frequency maintenance, which is organised by the Russian grid operator. It thus has depended on the Russian electricity system, even when there is no electricity trade between the two countries.[22] Ukraine's connection to the European grid would deprive Moscow of the opportunity to use this dependence to exert political influence in Kyiv. The Russian military seizure of the Zaporizhzhia site, and potentially the Yuzhnoukrainsk nuclear reactors, as well as other key energy infrastructure (the Kyiv hydroelectric plant and a hydroelectric plant in Nova Kakhovka are also being taken targeted)[23] is aimed at securing Russian control over a large part of Ukraine's electricity system. Securing southern Ukraine's electricity generation stations – nuclear, hydro, and others, also can be considered laying the conditions for future Russian annexation of the whole region.

One conclusion is that to secure these strategic assets the objective of Russian military attacks on Zaporizhzhia was not to cause damage but to take control. If the Russian military wanted to destroy the Zaporizhzhia reactors it would be able to do so, and the ground based military attack on 3-4 March was aimed at securing the reactors, not their destruction. The same could be about to occur at Yuzhnoukrainsk, but any military assault carries enormous risks.

Major safety and security risks in war

- **Loss of off-site power and emergency diesel generators**
- **Spent fuel**
- **Working conditions and personnel**
- **Design and ageing related safety**

Loss of off-site power and emergency diesel generators

An operational nuclear power plant requires at all times electricity supply to power pumps and water supply to cool its nuclear fuel, both in the reactor core and in the adjacent spent nuclear fuel pool. Reliable connection to the local electricity grid is an essential and fundamental requirement for nuclear power plant safety. In time of war none of that can be guaranteed. There are already reports from Ukraines SNIRU of damage to the grid in the Zaporizhia region at Vasylivka, approximately 50km from the Zaporizhzhia nuclear plant, warning that as of 8 March 2022, **"the 750 kV high-voltage line remains disconnected due to the damage occurred on 6 March 2022 in the area of Vasylivka settlement", during fierce fighting.[24] Damage to the off-site grid has also been reported at the Chornobyl nuclear plant as a result of Russian military air attacks, with SNRIU reporting on 6 March, "that the fragility of the electrical supplies to the site, with only one supply line out of**

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[21] Government of Ukraine, "Energy Security", March 2022, see https://www.kmu.gov.ua/en/reformi/ekonomichne-zrostannya/reforma-energetichnogo-sektoru
[22] Op.Cit. Suriya Jayanti, 2022.
[23] Kyiv Indendent, "The enemy intends to capture the dam of the Kaniv HPP - General Staff", 6 March 2022, see https://www.pravda.com.ua/news/2022/03/6/7328655/, and, Business Standard, "Nova Kakhovka has fallen to Russia: Ukraine media", 27 February 2022, see https://www.tbsnews.net/world/nova-kakhovka-has-fallen-russia-ukraine-media-377014
[24] SNRIU, "Zaporizhzhia NPP, status update", 10.00hrs, 8 March 2022, see https://snriu.gov.ua/en/news/zaporizhzhya-npp-status-update

three available and back-up diesel power having sufficient fuel supplies for only 48 hours."[25] Chornobyl lost all off site electrical power on the morning of 9 March 2022. Its diesel generators have sufficient fuel for 48 hours of operation.[26]

In the case of an operating nuclear plant, even when the reactor is shut down, there is an enormous amount of residual heat in the fuel core which requires continuous cooling. Without it , the water in the reactor core (and spent fuel pool) begins to heat. In the case of an operational reactor the heating is rapid. The water reaches the boiling point and begins to evaporate, and the hot nuclear reactor fuel assemblies are at risk of being exposed to air which then could lead to a thermal reaction of the nuclear fuel assembly cladding and reactor core fuel melt. In the case of nuclear fuel in the spent fuel pool, the highly exothermic chemical reaction is called a runaway zirconium oxidation reaction or autocatalytic ignition, with resultant release of a very large volume of radioactivity.

In March 2011, the magnitude 9.0 seismic event in Japan led to the loss of site power at the Fukushima Daiichi nuclear plant – the site was no longer connected to the grid. The tsunami that then struck the plant flooded it, including Emergency Diesel Generators (EDGs) and their fuel supply, all needed to power the cooling pumps.[27] All three reactor cores that were in operation at the time of the earthquake and flooding inevitably and rapidly melted down.

