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Impact of the War in Ukraine on Nuclear Waste Management in Arctic Russia

By Sergei Gladkov

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By Sergei Gladkov

Sergei Gladkov, M.A. (General History), works as a project researcher at the Pan-European Institute, Turku School of Economics, University of Turku, Finland. Previously, he worked as a consultant for the Maxwell Center, University of Cambridge, United Kingdom. His current research interests include environmental challenges for the Baltic Sea and the Arctic region.

Abstract

The objective of this report is to identify the changes that have occurred in the system of nuclear waste management in the Arctic territories of Russia. It is impossible to overstate the importance of the Arctic in the modern era. The economic, climatic, environmental and safety aspects of the Arctic are attracting increased attention from a variety of stakeholders. In considering the issues of radioactive waste management in Russia, it is essential to recon with the multicomponent nature of the nuclear power complex and the presence of a considerable number of nuclear legacy sites. The Russian nuclear industry, comprising both civilian and military operations, has amassed a considerable quantity of nuclear waste. A considerable proportion of this waste has accumulated in the Russian Arctic region, including on the seabed of the Arctic Ocean and its associated seas. Following the dissolution of the USSR, the Russian government has been engaged in the construction of a system for the management and ultimate elimination of radioactive waste and other issues related to the so-called 'nuclear legacy' for an extended period of time. International cooperation played a pivotal role in the development of this system. Foreign states provided substantial financial and technological assistance within the framework of various international structures. However, following the outbreak of the war in Ukraine, these ties were abruptly severed. Russia is now prioritizing economic projects for the utilization of nuclear energy in the Arctic, while environmental considerations have been largely overlooked. This approach poses a significant risk to the delicate ecological balance in the Arctic.

Key words: Russian Arctic, nuclear waste management, radioactive contaminants, war in Ukraine

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1. Introduction

The Russian Arctic, or the area situated to the north of the Arctic Circle, represents the most extensive Arctic zone in the world, extending over a distance of almost 5,000 kilometers along the Arctic Ocean from Kirkenes in Norway in the west to Anadyr near the Bering Strait in the east. In accordance with the definition set forth by the Russian government, the Arctic zone encompasses nine regions of the country, four of which are fully included, and five are partially included (Presidential Decree, 2014). This area is home to 2.6 million people, representing over half of the global Arctic population (Arctic Council, 2023).

The development of the Arctic has consistently been a significant area of focus for the USSR and modern Russia, particularly the Northern Sea Route along the Arctic coast and the western Arctic territories on the Kola Peninsula and in the waters of the Barents and Kara Seas. The utilization of nuclear technology in the Russian Arctic commenced in the early 1950s, with applications spanning both military and civilian domains. Russia's civilian nuclear infrastructure in the Arctic is the most advanced in the world and has been constructed to ensure the reliable provision of energy in challenging climatic conditions.

In general, nuclear power is used extensively in Russia. At present, the proportion of electricity generated by nuclear power plants in Russia is approximately 20 per cent of the total electricity produced. According to projections, this figure is anticipated to reach 25 per cent by 2045. As of 2023, 11 nuclear power plants (NPPs) with a total capacity of 30.6 gigawatts (GW) are in operation in Russia. Of these, three NPPs—two stationary and one floating—are situated in the Arctic territories (Rosatom, 2023b and c).

The deployment of nuclear power plants in the Arctic will soon be followed by the construction of numerous floating and mobile nuclear power plants, representing a novel development in the field of nuclear energy. The first such floating nuclear power plant, situated on the vessel Akademik Lomonosov, was commissioned in Russia in 2020 in Chukotka. Fifteen additional floating nuclear power plants are planned for utilization along the Northern Sea Route (Taimyr Telegraph, 2023). Additionally, there are plans to construct transportable land-based small modular reactors (transportable land-based small modular reactors) of in-house design and manufacture for the eastern part of the Russian Arctic (World Nuclear Association, 2021; Moshenets, 2024). Russia is not the only country to be considering the deployment of small modular reactors in Arctic territories, but its plans are more ambitious. For example, Norway is currently considering the construction of the first 600 MW small modular reactor (SMR) near Vardø, a remote Arctic island outpost situated in close proximity to the Russian border and facing the Barents Sea (Radowitz, 2024).

Russia is the sole nation in the world that both constructs and utilizes nuclear-powered icebreakers. These icebreakers are designed to facilitate navigation along the Northern Sea Route. Currently, there are seven such icebreakers, and one additional nuclear-powered light freight carrier (light freight carrier) (Savenkova, 2023; World Nuclear Association, 2021).

Additionally, the Russian Arctic is the location of numerous facilities pertaining to Russia's strategic nuclear forces. Russia's military nuclear infrastructure in this region is characterized by a high degree of diversity. In particular, the Kola Peninsula is the location of approximately two-thirds of Russia's naval nuclear strategic forces, nuclear submarine bases, and the headquarters of the Russian Northern Fleet. A number of nuclear bases belonging to the Air Force are located along the coast of the Arctic Ocean. In the northwestern region, there are facilities engaged in the construction of the nuclear fleet. A considerable number of nuclear submarines have been constructed and operated in the Russian Arctic (Kaspersky, 2019).

The utilization of nuclear technologies inevitably results in the generation of a plethora of radioactive wastes. These wastes are produced from the operation of nuclear reactors and their associated fuel cycle, the utilization of radioactive isotopes, industrial and research applications, and the manufacture and testing of nuclear weapons (Forsberg, 2003, p. 643; Gee et al., 2005).

At the early stages of their development, these technologies were not yet fully mature and the issue of nuclear waste management was not yet a priority. The practice of disposing of radioactive waste in the world's oceans was a common occurrence during the 1960s and 1970s. In 1983, the member countries of the London Convention (IMO, 1972) collectively decided to impose a moratorium on the dumping of radioactive waste into the seas. This moratorium was subsequently extended to a complete ban in 1993. In the Russian Arctic, liquid radioactive waste was discharged and solid radioactive waste was flooded from 1957 to 1993. Indeed, until the mid-1990s, the domestic nuclear industry existed in deferred decision mode. Consequently, a considerable quantity of radioactive waste has been accumulated on the territory of Russia throughout the period of nuclear technology utilization. By the beginning of the 21st century, the total volume of this waste was approximately 600 million cubic metres, including 515 million liters of liquid in over a hundred storage sites, a significant proportion of which are situated in the Arctic.

The majority of radioactive waste in the Russian Arctic is comprised of so-called 'nuclear legacy sites', amounting to approximately 17,000 tons as of 2018 (Rosatom, 2018). The term 'nuclear legacy' encompasses a range of radioactive waste materials that have been disposed of without adhering to the requisite safety standards, as well as the consequences of nuclear accidents and disasters, and the byproducts of nuclear weapons tests. In accordance with Russian legislation, the term 'nuclear legacy' is used to describe radioactive waste that was generated in Russia prior to the enactment of the federal law on radioactive waste management in 2011 (Russian government, 2011). In simplified terms, the nuclear legacy in the Russian Arctic comprises the remnants of the Soviet and Russian nuclear fleets and the basic nuclear infrastructure of these fleets. The transfer of these materials from the Russian Navy to the Russian Ministry of Atomic Industry (now Rosatom) commenced in 1998. As of 2002, the volume of liquid radioactive waste from the Russian Navy was approximately 330,000 cubic metres.

Given the location of the primary nuclear forces of the Russian Navy in the western Arctic, it is here that radioactive waste has been accumulated. Until 1993, the majority of this waste was disposed of in the Barents and Kara Seas, where approximately 18,000 objects of varying degrees of radiation hazard remain. In addition to containers of solid radioactive waste, there are three nuclear submarines that have sunk as a result of accidents, 16 nuclear reactors from submarines and icebreakers, 19 ships with solid radioactive waste on board, and hundreds of radioactive structures. Furthermore, numerous other structures, including blocks, are situated at the bottom of the Russian Arctic seas (Sarkisov et al., 2011; Nilsen, 2021; Russian Socio-Ecological Union, 2022). As a consequence of these factors, the western part of the Russian Arctic, and in particular the Kara Sea, has become one of the most radioactively contaminated areas in the world. The nuclear weapons tests conducted globally between 1950 and 1960, including those at Novaya Zemlya, have resulted in the sedimentary rocks surrounding the islands of the archipelago exhibiting considerable excesses in comparison to the global average radiation levels (Yushin et al., 2023).

In consideration of the nuclear legacy in the western Russian Arctic, the primary challenges that persist are as follows:

1. The storage of nuclear submarine reactors and liquid waste in Andreyeva Bay on the Kola Peninsula (Murmansk Oblast).

2. The storage facility for submarine cores with liquid metal coolant is located in Gremikha, within the boundaries of the Murmansk Oblast.

3. Storage facility for spent nuclear fuel from nuclear icebreakers (Atomflot, Murmansk Region).

4. Radioactive waste storage facilities at shipbuilding and ship repair enterprises on the Kola Peninsula (2) and in the Arkhangelsk Oblast on the White Sea coast.

