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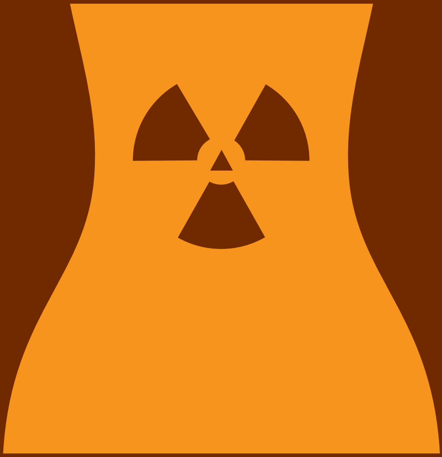
The Soviet NUCLEAR Archipelago

A Historical Geography of Atomic-Powered Communism

Per Högselius and
Achim Klüppelberg



THE SOVIET NUCLEAR ARCHIPELAGO

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Per Högselius and
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1. Introduction

Anyone who sets out to explore the fascinating—and tragic—history of nuclear energy in the Soviet Union and its successor states will quickly discover that it is an exceedingly complex history. It involves atomic projects across a huge territory, from power plants on the Baltic Sea to uranium mines in the Far East, and from nuclear weapons testing in the High Arctic to failed reactor sites in subtropical Crimea. It covers over a century of nuclear visions, stretching from early Soviet research on nuclear physics in the 1920s to recent Russian exports of commercial nuclear power plants to Bangladesh. It involves a mesmerizing network of actors—people and organizations—spanning the civilian and the military sectors.

Given this vastness of the Soviet nuclear industry, it might seem a nearly impossible task to distill a coherent narrative of the Soviet atomic age. And yet there is doubtless a need for precisely such a narrative: one that takes the totality of nuclear developments in the Soviet and post-Soviet realm into account. Accepting this challenge, this book lends itself as a basic companion on the journey of the enthusiast, the student, or the scholar through the Soviet Union's nuclear past. It navigates both the storms and the calmer waters of the "Soviet nuclear archipelago," as we call it, following the historical trajectories and destinies of individual nuclear projects and sites as well as the making and unmaking of the Soviet nuclear industry in its totality. Considering geopolitical and ideological, as well as technological and environmental aspects, we hope to inspire the reader to launch their own exploration of an adventurous, dangerous, and highly ambiguous past whose legacies continue to be felt today.

Taking the diversity and paradoxes of Soviet nuclear developments seriously, we suggest that the history of nuclear energy in the Soviet Union can be most fruitfully narrated by approaching it from a *spatial* perspective. On a macro-level, we will theorize the Soviet nuclear industry—with its extensions into Central Europe and Finland—as a Large Technical System (LTS),[1] consisting of a variety of components in the form of geographically situated nuclear power plants and fuel cycle facilities (uranium mines, enrichment plants, fuel element factories, reprocessing complexes, nuclear waste storage sites, etc.). These interact with and are dependent upon each other, often over vast distances, through what we will call "macro-entanglements," in which transport routes come to the fore as critically important for the system's functionality. Individual nuclear facilities, for their part, take the form of sub-systems. When zooming in on these, we find a range of "micro-" or "meso-entanglements," defined as each nuclear facility's dependence on—and shaping of—local and regional geographies, landscapes, and environments. We conceptualize these sub-systems as "envirotechnical" systems. The envirotechnical analytical lens has been found highly useful in previous historical analyses of nuclear energy, as demonstrated by Sara Pritchard in the case of France and Japan, while our "entanglement" perspective takes inspiration from the prominent nuclear historian Gabrielle Hecht.[2]

Seen through this spatial lens, we set out to tell the history of nuclear energy in the Soviet Union as an evolving "archipelago" of envirotechnical systems that interact with each other across—and beyond—the territory of the USSR. We borrow this Solzhenitsyn-inspired metaphor from the Russian anti-nuclear weapons activist Alexander Yemelyanenkov, who used it to analyze the history of Soviet nuclear weapons.[3] We extend the "archipelago" analysis to include not only the military, but above all, the civilian nuclear history of the USSR, while mobilizing the metaphor as part of our LTS and envirotechnical systems analysis. This is in line with nuclear historian Robert Jacobs' argument that both spheres—the civil and the military—should be thought of as one and the same system; while the applications differ, the underlying technology is the same.[4] It may also be observed that the Soviets used forced labor and military detachments to build numerous facilities and subsystems of their nuclear LTS, thus further justifying the implicit link to Solzhenitsyn's *Gulag Archipelago*.[5] Members of the Soviet and Russian nuclear community have, in a similar way, described the USSR's network of closed "atomic towns" as an archipelago.[6]

Our main argument will be that by putting the entanglements mentioned above at the center of analysis, we can discern and explain key events and trends as they unfold on several interconnected geographical levels. This allows us to grasp the most important aspects of the long-term evolution of the Soviet nuclear archipelago, and thus to develop a historical geography of what the historian of Soviet technology Paul Josephson has called "atomic-powered communism."[7]

The book is by no means the first to take an interest in the history of nuclear energy in the former Soviet Union. Back in the 1980s and 1990s scholars like Josephson and David Holloway set out to explore the origins of the Soviet nuclear program.[8] Charles Dodd analyzed Soviet nuclear siting policies, and Jane Dawson studied the rise of anti-nuclear movements in the perestroika years.[9] More recently, Sonja Schmid scrutinized the cultural and political genesis of the Soviet nuclear industry and its large-scale reactor programs, seeking to come to terms with the technological pride and the belief in progress that inspired Soviet nuclear engineers.[10] Klaus Gestwa, Stefan Guth, and Roman Khandozhko, for their parts, elaborated on what they call Soviet nuclear technopolitics and technoscience.[11] The spread of Soviet nuclear technology to Finland and Central Europe is another theme that has attracted ample scholarly attention.[12]

Some scholars have widened the analysis from nuclear reactors to the nuclear fuel cycle, which is where the civilian and military parts of nuclear engineering tend to interact most dynamically. Kate Brown's influential book *Plutopia* is the most prominent work in this category.[13] In a more recent book, Brown turns to the effects of Soviet nuclear accidents and, in particular, the 1986 Chernobyl disaster as an acceleration in the spread of radionuclides across the globe.[14] Chernobyl and the accident theme have recently been the focus of a range of additional books and articles.[15] Another interesting strand of research focuses on specific nuclear power plant sites such as Shevchenko (now Aqtau) in Kazakhstan and the unfinished Crimean NPP.[16] Moreover, authors such as Tatiana Kasperski, Andrei Stsiapanau, Eglė Rindzevičiūtė, and Anna Storm have investigated the USSR's nuclear program from a cultural heritage perspective.[17]

We make ample use of this existing literature on Soviet nuclear history, synthesizing these works while also adding substantial new sources. In terms of archival collections, we draw on documents from the Soviet Ministry of Energy and Electrification (Minenergo) and the planning and design institute Gidroproekt, consulted at the Russian State Archive of Economy in Moscow and the Russian State Archive in Samara, respectively. Moreover, three archives in Kyiv proved valuable in providing planning documents and accounts of technical discussions, party decisions, local administrative regulations, and protocols regarding Soviet Ukraine's nuclear history. For the discussion of the Chernobyl nuclear power plant, we further use archival sources from the Ukrainian KGB. Material from the Lithuanian Central State Archive has been another valuable source, while two East German archives have allowed us to deepen our analysis of the Soviet nuclear archipelago's "far reaches" into Central Europe. Additionally, the private archive of Dima Litvinov, campaigner from Greenpeace Russia during the 1990s, has been consulted.

This material is supplemented by numerous articles published in Soviet and Ukrainian newspapers, most notably *Pravda Ukrainy* and *Tribuna Energetika*, the Chernobyl Nuclear Power Plant's own periodical. Contemporary literature, published in the form of specific monographs and scientific articles, comprises another important corpus of sources. Publications by leading nuclear engineering pioneers play a special role here, along with the Russian journal *Atomnaya Energiya* and the publisher Energoatomizdat. Furthermore, publications about specific nuclear power plants on local anniversaries provide insights into the internal discourses among scientific-technical personnel.[18]

The book consists of 12 short chapters, including this brief introduction. Chapter 2, "Cultural Preparation," analyzes early Soviet activities of relevance for the country's nuclear program. We map the emerging—predominantly urban—geography of nuclear research activities in the Soviet Union during the 1920s and 1930s, and early geographies of uranium mining.

Chapter 3, "Bomb Geographies," shifts the focus from experimental to large-scale activities and the actual production of the Soviet Union's first nuclear weapons. Key components in the emerging military nuclear archipelago included a large-scale plutonium production facility in the southern Urals, the bomb-making factory at Arzamas-16 (Sarov), and eventually the first "testing" of a Soviet nuclear weapon in the Semipalatinsk Polygon in Kazakhstan. We also discuss how the railway system was mobilized to integrate different sites and activities into a coherent whole.

Chapter 4, "Incepting Peaceful Atoms," analyzes the first Soviet attempts to make military nuclear experiences relevant to civilian life. The iconic pilot project in this regard was the Obninsk nuclear power plant, which was famously connected to the electricity grid already in 1954. Soviet nuclear scientists, together with state and party officials, then continued by exploring how nuclear energy could be utilized for industrial purposes and where power stations would best be located. Two reactor models, known by their Russian acronyms VVER and RBMK, emerged as steppingstones for a wider civilian expansion of the Soviet nuclear archipelago.

Chapter 5, "The First Boom Phase," zooms in on the concrete sites where civilian nuclear power plants started to be built in large numbers from 1967 onwards. We start by elaborating on the key Novovoronezh nuclear site, located on the upper Don in western Russia, where VVER reactors of different generations were tried out in previous years. Novovoronezh became the first civilian "atomic town" in the Soviet Union. We elaborate on the intricate micro- and meso-entanglements that underpinned this development, showing how urban development and nuclear construction went hand in hand with a far-reaching re-engineering of the region's landscape. We make similar observations at the local sites hosting the Armenian, Kola, Leningrad, Smolensk, Kursk, Chernobyl, and Rivne (Rovno) nuclear power plants.

Chapter 6, "Winning New Territories," focuses on what some authors refer to as Soviet nuclear colonialism. It maps the geographical expansion of the Soviet nuclear archipelago to both the east and west. We discuss nuclear projects in distinctly colonial regions such as Kazakhstan and Siberia, but also in the communist satellite states of Central Europe and in Finland. In Central Europe, the Danube River basin emerged as a mecca for nuclear expansion.

Chapter 7, “Evolving Macro-Entanglements,” shifts the focus from the micro- and meso-level to the macro-level entanglements between different nuclear sites. We discern three layers of such entanglements. The first grew out of the fact that plants at different sites shared similar technologies. This stimulated the formation of networks of technological expertise. In the second layer, every Soviet NPP was integrated into one of the large electricity transmission systems that Minenergo constructed. In these systems the nuclear stations were connected both with other electric power stations—mainly coal and hydropower plants, along with oil- and gas-fired facilities—and with major industrial and urban consumption hubs. The third layer emerged because of the need to supply nuclear power plants with nuclear fuel and, at the “back end,” manage spent nuclear fuel and radioactive waste. Soviet and East European nuclear plants, guided by central authorities, forged connections with uranium mines, conversion and enrichment plants, nuclear fuel factories, reprocessing facilities, and interim storage sites. Transport between the sites depended critically on the Soviet railway network.

Chapter 8, “The Second Boom Phase,” which deals mainly with the period from the mid-1970s to the mid-1980s, centers on the rise of the new VVER-1000 reactor type to dominance in the Soviet nuclear system. From a geographical point of view, this was linked to the erecting of more reactors at already existing nuclear sites as well as to expansion to new nuclear-geographical frontiers. The envisaged construction of a string of new nuclear power plants along the Volga and its tributaries signified a notable geographical shift during this period. Here, or so Soviet visionaries thought, Soviet nuclear builders would be able to build on and tap into earlier achievements of industrial development. The industrial “taming” of the Volga in the 1950s and 1960s played an important role in preparing this river for the nuclear age. In the end, however, most of the nuclear projects in the Volga River basin failed to materialize. Nuclear construction was more successful elsewhere; in particular, through the vast nuclear investments in Soviet Ukraine and Soviet Lithuania.

Chapter 9, "Towards Energy Complexes," explores two fascinating Soviet planning and engineering visions. Both were linked to the idea of exploiting the possible benefits of geographical proximity in the Soviet nuclear archipelago, centering on the principle of co-locating different nuclear installations in one and the same geographical area. The Soviets conceptualized such spatial concentration as "energy complexes." An early energy complex idea was developed by Gidroproekt, the hydraulic engineering agency. By moving its established hydraulic expertise into the field of nuclear engineering, this institute became the place where nuclear and hydraulic engineering expertise met. On this basis Gidroproekt developed a grand vision of future NPPs that were to be combined with dams, hydropower plants, energy storage in pumped-storage HPPs, navigational projects, irrigation canals for agriculture, and facilities for pisciculture. The chapter zooms in on the actual creation of such an energy complex in southern Ukraine. The other vision was that of a "nuclear power generating complex" that would combine as many steps of the nuclear fuel cycle as possible. The main aim was to minimize dangerous and costly transport of nuclear materials. It was thus a proposal to better cope with or even fully eliminate macro-entanglements in the Soviet nuclear industry. Such a complex was never actually built.

Chapter 10, "Macro-Entanglements in the Second Boom Phase," discusses the further evolution of the three key dimensions of macro-entanglements in the Soviet nuclear archipelago, with a special focus on transnational cooperation around the VVER-1000 reactor and the transformation of the nuclear fuel cycle.

Chapter 11, “The Post-Chernobyl Stagnation—and the Third Boom Phase,” starts with an account of the 1986 Chernobyl disaster and how it radically changed the overall outlook for the Soviet nuclear archipelago. The second boom phase ended abruptly. This coincided with a deep economic and political crisis that culminated with the Soviet Union’s dissolution in December 1991. Still, neither the tragedy at Chernobyl nor the collapse of the Soviet Union put a decisive end to Soviet nuclear expansionism. When the ex-Soviet economies started to recover from around 2000, a post-communist nuclear renaissance set in. Even Ukraine and Belarus, the Chernobyl trauma notwithstanding, saw the completion of new reactors. At the time when Russia invaded Ukraine in February 2022, Ukraine was one of the world’s most nuclearized nations. Overall, the early twenty-first century has seen a third boom phase in the (post-)Soviet nuclear archipelago.

Chapter 12, finally, sums up our results in a concluding discussion. We close with an evaluation of how the war between Russia and Ukraine has impacted the Soviet nuclear archipelago and its international entanglements.

2. Cultural Preparation

The historical roots of Soviet nuclear engineering can be traced back to the 1920s and 1930s, when physicists and chemists in the service of the new Bolshevik state began to conduct experimental studies of the atom's inner structure. This research took place in a distinctly urban geography, tying into a metropolitan lifestyle and featuring strong connections to higher education. Leningrad, the former Imperial capital, emerged as the main scientific hotspot in this context. It hosted two key institutions. The first was the Physical-Technical X-Ray Institute, which focused on research in modern physics and was located in the city's northern outskirts. The other was the State Radium Institute, whose buildings were in the same area. It specialized in the chemistry of radioactive elements, building on a research tradition established well before World War I by the famous Russian scholar Vladimir Vernadsky.[19] The two institutes complemented each other in a way that would prove decisive for the future: the physicists laid the groundwork for understanding the atom and controlling nuclear chain reactions, while the radiochemists paved the way for mastery over what would become the nuclear fuel cycle.

Leningrad remained the most important site for nuclear research right up to Hitler's assault on the Soviet Union in June 1941, although scientists in Moscow, the new capital city, were eager to catch up. Moscow hosted several key universities and research institutes and in 1934 the Academy of Sciences moved there from Leningrad.[20] Another important research hotspot was the Ukrainian Physical-Technical Institute in Kharkiv (Kharkov), which was set up in 1928 "with the encouragement of the Ukrainian authorities."[21]

Historian David Holloway writes that Abram Ioffe, the leading figure behind the Leningrad Physical-Technical Institute, wanted his institution to be “a great center of European science,” an internationally leading hub in an open network of free-flowing communication. Developments in the 1930s, both in the Soviet Union and internationally, made this easier said than done. After 1933 Soviet scientists were hardly allowed to travel abroad, and fewer and fewer foreign scientists attended conferences in the Soviet Union or visited its laboratories. Then, the assassination of Leningrad’s party head Sergei Kirov in December 1934 ushered in a harsh period of repression. It culminated in the Great Terror of 1937–1938, to which many scientists fell victim. In spite of these shocking events, Soviet nuclear physics and radiochemistry continued to advance at an impressive speed in the years leading up to World War II.[22]

During 1939, a tumultuous year in nuclear research worldwide following the discovery of nuclear fission, the Soviet scientists immediately set out to confirm the new research results reported in the West, hoping to push the international research frontier further.[23] At about the same time, they started up the first Soviet cyclotron, built at the Radium Institute; it became a powerful new research tool.[24] Soon afterwards, the Soviets noted that Western researchers were publishing less and less of their research results in openly available scientific journals. Soviet physicists and chemists correctly interpreted the new trend as an effect of the militarization of nuclear research. In contrast, Soviet nuclear-scientific activities continued to be discussed openly, and scientists at the leading institutes continued to publish their research results in openly available Soviet journals throughout 1939 and 1940.[25]

Scientific research was not the only steppingstone for what would become the Soviet nuclear archipelago. Access to natural resources was equally critical. The Radium Institute was, as its name suggests, historically linked to the practical applications of one of the most curious elements in Mendeleev's periodic table. The 1910s and 1920s witnessed a radium boom in both Europe and North America. Since radium was usually extracted from uranium ore, this stimulated the prospecting and exploration of uranium deposits. Central Asia was widely regarded as the most promising uranium region in Imperial Russia. In the early Soviet years, the Radium Institute, whose scientists needed both uranium and radium for its scientific studies of radioactivity, initiated its own mining activities there. They first targeted an abandoned private mining site in the Fergana valley. A few years later they opened a second mine not far away from the first one, at Taboshar (Istiqlol) in what is now Tajikistan. Uranium ore from the two mines was taken by rail to a radium separation factory built at Bondyuga (Mendeleevesk) on the Kama River, a Volga tributary. The Radium Institute operated that plant until 1925, when production moved to a rare metals plant in Moscow. Around the same time, however, the Soviets began to extract radium in a totally different way: from brine pumped up from oil wells in Ukhta, a site in the northern Komi province. Over time Ukhta became the main source of radium for the radiochemists in Leningrad.[26]

The transition to a brine-based radium supply chain led to stagnation in Soviet uranium ore prospecting and exploration in the 1930s. This put the Soviets in a disadvantageous position vis-à-vis Germany and other Western countries in the emerging atomic age. Vernadsky and his close colleague Vitaly Khlopin, the two leading scientists at the Radium Institute, early on understood this Soviet disadvantage. Following the revolutionary advancements in nuclear research during 1939, they persuaded the Academy of Sciences to set up a Commission on the Uranium Problem. This enabled the revival of uranium ore exploration in Central Asia.[27]

A further steppingstone for the Soviet nuclear archipelago was the development of heavy industry in late Imperial Russia and the early Soviet Union. The country's frantic industrialization drive during this period saw the modernization of old industrial companies as well as the foundation of new ones, many of which would turn out to be of immense importance for Soviet nuclear engineering. Just as in the case of nuclear research, St. Petersburg/Petrograd/Leningrad became the main hotspot of activity. Key enterprises included the Izhorsk factories, which had started out as a sawmill and metal-working plant already in the early eighteenth century, and the Putilov Works, which in its early days produced cannonballs and subsequently, after reconstruction in the 1860s, diversified into the production of railway rolling stock. In the early Soviet years, it produced the country's first tractors and then tanks. It was later renamed the Kirov Factory. Another plant of immense significance was the Russian subsidiary of the German electrotechnical giant Siemens & Halske, founded in the late nineteenth century. In the early Soviet period, it was renamed Elektrosila. The radical expropriation of the earlier private owners of these plants and the transition to Bolshevik control came with disruptions and difficulties of all kinds, but by the 1930s the Soviets were set on a path to making use of the tsarist industrial achievements on a grand scale. The production of machinery and equipment needed for nuclear energy—and nuclear weapons—was subsequently integrated into this effort.

Large-scale infrastructural projects added to the overall industrial dynamism, starting with construction of a huge, nationwide railway network during the late Imperial and early Soviet era, and continuing with Lenin's famous quest for "electrification of the whole country."[28] Electrification was to rely on both hydropower and thermal power. Accordingly, it demanded the construction of huge river dams and the large-scale extraction of fossil fuels. Massive hydraulic engineering projects were launched, the most iconic being the Dnieprostroi hydropower plant in Ukraine, which was completed in 1933. It would serve as a model for the radical taming of other key Soviet rivers, notably the Don and the Volga. Other breathtaking engineering projects served irrigation and navigation. A showcase was the Fergana Canal in Central Asia, which was linked to a radical ambition to scale up cotton growing. Another was the infamous White Sea canal, a navigational project. Both made use of forced labor on a previously unseen scale.[29]

Without this broader industrial and infrastructural boom in the years leading up to World War II, and the forging of an ideological and technocratic culture that matched it, it is unlikely that the Soviet nuclear age would have materialized at all.

3. Bomb Geographies

Shortly after Germany's invasion of the Soviet Union in June 1941, Soviet intelligence sources unveiled that Britain and the United States were launching massive efforts aimed at developing a new weapon based on fission energy. Earlier it had been assumed that such a weapon could not be developed within the foreseeable future, but the secret reports suggested otherwise. This led the Kremlin to take greater interest in the Soviet scientific expertise that had been built up during the preceding two decades. For the first time, nuclear science was framed as having a very explicit practical purpose: to build a Soviet atomic bomb. Igor Kurchatov, a 40-year-old Leningrad physicist, was tasked with leading this effort.[30]

The Soviets explored two different avenues to the bomb. The first was based on the technology of uranium enrichment. This translated into efforts to separate out the fissile uranium isotope U-235, which comprised only 0.7% of natural uranium. The other, which Kurchatov discovered through the intelligence reports, was based on plutonium. Plutonium had to be manufactured in a two-step progression: first, processed—but not enriched—uranium had to be irradiated in a reactor, generating a material that contained fissile plutonium. Second, this plutonium had to be separated out using radiochemical methods. Like the United States, the Soviet Union sought to master both methods of bomb development. However, Kurchatov quickly concluded that the plutonium path was likely to be both faster and cheaper.[31]

The scientists set up two key experimental facilities to try out the plutonium path. They were both located in Moscow, which emerged as the new center for Soviet nuclear research from around 1943. Following the gradual retreat of the

Germans, the capital city was deemed a sufficiently safe place for strategic research activities, while Leningrad, which had hosted the nation's leading research centers in the past, remained under siege.[32] The first of the two facilities was an experimental nuclear reactor, F-1. It was built 12 kilometers northwest of central Moscow in an area that quickly developed into a suburban hub of research institutes. Using graphite as a moderator, the reactor went critical for the first time in late 1946, a year and a half after the war's end.[33] The other key facility was a radiochemical laboratory, the purpose of which would be to develop, adjust, improve, and test the chemical processes underlying plutonium separation. Stalin appointed Vitaly Khlopin from the Radium Institute to head this project. Just like in the case of the experimental reactor, it was deemed optimal to locate Khlopin's laboratory in Moscow. It was eventually erected next door to the F-1 reactor. Experiments started in the autumn of 1946, shortly before F-1 went critical.[34] Moscow subsequently came to host several additional experimental reactors and nuclear laboratories. Distributed among different research institutes, they generated far-reaching micro-entanglements in the form of both cooperation and competition between different research groups.[35]

The nuclear experiments also generated macro-entanglements. This was because the research reactors needed uranium, which was available only from faraway sources. Uranium scarcity became a key limiting factor in the early Soviet nuclear effort, and it was the main reason why the F-1 reactor was not completed until 1946.[36] Based on the results of the Academy of Science's geological expeditions to Central Asia, the Taboshar mine in Tajikistan was identified as the most promising domestic uranium source. As we have seen, this mine had already produced small amounts of uranium during the early Soviet years. Extraction was now started up again, but progress was painfully slow. The remote location made it difficult to integrate the mine into the emerging military nuclear archipelago, as the raw ore had to be moved by donkey and camel to a refining facility that was erected at Chkalovsk (Buston), near Leninabad (Khujand). There, the ore would undergo conversion into uranium concentrate. In December 1944, operations were transferred to NKVD, which sped up developments through the brutal deployment of forced labor.[37] The reliance on the Gulag system for uranium mining was later adopted at other sites as well, including at Magadan's infamous Coastal Camp in the Russian Far East.[38]

The Red Army's penetration into Central Europe in 1945 opened new prospects for Soviet uranium supply. The Soviets took control of the historically important Jáchymov mines in Czechoslovakia, which had been the world's most important source of uranium during the interwar era. Then they discovered even richer uranium resources in eastern Germany's Erzgebirge. Up to the early 1950s these non-Soviet regions supplied the lion's share of the uranium used by Kurchatov and his colleagues in the bomb project.[39]

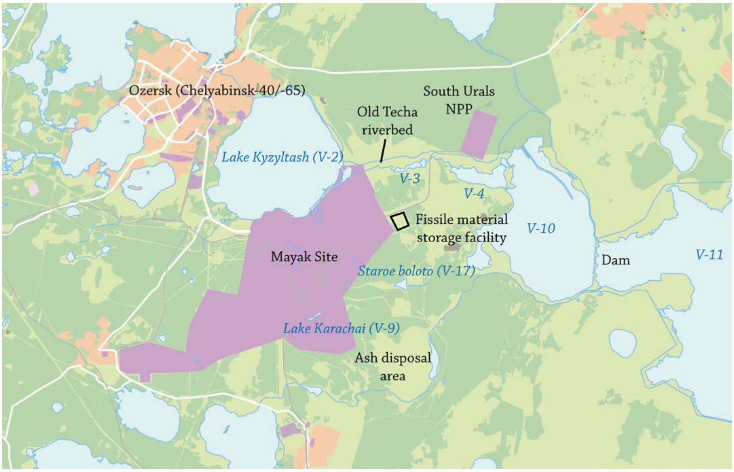
Over time, numerous other uranium mines came to serve nuclear weapons production. An interesting early site was Sillamäe, a seaside town in what, before 1940, had been the independent Estonian republic. In 1946 the Soviets set out to construct several facilities for the mining and processing of uranium there.[40] The ore was of poor quality and local mining was phased out after only a few years, but by then the processing facilities that were necessary to refine the ore on site had gained their own momentum. As a result, uranium processing continued at Sillamäe even in the absence of a local source of uranium ore. From 1952 onwards ore was brought in from elsewhere—chiefly from Czechoslovakia, Hungary, and East Germany—giving rise to new macro-entanglements of a transnational nature.[41] The strategic importance of Sillamäe led the Soviets to declare large parts of the Estonian northern coast a classified and restricted territory.[42] As in many other parts of the emerging Soviet nuclear archipelago, production at Sillamäe relied on forced labor in the form of prisoners and former conscripts to the German army.[43] As a matter of fact, the Soviets here followed in the footsteps of the Germans. During the Nazi occupation of Estonia (1941–1944) the SS had created concentration camps at Sillamäe and forced the prisoners to toil in the nearby oil shale mines. This gave Sillamäe a very grim character, remembered to this day.

In the years around 1950 Soviet geologists found several further deposits of uranium at more convenient locations: near Zhovti Vody (Zheltye Vody) in central Ukraine, near Pyatigorsk in the North Caucasus (known from Lermontov's *A Hero of Our Time*), and in the Urals. Further uranium finds were made in the Chitinsky district beyond Lake Baikal and, even further east, in the gold-producing areas along the Kolyma River in eastern Siberia. These discoveries led to further restructuring of the uranium supply chain.[44]

Before uranium could be used in the Soviet plutonium-producing reactors, it had to be transformed into pure uranium metal. The Soviets here took advantage of German prisoners of war who had worked on similar tasks in and around Berlin during World War II. An industrial facility for purifying the metal was built at Elektrostal, 60 km east of Moscow. The German leader of the project, Nikolaus Riehl, picked this site because it already hosted a strong metallurgical industry, based on the electric arc furnaces for iron ore smelting that had given the town its name.[45]

Based on these geographically complex arrangements, uranium became available for the F-1 reactor in Moscow. The Soviets then set out to scale up this reactor and build a large-scale plutonium production plant. It was now deemed too risky, from a security and secrecy point of view, to remain in a big city such as Moscow. Instead, NKVD chief Lavrentiy Beria and General Boris Vannikov, who headed the project, announced that a site was to be selected in the southern Urals. Kate Brown writes that this area was preferred for several reasons, including "sparse population, free-flowing rivers, and substantial government presence. The Urals also had trees for cover and lay deep in the continental interior, safe from the reach of enemy planes." In summer 1945 a team of Soviet geologists was already "hiking through the mosquito-rich forests of the southern Urals in search of a site for the first Soviet plutonium plant."[46] A location was eventually chosen in the vicinity of the old towns of Kyshtym and Kasli in Chelyabinsk province. There, a nuclear-military complex began to take shape during the following years. In this context, many nuclear scientists and engineers left their Moscow basements and headed east.

The nuclear center that gradually took form was referred to as the Mayak Production Association. A closed town, codenamed Chelyabinsk-40 (later: Chelyabinsk-65, or Ozersk) grew up near the complex. The first plutonium-producing reactor, Reactor A, was started up at Mayak in June 1948, while the first radiochemical plant, Factory B, without which Reactor A would have been pointless, began operations in December. Soviet engineers could now start dissolving spent fuel from Reactor A in Factory B. By February 1949, the plant had produced its first output of plutonium concentrate. Radioactive waste products generated as a by-product of plutonium production was dumped into the Techa River and the nearby Lake Karachai (Map 3.1).[47]



Map 3.1. **Envirotechnical entanglements at Mayak. The Mayak nuclear complex comprised numerous facilities that were closely interlinked with each other. The complex relied heavily on the active use of local streams and lakes. These were turned into reservoirs (vodoemy) that served specific purposes. Lake Kyzyltash (V-2) was used as a source of cooling and process water. The Techa River was dammed in such a way as to create a cascade of reservoirs (V-3, V-4, V-10, and V-11). These were used for disposal of low-level radioactive waste. Lake Karachai (V-9) and Staroe boloto (V-17), which were not part of any river system, were used for storing intermediate-level radioactive waste. Lake Karachai was initially much larger. The town of Ozersk was built upstream from all waste reservoirs. In the 1980s the Soviets started erecting the South Urals NPP at Mayak (see further Chapter 8).**

Source: Own work/Red Geographics

The bomb itself was assembled at another secret location, Arzamas-16, halfway between Moscow and Kazan. It was identical to the famous Orthodox pilgrimage site of Sarov. The water of the local Sarovka River was believed to have healing powers. But in 1923, in the aftermath of the Bolshevik Revolution and the Civil War, the Communists “closed the monastery, killing many of the priests and destroying several religious buildings."[48] In 1946, the nuclear weapons makers moved in. Chief of Soviet bomb-making was the Cambridge-educated Yuli Khariton. Later on, Andrei Sakharov would lead the development of the first Soviet thermonuclear weapons at Arzamas-16.

