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GLOBAL NUCLEAR THREATS CAUSED BY RUSSIA'S INVASION OF UKRAINE (AT THE PLACE OF FOREWORD)

Abstract. *The four-month experience of russia's invasion of Ukraine has already shown the failure of the world security system, primarily the system of nuclear safety and security. And although this is a future subject of research for decades, preliminary conclusions and urgent issues can already be drawn today. Ukraine is a nuclear state having most of constituents of the nuclear fuel cycle. Half of the electricity produced in Ukraine comes from nuclear power plants. During the wartime russian troops permanently bombarded, shelled and occupied nuclear facilities in Ukraine. The largest in Europe Zaporizhzhia NPP and the most worldwide dangerous radioactive contaminated Chornobyl Exclusion Zone were occupied in the very beginning of the russia's invasion. Russia's nuclear terrorism led to the radioactive contamination of the atmosphere, fire at the nuclear facilities sites and within radioactive contaminated areas. From all sources of man-made radioactivity, the main amount of artificial radioisotopes (more than 90 %) is concentrated in the spent nuclear fuel (SNF). SNF "wet" and "dry" storage facilities built from concrete are considerably more vulnerable than nuclear reactors designed to withstand high pressure, aircraft, and ballistic missile hits. The amount of radioactivity in SNF facilities in Chornobyl and Energodar corresponds to about 1,000,000 nuclear bombs dropped on Hiroshima. Russia's terrorists and looters do not need to fire nuclear missiles. A radioactive cloud that could form from the thousands of Chornobyl emissions released from occupied SNF facilities may destroy the Earth's Biosphere. The international organizations aimed to provide security for nuclear facilities in wartime were impotent to fulfill statutory functions. The modern system of military defense in the World is not able to provide Global Safety and Security. To prevent the global nuclear catastrophe the system of nuclear safety and security requires cardinal overhaul by urgent solution of a number of engineering, technical, environmental and socio-political problems.*

Key words: *russia's invasion, nuclear terrorism, nuclear looting, "dirty" nuclear bomb, fires, nuclear safety and security, spent nuclear fuel, shelling and occupation of nuclear facilitis, IAEA.*

Introduction

The russian invasion of Ukraine has completely changed the worldview of the entire population of the planet. Civilization has never been so close to collapse. The four-month experience of this war has already shown the failure of the global security system, primarily nuclear safety and security. And although this is a future subject of research for decades, preliminary conclusions and urgent issues can already be drawn today.

Nuclear power plants, civilian research reactors, certain naval fuel facilities, uranium enrichment plants, fuel fabrication plants, and even uranium mines are vulnerable to attacks which could lead destruction of the facilities and spreading of radioactivity over vast territories. The vulnerability of nuclear plants to a deliberate attack is of concern in the area of nuclear safety and security. The attacks can be of several general types: ground-based attacks of commando units on the facilities and equipment, external attacks such as an aircraft crash into a reactor complex, or cyber attacks [1]. They all can lead to a global catastrophe.

The United States 9/11 Commission has said that nuclear power plants were potential targets originally considered for the September 11, 2001 attacks. If terrorist groups could sufficiently damage safety systems to cause a core meltdown at a nuclear power plant, and/or sufficiently damage spent fuel pools, such an attack could lead to widespread radioactive contamination [2].

Nuclear reactors become preferred targets during a military conflict and, over the past three decades, they have been repeatedly attacked during military air strikes, occupations, invasions and campaigns [3].

Terrorists could target nuclear power plants in an attempt to release radioactive contamination into the community. According to the 2004 Annual report of the U.S. Congressional Budget Office, "The human, environmental, and economic costs from a successful attack on a nuclear power plant that results in the release

of substantial quantities of radioactive material to the environment could be great" [4]. An attack on a reactor's spent fuel pool could also be serious, as these pools are less protected than the reactor core. The release of radioactivity could lead to thousands of near-term deaths and greater numbers of long-term fatalities [1].

Ukrainian nuclear facilities

There are five nuclear power plants in Ukraine. Zaporizhzhia, PivdennoUkrainsk (South Ukrainian), Rivne and Khmelnytsky NPPs are still in operation and the Chornobyl NPP is decommissioned. At present, 15 units are in operation at four NPPs (Table 1). Twelve of them are located in the Dnipro River basin, which provides water supply to almost 70 % of the Ukrainian population. This fact raises the Tritium problem, since the Ukrainian water standard for Tritium exceeds the EU standard by 300 times and the US standard by 40 times.

Table 1. Nuclear Energy in Ukraine

Number and type of the power unit	Total electric power, 10^6 kW	Start of construction	Beginning of operation	Planned ceasing of operation, year
Zaporizhzhia NPP (ZNPP)				
N 1 – WWER-1000	1000	04.1980	10.12.1984	2015[1]
N 2 – WWER-1000	1000	04.1981	02.07.1985	2016[2]
N 3 – WWER-1000	1000	04.1982	10.12.1986	2017[3]
N 4 – WWER-1000	1000	01.1984	18.12.1987	2018[4]
N 5 – WWER-1000	1000	07.1985	14.08.1989	2019
N 6 – WWER-1000	1000	06.1986	19.10.1995[5]	2025
PivdennoUkrainsk NPP (PUNPP)				
N 1 – WWER-1000	1000	03.1977	31.12.1982	2015[5]
N 2 – WWER-1000	1000	10.1979	06.01.1985	2019[6]
N 3 – WWER-1000	1000	02.1985	20.09.1989	2010
Rivne NPP (RNPP)				
N 1 – WWER-440	440	08.1976	22.12.1980	2010[7]
N 2 – WWER-440	440	10.1977	22.12.1981	2011[8]
N 3 – WWER-1000	1000	02.1981	21.12.1986	2016[9]
N 4 – WWER-1000	1000	05.1984	16.10.2004	2035
Khmelnytsky NPP (KhNPP)				
N 1 – WWER-1000	1000	11.1981	22.12.1987	2018[10]
N 2 – WWER-1000	1000	1983	08.08.2004	2035
Chornobyl NPP (ChNPP)				
N 1 – RBMK-1000	1000	06.1972	26.09.1977	1996[11]
N 2 – RBMK-1000	1000	02.1973	21.12.1978	1991[12]
N 3 – RBMK-1000	1000	05.1977	03.12.1981	2000[13]
N 4 – RBMK-1000	1000	1980	10.11.1983	1986[14]