Other sources of radioactive waste in the Russian Arctic include the still-evident effects of atmospheric fallout from the 1986 Chernobyl disaster, as well as periodic radioactive releases from nuclear infrastructure facilities via the Ob and Yenisei river basins (Gwynn et al., 2012). Additionally, the Russian Arctic may receive radioactive waste via rivers during spring floods in the Urals, where nuclear legacy storage facilities are situated. Environmental experts have expressed concern that the floodwaters could transport radioactive materials into the Ob River system, potentially reaching the Arctic Ocean (Nilsen, 2024b).

Furthermore, it has been established that radioactive discharges from spent nuclear fuel reprocessing plants in the United Kingdom and France (Sellafield, United Kingdom and Cap de la Hague, France) have reached the Russian Arctic (Sarkisov, 2019). The two plants in question represent the primary sources of radioactive contamination with cesium and iodine (cesium and iodine) in the waters of the Barents and Kara Seas. In comparison, Russian sources occupy a secondary position (Reiersen et al., 2024).

Nevertheless, the current level of radioactive contamination in the Russian Arctic remains stable and is predominantly attributable to natural sources of radionuclides. The region's ecosystems and human health are not currently at immediate risk, despite the presence of short-lived radionuclides in bottom sediments along the Barents Sea coast (Atomic Energy 2.0, 2020b; Yakovlev et al., 2023). For example, measurements made in 2007-2009 in the Barents Sea demonstrated that the level of radioactive contamination of water and biota had decreased by an order of magnitude (Gwynn et al., 2012).

The system of radioactive waste management in Russia has its origins in the development of the nuclear industry. However, prior to the dissolution of the USSR, the classification system did not encompass the numerous military facilities. Subsequently, a number of attempts were made to unify this system. It was only in the early 2010s that it was finalized.

The question of the future of radioactive waste in the Russian Arctic after the outbreak of the war in Ukraine and the change in the country's foreign policy remains open. Russia's new priorities for the development of the Arctic territories are based on the wide use of nuclear energy. However, in practice, they do not take into account the need to dispose of accumulated radioactive waste, but only declare such intentions.

2. Russian System for Managing Nuclear Waste

In order to comprehend the alterations that have transpired in the system of radioactive waste management in the Russian Arctic following the outbreak of hostilities in Ukraine, it is essential to consider the historical context of Russia's development over the past three to four decades. The evolution of the radioactive waste management system in Russia was markedly shaped by the shifts in the international landscape and domestic political developments that occurred during that period, most notably by the dissolution of the USSR.

The Chernobyl disaster of 1986 constituted a pivotal moment, precipitating swift and far-reaching changes in nuclear safety standards and engendering heightened scrutiny of radioactive waste management, including in the Russian Arctic. Prior to the Chernobyl disaster, the USSR was a signatory to the 1972 International Convention for the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (IMO) and also signed the 1980 International Convention on the Physical Protection of Nuclear Material (IMO). In 1986, the USSR became a party to the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency (IAEA, 1986a) and the Convention on Early Notification of a Nuclear Accident (IAEA, 1986b). Subsequently, between 1988 and 1995, the USSR and Russia, as its legal successor, signed additional bilateral treaties on the notification of nuclear accidents with three Nordic countries: Sweden, Norway and Finland. These treaties were extended by Russia just before the outbreak of the war in Ukraine, in 2019-2020 (Lysenko et al., 2022).

Towards the end of the Soviet Union's existence, the issue of environmental concerns in the Arctic led to the formation of agreements among the countries whose territories are located within the region. In June 1991, at the instigation of Finland, eight Arctic countries, including the USSR, appended their signatures to a strategy for the protection of the Arctic environment in Rovaniemi. Among other things, this strategy recognized radioactive waste pollution as a threat to the environmental security of the Arctic region (Arctic Portal Library, 1991). Subsequently, the number of international forums that have addressed the problems of Arctic pollution, including radioactive waste pollution, has increased (the Arctic Economic Council, the Arctic Coast Guard Forum, the Barents Euro-Arctic Council, the Conference of Arctic Parliamentarians and the Nordic Council). The efficacy of these international platforms was variable until the outbreak of the war in Ukraine, at which point Russia's participation was either excluded or significantly limited.

The evolution of international environmental collaboration has considered the challenges associated with the management of nuclear waste in the Arctic, encompassing both marine and terrestrial domains. In the 1990s, as interest in the problems of nuclear waste management in the Arctic increased, Russia joined the 1994 Convention on Nuclear Safety (IAEA, 1994) and the 1997 Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste (IAEA, 1997). The 1997 Convention constituted the world's initial international treaty regulating the management of radioactive waste and spent nuclear fuel derived from civilian (non-military) nuclear reactors.

Nevertheless, Russia's involvement in global environmental collaboration in this area has encountered significant challenges, predominantly due to inadequate financial resources and unresolved matters concerning the apportionment of accountability for nuclear waste management between the military and civilian sectors. These difficulties were reflected, in particular, in the fact that Russia only ratified the

1997 Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste in 2005, a full eight years after it was first adopted.

Concurrently with the evolution of international collaboration, the Russian legislative framework governing nuclear energy began to take shape. Consequently, in the mid-1990s and early 2000s, the Russian Federation adopted a series of federal laws, including the 'On the Use of Atomic Energy' (1995), 'On the Radiation Safety of the Population' (1996) and 'On the Environmental Protection' (2002) laws. It is noteworthy that a federal law 'On the Management of Radioactive Waste' was in development between 1992 and 1995. However, it was never signed by the President of Russia (Talevlin, 2009). Until 2011, there was no separate law on radioactive waste management in Russia.

The global landscape of nuclear waste management is characterized by three principal technologies. The first method is the reprocessing of nuclear fuel, the second is the temporary storage of liquid or solid radioactive waste in pools or containers, and the third is the final disposal of nuclear waste in deep geological storage facilities (Sanders and Sanders, 2019). Each country employs its own method of nuclear waste management, based on its own classification of such waste types according to their level of hazard, cost, necessity for transportation to the disposal site, and other factors.

A significant aspect of the nuclear waste management system in Russia is its long-term development, which has been shaped by the conceptual framework established during the Soviet era. This concept entails the storage or disposal of radioactive waste at the point of its generation, with the subsequent possibility of retrieval or extension of its storage life (Russian Socio-Ecological Union, 2022). The majority of countries have opted to store both spent nuclear fuel and radioactive waste in dedicated storage facilities. Russia is attempting to reprocess spent nuclear fuel and utilize the resulting plutonium to create new nuclear fuel. In certain instances, radioactive waste is subjected to thermal and other treatments prior to disposal, with the objective of reducing the quantity and concentration of harmful waste (Rosatom, 2023c). Additionally, Russia is engaged in the advancement and implementation of cutting-edge nuclear fuel management technologies, collectively referred to as 'closed nuclear fuel cycles' (Pradeep et al., 2023).

The establishment of a national radioactive waste management system was first attempted in Russia in the mid-1990s. However, this initiative ultimately failed due to a combination of insufficient funding and interagency confusion. The initial radioactive waste management program (Russian government, 1995) was adopted in 1995 for a ten-year period. However, its implementation was halted after five years due to the decision to consider radioactive waste as part of the integrated development of the country's nuclear power industry and radiation safety. In 2000, Russia adopted the 'Strategy for the Development of the Russian Nuclear Power Industry for the First Half of the XXI Century' (Russian government, 2000a) and the simultaneous federal target program 'Nuclear and Radiation Safety of Russia' for 2000-2006 (Russian government, 2000b). The Russian Nuclear Power Development Strategy acknowledged the issue of the accumulation of high-level and long-lived waste, as well as the necessity to develop technologies for a closed nuclear fuel cycle and low-waste reprocessing of nuclear fuel. However, the challenges pertaining to nuclear waste in the Russian Arctic and the 'nuclear legacy' were not addressed in these documents.

Following the ratification of the 1997 Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste in 2005, Russia was compelled to address the considerable volumes of radioactive waste that had already been accumulated. Consequently, the concept of eliminating the 'nuclear legacy' was introduced. Russia has only been engaged with nuclear legacy issues within the framework of international projects since the 2000s. At the G8 meeting in Kananaskis (Canada) in June 2002, a decision was taken to allocate $20 billion to finance a ten-year program for the disposal of Russian weapons of mass destruction, including nuclear submarines. This decision provided the impetus for, among other things, the start of funding for major projects to eliminate radioactive waste in the Russian Arctic (IAEA, 2002).

Until the mid-2000s, the radioactive waste management system in Russia was characterized by the use of mainly simplified technologies, the primary objective of which was to ensure the storage of radioactive waste. Furthermore, there was a notable lack of efficiency in the spending of allocated budgetary funds, as well as a distinct absence of differentiation of responsibility for the 'nuclear legacy' between enterprises and the state. Additionally, there were notable deficiencies in the financial and structural mechanisms that were in place to ensure the disposal of radioactive waste (Abramov and Dorofeev, 2017).