For "testing" the Soviet bomb, another geographical location was needed: one far away from major population centers, and from agricultural and forest areas. The Soviet nuclear gaze, much like the American and British, and later the French, Chinese, and Indian, intuitively eyed the empire's vast colonial lands as the most suitable space for nuclear weapons tests.[49] The steppes of Kazakhstan, in particular, appeared to be unproductive, empty lands that were not of much value, and which could hence be sacrificed. This was far away from the location where the plutonium and the bomb were produced, but the Trans-Siberian Railway and the Turkestan-Siberia Railway (the "Turksib," built in the 1920s), allowed this physical distance to be coped with. The Soviets eventually favored a location 150 kilometers west of the multicultural city of Semipalatinsk (Semey). Starting in 1947, 15,000 soldiers, officers, and construction workers, along with thousands of prisoners shipped in from Gulag camps, started to erect their first atomic "polygon," the Soviet term for an area used to test weapons or conduct military exercises.[50] Togzhan Kassenova, in her book *Atomic Steppe,* writes that:

> The Kazakh steppe, which had been entirely free of man-made structures just two years earlier, was soon populated by giant buildings and complex equipment. At the testing field, a circular area that had been completely flattened, thousands of miles of wires and cables ran under the ground. At its center, engineers built a 30-meter (100-foot or twelve-story) metal tower from which the first bomb would be detonated in August 1949. In all directions from the heart of the testing

> site, the workers erected 10-meter (32-foot) iron-and-concrete structures that looked like huge geese (and were so dubbed by the military). These were special buildings to store the measuring equipment. Scientific labs, and even a vivarium for studying animals during nuclear tests, were also now part of the landscape.[51]

The Soviets created a new settlement about 60 km from the testing field, "tucked away on the banks of the Irtysh River and not marked on any maps." Living there in the late 1940s was far from comfortable, but the conditions improved for the bomb testers over the next few years. From the early 1950s the nuclear workers' families were allowed to join them, and the place began to look more and more like a regular town. By 1956–57 the military settlement on the Irtysh "offered some of the best living conditions in the Soviet Union."[52] It was later renamed Kurchatov in honor of the bomb project's scientific leader.

The first Soviet nuclear explosion was carried out successfully on August 29, 1949—four years after the American bombs had destroyed Hiroshima and Nagasaki. "Within hours, a radioactive cloud blanketed the area, spreading as far as Russia's Altai region a thousand kilometers (more than 600 miles) away." In the course of the following years, the Soviets carried out another staggering 450 tests at the Semipalatinsk Polygon, ending only in 1989, when Kazakhstan's antinuclear protests stopped them. "The explosions and shock waves damaged buildings, and people were injured from shattered glass. But the more sinister and long-term danger was an invisible one—radiation."[53]

The eastern orientation in the emerging military-nuclear geography, in which European sites were avoided, if possible, was further accentuated through the construction of several additional Soviet military-oriented nuclear complexes.

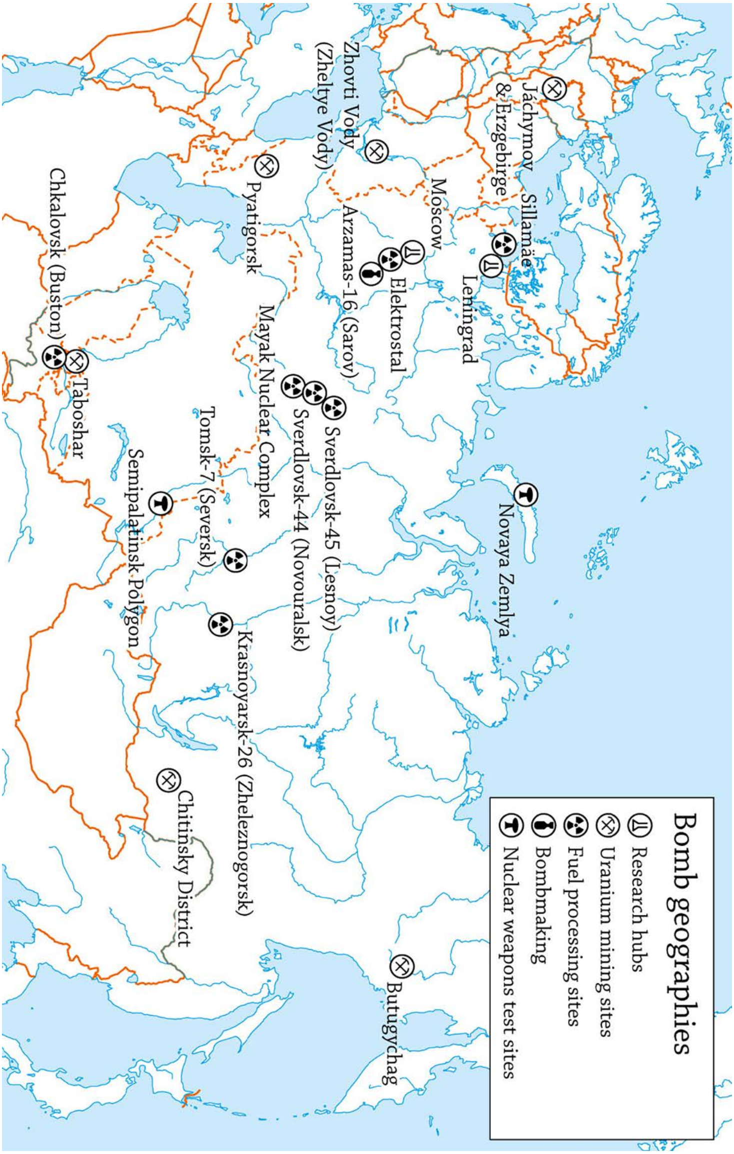
The first, Sverdlovsk-44 (Novouralsk), was created in 1946 about 50 kilometers north of Sverdlovsk (Yekaterinburg). Here the Soviets set out to master uranium enrichment for military purposes, paving the way for a uranium bomb. The site was macro-entangled with Mayak, because the uranium that formed the basis for its operations consisted of the uranium-rich waste products that Mayak's plutonium plant generated. A related site was the neighboring Sverdlovsk-45 (Lesnoy) settlement. Gulag prisoners played a key role in constructing these sites, where they were often forced to work in heavily contaminated areas.[54]

Another site, Tomsk-7 (later renamed Seversk), was constructed on the banks of the Tom River, a major Ob tributary, 15 kilometers northwest of Tomsk in central Siberia. Like Sverdlovsk-44, it specialized in the production of highly enriched uranium. A conversion facility producing uranium hexafluoride based on uranium oxide was also built at the site. The river was useful for transport purposes, but also for waste disposal and reactor cooling needs.[55]

Soviet engineers designed an additional nuclear complex even farther east, on the banks of the Yenisei, 60 kilometers downstream from Krasnoyarsk. Gulag prisoners were brought in to construct a 51-kilometer railway to the new site, which comprised not only nuclear facilities but also a range of enterprises related to non-nuclear extractive industries. Again, a new town, Krasnoyarsk-26 (later renamed Zheleznogorsk), sprang up in connection with the facilities. Similarly to Mayak, activities at Krasnoyarsk-26 were oriented towards the production of weapons-grade plutonium. For this purpose, several "production reactors" along with a radiochemical plant were built, in this case "under a hundred meters of rock" that protected it from outside view. The reactors made use of the Yenisei for cooling water supply, and the (radioactively contaminated) water coming out from the reactors was discharged directly into the river. At both Tomsk-7 and Krasnoyarsk-26, large volumes of liquid radioactive wastes were also pumped into underground cavities. From 1966, one of the "production reactors" at Krasnoyarsk-26 was utilized to supply district heating and electricity for the inhabitants of the new town, thus generating new meso-entanglements.[56]

In August 1953 the Soviets tested their first thermonuclear weapon at the Semipalatinsk Polygon. It resulted in "radioactive contamination of more than 1 roentgen up to 400 kilometers away from the testing site." The bombs were now becoming so powerful that Soviet leaders began to view the proximity to larger concentrations of people and urban centers as a problem even in the supposedly empty Kazakh steppe. For this reason, the Soviets started looking out for even more "remote" and "unpopulated" territories for nuclear testing. Hence the Semipalatinsk Polygon was eventually supplemented by the Arctic island Novaya Zemlya. Here, the most powerful Soviet bomb tests—in total more than a hundred—were carried out.[57] Novaya Zemlya was far from a major population center and became totally uninhabited "after about four hundred locals, mostly Nenets, a Samoyedic ethnic group native to northern Arctic Russia, were relocated to the Russian mainland." Nuclear tests were also carried out, on a smaller scale, at numerous other locations in the Soviet Union.[58]

From the late 1940s to the mid-1960s, the facilities at Mayak, Sverdlovsk-44, Tomsk-7, and Krasnoyarsk-26, together with the uranium mining and processing sites, the uranium purification plant at Elektrostal, the research reactors in the Moscow region, the bomb-making factory at Arzamas-16, and the test sites in Kazakhstan and Novaya Zemlya, formed a rapidly growing nuclear archipelago. The need for a range



Map 3.2. Sites of relevance for the Soviet atomic bomb project

Source: Own work/Red Geographics

of different facilities, which could not be built in one place, meant that the emerging geography of the Soviet nuclear industry took on a complex form, featuring far-reaching macro-entanglements between sites serving different parts of the (military) nuclear fuel cycle. The Soviet railway system, built mainly during tsarist times, played the main role in interconnecting these sites through a flow of nuclear materials in different forms.

On the local level, all nuclear sites quickly turned into exceptional places in the Soviet geography, often enjoying a secret status and even failing to appear on official maps, while shielded off from the wider region through restricted access. Yet, there were far-reaching micro- and meso-entanglements between each military facility and its surrounding region, not least in the form of extreme levels of pollution and radioactive contamination. Soviet scientists, engineers, and political leaders were in a hurry to build their nuclear weapons and would certainly not have let environmental and health concerns get in the way of this strategic pursuit. At Mayak, for example, large emissions of nitric acid used in plutonium production "killed the trees for many kilometers around the industrial zone," according to Zhores Medvedev.[59] Radioactive emissions took place on a continuous basis, punctuated by accidents, in which the emissions were much more severe.

The worst disaster occurred in autumn 1957, in the shadow of the Sputnik triumph, as a storage facility containing low- and medium-active nuclear waste from military reprocessing at Mayak exploded, disastrously contaminating a wider area in the Chelyabinsk, Sverdlovsk, and Tyumen Provinces. This resulted in the evacuation of several villages that were home to 10,180 people and the forced abandonment of 106,000 hectares of arable land. An area totaling 52,000 km^2 and 270,000 individuals received elevated doses of radiation. The number of casualties and otherwise harmed individuals as well as animals is difficult to establish. The Mayak tragedy was kept secret to the world and the wider Soviet public until 1989.[60] Unfortunately, this was not the only disaster in Mayak's dark history. Another serious accident occurred in 1967. Yemelyanenkov writes that the heavily contaminated "Lake Karachai shallowed and dry radioactive mud began to travel with the winds. Up to 600 curies of hazardous radionuclides was raised up in the air and fallouts were identified on an area of 2,700 square kilometers with a population of more than 40,000."[61] Mayak continued to leak radioisotopes into its surroundings during the decades that followed.

4. Incepting Peaceful Atoms

Encouraged by their own success and neglecting the bad omens that the early accidents and mishaps conveyed, the inventors of the Soviet atomic bomb project soon picked up on the idea to use the energetic potential of nuclear fission for additional purposes. The most urgent application of interest in this context was the use of atomic energy for submarine propulsion. Like the Americans, the Soviets expected this to revolutionize military navigation in the unfolding Cold War. Accordingly, they initiated experiments to determine whether they could build a nuclear reactor compact enough for installation on a submarine. Hoping to make use of their experience from plutonium production and bomb making, they first designed a graphite-moderated test reactor. But it soon turned out that such a device would not work in the navigational context, as it could not be reduced sufficiently in weight and size.[62] They then decided to imitate a submarine reactor design that was known to be under development in the United States: the pressurized water reactor. This path proved more successful and became the basis for a large fleet of nuclear-powered Soviet submarines. Construction of the first pioneering vessel, the *Leninskii Komsomol*, was launched at a shipyard in Severodvinsk on the White Sea coast in 1954.[63] The reactor was subsequently adapted for civilian transport as well, starting with a nuclear-powered icebreaker, the *Lenin*.[64]

In parallel with these applications the Soviets set out to harness the atom for electricity generation. For this purpose, several different reactor designs were explored.[65] Two dominant technological paths soon crystallized, both of which drew directly on the two successful military applications of nuclear energy: the graphite-water design (which was used in bomb-making) and the pressurized water reactor (used in military submarines).

In the graphite-water case, the inventors decided to take the failed submarine reactor project as their point of departure. What was initially known as the “naval atom” (atom morskoi) morphed into the “peaceful atom” (atom mirnyi), whereby the acronym AM-1 was retained. Aiming to demonstrate the feasibility of nuclear electricity production,[66] the Soviets installed a first version of this reactor in a power station at Obninsk, a small town located 100 km southwest of Moscow where a nuclear research institute had been established a few years earlier. The project comprised not only the reactor as such. Among other things, the engineers needed to dam the Protva River, which flowed through Obninsk, in order to ensure that cooling water for the reactor would flow reliably. In addition, they had to build a pumping station that could lift the cooling water into the plant and push it through the station’s condensers. The engineers also had to build a set of new power lines to connect the station with the Moscow region’s electricity grid.[67] In this way Obninsk already foreshadowed a set of micro-, meso- and macro-entanglements that would play out on a much larger scale in subsequent phases of Soviet nuclear construction.

The Soviets famously started up Obninsk NPP in 1954. With its 5 MWe, it became the world’s first nuclear power plant that fed electricity into a civilian transmission grid. After the United States had shocked the world by demonstrating its nuclear capacities in warfare at the end of World War II, only nine years later the USSR, or so it now seemed, had overtaken Western research and development in the area by demonstrating nuclear fission’s use for non-violent purposes. Soviet propaganda did not fail in underscoring this, while omitting the fact that civil and military appliances went hand in hand.[68]

The close connection between military and civilian purposes of Soviet nuclear energy became even more apparent in the next graphite-water reactor project. Nikolai Dollezhal, the engineer who had designed the plutonium production reactors at Mayak, suggested that plutonium production could be combined with electricity and heat production at one and the same site. He was disturbed by the observation that the uranium slugs in a plutonium production reactor generated heat that was directly discharged into nearby rivers or lakes. “Is that not a barbarism, to throw away energy where it could be made useful to the national economy?,” he rhetorically asked.[69] Dollezhal’s idea to make productive use of the waste heat was controversial, but the Ministry of Medium Machine Building (Sredmash), which oversaw all Soviet nuclear enterprises, eventually decided to give it a try at the Tomsk-7 military-nuclear combine.[70] Construction there of a dual-use plutonium and electricity-producing reactor, known as the Siberian Nuclear Power Plant, began in 1954 and was completed in 1958. The scheme was later duplicated at other military combines.[71] However, the micro- and meso-level entanglements it generated were far from unproblematic. Sonja Schmid writes that

> it proved tricky to run facilities that contained secret parts and processes related to military applications and were at the same time supposed to connect with the civilian power industry. Planners realized that it would be easier to separate nuclear power plants from military production reactors—the former could not only be optimized for electricity generation but also built at sites near large, energy-hungry urban centers.[72]

Building on this insight, the Soviets continued their efforts to develop the graphite-water line by spatially separating it from the plutonium-production reactors. They started out by building an all-civilian nuclear power station at Beloyarsk, 60 kilometers from Sverdlovsk (Yekaterinburg) in the Urals. Located in the middle of the taiga, this site had no direct connections with the growing number of Soviet military-nuclear sites. Construction of the plant, which was to host a reactor referred to as the AMB-100[73] ("Atom Mirnyi Bolshoi", the big peaceful atom) started in February 1958. The reactor was twenty times as powerful as that at Obninsk, a fact that was reflected in a much greater need for reengineering of the regional environment. By damming a small stream, the Pyshma River, the engineers managed to create an impressive, 38-km^2 artificial lake, which guaranteed a steady flow of cooling water. The reservoir soon started to be used by local fishermen, too. Construction of a second, larger reactor block, dubbed AMB-200, started at the same site in 1962.[74] The Beloyarsk project became the chief steppingstone for a standardized, large-scale reactor in the graphite-water tradition: the RBMK or, as it is often referred to, "Chernobyl type."

Meanwhile, Soviet nuclear scientists at Kurchatov's Laboratory No. 2 sought to scale up the submarine pressurized water reactors for deployment in electricity-generating nuclear power plants. This development began in 1954, when Kurchatov "instructed the construction bureau OKB Gidropress to draw up plans, and later a technical design, for a pressurized water reactor with thermal power of 760 MW."[75] "Schmid writes that planners considered several possible sites for this pioneering project, including a plant near Moscow that would provide not only electricity, but also heat."[76] Ultimately, they picked a location near Voronezh, a medium-sized city in central Russia 500 kilometers south of Moscow.

In the 1950s Voronezh had grown rapidly through the establishment of numerous industrial plants that made rocket engines, ceramics, tires, and machine tools. Seeking a compromise between proximity to and distance from an urban center, the nuclear builders opted for a location on the Don River, 45 kilometers south of the city. Here, they founded the brand-new town of Novovoronezh. It was to become the first Soviet civilian "atomic town," and as such it would inspire others. After the political decision to establish the site was taken in October 1956, construction of the first reactor block started in 1957. The reactor, labelled VVER-210, was an early version of what would become a standardized Soviet pressurized water reactor. Some authors claim that the VVER was based on blueprints from America's Westinghouse. Many different actors were involved in the construction of the facility. Teploelektroproekt, a design bureau specialized in thermal power engineering, oversaw engineering, while Gidropress designed the reactor vessels. Soiuzatomenergostroi supervised construction, and employees from the Kurchatov Institute oversaw "the scientific aspects of plant construction." Equipment specially fitted for the nuclear industry was produced by the historically well-known Kirov, Izhorsk, and Elektrosila factories in Leningrad, as well as at Ukraine's Kharkiv Turbine Factory.[77]

The VVER-210 version was further developed into the VVER-365 and then into the VVER-440, which became a main standard during what we will refer to as the "first boom phase" in the Soviet nuclear archipelago (see the next chapter). The VVER-440 came with some features that would be of critical importance from a geographical point of view. One had to do with its safety systems. While generally regarded as safer than RBMK plants, VVER-440 plants were not equipped with the advanced containment structures that became a main standard in the capitalist world. The reactor was designed to prevent radioactive leakages during normal operation, as well as to cope with smaller accidents. But the breakdown of a main cooling pipe in the primary loop—internationally regarded as the "maximum credible accident"—was beyond what a VVER-440 plant could manage. In such a case the VVER designers expected large amounts of radioactivity to escape into the environment.[78] Geographically, the implication was that VVER-440 plants must not be built in the immediate vicinity of densely populated areas.[79] In this way the safety systems directly shaped micro- and meso-level entanglements in the Soviet nuclear archipelago. Another feature of geographical significance was the reactor's strikingly compact design. Sonja Schmid writes that the reactor vessel "had to fit the load standards of Soviet trains so it could be transported from the factory to the nuclear power plant across bridges and through tunnels. In other words, the Soviet transportation system's capacity for oversized cargo determined the maximum size of the reactor, which at least initially limited its power output."[80]

Large-scale reactors aside, the 1950s also featured construction of new types of research reactors at numerous sites in the Soviet Union, including several non-Russian sites such as Minsk in Belarus, Tbilisi in Georgia, and Salaspils in Latvia. In connection with the first Geneva conference on atomic energy, held in 1955, the Soviet Union's satellite states in Central Europe started demanding access to research reactors as well. This led to the construction of Soviet-designed reactors in the outskirts of major cities like Dresden in East Germany, Warsaw in Poland, and Sofia in Bulgaria.[81]

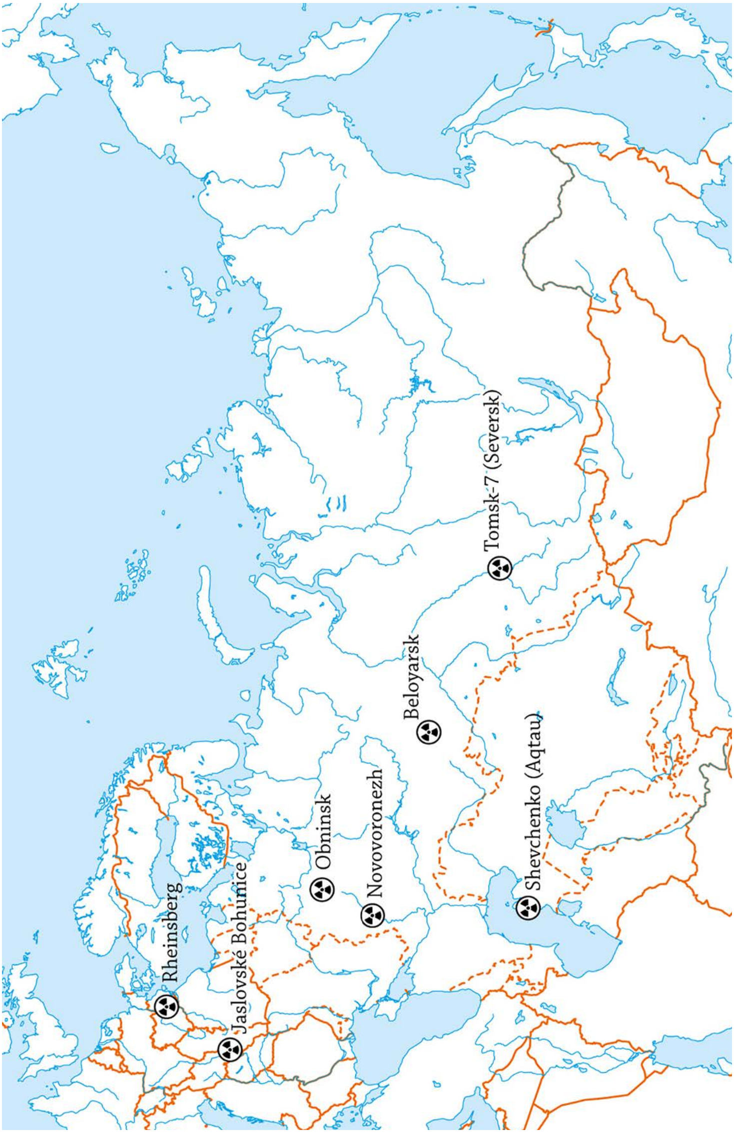
Cooperation between the Soviet Union and Central Europe continued through the erection of two larger, pilot-scale nuclear power plants in Czechoslovakia and East Germany. The Soviet-Czechoslovak project targeted the development of heavy-water reactor technology, which had been researched for some time in Moscow. A heavy-water research reactor had already commenced operation there back in 1949.[82] In 1958

Soviet and Czechoslovakian planners picked a site near the village of Jaslovské Bohunice, 60 kilometers north of Bratislava, for the erection of a larger, pilot-scale plant, designed for an electrical effect of 143 MW. There was much enthusiasm for this project initially, but the reactor was plagued by problems both during the lengthy construction period and its short operational life. After a serious (INES level 4) accident the reactor was shut down prematurely in 1977.[83]

Soviet cooperation with East Germany proved more successful. Following a 1956 bilateral agreement, the two countries set out to build a pilot-scale VVER (that is, pressurized water) reactor in the forests north of Berlin, near the town of Rheinsberg. Actual construction started in January 1960 and thus overlapped with the ongoing erection of the two larger VVER pilot plants at Novovoronezh. The facility made ingenious use of two lakes in the area: fresh cooling water was taken from Lake Nehmitz, and the warmed wastewater was subsequently discharged into Lake Stechlin. The Rheinsberg facility commenced operation in 1966.[84]

The plants erected at Obninsk, Tomsk-7, Novovoronezh, Beloyarsk, Bohunice, and Rheinsberg formed important pioneering "islands" in the Soviet Union's emerging nuclear archipelago. They signified that the archipelago was no longer only military in character; nuclear energy increasingly served civilian goals as well. The pilot facilities were of considerable significance from both a technical and symbolic point of view.

Yet in the more long-term views of Soviet nuclear engineers, the graphite-water, pressurized water, and heavy water lines of development were regarded merely as first steps in a development that would soon target much more advanced reactors. Even in these early years, the atomic visions—in the Soviet Union as well as in the West—were based on the idea of progressing through three reactor "generations."



Map 4.1. The geography of pioneering reactors in the Soviet nuclear archipelago

Source: Own work/Red Geographics

The first generation consisted of the "thermal" reactors that used uranium as a fuel in combination with one or the other moderator, and which in the Soviet Union mainly took the form of VVER and RBMK plants. The second generation would be based on "fast breeder reactors." The "third generation" referred to fusion reactors. Fusion reactors were expected to be feasible only in a relatively distant future, but fast breeders started to be developed early on.[85]

Breeders were, at least hypothetically, highly attractive, because they could in theory use uranium fuel up to a hundred times more efficiently than thermal reactors. This feature was of great interest at a time when the extent of available uranium resources was not yet known. Even after several new uranium deposits were found in the 1950s, Soviet nuclear engineers considered it important to economize on what many stakeholders believed would remain a scarce resource. This was seen to make it imperative to invest in breeder technology.

Early Soviet breeder experiments were carried out mainly at Obninsk, in conjunction with the 5 MW "thermal" reactor. The first experimental breeder, dubbed BR-1, achieved criticality there in May 1955. Paul Josephson has detailed how the Soviets then, under Aleksandr Leipunskii's authoritative leadership, built several increasingly large and more complex breeders. The BR-2, BR-5, and BR-10, as they were labeled, were all built at Obninsk. With the larger BOR-60, Leipunskii's breeder builders migrated to Melekess (or Dmitrovgrad, as the town was renamed in 1972) in the Volga region, which since 1956 hosted a sprawling nuclear R&D institute.[86] It was an important step in the effort to scale up Soviet breeder technology. Even more ambitious was a pilot project launched on the shores of the Caspian Sea. There, in western Kazakhstan's Mangyshlak desert, a base camp for uranium prospectors had been founded in 1958. It became the basis for the town of Shevchenko (Aqtau). By 1961, the Soviets had found not only uranium, but also oil and natural gas. In 1964, construction of a BN-350 fast breeder reactor—a radically scaled up version of the earlier breeders—commenced.[87] Stefan Guth, who has explored the site's history in depth, notes that it did not make sense from an energy supply point of view to locate a nuclear power plant in a region rich in oil and gas. However, it "made sense if the aim was to isolate a novel high-risk technology in a remote location where it would do limited harm in the event of failure."[88] In other words, the quest for distance was a decisive factor in the making of Shevchenko as a nuclear site.

The construction of fast breeders and the dream of a radically improved fuel economy depended on the idea of a "closed" nuclear fuel cycle, in which spent fuel from thermal reactors as well as from the breeders themselves would be reprocessed. Plutonium gained through reprocessing of spent fuel from thermal reactors was to be used to produce fast breeder fuel—unless it went to the bomb makers—while recovered uranium from reprocessing would be inserted into the "breeding mantle" of the fast reactors. Reprocessing and fast breeders were thus tightly interlinked in the larger Soviet nuclear LTS. If realized, this vision was bound to generate important macro-entanglements in the Soviet nuclear archipelago. How these turned out in reality will be discussed in detail in Chapter 7. Before turning to that analysis, however, it is necessary to discuss the wider adoption of thermal reactors—VVERs and RBMKs—in the Soviet Union and its Central European satellites.

5. The First Boom Phase

The pioneering Soviet reactors at Novovoronezh and Beloyarsk both started operation in 1964. In what followed, the civilian side of the Soviet nuclear industry entered what we will refer to as its "first boom phase." The time had come, or so the country's political leaders thought, to harvest the promised fruits of the "peaceful nuclear worker" on a grand scale. The expansion was to take place based on the two standardized light-water reactor types discussed in the preceding chapter, the VVER and the RBMK. The first was based on the developments at Novovoronezh. The second built on the Beloyarsk experience.[89]

The first boom phase took off in 1967, when Soviet nuclear builders started to construct the first VVER-440 reactor blocks at Novovoronezh. As noted in the previous chapter, this early VVER model, which was subsequently installed at several other locations in the Soviet Union and its communist satellite states, was unsafe in several respects. As we will see, however, the reactor type underwent a major redesign during the first boom phase, which significantly enhanced its safety features. The original version, which the engineers referred to as the VVER-440/230 model, gave way to the more modern VVER-440/213.[90]

In parallel with the development of the VVER-440, the Soviets set out to construct several nuclear power plants based on the Beloyarsk-rooted RBMK technology. This development took off with the construction of Leningrad NPP, which officially started in 1970. In both the VVER and the RBMK cases, the first boom phase produced complex micro- and meso-entanglements at the plant sites. These will be discussed in this and the following chapter. Chapter 7 concludes our analysis of the first boom phase by turning to the macro-entanglements that it produced.