Loss of Off-site Electrical Power (LOOP) requires the immediate and reliable operation of emergency diesel generators. There are indications that the same problems of replacement parts for these generators exist at the Yuzhnoukrainsk reactors as they do at Zaporizhzhia. In 2018, Energoatom signed a memorandum for direct cooperation with the French division of the Finnish company Wärtsilä - Wärtsilä Franc. Prior to this, "Energoatom tenders for the supply of sets of spare parts for the (Russian supplied) Z40 diesel generator running at Yuzhnoukrainsk reactors were exclusively attended by intermediaries."[28]

As with the Zaporizhzhia reactors, the Yuzhnoukrainsk diesel generators should have been upgraded under the Complex Consolidated Safety Upgrade Programme (CCSUP) of Energoatom, financed by a Euratom (EIB) and EBRD loan of 600 Mln EUR. The EBRD is the lead in this programme. In this programme, the diesels should have received modern electronic controls. The final date of completion of the CCSUP has been put back from 2017 to 2023.

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[25] ENSREG, "Statement on the safety of nuclear installations in Ukraine following the military aggression by Russia", European Nuclear Safety Regulators Group, 6 March 2022, see https://snriu.gov.ua/storage/app/sites/1/uploaded-files/ENSREG%20Statement%20Ukraine%206%20March%202022.pdf

[26] SNRIU, "Facilities of SSE "Chornobyl NPP", current situation as of 13:00 09.03.2022", see https://snriu.gov.ua/news/obyekti-dsp-chornobilska-aes-potochna-situaciya-stanom-na-1300-09032022

[27] Diet of Japan, "The National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission", 2012, https://warp.da.ndl.go.jp/info:ndljp/pid/3856371/naiic.go.jp/wp-content/uploads/2012/09/NAIIC_report_lo_res10.pdf

[28] Interfax Ukraine, "Energoatom agrees on cooperation with Finnish maker of diesel generator sets Wärtsilä" 3 November 2018, see https://en.interfax.com.ua/news/economic/544533.html

In the post Fukushima stress tests analysis of the Yuzhnoukrainsk reactors, it was disclosed that the reactors were at different stages of completing required safety upgrades, including to emergency power supply systems.[29] In the case of units 1 and 2, measures had been taken to use mobile diesel generators and pumping units (MDGPUs) for alternative emergency power supply, makeup of steam generator (SGs) and spent fuel pools (SFPs) and emergency water supply to safety relevant critical equipment. While for unit 3, as of 2021, improvement of the emergency power supply in long-term loss of power was not yet complete.

However, the design of unit 3 additionally provides for a common-unit reliable power supply system including two trains with independent diesel generators and batteries.

Spent fuel at the Yuzhnoukrainsk

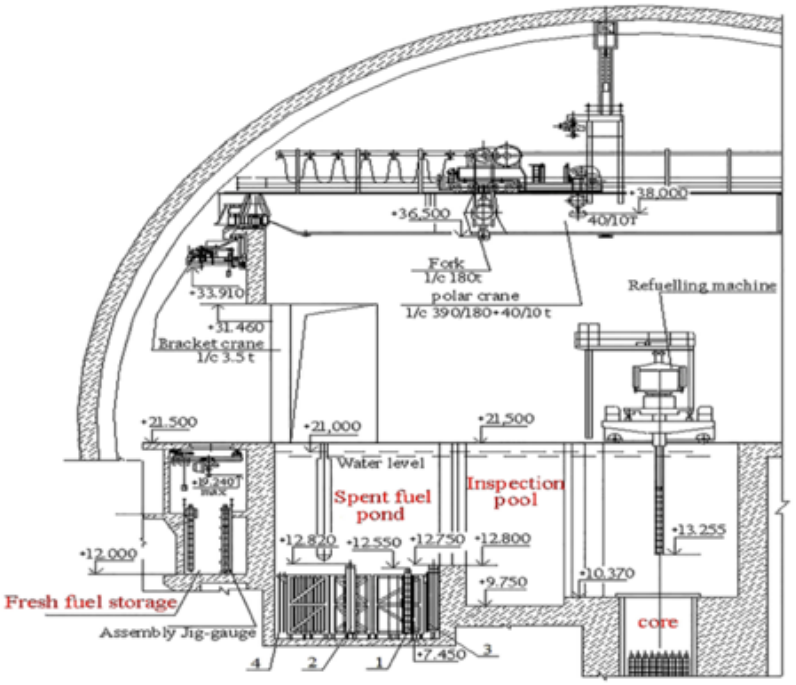
The spent fuel from the Yuzhnoukrainsk reactors is stored in pools inside the reactor containment, for 4-5 years for cooling. Annually, the Yuzhnoukrainsk reactors remove 42 fuel assemblies from each reactor core to the spent fuel pool. The annual refuelling of the Yuzhnoukrainsk nuclear plant is about 126 assemblies.[30] Each assembly weighs 430kg of heavy metal, therefore 18 tons of heavy metal (tHM) of spent fuel is generated each year at the Yuzhnoukrainsk plant. As of 2017, there were 946 assemblies weighing 409tHM of spent fuel in the pools of the Yuzhnoukrainsk reactors. The Yuzhnoukrainsk plant has both Russian supplied nuclear fuel and TVS-WR design fuel from Westinghouse, the latter is manufactured in Västerås, Sweden.[31] Reactor unit 3 is fully loaded with Westinghouse fuel as of 2018.[32]