In 2007, the Russian leadership made the decision to consolidate all civilian nuclear facilities into a single state-owned corporation. Consequently, the state corporation Rosatom was established on the basis of the corporatized enterprises of the Russian nuclear industry. In order to achieve this objective, a specific federal law was enacted (The Federal Law 'On the State Atomic Energy Corporation - Rosatom', 2007, with subsequent amendments (2010-2021)) (The State Duma, 2007). Subsequently, Rosatom has assumed responsibility for the implementation of Russia's federal nuclear energy policy, encompassing the operation of nuclear power plants and the financing, control, and management of federally owned radioactive waste storage facilities. Currently, Rosatom's organizational structure comprises approximately 400 enterprises (Sanders and Sanders, 2019; Rosatom, 2023d).

From 2008 to the present day, Russia has had a federal target program entitled 'Ensuring Radiation Safety' and a further program, the so-called 'Fundamentals of the State Policy of the Russian Federation in the Arctic'.

The initial phase of the federal target program, 'Ensuring Radiation Safety' (2008-2015), was conducted in secrecy, with only the explanatory note and financial calculations made available to the public (Russian Government, 2008b). The program outlined plans for the reconstruction of temporary storage facilities and their conversion into near-surface disposal facilities for radioactive waste, the construction of new storage facilities, and the development of new technologies and facilities for waste processing and immobilization. The initial phase of the 'Principles of State Policy of the Russian Federation in the Arctic' (2008-2020) outlined the objective of concluding the rehabilitation of 'nuclear heritage' sites situated within the confines of the Russian Arctic territories (Russian government, 2008a).

Since 2008, Rosatom has been engaged in the construction of a system of enterprises at the final stage of the life cycle of nuclear- and radiation-hazardous facilities. From its inception, Rosatom has been responsible for a system of special industrial plants, namely Radon, which are engaged in the final stage of the life cycle of nuclear and radiation-hazardous facilities. These plants are involved in the collection, transport, processing and storage of radioactive waste (Atomic Energy 2.0, 2008). A network of facilities for the storage of radioactive waste was established on the basis of these special industrial plants, which were transferred to Rosatom. Solid radioactive waste storage facilities were also available at NPPs and at Russian nuclear industry enterprises, which were designated as 'nuclear heritage' sites.

The scale of the nuclear waste management tasks and the necessity to secure state funding compelled Rosatom's management to advocate for the enactment of a special federal law based on existing foreign experience. Therefore, the Russian integrated system of nuclear waste management, including facilities with a radioactive legacy, was established in its current form only after the adoption of the law 'On Radioactive Waste Management' in 2011 (Russian government, 2011). The reform was based on the concept of creating a unified state system of radioactive waste management based on the principle of their mandatory final isolation, as well as the establishment of structures responsible for radioactive waste management.

The establishment of a unified Russian state system for the management of radioactive waste commenced in 2012-2013 with the registration of radioactive waste storage sites and the quantification of their volumes throughout the country, in addition to the implementation of an expanded classification system for radioactive waste (Russian government, 2012; 2013a). Prior to the enactment of the 'Law on Radioactive Waste Management', the classification of radioactive waste existed at the level of departmental regulatory documents and was not uniform. The new classification of radioactive waste distinguishes between two categories: special and disposable. Special radioactive waste is defined as waste for which retrieval from storage facilities is either impossible, or associated with high risks, or very expensive. In Russia, this type of radioactive waste is contained at 67 repositories, three deep disposal facilities, 567 long-term radioactive waste storage sites, as well as at the sites of peaceful nuclear explosions. Radioactive waste disposed of in Russia is divided into six classes, depending on the final isolation (from deep to near-surface disposal).

Since 2013, new processes have been introduced to the radioactive waste management system. These include the approval of the volume of radioactive waste generated on an annual basis, the setting of tariffs for radioactive waste disposal, and the formation of a reserve by Rosatom to finance the costs of creating a system of disposal sites (Abramov and Dorofeev, 2017).

Despite the adoption of a further government decree in 2016 (Russian Government, 2016b), the complex system of accounting and control of radioactive substances and radioactive waste in Russia remains fragmented and in need of streamlining. Consequently, there has been no tangible decrease in the quantity of radioactive waste, and the rate of its production exceeds the rate of its accumulation. Furthermore, the issue of establishing a disposal system for high-level radioactive waste in Russia remains unresolved. The issue was anticipated to be resolved by 2021, however, this has not materialized (Bellona, 2023b). Currently, Russia does not possess contemporary storage facilities for Class 1 and Class 2 radioactive wastes. The initial plan was to construct the first repository, which was to be 525 metres deep, in Zheleznogorsk, Krasnoyarsk Krai, by 2026. However, due to funding constraints, the completion date has been postponed to 2028, with commissioning anticipated to extend beyond 2040 (Lenz, 2023). A recent assessment of the territory of Russia in terms of its suitability for the storage of radioactive waste facilities designed on the basis of the deep borehole disposal method has indicated that certain areas of the Russian Arctic are deemed to be appropriate (Kochkin, 2024).

The entities responsible for the management of radioactive waste in Russia are now Rosatom and the individual companies that produce such waste. Rosatom assumed responsibility for the radioactive waste accumulated prior to 2011 (referred to as the 'nuclear legacy'), while the responsibility for the management of radioactive waste generated subsequent to 2011 was assigned to the entities responsible for its production. It was evident at the time that resolving the issue of the nuclear legacy in the Russian Arctic would be a highly complex undertaking, necessitating significant financial resources, the utilization of cutting-edge technologies and a considerable length of time. In 2011, Rosatom, following an inventory of the nuclear legacy site, estimated the timeframe for solving the problem to be 40 years (Rosatom, 2011).

The National Operator for Radioactive Waste Management (FSUE NO RAO), which has several branches in the European and Siberian parts of Russia, including an underground research laboratory in Krasnoyarsk Krai, is responsible for the final isolation of radioactive waste (Rosatom, 2024b; 2024c). It should be noted that there is no reprocessing or final isolation of radioactive waste in the Arctic territories of Russia. For example, spent nuclear fuel from the Kola NPP is transported for reprocessing to the Mayak plant in the Urals (Lysenko et al., 2022).

Rosatom bears responsibility for the management of spent nuclear fuel of military origin at FGUP FEO (formerly FGUP RosRAO). The structure comprises 19 branches and is responsible for the management of radioactive waste and spent nuclear fuel of military origin. Since 2013, FGUP Radon, a research center for the decontamination of radioactive waste, has been incorporated into the Rosatom organizational structure. Subsequently, FGUP SevRAO in Murmansk was incorporated, specializing in the disposal of nuclear fuel and radioactive waste generated during the disposal of nuclear submarines and surface ships with nuclear power plants (Rosatom, 2024a).

Another Rosatom entity, FGUP Atomflot in Murmansk, bears responsibility for the transportation and storage of spent nuclear fuel from Russian nuclear icebreakers in the Arctic, in addition to accepting spent nuclear fuel from submarines. Atomflot currently operates 31 vessels (of which seven are nuclear-powered, five are nuclear-powered support vessels, 19 are other vessels and watercraft) and ten onshore facilities for the handling of radioactive materials. Atomflot maintains a storage facility for treated nuclear fuel in containers, a spent nuclear fuel loading point, a site for the temporary storage of nuclear fuel transportation containers, as well as facilities for storing solid and liquid radioactive waste (Bellona, 2023a; 2023d).

Rosatom is similarly engaged in the advancement of the Northern Sea Route, encompassing the development of nuclear power and icebreaker fleets within these territories. As part of the subprogram 'Development of the Northern Sea Route and Ensuring Navigation in the Arctic' (Russian Federation program 'Social and Economic Development of the Arctic Zone of the Russian Federation'), activities such as ensuring the rehabilitation of the Arctic region from sunken and sunken objects with spent nuclear fuel and radioactive waste are financed through Rosatom (Rosatom, 2022b).

Since the 2010s, the development of the Arctic territories of the Russian Federation has been accorded an increasingly prominent role. This heightened focus on the Arctic has been reflected in legislative developments. In 2013, the initial phase of the 'Strategy for the Development of the Arctic Zone of the Russian Federation and National Security' (2013-2020) was adopted (Russian government, 2013b). This strategy acknowledged the interconnection between the environmental security of the Russian Arctic and various aspects of nuclear waste management, as well as the significant level of accumulated environmental damage. In 2014, the state program 'Development of the Nuclear Power Industry Complex' was adopted. This program set out a series of objectives, including the improvement of the environmental situation at radioactive waste storage sites and radiation-hazardous facilities by 2030, the completion of radioactive waste disposal, and the rehabilitation of radiation-contaminated areas (Russian government, 2014). In 2017, the Federal Law 'On Environmental Protection' (The State Duma, 2001) introduced a new section on the elimination of accumulated environmental damage.

