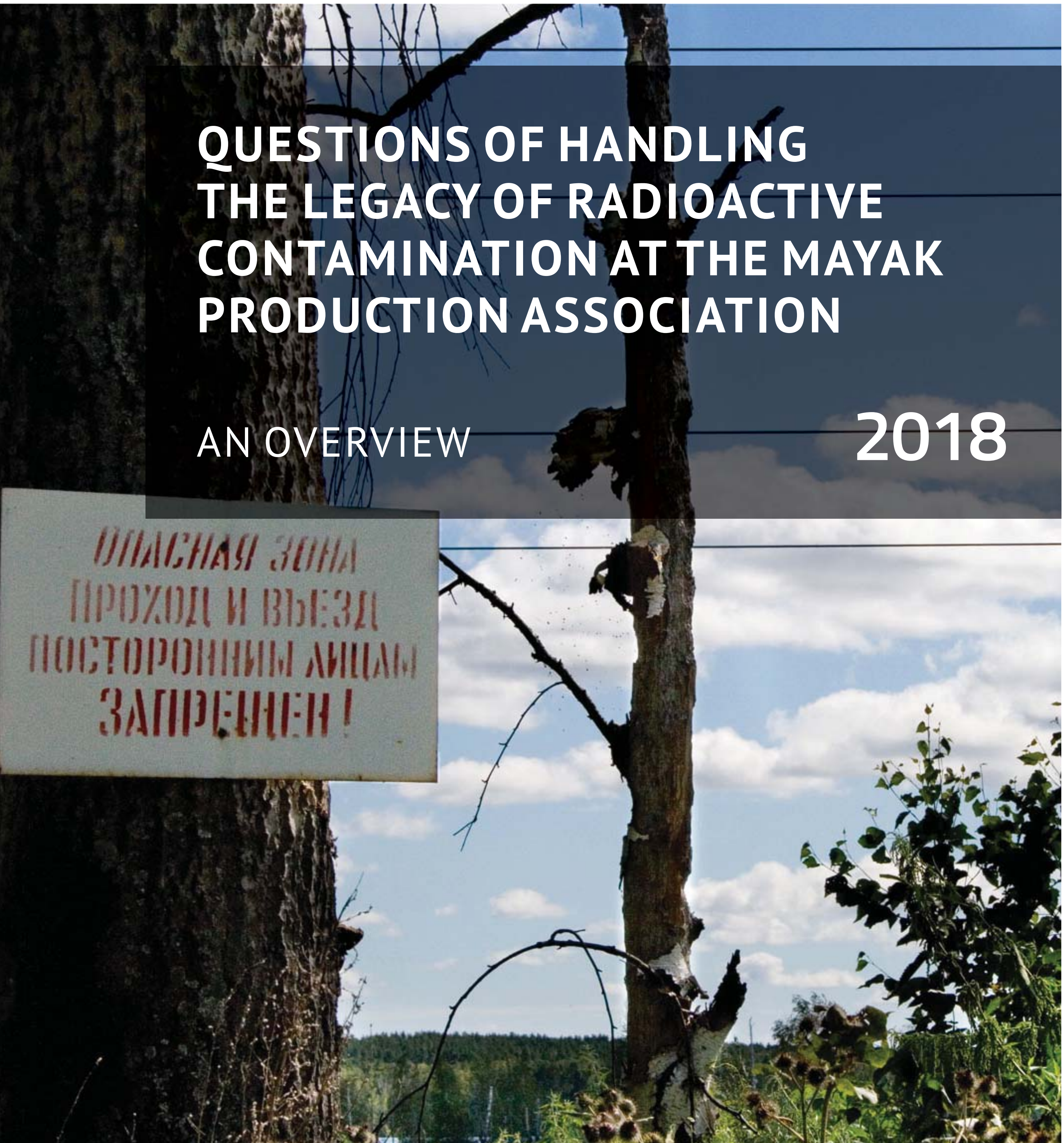
BELLONA

QUESTIONS OF HANDLING THE LEGACY OF RADIOACTIVE CONTAMINATION AT THE MAYAK PRODUCTION ASSOCIATION

AN OVERVIEW

2018



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1. Introduction

It's never been easy to pin down exactly what's going on at the Mayak Production Association, Russia's largest nuclear reprocessing center, and the home of the Soviet atomic bomb.

But doing so has come to be more important as Mayak begins to play a more central role in helping dispose of some of the Russia's oldest and most vexing nuclear problems — work which foreign governments, including Norway's, have helped to finance.

What is publicly known of Mayak, however, remains relatively obscure for the important place it occupies in Russia's nuclear industry. Much of that owes to the fact that the city that hosts it is still closed to foreigners, and is only accessible to Russian citizens by special pass. But Mayak's troubling history of accidents and environmental contamination demands that more be revealed about its daily operations – particularly when the Russian nuclear industry is making some efforts to redress that history.

At present, there are two longstanding issues that technicians at Mayak are working to solve. The first is how to ameliorate the facility's legacy of dumping nuclear waste into the Techa River Cascade, which has exposed thousands of Russians to radioactive strontium 90 contamination since the early 1950s. The second is how the facility intends to decommission five shut down nuclear weapons production reactors and isolate their radioactive innards from the environment.

In this paper, Bellona examines each case separately — in one case based on available environmental impact study documents released at a public hearing, and on the other, based on details of a what is called a Strategic Master Plan for decontamination.

In both cases, however, the attempts to grapple with these issues are insufficient, and both of the proposed solutions seem to be asking the public to leave well enough alone. In the instance of the reactor decommissioning, the documents made public elude several important matters of how the reactors will, in fact, be made safe, and gloss over rudimentary details that should be included in any efforts of their magnitude. Relative to reversing the over half-century of radioactive pollution that Mayak unleashed into the Techa River, the proposed solution seems to be that of literally doing nothing, and hoping that highly active radionuclides baked into the river's bed and banks will, over the next 150 years or so, become less active.

In both cases, this is far less than the local public, which has long suffered from health and environmental degradation caused by Mayak, deserves to hear. It is the hope of this paper that, by examining the deficiencies in the proposals to both plans, we might encourage officials to revise them.

A brief history of Mayak

It could be suggested that Mayak's incomplete plans to deal with its environmental difficulties are rooted in its history — for most of which it has never had to explain much of anything to the public.