Notes:

1 – The service life has been extended to December 23, 2025 (decision of State Nuclear Regulatory Inspectorate of Ukraine (SNRIU) of September 13, 2016).

2 – The service life has been extended to February 19, 2026 (decision of SNRIU of October 3, 2016).

3 – The service life has been extended to March 5 2027 (decision of SNRIU of November 3, 2017).

4 – The beginning of operation of the 6th Unit of ZNPP was planned for 02.04.1997.

5 – The service life has been extended to December 2, 2023 (decision of SNRIU of December, 2013).

6 – The service life has been extended to December 31, 2025 (decision of SNRIU of December, 2015).

7 – The service life has been extended to 22.12.2030.

8 – The service life has been extended to 22.12.2031.

9 – The service life has been extended to 11.12.2037.

10 – Work is underway to extend the service life.

11 –The unit was stopped on November 30, 1996 for decommissioning.

12 – The unit was stopped on November 30, 1996 for decommissioning.

13 – The unit was stopped on December 15, 2000 for decommissioning (Resolution of the Cabinet of Ministers of Ukraine N 598 of 29.03.2000).

14 – The unit was destroyed in the accident on 26.04.1986.

After the shutdown of the Chornobyl power units, the total electric power of four Ukrainian NPPs was 13.8 million kW, which is 21.94 % of the total energy capacity of the country.

In addition to nuclear power plants, there are other nuclear objects such as: two research reactors WWR-M (Institute of Nuclear Research of the National Academy of Sciences of Ukraine, Kyiv) and IR-100 (Sevastopol Institute of Nuclear Energy and Industry); a subcritical assembly "Neutron Source" in Kharkiv; the "Shelter" Object, a wet storage facility of spent nuclear fuel ISF-1 and a dry cask storage facility ISF-2 in the Chornobyl Exclusion Zone; a dry storage facility for spent nuclear fuel at the Zaporizhzhia NPP site; six interregional special facilities (ISFs) for radioactive waste disposal; five mining complexes and two hydrometallurgical plants for uranium processing; and about seven thousand enterprises using radioactive substances, radioisotope devices and sources of ionizing radiation which total to about 100 thousand units. More than 20 uranium deposits have been explored in Ukraine. At two of them – Ingulsky and Smolinsky – the ore is mined now. Novokostiantynivske deposit is ready for industrial mining (Fig. 1).



Fig. 1. Location of the radiation hazardous facilities on the territory of Ukraine

Russian attack and occupation of nuclear facilities

On February 24, 2022 russian military forces occupied the Chornobyl Exclusion Zone and took control over:

– Chornobyl NPP site;

– spent nuclear fuel wet and dry storage facilities located at the Chernobyl NPP site;

– "Shelter" Object;

– Chornobyl Exclusion Zone (ChEZ) with radioactive biotic and abiotic environment;

– radioactive waste disposal and interim storage facilities located in ChEZ.

On March 4, 2022 russian troops shelled the Zaporizhzhia NPP, that caused fire on the site, and took control over the largest in Europe Nuclear Power Plant (city of Energodar) and spent nuclear fuel dry storage facility at the Zaporizhzhia NPP site.

Also after direct missile attacks, bombings, and artillery shellings, the following objects were damaged ~~at~~ to a varying degree:

– surface radioactive waste repositories in Kyiv and Kharkiv;

– subcritical assembly "Neutron Source" in Kharkiv.

An attempt was made to seize the South Ukrainian nuclear power plant.

There are about 1,200 sources of ionizing radiation at the Ukrainian territories that were occupied in 2014, including:

– a nuclear reactor in Sevastopol (Crimea);

– Donetsk radioactive waste storage facility. The protection barriers were damaged by shell explosion in 2014;

– the flooded "Young Communard" mine ("Klivazh" facility), where underground nuclear tests were carried out by the USSR in 1979 for peaceful purposes.

The most dangerous nuclear facility in the world was occupied on February 24, 2022

The 4th power unit of the Chornobyl NPP exploded in 1986. It has been covered with Sarcophagus and recently with a new safe Confinement. In 1986, only 3-4 % of the irradiated nuclear fuel was released into the environment. The rest of it was localized inside the Sarcophagus (Table 2). But even this relatively small emission led to global pollution of vast territories not only in Ukraine, Belarus and Russia, but also in most Western and Northern European countries. Radioactive particles of the Chornobyl origin were scattered around the world and were detected in the air by Japanese researchers.

"Compared with other nuclear events: The Chernobyl explosion released 400 times more radioactive material into the Earth's atmosphere than the atomic bomb dropped on Hiroshima. Atomic weapons tests conducted in the 1950s and 1960s all together are estimated to have put some 100 to 1,000 times more radioactive material into the atmosphere than the Chernobyl accident" [5].