The second phase of the federal target program, entitled 'Ensuring Radiation Safety', is currently still in effect (Russian government, 2016a). In comparison to the initial phase of the program, the level of funding was increased fourfold, with 70% of the total funds derived from the federal budget and the remaining portion to be provided by Rosatom. The program's primary objective is the elimination of nuclear legacy facilities, including the disposal of 82 nuclear submarines and two nuclear icebreakers, the establishment of a repository for high-level nuclear waste, and so forth. (World Nuclear Association, 2020). (World Nuclear Association, 2020). However, the program did not encompass the remediation of radioactively dangerous objects sunken and submerged in the seas of the northwestern Arctic, nor did it address the issue of radiation-contaminated territories resulting from uranium mining operations. (FSP2, 2021). It was anticipated that by 2030, 90% of the issues pertaining to the management of spent nuclear fuel would have been resolved (Abramov, 2015). However, following February 2022, the feasibility of implementing these measures is uncertain.

In 2018, the Russian Federation adopted the Fundamentals of State Policy in the Field of Nuclear and Radiation Safety of the Russian Federation for the period until 2025 and beyond. The concept of nuclear heritage sites was introduced for the first time in this document (Russian government, 2018).

Since 2020, the second part of the Strategy for the Development of the Arctic Zone of the Russian Federation and National Security has been implemented. The document delineates Russia's principal national interests in the Arctic as the advancement of the Northern Sea Route. Radioactive waste is referenced solely in the context of the development of an integrated system for the management of all types of waste (Russian government, 2020b).

Therefore, the establishment of a radioactive waste management system in contemporary Russia was gradual and commenced with the active formalization at the legislative level and organizational sense only 15 years ago. The urgent necessity to address the issue of radioactive waste management in the Arctic ('nuclear legacy') has only been acknowledged in the last 10 years, concurrently with the setting of objectives for the economic advancement of the Russian Arctic territories.

International collaboration constituted a pivotal aspect of the Russian system for the management of nuclear waste in the Arctic until 2022. The system had been in development since the early 1990s and was expected to continue until 2022. Environmentalists have estimated that Russia received approximately $2.5 billion in international assistance, not including political, technological, informational, and other forms of support, to address the nuclear legacy in the Arctic (Bellona, 2020). Notable outcomes have been attained, contributing to an enhancement of the environmental situation. However, a definitive resolution to the issue remains elusive.

The principal programs of cooperation on nuclear waste management in the Russian Arctic have been operationalized by Russia within the framework of the Arctic Council, as well as through bilateral environmental cooperation with Norway.

The Arctic Council, established in 1991, represents the principal international organization for international cooperation on nuclear safety and security in the Arctic. The management of radioactive material in the Arctic Council is addressed by the Working Group on Emergency Prevention, Preparedness and Response (The Arctic Council, 2024b), which works in conjunction with the established Radiation Expert Group (RAD EG) (The Arctic Council, 2019) in accordance with the guidelines set forth in the Arctic Contaminants Action Program (The Arctic Council, 2024a). The Russian system of nuclear waste management in the Arctic has been largely contingent upon the Arctic Council. In the period preceding the outbreak of the war in Ukraine in 2021, the Arctic Council produced a report on the status of radioactive material management in the Arctic and made forecasts for the subsequent decade. Additionally, the report outlined potential scenarios for accidents at radioactive waste storage facilities in the Arctic and their consequences (The Arctic Council, 2021a). Given that all radioactive waste storage facilities in the Arctic are situated on Russian territory, the risk level for European countries was determined to be low. The issue of nuclear waste disposal in the Russian Arctic was identified as a key topic for discussion during the Russian chairmanship of the Arctic Council between 2021 and 2023. Furthermore, the Arctic Council Strategic Plan for the period 2021-2030 was adopted in 2021 with the objective of addressing pollutants and hazardous and radioactive substances (The Arctic Council, 2021b). The objective was to raise six submerged sites at an estimated cost of €278 million, with the K-159 in the Barents Sea representing the most expensive undertaking at a projected cost of €57.5 million (Nilsen, 2021).

In the context of the Norwegian-Russian Commission on nuclear safety, which operated from 1992 to 2022, Norway provided Russia with financial assistance amounting to over two billion Euros. This support was directed towards the storage of nuclear waste and the enhancement of safety measures at power plants and icebreakers (Government of Norway, 2004). The Joint Norwegian-Russian Expert Group for the Investigation of Radioactive Contamination in the Northern Areas conducted environmental studies in the Russian Arctic and radiological monitoring.

Other international programs that have provided assistance in the elimination of the nuclear legacy in the Russian Arctic include the following:

The EU's TACIS technical assistance program for CIS countries (1991-2006) included the provision of technical assistance in nuclear safety. Subsequently, from 2007 to 2013, nuclear safety projects in Russia were supported through the Instrument for Nuclear Safety Co-operation (INSC) and by the Instrument for Pre-Accession Assistance (IPA) (Pla et al., 2012).

The Barents Euro-Arctic Council (BEAC), established in 1993 by the Kirkenes Declaration, has facilitated regional cooperation, including on matters pertaining to nuclear safety and security (BEAC, 2021).

The Arctic Military Environmental Cooperation Program (AMEC, from 1995 to the early 2000s) (Defence International Environmental Program, 2024) provided funding for the elimination of radiation facilities in the Russian Arctic and for the advancement of radioecological safety in the management of radioactive waste and spent nuclear fuel from nuclear submarine dismantlement (Koval and Lyzhin, 2016).

The Northern Dimension Environmental Partnership's Nuclear Window (NDEP NW) program (Defense International Environmental Program, 2024) has been operational since 2003, with support from the Global Partnership (GP) Program of Western donors (Government of Canada, 2013). The program has financed initiatives aimed at eliminating the 'nuclear legacy' in the Russian Arctic, as well as the dismantling of decommissioned nuclear submarines, the safe handling of spent nuclear fuel and radioactive waste, and the remediation of relevant sites. Until 2022, the financing was implemented through the NDEP Support Fund, which had a total of EUR 350 million. This fund was extended until 2027 in 2021 (EU Commission, 2021).

As a consequence of international collaborative initiatives aimed at enhancing the environmental condition in the Russian Arctic and eradicating the 'nuclear legacy', a number of favorable outcomes were attained by 2022.

The majority of the radioactive and nuclear waste accumulated on the Kola Peninsula and in the Arkhangelsk region has been successfully identified and isolated. This conclusion was corroborated by the findings of the joint Norwegian-Russian commission meeting on nuclear and radiation, which revealed a significant reduction in the volumes of radioactive waste in the majority of facilities in Northwest Russia (Danilov, 2016). The French-funded facility for unloading spent extracted parts from liquid-metal cooled reactors, established in 2005 in Gremikha, enabled the deactivation of submarines (Bellona, 2023b). In 2017, a 12-year, €600 million Russian-German project to establish a long-term storage facility in Sayda Guba for the reactor compartments of dismantled nuclear submarines was completed (RGRU, 2017).

3. The Consequences of the War in Ukraine for the System of Nuclear Waste Management in Russia

The changes occurring in Russia's nuclear waste management system in the wake of the war in Ukraine are occurring against the backdrop of adverse developments within Russia's nuclear industry and shifts in the broader approach to the development of the Arctic territories.

For instance, the generation of electricity from Russian nuclear power plants has increased in recent years, reaching 223.4 billion kWh in 2022. However, there was a 2.8% decline in 2023 (Rosstat, 2024). This was the first occurrence in 10 years and only the second in 20 years. The proportion of nuclear energy in Russia's overall energy mix has been on a four-year decline, reaching 18.4% in 2023 (compared to 19.7% in 2021) (Rosatom, 2021b). It is unlikely that the objective of attaining a 25% share of nuclear power in the energy mix by 2045 will be met. Although the decline in the nuclear industry coincided with the outbreak of the war in Ukraine, the principal factor is the ageing of the nuclear fleet at nuclear power plants. In recent years, four large first-generation uranium-graphite reactors in Russia have been decommissioned, having reached the end of their operational lifespan of 45 years. This includes the Leningrad NPP. Of the 37 reactors installed at these NPPs, 23 are currently in operation with an extended lifetime, having been constructed more than 40 years ago (Rosatom, 2023b; 2024c). In the current decade, a significant process of decommissioning units that have reached their design life is anticipated (Russian Socio-Ecological Union, 2022). In the absence of a substantial number of new nuclear reactors to replace them, Russia's nuclear power generation is projected to decline by approximately 50% within the next 15-20 years (Bellona, 2023d).

Furthermore, the nuclear reactors at the stationary NPPs in the Arctic region of Russia were constructed several decades ago. At the Kola NPP in the western Arctic, all four reactors have been granted an extension to their operational lifespan, with the current operating period extending until 2033-2039. Furthermore, the construction of two additional units has not been scheduled until 2034. At the Bilibino NPP in Chukotka, the operational lifespan of three units has been extended until 2025, with one reactor decommissioned in 2019 (Nilsen, 2019).