The Mayak site was built in secret in 1948 by a government bureaucracy that itself had a name meant to obscure the reason for its own existence: The First Chief Directorate. Years later, elements of this directorate would

form the basis of the Ministry of Atomic Energy, which earlier this century was again renamed as Rosatom.

Even Mayak's original location had an anonymous ring. The area where it was built was first referred to as Industrial Complex No 817 until that, too, was modified to the sort of name-number combination the Soviets assigned to their closed nuclear cities: Chelyabinsk 65.

Chelyabinsk 65 became one of several closed Soviet towns devoted to producing plutonium and tritium as well fabricating warhead components from highly enriched uranium, or HEU and plutonium. It was, in fact, plutonium produced at Mayak that fueled the first Soviet atomic bomb, which was detonated in 1949. By the end of the Cold War, five plutonium production reactors, five tritium production reactors, numerous reprocessing plants and a plutonium metallurgy plant were operating in the closed city.

As of now, only Mayak's Plant 20 is involved in producing fissile materials for the Russian nuclear weapons program –though officials have reportedly discussed moving that to the the closed nuclear city of Seversk, which houses the Siberian Chemical Combine. The two still-functioning reactors at Mayak are called Ruslan and Lyudmila, and they are primarily involved in producing various isotopes. They nevertheless maintain some tritium producing capabilities. Mayak is also involved in storing HEU and plutonium and in dismantling the fissile components of nuclear bombs.

Mayak has also been involved in helping facilitate several important environmental initiatives and multilateral disarmament agreements. It was Mayak that received the spent nuclear fuel from hundreds of decommissioned nuclear submarines, which, at the end of the Cold War and through the 1990s, posed profound environmental threats. Mayak was also responsible for converting weapons grade high enriched uranium, or HEU, to low enriched uranium, or LEU, under the US-Russian Megatons to Megawatts disarmament program.

On the civilian side, Mayak works with separating and storing numerous kinds of spent nuclear fuel, including fuel from Russia's fleet of VVER reactor series, as well as spent fuel from reactors the Soviet Union built abroad — which arrives at Mayak under the Russian Reactor Fuel Return Program. It also maintains a facility for producing mixed oxide, or MOX fuel, for Russia's BN-600 fast neutron reactor in Beloyarsk.

The world's first industrial nuclear accident

By now, Chelyabinsk 65's Cold War nomenclature has been stripped away, and the town is now known as Ozersk, located 100 kilometers northwest of Chelyabinsk, the administrative center of the Southern Urals region. But even the very location of Mayak has been the source of official misdirection.

In 1957, a tank containing nuclear weapons waste on the premises of Mayak exploded. The fallout spread over some 200 towns in the Southern Urals region and eventually forced the evacuation of 272,000 people. But in the beginning, Russian citizens weren't even told where the accident happened, or how dangerous it was. That information came to light only in the 1980s.

At the time, however, Russian officials blamed the catastrophe on a coal boiler explosion, not in Chelyabinsk 65, but somewhere else — a nearby village called Kyshtym. A frightened post-war population of mostly women and children were assembled to manage cleanup and were given mops and rags — and little protective gear – to sop up radioactive ash. The accident would later rate as a "6" on the International Nuclear Event Scale — a score achieved since by only Chernobyl and Fukushima. The world's first industrial-scale nuclear accident is still know today as the "Kyshtym Disaster" – a nod to the Soviet-era misinformation.

Decades of contaminating the Techa River

But a slower-motion catastrophe has been unfolding at Mayak that dates back to before the Kyshtym disaster. Staring as far back as 1950, the facility dumped largely untreated liquid radioactive waste into the Techa River – a tributary of the Tobol River, which empties into the Arctic Ocean.

Russian regulators say the plant stopped its dumps in 2004 – after a lawsuit and criminal charges unseated the facility's then-director. But various environmental groups have since questioned that claim. Rosatom, however, has repeatedly denied these assertions, saying radiation levels in the Techa River now correspond to environmental guidelines.

Still, to follow the river's northerly flow is to draw a map of mortality and disease: record rates of chromosomal abnormalities, birth defects and cancers vastly higher than the Russian average mark each new village it passes.

It was only in 2008 – more than a half a century after the dumps began – that Rosatom undertook to evacuate some of the rural villages supping on this radioactive bilge. But only partially.

The population of Muslyumovo, the village long bearing the brunt of the contamination, was resettled only two kilometers upriver. The town's people were issued cards identifying them as residents of an irradiated zone, which entitled them to certain government benefits. But claiming those benefits often begets yet more red tape.

But many residents of Muslyumovo were prevented from moving. When the time for resettlement came, some officials in the bureaucracy took issue with their paperwork or their medical records.

Yet others decided to stay put on their own. Abandoning homes their families had lived in for generations in exchange for small resettlement funds – only to rebuild in small state-furnished apartments – struck many as a poor trade. Yet regardless of where they choose to live, the residents of Muslyumovo continue to receive visits from medical officials, who keep records of their illness and decay.

Among those who live along the river, the doctors say, cancer is present at rates 3.6 times higher than the national average. They suffer 25 times more from incidence of birth defects than in other places in the country. Miscarriages continue to climb, and children carried to term are born with malformed limbs and organs. Many of the remaining adults suffer from lymph node swelling so severe that their words are unintelligible to visiting physicians. The strontium 90 flowing through the river, doctors have concluded, has settled into the population's bones.

It is this breathtaking history of contamination that the Russian nuclear industry is now seeking to partially redress. In the following chapters, this report will present suggestions on the most recent plan the government has devised to deal with this issue.

Isolating plutonium production reactors from the environment

Mayak was first and foremost a weapons production facility, and in the high pressure race to produce a nuclear weapons, a series of graphite moderated production reactors were built in haste at the site to produce weapons grade plutonium.

The first of these was called simply Reactor A. Reactor A began producing plutonium in 1948, and, driven by the winds of an arms race with the United States and Great Britain, the Soviets would, by 1952, build four more graphite moderated production reactors, known as reactors AV-1, AV-2, AV-3 and AI.