[29] Op.Cit. Oda Becker, 2021.
[30] Op.cit. Energoatom 2015.
[31] Op.Cit. NucNet, 2021.
[32] WNN, “South Ukraine 3 fully loaded with Westinghouse fuel”, 20 July 2018, see https://www.world-nuclear-news.org/UF-South-Ukraine-3-fully-loaded-with-Westinghouse-fuel-20071801.html

Annex 2. Inventory of Spent Fuel as of 1 July 2017

Material	Location	Number of SFAs	Weight of heavy metal, t
VVER-1000 SFAs	KhNPP Unit 1	433	184.75
VVER-1000 SFAs	KhNPP Unit 2	491	212.56
VVER-440 SFAs	RNPP Unit 1, 2	1217	146.47
VVER-1000 SFAs	RNPP Unit 3	508	212.45
VVER-1000 SFAs	RNPP Unit 4	421	177.79
VVER-1000 SFAs	SUNPP Unit 1	270	117.29
VVER-1000 SFAs	SUNPP Unit 2	252	111.09
VVER-1000 SFAs	SUNPP Unit 3	424	180.82
VVER-1000 SFAs	ZNPP Unit 1	326	141.32
VVER-1000 SFAs	ZNPP Unit 2	305	131.65
VVER-1000 SFAs	ZNPP Unit 3	356	153.82
VVER-1000 SFAs	ZNPP Unit 4	334	144.77
VVER-1000 SFAs	ZNPP Unit 5	363	157.25
VVER-1000 SFAs	ZNPP Unit 6	299	129.25
VVER-1000 SFAs	ZNPP DSFSF	3354	1349.87
RBMK-1000 SFAs	ChNPP ISF-1	21284	2396.111
Research reactor VVR-M SFAs	NRI	0	0
Research reactor IR-100 SFAs	SUNEI	0 *	0

For the storage of spent nuclear fuel, we need to distinguish between the smaller pool adjacent to the nuclear reactor and the larger longer term storage (dry storage) outside the containment. The pool's in the case of the Yuzhnoukrainsk reactors are located inside the reactor containment building (see image below), where the very hot spent fuel is cooled during 4-5 years after being unloaded from the reactor building (see image below).



VVER-1000/320 reactor containment showing location of spent fuel pool[33]

The spent fuel pool Yuzhnoukrainsk units 1 and 2 are housed in the reactor containment and consists of two compartments: assembly compartment designed for storage of spent fuel assemblies and the container compartment provided with a stationary rack and multi-purpose slot that is used as the area for loading of transport casks with spent fuel assemblies and unloading of a fresh fuel assembly casing. Dividing the spent fuel pool into compartments allows for maintenance in one of them while spent fuel assemblies are placed into the other. The spent fuel pool is adjacent to the reactor pressure vessel (RPV).

Significance for Yuzhnoukrainsk reactors

The vulnerability of a spent fuel pool strongly depends on key parameters such as the burnup of the fuel and especially how densely the fuel is racked inside the spent pool, and how recently the latest batch was unloaded from the reactor into the pool. Burn-up is a critical factor, and refers to the amount of energy generated with one tonne of nuclear fuel, which is equivalent with the amount of radioactivity in the fuel and its residual heat generation. This is one of the principle factors that determines the heat generation of the fuel and the radiological inventory. It is given as Gigawatt days per ton of heavy metal - GWd/tHM.