In terms of plant siting, Soviet planners did their best, as already noted for the pilot-scale projects, to deal with the fundamental tension between the quest for distance and proximity in nuclear construction. A large-scale nuclear power plant should ideally be in reasonable proximity to industrial and urban areas since these constituted the main hubs of electricity use. The plant should also be sited in such a way as to positively influence the balance of the (rapidly expanding) electricity grid. This meant that many nuclear plants were built in places where the logistics of accessing fossil fuels were unfavorable. Moreover, the plant needed to interconnect smoothly with existing transport infrastructure, in the form of roads and railways. At the same time, it was not deemed acceptable to locate a large-scale nuclear facility of the VVER-440 and RBMK-1000 types in immediate proximity of major cities, due to the risks discussed in the preceding chapter concerning the anticipated effects of a nuclear accident.[91]

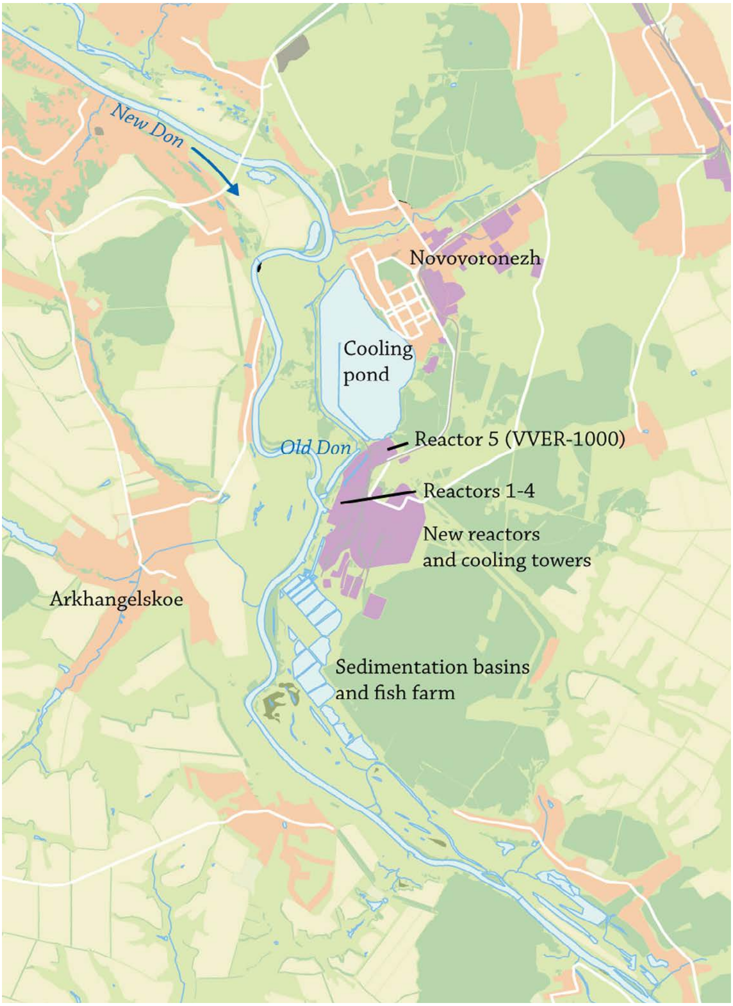
The most fundamental component of nuclear siting decisions, however, was that NPP sites needed to be smoothly integrated into their physical environments. In particular, the plants had to be able to tap into regional hydrological systems, since access to very large volumes of cooling water—around 50 cubic meters of water per second were needed for a 1000 MWe reactor such as the RBMK-1000—was the *sine qua non* for the operation of large-scale NPPs. Water would have to be continuously pumped through the condensers, absorbing the part of the heat that could not be turned into electricity, before being discharged into the environment. Over time, the quest for smoothly and safely operating nuclear power plants thus translated into a challenge of forging strong micro- and meso-entanglements between nuclear plants and the regionally available water resources.[92]

In most parts of the Soviet Union there was no lack of water, which meant that the country was in a better position than more arid places with nuclearizing ambitions, such as Spain, the western US, or northern China. The USSR was home to some of the largest rivers in the world—including the Dnieper, the Don, and the Volga (and their sizeable tributaries) in the European part of the country and the Ob, the Yenisei, and the Lena in Siberia, along with an intricate patchwork of lakes. This increased the number of potential sites for NPP construction. A disadvantage was that most of the industrialized and urbanized areas, where electricity was most direly needed, were located far away from the sea, whose water, in the eyes of nuclear engineers worldwide, was generally considered more attractive from a cooling perspective than rivers and lakes. The large Siberian rivers were also largely irrelevant for civilian nuclear projects since they were too far away from the Soviet industrial heartlands.

In the end a vast majority of Soviet nuclear facilities were erected by one or the other river, and more specifically along rivers in the European part of the country. This generated considerable challenges for Soviet nuclear builders. The plants needed not only lots of water, but also and above all a *steady* and fully *reliable* water flow.[93] The water flow must not be disrupted even for a minute; if that happened, the reactor might start to heat up in a dangerous way and in the worst case a core meltdown might occur. In practice, this meant that NPPs could not be built along wildly flowing, pristine rivers. They could only be built along rivers that had undergone substantial regulation and "improvement" through damming, deepening, and straightening. If such sites could not be found, the nuclear builders themselves would have to take on the task of regulating and "improving" the river. Alternatively, a plant could be built on a larger lake, but the logic was the same there: pristine lakes were not suitable, since their water levels might vary unpredictably. Instead, nuclear builders needed lakes whose water levels could be controlled.

The Novovoronezh reactors were built on the Upper Don's main floodplain. This river was, as of the 1950s, largely pristine. Having escaped earlier Soviet hydraulic engineering initiatives, it was still flowing freely at the planned NPP site. It had not been subject to any significant regulation or reengineering in the past. Hence it was up to the nuclear builders to "tame" the river and adapt it for their purposes. They did so by straightening it and digging out new channels to create a more regular flow. This was considered enough for the purpose of guaranteeing the water needs of the first two pioneering reactors discussed in Chapter 4. When the Soviets set out to expand the plant by adding two VVER-440 reactors, however, they did not trust the river's cooling capacity. Instead, they built several cooling towers. These made it possible to recirculate river water, in a way that reduced—while not eliminating—the plant's dependence on the river. Later, in preparation for adding a fifth reactor, the rectified river and the cooling towers were radically supplemented through the construction of a 5 km^2 cooling pond. The engineers constructed an earthen dam 10 meters high to make sure the water remained in the pond. In connection with the pond construction, they diverted the Don into a new course. Seen as a whole, these extensive envirotechnical arrangements were considered sufficient to guarantee the plant's uninterrupted, continuous access to cooling water. The cooling pond was further integrated into the urban planning of the adjacent nuclear town, Novovoronezh, where the plant workers lived, and its embankment became the most popular place for taking a stroll on a Sunday afternoon. The NPP, the river, the cooling towers, the cooling pond, and the nuclear town thus became part of one and the same envirotechnical system (Map 5.1

and Figure 5.1). This exemplifies what we, in the introductory chapter, conceptualized as micro- and meso-entanglements in the Soviet nuclear archipelago.[94]



Map 5.1. Envirotechnical entanglements at Novovoronezh

Source: Own work/Red Geographics

Figure 5.1. View from Novovoronezh showing the cooling pond and in the background the nuclear power plant, as of 2007. The fifth reactor, for which the pond was built, is visible to the upper left, whereas the first four, smaller reactors are hidden behind the cooling towers that supplement the Don as a cooling source.

Source: Wikimedia Commons, https://commons.wikimedia.org/wiki/File:Novovoronezhskaya_Nuclear_Power_Plant.jpg

Novovoronezh, however, was only the beginning. Before operation of the first VVER-440 reactor had been launched on the Don, the foundation was laid for another VVER plant, this time on the Kola peninsula in the High Arctic. Planners viewed the construction of a nuclear facility there as an excellent way to power the sprawling extractive industries that dominated Kola's economic life. There were no large-scale fossil fuel deposits nearby, so any alternative energy sources were much welcomed. A suitable site was found 200 kilometers south of Murmansk, near the peninsula's southern coast. Factors that made the site attractive included a reasonable distance to nearby population centers in accordance with Soviet safety regulations, an available workforce, an existing electricity grid, and the vicinity of the Kirov Railway (to Leningrad) and the Leningrad-Murmansk Highway.[95]

Cooling water was also readily available. The proximity of the White Sea aside, the region was rich in lakes. The nuclear builders decided to make use of the large Lake Imandra. This was not a pristine water body. During the preceding decades both the lake and the rivers flowing into and out of it had been subject to far-reaching re-engineering. Several hydroelectric plants had been erected in the area between 1934 and 1952, some of them forming cascades of multiple interconnected facilities. Critically for the nuclear builders, since 1952 the water level in the lake was artificially controlled through a dam at its southern outlet. In this way, Kola NPP was able to link up with an already existing, pre-nuclear envirotechnical system. It became deeply entangled with a wider wet environment spanning a large part of the peninsula. On the lake's shore, the nuclear workers' town Polyarnye Zori was founded. A negative side-effect of the entanglement was that releases of warm cooling water from the nuclear facility caused thermal pollution and eutrophication. This was seen as potentially problematic, not least because Lake Imandra supplied the region with both drinking and industrial water. For this reason, the lake was carefully monitored by the Kola branch of the Soviet Academy of Sciences. However, the Soviets turned part of the problem of thermal pollution into an opportunity by utilizing the heated water for fish cultivation, and for terrestrial vegetable agriculture featuring specially bred species in greenhouses, in a project endorsed by the Ministry of Health.[96]

While the Kola NPP was built in the very north of the Soviet Union, another VVER-440 facility was constructed in the very south. The Armenian NPP (also known as the Metsamor NPP) was erected 30 kilometers west of Yerevan and only 16 km from the Soviet-Turkish border. The idea was to let the atom compensate for Armenia's lack of fossil fuel resources. The site was problematic in at least two respects, however. On the one hand, the area was known to be seismically active. For this reason, the Armenian NPP was fitted with a version of the VVER-440 reactor type that was more resilient to earthquakes. On the other hand, the location was far from perfect from a water-supply perspective, as the Metsamor River, the only reasonable source of cooling water in the area, was very small. The nuclear-hydraulic engineers coped with this dilemma by adding four large cooling towers, which minimized water withdrawal from the Metsamor.[97]

The Soviets built a fourth VVER-440 plant on the Styr River in western Ukraine. Rivne (Rovno) NPP, as it was called, saw the construction of two reactors of the modified, safer VVER reactor type mentioned in the beginning of this chapter: the VVER-440/213. Construction started in 1973. The region, known for machine-building, food-processing, metal works, chemical, clothing, and light industries, was in dire need of more electricity, but as in Armenia, it proved difficult to harmonize this need with the NPP's demand for large volumes of cooling water. The Styr was, like the Metsamor, a very small watercourse. Again, Soviet engineers coped with this delimitation by adding several imposing cooling towers, each so large that Leningrad's "St. Isaac's Cathedral could easily have fitted within it," as *Ukrainskaya Pravda* put it.[98]

In parallel with these starts of VVER construction, Soviet nuclear builders set out to erect their first RBMK facility. It was built on the shores of the Gulf of Finland, where a town called Sosnovy Bor had been founded in 1958. It already served as a base for military oriented nuclear-industrial activities, comprising facilities for activities ranging from waste storage, over research and development, to the testing of marine nuclear plants. Due to the classified character of these operations, visitors needed special permits to enter the town.

Sosnovy Bor exemplifies what would become a main trait of Soviet and Russian nuclear geography: whenever possible, new nuclear facilities were erected where old ones already existed. In hindsight, Sosnovy Bor was a unique location for a Soviet nuclear power plant, as it was built directly on the seashore and used seawater for cooling.[99]

Leningrad NPP, as it was—and still is—officially called, was aptly named because its main purpose was to supply electricity for growing industrial and urban needs in Leningrad, which, just like Kola and Armenia, was located far away from the country's main coal mines and oil and gas fields. But in effect it also became part of a wider energetic territory, which included the vast oil shale mines in northeastern Estonia and its huge Balti (765 MWe) and Eesti (1,615 MWe) power plants that were built to burn this inefficient, dirty fossil fuel en masse, as well as the hydroelectric facilities in the Narva and the Volkhov Rivers. Narva HPP, which had been completed back in 1955, played an important role in balancing the region's electricity system. Leningrad NPP was built quickly, and soon after construction of the first reactor block had commenced a second one was laid out. Driven by an urge to rapidly expand, the Soviets subsequently added reactors three and four in 1973 and 1975.[100]

Soviet nuclear builders erected three subsequent RBMK plants inland rather than on the sea. These facilities made use of river water for their cooling needs. Two of the plants were in Russia and one in Ukraine, but hydrologically they were united by the fact that they were all in the Dnieper River basin. However, since the water flow was as a rule not sufficiently stable and reliable, the main Soviet hydraulic engineering agency, Gidroproekt, which played a dominant role in designing the three plants, judged that substantial reengineering of the wet landscapes at the respective sites was necessary.

The key components in the envirotechnical systems that emerged took the form of artificial water reservoirs (cooling ponds). As in the case of Novovoronezh, this radically transformed the hydrology and visual appearance of entire regions.

The first of the three inland RBMK plants was Chernobyl NPP (Figure 5.2). It was built on the shores of the Pripyat, a tributary to the Dnieper, just a few kilometers upstream from Kyiv's large drinking water reservoir. The latter had been constructed in tandem with the Vyshhorod (Vyshgorod) hydroelectric plant in the 1960s. The NPP site was strategically located between several industrialized areas to the south and north: the Kyiv metropolitan region and the Belarusian industrial cities of Homel (Gomel), Babruisk (Bobruisk), and Minsk. Furthermore, the important city of Chernihiv (Chernigov) was located east of the plant.[101]

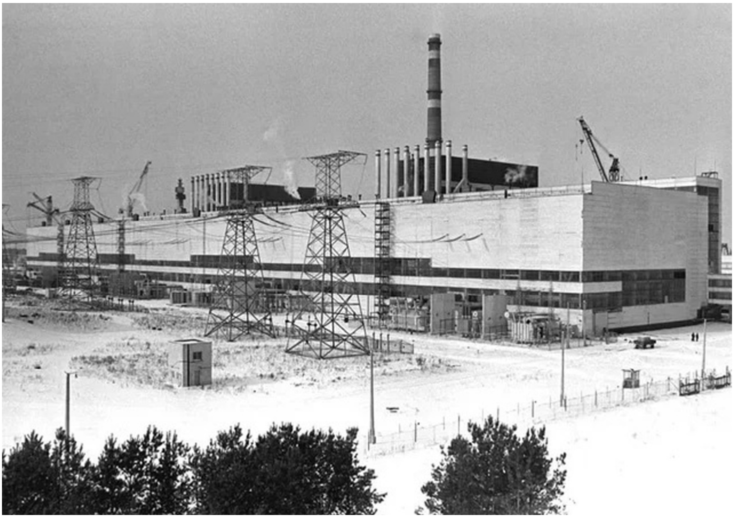
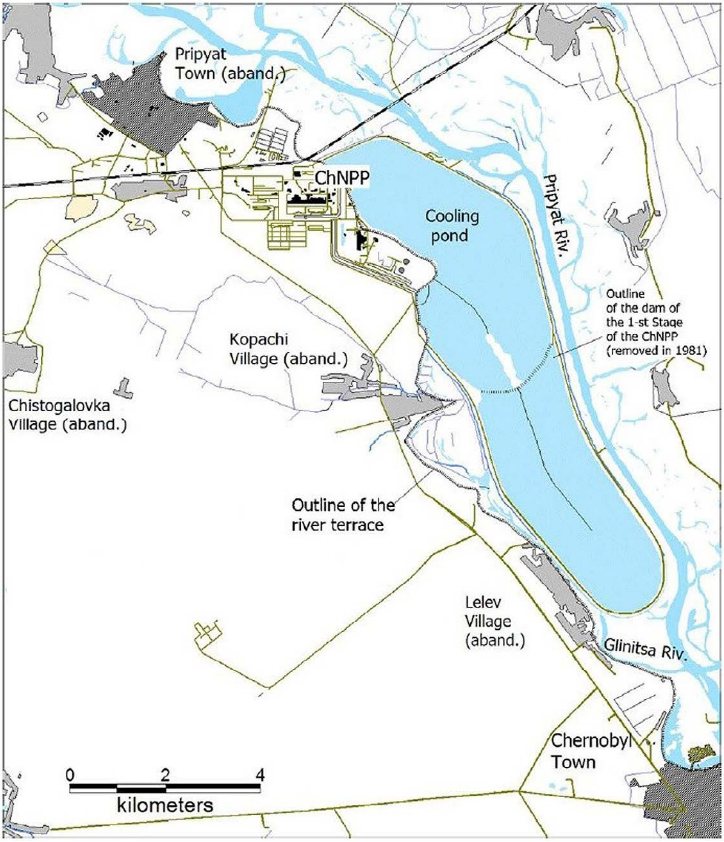


Figure 5.2. Chernobyl NPP under construction in the 1970s

Source: Wikimedia Commons

Chernobyl's cooling pond showed some similarities with its counterpart at Novovoronezh. Rather than having the Pripyat dammed, Gidroproekt designed a separate reservoir on the river's right bank. It covered a surface area of 23 km^2 and its water level was 7 meters higher than the river (Map 5.2). To support the dam, the construction trusts built a system of earthen dams. River water could not flow into this artificial water body by gravity alone; instead, a set of powerful pumps were deployed to lift water from the river into the pond. Other pumps were then used to move pond water into the nuclear plant and its powerful condensers. The pond was divided into two parts that were separated by an additional dam, which prevented the warmed, discharged cooling water from mixing prematurely with the cooler water that was pumped into the plant. Chernobyl's cooling pond is a fine example of the merging of hydraulic and nuclear engineering traditions in Soviet nuclear history. The plant's adjacent nuclear town was named after the river: it was called Pripyat and was built a few kilometers upstream from the plant itself. A total of six reactors were planned at Chernobyl, all of them RBMK-1000s. Construction of the first reactor block's main buildings started in 1970, but progress was so slow that the first nuclear electricity was fed into the grid only in 1977. The site continued to be haunted by problems and crises of different kinds in the years that followed, culminating in the 1986 Chernobyl catastrophe. Before that disaster, Chernobyl was nevertheless proudly referred to as "the first and most prestigious" nuclear power plant in Soviet Ukraine.[102]



Map 5.2. Map of Chernobyl NPP and its cooling pond as of 2019

Source: IAEA, "Environmental Impact Assessment"

The other two inland RBMK plants were built in the westernmost regions of the Russian SFSR, near the important cities of Kursk and Smolensk. Construction of the Kursk RBMK plant officially commenced in 1972. It was erected on the Seim River, the largest tributary to the Desna, which flowed into the Dnieper. Just like at Chernobyl, the nuclear builders created a huge cooling pond, supported by earthen dams, that paralleled the river. Two workers' towns, Kurchatov and Ivanino, were founded within three kilometers of the plant. Just like Novovoronezh and Polyarnye Zori, the nuclear town of Kurchatov was built directly on the shore of the cooling pond, from where the town also sourced its drinking water. Over time, this gave rise to concerns about drinking water safety.[103] Four RBMK reactors were eventually erected at the Kursk site.

Likewise, in the Desna River basin, following a basic plan developed by Gidroproekt, the Soviets began construction of the Smolensk NPP. Its water supply was guaranteed through the construction of a large reservoir at the confluence between the Desna and several smaller tributaries. The Desna was a relatively small river, which had not been subject to any far-reaching regulation before the arrival of the nuclear-hydraulic engineers. The nuclear builders set out to dam the river in a radical way, raising the water level by 12 meters. This gave rise to what has been one of the largest nuclear cooling reservoirs worldwide ever since, covering a surface of 44 km^2. On the shores of the new lake, the nuclear town of Desnogorsk was founded. The Desnogorsk water reservoir, as the lake was called, became a popular part of the local landscape, used for various leisure activities like hiking, fishing, and swimming. While construction of the first of four planned RBMK reactors commenced in 1975, the filling of the lake began in 1979 and was not completed until 1984.[104]

The Soviet Union's nuclear planners intended to build a fifth RBMK plant in either the Lithuanian or the Belarusian SSR. This seemed logical in view of the lack of other large-scale electricity capacities in that region, which suffered from a lack of coal, oil, and gas, leaving it to rely extensively on local peat for its energy supply. In November 1972 the Soviet Council of Ministers, with limited participation by Lithuanian institutions, decided to construct the envisaged RBMK

Map 5.3. Reactor sites of relevance for the first boom phase. The sites in Finland and Central Europe are discussed in Chapter 6.

Source: Own work/Red Geographics

plant in the northeastern part of Lithuania, more precisely on the shores of Lake Drūkšiai, which was partly in Lithuania and partly in Belarus. This freshwater body was identified as a suitable source of cooling water. An interesting reason for the choice of location was, as Andrei Stsiapanau notes in a study, that it was "relatively close to the Leningrad NPP site," implying that Soviet planners considered fruitful macro-entanglements between different RBMK construction sites an important factor. However, the site selection gave rise to controversy. Lithuania's Geological Directorate, a body under the control of the republic's Council of Ministers, and the Lithuanian Geological Institute were particularly critical and called for additional geological studies. Later on, concerns were raised by scientists from the Lithuanian branch of the Soviet Academy of Sciences, who questioned, among other things, the cooling capacity of Lake Drūkšiai.[105] It was most probably these internal disagreements between central Soviet and Lithuanian stakeholders that prevented construction of the plant according to the envisaged schedule. It would eventually be built, but only after years of delay. We will return to Ignalina NPP in Chapter 8.

The four Soviet VVER-440 plants and the five RBMK nuclear stations discussed in this chapter laid the basis for two Soviet reactor geographies that we will refer to as "VVER land" and "RBMK land." Even at this early stage we can see how they already differed: while the VVER plants were spread out across a vast territory, from the Kola peninsula in the north to Armenia in the south and from Rivne near Ukraine's western border to Novovoronezh in central Russia, the RBMK plants were strikingly concentrated to a relatively small region in the northwestern part of the Soviet Union. This fundamental difference between VVER land and RBMK land would grow even more pronounced over time, as we will see in subsequent chapters.

Nuclear power plants aside, the first boom phase also featured new uranium mining capacities, most of which were in the eastern rather than in the western part of the Soviet Union. A notable case was the creation of the massive Priargunsky Mining and Chemical Production Combine in Eastern Siberia. A 1968 decision by the USSR Council of Ministers paved the way for it. The combine was located near the town of Krasnokamensk, close to the Chinese and Mongolian borders. Priargunsky would grow to become one of the world's largest uranium mines, helping the Soviets to overcome any potential uranium scarcity—in the Soviet Union itself as well as in the Central European satellite states. The Priargunsky combine thus completed the earlier trend that had started in the 1950s, mentioned in Chapter 3, of uranium scarcity gradually giving way to abundance.[106] Meanwhile, uranium extraction also increased in the Kazakh SSR, with multiple mines spread across different parts of the republic. Much of the Kazakh ore was sent for processing to the Tajik SSR, whose northern regions had been active in this segment of the nuclear industry since the early 1940s.[107]

6. Winning New Territories

The Soviet Union's first civilian nuclear power plants were built in the European part of the country, and especially in the European part of the Russian SFSR. Soviet nuclear system builders then set out to build plants in other union republics, and to export nuclear reactors. We have already seen how the nuclear boom in the 1970s spread to northern Ukraine, where the Chernobyl and Rivne plants started to be erected early on, and to Armenia in the country's far south. Two more radical projects targeted western Kazakhstan, as already touched upon in Chapter 3, and the Russian Far East, both of which can be regarded as colonial regions. Here, the energy planners at Minenergo and Gosplan proposed nuclear projects as "tools of empire," to use Daniel Headrick's term, mobilizing the atom as part of their *mission civilisatrice*.[108]

Stefan Guth writes that the fast breeder at Shevchenko, on the shores of the Caspian, was originally envisaged as a source of weapons-grade plutonium. In 1973, however, when the facility was finally ready to be taken into operation, Sredmash head Yefim Slavskii decided that electricity generation was to be prioritized. In this connection, the military profile gave way to a vision in which nuclear electricity would be used to power a huge seawater desalination plant (Figure 6.1). The freshwater produced in this way would be used to turn Mangyshlak's barren desert landscape into a green "nuclear oasis," where tens of thousands of people could live. Shevchenko was to demonstrate how a socialist model city with big industrial potential could spring up in a seemingly empty and arid landscape that had earlier functioned mainly as a home to nomadic Turkic peoples. The micro- and meso-entanglements of the breeder project thus combined a radical transformation of the landscape with far-reaching social and economic transformation along colonial lines.[109]

Figure 6.1. **Water conduit at Aqtau (formerly Shevchenko), Kazakhstan, leading from the nuclear desalination plant into the city. The reactor building is located between the chimneys.**

Photo by Stefan Guth, 2012

Starting in 1969, fast breeder technology was put to work at the already existing Beloyarsk NPP as well. That station's third reactor became a BN-600 breeder reactor, designed for almost twice the capacity of its Shevchenko counterpart. Overall, however, the fast breeder development line did not prove successful. Stability risks, safety issues, proliferation concerns, environmental and, probably most decisively, economic considerations ensured that fast breeders remained marginal, at best, in the Soviet nuclear archipelago.[110]

Meanwhile in the Russian Far East, well above the Arctic Circle, in 1970 the Soviets began construction of four reactors simultaneously, which were to make up the Bilibino NPP. It was built to power gold mines and nearby living quarters, thus countering—or so the argument went—the harsh climatic conditions of northern Chukotka with modern, science-based technology. With a capacity of only 12 MWe each, the Bilibino reactors were much smaller in scale than their VVER and RBMK counterparts. This design, which would later inspire the vision of "small modular reactors" (SMRs), was seen to allow the exploitation of remote locations and thus create countless new "islands" in the Soviet nuclear archipelago.[111] Once in operation, the Bilibino station was recognized as the world's only nuclear power plant persisting in the conditions of permafrost. It provided not only electricity but also district heating to the inhabitants of Bilibino town.[112]

The example of Bilibino NPP illustrates a dark chapter in Soviet nuclear history. Just like in gold rush regions elsewhere in the world, the Soviet state was keen to quickly exploit the precious metal. However, the indigenous Chukchi and Evens lived in the fragile ecosystem of the permafrost. The "civilizers" from the metropole changed the homelands of these peoples profoundly and, due to the nuclear residue they left behind, forever. The area faced widespread radioactive contamination and permanent alteration of the previous interplay of flora, fauna, and humans.[113]

The Soviets were even more keen to win new territories through the export of nuclear technology. Their most noteworthy success in this regard was the sale of two VVER-440 reactors to Finland in the 1970s. On that basis, the Finnish state-owned power company Imatran Voima constructed the Loviisa NPP in the Finnish archipelago. Many more VVER plants were built in communist Central Europe, in what Sonja Schmid conceptualizes as the USSR's "nuclear colonization" of that region.[114] The Soviets initiated exports of VVER-440 reactors to Czechoslovakia (where construction of an impressive twelve reactor blocks commenced at three sites—Bohunice, Dukovany, and Mochovce), Hungary (four blocks at Paks), East Germany (eight blocks at Greifswald), Poland (four blocks at Żarnowiec), and Bulgaria (four blocks at Kozloduy). These projects rested on close cooperation between the Soviet Union and the Central European countries. Soviet agencies and experts played the key part in supplying the nuclear technology—the “nuclear island” of the plant, as they termed it—while the Central Europeans usually supplied a large part of the “non-nuclear” machinery, which the Soviets defined as all parts of the plant that were not part of the primary cooling loop. Siting decisions were typically arrived at through joint consultations between the Central Europeans and Soviet experts.[115]

It is interesting to explore the envirotechnical entanglements that resulted at the Central European sites in connection with the VVER-440 projects. The East Germans, following up on their experience with the Rheinsberg pilot-scale VVER plant, initially considered potential sites for a first large nuclear plant on the Baltic coast as well as on the country’s two main rivers, the Elbe and the Oder. Already at an early stage, however, they decided that the rivers were not optimal as sources of cooling water, because they would necessitate costly investments in cooling towers. The East Germans proposed, in their consultations with the Soviets, a site next to Lubmin, a Baltic seaside resort located around 20 km east of the old Hanseatic town of Greifswald. This choice presented several drawbacks. Because it was far away from the more industrialized parts of the GDR and hence from those most in need of the electricity, expensive new high-voltage transmission lines had to be built to transfer the power. Lubmin’s official representatives and the tourist industry, for their parts, were far from happy with the location, fearing fewer vacationers and competition with the plant construction workers for scarce food supply.[116] But since optimal access to cooling water was so critical, Lubmin was still found to be the best option. There are also indications that the East Germans did not trust the safety of the Soviet-designed VVER reactors. As we have seen, the first generation of VVER-440 reactors were not designed to be able to cope with a major rupture in the primary cooling loop. The East Germans were aware of this and concluded that they had better build their first VVER-440 plant as far away as possible from the more densely populated parts of the country.[117]

In January 1968 the first worker brigades arrived at what was then a forested area east of Lubmin. Having cleared the forest, they proceeded by digging out a cooling water inlet and discharge canal several kilometers long. Then, in October 1969, the actual buildings started to be erected next to this waterway. The construction workers were initially hosted in buildings belonging to the tourist agencies in Lubmin, including those of a large children's summer camp. Later, several new, modern suburbs were built on the outskirts of Greifswald, radically changing the urban culture in what had for centuries been a sleepy medieval town with a university. A new railway line was built from Greifswald to Lubmin to enable thousands of construction workers to commute to the plant daily. In the early 1980s the entanglements between Greifswald and the NPP were further tightened through the construction of a district heating system that made use of some of the plant's waste heat for warming the new suburbs.[118]

The first VVER-440 reactor in Lubmin was connected to the grid in December 1973, followed by a second one year later. In 1975, however, the first reactor block already suffered a major accident, as a fire disrupted the operation of five of the six primary coolant pumps. The sixth pump saved the brand-new Greifswald NPP from a Chernobyl-like disaster, thanks to the lucky circumstance that it was temporarily connected to the electricity supply of the second reactor block.[119]

Two more VVER-440/230 reactors were completed by 1978. The plan was then to further expand the plant by adding another four reactors of the safer VVER-440/213 type. Had it been completed, these would have made Greifswald one of the largest nuclear power plants in the world, comprising a total of eight reactors. But although construction of the additional blocks started in 1976, progress was slow and the first VVER-440/213 reactor was connected to the grid only in October 1989—just weeks before the Berlin Wall came down.[120]

Further south in Central Europe, the Danube became the focal point for the erection of VVER-440 stations. Bulgaria's Kozloduy NPP was the first of these. Following an agreement in principle with the Soviet Union on cooperation in constructing large-scale nuclear power plants, the Bulgarian energy design organization Energoproekt was given responsibility for overall planning of the station. It was an interesting agency, having been set up in 1948 "to design and construct hydropower plants," as Ivaylo Hristov notes. A decade later it expanded into thermal power plant construction. Energoproekt started looking for a suitable site for the planned NPP early on. It conducted extensive hydrological, geological, and hydro-geological measurements, while also studying meteorological conditions, radiation safety, and the environmental protection for twenty-one potential sites. Eventually the immense water needs of the planned facility dictated that it would have to be built on the Danube, and a site was picked in a sparsely populated area. At a party plenum held in November 1969, it was decided to build the country's first nuclear plant near the town of Kozloduy in northwestern Bulgaria, on the Danube's right-hand bank.[121]

Kozloduy NPP's design rested on withdrawing water from the Danube via two artificial canals, each 4 km in length, with a very high throughput. The used, warmed water was then released back into the river. A port serving the NPP was built on the Danube's banks for unloading equipment shipped from the Soviet Union and elsewhere. Hristov writes that the first brigades for plant construction arrived at the Kozloduy site at the beginning of 1970. They

> started work in extremely bad weather conditions. There was no temporary housing in the region. The workers had to sleep in tents while the directors and officers used abandoned farm buildings. These farm buildings served as makeshift headquarters based in the closest village located seven kilometers from the platform.[122]

Such logistical challenges aside, it was soon found that the site was problematic due to instability of the soil. The Bulgarian Academy of Sciences was called upon to devise solutions. In the end, the Bulgarians miraculously managed to overcome both this and a range of further difficulties, allowing the first reactor at Kozloduy to go critical in June 1974—an impressive feat. Another reactor followed the next year, and by 1982 four VVER-440/230 reactors were in operation on the Danube.[123]

Apart from the practical and technical problems at the Kozloduy site, the Bulgarians were troubled by the fact that the Danube formed the political border with Romania. The Romanians feared the consequences of a potential accident. These concerns were linked to a wider debate in the entire Danube region about potential radioactive pollution of Danubian waters. In 1975 the IAEA proposed to set up "a special working group to study the cooperation among the countries bordering on the River Danube"—including the Danube basin's two capitalist riparians, Austria and West Germany. At the group's second meeting, held in Bucharest in 1977, representatives from all Danube countries "discussed statements and reports on the radiation pollution of the Danube" and "the protection of the Danube basin and its population from radiation fallout and exposure to radiation."[124] In parallel, the fear of radioactive pollution of the Danube was discussed in the CMEA's Permanent Commission for the Peaceful Uses of Atomic Energy. The Romanians became very active in this arena, suggesting that nuclear safety cooperation be intensified among the member states. The result was the formulation of "uniform methods for measuring and observing radiation pollution in the environment of nuclear power plants, in border areas, and near water bodies" along with "procedures for timely informing neighboring countries in case of a nuclear accident."[125]

Czechoslovakia and Hungary also built their VVER-440 plants in the Danube River basin. Czechoslovakia, Central Europe's industrial powerhouse, would over time become the most active of all Central European countries in exploiting nuclear energy. In contrast to the Bulgarians, however, Czechoslovakia's nuclear builders never targeted the Danube itself in these efforts. Instead, they opted to exploit a number of small and large Danubian tributaries. Why did the Czechoslovaks avoid the main river? The main reason appears to have been that the only segment of the Danube that they fully controlled was in the immediate vicinity of Bratislava, Slovakia's capital city, which was an unacceptable site for a nuclear power plant with VVER-440 reactors, given their lack of full containment. Further downstream, moreover, the river formed the political border with Hungary, a country with which Czechoslovakia traditionally had a troubled geopolitical relationship. Against this background the country's nuclear-hydraulic engineers were driven to retreat to the valleys of several left-side Danubian tributaries. These were located fully on Czechoslovakian territory and offered sites at suitable distances from major cities.