The radioactivity released at Chernobyl is more long-lived than that released by a bomb explosion. Hence, it is not possible to draw a simple comparison between the two events. Also, a dose of radiation spread over many years (as is the case with Chernobyl) is much less harmful than the same dose received over a short period. The relative size of the Chernobyl release is from 25 (by ^{131}I) to 890 (by ^{137}Cs) times more when compared with the release due to a hypothetical ground burst of a bomb similar to the Fat Man device dropped on Nagasaki.

The part of the nuclear fuel, which remained in the damaged power unit (> 96 %), has undergone

Table 2. The main dose-forming radionuclides in the ChNPP 4th power unit and assessment of the environmental release (Calculated according to [6])

Radionuclide	Half-life	Accumulated activity, Bq as of 26.04.1986	Activity release, Bq*	Content in the environment as of 26.04.2021
^{90}Sr	28.80 years	$2.3\cdot10^{17}$	$1.00\cdot10^{16}$	4.31×10^{15}
^{131}I	8.02 days	$3.1\cdot10^{18}$	$1.76\cdot10^{18}$	Completely decayed
^{137}Cs	30.17 years	$2.6\cdot10^{17}$	$8.50\cdot10^{16}$	$1.51\cdot10^{16}$
^{238}Pu	87.71 years	$1.3\cdot10^{15}$	$1.50\cdot10^{13}$	$1.14\cdot10^{13}$
^{239}Pu	24.113 years	$9.2\cdot10^{14}$	$1.30\cdot10^{13}$	$1.30\cdot10^{13}$
^{240}Pu	6. 564 years	$1.5\cdot10^{15}$	$1.80\cdot10^{13}$	$1.79\cdot10^{13}$
^{241}Pu	14.4 years	$1.8\cdot10^{17}$	$2.60\cdot10^{15}$	$4.82\cdot10^{14}$
^{241}Am	432.6 years	$1.6\cdot10^{14}$	@$4.80\cdot10^{12}$	$2.15\cdot10^{15}$

** – estimation error 50 %.*

fundamental changes over the past 35 years. Due to the radioactive decay of Plutonium-241, the content of one of the most dangerous from the medical and biological point of view isotope of Americium-241 has increased in more than 400 times, amounting now up to $1.47\cdot10^{17}$ Bq. Radiation destruction and dispersion of the irradiated nuclear fuel led to formation of hundreds of tons of dusty high-volatile particles. Each particle of micrometer size if being inhaled can cause mortality.

SNF wet storage facility at the Chornobyl NPP site

About of 21,000 fuel assemblies unloaded from the 1, 2 and 3 Chernobyl power units were stored in the wet repository for spent nuclear fuel after shut down of the Unit 3 on December 15, 2000. This makes about 8,500 tons of spent nuclear fuel with a total activity of up to $2.5\cdot10^{20}$ Bq (as of 2001). Now 19,442 fuel assemblies are stored here.

During 6 days (March 9-14, 2022), the wet SNF (ISF-1) at Chernobyl NPP site was disconnected from the electricity supply. Since the fuel removal, most short-lived isotopes have decayed. The temperature inside the assemblies does not exceed 250 °C and the assemblies can be kept for a long time without cooling.

However, as it is published in IAEA documents and scientific papers, hydrogen is released during the spent nuclear fuel storage as a result of radiochemical reactions [7-9].

Under normal conditions, the gas emissions are discharged through a forced ventilation system. Without electricity supply, the ventilation system stops working and hydrogen accumulates in the premises. At a ratio of hydrogen:oxygen 2:1, an explosive mixture is formed which can be exploded by just one spark. As it is known, it was as a result of accumulation of an explosive mixture that the Chernobyl and Fukushima reactors exploded causing global nuclear catastrophes..

At present, the content of the most dangerous from the medical and biological point of view radionuclides ^{137}Cs and ^{90}Sr in the ISF-1 at the Chernobyl NPP (taking into account the decay) is about $2.0\cdot10^{19}$ Bq and $1.5\cdot10^{19}$ Bq, respectively. This is 60-80 times more than there was accumulated in the 4th Chernobyl power unit at the time of the accident. And it is from 240 (^{137}Cs) to 1500 (^{90}Sr) times more than was released into the environment due to the Chornobyl catastrophe. Now the amount of the stored radioactivity is three orders of magnitude higher than the released by the Chornobyl accident in 1986.

Contaminated ecosystems within Chornobyl Exclusion Zone

From the very beginning, russian troops moved through the most radioactively contaminated territories. Radioactive dust raised by military hardware caused air pollution. This had been observed by the automatic radiation monitoring system (Fig. 2), which was damaged on the morning of February 25. By the red dots, which indicate exceeding of the control levels, located along the transport routes, one can trace the ways of russian troops movement. The radioactive contamination of the near-surface layer of the atmosphere measured by the authors on the northwestern outskirts of Kyiv doubled on February 25.

Table 2. At present, radionuclide storage in natural and artificial objects within ChEZ* Calculated according to the data: [10-12]

Objects	Activity, $n\cdot10^{15}$ Bq			
	Total Activity	^{137}Cs	^{90}Sr	TUE**
Biotic and abiotic environment within ChEZ	4,60	3,10	1,37	0,13
Cooling pond of ChNPP	0,15	0,09	0,05	0,005
Radioactive waste disposal facilities in ChEZ	3,60	1,91	1,53	0,15
Temporary localization point for radioactive waste in ChEZ	1,04	0,62	0,38	0,04
Totally ChEZ, excluding damaged unit	9,39	5,72	3,34	0,33
"Shelter" Object	349	76,5	92,5	180
SNF wet facility	4050	2000	1500	~550

* Sources utilized for calculations [10-12]