Concurrently, the quantity of accumulated spent nuclear fuel is rising in Russia. In 2021, the accumulated quantity reached 409 tons, while in 2022 it has already reached 530 tons (with the total volume of accumulated spent nuclear fuel reaching 26,199 tons in 2022). Approximately 1,000 tons are transported from nuclear power plants to facilities for disposal or reprocessing on an annual basis. Concurrently, the proportion of spent nuclear fuel undergoing reprocessing is increasing rapidly. In 2021, it constituted 14.8% of the total, while in 2022, it reached 25.1% (Rosatom, 2022c).

In 2022, the total volume of accumulated radioactive waste in Russia was 5.72×108 m^3, with the majority (96%) classified as accumulated waste, also known as the nuclear legacy. This indicates that while Russia is addressing the reprocessing of current nuclear waste, there is still a need to address the remaining waste from the past (Rosatom, 2021b; 2022a).

In 2022, Russia's Arctic policy underwent a notable shift, largely influenced by the imposition of Western sanctions. At the present time, the priorities of the Russian Federation in the Arctic can be formulated as follows.

1. In the context of the new conditions, it is imperative for Russia to prioritize the consolidation of its domestic resources as a means of addressing the challenges it faces in the Arctic. This approach also extends to the crucial issue of nuclear and radiation safety, as highlighted by TASS (2022).
2. Russia's new priority in the Arctic is the development of the Northern Sea Route, which will be carried out with the utilization of the country's own resources. This will be achieved through the advancement of the nuclear icebreaker fleet and nuclear power.
3. Russia will seek to develop collaborative relationships with non-Arctic states that espouse similar approaches to the Arctic.

Russia is currently prioritizing the implementation of large-scale projects with the objective of fostering economic development in the Arctic region. These projects are designed to generate income through the establishment of new transport routes and the extraction of minerals. Russia's heightened interest in the Arctic is exemplified by its recent efforts to delineate the outer limits of its continental shelf in the region. In early 2024, Russia indicated its potential intention to withdraw from the United Nations Convention on the Law of the Sea in the Arctic (Arctic Age, 2024). The Convention was adopted in 1982, but the USSR did not join it at that time, as the Convention defined the concept of a 12-mile zone of territorial waters, which was incompatible with the Soviet Union's sectoral approach to defining borders in the Arctic. Russia ratified the treaty only in 1997.

Addressing environmental problems in the Arctic, including nuclear waste disposal, is being sidelined. For example, in 2022 Russia announced an increase in state funding for Arctic projects (RGRU, 2024), but this comes against a backdrop of decreasing funding for environmental programs in the Arctic. In 2023, 2 billion Rubles were allocated to them; in 2025, half that amount is planned (Shumanov, 2024).

The decline in interest in environmental issues is particularly evident in a study conducted in 2023. Its results show that among those who influence decisions on the future of the Russian Arctic, there is no one connected with the environment (Arctida, 2024).

A content analysis of Russian media publications concerning the issue of radioactive waste in the Arctic reveals a notable decline in the number of such publications over the two-and-a-half years since the onset of the war in Ukraine. Specifically, the analysis indicates a reduction of approximately 25% in the number of publications on this topic. The Information and Analytical Centre at the Russian 'State Commission on Arctic Development Issues' has been engaged in the regular preparation of media reviews on a range of Arctic-related topics, including environmental issues, since 2015 (State Commission on Arctic Development Issues, 2024). The subject of radioactive waste in the Russian Arctic is predominantly associated with the 'nuclear legacy' issue. In the 2.5 years preceding the commencement of hostilities with Ukraine, there were 33 original publications on this topic; in the subsequent 2.5 years, there were only 25. In addition to the general decline in attention to the problem of radioactive waste in the Arctic, the following trends can also be identified. The proportion of publications addressing the issue of radioactive waste in the Arctic has declined markedly, from 52% to 15%. Conversely, the share of publications highlighting achievements in the eradication of the 'nuclear legacy' has increased, rising from 24% to 30%. Additionally, the number of publications pertaining to financial challenges associated with the cleanup of nuclear legacy sites has grown, rising from 8% to 12%.

Since 2022, Russia has been subject to a series of sanctions that have imposed restrictions on trade and technology exchange. However, in contrast to other sectors, the Russian nuclear industry is not as reliant on Western technology. Rosatom remains the sole Russian agency with technology and resources that are comparable or even superior to those of foreign competitors (Bellona, 2023d). Consequently, in contrast to numerous other prominent Russian enterprises, the Russian nuclear industry and Rosatom Corporation have thus far evaded the imposition of significant Western sanctions.

Nevertheless, the level of pressure exerted by sanctions on Rosatom is gradually intensifying. In 2023, the United States and the United Kingdom imposed sanctions against ten subsidiaries of Rosatom, including Atomflot. However, the sanctions did not affect those Rosatom structures that provide nuclear fuel to Western countries. The European Commission did not include the civilian nuclear industry in the sanctions lists, with the exception of Atomflot, which was subsequently included in 2023. Western countries remain heavily reliant on Russian nuclear fuel supplies, a dependency that is unlikely to change in the near future. Rosatom and its subsidiaries continue to play a pivotal role in the import of uranium for the EU, accounting for nearly 17% of uranium imports, 22% of conversion, and 30% of enrichment (Moshenets, 2024).

In early 2024, the United States government introduced sanctions against Rosatom subsidiaries that provide support for Russia's development of the Arctic region, as well as Russian companies engaged in the production of nuclear weapons, including JSC Rusatom Arctic, Innohub and the Alexandrov Research Institute of Technology (U.S. Department of State, 2024). Subsequently, additional sanctions were imposed against Rosatom by Canada (Government of Canada, 2024) and Japan. However, there are no Rosatom companies on the UK and Australian sanctions lists (Bellona, 2024a).

It can thus be observed that the sanctions imposed by Western countries are gradually beginning to affect Russia's nuclear industry, although they do not directly address the issue of radioactive waste disposal in the Arctic. The Russian government's approach to this issue is becoming less clear due to financial constraints, yet it remains a significant concern, particularly given the ambitious goals associated with the Northern Sea Route and its close ties to environmental considerations. The activities of Rosatom have undergone notable shifts since the onset of the war in Ukraine, which has also had an impact on the nuclear waste management system.

Before the war in Ukraine, Rosatom was actively earning money from international contracts. In 2021, Rosatom's revenues grew by 20 per cent, and total revenues reached almost $9 billion US Dollars. The management of radioactive waste and spent nuclear fuel, as well as addressing nuclear legacy issues, were on Rosatom's list of key tasks, along with the issue of Arctic development. In 2021, Rosatom launched a major project to develop the Great Northern Sea Route from Norway in the Barents Sea to the Korean Peninsula, which is still ongoing in one form or another (Rosatom, 2021b).

After 2022, Rosatom's activities in the nuclear energy market have changed significantly. Due to geopolitical constraints, the largest market segments (Europe, USA and Japan) were not available (the reduction of the available market was more than 80%), so Rosatom reoriented itself towards the markets of the CIS countries, Latin America and Asia (Rosatom, 2022a).

In 2022, a federal law was passed (Russian Government, 2022) authorizing Rosatom to carry out all work related to the Northern Sea Route and the development of nuclear shipping in the waters of Russia's Arctic territories. One of the areas of development was the creation of a fleet of floating nuclear power plants for the Arctic, and in 2024 Rosatom received an additional order for the production of 15 units of such floating nuclear power plants (Arctic Age, 2024).

Concurrently, Rosatom's comprehensive nuclear waste management system remains unaltered, encompassing the full spectrum of activities related to nuclear power plant (NPP) operations, spent nuclear fuel reprocessing, and spent nuclear fuel management. The management of radioactive waste and spent nuclear fuel encompasses a series of stages, including extraction, transportation, reprocessing or conditioning, storage or disposal, and recycling of nuclear materials, which may be used to create nuclear fuel components.

The national radioactive waste disposal operator, FGUP NO RAO, has yet to determine the feasibility of establishing a deep disposal facility for radioactive waste, which may be indicative of financial constraints (NO RAO Rosatom, 2024c).

Given the decline in funding, there is a reduced likelihood of Rosatom organizing scientific expeditions to investigate radioactive waste dumps, colloquially known as the 'nuclear legacy', in the Arctic. Rare examples of such expeditions include the 2023 expedition in the Kara Sea (Flint, 2023), which was conducted to determine the exact coordinates of sunken ships and nuclear submarines with radioactive waste in Novaya Zemlya. Additionally, research has been conducted in the Gulf of Currents and the Novaya Zemlya Depression (Kramarev, 2024), as well as along the Northern Sea Route (Rosatom, 2022a), with the aim of monitoring the environment.