Like Bulgaria, the Czechs concluded an agreement on nuclear cooperation with the Soviet Union in 1966, focusing on the transfer of VVER technology. This was followed by the government's decision to build a full-scale commercial nuclear power plant, which would comprise several VVER-440 reactors. In the siting decision process, path dependence prevailed, as planners thought it convenient to use Jaslovské Bohunice, the site that was already used for a pilot-scale heavy-water nuclear plant (cf. Chapter 4). That would enable them to utilize "already existing construction site facilities" and, more importantly, draw on "the continuity of work for the supplier organizations and the utilization of experience of the investor's and the operator's workforce in the preparation, realization and commissioning processes."[126]

From a cooling water point of view, the solution was far from ideal. The Váh (in German: Waag), a Danubian tributary, was the only reasonable water supply source nearby, but it was a hefty 7–8 km away from the construction site, and the river's flow was modest and irregular. Against this background the Czechoslovak nuclear-hydraulic engineers had to combine nuclear construction at Bohunice with a major reengineering of the Váh, rectifying and damming the river while equipping it with a hydroelectric facility. They also found it imperative to equip the plant with expensive cooling towers, because the river's water did not suffice. The first VVER reactor at Bohunice was connected to the grid just before Christmas 1978, marking the real entry of Czechoslovakia into the civilian nuclear age. By 1985 the site boasted four operational VVER-440 reactors, all of them supported by the tiny Váh.

Further west, in Moravia, Czechoslovakia built Dukovany NPP. Here, in the southeastern foothills of the Bohemian-Moravian Highlands, Czech nuclear-hydraulic engineers designated the Jihlava, a small river in the basin of the Morava, a Danube tributary, as a suitable site. By 1987 four VVER-440 reactors had been taken into operation there. The facility was equipped with eight large cooling towers, each approximately 120 meters tall.[127]

While Bohunice and Dukovany were still under construction, the Czechoslovakians set out to build a third Danubian NPP: the Mochovce facility. This time they targeted eastern Slovakia and the basin of the Hron River. Once again, however, the engineers found that the natural water flow in the river was too limited and, above all, too unreliable. By now experienced in the art, they set out to remake the Hron by straightening and damming it. They also used the opportunity to install a hydroelectric turbine next to the dam. Construction of the dam started in spring 1984 and was completed in summer 1988. Damming the river raised its water surface by 7.5 meters, leading to inundation of large tracts of land and generating a large cooling water reservoir for the NPP, supported by dikes. The regional government was highly supportive of the project, because apart from serving nuclear cooling needs, the system allowed for the irrigation of more than 13,000 ha of land. It also strengthened the reliability of the region's urban and industrial water supply. "Another use of the reservoir," local agencies argued, was "landscaping." The reservoir was regarded as "an important element of the ecosystem" and served "recreational purposes," while "fishermen also enjoy themselves."[128] By the time of the Chernobyl disaster in 1986, however, none of the reactors at Mochovce had been completed.

Hungary's starting point for nuclear construction was very different from that of Czechoslovakia. The Hungarian natural geography was characterized by vast plains and a lack of mountainous river valleys of the kind that captured the imagination of Czech nuclear builders. On the other hand, the Danube itself, impressive in its width, flowed across the country's central regions. In the eyes of Hungary's nuclear planners, it seemed natural to build the nation's first nuclear power station, the Paks NPP, directly on the Danube. A site was picked 110 km downstream from Budapest, where the river was 400 meters wide. The Danube's flow varied over the year, being richer in summer than in winter, but since it was such a massive river nobody worried about potential water scarcity. The plant was erected one kilometer from the right-hand riverbank. A cooling-water intake canal, 70–80 meters wide, protected by trash racks (to prevent debris from entering the system), connected the river with the NPP's pumping station. There, the water first passed through a series of filters before being moved into a system of pipes and onwards to the main condensers. The warmed water was then discharged into a separate, narrower discharge canal, which emptied directly into the Danube just downstream from the point of cooling water intake. This overall hydraulic architecture appears to have been inspired by the Kozloduy NPP in Bulgaria, which used a similar system to harness the Danube's waters. By 1987 four VVER-440 reactors had been connected to the Hungarian electricity grid. From this time on, the Paks NPP became "the greatest industrial water consumer of Hungary," with an average need of 80–100 m^3/s for a total of 1760 MW installed capacity.[129]

For some time, it also seemed as if Poland would join the Soviet nuclear archipelago with a VVER-440 nuclear plant. Northern Poland, in particular, was poor in fossil fuel resources but needed more electricity to power the key cities of Gdynia and Gdańsk and their massive shipyards. In December 1972 the Polish Planning Commission decided to erect the nation's first nuclear power plant on the shores of Lake Żarnowiec in Pomerania. It is not clear why the Poles preferred this lakeside location, although the Baltic Sea was located just a few kilometers away. The lake was deemed suitable as a cooling source. It was also a major fishing ground, but the nuclear builders suggested that thermal pollution from the power plant would not negatively affect fisheries. On the contrary, proponents proposed the idea of scaling up the local fishing industry by "populating the lake with warm-water fish." It took until 1982 before actual construction of Żarnowiec NPP started. However, no reactor had been completed at the time when the Chernobyl disaster changed the outlook for nuclear energy in Poland.[130]

In summary, we can see that the Danube River basin was gradually integrated into the Soviet nuclear archipelago on a grand scale, hosting an impressive number of large-scale nuclear reactors. The other large Central European rivers—the Elbe, the Oder, and the Vistula—remained unexploited during the first boom phase, while the Finns and the East Germans relied on the Baltic Sea for cooling their VVER plants. The Poles targeted a lake, but only very hesitantly, and ultimately did not manage to complete any reactor before the Chernobyl disaster. Micro- and meso-entanglements at each site were extensive and multifaceted, comprising far-reaching changes of entire landscapes and, at several sites, close interaction between nuclear construction, tourism, and fisheries.

7. Evolving Macro-Entanglements

In the previous two chapters we have seen how Soviet nuclear builders—and their foreign partners—devoted intense efforts to constructing nuclear facilities at a growing number of sites and to integrate these into local and regional geographies and environments. In parallel, centrally placed system builders in Moscow—mainly Minenergo and Sredmash—elaborated on the functionality of the system as a whole. This entailed the challenge of managing the intricate interdependencies that arose between different facilities. These interdependencies generated three important layers of macro-entanglements.

The first layer grew out of the fact that nuclear power plants at different sites, to a varying extent, were similar in technological terms. All RBMK sites were dependent on a similar set of nuclear technologies, while all VVER sites shared a somewhat different set. The two reactor types were radically different. The RBMK was a boiling-water reactor and, as such, it lacked major components such as steam generators and pressurizers, which were of critical importance for VVER plants. The RBMK used graphite as a moderator and the core was organized in "channels" that testified to their close relationship with the military plutonium-production reactors; it is no coincidence that Nikolai Dollezhal, widely regarded as the father of the RBMK model, had earlier designed the first plutonium production reactors at Mayak. The VVER, on the other hand, was a pressurized-water reactor. Its cooling system was more complex, as an additional cooling loop was needed to prevent the water in the primary loop from boiling. It used no graphite, but plain water as coolant and moderator. The two reactor types also used different kinds of nuclear fuel, with different degrees of enrichment. All in all, this stimulated the formation of two different communities of practice and networks of technological expertise, within which engineers, technicians, and operators communicated more intensely than they did with their technologically more "distant" colleagues. In the case of VVER-440 reactors, the resulting geography spanned a vast region from the Kola peninsula in the north to Armenia in the south, and from East Germany's Baltic coast in the west to Novovoronezh in the east. The RBMK technological geography was much more limited, as it was deployed at only four sites that were remarkably close to each other: Sosnovy Bor, Chernobyl, Kursk, and Smolensk.[131]

The dynamics of the technology-based macro-entanglements can be exemplified by the interaction between VVER-440 nuclear builders in the Soviet Union, Finland, East Germany, Hungary, and Czechoslovakia. As noted in the previous chapter, the Soviet Union managed, against all odds, to export its VVER technology to Finland. The Finns agreed to this deal even though they would have preferred to buy a Western reactor. Finnish historian Karl-Erik Michelsen writes that the Soviet offer "turned out to be both technologically and economically inferior and could not compete with the much stronger tenders of the Western companies." Yet the Finns eventually accepted it, succumbing to political pressure from Moscow. Being worried about the VVER's inferior safety features, however, they adopted a tough negotiation strategy when the detailed discussions about the project began in 1969. The Finnish delegation requested that the reactor and the reactor building be covered by a gas-tight steel containment. They also demanded that all key components be designed according to the American ASME standard. The Soviets found these demands unacceptable. Nevertheless, a deal was eventually worked out that, in effect, reduced the role of the Soviet Union to that of a subcontractor: Moscow would deliver the reactor pressure vessel and a few additional key components, while allowing Imatran Voima, the Finnish electricity company in charge of the project, "to redesign the power plant, adapt it so that it matched Finnish requirements, manage the project as a whole and find subcontractors—in Finland and abroad—for those parts that Technopromexport did not provide." When the first reactor at the Loviisa NPP went critical in January 1977, the Soviet engineers who, along with Premier Alexei Kosygin, participated in the opening ceremony, were surprised to see that their VVER-440 reactors had been combined with a massive steel containment of a distinctly Western kind, along with an impressive number of additional non-Soviet safety and control technologies (Figure 7.1).[132]

Figure 7.1. **Loviisa NPP, Finland. The plant, beautifully situated in the Finnish archipelago, combines Soviet VVER-440 reactors with Western safety components, most visible here through the US-style containment domes. These make the Loviisa plant visually different from all other VVER-440 plants.**

Photo by Per Högselius, 2003

When the East Germans, who were aware of the shortcomings of Soviet nuclear safety, heard that Finland had found a way to build VVER-440 plants with significantly improved safety standards, they became very interested. At a nuclear engineering fair held 1972 in Basel, Switzerland, East German government officials met with Finnish representatives, who optimistically told the East Germans that the Finnish industrial company Wärtsilä, which had built Loviisa's containment, might be willing to sell such containments to East Germany for its future VVER-440 plants. Czechoslovakia and Hungary were also reported to be interested in the Finnish containment technology.[133]

In the end, this idea did not work out, but the strong interest in containment technologies displayed by Finland and the Central European countries appear to have convinced the Soviet Union that the VVER technology, if it was to be attractive in the international market, needed to be improved from a safety point of view. The Hungarians, in particular, where the Paks NPP was in the planning stage, pushed for a more modern reactor in their discussions with Moscow. This ultimately led to the significantly modified version of the VVER-440 reactor mentioned in Chapter 5: the VVER-440/213. It did not include a full containment of the Western type, but a slightly inferior containment technology that, as Western experts recognized, represented a clear improvement.[134]

The VVER-440/213 was pioneered at Paks, where construction of the first reactor block began in 1974. Subsequently it was adopted for the third and fourth units at Czechoslovakia's Bohunice NPP and at all units of the Dukovany and Mochovce plants. From 1976 it was also adopted internally in the Soviet Union, where the third and fourth reactor blocks at the Kola NPP and the two VVER-440 blocks at Rivne adopted the modernized version.[135] In this way the technological macro-entanglements between different VVER plants in the Soviet Union, Finland, and Central Europe evolved dynamically in response to a quest for improved safety.

In the second layer of macro-entanglements, every Soviet NPP was integrated into one of the large electricity transmission systems that Minenergo constructed.[136] High-voltage transmission lines connected the nuclear stations with other electric power plants—mainly coal and hydropower plants along with some oil- and gas-fired facilities—as well as with major industrial and urban consumption hotspots. Soviet engineers referred to the transmission grids, which spanned vast territories, as "rings." For example, the Leningrad NPP was integrated into the "Northwestern Ring," which relied on a system of 330-kV transmission lines and comprised the territory of the three Baltic republics plus the Leningrad region, the Kaliningrad region, and the Belarusian SSR.[137] In this regional system the turbo generators of the Leningrad nuclear blocks were made to operate synchronously with nearby Estonian oil shale-fired power plants, with Lithuanian and Belarusian thermal plants and, most importantly, with several large hydropower facilities that were constructed in Latvia's Daugava River, Russia's Volkhov River, and the Narva River on the Russian-Estonian border. The resulting combination of nuclear energy and thermal power with rich hydropower resources embodies what Thomas P. Hughes referred to as a favorable "economic mix." Hydroelectricity allowed fluctuations in demand to be evened out, which allowed the nuclear stations to operate with a nearly constant "baseload." Major consumption hotspots, in the case of the Northwestern Ring, included the multimillion metropolis of Leningrad, the strategic military city of Kaliningrad (built on the ruins of Germany's Königsberg) and the republic capitals of Tallinn, Riga, and Minsk. As a result of the synchronous integration into the Northwestern Ring, these key cities all came to profit from—and depend on—nuclear electricity from the Leningrad NPP, testifying to a new type of macro-entanglements in the Soviet nuclear archipelago.[138]

Several analogous rings—or power pools, as they were called in the West—materialized further east and south in the Soviet Union. In 1967, Brezhnev's engineers, under the command of the powerful Minister of Energy and Electrification, Piotr Neporozhny, created a Central Dispatch Center in Moscow, through which the different pools were synchronously linked to each other. They also built a set of new high-voltage transmission lines. This allowed for massive "exports" of electricity from one pool to another, with deliveries toward Moscow playing a particularly important role.[139] In this way almost all Soviet nuclear power plants built during the first boom phase were electrically interlinked with each other. A similar integrated electricity grid was built in communist Central Europe, allowing the VVER-440 stations there to develop electrical macro-entanglements with each other. Prague was at the heart of this integrated system, as it hosted the central dispatch center, whence orders could be sent to power plants and grid operators in the other communist countries.[140]

The third layer of macro-entanglements, finally, emerged out of the need to supply nuclear power plants with nuclear fuel and, after irradiation in the reactors, manage spent nuclear fuel and radioactive waste. This produced a set of complex interdependencies between nuclear sites within and beyond the Soviet Union. The Soviets developed a strategy that, in terms of "front end" activities, centered on moving uranium ore to processing, conversion, and enrichment plants, and from there to nuclear fuel element factories. The most important Soviet fuel element factory was at Elektrostal,[141] where uranium had already been purified for military purposes during the 1940s. From Elektrostal the fuel elements traveled by rail to each NPP in the European part of the Soviet Union as well as to Loviisa in Finland and the VVER-440 sites in Central Europe. On the "back end," spent fuel from these sites, which was more difficult to handle than fresh fuel due to very high levels of heat and radioactivity, would be left to cool in pools next to the reactors. The idea was then that the spent fuel, after a few years in the pools, would be picked up by Soviet trains and moved to the Urals in specially designed rail cars.[142] There, at the Mayak complex, which had originally been created for military purposes, Sredmash planned to build a reprocessing facility, specially designed for handling civilian spent fuel from (domestic and exported) VVER reactors.[143]

The planning of this civilian reprocessing facility, dubbed RT-1, coincided with the decommissioning of the first Soviet military reprocessing facility, Factory B, where the plutonium used in the first Soviet atomic bomb test had been produced back in 1948/49. The Soviets reasoned that it would be practical if RT-1 could make use of the already existing (military) infrastructure. The result was that the civilian reprocessing facility started to be built in the very same rooms as its military predecessor. A Sredmash decree confirmed the arrangement in 1966, at the beginning of the first boom phase. The decision was not uncontroversial. It gave rise to protests from several deputy ministers and representatives of the nuclear industry, who regarded the co-location of RT-1 with Factory B as much too dangerous and complicated due to severe radioactive contamination of the buildings and surroundings.[144] Sredmash head Yefim Slavsky, however, argued that the need for the RT-1 facility was urgent, because shipments of large volumes of spent fuel from civilian nuclear power plants would start arriving in the near future. The volumes of spent fuel were expected to increase exponentially as more and more

VVER-440 reactors began operation in the Soviet Union, Finland, and Central Europe. Additional spent fuel was expected from research institutes, nuclear-powered submarines, and icebreakers. There was also a demand-side aspect: Sredmash expected that a lot of plutonium—the main output of value from the RT-1 still to built—would be needed for its emerging fleet of fast breeder reactors. Reprocessing was a crucial task in managing this new nuclear dynamism. The scattered protests thus remained unheard, and to save time and money, construction of the RT-1 started literally on top of the decommissioned military reprocessing plant.[145]

Sredmash delegated the main responsibility for developing the reprocessing project to the Research Institute of Inorganic Materials (VNIIMN) in Moscow. After unexpected problems emerged during the design stage, a whole array of other institutes became involved over the course of the project. The Radium Institute in Leningrad, with its long experience in radiochemistry, played an increasingly important role. The institute even carried out actual reprocessing of spent fuel from civil reactors on an experimental scale. For this purpose, it established a center for research on the chemical treatment of spent fuel at Gatchina near Leningrad.[146] In spite of their hard work, however, the Soviets faced severe construction delays at Mayak and it took until 1977 before the first of RT-1's three planned sections went into regular operation.[147]

Meanwhile, discussions were under way on how spent fuel from RBMK reactors would be managed. Most Soviet nuclear scientists and engineers regarded it as self-evident that the nuclear fuel cycle should be a "closed" system, and that all types of spent fuel should thus be reprocessed. The lower degree of enrichment in the RBMK fuel, however, made spent RBMK fuel a less valuable resource than spent VVER, submarine, and research reactor fuel. For this reason, R&D activities in the field of reprocessing did not prioritize solutions for RBMK fuel. Moreover, in the 1970s, new technical and economic studies carried out within Sredmash indicated that the RBMK technology might not be competitive in the long term. The VVER path appeared much more promising for the future.[148]

It was thus decided to await future developments before making concrete decisions on the future of spent fuel from RBMK reactors. However, this development did not mean that the RBMK concept lost its relevance in the overall nuclear fuel system. On the contrary, following the inauguration of RT-1, RBMK fuel filled an important function in the Soviet fuel system. Since RBMK reactors were designed to use very low-enriched uranium, the Soviets found it suitable to use recycled uranium from spent VVER fuel as a basis for production of fresh RBMK fuel. Recovered uranium from spent VVER fuel had a lower U-235 content than before its irradiation, of course, but it still contained enough U-235 (or almost enough) for it to function as new fuel in RBMK reactors. To reach a suitable level of enrichment, the recovered uranium from spent VVER fuel was mixed with a certain amount of recovered uranium from spent submarine or research reactor fuel, which was more highly enriched than VVER fuel.[149] The advantage with this arrangement was that the re-enrichment stage could be skipped in RBMK fuel fabrication; the uranium mix could go directly from reprocessing at Mayak to fuel element production at Elektrostal. To be able to utilize recovered uranium in reactors that were designed for a *higher* degree of enrichment, however, the Soviets had to let the fuel go through renewed enrichment. Such re-enrichment of spent fuel was a task that the military combine at Tomsk-7 specialized in.[150]

Apart from using recovered uranium from reprocessed VVER and submarine fuel for the manufacturing of RBMK fuel, Soviet engineers started to use recovered uranium from RT-1 as a resource for the "breeding mantle" in fast breeder reactors. In this way remnants of fuel that had once been deployed at the various VVER and RBMK sites in the Soviet Union, Finland, and Central Europe ended up in Aktau in Kazakhstan, where the BN-350 breeder plant, as we have seen, was taken into operation in 1973, and at Beloyarsk, whose BN-600 breeder reactor was started up in 1980.[151]

In addition to the delays with getting RT-1 up and running, the fuel cycle entanglements were complicated by obstacles in the rail-bound transport of spent fuel, especially when it came to cross-border shipments. The Soviet railway network relied on the broad 1520 mm gauge. So did its Finnish counterpart, which had been built at a time when Finland was a Grand Duchy within Imperial Russia. All Central European countries, by contrast, used the western European 1435 mm standard. This meant that the trains from Central European NPPs, loaded with spent nuclear fuel, had to undergo time-consuming change of bogeys at the border crossings. Formal bi- and multilateral agreements also had to be worked out for the cross-border transfer of the dangerous, highly radioactive materials. East Germany faced the greatest challenge in this respect, as a consequence of its geographical location: representatives of the East German transport ministry had to sit down together not only with their Soviet, but also with their Polish colleagues, whose state railways would take responsibility for the safe transfer of East German spent fuel through Poland's territory. Having changed bogeys at Brest on the Polish-Soviet border, the specially designed Soviet TK-6 cars—which would weigh up to 169 tons when fully loaded, a weight that was distributed over twelve axes so as not to destroy the rails—and accompanying VS-TK-3 and VS-TK-4 cars could continue towards the Urals.[152]

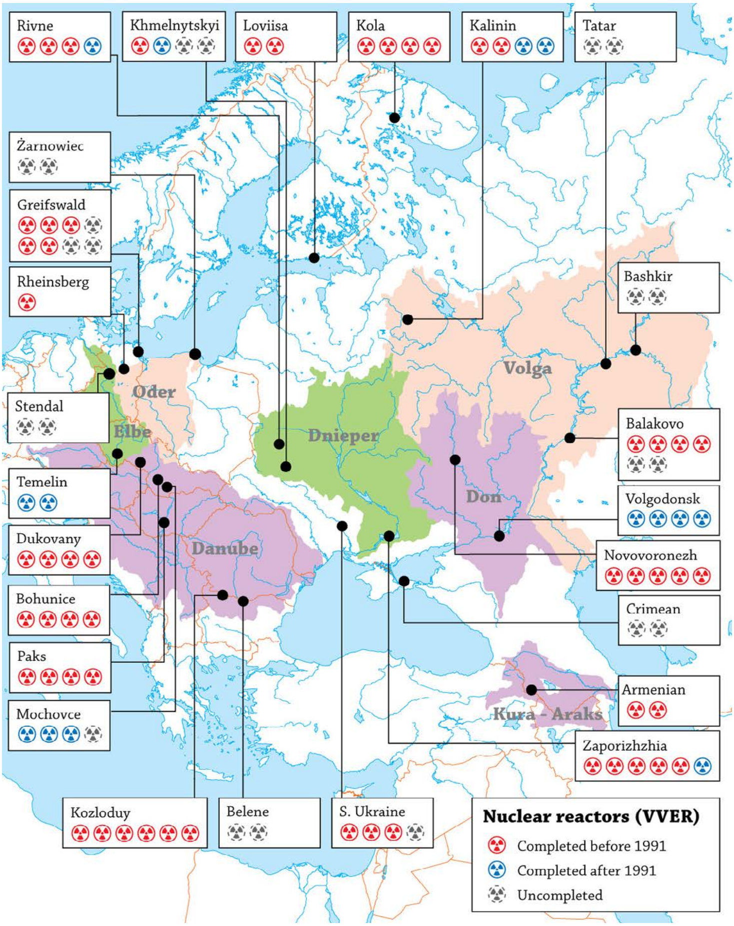
Unfortunately, it turned out that the Soviets had difficulties making their spent fuel trains available on schedule. At Greifswald, as we have seen, the first two VVER-440 reactors were taken into operation in 1973 and 1974. After several rounds of refueling in the years that followed, spent fuel began to accumulate in the temporary storage pools next to each reactor. These pools had been dimensioned to store spent fuel for only two years. In a 1972 agreement, the Soviets had promised to pick up the fuel as soon as possible and under no circumstance later than three months after the end of the two-year period. When the time came in 1978, however, the Soviets suddenly informed the East Germans that the specially designed railway cars were not available and that the spent fuel could not be picked up. The East Germans tried to cope with the situation by mobilizing a train designed to handle spent fuel shipments from the smaller Rheinsberg NPP. While in the Soviet Union, that train was damaged and had to be repaired. It took several months before it could return to the GDR. In the meantime, the situation in Greifswald's storage pools worsened. In early 1979 the East Germans identified this as "a serious problem for the further operational ability of blocks 1 and 2" at Greifswald, because the looming scarcity of free storage would make it impossible to refuel the reactors as planned in 1980.[153] By extension, this threatened East Germany's electricity supply. Czechoslovakia faced similar problems regarding its Bohunice NPP, and sought cooperation with the East Germans to deal with the situation.[154]

Meanwhile, RT-1 continued to face serious problems so that the actual reprocessing of spent fuel from VVER-440 reactors advanced only very slowly. This made Mayak increasingly reluctant to accept new shipments of spent fuel from reactors across the Soviet Union and Eastern Europe. The result was the same as in the case of the missing trains: spent fuel produced at the VVER plants in the Soviet Union, Finland, and Central Europe got “stuck” and could not be sent anywhere. The only solution to this problem seemed to lie in the construction of interim storage facilities for spent fuel. In December 1978, Soviet energy minister Neporozhny informed his Central European counterparts that the temporary storage of spent fuel at each VVER reactor site needed to be extended to a minimum of five years. Minenergo ordered all operators of VVER-440 facilities to construct new storage capacities in separate buildings, to accommodate of spent fuel volumes corresponding to up to ten years of consumption.[155] Such facilities started to be built from around 1980. Imatran Voima, for example, took into operation its new interim storage facility at Loviisa in 1985. In Czechoslovakia, a centralized facility was constructed in which spent fuel from all Czechoslovak nuclear power plants could be stored.[156] Altered macro-entanglements thus had a direct influence on the micro-entanglements at specific NPP sites.

8. The Second Boom Phase

The first boom phase established nuclear energy as one of the main sources of electricity in the expanding Soviet energy system. Two main reactor types were at focus: VVER-440s (in its two main versions) and RBMK-1000s. Towards the end of the 1970s, then, the nuclear industry gained even more momentum and political support.[157] Stagnation in coal and oil production from around 1977 accentuated this strategy.[158] As large funds were channeled to nuclear construction, the new VVER-1000 reactor type became the most important vehicle of expansion. From a geographical point of view, this was linked both to the erection of more reactor blocks at already existing NPP sites and to the creation of new nuclear sites. We will refer to this rapid growth, which eventually came to an end after the catastrophe at Chernobyl in April 1986, as the "second boom phase." It led to a significant territorial growth of "VVER land," while "RBMK land" grew much more slowly (Maps 8.1 and 8.2 below). Even the VVER projects, however, featured delays and technical problems that threatened to disrupt the boom. An impressive number of new nuclear projects were initiated, but many of these faced stagnation along the way. A large number of plants would never be completed.