** Now 81.5% of Transuranium elements activity is corresponded to ^{241}Am

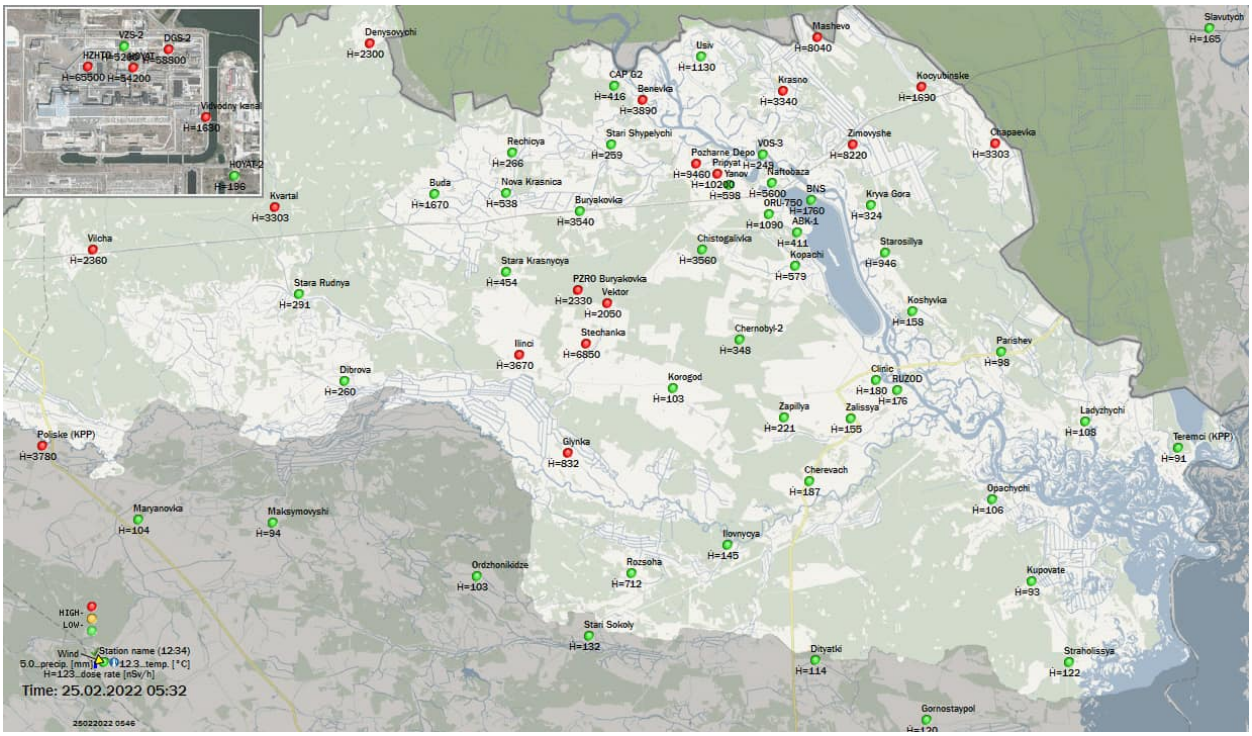
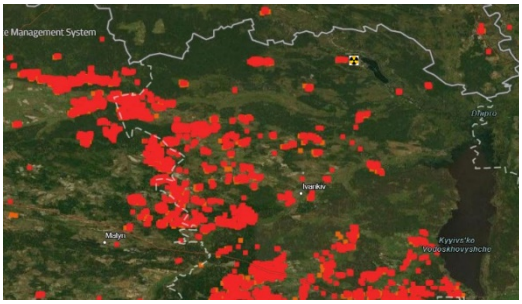
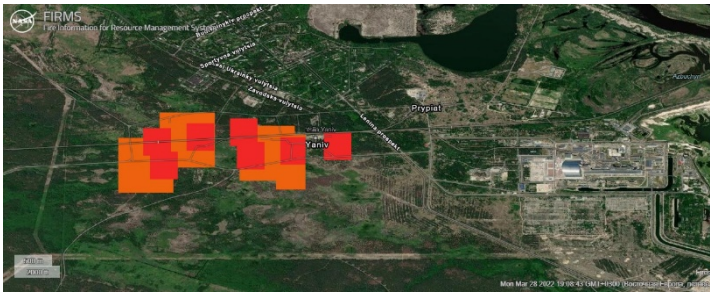


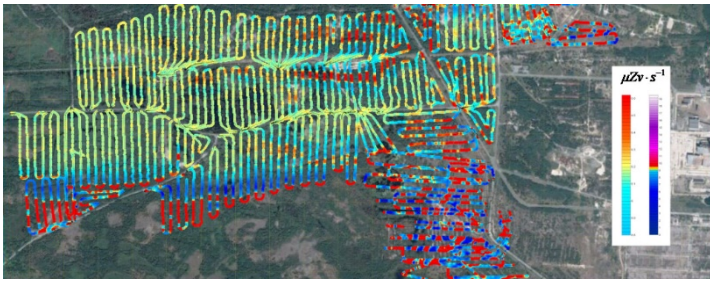
Fig. 2. The record of the automatic radiation monitoring system at 5.32 AM on February 25, 2022 (received from the State Nuclear Regulatory Inspectorate of Ukraine). Red dots indicate exceeded control levels.



a



b



c

Fig. 3. Fires within radioactive contaminated areas during March 11-29, 2022 (a); "Red Forest" site fire on March 27-29 (b) [13]; radioactive contamination of "Red Forest" site (c) (our data from 2021).

Radioactive lands in fire

From March 11 to 29 fires covered more than 1,000 square kilometers of radioactive contaminated lands of Ukrainian Polissia, including the most contaminated forests and meadows of the Western Heritage in Narodychi and Polisske districts (Fig. 3a). Ukrainian firefighters were not allowed to put out the fire.