The reactors, which in many ways resemble Russia's line of RBMK commercial reactors, all ceased operation by 1990 as the arms race began to bankrupt the Soviet Union. But it is their shutdown that now requires Mayak to undertake yet another first: The dismantlement and safe handling of graphite moderated weapons reactors – something that has only been achieved, with limited success, by Moscow's old Cold War foes.

To be fair, this dismantlement process in the US and UK hasn't been characterized by an abundance of transparency, skill or a full apprehension of the project's impact on the civilian public. Decommissioning work at Washington States Hanford Site, for instance, which produced plutonium for the Manhattan Project, remains a continual blight on the local environment and an evolving headache for the US Department of Energy. Even by the most optimistic estimations, bring the radiation at the Hanford Site to heel is expected to take until 2060, at a cost topping $100 billion –– even as decommissioning work there began as long ago as 1989.

But what has been made public about the process at Mayak is worrying. In public hearings in May of 2018 — hearings that confined to those who lived within the closed city of Ozersk — Mayak provided a look at what it plans to do with its own weapons production reactors.

But the plans, as outlined in a sparse, short preliminary environmental impact study, show that Rosatom hasn't considered the matter as thoroughly as it should. In the following chapters we will examine how Mayak plans to isolate these reactors — which are expected to remain radioactive for thousands of years – from the environment. Granted, no nuclear-armed nation has yet developed a fool-proof plan to cope with reactors like these. Buy by pointing out the blind spots in the Russian government's proposal, we hope to improve the results.

2. An analysis of proposals to decontaminate the Techa River Cascade

In March 2003, the president of Russia issued instructions to develop a set of additional measures aimed at preventing an environmental disaster at the Techa River Cascade. The appearance of this document was preceded by events that resulted in monitoring, which was performed on the river in 2002. This monitoring indicated that the annual concentration of Strontium 90 in river water near the village of Muslyumovo exceeded established limits by 5.7 times. The situation around the Techa River Cascade caused concern not only among the Russian public, but among law enforcement agencies as well. In 2005, a criminal case was initiated against the director of the Mayak Chemical Combine under article 246 of the Criminal Code of the Russian Federation, which deals with violations of environmental protection regulations.

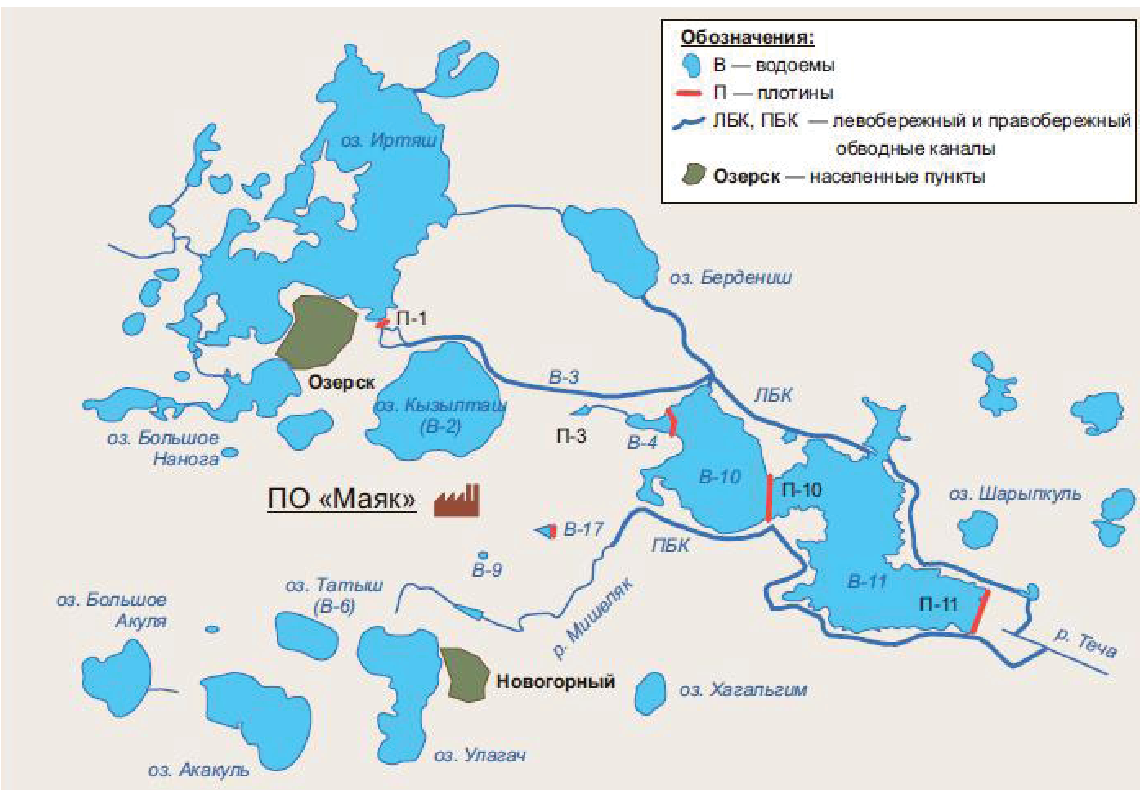

Figure 1 Flood zones in the even of an accident

According to the results of the monitoring, some 360 million cubic meters of radioactive waste have accumulated in the Techa River Cascade. The alarm provoked all levels was caused not only by the amount of radioactive waste and the increased concentration of radionuclides in the reservoirs of the Techa River Cascade, but also the high probability that this contaminated water could overrun the P-11 dam, which was designed to hold back water stored in the B-11 reservoir along the Techa River. If this should occur, some 30 thousand hectares of the territory (10 thousand hectares of forest and 20 thousand hectares of farmland) and 200 km of roads would be threatened by flooding (see figure. 2).