In the wake of the war in Ukraine, all collaborative initiatives between Rosatom and Western countries in the domain of nuclear legacy elimination and radioactive waste disposal have been brought to a halt. A considerable number of countries and the majority of banks have ceased to provide funding for initiatives aimed at eliminating the legacy of the Soviet nuclear program, as well as for the involvement of foreign experts in such projects (Bellona, 2023a). The cessation of financial support from Western sources for the disposal of nuclear waste in the Russian Arctic represented a significant setback for Russia, given the substantial scale of this funding. For instance, in excess of €6 million was received for the disposal of the Lepse nuclear waste ship alone (Rosatom, 2021b).

It had been anticipated that the completion of nuclear waste disposal in the Arctic would be supported by Norway. A third five-year program of cooperation with Norway on nuclear waste disposal in Andreyeva Bay was in place until 2022, and $250 million had already been spent on it. A fourth five-year program, comprising the removal and disposal of spent nuclear fuel to a permanent storage site, was scheduled for implementation in 2022 (Rosatom, 2021a). A number of joint expeditions with Norway were scheduled to analyze the seabed of the Russian Arctic in order to assess the most dangerous nuclear sites (Danilov, 2016). At the onshore complex at Gremikha, work was planned to transfer accumulated high-level waste to storage and reprocessing at Sayda-guba (Bellona, 2023b).

However, following the outbreak of war in Ukraine, the Norwegian government took the decision to freeze funding for nuclear safety projects under the Commission for Cooperation on Nuclear and Radiation Safety, and also to halt cooperation between Norway's northern provinces and Russian regions. In response, Rosatom announced the termination of the commission, stating that funding for nuclear legacy elimination projects in the Russian Arctic has been suspended indefinitely. In 2022, the final piece of Western spent nuclear fuel unloading equipment was delivered to Andreyeva Bay, and Rosatom has since assumed responsibility for the work independently (Rosatom, 2022b, 2022c).

It is also important to note that a certain level of cooperation between Western countries and Russia in the Arctic still exists.

Russia remains a member of the Arctic Council and its activities within the council have not been suspended. Russia has suspended its contributions to the Arctic Council until such time as it resumes its 'full-scale' work, although it continues to participate in the Council's activities. Western countries hold disparate views on the feasibility of Russia's involvement in international scientific collaboration within the Arctic Council framework. For instance, Norway maintains that the dearth of communication hinders scientific endeavors, particularly with regard to the exchange of climate data. The Norwegian Institute of Marine Research, operating with the requisite authorization, engages in marine ecological collaboration with Russia. In 2023, a joint ecological expedition to the Barents Sea was conducted. Exceptions are also made for search and rescue, border cooperation, and fishery (Jonassen, 2023).

Another notable trend in Russia's international cooperation in radioactive waste management has been the strengthening of bilateral relations with Belarus.

In 2021, Russia and Belarus entered into an agreement concerning the transportation of nuclear materials (Rosatom, 2021b). In 2023, Belarus approved a National Strategy for Radioactive Waste Management, with the first RAW disposal facility scheduled to become operational by 2030. In March 2024, Belarus and Russia signed a roadmap to train personnel for a radioactive waste (RW) disposal facility in the republic with the assistance of Rosatom (Parliamentary Assembly of the Union of Belarus and Russia, 2024). It seems probable that Rosatom has plans to utilize the radioactive waste disposal facilities in Belarus for its own benefit. Furthermore, in addition to Belarus, NO RAO is engaged in the development of collaborative initiatives with Pakistan and China pertaining to the disposal of radioactive waste (NO RAO Rosatom, 2024c).

In the period preceding the outbreak of war in Ukraine, Russia identified priority areas of development in the nuclear sphere, one of which was the realization of state tasks in the Arctic. Russia intends to fulfil these tasks with the help of a fleet of nuclear-powered icebreakers. The construction of new icebreakers is ongoing, while older vessels are being utilized and the spent nuclear fuel from them is buried (Rosatom, 2018).

In 2022, the nuclear icebreaker fleet comprised seven nuclear icebreakers, one nuclear-powered container lighter carrier, two floating technical bases utilized for the recharging and maintenance of nuclear icebreakers, and two ships designed for the transportation of RW and SNF. It is anticipated that a further four nuclear icebreakers will be constructed by 2030. Construction of a floating dock for the servicing of universal nuclear icebreakers is currently underway. The process of reloading two cores on the Yamal nuclear icebreaker has been completed. The nuclear-powered lighter carrier Sevmorput completed two round trips from ports in the European part of the country to Far Eastern ports (Rosatom, 2022a). In the summer of 2024, construction commenced on a new vessel with the objective of recharging reactors on nuclear icebreakers and transporting spent nuclear fuel to Atomflot's base in Murmansk. The vessel will be capable of operating in ice. The vessel will have compartments for both liquid and solid radioactive waste. In addition to icebreakers, it will also serve new floating nuclear power plants along the Northern Sea Route. Commissioning of the vessel is scheduled for 2029 (Reiersen et al., 2024; Nilsen, 2024a).

Operations of the Russian nuclear fleet on a large scale in the Arctic and the transport of radioactive waste present significant challenges.

In 2023, Russia transported nuclear fuel along the Northern Sea Route on vessels that were not designed for this purpose (Humpert, 2024). The nuclear fuel was transported from Murmansk to Pevek for the purpose of replenishing the floating nuclear power plant, the Akademik Lomonosov. It seems probable that in the future ships not designed for such transport will also be used to convey nuclear waste in the Arctic. The expansion of Russia's fleet of nuclear icebreakers and the necessity of transloading spent nuclear fuel have increased the probability of nuclear accidents (Savchuk et al., 2023).

A system of state radiation and environmental monitoring has yet to be established in the Northern Sea Route region. Throughout the operational lifespan of the nuclear icebreaker fleet and nuclear submarines, the requisite infrastructure has not been constructed in the ports of the Northern Sea Route to facilitate emergency communications for nuclear-powered vessels (Kuznecov and Yurchevskij, 2023). As of 2023, Rosatom had not yet commissioned a system of on-site radiation monitoring for the Akademik Lomonosov floating nuclear thermal power plant in Pevek.

Furthermore, there are indications that Russia may be transporting nuclear waste from Gremikha to Novaya Zemlya for burial in permafrost. For instance, in September 2023, a nuclear waste ship made its inaugural visit to Novaya Zemlya following a stop at the Gremikha radioactive waste storage complex (Nilsen, 2023b).

No substantial modifications have been made to the nuclear waste disposal system subsequent to 2022. The organizational structures of Rosatom responsible for this area of activity remain unchanged. In principle, the eradication of nuclear legacy sites in the Arctic remains a priority for Rosatom, given that the Russian government has designated Rosatom as the entity responsible for nuclear waste management in the region. To date, the majority of practical efforts to establish radioactive waste disposal sites have been realized in the Urals and in more eastern regions of Russia. The construction of new disposal facilities is scheduled for completion by 2033, with the Leningrad region (Linge and Barinov, 2024) among the planned locations. Such facilities will be required, inter alia, for the disposal of decommissioned NPP units and nuclear fuel from Arctic icebreakers and floating NPPs. Currently, spent nuclear fuel from the Kola NPP, located in the Arctic, is transported almost 3,000 kilometers to the disposal site, which increases the risk of environmental incidents.

The presence of radioactive waste in the Arctic represents an ongoing environmental challenge for Russia, particularly in light of the ambitious plans to develop the Northern Sea Route.

In the period preceding the outbreak of the war in Ukraine, the Russian government was of the opinion that the program to dismantle nuclear legacy sites in the Arctic was nearing completion. In 2019, an international commission reached the conclusion that six additional objects, comprising submarines and sunken reactors, which collectively account for 90% of the background radiation in these regions, needed to be removed from the seabed of the Kara and Barents seas in the Russian Arctic zone. The remaining objects would be subject to continuous monitoring (Atomic Energy 2.0, 2020b). Rosatom anticipated that these tasks could be completed by approximately 2035 (Rosatom, 2020).

In 2021, when Russia assumed the chairmanship of the Arctic Council, plans to eliminate the nuclear legacy included the raising of a significant number of sunken Soviet-era radiation-hazardous facilities, including two nuclear submarines, from the Arctic floor. The projected cost of the project was approximately $394 million, with the European Bank for Reconstruction and Development having already committed to funding the submarine lifting studies (Digges, 2022). In late 2021, the final formal impediments to this undertaking were removed when the Russian government determined that Rosatom would assume responsibility for the disposal of all radiation-hazardous facilities in the Arctic (FSP2, 2021). In the same year, specific guidelines were established to guarantee the safety of nuclear and radiation-related matters during the retrieval of the sunken submarines K-27 and B-159 (Arctic Council. Russian Chairmanship, 2022).