The predominant wind direction (WSW) during this period was towards Belarus and Russia.

On May 27, a fire broke out near the Chernobyl NPP site. A fire in 2 kilometers from the destroyed Chernobyl reactor, at the "Red Forest" site covered 2,000 hectares in 5 hours (Fig 3b). "Red Forest" is the most radioactively contaminated area in the World.

The bottom map (Fig. 3c) shows the test results of a remote radioactive radiation detector installed at a DRON. This is a technique developed at the Institute of Environmental Geochemistry of NAS of Ukraine,

and tested in 2021. The trenches (in red) with disposed trees died from radiation in 1986 are very well identified.

In the chaos of the russian occupation, russian looters raided two labs in Chornobyl and, apparently, stole radioactive isotopes used to calibrate instruments and samples of radioactive waste. These were powerful sources of gamma and neutron radiation that were used to test devices, as well as intensely radioactive samples of material left from the Unit Four meltdown. The fate of these sources that can be used for "dirty bomb" construction is unknown, so the thieves would spread contamination over a vast area [14].

The russian troops occupied the NPP (city of Energodar)

Chornobyl is not the only Ukrainian nuclear installation at risk in the war. On March 4, Russian forces shelled the Zaporizhzhia nuclear power plant (ZNPP), fortunately missing its reactor halls. The bombarding caused fire at the ZNPP site. Fortunately, it was eliminated by Ukrainian firefighters.

The NPP, which has been operating since 1984 and has 6 WWER-1000 power units, is the largest nuclear power plant not only in Ukraine but also in Europe.

The NPP is located 400 km southeast of Kyiv in the steppe zone on the Kakhovka Reservoir shore. The regional center – the city of Zaporizhzhia is located in 55 km northeast of the NPP. The closest city is Energodar.

In the 30 km zone, there are 59 settlements: 27 in Zaporizhzhia region, 30 in Dnipropetrovsk region and 2 in Kherson region.

The sanitary protection zone of the Zaporizhzhia NPP is within a 3 km radius. The observation area is a circle with a radius of 30 km.

The design features of the WWER-1000 reactors at the Zaporizhzhia NPP provide physical protection against an aircraft crash. Though it is obvious that any nuclear facility can be damaged (as evidenced by Fukushima's experience). But the most dangerous can be a terrorist attack aimed at the storage of spent nuclear fuel located at the territory of ZNPP.

Since March 4, the personnel of the NPP has been working under the pressure of occupational troops. The power units are carefully monitored ensuring their safe operation in accordance with the requirements of the technological regulations. Regular monitoring of the site is carried out to identify the damage. The state of the Zaporizhzhia NPP power units was as follows:

- Power unit 1: scheduled repairs.
- Power units 2, 3: disconnected from the grid .
- Power unit 4: connected to the grid, electric power 690 MW.
- Power units 5, 6: shut down.

Cooling of the nuclear fuel at the Zaporizhzhia NPP power units was provided by the cooling systems of the units in accordance with the requirements of the technological regulations for safe operation. Damage of the cooling system will lead to significant release of radioactivity into the environment, as it happened in Fukushima. Such event may exceed the impact of all previous accidents at NPPs, including the accidents at the Chornobyl and Fukushima-Daichi nuclear power plants.

Now the russian army is transforming Europe's largest nuclear power plant into a military base overlooking an active front, intensifying a months long safety crisis for the vast facility and its thousands of staff. At the ZNPP, there are more than 500 Russian soldiers who have deployed heavy artillery batteries and laid anti-personnel mines along the shores of the water-cooling reservoir. The carefully regulated atomic-energy industry has never seen before the slow-motion transformation of a nuclear power station into a military garrison. In a lesser-scrutinized aspect of its war strategy, the russian army is day-by-day positioning the weaponry around a nuclear plant that is among the world's largest, using it to cement control of the front line where their advance through southern Ukraine ground to a halt." – informs The Wall Street Journal [25].

In addition to the six power units at the Zaporizhzhia NPP site, there is a spent nuclear fuel storage facility. Destruction of the facility caused by bombarding will lead to a global nuclear catastrophe.

Radioactive nuclides formed as a result of electricity generation at the NPP are mainly contained in the spent nuclear fuel stored in special repositories on the territory of the NPP's industrial sites. The Ukrainian Government planned that since 2020 Ukraine would stop sending the spent nuclear fuel (SNF) from the Ukrainian nuclear power plants to Russia for recycling, and store it in a centralized repository of the spent nuclear fuel in the Chornobyl Exclusion Zone.

For 20 years from 2001, SNF has been accumulated in a dry storage facility at the Zaporizhzhia NPP site. Each year, 42 fuel assemblies are unloaded from the WWER-1000 (PVR of 1000 MVt capacity) power unit, which makes 17 tons. The specific activity of one assembly after 3-year exposure is $3 \cdot 10^{16}$ Bq/t. During one year, $5.1 \cdot 10^{17}$ Bq of radioactive materials come from each of the six power units. From this activity $8.16 \cdot 10^{16}$ Bq accounts for ^{137}Cs and $5.95 \cdot 10^{16}$ Bq for ^{90}Sr.

Simple calculation shows:

The SNF from the 6 WWER-1000 power units of the Zaporizhzhia NPP that has been accumulated in the dry repository during 20 years contains more than $6 \cdot 10^{19}$ Bq of long-lived radionuclides including $9 \cdot 10^{18}$ Bq ^{137}Cs and $7 \cdot 10^{18}$ Bq ^{90}Sr (taking into account the decay). This is over 30 times more than it had been accumulated in the IVth power unit of the Chornobyl NPP at the time of the accident. This is 100 times more than the amount of ^{137}Cs and 700 times more than that of ^{90}Sr that was released from the Chernobyl NPP unit 4 as a result of the accident in 1986. The storage of TUE (more than 75 % of ^{241}Am) is assessed to be $1.25 \cdot 10^{18}$ Bq.