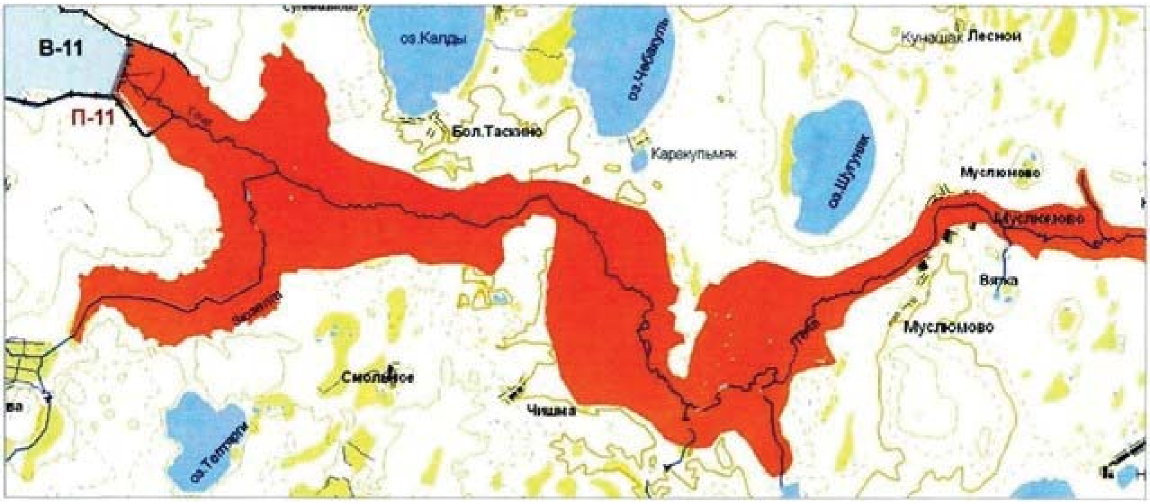

Figure 2

In addition, about 62 000 people living in this area would fall into the flood zone. The cost of eliminating such an accident would exceed 10 billion rubles. Therefore, after the President's instructions were issued, a comprehensive plan of measures was developed to solve environmental problems related to the current and past activities of the Mayak Production Association.

The main thing in this regard was the fortification of the P-11 dam. An impervious curtain, which provided a sort of underground wall, was constructed between 2005 and 2007, which ensured the dam's stability and reduced the likelihood of its collapse in the near-term. (see Fig. 3).

In addition, additional installations for cleaning liquid radioactive waste were installed, as well as the first and second stages of the common drainage system.

Despite these measures, problems remained within this strategic plan, leaving the following important issues unresolved:

- The legal status of the Techa River Cascade has not been determined;

- Significant uncertainties remained regarding the water balance of the Techa River Cascade, both the mutual influence of its elements, and its "reaction" to external influences;

- The operating regulations did not provide for the management of the water level and the intake of radionuclides into the Techa River;

- The possibility of self-purification of water was not considered even in the long term;

- The prospects for the Mayak Chemical Combine's production sites were not evaluated in conjunction with the operation of the Techa River Cascade.

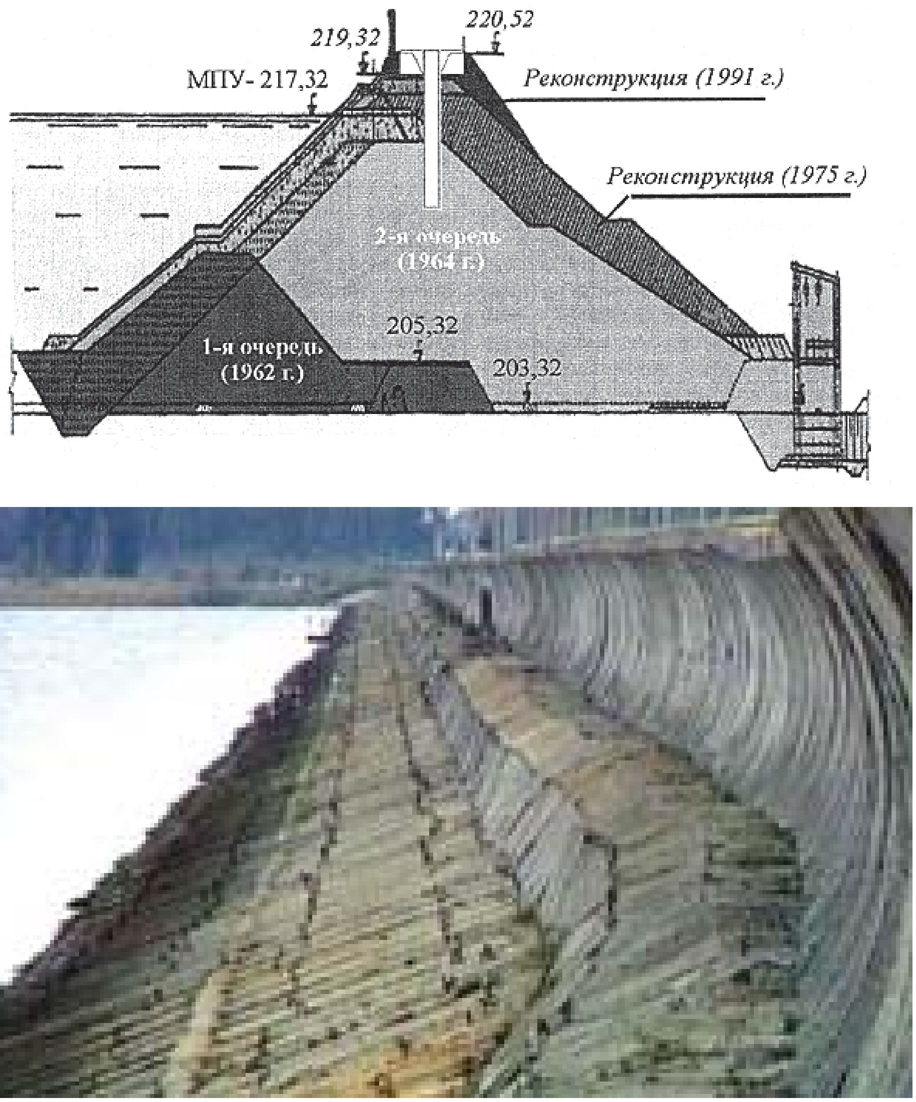

Figure 3

To conclusively solve the above issues, a broad analysis was required. This analysis took the form of a Federal Target Program for Nuclear and Radiation Safety for 2008 to 2015, which led to the adoption of a so-called Strategic Master Plan to deal with the issues presented by the Techa River Cascade.

The ultimate goal of this Master Plan was the development of strategies to ensure the long-term safety of the Techa River Cascade, as well as organizational and technical measures for monitoring.