In mid-2022, Russia continued to identify the elimination of nuclear legacy as a priority of state policy. Additionally, the country emphasized the necessity of resolving the environmental issues accumulated in the Arctic as a prerequisite for the development of the Northern Sea Route into a global transport corridor. One of the key areas of focus was the research and monitoring of environmental safety in the waters of the Northern Sea Route, both on the surface and underwater. Concurrently, Rosatom submitted a budget request for 2.5 billion Rubles to maintain funding for the state program for the elimination of nuclear legacy, which has a total volume of 22 billion Rubles (Atomic Energy 2.0, 2022). Nevertheless, this occurred prior to Russia's suspension from the Arctic Council.

The 2023 report from Rosatom reveals that the state corporation's total expenditure on environmental protection was 29 billion Rubles (RUB), equivalent to €322 million at the 2023 average exchange rate. This represents a 18% increase compared to the figure reported for 2022. Rosatom's investment in environmental fixed capital reached RUB 6.5 billion, representing a notable increase from the RUB 4.9 billion allocated in 2022. The majority of these funds were directed towards the protection and rational utilization of water resources (62.6%) and air protection (23.4%) (Rosatom, 2024d).

The success of pre-war projects was contingent upon the provision of international financial and technological assistance. Rosatom experts have posited that approximately 50% of nuclear legacy issues will be resolved by 2035 (Bellona, 2023e). The raising of sunken submarines was considered impractical due to the lack of specialized vessels designed with lifting equipment in Russia, as well as the absence of any current construction plans for such vessels. In light of these circumstances, the distribution of financial resources was also deemed inadvisable (Atomic Energy 2.0, 2024b). In the absence of external financial support, the projected timeline for the disposal of decommissioned Atomflot vessels has been extended (Rosatom, 2017; FSP2, 2023). The anticipated delivery of new equipment for ship recycling has been delayed due to international sanctions, raising questions about the feasibility of future plans for the disposal of Atomflot's vessels.

In contradiction to Rosatom's assertions of self-sufficiency, the unfinished nuclear legacy disposal projects from before the war have not seen any substantial progress. The removal of spent nuclear fuel from the emergency storage facilities in Andreyeva Bay and Gremikha, as well as from Atomflot's base, has been subject to delays. The deadlines for the deactivation of the largest emergency storage facility for spent nuclear fuel in Andreyeva Bay have been extended. In the absence of foreign equipment and funding, the construction of a sarcophagus over the repository is being considered, while the recovery of submarine wrecks has been postponed indefinitely (Bellona, 2023a; 2023b).

It is important to acknowledge the significant discrepancy in estimated costs associated with the elimination of the 'nuclear legacy'. To illustrate, the estimated cost of the program for the complete rehabilitation of the Russian Arctic marine areas in 2015 was 600 million Euros (in 2010 prices) (Sarkisov et al., 2015). In 2021, the elimination of the 'nuclear legacy' of the Soviet nuclear project was estimated by Russian scientists at 2 trillion Rubles (equivalent to 23 billion Euros at 2015 exchange rates) (Bellona, 2021). By the end of 2022, following the outbreak of the war in Ukraine, estimates of the cost of the work outlined in the plan to eliminate the nuclear legacy in the Arctic were approximately 22 billion Rubles, equivalent to 355 million Euros (Bellona, 2023e). There seems to be no consensus among Russian experts regarding the financial costs of such projects.

The unloading and subsequent transportation of spent nuclear fuel from nuclear submarines situated in Russia's Arctic zone to storage facilities located in the Urals region continued. In 2022, the radioecological monitoring of the Yenisei River floodplain continued, and no areas requiring remediation were identified (Rosatom, 2022a).

In 2023, the Murmansk Region concluded a decade-long decommissioning process for the Lepse floating technical base, which had supported the initial nuclear icebreakers and whose spent nuclear fuel storage facility had posed a significant risk to the region for an extended period. Rosatom persists in the endeavor of removing radiation-hazardous facilities from the waters of the Arctic and the Far East (Atomic Energy 2.0, 2024a). In 2023, Rosatom officials declared that they were concluding work on the disposal of spent nuclear fuel from nuclear submarines in the Arctic (1035). However, independent environmental organizations have refuted the veracity of Rosatom's assertions (Bellona, 2023c).

In 2022, proposals were put forth that large Russian commodity corporations with an interest in the development of the Arctic and the Northern Sea Route should be involved in the removal of nuclear legacy tasks (Arctic Council. Russian Chairmanship, 2022). However, at present, the only mechanisms for the removal of nuclear legacy materials remain the federal target programs.

The current program plans of the Federal Target Program for Nuclear Safety (FTP-2) indicate that 76 nuclear legacy facilities, including two icebreakers and three nuclear service vessels, are to be decommissioned between 2023 and 2035. It is proposed that 23% of the total budget funding be allocated to the decommissioning of nuclear and radiation hazard facilities and the conservation of radioactive waste storage facilities. Initially, the funding of the FTP NRS-2 was relatively stable; however, subsequent budgetary allocations were reduced (Bellona, 2023e). Nevertheless, the FTP NRS-2 objectives remain largely achievable. In 2022, the program's main goal was 33.8% complete against a planned 33%. This resulted in the decommissioning of eight nuclear and radiation hazard facilities, the completion of the decommissioning of two nuclear submarines, and the placement of four block-packs of nuclear service vessels in long-term storage.

The Directorate for State Policy on Radioactive Waste, Spent Nuclear Fuel and Decommissioning of Nuclear and Radiation Hazardous Facilities, within Rosatom, bears responsibility for the elimination of nuclear legacy issues. The General Inspectorate of Rosatom is responsible for the formulation of state policy in the domain of nuclear and radiation safety. The Department of Nuclear and Radiation Safety of Rosatom is tasked with ensuring the preparedness of the necessary resources to respond to emergencies and exercising control. The Department of Technical Regulation of Rosatom is responsible for modernizing the system of technical safety requirements (Rosatom, 2021b). The organizational system remains unchanged at the present time.

The plans put forth by Rosatom for the implementation of the measures outlined in the Federal Target Program 'Ensuring Nuclear and Radiation Safety for 2016-2020 and for the Period until 2030' for the years 2022 and 2023 are largely similar in nature (Rosatom, 2021b; 2022a). The plans mention the remediation of radiation-contaminated territories, the disposal of nuclear submarines, and the removal of radiation waste accumulated in the Arctic. However, there is no mention of the reduction of Western funding or the technological problems associated with the disposal of nuclear waste in the Arctic.

Rosatom's preliminary report for 2023 briefly mentions the continued clean-up of the Arctic and Far East from radiation-hazardous objects, but provides no further detail (Rosatom, 2024c).

4. A Potential Future Development of the Radioactive Waste Management System in the Russian Arctic

In the context of ongoing geopolitical instability and the ongoing war in Ukraine, the future of the nuclear waste management system in the Russian Arctic remains uncertain. A multitude of factors, both domestic and international, exert an influence on its development.

Thus far, international attention has been somewhat diverted from the environmental issues facing the Arctic region. However, this situation will undoubtedly change in the future. This will be facilitated by climate change, the impact of which is particularly pronounced in this region and whose effects on nuclear waste disposal remain poorly understood. Concurrently, the prevailing geopolitical climate underscores the necessity of addressing nuclear safety concerns. The imperative to establish an international consensus on nuclear safety, emergency preparedness and response, and radiological contamination remediation is becoming increasingly pressing (Koivurova and Shibata, 2020).

The ongoing war in Ukraine has resulted in the disruption of the decision-making system that has developed over the past decades on issues of importance to the Arctic states, including nuclear waste management. In light of the paramount importance of addressing environmental concerns, it is inevitable that the Arctic decision-making system will be reinstated in one form or another. This will inevitably exert an influence on the Russian system of nuclear waste management in the Arctic, ensuring its consistency with international norms. It is not feasible for Russia to adopt an uncompromising stance in this domain, given that its economic interests in the development of the Northern Sea Route are contingent upon the environmental image of the Arctic region.

The nuclear waste management system in Russia has already undergone the initial establishment and formation period. The principal federal laws and departmental legal instruments have already been enacted. In recent years, only departmental instructions have been adopted to elucidate specific aspects of radioactive waste management, such as the sanitary norms and rules pertaining to radioactive waste management. It seems unlikely that any new fundamental legislation in this area will emerge in the near future. However, a significant challenge in the evolution of the Russian state system for radioactive waste management is the formulation and alignment of legislative and regulatory frameworks. In particular, the question of liability between enterprises and the state for radioactive waste generated as a result of the decommissioning of their storage facilities and the rehabilitation of radioactively contaminated territories, especially in the Arctic territories, has not been addressed at the legislative level. It is unclear whether these issues will be effectively addressed under the prevailing circumstances.