The 3 WWER-1000 power units of the Yuzhnoukrainsk NPP (Mykolaiv region) during more than four months are under a permanent terrorist attack.

"Radon" radioactive waste storage facilities

There are 6 radioactive waste storage facilities (RWSFs) in Ukraine governed by interregional special enterprises (ISE). They are designed to collect and dispose of radioactive waste that is not related to the nuclear fuel cycle. At the moment there are such RWSFs: Dnipropetrovsk, Kyiv, Lviv, Odessa and Kharkiv. Donetsk RWSF was shut down in 1965. According to data available on 2010, these RWSFs contain radioactive waste (solid (RW), liquid (LRW) biological (BRW) and ionizing radiation sources (IRS) with a total activity of about 1,000,000 Ci ($3.7 \cdot 10^{16}$ Bq). The characteristics of RWSFs and wastes stored in them are given in Table 3.

Around midnight on February 28, as a result of a bombing raid near the village of Pirogovo close to the Kyiv radioactive waste storage facility, there was a powerful explosion which damaged the integrated automated radiation monitoring system "Nuvia" and no information could be received from it. The storage facilities containing $2.7 \cdot 10^{16}$ Bq of radioactivity remain at risk of destruction.

The amount of radioactivity in the Kharkiv radioactive waste storage facility is $3.5 \cdot 10^{14}$ Bq. The storage facilities are under permanent threat of destruction. At present, the work of the automated radiation control system at the Kyiv and Kharkiv facilities has been restored. There is no data on the damage to the near-surface radioactive waste storage facilities themselves and probable leakage of radioactivity from them.

Beginning from the February 24 all "Radon" facilities in Ukraine containing totally a 1,000,000 Ci of radioactivity have been attacked by russian nuclear terrorists.

On March 6 a rocket attack damaged a research subcritical assembly the "Neutron Source" used to generate neutrons for experiments at the Kharkiv Institute of Physics and Technology. The attacks have been repeated. Fortunately there was no nuclear accident.

Thousands of other sites in Ukraine have radioactive materials. Most of them are under the watchful eye of the Ukraine's nuclear regulator.

IAEA's assistance and support on nuclear safety and security

"The safety and security of Ukraine's nuclear facilities remains my top priority," said the IAEA Director

Table 3. Characteristics of "Radon" RW interregional facilities in Ukraine

№	Facility	Operational date	Storage	Total activity, Ci (Bq)	Nuclides
1	Kharkiv ISE	1961	SRW – 16 LRW– 3 HLW – 2	9443 ($3.5 \cdot 10^{14}$)	^{3}H
					^{137}Cs
					^{60}Co
					^{90}Sr
					^{239}Pu
2	Dnipropetrovsk ISE	1962	5 underground concrete vaults	147781 ($5.5 \cdot 10^{15}$)	^{3}H
					^{137}Cs
					^{60}Co
					^{90}Sr
					^{239}Pu
					^{170}Tm
					^{210}Po
3	Kyiv ISE	1962	SRW – 6	733285 ($2.7 \cdot 10^{16}$)	^{3}H
					^{241}Am
					^{137}Cs
			LRW – 5		^{60}Co
			HLW – 2		^{192}Ir
					^{239}Pu
					^{226}Ra
4	Donetsk ISE (under preservation from 1965)	1959	7 simple banked silos	280 ($1.0 \cdot 10^{13}$)	^{226}Ra
					^{232}Th
5	Odesa ISE	1962	14 underground silos	60513 ($2.2 \cdot 10^{15}$)	
6	Lviv ISE	1962		7115 ($2.6 \cdot 10^{14}$)	^{3}H
					^{137}Cs
					^{60}Co
					^{90}Sr
					^{238}U
					^{192}Ir
					^{210}Po

General Mariano Grossi in Update 76 – IAEA Director General Statement on Situation in Ukraine from May 17, 2022 [15]. Starting from the February 24, he more than 75 times officially "stressed a deep concern on the conflict in Ukraine". At the same time, he considers that during the occupation and attacks of nuclear facilities by the military aggressor "the primary responsibility for nuclear safety rests with national authorities" [16].

On February 24, "Ukraine has informed the IAEA that "unidentified armed forces" have taken control of all facilities of the State Specialized Enterprise Chornobyl NPP, located within the Exclusion Zone" [17]. The IAEA assesses that the readings reported by the regulator – of up to 9,46 microSieverts per hour – are low and remain within the operational range measured in the Exclusion Zone since it was established, and therefore do not pose any danger to the public [18].

Relating to the attack of surface nuclear storage facilities in Kyiv and Kharkiv, the Director General said: "While these disposal sites do not contain high-level radioactive waste, the stored and disposed radioactive waste can still cause a serious radiological impact event, underlining the necessity to protect them". He praised the SNRIU and staff at the affected facilities for their vigilance and courage in ensuring continued safety and security [19].

On March 1, IAEA Director General said "Earlier this week, Ukraine's Foreign Ministry informed the IAEA that Russian military forces were advancing close to the largest of the sites – the Zaporizhzhia Nuclear Power Plant (NPP) in eastern Ukraine" [20].

On March 2, "Russia has informed the International Atomic Energy Agency (IAEA) that its military forces have taken control of the territory around Ukraine's Zaporizhzhia Nuclear Power Plant (NPP)" In an official letter to the Director General dated 1 March, the Permanent Mission of the Russian Federation to the International Organizations in Vienna also said personnel at the plant continued their "work on providing nuclear safety and monitoring radiation in normal mode of operation. The radiation levels remain normal" [21].