In 2015, the development of the Strategic Master Plan was completed, and in 2016 it was approved by the general director of Rosatom. Prior to this, the Master Plan was brought up for limited discussion among interested parties, including the Public Council of the State Corporation Rosatom. The document was not submitted for public review.

Results, forecasts, and proposals for the Strategic Master Plan

The plan proposed developing a legal status for the Techa River Cascade, which would operate on the same principles that allow radioactive waste to be classified as "special" – a procedure provided by the Russian law on radioactive waste management. At present, the Techa River Cascade is defined as an installation that is used in producing nuclear energy, and its B-10, B-11, B-3 and B-4 reservoirs are classified as sites used for the disposal of radioactive waste.

The Master Plan further assumes that these four reservoirs could be re-categorized as conservation points for special radioactive waste by the year 2040. From that year until about 2170, the water in the cascade, as well as the bottom sediments, would be purified naturally as the radionuclides decayed by themselves. Thus, by 2200, the reservoirs could be removed from regulatory control and re-categorized as permanent disposal sites for radioactive waste.

According to the Master Plan, the B-3 and B-4 reservoirs would become swamplands between 2040 and 2170, and would be reclassified as permanent disposal sites for radioactive waste. (see figure 4)

Developing legas status of Techa reservoirs

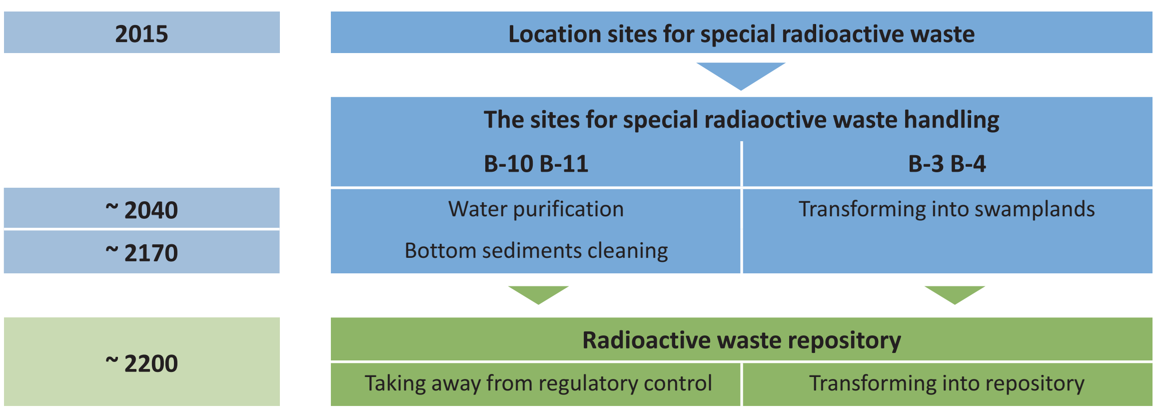

Figure 4

The Master Plan further presents a priority strategy that envisions the conditions for the self-purification of the Techa River Cascade's waters bodies, including the Techa River.

In order for this to occur, however, a number of other things must happen first. Chief among these is stopping the discharge of liquid radioactive waste into the Techa River Cascade. Next, the cascade's hydrotechnical system must be upgraded to cope with water levels in reservoir B-11. Current calculations indicate it would take about 180 years to implement this strategy. This accounts for the time it takes for radionuclides to decay naturally, and water bodies where radionuclides remain would be reclassified as radioactive waste disposal facilities. According to forecasts outlined by the strategy the water in reservoir in the reservoirs would be cleansed for various periods of time until they are no longer considered liquid radioactive waste: the B-3 reservoir for 15 years; the B-4 for 25 years; the B-10 for 30 years, and the B-11 for 20 years. Likewise, the bottom sediments of these reservoirs would be cleansed until they are not considered solid radioactive waste for the following periods: the B-3 and B-4 reservoirs for 370 years; the B-10 reservoir for 170 years, and the B-11 reservoir for 120 years. The cost of implementing this strategy is about 4.2 billion rubles, which must be invested by 2090.

The strategic Master Plan considered two additional alternatives. The first suggested using different technologies for purifying the water in the Techa River Cascade, such as hydro-wave, electro-sorption, sorption-filtration and sorbent (slag dump) technologies. The second one took into account the possible construction of a 2400 megawatt nuclear power plant in the area. The cost of the cleansing strategies would be approximately 12.3 billion rubles, and strategies using nuclear power plant closer to 170 billion rubles, excluding profits from the sale of electricity. The first strategy is more economically appealing. The only advantage of the second is that it might solve the issue of cleansing the Techa River Cascade within a shorter timeframe. (see Figure 5).

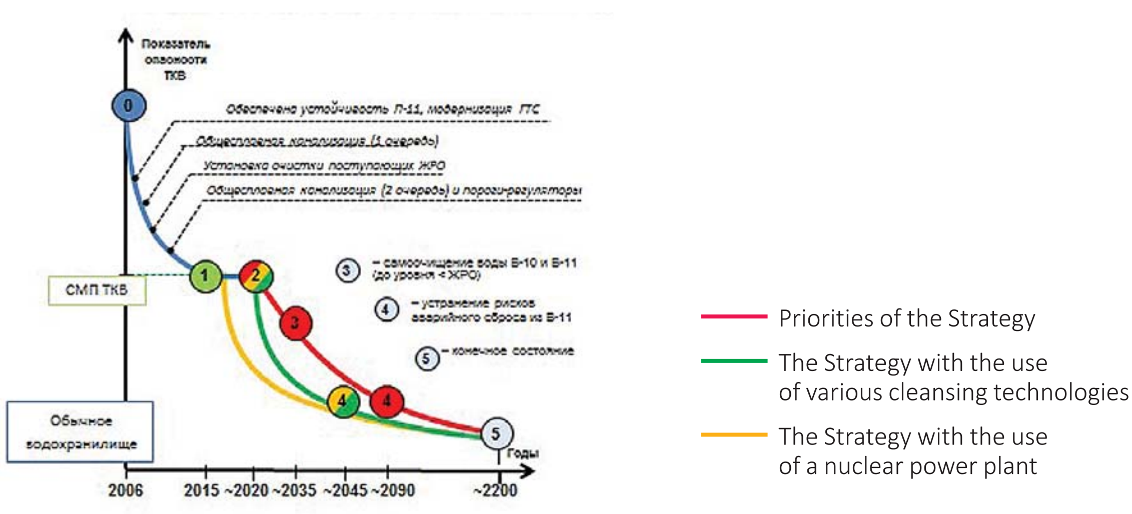

Figure 5

Yet the question of the next steps in solving the Techa River Cascade's problems has not yet been answered. So far it appears that those developing the Strategic Master Plan have presented solutions that catapult us forward 100 to 150 years, absolving us of taking concrete steps in the present. The recommendations seem to suggest that if we just wait a century and a half, the problems will simply sort themselves out. These recommendations aren't likely to please the public. Therefore, in the near future, it will be necessary to get a better look at the roadmap for implementing these strategies so we can get a better idea of the time frame in which these recommended measures will be implemented.