The VVER-1000 reactor was a radically improved version of the VVER-440, in terms of not only its electrical output, but also its safety features. They were the first Soviet reactors to be equipped with a full containment that hermetically surrounded the reactor core.[159] Its volume sufficed, in theory, to absorb and condense the entire steam-water mix that might escape in the case of a rupture of a main cooling pipe, internationally defined as the "maximum credible accident." Hence, in theory, no significant amounts of radioactivity would leak



Map 8.1. **VVER land. The map includes all VVER reactor projects initiated during the first and second boom phases, and the river basins in which the inland VVER plants were built.**

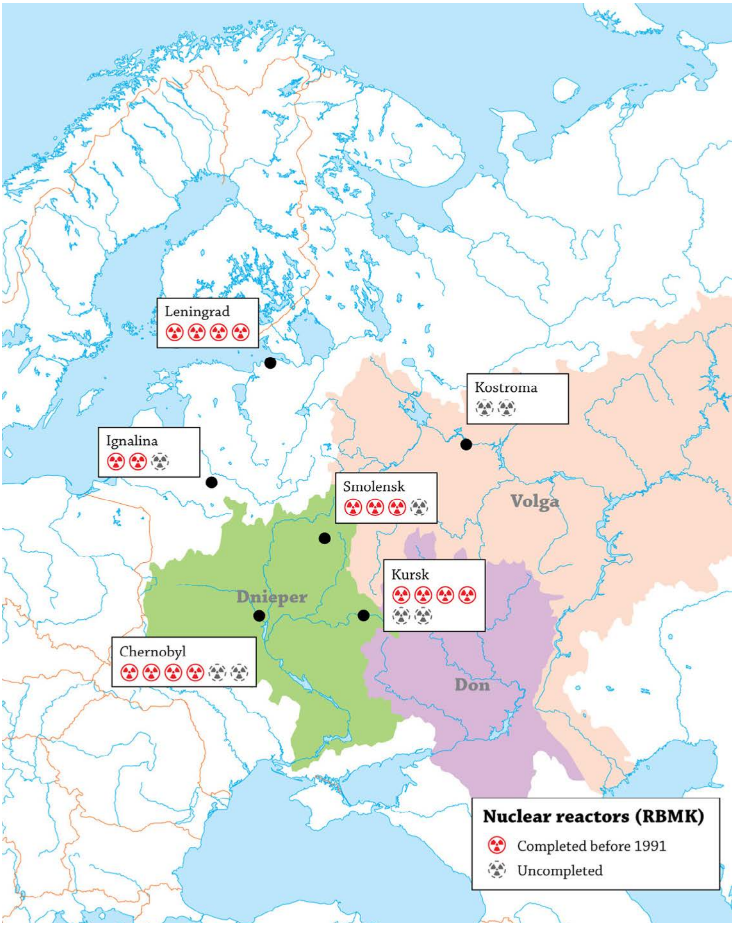
Note: Construction of Mochovce NPP's fourth reactor is likely to be completed in 2024.

Source: Own work/Red Geographics

into the surroundings in the event of such an emergency. From a geographical point of view, the main implication was that VVER-1000 reactor blocks could be built near major cities—a feature that was especially appreciated in densely populated territories such as East Germany.[160] In the Soviet Union itself, the new safety technologies inspired intense efforts, in the 1980s, to build "dual use"—that is, electricity and heat producing—VVER-1000 plants in the immediate vicinity of large cities such as Minsk, Kharkiv, and Odessa.[161] In this sense, the second boom phase marked a partial return to an urban nuclear geography, reminiscent of the first research reactor projects initiated in the 1940s.

In close relation to this trend, during the second boom phase the Soviets developed a new reactor specifically designed to supply urban regions with energy: the AST-500 model. It was optimized for district heating rather than for electricity production, being smaller in size and featuring passive safety systems. The underlying ambition was to use it to save fossil fuel resources. Both the Soviet Union and its communist satellites—East Germany being the most eager—held high hopes for the AST-500. The East Germans hoped to use it to supply the sprawling chemical industry in the country's southern regions with process heat.[162] However, both the AST and the urban VVER-1000 plants would grow controversial over time. In the end, only one heat-producing reactor was ever taken into operation; it was built outside the city of Voronezh.[163]

Finally, the second boom phase featured an attempt to scale up the RBMK reactor by boosting its electrical output to 1500 MWe and, as some Soviet engineers envisioned, to as much as 2400 MWe. As we have seen in the preceding chapter, however, Soviet nuclear planners increasingly looked upon the RBMK's development line as less promising than the VVER's. This meant that investments in improving and expanding the RBMK were not prioritized.



Map 8.2. RBMK land. The map includes all RBMK reactor projects initiated during the first and second boom phases. Note the strikingly limited region in which the RBMK plants were built, compared to the wider geography of VVER land.

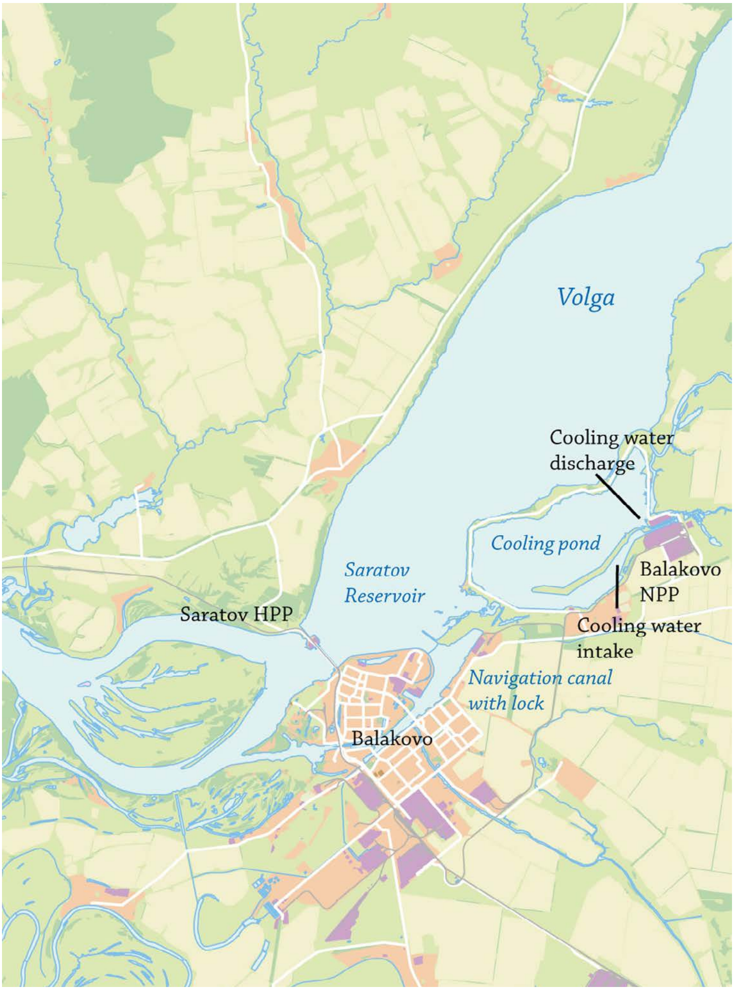
Source: Own work/Red Geographics

As for the VVER-1000, the Soviets started outlining this reactor type as early as the late 1960s. Initially there were hopes that it would be available as soon as the early 1970s. Progress was delayed, however, by technical obstacles of all kinds as well as by the perennial Soviet lack of material and financial resources. In 1974 the Soviets eventually began building the first VVER-1000 reactor at Novovoronezh, which since 1957 had been the site where new VVER designs were tried out. A year before they had founded Atommash, a large-scale enterprise that aimed to bring about serial production of nuclear reactors, of which the VVER-1000 was the main target. This reactor "factory" complemented Leningrad's Izhora works, which so far had been the main manufacturer of reactor pressure vessels. Atommash's facilities were established at Volgodonsk in southern Russia, next to the Volga-Don Canal, a Stalinist megaproject that had been inaugurated in 1952. Access to the canal—and hence to the entire Don and Volga river basins—facilitated both the procurement of necessary resources and the shipment of finished parts.[164]

Atommash's location seemed particularly favorable in view of a key geographical shift during the second boom phase: the construction of multiple new nuclear plants along the Volga and its tributaries.[165] During the first boom phase no large-scale nuclear projects had been initiated in the Volga basin, although an important nuclear research hub with small-scale experimental reactors existed at Dmitrovgrad. In the course of the late 1970s, Soviet nuclear visionaries became increasingly interested in the river's potential as a source of cooling water. This was closely related to the river's dramatic transformation during the postwar decades. Building on the experience of Dnieprostroi and other early Soviet hydraulic projects, a range of hydropower plants, water reservoirs, sluices, dams, and rectification projects were completed along the river. The massive 2300 MW Kuybyshev HPP (today: Zhiguli

HPP), finished in 1959, exemplifies this development. As of the 1960s and early 1970s the Volga was still in a phase of intense remaking, which in the planners' eyes made the basin unsuitable for nuclear construction. By the late 1970s, however, Soviet hydraulic engineers already prided themselves in having tamed the mighty river, controlling its water flows in a way that would have been unthinkable for early twentieth-century observers. It had now become an industrialized waterway on a par with major West European rivers such as the Rhône and the Rhine. This allowed nuclear engineers to see the Volga in a new light; the river was now "ready" for the nuclear age, offering cooling water in large volumes at a reliable, regular pace all year round. By the dawn of the 1980s, river conditions for nuclear development were thus met and several new construction sites could be prepared.

The main showcase was Balakovo NPP, erected on the Lower Volga. This was the first Soviet nuclear power plant located directly on the banks of a major Soviet river, thus diverting from the general pattern during the first boom phase of building nuclear plants on smaller watercourses and tributaries to larger waterways. The facility's construction was preceded by major hydraulic works in the area, allowing the NPP to link up with an already existing envirotechnical system. In 1967 Soviet hydraulic engineers had dammed the Volga at Balakovo, an old Russian port town founded in the eighteenth century, which raised the water level and broadened the Volga, producing the immense Saratov Reservoir. The dam was equipped with the 1415 MW Saratov Hydroelectric Power Station. Once the reservoir had come into being, the nuclear power plant could use it to supply its cooling water. Based on these meso-entanglements, construction of the first VVER-1000 began in 1980.[166] Construction of no fewer than five further reactors began over the course of the 1980s. The Volga had joined the ranks of Soviet nuclearized rivers.



Map 8.3. Envirotechnical entanglements at Balakovo NPP. This plant relied on the Volga and, in particular, the Saratov Reservoir for cooling water supplies. The map shows how the nuclear builders opted to create, as part of the reservoir, a separate cooling pond. The Saratov hydroelectric station and the town of Balakovo are located a short distance downstream from the nuclear facility, which is surrounded by agricultural fields.

Source: Own work/Red Geographics

Soviet nuclear builders set out to erect two further VVER-1000 plants further upstream in the multicultural Volga basin. The Tatar and Bashkir NPPs, as they were called, were both approved by the government in 1980. For each of them a total of four reactor blocks were planned. For Tatar NPP a site was picked on the lower reaches of the Kama, a large Volga tributary, near the town of Kamskie Polyany.[167] Bashkir NPP, meanwhile, started to be built about 170 kilometers to the east from there at the Kama's confluence with the smaller Belaya River. For unknown reasons, the Soviets eyed the latter river as a better source of cooling water than the Kama itself, a fact that became controversial over the years, given the limited flow of this stream. Construction of Bashkir NPP brought with it a brand-new town, Agidel, which was founded in 1980. A decade later Agidel had a population of nearly 20,000, but still no operating nuclear reactor.[168]

In the years around 1980, Gidroproekt, which played an important role in the design of both Tatar and Bashkir NPPs, was in the process of carrying out seismic studies for further VVER-1000 plants along the Volga, one of them tentatively planned to be built near the important industrial city of Togliatti.[169] By 1986, however, when the Chernobyl disaster struck, no such plant was actually under construction.

The Kostroma (or Central) NPP, a project envisaged for the Upper Volga, was of a different kind. Here, the plan was to build two reactors of the graphite-moderated development line. Initial planning foresaw a reactor type called RBMKP-2400, a further development of the RBMK-1000 and 2.4 times more powerful than its predecessor. That reactor was subsequently abandoned, however, as Sredmash decided to focus on the RBMK-1500 version, which was "only" 50 percent more powerful than those built at Chernobyl and elsewhere during the first boom phase. Construction of the first such reactor block commenced in 1981, followed by the second in 1983.[170] Yet the Volga's nuclear career did not turn out to be as successful as the impressive number of construction starts suggested. A lack of material resources, funds, and skilled workers halted construction at several of the sites mentioned. By 1986, when the Chernobyl disaster and its aftermath changed the outlook for the Soviet nuclear archipelago, the only Volga reactor that had been connected to the grid was the first VVER-1000 block at Balakovo.[171]

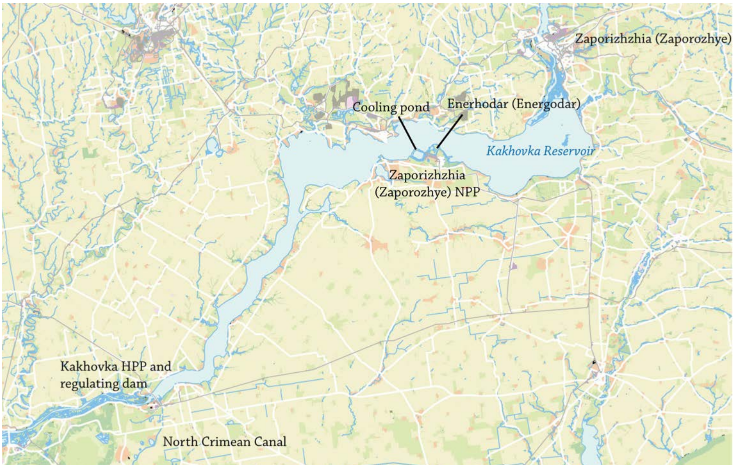
Two other main Soviet rivers, the Don and the Dnieper, became focal points of nuclear construction during the second boom phase. During the first boom phase, nuclear plants had been erected on the Upper Don and in the basin of two Dnieper tributaries, the Pripyat and the Desna. During the second boom phase the geographical emphasis shifted to the lower parts of both rivers, where the water flow was much greater. Along the Don, the Soviets started to erect a VVER-1000 station just a few kilometers from Atommash's facilities in Volgodonsk. Its envirotechnical characteristics resembled those of Balakovo in the Volga basin. In the early 1950s, in connection with construction of the Volga-Don Canal, Soviet hydraulic engineers had dammed the Don near the town of Tsimlyansk, generating a huge water reservoir. With a length of 150 km and up to 20 km wide, this monstrous waterbody forever changed the geography of southern Russia. The dam at Tsimlyansk was combined with a hydropower plant, and Volgodonsk was then founded as a new town for the energy workers.[172] Tapping into the envirotechnical system, the Volgodonsk (also known as the Rostov) NPP was to draw on the reservoir for its cooling water needs.[173] Construction of the first reactor block commenced in 1981, followed by a second in 1983. Two more blocks were planned. Meanwhile, the town of Volgodonsk grew rapidly from 28,000 inhabitants in 1970 to

175,000 in 1989. However, the Volgodonsk NPP was plagued by endless problems and faced severe delays, one reason being that the construction site on the reservoir's shore turned out to be water-saturated, unstable ground.[174] By spring 1986 none of the reactors had yet been completed.

On the Lower Dnieper, the Soviets erected the huge Zaporizhzhia (Zaporozhye) NPP. It followed the same envirotechnical model as the Balakovo and Volgodonsk plants. The plant was built in a region where Soviet hydraulic engineers had already changed Ukraine's great river in a radical way through construction of the immense Kakhovka Dam and Reservoir. With a length of 240 km and over 20 km wide, the reservoir allowed larger ships to head up the Dnieper. It served irrigation of farmland on a large scale and satisfied the growing water demands of regional industries. The reservoir further helped to regulate the water flow in two important canals, the North-Crimean and the Dnieper–Kryvyi Rih (Krivoi Rog) Canals.[175] Construction of the nuclear power plant, then, became yet another way of making productive use of the huge artificial waterbody.

The pace and scale with which the Zaporizhzhia NPP was constructed was astounding, testifying to the sophistication that the Soviet nuclear industry had reached by the early 1980s. No fewer than six powerful VVER-1000 reactors started to be built, three of which were successfully connected to the grid by 1986. "This construction site on the banks of the Kakhovka Reservoir," *Pravda Ukrainy* commented in 1982, "is often compared to a well-oiled assembly line for its rhythm and precision." The newspaper lauded the engineers and workers who "not only followed in the footsteps of the builders of the legendary Dnieper HPP, but stepped further."[176] In the end, the new station was to become the biggest NPP in Europe in terms of total electricity output (Figure 8.1). A new worker's town did not need to be built, because the town of Enerhodar

(Energodar) had already been founded back in 1970 as a workers' base for a nearby fossil power station.



Map 8.4. Envirotechnical entanglements at Zaporizhzhia NPP. Just like at Balakovo, this plant comprised a cooling pond built in a large, dammed river, in this case the Dnieper. The water level in the cooling pond was a few meters higher than in the Kakhovka Reservoir. Until June 2023 the reservoir's water level was regulated by the Kakhovka Dam, built in 1956 and located 140 km downstream. The violent destruction of the dam in the Russo-Ukrainian war jeopardized this arrangement for the foreseeable future.

Source: Own work/Red Geographics

For some time, it appeared that the Dnieper would come to host another large-scale nuclear plant. It had its origins in a thermal power plant that the Soviets began to build in the 1970s on the shores of the Kremenchug Reservoir. The latter was the product of hydraulic works carried out in the 1950s. In 1981 Minenergo decided, for unclear reasons, to abandon the thermal power project. Two years later, in 1983, it decided to replace it with a nuclear power plant, referred to as the Chyhyryn (Chigirin) NPP.[177] As of 1986, however, construction had not yet officially started.

Figure 8.1. **Zaporizhzhia NPP viewed from across the Kakhovka Reservoir. The large building between the cooling towers and the reactors, and the two tall smokestacks, belong to the Zaporizhzhia thermal power station, located about 3 km beyond the nuclear plant.**

Source: Wikimedia Commons, https://upload.wikimedia.org/wikipedia/commons/2/2c/Kernkraftwerk_Saporischschja.JPG.

The projects on the Volga, Don, and Dnieper can be regarded as bold projects that pushed the geographical frontiers of the Soviet nuclear archipelago by opening up the country's mightiest rivers for nuclear construction. Yet the second boom phase also featured several endeavors that followed the geographical tradition of the first boom phase, being built on smaller rivers and lakes. Thus in Ukraine, the Soviets decided to expand Rivne NPP, which already hosted two VVER-440 reactors, with two VVER-1000 blocks. In addition, they started to build the brand new Khmelnytskyi (Khmelnitskyi) NPP in 1981.[178] To enable sufficient supplies of cooling water to the latter plant, the engineers decided to make use of the small

Horyn (Goryn) River and dam another, even smaller watercourse, the Hnylyi Rih (Gniloi Rog), both of which were in the Pripyat's and hence in the Dnieper's basin. The dam structures gave rise to a new artificial water body of critical importance to the nuclear station: the Netishyn (Neteshin) cooling water reservoir.

Another new plant was the Kalinin NPP, which was built in Russia on the shores of Lake Udomlya halfway between Moscow and St. Petersburg. The lake had undergone substantial hydraulic manipulation in the past, which prepared it for the nuclear age. Among other things, the earlier water wizards had dammed it at the outlet of a small stream, the Syezha. The dam allowed the engineers to artificially control the water level, thus reinforcing the reliability of cooling water supply. The town of Udomlya, which had been founded as a railway settlement in 1869, was turned into a nuclear town. Four reactors started to be built, one of which had become operational by 1986.

Further south, Minenergo identified Crimea as a suitable location for a nuclear power plant. On December 10, 1982, the first concrete was poured for the first VVER-1000 reactor block there. The plan was to build four such blocks near the Cape of Kazantip, on the coast of the Sea of Azov. Cooling water arrangements for this NPP were peculiar. Instead of sourcing cooling water directly from the sea, seawater was to be pumped up to a cooling pond, which was to be created by reengineering a salt lake next to the construction site: Lake Aktash. The town of Shcholkine (Shchelkino) was built as a worker's base, being founded in 1978. However, the Crimean nuclear project was controversial, not least in view of Crimea's fame as a tourist destination, leading to repeated delays. When the Chernobyl disaster struck in 1986, no reactor block had been completed.[179]

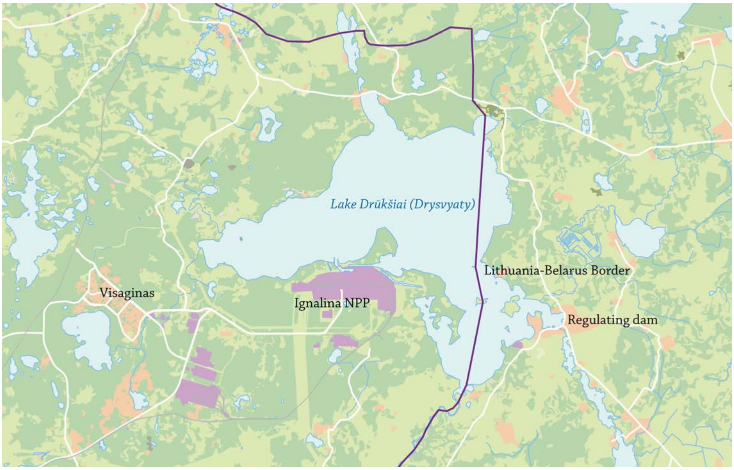
The Central European communist countries were also very interested in the VVER-1000 reactor and hoped to mobilize the necessary resources to erect such blocks, either at already existing NPPs or at new locations. The GDR announced its interest in the VVER-1000 reactor as early as 1971, in connection with the siting process for what would become the Stendal NPP.[180] The East Germans had originally wished to erect this plant near Magdeburg on the Elbe, which they had identified as a suitable site from the point of view of cooling water supply, access to electricity grids, roads and railways, and the availability of workers. However, the location near one of East Germany's key cities meant that the existing VVER-440 reactor type was not suitable, a viewpoint that was accentuated by the observation that the Magdeburg area was seismically active. This made GDR planners greatly interested in the safer VVER-1000 model. At a workshop held in June 1972, however, Soviet energy minister Neporozhny informed the East Germans that the development of the VVER-1000 was behind schedule, so that no promises could be made for delivery of such a reactor.[181] This forced the German planners to look for an alternative site downstream the Elbe,and so they arrived at the Stendal area, which was seismically less active and featured a lower population density; hence it was more acceptable from a safety point of view. Yet the site was logistically problematic precisely because of the distance (80 km) from Magdeburg; it was seen difficult to integrate Stendal infrastructurally and to recruit workers. In 1974 the East Germans started preparing the construction site, planning to erect four VVER-440 reactors. In January 1976, however, Moscow informed East Berlin that they no longer considered the 4 x 440 MW project rational, hinting at the possibility to offer VVER-1000 technology after all. A formal decision that confirmed this followed in 1978.[182]

The Czechs decided in early 1980 to build their first VVER-1000 plant at Temelín, only 13 km to the north of Česke Budejovice. In contrast to Czechoslovakia's three other NPPs, which were all in the Danube River basin, Temelín was on the Vltava (in German: Moldau), a key Elbe tributary. The decision to build a nuclear station there followed the completion, in 1977/78, of one of Central Europe's most astounding hydraulic projects, comprising two immense dams equipped with hydroelectric turbines. The upper dam, Dalešice, was 100 meters high and functioned as a pumped-storage hydropower plant whose turbines had an impressive capacity of 450 MW. The lower dam, Mohelno, was 39 meters high. The nuclear engineers were inspired by what the hydraulic engineers had accomplished and aimed to construct the VVER-1000 plant between the two dams, on the water reservoir created by the Mohelno dam. This was seen to guarantee uninterrupted access to cooling water, while the upper Dalešice dam ensured that the site would not be flooded.[183]

In the Danube basin, meanwhile, Bulgaria signed an agreement with the Soviet Union in October 1981 regarding the construction of two VVER-1000 reactor blocks. But where should they be built? The Soviets actively assisted the Bulgarians in site selection. There appear to have been major concerns regarding seismic activity, with the traumatic experience in fresh memory of a 1977 earthquake that had affected the Kozloduy NPP. Even so, the site selection process ended with geographical path dependence triumphing: the two new reactors would be added to the already existing Kozloduy plant. In March 1984, then, the Bulgarians concluded another agreement with the Soviet Union. This paved the way for construction of the country's second NPP, to be equipped with two VVER-1000s, this time further downstream the Danube, at Belene. As in the Kozloduy case, the river here formed the border with Romania.[184]

Hungary likewise started preparations for expanding its Paks plant, hoping to add two VVER-1000s to the already operational VVER-440s. However, by the time the Chernobyl disaster struck, none of Central Europe's VVER-1000 reactors had gone into operation. As we will see in Chapter 11, they would face divergent destinies in the post-Chernobyl era.

For some time, a group of leading Soviet nuclear engineers and planners sought to bring about a second boom phase for the RBMK reactor line, too, based on a scaling up of the RBMK-1000 to the RBMK-1500 model and, as we have seen in our survey of the Volga's nuclearization, even an RBMKP-2400 variant. In actual practice, only one scaled-up RBMK station was eventually built: the Ignalina NPP in Lithuania. As touched upon in Chapter 5, Lake Drūkšiai (Drysvyaty), which was partly in Lithuania and partly in Belarus, was to provide cooling water for this plant. The Soviet plans specified that Ignalina NPP would host four RBMK-1500 reactors. Construction of the first two blocks began in 1977 and 1978, respectively. In 1985 block one was successfully put online, while block two was connected to the grid in 1987. Feeding huge volumes of electricity into the North-Western Soviet grid, the two reactors not only provided power to Lithuania's 3.5 million inhabitants, but significantly boosted a wider region's electricity supply. A third reactor block started to be built in the early 1980s. As of April 1986, it was sixty percent complete. Ignalina NPP had its own worker's town, known in Soviet times as Sniečkus. It was built at the site of a former village and had a population of more than 30,000 by 1989. In 1992 it was renamed Visaginas, after a small lake on whose shores the town emerged.[185]



Map 8.5. Envirotechnical entanglements at Ignalina NPP. Note that while the nuclear power plant was built in the Lithuanian SSR, the dam that regulated the water level in Lake Drūkšiai was in the Belarusian SSR.

Source: Own work/Red Geographics

The further development of fast breeder reactors also made some progress during the second boom phase. The most ambitious breeder project was launched at the predominantly military Mayak site in the Urals, which had played a prominent role in the making of the Soviet Union's first nuclear weapons, and which had hosted a spent fuel reprocessing plant since the 1970s (Map 3.1). From a geographical perspective it seemed to make good sense to locate a nuclear power plant based on fast breeders there. The breeders would be able to use plutonium from Mayak's reprocessing facilities as nuclear fuel, thus eliminating the need for long-distance fuel transport. The Soviets planned to equip the Southern Urals NPP, as the breeder plant at Mayak was called, with three fast breeders of the newest version, BN-800. Construction started in 1982, but when the Chernobyl accident struck in 1986 it appeared uncertain whether any of the reactors would ever be completed.[186]

Many of the nuclear power plants discussed in this chapter comprise the phenomenon of "atomgrady" – nuclear towns. While we have occasionally come across such towns in earlier chapters, too, it may be of interest to discuss them here at more length, as they were such a distinct feature of the Soviet nuclear archipelago. While mono-industrial towns, built for workers of major factories, extractive enterprises, or power plants, have been a common feature across the industrialized world, those built for nuclear purposes in the Soviet Union were special. Anna Storm and Tatiana Kasperski identify several common denominators for these intriguing places. They point to the advantages for a young specialist's family to move to a remote, undeveloped area for a higher salary and stimulating work opportunities. Young couples had unique opportunities to start a new life in a nascent nuclear town, which offered a good supply of consumables, generous medical coverage, cultural facilities, schools, kindergartens, and other welfare opportunities that were typically not available to the same extent elsewhere. Additionally, workforce and managers formed a specific bond due to the nature of nuclear endeavors, characterized by mutual trust and loyalty in exchange for significant benefits for the workers.[187]

Soviet atomic towns were strongly influenced by the secrecy of the nuclear industry. High levels of security concerns and restrictions co-existed with the nimbus of an ostensibly progressive and futuristic technology and the specific threat of potential radioactive contamination.[188] These towns could be entered only with special documents and permits. In their capacity as closed communities, they fostered a nuanced form of solidarity plus a feeling of belonging among its residents. Soviet urban planners used this chance to build small socialist utopias, which would showcase the superiority of the Soviet political system. The residents were expected to look upon themselves as a political and technological avantgarde, actively contributing to the establishment of communism.

For nuclear planners, the closed monotowns had several advantages. First, it was easier to keep the desired level of secrecy if residency was restricted and granted mostly to politically reliable people or forced labor. Secondly, the high degree of specialization ensured a sophisticated level of work, especially among the nuclear scientific-technical personnel. Thirdly, since the nuclear towns had fewer than 100,000 inhabitants, it was legally permitted to build nuclear power stations directly next to them.[189] Last but not least, the avant-garde character of specialized atomgrady fit perfectly with the communist ideology that emphasized the importance of serving the common good while paving the way for the "new Soviet person."[190] In this way, the phenomenon of Soviet atomgrady was embedded into a wider ideological narrative of building advanced socialism.

9. Towards Energy Complexes

Over the course of the second boom phase, Soviet nuclear planners developed two intriguing ideas on how to benefit from co-locating different energetic installations in one and the same area. The Soviets conceptualized such geographical concentration as "energy complexes." Nuclear energy played the most important role in their formation.