On March 4, "Ukraine informed the International Atomic Energy Agency (IAEA) that the site of the Zaporizhzhia Nuclear Power Plant (NPP) had been shelled overnight and Director General Rafael Mariano Grossi immediately spoke with Prime Minister Denys Shmyhal as well as the country's national nuclear regulator and operator about the serious situation [22].

On March 6, Ukrainian authority ***completely lost control*** over the Zaporizhzhia NPP. "Ukraine informed the International Atomic Energy Agency (IAEA) today that although regular staff continued to operate the Zaporizhzhia Nuclear Power Plant (NPP), the plant management is now under orders from the commander of the Russian forces that took control of the site last week, Director General Rafael Mariano Grossi said. Furthermore, Ukraine reports that any action of plant management – including measures related to the technical operation of the six reactor units – requires prior approval by the Russian commander" [23].

On March 14, Ukraine told the International Atomic Energy Agency (IAEA) today that a new nuclear research facility producing radioisotopes for medical and industrial applications had been damaged by shelling in the city of Kharkiv, Director General Rafael Mariano Grossi said. The national nuclear regulator said the incident did not cause any increase in radiation levels at the site. The facility in north-eastern Ukraine is used for research and development and radioisotope production. Because the nuclear material in the facility is always subcritical and the inventory of radioactive material is very low, the IAEA's assessment confirmed that the damage reported to it would not have had any radiological consequence, the Director General said [24].

On March 3, the Ukrainian Government appealed to the International Atomic Energy Agency (IAEA) asking to address NATO to close access of any aircrafts to the air space over the Ukraine's nuclear facilities and to intensify efforts to prevent nuclear terrorism, such as seizure of the Chornobyl Exclusion Zone and other nuclear objects by russian troops.

The Appeal was signed by German Galushchenko – the Minister of Energy of Ukraine, Oleg Korikov – the director of State Nuclear Regulatory Inspectorate and Petro Kotin – the director of NNEGC Energoatom.

As it is stated in the Appeal, the representatives of Ukraine insist on active actions of the IAEA directed at immediate ceasing fire and prevention of the Russian military forces coming into the 30-kilometer zone of the NPPs.

The authors stress that one shift of the Chornobyl NPP personnel has been working without rotation since occupation of the territory by russian troops. The personnel is stressed and exhausted, they work under constant pressure. Any communication and movement of the personnel about the territory is prohibited. This situation does not favor normal work and threatens their lives and health.

The authors emphasize that the russian federation completely ignores the principles of peace and security, which is the aim of creation of IAEA within the UN. They ask to ban the access of the russian federation to intellectual and technical resources of the agency, and to strengthen control over use of nuclear materials in this country.

They also insist on suspending any relations with all russian nationals responsible for the nuclear energy, who are employed in the UN structures. They also stressed that russia's military aggression, as a nuclear State, against Ukraine which the russian president putin cynically calls the "Special operation to enforce peace" destroyed the foundations of the international security system formed after the World War II.

Currently, the Administrative building of the Zaporizhzhia NPP and the plant's checkpoint are under the control of the russian occupiers. The personnel continue working ensuring the stable operation of all nuclear facilities. The radiation background is normal.

Employees of the Moscow Center of the World Association of Nuclear Power Plant Operators (WANO)

Andriy Lukyanenko and Anatoliy Vasylchuk addressed to their colleagues, partners and friends to tell the world the truth about the real threat to the nuclear power plants in Ukraine caused by the aggression of the russian federation

As you know, the World Association of Nuclear Operators (WANO) was established in 1989 after the Chernobyl accident to unite the efforts of nuclear operators to improve the safety and reliability of existing nuclear power plants around the world.

The members of the Association cooperate in the framework of various programs of its regional centers located in Moscow (Moscow Center), Paris (Paris Center), Atlanta (Atlantic Center) and Tokyo (Tokyo Center). The Focal Point of the Association is in London.

The Moscow Center comprises the nuclear power plants and operating organizations in Armenia, Belarus, Bulgaria, Hungary, India, Iran, China, Lithuania, Russia, Slovakia, Turkey, Finland, and the Czech Republic. Since 2022 Ukraine belongs to the Paris Center.

NNEGC Energoatom has been fruitfully cooperating with WANO for several decades and demonstrates full openness and readiness for partnership and exchange of experience with world nuclear power plants.

Unfortunately, the WANO leadership has not reacted to the war in Ukraine, and the IAEA has not taken any decisive action. None of the officials of russian nuclear energy industry has condemned the russia's criminal actions, and has not even expressed concern about the consequences of the bombarding.

According to the Law of Ukraine "About use of nuclear energy and radiation safety", "*a radiation accident is an event that results in loss of control over a nuclear facility or a source of ionizing radiation, which causes or may cause the exposure of humans and the environment to radiation that exceeds the permissible limits established by the safety standards and regulations*". This Law is fundamental in the nuclear legislation of Ukraine.

The radioactivity of the material that is under the risk of terroristic attack and russian occupation in Ukraine was amounts up to 1,000,000 dirty nuclear bombs dropped on Hiroshima and twice exceeds the atmospheric release from atomic weapons tests conducted in the 1950s and 1960s all together.

In spite of the daily statements of the Ukrainian nuclear regulator, official Governmental and Parliament authorities, IAEA disseminated the obviously unreliable data on the situation at the nuclear facilities in Ukraine and the nuclear threats in the context of the annexation of nuclear facilities by russian military troops.