3. An analysis of plans to isolate Mayak's graphite moderated plutonium production reactors from the environment

The Mayak Producton Association is examining the possibility of burying its graphite moderated plutonium production reactors, which ceased operation about 30 years ago. Yet the preliminary environmental impact assessment Mayak performed to assess this possibility runs merely 24 pages and doesn't provide ample information on whether this option of decommissioning these parts of Russia's nuclear legacy is valid.

In May 2018, Mayak held a public hearing in the closed city of Ozersk, to discuss the decommissioning work surrounding the reactors, which were built between 1948 and 1952 for the production of weapons-grade plutonium. The reactors were shut down between 1987 and 1990. According to guidelines form Rosatom, Russia's state nuclear corporation, the reactors are to be partially dismantled, but there are no plans to disassemble the graphite stacks of the reactors, nor will a number of other radioactive elements of the structures be broken down. What the public hearing addressed was the suggestion that these reactors simply be buried where they stand, a measure referred to as "isolation-in-place." Because the reactor cores are located beneath the earth's surface, this is prospect is technically achievable. But much of the reactors have degenerated into fragmentary radioactive waste, and the complete isolation of these elements cannot be achieved. This approach to decommissioning the reactors therefore raises many questions.

What are Graphite Uranium Production Reactors? Unfortunately the Environmental Impact Study presented at the public hearings lacks even an approximate description of the reactor's designs. Such information is necessary for an appropriate evaluation of the decommissioning project. Our own information on graphite moderated reactors, presented below, is drawn from open sources.

The world's first nuclear reactors — the Chicago Pile 1 in the US, and the F-1 research reactor in Russia — were built to designs similar to Mayak's five graphite moderated production reactors.

By this design, small cylindrical blocks of unenriched uranium metal were placed along grooves of chemically pure graphite bricks of various shapes. These reactors were of such low energy that they did't require cooling systems, and heat was carried out by air flow.

The next generation of reactors — the so called production reactors — was created to produce weapons grade plutonium. These were channel reactors run on thermal neutrons with a graphite moderator and a direct-flow water cooling system. These are what are commonly called graphite uranium production reactors.

The first such reactor in the Soviet Union was called reactor A. Reactor A had a thermal capacity of 100 MW, which was later increased to 900 MW, and was commissioned in Russia's Chelyabinsk Region by Igor Kurchatov, the father of the Soviet nuclear program, in May of 1948. It was this reactor that produced the plutonium for first Soviet nuclear, which was tested in September 1949.

Over the next four years reactors AV-1, AV-2, AV-3 and AI were built alongside reactor A in the area that is now the Mayak Production Association. The reactors' designs were similar, and we here offer information on reactor A as an example.

Reactor A's active zone comprises a collection of graphite bricks arranged cylindrically at a diameter and height of about 9 meters, and weighing about a thousand tons. The graphite stack is permeated with 1,124 aluminum alloy pipes, called process channels. The inside of the channels were loaded with nuclear fuel in the form of cylinder blocks, which were made of uranium metal packed into an aluminum alloy shell. At any given time there were about 15 tons of uranium in the reactor. Between the blocks and the walls of the technological channels was a gap to accommodate cooling water to remove heat produced by the chain reaction of the uranium fuel. A complex piping system accommodated the influx of cooling water to each channel and its subsequent discharge. Via specially laid underground tunnels – refereed to by technicians at Mayak as the "metro" tunnels – the water passed through the reactor core where it was heated to about 85 to 90 degrees celsius, and was then discharged into the nearest lake. This was known as the "direct cool" system. The graphite stacks also housed control and emergency protection channels to be used for emergency shutdowns.

Beneath the reactor at a depth of 50 meters is a discharge bunker filled with water. After uranium blocks spent several months in the reactors, they were dropped into the bunker, producing not only plutonium, but other dangerous fission products such as cesium, strontium, iodine, ruthenium, etc. In current times, such blocks would be classified as spent nuclear fuel, or SNF. But in the from the 1940s to the 1960s it was considered a product from which weapons grade plutonium was culled.

The reactor core was located a few meters below the surface of the earth and surrounded by biological protection in the form of heavy concrete and water tanks.

Is it possible to describe the decommissioning of five reactors in only 24 pages?

Because the reactors at the Mayak Production Association were used for military purposes, information about their current status and the work being done to decommission them is very scarce. The Closed Administrative Territorial of Ozersk — the closed city in which the Mayak Production Association is located — publicized on its website the preliminary Environmental Impact Assessment of the reactor dismantling project. It was titled: "Materials on environmental impact assessment of the proposed economic activity for decommissioning industrial the graphite moderated production reactors of the Mayak Production Unit A, AI, AB-1, AB-2 and AB-3. Hereafter the document will be referred to as the EIA.

Unfortunately, the EIA is very brief – only 24 pages. It is difficult to understand from it exactly what kind of decommissioning activity has already been carried out, what is planned to be done in the near future, how isolating the decommissioned reactors from the environment is to be achieved, what of the reactors remains to be removed, and how much radioactive waste will be amassed as a result of the decommissioning works. The document contains almost no technical information. It gives no description of the reactors and their status at the moment. But it does contain many declarations and peremptory statements about there being "no alternative" to burying the five reactors at the site. **"Final Isolation in place"** We will here quote a few passages of the EIA and analyze them in turn. *"At present, the Rosatom State Corporation has determined an option for decommissioning and has taken the decision* *to create a final isolation facility at the location of the decommissioned graphic moderated production rectors."* This method is called conservation. The EIA does not, however, say how and when the decision was made to employ the conservation mthod on the decommissioned reactors, and it is not known if this decision was discussed with the public.