Comparing the Fukushima-Daiichi-4 pool inventory with the VVER-1000 pools and how fast the cooling water would evaporate in case of a long power outage, is complex, given the many variables, and beyond the scope of this briefing. So the analogy with the spent fuel at Fukushima Daiichi-4 is only a rough indication of the risks at the Yuzhnoukrainsk and other nuclear power plants.

The amount of spent fuel in each of the pools at the three Yuzhnoukrainsk reactors ranges from 117-180 tons as of 2017, and in total 409 tons of spent fuel are in the three pools. This is the latest publicly available data we have access to. It is not possible without precise data to say what the radiological inventory is of this spent fuel, however, in our review of the scientific and technical literature of the past two decades it appears that the average fuel burn-up of the nuclear fuel used over the last 20 years at Ukraine's VVER 1000 reactors is 44-49GWd/tHM.[34] This is comparable, and perhaps higher, than the nuclear fuel in the pools at Fukushima Daiichi.

In the event of a loss of cooling and resultant fire in any one of the spent fuel pools at Yuzhnoukrainsk, as well as at Zaporizhzhia, has the potential for a very large release of radioactivity which would have a devastating effect not only on Ukraine but also its neighbouring countries, including Russia, and potentially, depending on the weather conditions and wind directions, on a large part of Europe. Again, it should be stressed that in the event of such a catastrophic event, the entire Yuzhnoukrainsk power plant might have to

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[33] VVER-1000/V446 spent fuel pool risk assessment and support through portable mitigating equipment N. Afshar a, A. Pirouzmand a,b,⇑, F. Faghihi, 2021, Annals of Nuclear Energy 156 (2021), see 108204, https://www.sciencedirect.com/science/article/pii/S0306454921000803

[34] This is data for the Zaporizhzhia plant, we have yet to confirm those for Yuzhnoukrainsk, IAEA, International Conference on the Storage of Spent Fuel from Power Reactors, 2003, see https://www-pub.iaea.org/MTCD/Publications/PDF/csp_020c/Start.pdf

be evacuated and a cascade of similar accidents at the other two pools as well as the other two reactors might take place.

Working conditions and personnel

"The presence of armed enemy troops on the territory of Zaporizhzhya NPP and in Enerhodar negatively affects the possibility of inter-shift rest of the plant personnel and significantly increases the probability of errors during operation, which can lead to severe radiation consequences."
- State Nuclear Regulatory Inspectorate of Ukraine, 5 March 2022.[35]

The conditions for thousands of nuclear power plant workers within the Ukraine, as with the entire population of Ukraine, is horrific. The chaos, suffering, death and injury, and destruction inflicted on millions of people as result of war is beyond comprehension of these authors. There is no business as usual at Ukraine's nuclear plants. As of 12.00 local time 8 March 2022, the Yuzhnoukrainsk nuclear plant is under civilian control of the Ukrainian operator Energoatom. But the workers have seen what has happened at Chornobyl[36] and Zaporizhzhia, and they know they are likely to be a target for the Russian military.

In a scenario where there would be a technical disruption, which could be for instance the electricity grid failing, some of the diesel generators not starting up properly, you would need the ability to quickly mobilise vast amounts of equipment and additional personnel, such as fire brigades or crane operators. The example of Fukushima again demonstrated the need to be able to bring in heavy equipment such as massive cranes and specialised crane operators, fire brigades, heavy pumps etc. Every technical disruption, for whatever reason, could require a major logistical operation at a nation-wide level which could be severely compromised through the war activities around the power plant.