In his daily Statements, IAEA Director General has not even mentioned that russia violated the UN Charter, the IAEA Charter, the resolution of the IAEA General Conference and a number of international law ratified by the governments of russia and Belarus, namely:

- The Convention on Early Notification of a Nuclear Accident,
- The Convention on Nuclear Safety
- Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management
- Agreement Between Ukraine and the International Atomic Energy Agency for the Application of Safeguards in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons
- According to The Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency "IAEA Director General Rafael Mariano Grossi stressed his continued concern about the conflict in Ukraine.."

Permanent "deep concern" of high-ranking diplomats is very close to the trajectory of the russian warship movement determined by the Ukrainian border guard.

During the russian attack and occupation of nuclear facilities in Ukraine, IAEA did not fulfill its statutory objectives on Nuclear Safety and Security «The Agency shall seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world. It shall ensure, so far as it is able, that assistance provided by it or at its request or under its supervision or control is not used in such a way as to further any military purpose".

So, National Committee for Radiation Protection of Ukraine applied to UN Security Council:

– to express a vote of no confidence in the Director General of the IAEA, Rafael Mariano Grossi,

– to suspend the membership of the russian federation in the IAEA and the work of the Permanent Mission of the russian federation to international organizations in Vienna;

– to remove from work in the IAEA citizens of the russian federation headed by the Deputy Director General of the IAEA and the head of the Department of Nuclear Energy Mikhail Chudakov;

– in order to prevent a global nuclear catastrophe, bring UN troops into the territory of Ukraine's nuclear facilities and ensure their protection from bombings, missiles, artillery strikes and terrorist acts.

American official sources speak about "speculation on the nuclear threat by the President Zelensky". But the above figures speak for themselves. Putin does not need to fire nuclear missiles. Putin today can make a thousand of Chornobyls just shooting into occupied nuclear objects and destroy all Europe! It might reach America. NATO has enough weapons to protect the world from russian nuclear missiles. But it will not be able to protect it from a radioactive cloud. This is evidenced by the experience of the Chornobyl and Fukushima.

Conclusion

Modern system of military defense in the World is not able to provide World Safety and Security. Experience has shown that the decision-making system for military assistance is too complex, complicated and time-consuming. However, while the vote is going on, putin will reach the English Channel.

The World system of Nuclear Safety and Security requires fundamental reconstruction. International organizations aimed to provide the security for nuclear facilities were impotent to fulfill statutory functions. International humanitarian organizations cowardly fled from the humanitarian disaster area.

The main amount of artificial radioactivity (more than 90 %) in the World is contained in the spent nuclear fuel. However the wet and dry concrete spent nuclear fuel facilities are less protected than the nuclear reactor facilities that are capable of withstanding an aircraft or a missile strike.

We are faced to a global nuclear catastrophe able to destroy the Earth Biosphere. To prevent this terrifying prospect, we must urgently create an international scientific consortium able to completely solve the global problem of nuclear safety and security in the wartime due to bombings, missile and artillery strikes, and terrorist acts at the nuclear facilities. This consortium has to solve engineering, technical, environmental and socio-political problems.

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ГЛОБАЛЬНІ ЯДЕРНІ ЗАГРОЗИ ВНАСЛІДОК РОСІЙСЬКОГО ВТОРГНЕННЯ В УКРАЇНУ (ЗАМІСТЬ ПЕРЕДМОВИ)

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Анотація. *Чотирьомісячний досвід російського вторгнення в Україну показав недосконалість системи світової безпеки, насамперед, ядерної безпеки. І хоча це предмет майбутніх досліджень на десятиліття, попередні висновки та нагальні завдання можна визначити вже сьогодні. Україна є ядерною державою, яка має більшість складових ядерного паливного циклу. Майже половина виробленої в Україні електроенергії, припадає на АЕС. Протягом війни російські війська постійно бомбардували, обстрілювали та окупували ядерні об'єкти України. Найбільша*

в Європі Запорізька АЕС і найнебезпечніша у світі радіоактивно забруднена Чорнобильська зона відчуження були окуповані на самому початку російського вторгнення. Ядерний тероризм Росії призвів до радіоактивного забруднення атмосфери, пожеж на проммайданчиках ядерних об'єктів та на радіоактивно забруднених територіях. З усіх джерел техногенної радіоактивності основна кількість штучних радіоізотопів (понад 90 %) зосереджена у відпрацьованому ядерному паливі (ВЯП). Сховища ВЯП «мокрого» і «сухого» типу, побудовані з бетону, значно вразливіші, ніж ядерні реактори, розраховані на вплив високого тиску, падіння літаків і балістичних ракет. Обсяг радіоактивності ВЯП у Чорнобилі та Енергодарі відповідає приблизно 1 000 000 ядерних бомб, скинутих на Хіросіму. Російським терористам і мародерам не потрібно стріляти ядерними ракетами. Радіоактивна хмара, яка може утворитися внаслідок тисяч «чорнобилів», зосереджених у ВЯП, що зберігаються на окупованих ядерних об'єктах, може знищити біосферу Землі. Міжнародні організації, покликані забезпечити безпеку ядерних об'єктів у воєнний час, виявилися неспроможними виконувати статутні функції. Сучасна структура світової системи воєнної оборони не в змозі забезпечити глобальну безпеку та захист. Для запобігання глобальній ядерній катастрофі система ядерної безпеки потребує кардинальної перебудови шляхом невідкладного вирішення низки інженерно-технічних, екологічних та соціально-політичних проблем.

Ключові слова: *російське вторгнення, ядерний тероризм, ядерне мародерство, «брудна» ядерна бомба, пожежі, ядерна та радіаційна безпека, відпрацьоване ядерне паливо, обстріл та окупація ядерних об'єктів, МАГАТЕ.*