"The decommissioning of Mayak's reactors is based on the final isolation-on-site option, which assumes that the reactors will be isolated without removing radioactive structural elements from the reactor shaft for reprocessing or further disposal. Localization of reactor equipment (including graphite masonry) will be carried out in reactor shafts. " The purpose of the planned activity is to ensure the safe decommissioning of Mayak's graphite moderated production reactors and to bring them into a radiation-safe state, to ensure reliable isolation of radioactive waste in the area of the reactor site, and to ensure the radiation safety of humans and the environment for the entire period of potential danger RW" (p. 4)

It should be noted here that the "radiation-safe "state of the reactor's graphite stacks cannot be achieved for thousands years due to the presence of the carbon 14 isotope within the reactors, the half-life of which is 5,730 years.

There is also the question of how the buried reactors will be classified when they are, in fact, buried. If they are to be considered permanently interred radioactive waste, then under current Russian legislation, future oversight of the reactors must be transferred to another Rosatom structure — the National Operator for Radioactive Waste handling, or NO RAO. But the EIA documents mention nothing about this. "*Isolation of the reactor's radioactive equipment will be carried out in the reactor's shaft without removing radioactively hazardous structural elements except for those that may adversely affect the reliability of safety barriers, or that would impede the execution of decommissioning work."* (p. 22)

The IEA documents make no mention of how many "radioactively hazardous structural elements" there, in fact, are in the reactors, or how many of them will have to be extracted. Obviously, these items would be categorized as radioactive waste, and their quantity is important for assessing what environmental impact the decommissioning project will have. Yet the EIA provides no such information.

"The safety of the isolation-in-place option is achieved by a variety of measures using existing protective barriers, as well as a number of new ones, to localize the reactor equipment and its graphic stack within the reactor shaft, ensuring reliable isolation of radioactively contaminated equipment and the structure of the graphite moderated production reactors, which will prevent unregulated (unpredictable) releases of radioactivity into the environment." (p. 6). This assertion needs at least some justification. Questions are raised about preventing the "unregulated (unpredictable) release of radioactive substances into the environment." Yet the EIA documents fail to explain what would constitute a regulated and predicable release.

Description of the planned decommissioning work is incomplete and fragmentary

The EIA documents present no information on what kind of conservation work will be carried out for each of the five graphite moderated production reactors. One of the sections of the EIA (pp. 16-18) makes some mention of conservation at reactor AV-1, but none of the other four are mentioned. The following is what the EIA reports as the to-do list for reactor AV-1:

"The process of decommissioning the graphite moderated production reactor will be carried out in stages: Stage 1. The first stage is preparation for decommissioning, which includes unloading fuel and bringing the reactor plant to a safe state. This will include an integrated engineering and radiation survey of the shutdown reactor, of which a report will be released. At present, the AV-1 is decommissioned, is in a state of long-term mothballing and is not a nuclear hazardous facility. At this time, this stage has been completed.

Stage 2. Stage two includes decommissioning at the reactor plant and outside the shaft of the reactor. At this stage, the following work is being performed: – preparation for the final isolation-on-the spot - Decontamination of the premises (if necessary); dismantling of equipment and systems located in the reactor building and on the site; – filling of the internal cavities of the reactor, the reactor shaft and the total structural volumes of the reactor building with absorbent and insulating materials up to ground level; – creation of an additional barrier in the form of an upper hermetic protective plate above the reactor shaft (if necessary); – bringing the existing storage facilities of radioactive waste located within the site of the AV-1 reactor to a radiation-safe state; – dismantling of buildings, structures and trench-type (soil) radioactive waste storage facilities.'

The EIA documents also briefly lists the work at the shutdown reactor that is already in progress:

"At the 2nd stage the following works are performed: – partial dismantling and removal of clean, low contaminated and low-active equipment and reactor systems with subsequent disposal of clean equipment (in progress); – removal, processing, conditioning, transportation and disposal of radioactive waste generated in the process of decommissioning, either in special storage facilities, or, after special preparation, as part of a "buried" facility (in progress); - localization of highly active equipment (including graphite masonry) within the reactor shaft by creating at-depth defenses that combine existing safety barriers and newly-created additional barriers (in progress)." The EIA documents make the following note of other work that remains to be done at the AV-1 (pp. 17-18): *"Reactor equipment remaining in the reactor shaft, including graphite masonry, must be reliably isolated from the environment by creating and strengthening protective barriers that reliably insulate reactor equipment: – The floor and walls of the reactor shaft are to be sealed by concrete; – all internal cavities of the reactor and the shaft are to be filled with bulk absorption waterproofing materials; – the external walls of the reactor shaft are to be insulated with a hermetic sealing of concrete;*

– The premises outside the reactor shaft are to be filled to ground level with clay containing materials, which will assure the safety of the reactor shaft's reinforced concrete walls, as well preserve the integrity of safety barriers inside the reactor shaft." As the EIA documents devote merely two pages to describing decommissioning activities, and refer only to those undertaken at the AV-1 reactor, its is exceedingly difficult to draw any conclusions regarding the safety of what is being proposed. Specifically, it's unclear how exactly technicians plan to fill "all internal cavities of the reactor and shaft" with waterproofing materials. The possibility if accomplishing this are doubtful.

For example, beneath each reactor is a so-called "Scheme P" which is effectively a picket fence of vertically installed hollow pipes, and which is so radioactive that human beings cannot work anywhere near it. It would be possible to dismantle the pipes and fill up the Scheme P area with barrier materials using robotic devices, but this, like dozens of other similar problems, is not mentioned the EIA documents. In the absence of robotic assistance, it can be assumed that any personnel from the Mayak Production Association who would work within this reactor space will receive significant doses of radiation.

Problems of graphite masonry and drainage tunnels Let us dwell here on two problems associated with particular design features of the graphite moderated production reactors — their graphite masonry and their drainage tunnels, which, it seems from the EIA documents, no one intends to seal at all. Compared to pressurized water reactors, such as the VVER type –

from which the main radioactive waste is the metal shell, the primary circuit pipelines, pumps and steam generators – graphite moderated reactors, both military production reactors as well as the RBMK line, create serious problems in decommissioning. This is because much of radioactive waste generated by these reactors is accounted for by their irradiated graphite masonry.