Clearly an armed assault on any nuclear plant carries a major risk. The very fact that the nuclear plants of Ukraine are operating under a full-scale war launched by Russia has the potential for catastrophic impacts. Added to that are the threats to the lives of workers and plant security which is horrific enough, but what about in the coming days, weeks, months? For example, on 5 March, Energoatom reported that staff at the Chornobyl nuclear plant under the control of Russian forces had not been permitted to leave the site since 23 February and without being able to rotate the shift of technical personnel and guards, the regulator said.[37] In the case of Zaporizhzhia the head of the national operator Energoatom, Petro Kotin, informed the IAEA Director General on 4 March that the plant was now allowed to change work shifts.[38]

Olena Pareniuk of the National Academy of Sciences of Ukraine has warned that, "The most dangerous thing for the (Zaporizhzhia) plant is when people do not go on rotation,", a

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[35] State Nuclear Regulatory Inspectorate of Ukraine, "Current situation on ZNPP", 5 March 2022, see https://snriu.gov.ua/en/news/current-situation-znpp
[36] Also known by alternative spelling 'Chernobyl'
[37] IAEA, "Update 12 – IAEA Director General Statement on Situation in Ukraine", 5 March 2022, see https://www.iaea.org/newscenter/pressreleases/update-12-iaea-director-general-statement-on-situation-in-ukraine
[38] Ibidem.

nuclear safety expert at the National Academy of Sciences of Ukraine. “They get tired. But to work at the nuclear plant is like to be a surgeon, it is important for people to be rested and not stressed to avoid mistakes.”[39]

As communications between Ukraine’s nuclear regulator, SNRIU and the plant workers break down, a vital nuclear safety function is being removed. What will be the impact on the ability of workers to do work under conditions that are not in any way normal, and what authority will they have to make decisions? As a result of the Russian military control of the six reactors at Zaporizhzhia and operational decision to be made by plant management is only possible with the prior approval of the Russian military commander.[40] What will be the short, medium and long term effect of the enormous physical and mental stress they will be under to continue to maintain the safe operation and control of the reactors? The SNRIU has already warned that at Zaporizhzhia, “any psychological pressure on NPP personnel and interference in their work has a negative impact on nuclear and radiation safety!”[41]

The war conditions outside the Zaporizhzhia nuclear plant are such that the basic necessities for life – food, water, access to medical facilities all are missing or under threat, and with dire consequences for the families of the nuclear workers.

This is a uniquely terrible reality for these workers, their families and for the people of Ukraine and Europe. It should not need stating, but it would be wholly wrong to think that the Ukranian nuclear plants can be operated safely under Russian military control, and any reassurances from Moscow should not be considered credible.

Greenpeace has much to criticise of the role of the International Atomic Energy Agency (IAEA) in its active global promotion and advocacy of nuclear power, the flawed safety assessments that have been used to justify the continued operations of ageing reactors, including in the Ukraine, and deep ties to the nuclear industry, including Rosatom, the Russian state nuclear company responsible for nuclear power and nuclear weapons. However, Director General Grossi is absolutely right to, “repeatedly stressed the importance of staff operating Ukraine’s nuclear facilities being allowed to rest and rotate in order to be able to carry out their jobs safely and securely.” He has also said that a “tense” situation with Russian forces controlling the Zaporizhhzhya NPP site and Ukrainian staff operating it “certainly cannot last for too long”.[42] But how long ?

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[39] Valerie Hopkins and William J. Broad, “Combat at Ukraine Nuclear Plant Adds Radioactive Dangers to Russian Invasion”, 4 March 2022, New York Times, see https://www.nytimes.com/2022/03/04/science/ukraine-nuclear-power-plant.html

[40] IAEA, "Update 13 – IAEA Director General Statement on Situation in Ukraine", 6 March, 2022, see https://www.iaea.org/newscenter/pressreleases/update-13-iaea-director-general-statement-on-situation-in-ukraine

[41] Op.Cit. SNRIU, 8 March.

[42] Ibidem.

Safety at ageing reactors

Ukraine's operating nuclear plants were designed in the 1980s and, like the VVER-1000 reactors, only partly meet modern design principles concerning redundancy, diversity and physical separation of redundant subsystems or the preference of passive safety systems.

In 2021, the Yuzhnoukrainsk reactor units 1-3 exceeded their design lifetimes by up to eight years. However, Ukrainian regulators had granted lifetime extensions for all three reactors. As such the decision to issue licence extension was done in violation of European legislation, ESPOO which requires trans-boundary Environmental Impact Assessments (EIAs) be conducted before the licensing process is completed (ESPOO CONVENTION 1991, Art. 2.3).