The first energy complex idea was developed by Gidroproekt, the main Soviet hydraulic agency.[191] Originally set up in 1932, Gidroproekt became the place where nuclear and hydraulic engineering expertise met. With its solid experience from hydroelectric construction, river improvement projects, and large-scale irrigation undertakings, Gidroproekt found it tempting to view nuclear power plants, with their vast cooling water needs, as components in larger hydraulic engineering efforts. After its first experiences with nuclear construction in the years around 1970, the agency came up with a strikingly ambitious approach to nuclear planning. The idea was that new nuclear power plants would not only draw on the accomplishments of earlier hydraulic projects of the kind discussed in earlier chapters of this book, in terms of existing dams, historical river rectification projects, hydropower plants, and so on. Instead, such facilities should be designed conjointly with nuclear facilities. This translated into plans for mammoth new energy projects in which the water flows and water uses in an entire region would be planned as part of one and the same system—centered around the cooling water needs of the nuclear facility. NPPs were to be combined, in particular, with brand new dams, hydropower plants, energy storage in pumped-storage HPPs, navigational projects, irrigation canals, and facilities for pisciculture.[192]

Finding the right location for such an energy complex was not easy. It needed to be a place with sufficient water supply, with suitable ground conditions, and without earthquake or flood dangers. It also needed to be located in the vicinity of both large-scale electricity users and agricultural hotspots, while offering benefits for fisheries and fish farming. A key issue was the potential for combining the baseload power provided by the nuclear plant with the peak electricity supply that a nearby hydropower plant would be able to supply. Ideally the hydropower plant should take the form of a pumped-storage HPP.[193] At the same time, following the general Soviet siting policy, a nuclear-centered energy complex should not be located too close to major population centers. If the site was selected wisely, the construction process could profit, or so the planners believed, from economies of scale and scope, supported by the specifics of the Soviet economic system, which favored grand-scale industrial investments. Costs could be cut by constructing all facilities together. For example, it would be possible to employ the same construction crew for different parts of the complex. Additionally, money could be saved by ordering huge amounts of building material at once. The planning of infrastructure such as railroads, streets, and living quarters as well as research, testing, and design only needed to be carried out once. Furthermore, different facilities could share common installations. Culturally speaking, all of this suited the Soviet way of planning, and the sheer size of the envisaged complexes served as a symbol of progress.[194] The concept seemed to fit perfectly, ideologically and economically, with the communist party's political agenda.[195]

In at least one case, an energy complex of this kind became reality. In Mykolaiv (Nikolaev) Province in southern Ukraine, at the confluence of the Tashlyk and the Southern Bug rivers 350 km south of Kyiv (Kiev), Gidroproekt cooperated with Minenergo and other agencies to build a unique set of facilities. They started out in 1975 by laying the groundwork for the South Ukraine NPP, featuring three VVER-1000s (construction of the reactors started in 1976, 1981, and 1984) and founding the brand-new town of Yuzhnoukrainsk. In 1981, with the first nuclear reactor block nearing completion, they continued by constructing the Tashlyk pumped-storage HPP.[196] Damming of the Tashlyk created a reservoir, whose regulated waters served as a reliable source of cooling water for the NPP. Below the dam, the water flowed into the Southern Bug. Around 15 km downstream, construction of another facility, the Oleksandrivka (Aleksandrovka) HPP, began in 1985. The combination of nuclear and hydro capacities allowed changes in electricity demand to be balanced out. The South Ukraine NPP profited from the two hydropower plants as well, as they made sure that the NPP would always have access to the electric power needed to power its cooling water pumps, even if the NPP itself had to be shut down.[197] The water reservoirs formed by the Tashlyk and Oleksandrivka dams were further used for irrigation of the surrounding agricultural lands. There were also plans for developing pisciculture (Map 9.1).[198]

This way of thinking about nuclear power plant construction as co-constructed with other hydraulic engineering projects inspired nuclear construction elsewhere, including in Central Europe, as became apparent in the planning of Czechoslovakia's Dukovany NPP. We discussed this facility in Chapter 6, where we linked it to the first boom phase. However, actual construction started only in 1979, and there are indications that Dukovany looked to the South Ukraine Energy Complex for inspiration, as construction of that facility's first VVER-1000 reactor block had started a few years earlier. Apart from the nuclear plant itself, which was built on the tiny Jihlava River, the Dukovany complex comprised two

Map 9.1. **The South Ukraine Energy Complex**

Source: Own work/Red Geographics

large water reservoirs supported by huge dams, along with a once-through hydropower facility and, most importantly, a pumped-storage hydropower plant. Downstream from the two reservoirs, the Jihlava was reported to flow "through a recreation and fishing area" and subsequently into the Dyjsko-Svratecký valley, where it was "intensively used for irrigation." Its "recreational and fishing use" was also significant. In addition, the Jihlava was used as a source of drinking water. Dukovany hence became tightly interlinked with a range of other uses of the available river.[199]

A less sprawling, but still ambitious combination of nuclear energy and hydraulic engineering was Poland's Żarnowiec site, mentioned in Chapter 6, where the construction of several VVER-440 reactors was combined with a pumped hydropower storage arrangement. This was possible thanks to the natural features of the Pomeranian landscape, which enabled a small artificial lake to be constructed on top of a hill just above Lake Żarnowiec. From the latter, which was intended to serve as the cooling water source for the nuclear plant, lake water was to be pumped up to the artificial water reservoir in times of excess electricity production, and released again when electricity consumption was high. Construction of Żarnowiec NPP was eventually abandoned. Yet the Poles did complete construction of the pumped-storage HPP (Figure 9.1).[200]

The second concept of an energy complex was proposed by reactor builder Nikolai Dollezhal. To him, one of the biggest challenges of nuclear expansion at the end of the 1970s was the need for large cooling ponds in the European part of the Soviet Union. As we have seen, these often covered dozens of square kilometers. Dollezhal found it disturbing that the construction of many new nuclear power plants with cooling ponds used up so much sparse land, which in his view could be better exploited for other purposes. An alternative to cooling ponds were cooling towers, but Dollezhal opposed this technology. By using such towers, he argued, valuable water would be extracted from the nation's watercourses and evaporated into the air.[201]

Figure 9.1. **The Żarnowiec pumped-storage hydropower plant, Poland. Construction of Żarnowiec NPP, which started on the opposite shore of Lake Żarnowiec, was eventually abandoned. Yet the Poles did complete construction of the pumped-storage HPP.**

Photo by Per Högselius, 2022

Pondering on this problem, Dollezhal and his colleague Yurii Koryakin also considered the fact that the Soviet nuclear industry faced serious challenges in terms of not only micro- and meso-, but also macro-entanglements. The two authors were concerned by the vast distances between nuclear power plants and the various fuel cycle activities on which they relied. Distance translated into a higher risk of accidents during transport, especially in view of the USSR's poor infrastructure maintenance. We have seen earlier how spent fuel transports suffered from this. Looking for a way to cope with the multiple geographical dilemmas in the growing

Soviet nuclear archipelago, Dollezhal and Koryakin then proposed the idea of a concentrated "nuclear power generating complex." Their idea was to combine as many steps of the nuclear fuel cycle as possible in one and the same location, which would thus feature a massive concentration of nuclear reactors and various fuel cycle activities at certain carefully selected sites. In their eyes, such a nuclear energy complex could be located far out in an isolated area, where it would not appropriate too much valuable land.[202] However, their idea never materialized. The planned Southern Urals NPP at the Mayak reprocessing site may have been the most serious attempt to make reality of Dollezhal's vision.

10. Macro-Entanglements during the Second Boom Phase

In the preceding two chapters we have seen how the second boom phase gained momentum through the VVER-1000's breakthrough, the scaled up RBMK reactor, and the promises of the AST-500. The construction of numerous new civilian nuclear facilities based on these technologies posed new challenges not only locally and regionally at the respective sites. The interconnectedness of the Soviet nuclear archipelago was also at stake. Just as in the first boom phase, this generated macro-entanglements on three different levels.

On the technological level, the VVER-1000's rise to prominence generated a need for intense interaction between different sites that sought to deploy this reactor type. The resulting entanglements comprised the exchange of knowledge both within the Soviet Union and between the Soviet Union and several Central European countries.[203] In summer 1980 the CMEA member states formalized a cooperative scheme for the development and building of VVER-1000 reactor blocks, coming together for this purpose at Hradec Králové in Czechoslovakia. There, they signed an "Agreement for multilateral cooperation of CMEA member countries in the research and construction works on the problem of utilization of energy blocks with water-water reactors of 1000 megawatt capacity and the further perfection of the reactors of this type." Ivaylo Hristov writes that the partners "elaborated on safety regulations for the VVER-1000, concerning the design, construction and assembly works, equipment repair, methods for deactivation of the active zone, and construction technology, including the construction of a protective concrete containment in response to the Three Mile Island accident."[204]

There was also cooperation around the VVER-1000 on the bilateral level. The East Germans, for example, identified the Zaporizhzhia NPP in Ukraine as a model from which to learn for the construction of its own Stendal NPP. The "exchange of experiences" between the two sites began immediately after the formal construction start in Ukraine in 1980. The Germans paid several visits to the emerging plant on the Dnieper. They also managed to access an impressive amount of technical documentation from the Soviet side. The Germans were especially interested in the modern containment solution, which was new to them. The cooperation was then extended to include the direct participation of East German nuclear engineers and technical specialists in building Zaporizhzhia NPP. The cooperation intensified as construction at Stendal gained momentum, and a formal "friendship contract" was signed between the two plants.[205]

The Khmelnytskyi NPP, also in Ukraine, was remarkable in terms of its macro-entanglements, as it was a multinational joint venture between the USSR, Czechoslovakia, Hungary, and Poland. Moreover, the four states agreed to build a set of ultra-high voltage (750 kV) transmission lines that would allow nuclear electricity to be exported from western Ukraine across the border to Rzeszów in Poland. There, the lines would link up with the already interconnected Central European grid.[206] East Germany, Bulgaria, and Romania also contributed to Khmelnytskyi NPP. According to historian Falk Flade, 19.2% of the materials for the construction of the plant were produced in Czechoslovakia, 18.5% in Poland, 8.4% in Bulgaria, 4.4% in Hungary, 4.2% in the USSR, 3.1% in East Germany, and another 3.1% in Romania.[207] This testified to a spirit of international cooperation, but also hinted at the Soviet Union's growing problems to deliver all equipment and supply the necessary labor for the large number of VVER-1000 projects that were initiated during the second boom phase.

In the case of the RBMK community, cooperation between different power plant sites was less transnational, since RBMK plants were built exclusively in the Soviet Union. However, the Chernobyl accident in 1986 dramatically highlighted the technological affinities between these plants, and in the subsequent period managers and engineers from different RBMK NPPs came together to evaluate the flaws in the technology and work toward improving it. Subsequently a number of foreign actors, including the IAEA, became involved in this work as well.[208]

On the second level of macro-entanglements, the new NPPs initiated during the second boom phase were linked to the construction of electricity grids. For example, Balakovo NPP was integrated into the Central Volga regional grid, in which several powerful hydroelectric stations and numerous fossil-fueled power plants had earlier provided the main load. Ignalina NPP was, as we have already seen, integrated into the Northwestern Ring in a similar way. There, it worked in tandem with other key facilities such as the Leningrad NPP and the large hydroelectric plants on the Daugava River in Latvia.[209] A result of this was a further strengthening of the electrical interdependencies between different Soviet republics. As a matter of fact, planners deliberately targeted nuclear sites near the borders of the latter, so that two or more union republics became dependent on the same plant for their electricity supply. As a result, there was no such thing as a republic-level electricity grid; all that existed was a wider geography of regions that were bound to—and dependent on—each other through powerful transmission lines. Nuclear expansion during the second boom phase directly stimulated even more powerful electricity interconnections of this kind, as larger nuclear reactors were seen to require more powerful transmission systems. This paved the way for a grand Soviet vision centering on a vast 750 kV supergrid.[210]

This grid not only tied the different Soviet republics to each other, it was also deployed to bind the CMEA countries together in a joint network. The new Ukrainian VVER-1000 plants played a key role in this effort. The 750 kV transmission lines from Khmelnytskyi NPP to Poland, mentioned above, exemplifies this. In a similar way, the South Ukraine energy complex exported part of its electricity output through newly built 750 kV transmission lines to southeastern Europe, a region that by the 1980s had come to suffer a shortage of baseload power. In financial terms, these arrangements allowed the Central Europeans to access large amounts of Soviet electricity as payment for their participation in nuclear construction in Ukraine. As a result of this cooperation, the Soviet electricity grid was synchronized with the Central European grid. And the plans continued to grow; Soviet planners looked forward to an even more powerful, 1500 kV network.[211]

On the third level of macro-entanglements, the rapid upscaling of nuclear capacities and the introduction of new, more powerful reactor types posed new challenges for the nuclear fuel cycle. More uranium was needed, spurring new mining projects, especially in Kazakhstan and its Chu-Sarysu province (in the central south of the republic), along with a nationwide expansion of conversion and enrichment capacities. At the back end, meanwhile, it became obvious that RT-1, which was to reprocess VVER-440 fuel, would not be sufficient to meet future demand. In 1976 Sredmash hence decided to start construction of another, much larger reprocessing plant. This new facility, RT-2, was to be built at Krasnoyarsk-26, the easternmost of the large (originally military) nuclear complexes discussed in Chapter 3. Here, spent fuel from the new reactor type VVER-1000 would be reprocessed. Sredmash ordered the Radium Institute, together with VNIPIET, to design the plant.[212]

Construction of RT-2, however, met with problems early on and proceeded only very slowly. It soon became clear to everyone that the plant would not be ready in time to receive the first batches of spent VVER-1000 fuel after the first reactors of this type had been taken into operation. The Soviets dealt with this problem by constructing large interim storage capacities next to the reprocessing plant. Initially these were designed to store up to 3,000 tons of spent fuel; in this form the storage facility began operation in 1985. From then on, spent fuel from the new VVER-1000 plants at Novovoronezh, South Ukraine, Kalinin, Zaporizhzhia, Balakovo, Rivne, and Khmelnytskyi (in that order) were dispatched by railway to the construction site on the Yenisei. Construction of RT-2 would turn out a major headache for Sredmash, and continued delays forced the Soviets to expand the interim storage facility several times over in the years around 1990.[213]

11. The Post-Chernobyl Stagnation and the Third Boom Phase

On April 26, 1986, the Soviet Union suffered what turned out to be the world's most severe nuclear accident. The explosions at Chernobyl NPP's fourth block, whose tragic consequences continue to be debated to this day,[214] were by no means the first time things went horribly wrong in the Soviet nuclear archipelago. As a matter of fact, the Chernobyl disaster was only the most prominent in a long row of incidents and accidents that had plagued the Soviet and Central European nuclear industries from the 1940s onwards. The 1957 Kyshtym tragedy, discussed in Chapter 3, along with serious accidents at Leningrad NPP in 1974–75, at Greifswald in 1975, at Bohunice in 1977, at Beloyarsk in 1977–78, at Chernobyl's first reactor block in 1982, and at Balakovo in 1985 are examples of serious events that, more often than not, led to releases of large amounts of radioisotopes into the environment.[215] Even so, it was only the Chernobyl disaster that changed the overall trajectory of the Soviet nuclear archipelago, through the terminating effect it had on the RBMK development line, on new power plant construction, and on the previously untouchable nimbus of Soviet nuclear progress.

It is hard to fully assess Chernobyl's impact on the Soviet nuclear industry, because the catastrophe meshed in complex ways with the economic, political, and spiritual crisis that the country was heading into rapidly during the second half of the 1980s. Elevated levels of awareness about nuclear safety and the resulting cancellation of some projects became interlinked with struggles for national independence in some union republics, economic hardship, and the loosening grip of the Communist party on society.[216]

RBMK enthusiasts did what they could to save the Chernobyl-type NPPs that were still in operation and under construction. They were more successful at some sites than at others. The most grotesque feat was that they managed to keep the remaining three reactors at Chernobyl in operation in spite of the severe radioactive contamination at the site. For a time, Soviet nuclear builders even continued their work on two new reactors—blocks 5 and 6—at Chernobyl.[217] They also managed to complete two RBMK reactors at other sites that had reached an advanced stage of construction. The first was at Smolensk, whose third reactor went into regular operation in 1990. The other was the second block at Ignalina in Lithuania, which was successfully connected to the grid in August 1987. A planned fourth reactor at Smolensk and a third at Ignalina, however, were cancelled. As we have seen, Ignalina's third reactor was sixty percent complete when the Chernobyl disaster occurred. Initially the Soviets hoped to complete it, but to no avail.[218] The abandonment of the project was linked not only to technical and economic problems, but also to a rapidly changing political climate. Gorbachev's glasnost policy made it possible, for the first time ever, to openly discuss and criticize the Soviet nuclear industry and the risks it posed from a health and environmental point of view. Geographical factors were at the heart of this critique, a key argument being that Lake Drūkšiai, from which the Ignalina NPP sourced its cooling water, was too small to support two more RBMK-1500 reactors. Opposition to the plant's expansion was further accentuated by the secrecy surrounding the Soviet plans for Ignalina's future. Eventually Moscow found itself forced to halt construction. The nuclear debate at Ignalina subsequently metamorphosed into a Lithuanian national liberation movement, in a prime example of what Jane Dawson calls "eco-nationalism." Soon after the goal of national independence was reached, however, the Lithuanians turned more pro-nuclear.[219]

Environmental protests also broke out at several sites with ongoing nuclear construction in the Volga basin. The Tatar, Bashkir, and Gorky plants were stopped in 1990, and their construction sites were abandoned. As in the case of Ignalina, technical issues relating to cooling water played a prominent role in these controversies.[220] In the case of Kostroma NPP, the ambitious plans were first scaled down from the radical RBMKP-2400 design to the still formidable RBMK-1500 and then to a smaller reactor of the new VPBER-600 type.[221] But even that version of the project failed to materialize. With the notable exception of Balakovo, where four of six planned VVER-1000 reactors were completed, the vision of the Volga as a Soviet nuclear frontier failed to materialize.

Crimea also evaded its planned accession to the Soviet nuclear archipelago. The completion of Crimean NPP was stopped in Chernobyl's aftermath, for a plethora of reasons, of which local environmental protests may have been decisive. Opponents further pointed to seismic activity in the area. Proponents of the project had to cope not only with these issues, however, but also with a perpetual lack of funds, workers, and material as well as with the lack of a central will to push the project in times of perestroika. For the local residents, the status of Crimea as a health and tourist destination did not go well together with industrial development, as embodied by the nuclear power plant.[222] For them the choice stood between Crimea as a *Kurort* (sanatorium) and as a *Krymbas* (an industrial area similar to the Donbas or Kuzbas regions) and the answer was overwhelmingly in favor of the former.[223] In post-Soviet times the ruins of the Crimean NPP were turned into a recreational scenic space where music festivals were organized.[224]

Construction at Volgodonsk also stalled, for the time being. So did the preparatory work for new VVER-1000 plants outside Kharkiv, Minsk, and Odessa, which were to have supplied these cities with both heat and electricity. By contrast, construction continued at Kalinin, where the Soviets managed to take one more VVER-1000 reactor into operation after the Chernobyl disaster. At Zaporizhzhia in Ukraine an impressive five out of six planned VVER-1000 reactors were taken into commercial operation by 1989—making it the largest of all plants in the Soviet nuclear archipelago. Likewise in Ukraine, one of Rivne's two VVER-1000 reactors went into operation after the Chernobyl disaster but before the collapse of Communism, as did the third reactor at the South Ukraine energy complex, and the first reactor at Khmelnytskyi. From 1988, however, protests against continued construction at Khmelnytskyi mounted in a dramatic way, eventually preventing completion of the plant's second reactor block.[225] Further south in the Soviet Union, meanwhile, the Armenian nuclear power plant, comprising two VVER-440 reactors, was closed in 1989 following public opposition in the aftermath of Chernobyl and the terrible Spitak earthquake.[226]

Nuclear construction in Central Europe likewise stagnated in the post-Chernobyl period. In Poland, protests against Żarnowiec NPP, which had been under construction since 1982, became an important tool in the struggle for democracy, and the project was ultimately abandoned.[227] Erection of Bulgaria's VVER-1000 reactors at the Danubian sites of Kozloduy and Belene was also delayed, first by the Chernobyl disaster and then by the rise of a wider Bulgarian environmental and anti-nuclear movement. Mirroring the Lithuanian and Polish developments, the anti-nuclear protests in the country soon turned into an outright anti-communist and anti-Soviet movement. By 1989 "eighty percent of the equipment had been supplied and about forty percent of the first reactor had been completed" at the Belene site. But the facility never went online, in spite of later attempts to revive the project.[228] Bulgaria's nuclear enthusiasts were more successful at Kozloduy, where they managed to connect the first VVER-1000 block (the site's fifth reactor) to the grid in 1987, followed by another block in 1991.

Hungary, East Germany, and Czechoslovakia also had high ambitions to build VVER-1000 plants. Hungary started expansion of its Paks NPP in September 1986, hoping to add, just like at Bulgaria's Kozloduy NPP, two VVER-1000 reactors to the already operating four VVER-440 reactors. However, construction stalled in the late 1980s. An anti-nuclear movement arose that not only questioned the safety of the reactors, but also criticized the adverse effects of thermal pollution that the plant gave rise to. It was found that since Paks lacked cooling towers, the Danube's temperature increased by 7–9°C in summer. Water experts found that thermal pollution from the Paks NPP had a clear impact on the river temperature all the way down to the Hungarian-Yugoslavian border. The impact on the Danubian eco-system was in no way negligible, as Hungarian scientists noted.[229] Meanwhile East Germany's Stendal NPP, which was being built on the Elbe, faced stagnation, and was then stopped indefinitely in connection with Germany's reunification (Figure 11.1). Another GDR plant tentatively planned further upstream on the Elbe, near Dessau, was also shelved.

Figure 11.1. Ruins of Stendal NPP, East Germany

Photo by Per Högselius, 2022

In Czechoslovakia, construction of the Mochovce and Temelín NPPs was severely delayed—first by the 1986 Chernobyl disaster and then by the collapse of Communism and the partition of Czechoslovakia in 1992–93. At Temelín, where planning of four VVER-1000 reactors had started back in 1980 and basic preparation of the site was in progress at the time of the Chernobyl disaster, local authorities decided to award a license to erect the main buildings just a few months after the catastrophe in Ukraine. Construction then actually started in March 1987. A complicating geographical factor was that Temelín was only 60 km from the Czech-Austrian border. In a 1978 referendum, the Austrians had voted to phase out nuclear energy, and their anti-nuclear sentiments grew even stronger in the aftermath of the 1979 Three Mile Island accident. This made the Temelín project all the more controversial in Austria. It didn't help that the new Soviet reactor implemented impressive new safety technologies. In 1990 the first post-socialist Czechoslovak government decided to continue construction, but also to limit it to two rather than four reactors. Concerns over the Soviet VVER technology also led to demands for a range of technical modifications.[230]

In the longer term, however, we can conclude that the tragedy at Chernobyl did not constitute the end of the Soviet nuclear archipelago. While its prospects remained bleak throughout the 1990s, a post-Communist "nuclear renaissance" set in as soon as the post-Soviet and Central European economies started to recover from their deep recession. Funds were mobilized and numerous projects that had come to a standstill after 1986 were resumed, while several new plants started to be planned. This resulted in a third boom phase in the (post-) Soviet nuclear archipelago (Figure 11.2 and 11.3).[231]

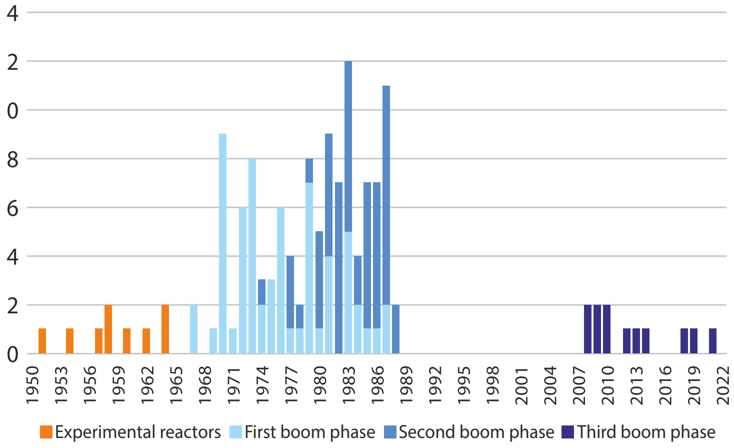


Figure 11.2. Annual construction starts in the Soviet nuclear archipelago, 1950–2022. Apart from the Soviet Union and its successor states, the count includes all VVER construction starts in Finland and Central Europe.

Source: Own graph based on IAEA data

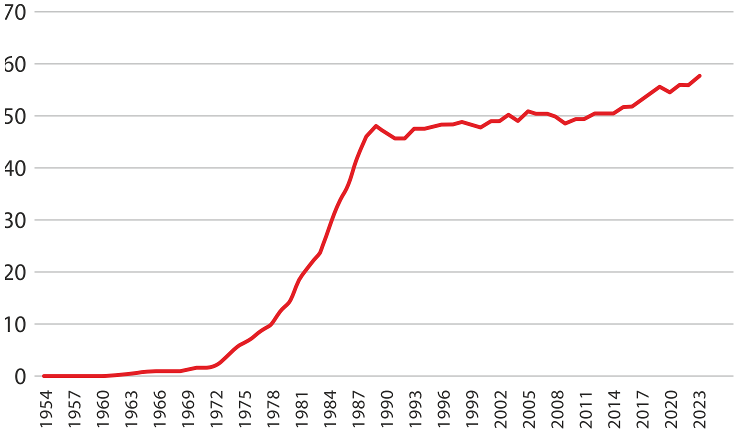


Figure 11.3. Installed gross capacity in the Soviet nuclear archipelago, 1950–2022 (GWe). Apart from the reactors in the Soviet Union and its successor states, the numbers include the VVER capacities in Finland and Central Europe.

Source: Own graph based on IAEA data

At Volgodonsk, for example, where none of the planned reactors had become operational during Soviet times, all four were eventually completed in the twenty-first century. They became powerful symbols of Russia's nuclear revival, with grid connections in 2001, 2010, 2015, and 2018. At Kalinin, where two reactors were already in operation, the remaining two blocks were completed in 2005 and 2012, as was the BN-800 reactor at Beloyarsk in 2016. Ukraine, now an independent country, likewise managed to complete the sixth reactor at its massive Zaporizhzhia complex by 1996, and a second VVER-1000 reactor at Rivne by 2006. These projects thus survived not only the Chernobyl disaster, but also the political and economic turmoil of perestroika, the dissolution of the USSR, and its successor states' early "gangster capitalism."[232] In Armenia, meanwhile, the government decided to restart one of the two VVER-440 reactors that had been closed back in 1989. In 2021, moreover, Belarus, which in Soviet times had been left without large-scale reactors, started up its first nuclear power plant, based on VVER technology.[233]

Central Europe also showed some signs of a nuclear renaissance, albeit not as strong as in Russia and Ukraine. This was evident, in particular, in what had been Czechoslovakia until 1992. Through the division of the country in 1993, the Bohunice and Mochovce plants ended up in the new Slovak Republic, while Dukovany and Temelín found themselves in Czechia. At Mochovce, where construction had been disrupted in the late 1980s, the first reactor was eventually completed and connected to the grid in 1998. The second was completed a year later. The additional reactors that were part of the original Communist-era plans continued to be "under construction" until 2023, when one of them eventually was connected to the grid.

In May 1999 the Czech government, which was unable to reach a consensus on the project's future, voted—with eleven votes to eight—to complete the Temelín facility. Westinghouse was called upon to help the Czechs ultimately finalize the project. The two reactors eventually went into commercial operation in 2002 and 2003, respectively.[234]

By contrast, a number of VVER projects that had been under construction in East Germany, Hungary, Poland, and Bulgaria at the Cold War's end were never revived. Many operational reactors were even forced to permanently shut down. The first site to face this destiny was Greifswald in East Germany, whose five operational VVER-440 blocks were taken out of operation immediately after Germany's 1990 reunification. The smaller Rheinsberg reactor was also closed. The shutdowns continued with Ignalina's two RBMK reactors in Lithuania, the four old VVER-440/230 reactors at Kozloduy, and two similar reactors at Bohunice. These plants were all regarded by Western observers as too dangerous, and the EU even made their closure a condition for Lithuania, Bulgaria, and Slovakia to join the European Union (Figure 11.4). Ukraine eventually also closed the remaining three reactors at Chernobyl, the last of which went permanently offline in December 2000. Even Russia shut down several reactors in the early twenty-first century, although in this case the closures were closely coordinated with the launch of new, more modern reactors at the same sites.

Figure 11.4. **Decommissioning of Ignalina NPP. In the post-Soviet era, most Lithuanians were in favor of keeping their one and only nuclear power plant in operation. The EU, however, demanded the Chernobyl-type plant's closure as a prerequisite for Lithuania's accession to the European Union.**

Photo by Achim Klüppelberg, 2021

The developments at the respective nuclear sites aside, the collapse of Communism and the dissolution of the Soviet Union strongly affected macro-entanglements in the Soviet nuclear archipelago. This concerned first and foremost nuclear electricity interdependencies and cooperation in the nuclear fuel cycle.