Concurrently, there is a potential for a gradual reinstatement of the practices observed during the Soviet era, whereby all data pertaining to radioactive waste in the Arctic will be classified and excluded from public scrutiny. This is a particularly probable scenario given that a considerable number of the 'nuclear legacy' sites in the Russian Arctic are under the jurisdiction of the Ministry of Defense. At this time, Russia is limiting access to environmental data regarding nuclear safety in the Arctic. No comprehensive assessments of the situation have been conducted, and there is a dearth of data on plans to eliminate the nuclear legacy. Instead, there are only unsubstantiated assertions about the continuation of work in the absence of funding (Bellona, 2024b). Such a scenario is indicated by the pressure exerted on environmental organizations, in particular the Norwegian environmental foundation Bellona. The organization, which is engaged in research on the topic of nuclear waste in the Arctic, was designated as undesirable in Russia in 2023.

In the preceding 10–15 years, Russia has established a network of organizations engaged in the management of nuclear waste in the Russian Arctic. The distribution of powers and areas of responsibility is undertaken by Rosatom's divisions, which are collectively referred to as the 'environmental division'. Following the outbreak of the war in Ukraine, Rosatom underwent significant structural and personnel changes within its management of divisions responsible for the elimination of nuclear legacy, the disposal of radioactive waste and the decommissioning of nuclear and radiation-hazardous facilities. The transfer of radioactive waste storage facilities intended for the disposal of nuclear legacy facilities to Rosatom structures has been temporarily halted (Bellona, 2023e). A review of the reporting structures at Rosatom responsible for nuclear waste disposal reveals an increasing formalization and vagueness. The data presented in these statistics is becoming increasingly vague and devoid of concrete information. This development may signify that in the future, Rosatom's environmental activities pertaining to nuclear waste management will ultimately assume a secondary role.

The current priorities of Rosatom are the production of weapons-grade nuclear material, the generation of electricity, and the construction of nuclear power plants outside the boundaries of the Russian Federation. Russia's current priorities in the Arctic are focused on the operation of the Northern Sea Route and the development of a system of nuclear power plants in the region. In 2023, the subject of the environment was only broached in the context of issues unrelated to nuclear waste. Therefore, the issue of eliminating the 'nuclear legacy' in the Russian Arctic is no longer a priority and is unlikely to become one in the near future.

The development of the Northern Sea Route with a fleet of nuclear icebreakers, floating nuclear power plants, and modular nuclear reactors, which the Russian leadership is currently promoting and expects to implement with the assistance of Rosatom, may potentially exacerbate the issue of nuclear waste management in the Arctic territories. To illustrate, the interval between repairs for a floating nuclear power plant is 10-15 years. During this period, solid and liquid radioactive waste, including high-level radioactive waste, will be stored at the floating nuclear power plant itself. The challenge of establishing a system of state radiation and environmental monitoring along the Northern Sea Route and constructing docking facilities for emergency calls regarding nuclear-powered vessels remains unresolved. In the context of ongoing military operations and the unpredictability of the economic outlook, the resolution of these challenges is likely to be complex.

The regulation of the export of spent nuclear fuel and its subsequent transportation to permanent storage sites represents a significant environmental and economic challenge. Should the Northern Sea Route shipping development project be implemented with Chinese assistance or leadership, it seems probable that attention to the nuclear waste issue in the Russian Arctic will be given a higher profile.

The withdrawal of Western funding has had a detrimental impact on the budgetary funding for nuclear waste environmental projects in the Russian Arctic, exacerbating the challenges that have existed since the outbreak of war in Ukraine. It is estimated by independent environmentalists that it will be virtually impossible to eliminate nuclear legacy sites in the Russian Arctic within the next 10-15 years, or at the very least, to bring them to a safe condition, given the unfavorable geopolitical and economic conditions currently faced by Russia (Bellona, 2024b). The proximity of the western part of the Russian Arctic to Europe renders it impossible for Western countries, especially those located in the north of the continent, to ignore the deteriorating environmental situation. Such developments could potentially give rise to environmental disasters on the periphery of the EU.

It is anticipated that, at the very least, funding for nuclear legacy projects in the West will resume in the long term. The issue of nuclear legacy in the Arctic remains a significant challenge that has yet to be fully addressed. It is recommended that international cooperation be encouraged which can utilize the most advanced technologies and international economic, technical, scientific and other resources in order to address this problem. In its assessment of the past two years, Rosatom has identified the completion or pending status of international funding-assisted projects as the sole tangible outcome in the elimination of the 'nuclear legacy' in the Russian Arctic. No other achievements in this area have been reported, and funding for the principal federal program to decommission and eliminate the legacy of the Soviet nuclear program, as well as the targeted nuclear submarine decommissioning program, is in decline. It seems probable that this situation will persist in the future.

Presently, there is a cessation of environmental collaboration between Western countries and Russia, a disruption of data exchange, and an exacerbation of awareness regarding the issue of radioactive waste. The cessation of environmental collaboration with Russia has resulted in a significant reduction in the level of comprehension of the radioactive waste situation in the Russian Arctic among Western entities. The current situation bears resemblance to the circumstances preceding the late 1980s, when there was a paucity of reliable data concerning the environmental conditions in this region of the Arctic, and the full extent of the radioactive waste issues was not fully appreciated. The disruption of communication channels can have a detrimental impact on nuclear and radiation safety, as well as on the transparency of information, thereby limiting the scope for public influence and oversight of activities at nuclear heritage sites (Bellona, 2024b).

Nevertheless, it seems inevitable that cooperation with Russia on matters pertaining to nuclear safety and radioactive waste in the Arctic will resume at some point in the future. These issues cannot be resolved without the involvement of Russia. In light of these circumstances, it is untenable for Western countries to persist in their refusal to accept environmental data from Russia pertaining to the legacy of nuclear energy and the management of radioactive waste. It seems inevitable that scientific cooperation, albeit in limited forms, will be resumed at some stage, and that it will continue to develop after a period of complete isolation. The foundation for renewed environmental collaboration with Russia could be the preexisting treaties between the Arctic states on circum-wide Arctic matters, including international scientific cooperation (The Arctic Council, 2017; Koivurova and Shibata, 2020).

Russia also anticipates that collaboration is likely to resume within the Arctic Council, irrespective of whether there are alterations to its structure (Lysenko et al., 2022). Concurrently, in light of the prevailing geopolitical tensions, it is conceivable that an alternative format for Arctic collaboration may emerge, serving as a counterbalance to the Arctic Council for Russia and the Far Eastern countries. It seems highly unlikely that new treaties will be negotiated and adopted in the Arctic in the near future, given the prevailing geopolitical tensions and mistrust between the Arctic states. Nevertheless, it would be prudent to factor the priority of treaty cooperation into future models of Arctic governance.

The issue of radioactive waste, particularly in the Arctic, is a matter of transboundary and transnational concern. The restoration of at least a minimal level of cooperation with Russia could be based on the resumption of projects to eliminate 'nuclear legacy' sites (Paul, 2024).

In the context of the ongoing war in Russia, it is not possible to make any far-reaching predictions. The high level of volatility is reflected in the actions of the Russian leadership in the sphere of nuclear waste management.

5. Conclusions

The system of nuclear waste management in the Russian Arctic was established over the course of three decades following the dissolution of the Soviet Union and is currently undergoing a period of significant transformation. The adoption of federal legislation and other regulatory instruments has distributed responsibility among the entities responsible for specific areas of nuclear waste management, as well as provided the necessary budgetary funding. The state corporation Rosatom and its subdivisions, with the support of Western funding, had the objective of cleaning up the Arctic of radioactive waste.

The process was disrupted by the outbreak of war in Ukraine two and a half years ago. The priorities of the state with regard to the development of the Arctic territories in Russia have undergone a change of focus, with environmental concerns, including those pertaining to nuclear waste, assuming a secondary position. Rosatom remains responsible for nuclear waste management in Russia, but its environmental divisions are undergoing a period of reorganization, during which their powers are being reduced. The reporting by Rosatom on nuclear waste-related issues is being reduced and made more formal. Access to information related to nuclear waste in the Arctic is gradually being restricted. The main focus of Rosatom is now on the construction of a fleet of nuclear icebreakers for the Northern Sea Route and floating and modular nuclear power plants. Rosatom is shifting its focus to environmental safety in the Arctic.

The accumulation of nuclear waste of military origin since the Soviet era represents a significant risk to the regional economy. In the past, the costs associated with the elimination of the 'nuclear legacy' were primarily borne by foreign countries. Since the outbreak of the war in Ukraine, international funding and technological assistance in this area has ceased, and Russian budgetary funding has been significantly reduced, thereby endangering the completion of projects that are already underway. The reduction in funding is resulting in delays to the completion of projects aimed at the deep disposal of radioactive waste, including that originating from the Russian Arctic.

The future development of nuclear waste management in the Russian Arctic is currently uncertain. The breakdown of international ties is detrimental to the region's ecology, yet Russia continues to adhere to the main international nuclear waste management treaties. It seems likely that there will be a resumption of the scientific contacts necessary to maintain awareness of the environmental situation in the Arctic. The issue of nuclear legacy elimination could be a subject for renewed environmental negotiations with Russia.

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