Table 1: SUNPP data and licenses (SUNPP Non-technical Summary 2015, p. 12; https://www.sunpp.mk.ua/en/energocomplex/perspectives, seen 2021-07-09)

Unit No.	Start of commercial operation	Design operation period in years	End of design life	License issued until
SUNPP 1	1982-12-31	30	2013-12-02	2022-12-02
SUNPP 2	1985-01-09	30	2015-05-12	2025-12-31
SUNPP 3	1989-09-20	30	2020-02-10	2030-02-10

NPP South Ukraine Lifetime Extension EIA[43]

"The EU Stress Tests had revealed as early as 2011 that Ukrainian NPPs are compliant only with 172 of the 194 requirements according to the IAEA Design Safety Standards published in 2000. Implementation of necessary improvements is under way in the framework of the ongoing Comprehensive (Integrated) Safety Improvement Program (C(I)SIP). The completion of the program was postponed several times. As of March 31, 2021, still a high number of measures are awaiting implementation. In spite of some progress, the program ran into a long delay. As lead author of the assessment of Ukraine's stress tests and EIA concluded, "From a safety point of view, it is incomprehensible that the completion of the measure was not a prerequisite for the lifetime extension."[44]

There are major concerns over maintaining containment integrity under severe accident conditions remains an important issue for accident management. Filtered containment venting is a well-known approach to prevent containment overpressure failure, but it is not implemented at unit 3 of the SUNPP yet. Furthermore, there is no system for cooling and stabilising a molten core for the SUNPP available. In the framework of the Stress Tests a strategy for possible corium confinement within the reactor pressure vessel has to be analysed by 2023. The deadline was postponed from 2015. It is not known whether there will be any result, which would lead to the implementation of an appropriate measure.

[43] Op.Cit. Becker, 2021
[44] Op.Cit. Becker, 2021.

As far as can be seen from the documents provided and available, many identified safety shortcomings requiring upgrades have not yet been implemented and therefore there is a higher probability that accident scenarios will develop into a severe accident that threatens the integrity of the containment and results in a large release.

The results of the EU Stress Tests have revealed many shortcomings in the prevention of severe accidents and the mitigation of its consequences. One characteristic of nuclear safety in the Ukraine is the constant severe delay of the implementation of upgrading measures.

Safety issues

Ukraine's nuclear power plants were in crisis before the Russian military invasion in February 2022, due in part to severe shortage of financing for safety upgrades, and the weakening of nuclear regulation during the last years. These have safety implications for the current situation where one nuclear plant is under military control, with the likelihood that the Yuzhnoukrainsk plant will come under attack.

For several years from October 2014, Ukraine did not have a chief inspector for nuclear and radiation safety. As the former Chornobyl nuclear power plant director, Mikhail Umanets warned in 2016, "The position was eliminated, and no self-respecting professional would agree to take it after the cabinet proposed a bill to Ukraine's parliament which stated that 'the inspector's decisions may be cancelled by the head of the state regulator or his designated representative".[45] Umanets calculated that within seven years, Ukraine will face a "collapse" in its nuclear energy sector, since it does not have the necessary funds to maintain or expand the plants' operations.

In 2016, the head of the non-governmental organisation, Atominfo-Centre, warned of safety risks at Ukraine's reactors noting that, "Ukraine's nuclear power units are mostly Soviet-made. Their 30-year life span is coming to an end. To extend their operation and put them in order, funds are required. If there is no money, Kyiv has only two options: either extend the life of the power units, ignoring the lack of necessary maintenance, at their own risk, or taking the units offline, resulting in power outages."

Like other nuclear reactors in the Ukraine, Energoatom has attempted to reduce its dependence on Russian supplied nuclear fuel. This has led to contracts with Westinghouse for the manufacture and supply of nuclear fuel assemblies, including for the Yuzhnoukrainsk plant.[46] "Nuclear fuel is being placed in Russian (designed) reactors without the consent of the chief designer…We have no right to play around when it comes to safety – no way, no matter what political aspects exist. One 'Chornobyl' was enough for us," said former Chornobyl nuclear power plant director, Mikhail Umanets.[47]

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[45] Ibidem.

[46] NucNet, "Ukraine / Westinghouse And Energoatom Sign Contract For Fuel Assembly Documentation", June 2021, see https://www.nucnet.org/news/westinghouse-and-energoatom-sign-contract-for-fuel-assembly-documentation-6-1-2021

[47] NEI, "Ukraine looks to NPP life extension amid safety concerns", 24 August 2016, see https://www.neimagazine.com/news/newsukraine-looks-to-npp-life-extension-amid-safety-concerns-4988062