As we have seen in the previous chapters, the Soviet electricity grid was developed as an all-union system. This architecture made it attractive, from a technical and economic point of view, to continue cooperation even though the Soviet Union had been dissolved as a political entity. However, this was not attractive at all from a geopolitical perspective. The governments of newly independent republics such as Estonia, Latvia, and Lithuania regarded continued electricity cooperation with Russia and Belarus as counterintuitive; they aspired to apply for NATO and EU membership and reorient themselves towards the Western world. Yet the Baltic countries pragmatically retained their role in the post-Soviet electricity system, benefiting from its technical and economic advantages. This meant that the Ignalina NPP, until its closure in 2009, continued to function as a key constituent of the Northwestern Ring (which in the post-Soviet era was renamed BRELL, an acronym derived from the names of the now independent states involved). Nuclear electricity exports to Russia, Belarus, Latvia, and Estonia became one of Lithuania's chief sources of export revenue in the early post-Soviet era. In a similar way, Ukraine continued cooperating with Russia on nuclear electricity transmission.[235]

In the 2010s both Russia and Belarus sought to further expand nuclear electricity cooperation within the Northwestern Ring. Thus, the Astravets nuclear power plant in Belarus, which was built only 50 km from the Lithuanian capital Vilnius, was initially linked to the idea of Belarusian nuclear electricity exports to Lithuania and the Baltic region more broadly. So was the Russian project of a nuclear power plant in the Kaliningrad exclave, which Rosatom started to erect in 2012 only 10 km from the Lithuanian border. Gradually, however, the political relations between the Baltics, Belarus, and Russia deteriorated. As a result, instead of seeing the new nuclear projects in Belarus and Russia as a convenient source of cheap electricity, the Lithuanians grew increasingly critical of the Astravets and Kaliningrad plants. Showing their dislike of the projects, they even started handing out iodine tablets to the inhabitants of Vilnius. In 2018 the three Baltic countries eventually agreed to delink their electricity systems from Russia and Belarus by 2025 and join the EU grid. The war between Russia and Ukraine sped up these efforts.[236]

Fuel cycle cooperation became just as paradoxical and problematic. After the Kremlin in 1989 for the first time officially confirmed that a disastrous radioactive explosion had occurred at Mayak more than four decades earlier (cf. Chapter 3), regional and local authorities in Russia took an increasingly critical stance toward the nuclear complex. Lobbied by the growing anti-nuclear movement, the authorities imposed new regulations on reprocessing at RT-1, limiting it to 250 tons of spent fuel per year.[237] The anti-nuclear protests also targeted the much larger reprocessing plant RT-2, which was still under construction at Krasnoyarsk-26. As mentioned in the previous chapter, the construction of this facility stagnated in the early 1980s. Arguments for abandoning the project had already been raised back then, but powerful actors within the Soviet nuclear archipelago lobbied for the plant to be completed. The Radium Institute, for example, argued that the excess plutonium that was accumulating following the stagnation in breeders could, instead, be used to produce thermal reactor MOX fuel. The actual result, before Gorbachev, was a compromise: the construction of RT-2 continued, but only at half speed.[238] By 1989, the new reprocessing facility was around thirty percent complete, but further construction was now halted—for reasons that with hindsight have been interpreted differently by different actors. The anti-nuclear movement regarded it as a result of its own intense anti-nuclear campaigns in Siberia. The government, however, explained that the reason for the interruption was lack of funds.[239] In a wider perspective, the decision not to prioritize the plant can also be interpreted as a natural consequence of the dramatic stagnation in the rest of the nuclear fuel system. With stagnation of the construction of new VVER-1000 reactors whose fuel was to be reprocessed at RT-2, and the persistence of problems in the breeder sector, there did not seem to be any urgent need for the new reprocessing plant. In January 1991 Sredmash, which by that time had been renamed the Ministry of Atomic Energy (Minatom), decided to "conserve" RT-2's construction for a five-year-period.[240]

In parallel with the discussions about the future of the reprocessing plants, actual reprocessing of spent fuel from commercial reactors at RT-1 stagnated. The formal limit imposed by regional authorities regarding its annual throughput turned out to be unnecessary, because financial problems made it economically and logistically impossible to keep the facility operating at full capacity. As a result, the throughput of RT-1 declined from 200 tons in 1990, to 170 tons in 1991, and 120 tons in 1992.[241] A similar trend applied to breeder developments at the same site: in 1992 the construction of the Mayak-based South Urals NPP with its three fast breeders, which had been in progress since the early 1980s was terminated due to lack of funds. The plant was then torn down.[242]

Military components of the Soviet nuclear archipelago also stagnated during the last few years of the Soviet Union's existence. The main driving force was the new disarmament policies launched by Gorbachev. Several military reprocessing plants and plutonium production reactors at Mayak, Tomsk-7, and Krasnoyarsk-26 were shut down. When the Soviet Union was dissolved and the Cold War ended, the need for plutonium was further reduced as a consequence of stagnation in nuclear weapons production. Excess plutonium began to be seen as a problem rather than as a valuable resource. The last weapons-grade plutonium at Mayak was produced in 1991. The enterprise increasingly directed its activities towards non-military applications. At Zheleznogorsk (Krasnoyarsk-26) the last plutonium-producing reactor was eventually shut down in 2010.[243]

In the post-Soviet era—and to a certain extent already during the Gorbachev years—there was a strong international interest in assisting Russia and other former union republics with managing their radioactive legacy. This related above all to the military sector, the problems of which by far overshadowed any civilian challenges. Opinions often differed between Russian and foreign actors concerning strategies for dealing with the (military) plutonium. The Russians were reluctant to abandon the old Soviet dream of fast breeders as the ultimate future reactor type and regarded these as a solution to the military plutonium legacy. Russian nuclear experts argued that three BN-800 reactors—like the ones that had been under construction at Mayak—could "consume all Russia's weapons-grade plutonium in 10 years." In the West, however, breeder reactors were a very sensitive topic and any foreign investment in a Soviet breeder scheme was unthinkable from a political point of view. The US arms control community, pointing to the worldwide shortage of capacity to fabricate MOX fuel and fears of diversion by terrorists, favored vitrification, i.e., containment of the plutonium in vitrified high-level wastes.[244]

The renaissance of the Soviet nuclear archipelago in the twenty-first century, however, opened the way for new visions in the nuclear fuel cycle. Among other things, the moratorium regarding the finalization of RT-2 was lifted.[245] At the same time Russia decided to invest considerable sums in developing a new, "green" reprocessing technology, as Rosatom proudly called it. The goal was to radically reduce the volumes of liquid radioactive waste emanating from reprocessing of spent fuel. A pilot-scale facility based on this development was taken into operation in 2017. They hoped to proceed to industrial-scale reprocessing in the 2020s.[246] Zheleznogorsk also began producing large volumes of MOX fuel, manufactured based on legacy weapons-grade plutonium. The fuel elements were sent by rail to the BN-800 reactor at Beloyarsk, as well as to Balakovo NPP on the Volga.[247]

The Chernobyl accident and the collapse of the Soviet Union created new difficulties for Finland and the Central European countries that had been part of the Soviet nuclear archipelago. The Finnish case illustrates the complexity of this challenge. From around 1988, it became known that the spent fuel from Finland's Loviisa NPP was reprocessed at Mayak, where several military reactors were also in operation and where weapons-grade plutonium was produced in large quantities. Earlier, the return of spent fuel to the Soviet Union had been regarded as a perfect solution for Finland, and no one in Finland had bothered to ask any detailed questions about where the fuel actually went after having crossed the Finnish-Soviet border. In the new Finnish political debate, however, the question started to be debated as to whether it was ethically acceptable to export spent nuclear fuel. The debate testified to a marked change in public opinion, where "national responsibility" for spent nuclear fuel and nuclear waste was increasingly stressed. Following the collapse of the Soviet

Union and Finland's application for EU membership, it became politically impossible to support the continued export of spent fuel from Loviisa to Mayak. In Finland's negotiations about EU membership, this became a bone of contention. In 1994 the Finnish nuclear energy law was changed in such a way that exports of spent fuel were declared illegal from 1996. Imatran Voima then faced a totally new situation, as direct disposal of spent nuclear fuel became the only permissible spent fuel management solution.[248]

Existing macro-entanglements at the back end of the nuclear fuel cycle were thus problematized in the aftermath of the Soviet Union's dissolution. A similar problematization occurred at the front end. Sredmash, which was renamed Minatom and then Rosatom, had historically supplied all VVER plants in the Soviet nuclear archipelago with fresh nuclear fuel. In the post-Communist era this arrangement started to be framed, in Ukraine and several Central European countries, as a form of energy dependence, which Russia might potentially use as a metaphorical "weapon." Ukraine was the first country to respond to this dilemma. Tatiana Kasperski writes that in April 1995, the Ukrainian government approved "an ambitious program to produce all nuclear fuel for Ukraine's reactors, existing and planned, domestically." One part of the program involved reviving uranium mining at Zhovti Vody in central Ukraine, where Stalin's geologists, back in 1948, had started extraction of ore for military purposes (see Chapter 3). Another part involved cooperation with Westinghouse, with the goal to enable the use of US-made nuclear fuel in Ukraine's VVER-1000 reactors. The program proved unable to meet its targets, but in 2009 a new, more forceful initiative with a similar goal was launched. After Russia's annexation of Crimea in 2014, Ukraine further stepped up its efforts to become independent of Russian nuclear fuel and Russian fuel cycle services.[249] The Soviet nuclear archipelago thus seemed to be in pieces.

Paradoxically, however, the archipelago also underwent a dynamic expansion. As we have seen, Rosatom continued to develop VVER technology and to build nuclear power plants in Russia and other post-Communist countries. Through an aggressive export strategy, it is now even expanding far beyond the territories that have been at the center of this book, with reactor and turnkey plant sales to countries such as Turkey, China, India, and Bangladesh. As a matter of fact, while Western suppliers of nuclear power plants, notably Westinghouse and Framatome, faced immense financial stress as the twenty-first century progressed, Roastom rose to global dominance in nuclear construction. A recent survey found that “between 2009 and 2018, the company accounted for 23 of 31 orders placed and about a half of the units under construction worldwide.” Through its subsidiary TVEL, Rosatom also provided nuclear fuel, controlling, by the early 2020s, “38% of world’s uranium conversion and 46% of uranium enrichment capacity.” Not only ex-Soviet republics, Central European nations, and countries in the Global South, but also West European and North American nuclear operators developed a dependence on Russia in one way or the other. By the time of Russia’s full-scale invasion of Ukraine in February 2022, nearly all countries in the world with nuclear reactors in operation relied on Rosatom’s services or cooperated with the Russian company. Even the United States relied on “Rosatom subsidiaries and Russian-controlled supply chains for almost a half of its uranium supplies,” while the same applied to “40% of EU imports.”[250] Kazakhstan rose, in an equally spectacular way, to global prominence in the international uranium market. In 2009 it overtook Canada as the world’s leading uranium producer. The rapid growth of production was enabled largely through a flurry of foreign investment in its uranium mining sector, featuring cooperation with Russia as well as with Japan, China, and several Western nations. By 2019, Kazakhstan supplied a staggering forty-three percent of the world's uranium.[251]

12. Conclusion

This book has sought to come to grips with the history of nuclear energy in the Soviet Union and its successor states, with its far reaches into Central Europe, from the early days of tentative nuclear research to today's strained and ambiguous situation. This history has in no way reached its end. In the 2020s, the quest for a "nuclear renaissance" is omnipresent in both Russia and in some Central European countries. So are the terrible environmental and health legacies of the Soviet nuclear archipelago. And as this book goes to publication, Russia's military seizure of nuclear power plants in Ukraine is making headlines, along with renewed, existential fears of a coming nuclear war. This is a situation that early nuclear visionaries like Vladimir Vernadsky, Igor Kurchatov, and Nikolai Dollezhal could hardly have anticipated, but for which they laid the foundation.

The Soviet nuclear archipelago went through two main boom phases, each defined by rapid deployment of certain reactor types. The VVER-440 and the RBMK-1000 were at the heart of the first boom phase, while the scaled-up and improved VVER-1000, and to a lesser extent the RBMK-1500, together with the AST-500, laid the basis for the second. The Chernobyl disaster put an abrupt end to the second boom phase. In the twenty-first century, we can discern a third, post-Soviet boom phase, in which the RBMK development line no longer plays any role, and where the VVER-1000 reactor type is supplemented by newer models.

The book has argued that a spatial perspective can help us better understand the successes, failures, tragedies, and paradoxes in the making of the (post-)Soviet nuclear industry. We discussed the making and unmaking of the Soviet nuclear archipelago on two different geographical levels: on the local/regional level, where nuclear facilities tie into environments, landscapes, and a range of human activities, and on a macro-level, where the interconnectedness of the "islands" in the Soviet nuclear archipelago comes to the fore. Our analysis suggests that both levels need to be properly understood if we are to grasp the dynamics and evolution of "atomic-powered communism."

On the macro-level, the Soviet nuclear archipelago saw a progressive geographical shift over time. At the outset, system-builders sited research institutes and experimental reactors in and around Moscow, Leningrad, and other major cities, giving rise to a distinctly urban nuclear geography. By contrast, uranium mining, fuel cycle activities, bomb plants, and testing grounds were spread across the vast country and beyond. Together with the urban R&D activities, this generated highly fragmented "bomb geographies."

While territories beyond the Urals dominated military-nuclear activities, the diversification into civilian applications called for locations mainly in the European part of the country, which faced by far the greatest electricity demand. It became important to site civilian nuclear plants on suitable waterways and at places that were deemed useful for industrial expansion and transmission grid optimization. Locations enabling further synergies with already existing enterprises were preferred. In numerous cases—notably at the military combines and uranium mines in the Urals and Siberia, but also at more civilian-oriented sites like Bilibino and Shevchenko—nuclear development opened up indigenous territories for industrial development and settlement. There, atomic-powered Communism fused with a Soviet *mission civilisatrice*.

We identified three main types of macro-entanglements. The first took the form of technological cooperation and knowledge exchange between different nuclear sites. In the construction of civilian nuclear plants, this produced two distinct geographies: "VVER land" and "RBMK land," of which the former was substantially larger and more dynamic than the latter. RBMK land was strikingly limited in a geographical sense, covering a comparably small region bordered by the Gulf of Finland in the north, Ignalina in the west, Chernobyl in the south, and Kostroma in the east. (The latter site never actually saw the completion of any RBMK reactor block.) VVER land, by contrast, spanned a vast territory. It comprised remote sites such as the Kola peninsula in the High Arctic and Armenia in Soviet Union's far south. In the west, it transcended the country's borders; by the late 1970s it extended into several Central European states as well as into Finland. Interaction within this vast geographical space shaped the further evolution of the VVER technology, as Finnish and then Central European stakeholders pushed Soviet reactor developers to improve reactor safety systems. The technological expertise that the Soviets acquired in this context helps explain Rosatom's remarkable ability, in the post-Soviet era, to conquer international markets.

The second layer of macro-entanglements stemmed from the integration of nuclear plants into regional and national electricity grids. The Soviet electricity grid, as it evolved in the 1970s and 1980s, was strongly shaped by nuclear developments. Electricity grid integration allowed both VVER and RBMK reactors to operate in tandem with both near and distant hydroelectrical and fossil-fueled power plants, and to supply electricity to industrial and urban centers in large regions. The establishment of geographically wider electricity systems also strengthened the safety of the Soviet nuclear plants, since reactor cooling water pumps, of critical importance for preventing accidents and meltdowns, depended on robust connections to external electricity grids. Ultimately the perceived advantages of nuclear-based electricity interconnections led to the construction of several ultra-high-voltage (750 kV) transmission lines from the Khmelnytskyi and South Ukraine NPPs to Central Europe, laying the foundation for a synchronized Soviet-Central European electricity grid—the "Mir"—that symbolized the unity of the Communist world.

On the third level, nuclear facilities in the Soviet Union and Central Europe became entangled with each other through the nuclear fuel cycle. Here, a system took shape in which uranium, mined at a variety of sites—from the Soviet-East German Wismut complex in the west to the Siberian Priargunsky combine in the east—was sent to nearby processing sites, then to enrichment facilities, most of which were in Siberia, and onward to Elektrostal near Moscow, where the fuel elements were manufactured. These could then be shipped to power plant sites dispersed across RBMK and VVER land. Such uranium and fuel transports depended critically on a railway system that had largely been built during tsarist times and then expanded under early Bolshevik rule. At the back end of the nuclear fuel cycle, the vision was that the spent fuel would be reprocessed at specially designed facilities in the Urals and Siberia. Actual reprocessing, however, failed to materialize on the envisaged scale, forcing nuclear operators across the Soviet Union, Finland, and Central Europe to erect large interim storage facilities for spent fuel next to the power plants. Apart from technical problems with the reprocessing plants themselves, disturbances in railway transport contributed to stagnation in fuel-based macro-entanglements.

On the micro- and meso-levels, meanwhile, Soviet nuclear planners and engineers had to find a way to smoothly integrate their facilities into regional economies, environments, and landscapes. The construction of new towns and the expansion and reconfiguration of local infrastructure constituted omnipresent challenges in this context. The most central task, however, was to construct hydraulic systems that allowed the nuclear builders to tap into natural water flows. The Soviets initially favored building NPPs on surprisingly small waterways, which they usually had to “tame” to make suitable for large-scale cooling water withdrawal. In doing so they often radically altered the regional environment. Rivers aside, a few plants were built on lakes. Only one large nuclear plant, the Leningrad NPP, was built by the sea.

Only in the second boom phase did Soviet nuclear builders opt to locate nuclear plants on larger rivers: on the Lower and Middle Volga, the Lower Don, and the Lower Dnieper. Here, they were able to make productive use of earlier hydraulic-engineering achievements, especially in terms of the huge damming, rectification, and hydropower projects that had been carried out between the 1930s and the 1970s. By extension, Gidroproekt came up with the vision of grand “energy complexes” where nuclear construction would be combined, from the outset, with a range of other hydraulic engineering projects—from new hydroelectric plants to ambitious irrigation systems. All in all, our analysis suggests that the quest for proximity of nuclear power plants to resources and industries often trumped the classical quest for distance in nuclear matters.

We ended the last chapter by noting how the legacy of the Soviet nuclear archipelago has produced highly ambiguous and contradictory geographical trends in the twenty-first century. On the one hand, there have been efforts in several post-Communist countries to delink their nuclear industries from that of Russia. On the other, Russia has sought to not only maintain, but further expand and deepen its nuclear relations with the same states. An obvious question for the future is how the new geopolitical situation that has emerged since Russia invaded Ukraine in February 2022 will influence nuclear energy activities in the ex-Soviet and Central European space. The invasion marked the culmination of a conflict between Moscow and Kyiv that had been escalating since the change of government in Ukraine after the Euromaidan demonstrations in 2013/2014. It destroyed many of the previously established nuclear entanglements between Russia and Ukraine, as well as between Russia and the rest of Europe.

The war was profoundly linked with nuclear energy. During the very first days of the invasion, Russian military forces captured Chernobyl NPP, disrupting safety routines and staffing and inciting fears of another nuclear disaster at the site. After the Russians retreated from the Chernobyl zone following their failed attempt to seize Kyiv, the Ukrainian authorities discovered that Russian soldiers had dug trenches in the highly contaminated Red Forest, next to the nuclear plant. Concerns were raised in international media over cases of radiation sickness and the possible redistribution of radioisotopes in the form of contaminated dust blown away by wind.[252]

Later on in the war, the attention shifted to Zaporizhzhia NPP, the largest of all civilian facilities in the ex-Soviet nuclear archipelago. Captured by the Russian army, it came repeatedly under attack in the following months. This unprecedented case of a nuclear power plant caught up in a violent war raised widespread concern. Pointing to the potentially disastrous consequences of military action in the immediate vicinity of Zaporizhzhia NPP, IAEA Director General Rafael Grossi, who visited the plant on several occasions during 2022 and 2023, repeatedly called for an end to all fighting in the area.[253] The plant ceased regular operation, but significant decay heat from the nuclear fuel in the reactors and in spent fuel ponds meant that the situation remained dangerous. Macro- as well as micro- and meso-level entanglements at Zaporizhzhia were identified as threats. The plant repeatedly lost its electricity connections for both shorter and longer periods of time, forcing the NPP operators to run the plant in island mode based on electricity supplied by emergency diesel generators. At one point the uncertainty regarding longer-term access to diesel, given the raging war, even prompted the staff to keep one reactor in operation to guarantee the electricity supply of the other, closed reactors. By spring 2023, moreover, it was reported that Russian forces had opened the sluice gates at the Kakhovka Dam (cf. Map 8.4). This resulted in unprecedentedly low water levels in Kakhovka Reservoir, from which Zaporizhzhia NPP sourced its cooling water. Some observers feared that this would make it impossible to replenish the nuclear plant's cooling pond, with potentially dire consequences.[254] Unsurprisingly, these concerns grew even stronger after the catastrophic destruction of the Kakhovka dam—and thus of the envirotechnical system of which the nuclear plant was part—in June 2023.[255] Weinthal and Bruch, in an early analysis of the security situation at Zaporizhzhia and Chernobyl Nuclear Power Plants during Russia's war on Ukraine, conclude that the Russian army had weaponized both nuclear power plants.[256]

In parallel with these dramatic developments linked to the war, a power struggle can be discerned that has to do with attempts to shape the long-term future of the ex-Soviet nuclear archipelago. Needless to say, the war accentuates the desire in several post-Communist countries to break away from their Soviet nuclear heritage. From a purely (geo)political point of view, and to the extent that they regard nuclear energy as a significant component of their future energy supply, they would prefer to distance themselves from Russian and ex-Soviet technologies and, instead, embrace those from the West. This logic is countered, however, by the continued existence of strong macro-entanglements with Russia. As long as Ukraine, the Czech Republic, Slovakia, Hungary, and Bulgaria continue to operate VVER reactors, they also continue to inhabit “VVER land.” The nuclear industries in this geographical region continue to share many challenges, making it logical and natural, from a technological point of view, to continue cooperation. There are also efforts, in several Central European countries, to maintain cooperation around the VVER nuclear fuel cycle—both in terms of fresh fuel supply and spent fuel management. When it comes to possible new nuclear power plants in these countries, technological path dependence further translates into a temptation to build new VVER reactors rather than reactors of Western origin. Whether the ex-Soviet nuclear archipelago is ultimately broken up or, on the contrary, can look forward to a new dynamic phase, thus remains to be seen.

Acknowledgments

When we began our work on this volume in 2019, our intention was to write a brief overview article that would sketch the historical geography of nuclear energy in the former Soviet Union. However, the text quickly acquired a life of its own, swelling far beyond the word limits of what would have been acceptable for an academic journal. Reluctant to radically shorten the manuscript, we then decided to try and rework the article into a (short) book. We are grateful to the Central European University Press and, in particular, Jen McCall, for seeing the potential in this idea and believing in it. We hope that readers both within and beyond academia will find it useful.

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Some parts of the discussion about spent nuclear fuel in Chapters 7, 10, and 11 appeared previously in Per Högselius, “The Decay of Communism: Managing Spent Nuclear Fuel in the Soviet Union,” *Risk, Hazards, and Crisis in Public Policy* 1, 4 (2010): 83–109. They are reprinted here with permission.

Notes

1 Hughes, *Networks of Power.*

2 Hecht, *Entangled Geographies;* Pritchard, *Confluence*.

3 Yemelyanenkov, *Sredmash Archipelago.* In an article published in January 1992, Robert Norris used the term “Soviet Nuclear Archipelago” to describe the USSR’s facilities that created and supported the country’s nuclear weapons program. Like Yemelyanenkov, he did not include civilian applications of nuclear energy in his analysis (Norris, “Soviet Nuclear Archipelago,” 24).

4 Jacobs, “Born Violent,” 10–11, 25–26.

5 For military detachments (“voenno-stroitelnye otryady”), see Russian State Archive of Economy (RGAE), F.R-7964, op. 16, d. 2593, l. 168. Gestwa, *Stalinsche Großbauten*, 135 and 394–97, discusses the “hydrotechnical Arkhipel GULag.” See also Guth, “Breeding Soviet Progress,” 288 and 294.

6 Khandozhko, “Territoriya politicheskoi anomalii,” 169.

7 Josephson, “Atomic-Powered Communism,” 297–324.

8 Josephson, “Physics, Stalinist Politics of Science and Cultural Revolution”; Josephson, “Atomic-Powered Communism”; Holloway, *Stalin and the Bomb.*

9 Dodd, Industrial Decision-Making and High-Risk Technology; Dawson, Eco-Nationalism.

10 Schmid, *Producing Power*; Schmid, “A New ‘Nuclear Normalcy’?”

11 Guth et al., “Soviet Nuclear Technoscience”; Khandozhko, “Territoriya politicheskoi anomalii.”

12 Michelsen, “An Uneasy Alliance”; Hristov, “The Communist Nuclear Era”; Schmid, “Nuclear Colonization?”; Högselius, *Die deutsch-deutsche Geschichte des Kernkraftwerkes Greifswald*; Flade, *Energy Infrastructures in the Eastern Bloc*; Szulecki et al., *The Chernobyl Effect.*

13 Brown, *Plutopia*; See also Stulberg, “The Federal Politics of Importing Spent Nuclear Fuel”; Högselius, “Decay of Communism.”

14 Brown, *Manual for Survival*. See also Brown, “Dystopic Pieta.”

15 See, for example, Wendland, “Ukrainian Memory Spaces”; Higginbotham, *Midnight in Chernobyl*; Plokhy, *Atoms and Ashes*.

16 Guth, “Oasis of the Future”; Popov, “Krym i AES nesovmestimy!”

17 Kasperski, “From Legacy to Heritage”; Storm, *Post-Industrial Landscape Scars*; Storm et al., “Urban Nuclear Reactors.”

18 Batrakov et al., Ignalinskoi AES 25 let; Lebedev et al., Leningradskaya AES.

19 David Holloway, in *Stalin and the Bomb*, 8–28, offers a detailed history of the Leningrad Physical-Technical Institute, while also discussing at some length the parallel evolution of the Radium Institute.

20 Holloway, *Stalin and the Bomb*, 17 and 44.

21 Holloway, *Stalin and the Bomb,* 41–44. See also Josephson, *Nuclear Russia*, 11–20, which provides further details on the history of the Ukrainian institute.

22 Holloway, *Stalin and the Bomb,* 34–48; Josephson, *Red Atom,* 14.

23 For example, they correctly found, more or less at the same time as Western scientists came up with similar results, that on average approximately three neutrons were emitted per fission. Holloway, *Stalin and the Bomb,* 50–51.

24 Rukavichnikov, "First USSR Cyclotron," 1077. Holloway writes that Kurchatov, forging a cooperation between Ioffe's institute and the Radium Institute, gradually took charge of the cyclotron. "The cyclotron began to be used for research in 1939, but it was not until the end of 1940 that it went into normal operation." (Holloway, *Stalin and the Bomb,* 40).

25 Holloway, *Stalin and the Bomb*, 49–59.

26 Holloway, *Stalin and the Bomb*, 30–34; Mellor, "Soviet Uranium Boosters," 31–33.

27 Pondrom, *Soviet Atomic Project,* 482; Holloway, *Stalin and the Bomb,* 60–66.

28 This derives from Lenin's famous slogan: "Communism is Soviet power plus the electrification of the whole country." V.I. Lenin, "Our Foreign and Domestic Position and Party Tasks. Speech Delivered to the Moscow Gubernaia Conference of the R.C.P.(B.)", November 21, 1920.

29 Graham, *Ghost of the Executed Engineer*; Högselius, "The Hidden Integration of Central Asia," 227.

30 Holloway, *Stalin and the Bomb*, 72–95.

31 Holloway, *Stalin and the Bomb*, 92; Josephson, *Red Atom*; Brown, *Plutopia,* 79–80.

32 When the Red Army managed to open a narrow corridor into Leningrad in January 1943, Kurchatov's team flew in to collect equipment and materials belonging to the cyclotrons built at the institutes there, moving everything to Moscow (Holloway, *Stalin and the Bomb,* 92). After the war, however, nuclear research in Leningrad was revived, so that during the Cold War period both cities served as important hubs for nuclear physics and chemistry.

33 Storm et al., "Urban Nuclear Reactors," 111–119; Holloway, *Stalin and the Bomb,* 181–82; Josephson, *Red Atom*, 17.

34 Högselius, "Decay of Communism."

35 For example, Laboratory No. 2 under Kurchatov competed with Laboratory No. 3, which was later renamed the Alikhanov Institute of Theoretical and Experimental Physics. While Kurchatov experimented on graphite-moderated and water-cooled reactor types, Laboratory No. 3 worked on a heavy-water reactor. Yemelyanenkov claims that by 1991 no fewer than 34 research reactors were built by six institutes in Moscow alone. See Yemelyanenkov, *Atom Declassified*, 75–76. The six institutes were: 1. Kurchatov Institute; 2. Alikhanov Institute; 3. Moscow Institute of Physical Engineering (MIPE); 4. Research and Design Institute of Power Engineering (RDIPE); 5. Moscow Energy Institute (MEI); and 6. Research Institute of Chemical Technologies (RICT).

36 Holloway, *Stalin and the Bomb,* 64.

37 Cf. Pondrom, *The Soviet Atomic Project*, 116.

38 Medvedev, "Atomic Gulag"; Holloway, *Stalin and the Bomb,* 176.

39 Medvedev, “Atomic Gulag,” 91–93; Holloway, *Stalin and the Bomb,* 174–77.

40 Ehdwall, *Waste Depository in Sillamäe*, 6. While Ehdwall et al. speak of 1948, Silmet, the company conducting operations at Sillamäe today, claims 1946 as the founding date. See NPM Silmet OÜ: *History,* http://www.silmet.ee/ [2020-09-14]; Storm, *Post-industrial Landscape Scars,* 82.

41 NPM Silmet OÜ, *History*, http://www.silmet.ee/ [2020-09-14]. For the chemical steps that Sillamäe focused on, see Maremäe, *Nuclear Non-Proliferation in Estonia*, 21 and 27.

42 Maremäe, *Nuclear Non-Proliferation in Estonia*, 11. The Estonian Minister of Environment from 1991 to 1992, Tõnis Kaasik, said: “The first atomic bomb of the Soviet Union was obviously built of the uranium extracted at Sillamäe.” (ibid., 5) While there is no direct evidence supporting this claim, the statement seems plausible. Nevertheless, it is not probable that the amount mined in Sillamäe was enough for the bomb(s), which means that if it was used, it was only one source of uranium among many for the military project.

43 Maremäe, *Nuclear Non-Proliferation in Estonia,* 17. Ello Maremäe estimates that only 2% of workers present in the uranium mining effort at Sillamäe were volunteers in the sense of “free labor.” Many forced laborers died. Cf. Vseviov, *Sillamäe*, 3, 4, 9, and 13.

44 Cybriwsky, *Along Ukraine’s River,* 95–96; Medvedev, “Atomic Gulag,” 95; Holloway, *Stalin and the Bomb,* 176.

45 Holloway, *Stalin and the Bomb,* 178.

46 Brown, *Plutopia*, 81–87.

47 Högselius, “Decay of Communism”; Yemelyanenkov, *Sredmash Archipelago,* 18; Joint Norwegian-Russian Expert Group, *Techa and Mayak*; Komissiya po otsenke ekologicheskoi situatsii v raione deyatelnosti PO “Mayak” Minatomenergoproma SSSR, “Radiatsionnaya obstanovka,” 11–18, Private Archive of Dima Litvinov.

48 Pondrom, *Soviet Atomic Project,* 441–43; Kassenova, *Atomic Steppe,* 33–34.

49 Cf. Jacobs, *Nuclear Bodies*.

50 Kassenova, *Atomic Steppe,* 13.

51 Kassenova, *Atomic Steppe,* 24–25.

52 Kassenova, *Atomic Steppe,* 30.

53 Kassenova, *Atomic Steppe,* 27–30 and 54. Kassenova writes that “In their rush to develop a nuclear arsenal, Soviet leaders gave little thought to protecting the locals and the Polygon workers… Within a few years after the first test of 1949, however, the Soviet government began to monitor the health of the local population, gaining insights into the effects of radiation on people.” See also Pondrom, *Soviet Atomic Project,* 539–42.

54 Medvedev, *Atomic Gulag*, 97; Higginbotham, *Midnight in Chernobyl,* 221.

55 For Tomsk-7 see Dollezhal, *Pervym vsegda trudnee,* 33–34.

56 Högselius, “Decay of Communism,” 6; Egorov, *The Radiation Legacy of the Soviet Nuclear Complex*; Yemelyanenkov, *Sredmash Archipelago,* 19. Yemelyanenkov recalls how he was allowed to visit this site in the perestroika period (Yemelyanenkov, *Sredmash Archipelago,* 8).

57 Kassenova, *Atomic Steppe,* 29.

58 Siragusa and Arzyutov, "Indigenous groups in the Russian North," 45–46; Kassenova, Atomic Steppe, 29.

59 Medvedev, "Atomic Gulag."

60 The Kyshtym disaster is described in detail by, for example, Kuznetsov and Nazarov, *Radiatsionnoe nasledie kholodnoi voiny*. See also IAEA, "USSR Provides Details of Accident," July 26, 1989 (press release); Komissiya po otsenke ekologicheskoi situatsii v raione deyatelnosti PO "Mayak" Minatomenergoproma SSSR, "Radiatsionnaya obstanovka," 11, Private Archive of Dima Litvinov; Nikipelov et al., "Accident in the Southern Urals on 29 September 1957," 2–3. The Soviet nuclear industry used the remaining inhabitants of contaminated land from the accident as a sample for studying the long-term effects of exposure to low- to mid-level radiation in humans.