A report written by Dr. Oleg Muratov, Secretary of the Northwest Division of the Nuclear Society of Russia, wrote a 2014 report illustrating some of these dangers.

*"Irradiated graphite carries a potential hazard to humans and the environment due to the accumulation in it of long-lived genetically significant radionuclides — Carbon 14 (with a half-life of 5.73 * 103 years) Chlorine 36 (half-life of 3.01 * 105 years) and Hydrogen 3 (half-life of 12.3 years). Carbon 14, which contributes some 95 percent of the activity to graphite, and Hydrogen 3 are a part of almost all organic compounds, actively participate in the biological cycle, and cannot be removed from the human body. Therefore, when these isotopes enter the atmosphere, global pollution of the Earth's natural complexes will occur. In addition, fragmentation radionuclides like Cesium 317, Strontium 90 and Europium 154, which are formed as a result of coolant leaks, contribute to the radiation pollution of graphite."* The EIA doesn't mention the problems of the reactor's graphite stacks and their radionuclide composition at all. Dangerous radionuclides accumulated in graphite masonry can be released into the environment via the water table, which, at the location of Mayak's reactors, is located approximately 22 meters underground. This itself is a good deal higher than the reactors' discharge bunkers, which are located at 53 meters underground.

As groundwater enters the site of the buried reactor, it washes radionuclides that have accumulated in the graphite masonry into aquifers. To guarantee the watertightness of the buried reactors for thousands of years is problematic; it is especially so when we consider that the reactors were built in haste in the 1940s and 1950s at the dawn of the nuclear age. No studies on how the concrete meant to encase the reactors for their burial were offered in the EIA documents, including specific estimates concerning the erosion rate of the concrete and rate at which radionuclides could migrate from the buried reactors into water tables.

Other problems arise around the underground tunnels — referred to at the "metro" tunnels — that were used to drain cooling water from the reactor cores to the nearest reservoirs. If these tunnels are sealed with concrete or clay, it would prevent water drainage from the buried reactors should they flood with groundwater. Yet keeping the tunnels open for drainage purposes would thwart the very thing that the isolation-in-place burial plan is meant to prevent: The buried radioactive equipment and graphite masonry would be in constant contact with the environment thanks to water flushing through the pipes.

As illustrated by Dr Muratov, first generation reactors such as the ones at Mayak were not built with their eventual decommissioning in mind. The problems with the isolation-in-place method suggested for the five graphite moderated production reactors at Mayak are myriad. But it appears that Mayak officials would prefer not to discuss these issues with the public — which may account for why the IEA documents submitted for public discussion are so insufficient, and perhaps meant more for advertising purposed than serious consideration.

Doubts remain The authors of the EIA documents are categorical in their statement of intent: "*There is no doubt that safely decommissioning the graphite moderated production reactors at the Mayak Production Association, thus bringing them into a safe radioactive condition and isolating their radioactive waste within the existing industrial site and sanitary protection zone, is the most acceptable option from the point of view of minimizing and preventing negative environmental impacts.*" (p. 24)

Of course no one doubts that these old reactors should be safely decommissioned, just as there is no doubt that their radioactive waste should be reliably isolated from the environment for as long as it is dangerous. But these are only declarations. The question is whether what is desired can be achieved on more than paper. After reviewing the IEA documents, doubts remain over whether disposing of these reactors by burying them at their current location can provide safe and reliable isolation of their radioactive remains from the environment — especially since they contain isotopes that have a half life of 5,730 years.

Alternatives to the isolation-in-place method The EIA documents state that, "there are no real alternatives" to the isolation-in-place method of dealing with the decommissioned reactors, but this is not at all the case. Lithuania is currently endeavoring to decommission RBMK-style graphite moderated reactors, very similar in design to the graphite moderated production reactors, at its Ignalina nuclear power plant. Technicians there intend to completely disassemble the reactors – including the graphite stack. The resulting radioactive waste, including radioactive graphite, will be packed in containers and placed in near-surface radioactive waste disposal points. So as it turns out, there is a very concrete alternative to burying the old reactors at Mayak. Current Russian regulatory documents (specifically NP-007-17) even provide for complete dismantlement of graphite moderated reactors. This practice is called liquidation.

The US approach to decommissioning graphite moderated reactors is entirely different. The Hanford Site in Washington state has eight decommissioned uranium graphite moderated reactors that are of similar design to those at Mayak, which likewise began operations in the 1940s and 1950s. Most of these reactors ceased operations in the 1960s and early 1970s, with the last shutting down in 1987, and since have been decommissioned on a system that combines both immediate and deferred dismantlement. Burial of the reactors at the site has not been considered. Under the decommissioning framework, some 80 percent of the reactor buildings and related structures are dismantled, while some 20 percent of the reactors — including their cores — are enclosed in a so-called "cocoon." This cocoon is a hermetic steel and concrete shell, which allows ongoing access for technicians to inspect the state of protective barriers. After a period of 75 years, during which time it is expected that the radionuclides will disintegrate, the cocoons, as well as what remains of the reactors, will be disassembled. Currently, six reactors at the Hanford site — the C, D, DR, F, N, and H – have been mothballed under this scenario.

Inaction is not the best option Of course the "zero option" — that is the option of doing nothing — is unacceptable. Over the next century, the concrete and metal structures of the reactors will dangerously degrade. Groundwater and precipitation will begin to wash radionuclides out into the environment, causing not only contamination on the territory of the Mayak Production Association, but beyond, particularly the long-long-suffering lakes and rivers that surround it, including the Techa River.

Radiation hazards will be significantly reduced if the interred reactors are created as radioactive waste disposal facilities that meet the modern requirements of that designation. This would imply they be dismantled and their radioactive remains, including the graphite masonry, be placed in certified containers and sent to appropriate waste storage facilities. Unfortunately, the isolation-in-place option chosen by Rosatom is describe only very briefly by the EIA documents currently furnished, and doesn't provide ample information to assess the validity and engineering compatibility of the proposal. At this point, the question of which decommissioning option should be chosen is best left open.

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