61 Yemelyanenkov, *Sredmash Archipelago*, 19.

62 Schmid, *Producing Power*, 46.

63 Josephson, *Red Atom,* 143. The vessel was ultimately commissioned in 1958.

64 Schmid, *Producing Power,* 109. See also Bellona, "Nuclear Icebreaker Lenin," June 20, 2003, https://bellona.org/news/arctic/russian-nuclear-icebreakers-fleet/2003-06-nuclear-icebreaker-lenin [2022-10-27]. The Lenin was launched in 1957 and started full operation in 1959. It carried three small reactors with a total heat producing capacity of 90 MW, which translated into 44,000 horsepower. These compact reactors had a core measuring 1.6 meters in height and 1 meter in diameter.

65 For a detailed discussion of the variety of reactor types that were tentatively explored, see Josephson, *Red Atom,* and Schmid, *Producing Power.*

66 Schmid, *Producing Power*, 45–46.

67 Josephson, *Red Atom,* 25; Cf. Trifonov, "Na atomnoi elektrostantsii," *Pravda Ukrainy*, August 11, 1955.

68 Josephson, *Red Atom,* 25.

69 Quoted in Holloway, *Stalin and the Bomb,* 348.

70 Holloway, *Stalin and the Bomb,* 348.

71 Schmid, *Producing Power*, 106.

72 Schmid, *Producing Power*, 107.

73 RGAE, F.R-9599, op. 2, d. 5, l. 87 [1956].

74 Josephson, *Red Atom*, 28–29; RGAE, F-R.-9599, op. 2, d. 5, l. 70 a. 80 [1956].

75 Schmid, *Producing Power,* 108.

76 Schmid, *Producing Power*, 108.

77 RGAE, F.R.-9599. op. 2, d. 9, l. 3 [1956–57]; Josephson, *Red Atom*, 37–40; Flade, *Energy Infrastructures in the Eastern Bloc,* 153.

78 This was because the components of the primary circuit were placed in a "pressure room system" whose volume did not suffice to absorb the entire water-steam mix that would leak into the facility from the primary circuit. In order to prevent a collapse of the reactor building, it was equipped with pressure release valves, which in case of a big accident would release radioactive gases into the atmosphere.

79 This is excellently described in East German government sources; see "Information für den Staatssekretär Genossen Mitzinger: Festlegung des Standortes für das Kernkraftwerk III," October 2, 1972. This document also mentions that the Soviets considered the possibility of adding a containment structure to the VVER-440, but in September 1972 this option was eventually given up.

80 Schmid, *Producing Power,* 109–110.

81 Hristov, "Communist Nuclear Era," 72–73. The Central European research reactors were typically located in the outskirts of cities. Thus Bulgaria's first research reactor was built at a distance of 7 km from downtown Sofia, while East Germany built its nuclear research center at Rossendorf, 15 km from central Dresden.

82 Schmid, *Producing Power*, 116. The reactor was built at Laboratory No. 3, which was later renamed the Institute of Theoretical and Experimental Physics.

83 Kuruc and Mátel, "Thirtieth Anniversary of Reactor Accident in A-1 Nuclear Power Plant Jaslovské Bohunice"; Schmid, *Producing Power,* 117.

84 Högselius, *Die deutsch-deutsche Geschichte des Kernkraftwerkes Greifswald*, 16–17; Turnbull and Lau, "Lake Stechlin."

85 I.S. Morokhov, "Atom i progress chelovechestva," *Pravda Ukrainy*, August 10, 1965.

86 Josephson, *Red Atom,* 60–68.

87 Guth, "Oasis of the Future," 94–100; Guth, "Breeding Soviet Progress," 285; "Budushchee yadernoi energetiki." *Pravda Ukrainy*, September 30, 1971.

88 Guth, "Oasis of the Future," 95.

89 I.S. Morokhov, "Atom i progress chelovechestva," *Pravda Ukrainy*, August 10, 1965; "Stroitelstvo novykh atomnykh elektrostantsii v Sovetskom Soyuze," *Pravda Ukrainy*, August 30, 1957; Dollezhal and Koryakin, *High-Temperature Reactors*, 154; Dodd, *Industrial Decision-making,* 19–20 and 81–82.

90 Schmid, "*Chernobyl* the TV Series," 1158; cf. Dodd, *Industrial Decision-making,* 19–20.

91 Sidorenko et al., *Standards for Safety,* 285–290; cf. Schmid, *Producing Power,* 107. Schmid writes that Soviet power plant sites had to meet demands for "sufficient water supply, suitable seismic conditions, and adequate space for an occupational health and safety zone" and that they also had to "demonstrate sufficiently high energy demand, existing transmission lines, and easy access to both a developed industrial base and large numbers of construction workers."

92 Högselius, "Atomic Shocks of the Old."

93 Pritchard, *Confluence*, 100–114.

94 Kovaleva and Chernikova. "Radioekologicheskie monitoring," 57; "Novovoronezhskaya AES obnarodovala informatsiyu o svoei ekologicheskoi politike," *Atomnaya Energiya* 2.0, March 24, 2020, https://www.atomic-energy.ru/news/2020/03/24/102394 [2021-01-19].

95 Russian State Archive in Samara (RGA Samara), F.R-109, op. 1–6, d. 924, l. 193–202; Solotkov et al., *Kolskaya AES*; Frey, *Arktischer Heizraum,* 16–17, 38, 42, 79–82, 266 and 271; Nornickel, "Kolskii Poluostrov," https://www.nornickel.ru/business/assets/kola/ [2021-01-19]; Ministerstvo Rossiiskoi Federatsii po Atomnoi Energii, Kontsern Rosenergoatom, *Ekspluatatsiya atomnykh elektrostantsiy*, 10. The relevant resources in the region comprised a broad range of minerals and ores, including iron ore, apatite, nickel, platinum, and even zirconium, which was used in the nuclear industry for the manufacture of fuel rods.

96 Frey, *Arktischer Heizraum,* 271–280; Gestwa, *Stalinsche Großbauten*, 23–24; Moiseenko, "Long-term Modification of Arctic," 10–12; Frey, *Arktischer Heizraum,* 278–280; A. Burnazyan, "Plantatsii vokrug atomnoi," *Pravda*, July 30, 1977.

97 Kozlova, *Nikolai Fedorovich Lukonin,* 146f.; Petrosyants, *Atomnaya energiya v nauke,* 153–156. The modified reactor type was called VVER-440/270.

98 RGAE, F.R-7964, op. 16, d. 2638, l. 246; Belosotskii, "My – s Atomnoi!," *Pravda Ukrainy*, April 18, 1976; T. Odinokova, "Lyudi Rovenskoi Atomnoi," *Pravda Ukrainy*, February 6, 1979; Energoatom, "SS Rivne NPP," http://www.energoatom.com.ua/en/about-6/separated-59/npp_rivne-61 [2020-11-30]; Wendland, "Nuclearizing Ukraine," 353–362; "Dni i nochi Atomstroya," *Pravda Ukrainy*, May 8, 1977.

99 Lebedev, "Vizhu budushchee," 9–13.

100 Lebedev, "Vizhu budushchee," 9; Dollezhal, *Pervym vsegda trudnee*, 35; Majandus-ja Kommunikatsiooniministeerium, *Eesti energeetika arvudes 2007*, 29; Gazprom Territorialnaya Generiruyushchaya Kompaniya No. 1, "Energiya i teplo," https://www.tgc1.ru/production/complex/spb-branch/narvskaya-hpp/ [2021-04-07].

101 Cybriwsky, *Along Ukraine's River,* 29, 69; Klüppelberg, "Water, Fish, and Contamination," 3–8.

102 IAEA, "Environmental Impact Assessment," 1, 5–8; Wendland, "Ukrainian Memory Spaces," 1166.

103 Ofitsialnyi sait munitsipalnogo obrazovaniya "Gorod Kurchatov" Kurskoi oblasti, "Chistaya voda – eto realno!," March 2, 2017, http://kurchatov.info/index.php?option=com_content&view=article&id=8812:chistaya-voda--eto-realno&catid=18:novosti&Itemid=8 [2020-11-21].

104 Potekhina, "Za chetvert veka," 55, 57, 59.

105 Stsiapanau, "Nuclear Waste Management in Lithuania and Sweden," 465.

106 Interview with Dima Litvinov, former campaigner from Greenpeace Russia during the 1990s; presentation by Litvinov in the NUCLEARWATERS Seminar Series on February 18, 2022, KTH Royal Institute of Technology, https://nuclearwaters.eu/2022/02/09/upcoming-nuclear-waters-seminar-series/ [2022-10-28]; Litvinov's private archival documents and video tapes; PPGHO ROSATOM, "Priargunsky Mining and Chemical Production Association," https://priargunsky.armz.ru/en/ [2022-10-28].

107 World Nuclear Association, "Uranium and Nuclear Power in Kazakhstan"; Mirsaidov et al., "From History of Reception of Native Uranium."
108 Headrick, *Tools of Empire*. Cf. Schmid, "Nuclear Colonization?," 130, 133–134, 140, and 146.
109 Guth, "Oasis of the Future," 94 and 99–100; Guth, "Breeding Soviet Progress," 281–289; Josephson, *Red Atom*, 49.
110 Guth, "Oasis of the Future," 100; cf. I.S. Morokhov, "Atom i progress chelovechestva," *Pravda Ukrainy*, August 10, 1965.
111 RGAE, F-R.-9599, op. 2, d. 5, l. 88 [1956].
112 See the discussion on nuclear heating in RGA Samara, F.R-109, op. 1–6, d. 1004.
113 Gestwa, *Stalinsche Großbauten*, 16; Guth, "USSR Incorporated," 177–79.
114 Schmid, "Nuclear Colonization?," 125, 130, 133, 137, and 140; Gestwa, *Stalinsche Großbauten*, 132–33; Karl-Erik Michelsen, "An Uneasy Alliance"; RGAE, F.R-7964, op. 16, d. 2638, l. 246 [1978].
115 Hristov, "Communist Nuclear Era," 101.
116 "Protokoll über die Parteiaktivtagung am 9. Januar 1968 mit allen am Bau des Kernkraftwerkes Nord unmittelbar beteiligten Grundorganisationen," Regional Archive of Mecklenburg-Vorpommern (LAMV), Rep. 295, IV/B/7/5.
117 Rambusch (VEB Atomkraftwerk Rheinsberg) to Gies (Ministerium für Grundstoffindustrie), "Kurzbegründung für den Standort des Kraftwerkes Nord," February 17, 1966, Federal German Archives (BArch) DG 12/181.
118 Högselius, *Die deutsch-deutsche Geschichte des Kernkraftwerkes Greifswald*, 18–21.
119 The accident was not made public at that time, but in connection with Germany's reunification in 1990 it was highlighted in a much-cited article in *Der Spiegel* (January 22, 1990). In what followed, the accident influenced the discussions on whether or not the Greifswald plant should be closed.
120 Högselius, *Die deutsch-deutsche Geschichte des Kernkraftwerkes Greifswald*.
121 Hristov, "Communist Nuclear Era," 105.
122 Hristov, "Communist Nuclear Era," 107–108.
123 Hristov, "Communist Nuclear Era," 109.
124 Hristov, "Communist Nuclear Era," 130–131.
125 Hristov, "Communist Nuclear Era," 131.
126 Javys, "V1 Nuclear Power Plant: History," https://www.javys.sk/en/nuclear-facilities/v1-nuclear-power-plant/history [October 3, 2022].
127 Rabusic, "Vodni hospodarstvi jaderne elektrarny Dukovany," 20–26; Skokan, "Construction of Dukovany Nuclear Power Station," 51–55.
128 "Vodná stavba Veľké Kozmálovce," https://www.velkekozmalovce.sk/vodna-stavba-velke-kozmalovce.phtml?id3=44779 [October 2, 2022].
129 Szolnoky and Raum, "Regulation of the Thermal Loading by Paks Nuclear Power Station," 41–50.
130 Szulecki et al., *Chernobyl Effect,* 80.
131 On the dynamics of the RBMK community, see Schmid, *Producing Power*.
132 Michelsen, "An Uneasy Alliance."

133 "Möglichkeiten zur Verbesserung der sicherheitstechnischen Auslegung der 440-MW-Blöcke," November 8, 1972, BArch DG 12/951.

134 See, e.g. Gesellschaft für Reaktorsicherheit, *Sicherheitsbeurteilung des Kernkraftwerkes Greifswald*, 126.

135 Högselius, *Die deutsche-deutsche Geschichte des Kernkraftwerkes Greifswald*, 115–16.

136 The exceptions were the Bilibino and Shevchenko NPPs, which supplied electricity in more localized grids.

137 Central State Archive of St. Petersburg (TsGA Spb), F.R-1842, op. 4, d. 890, l. 3, 27, 37–38.

138 Högselius, "Connecting East and West?"

139 Sistemnyi operator edinoi energeticheskoi sistemy, "Istoriya," http://www.so-ups.ru/index.php?id=925 [February 28, 2023]

140 Tchalakov et al., "Bulgarian Power Relations"; Hegmann, "Die Entwicklung der Zusammenarbeit im RGW," 21.

141 Kuznetsov and Nazarov, *Radiatsionnoe nasledie kholodnoi voiny*, 413.

142 For the case of the Kola NPP, see Frey, *Arktischer Heizraum*, 282; Zubkov (Gosatomnadzor) to Tolnatskii (Greenpeace Russia), "Informatsiya po voprosam litsenzirovaniya deyatelnosti PO Mayak," Moscow, 1994, Private Archive of Dima Litvinov.

143 Högselius, "Decay of Communism."

144 Kudrik et al., *Russian Nuclear Industry*.

145 Högselius, "Decay of Communism."

146 Lazarev, "Pererabotka yadernogo topliva."

147 Its annual reprocessing capacity was then 60–70 tons of uranium. When the second section was taken into operation, the annual capacity of the plant rose to 150–200 tons. In the third and last section of the facility, the plan was to expand the capacity to 400 tons. See Högselius, "Decay of Communism."

148 Högselius, "Decay of Communism."

149 Kuznetsov and Nazarov, *Radiatsionnoe nasledie kholodnoi voiny.*

150 Bradley, *Behind the Nuclear Curtain.*

151 Egorov, Radiation Legacy of the Soviet Nuclear Complex.

152 "Protokoll der Beratung der Vertreter der UdSSR, der VRP und der DDR über die Durchfahrt von TK-6-Aggregaten und Begleitwagen WS-TK-3 und WS-TK-4 über Schienenwege der VRP und der DDR," Brest, May 30, 1980, BArch DG 12/1021. The spent fuel was inserted into cylindrical steel canisters measuring 3.5 meters in height and 1.5 meters in diameter. Since the spent fuel emitted considerable decay heat, the canisters contained a system of cooling fins powered by electrical engines. As a disruption in the cooling could be disastrous, producing a core meltdown, the trains included a car loaded with emergency diesel generators. See Staatliche Zentrale für Strahlenschutz, "Konzeption zur Durchführung des Transports abgebrannter Kernbrennstoffkassetten des Kernkraftwerkes Rheinsberg" (undated), BArch DG 12/1021.

153 Kraemer (Ministry of Coal and Energy) to Minister Siebold, "Information zum Rücktransport von abgebrannten Kernbrennstoffkassetten aus dem KKW 'Bruno Leuschner'," March 1, 1979, BArch DG 12/1021.

154 Vl. Ehrenberger (Czechoslovak Minister of Fuel and Energy) to Klaus Siebold (East German Minister of Coal and Energy), January 26, 1979, BArch DG 12/1021.

155 "Information für Genossen Ziergiebel," Ministerium für Kohle und Energie, December 29, 1978, BArch DG 12/1021.

156 Dawson and Darst, "Meeting the Challenge"; Bradley, *Behind the Nuclear Curtain*; *Nucleonics Week* 9/80 cited in Bradley, *Behind the Nuclear Curtain*; N.G. Rybalskii (Minpriroda) to T.V. Zlotnikova (Deputat Gosduma), *O vvose radioaktivnykh otkhodov*, 1–3; "Information für Genossen Ziergiebel" (undated), BArch DG 12/1021. At Greifswald in the GDR the problem became acute in 1979, leading to a series of meetings between German and Soviet representatives, see "Protokol konsultatsii spetsialistov SSSR i GDR po voporsam stroitelstva dopolnitelnogo khranilishcha otrabotavshego topliva na AES 'Bruno Leuschner' i organizatsii transportirovki otrabotavshego topliva," Moscow, June 8, 1979, BArch DG 12/1021. The Soviets pointed to the ongoing construction of a similar storage facility in Bulgaria as a solution to be replicated at Greifswald.

157 Especially through Brezhnev's speech to the plenary of the Central Committee of the Communist Party in 1977. See how Minenergo reacted in RGAE, F.R-7964, op. 16, d. 2593 and F.R.-7964, op. 22, d. 68, l. 28 [1979]. In reaction to Brezhnev's directives, Minenergo head Neporozhnyi traveled to NPPs in Ukraine, especially Chernobyl, to increase the pace of construction. See ibid., l. 45–47, 89 and 145.

158 See "Information über Beschlüsse zur Sicherung des Kernkraftwerksprogramms der UdSSR bis 1985," February 8, 1982, BArch DG 12/951; Cf. I.S. Morokhov, "Atom i progress chelovechestva," *Pravda Ukrainy*, August 10, 1965.

159 Josephson writes that the plenary session of the Central Committee in December 1977, already mentioned, "seems to have led to the decision to put containment on the fifth Novovoronezh unit and all future VVERs." Josephson, *Red Atom,* 40.

160 This is nicely described in East German archival sources. See "Information für den Staatssekretär Genossen Mitzinger: Festlegung des Standortes für das Kernkraftwerk III," BArch DG 12, October 2, 1972.

161 "Atomnaya Energetika," *Pravda Ukrainy*, February 3, 1981.

162 "Wärmeversorgung der Kombinate Buna und Leuna aus Kernenergieanlagen im Prognosezeitraum 1980-2000," 1971, BArch DG 12/1046.

163 "Budushchee yadernoi energetiki," *Pravda Ukrainy*, September 30, 1971; Josephson, *Red Atom,* 41–43. For an account of the failed AST-500 project at Gorky, see Dawson, *Eco-Nationalism,* 101–102.

164 Gestwa, *Stalinsche Großbauten,* 23, 397, and 513–514; on Atommash see Josephson, *Red Atom,* 97–106, and Petrosyants et al., *Atomnaya nauka i tekhnika,* 98–101.

165 Gestwa similarly describes an "Ostwanderung" (movement eastwards) with regard to the expansion of Soviet hydropower: ibid., 34.

166 IAEA, *Nuclear Power Reactors in the World 2020*, 39.

167 Dawson, *Eco-Nationalism*, 131.

168 Minenergo Rossii, "O vklyuchenii Bashkirskoi AES v Generalnuyu skhemu razmeshcheniya obyektov elektroenergetiki do 2020 goda," June 17, 2010. The document is available at Agidel's official website, https://web.archive.org/web/20101120142949/http://www.adm-agidel.info/index/0-23.

169 "Tematicheskii plan proektno-izyskatelskikh rabot Moskovskogo proizvodstva instituta 'Gidroproekt' Minenergo SSSR na 1979 god," RGA Samara F.R-109 d. 1646.

170 RGA Samara, F.R-109, op. 1–6, d. 1353, l. 161; IAEA, *Nuclear Power Reactors in the World 1985,* 38.

171 IAEA, *Nuclear Power Reactors in the World 2020,* 39. The first reactor at Balakovo was connected to the grid for the first time in December 1985 and entered "commercial" operation in May 1986.

172 Gestwa, *Stalinsche Großbauten*, 28.

173 Paul Josephson writes that the site was picked by Eduard Mustafinov, the main engineer for the Armenian NPP mentioned in Chapter 5. "He chose the most economical location on the shores of the Tsimlianskoe reservoir, so as not to waste money on canals and on cooling ponds and towers (Josephson, *Red Atom,* 105).

174 Ibid., 104.

175 Cybriwsky, *Along Ukraine's River*, 31–36.

176 "Skorostnoi potok," *Pravda Ukrainy,* April 14, 1982.

177 Cf. Cybriwsky, *Along Ukraine's River,* 143–144.

178 Flade, *Energy Infrastructures in the Eastern Bloc*, 153.

179 Khandozhko, "How the 'Peaceful Atom' Did Not Come to Crimea"; Popov, "Krym i AES nesovmestimy!", 122–125.

180 Siebold to Neporozhny, October 8, 1971, BArch DG 12/951.

181 "Information für den Staatssekretär Genossen Mitzinger: Festlegung des Standortes für das Kernkraftwerk III," October 2, 1972, BArch DG 12.

182 Krause (East German Ministry of Coal and Energy) to Neporozhny (Soviet Minister of Energetics and Electrification), December 1, 1972, BArch DG 12/951; Heinze, Ministry of Coal and Energy (East Berlin), to N.N. Slyunkov, Deputy Chairman of Gosplan (Moscow), February 4, 1976. BArch Berlin, DG 12/931; "Protokoll über die Konsultation der Spezialisten der sowjetischen Seite und der DDR-Seite zur Frage der Projektierung des KKW Stendal," April 27, 1978, BArch DG 12/949.

183 For an account of Temelín's history, see Hummer, "Temelín: Das Kernkraftwerk an der Grenze."

184 Hristov, "The Communist Nuclear Era," 137–141.

185 Lithuanian Central State Archives (LCVA), R-182, op. 1, d. 2989, l. 76-113 [Minenergo SSSR and LSSR]; Gabaraev, "Uvazhaemye druz'ya i kollegi!," 17;

Shevaldin, "Etapy istorii Ignalinskoj AES," 135; IAEA, *Nuclear Power Reactors in the World 2020,* 50.

186 Saraev et al., "Obosnovanie proekta," 197; Alimov, "Fate of Southern Urals," https://bellona.org/news/nuclear-issues/nuclear-russia/2008-08-fate-of-southern-urals-nuclear-power-plant-to-be-decided-in-russia-supreme-court [2021-09-27]; Talypova, "Mirnyi atom," https://chel.aif.ru/society/science/1219825 [2021-09-27].

187 Storm and Kasperski, "Mono-Industrial Town," 37–42; Brown, *Plutopia*; cf. Högselius, *Die deutsch-deutsche Geschichte des Kernkraftwerkes Greifswald*.

188 Khandozhko, "Territoriya politicheskoi anomalii," 167, 172, and 176.

189 Sidorenko et al., "Standards for Safety," 285–290.

190 Cf. Guth, "Breeding Soviet Progress," 281, 304–307.

191 Since 1962, the full name of the institute was the All-Union Design, Survey, and Scientific Research Institute "Gidroproekt" of the order of Lenin in the name of S.Ya. Zhuk in the city of Moscow. See RGA Samara, F.R.-109, op. 1–6, front page.

192 For the case of the Kola NPP, see Frey, *Arktischer Heizraum*, 279–281.

193 RGA Samara, F.R-109, op. 1–6, d. 1087, l. 166; Dollezhal and Koryakin, "Some Aspects of Operation," 1205–1206; Timchenko, "Yuzhno-Ukrainskii Energokompleks," *Pravda Ukrainy,* January 14, 1981; Josephson, *Industrialized Nature,* 44. For the desolate situation of fish stocks in Soviet rivers, see Gestwa, *Stalinsche Großbauten*, 522–527.

194 Cf. Gestwa, *Stalinsche Großbauten*, 18, on the perceived progressiveness of hydropower, which here is supposed to be linked with the nimbus of nuclear energy.

195 Gestwa, *Stalinsche Großbauten*, 250.

196 Cf. "Atomnaya Energetika," *Pravda Ukrainy*, February 3, 1981.

197 Timchenko, "Yuzhno-Ukrainskii Energokompleks," *Pravda Ukrainy,* January 14, 1981.

198 RGA Samara, F.R-109, op. 1–6, d. 924, (12.01.1971–31.03.1971): Gidroproekt, "Protokoly zasedanniy sektsiy Tekhnicheskogo soveta instituta," l. 60–66; RGA Samara, F.R-109, op. 1–6, d. 924, l. 85 (translation by the authors). See also Ministerstvo Energetiki i Ugolnoi Promyshlennosti Ukrainy, *Otsenka vozdeistviya,* 11–12.

199 Rabusic, "Vodni hospodarstvi jaderne elektrarny Dukovany," 20–26; Skokan, "Construction of Dukovany Nuclear Power Station," 51–55.

200 Szulecki et al., *Chernobyl Effect,* 80.

201 Dollezhal, *U istokov rukotvornogo mira*, 234–236; I.S. Morokhov, "Atom i progress chelovechestva," *Pravda Ukrainy*, August 10, 1965.

202 Dollezhal and Koryakin, "Nuclear Power Engineering," 37.

203 Tchalakov et al., "Bulgarian Power Relations," 131–156.

204 Hristov, "Communist Nuclear Era," 136.

205 Mitzinger, "Probleme zur Beratung mit dem Genossen Akopjan," February 12, 1982, BArch DG 12/949; Gärtner, "Reisebericht über die durchgeführte

Dienstreise nach Moskau und Saporoshje vom 28.9 –2.10.1981." BArch DG 12/949. The East Germans also hoped to be able to follow a similar model of knowledge transfer in the case of nuclear heating plants.

206 The costs of building Khmelnytskyi NPP were to be shared by the participating states in exchange for 20 years of electricity deliveries. After the dissolution of the USSR, however, independent Ukraine did not adhere to its part of the deal. Electricity supply to Rzeszów was canceled in 1992, as Poland synchronized its grid with that of Czechoslovakia, Hungary, and continental Western Europe—excluding the former Soviet republic Belarus, and Russia. Ukraine resumed the export of 215 MWe from Khmelnytskyi NPP to Rzeszów only in March 2022, as a means of infrastructural integration with the European Union in the early phase of Russia's invasion of the country. See UkraineInvest. "NPC Ukrenergo works on increasing electricity export to Poland," https://ukraineinvest.gov.ua/news/17-08-22-2/ [2023-05-10].

207 Flade, *Energy Infrastructures in the Eastern Bloc,* 152.

208 Lederman, "Safety of RMBK Reactors."

209 Högselius, "Connecting East and West?"

210 Högselius et al., *Europe's Infrastructure Transition*, 93–94.

211 Tchalakov et al., "Bulgarian Power Relations"; Flade, *Energy Infrastructures in the Eastern Bloc,* 152–153; Timchenko, "Yuzhno-Ukrainskii Energokompleks," *Pravda Ukrainy,* January 14, 1981; Högselius et al., *Europe's Infrastructure Transition,* 93–94.

212 Perera, *Nuclear Industry in the Former Soviet Union*; Lazarev, "Pererabotka yadernogo topliva."

213 Lazarev, "Pererabotka yadernogo topliva."

214 See, in particular, Brown, *Manual for Survival.*

215 Medvedev, *The Legacy of Chernobyl,* 1; Medwedew, *Verbrannte Seelen,* 28–29; Joint Norwegian-Russian Expert Group, *Techa and Mayak*; Bellona, *Beloyarsk Nuclear Power Plant,* https://bellona.org/news/nuclear-issues/nuclear-russia/1999-12-beloyarsk-nuclear-power-plant [2021-09-28]; Schoenfeld, *Rad Storm Rising,* https://www.theatlantic.com/magazine/archive/1990/12/rad-storm-rising/306380/ [2021-09-28]; Higginbotham, *Midnight in Chernobyl,* 69–71.

216 The best study of mobilization against nuclear energy in the aftermath of Chernobyl is Jane Dawson's book *Eco-Nationalism: Anti-Nuclear Activism and National Identity in Russian, Lithuania, and Ukraine*.

217 Uoker, "Uglublyat vzaimodeistvie v oblasti yadernoi energetiki," *Pravda Ukrainy*, December 19, 1986.

218 IAEA, *Nuclear Power Reactors in the World 2020*, 50.

219 Dawson, *Eco-Nationalism*; Högselius, "Connecting East and West," 252–253.

220 Dawson, *Eco-Nationalism*, 132.

221 The VPBER-600 was a reactor design featuring a water-moderated and water-cooled setup, which can be interpreted as a reaction to Chernobyl in terms of safety features. For more information on this unusual reactor type, see Glinskikh, *AS novogo pokoleniya*; Dollezhal, *Pervym vsegda trudnee*, 37.

222 Popov, "Krym AES nesovmestimy!," 122–126. Popov writes that Lenin supposedly said, in 1920, that Crimea should become a sanatorium, which yielded weight to the protester's cause within the Soviet ideological framework.
223 Ibid., 126–127.
224 The ruins of the NPP became host to the Kazantip Festival, which took place between 1992 and 2013 in a village near Shchelkino. Cf. Jobst, *Geschichte der Krim*, 13–33, 149, 227, and 307; Uekötter, *Ökologische Erinnerungsorte.*
225 Dawson, *Eco-Nationalism,* 83–98.
226 World Nuclear Association, "Nuclear Power in Armenia."
227 Szulecki et al., *Chernobyl Effect*.
228 Hristov, "Communist Nuclear Era," 140–141.
229 Szolnoky and Raum, "Regulation of the Thermal Loading by Paks Nuclear Power Station."
230 Hummer, "Temelín: Das Kernkraftwerk an der Grenze."
231 *Nuclear renaissance* is a term coined in the early 2000s to describe a new boom in the nuclear industry. See for example Darst and Dawson, "Waiting for the Nuclear Renaissance," 49–82.
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234 Hummer, "Temelín: Das Kernkraftwerk an der Grenze."
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240 Kuznetsov and Nazarov, *Radiatsionnoe nasledie kholodnoi voiny*.
241 Perera, *Nuclear Industry in the Former Soviet Union.*
242 Joint Norwegian-Russian Expert Group, *Techa and Mayak*; Saraev et al., *Obosnovanie proekta*, 197; Alimov, *Fate of Southern Urals*, https://bellona.org/news/nuclear-issues/nuclear-russia/2008-08-fate-of-southern-urals-nuclear-power-plant-to-be-decided-in-russia-supreme-court [2021-09-27]; Talypova, *Mirnyi atom,* https://chel.aif.ru/society/science/1219825 [2021-09-27].
243 Kudrik et al., *Russian Nuclear Industry*; Joint Norwegian-Russian Expert Group, *Techa and Mayak.*
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