# Radioactive waste management in the Russian nuclear development strategy: a view of the Kurchatov Institute

*A.Yu. Gagarinskiy*

National Research Centre „Kurchatov Institute“
1, Kurchatov sq., 123182 Moscow, Russia

**Abstract:**
This paper addresses the status and prospects of Russia’s radioactive waste management system. It discusses the country’s nuclear energy strategy adopted for the near term (to 2030), as well as the recently launched inception of a new technological line – closed fuel cycle with spent fuel reprocessing. A roadmap is provided for the fuel cycle back-end, including the facilities intended for final disposal of medium- and high-level waste. For the longer term, this paper outlines the “unique diversity” of reactor systems, which would determine the choice of future fuel cycle and waste management options.

## 1 STATUS OF THE RUSSIAN RADIOACTIVE WASTE MANAGEMENT SYSTEM

Russian environmentalists use to say – and they seem to be right – that nuclear industry in Russia (as well as in some other countries) was somewhat late with building a system of radioactive waste management. Even 25 years ago experts [1] have supposed the issues of nuclear fuel reprocessing and radioactive waste disposal to become pressing in the first decade of the new century – and to be solved-in-principle by then. As we now see, it was an obvious overstatement.

The policy of “postponed decisions” in the field of reprocessing and management of waste continued for many decades. As a result [2], the unavailability of regulatory framework respective to accumulated and newly-produced waste disposal, as well as of any incentives to minimize the amount of waste, have resulted in the current situation, when over 99% of all wastes are stored on the sites of their production. One-third of Russian regions host more than a thousand of so-called controlled temporary storages containing over a half billion cubic meters of waste with cumulative activity of roughly $10^{20}$ Bq [3], most of which comes from the past military programs.

In the same time, virtually all nuclear specialists agree that “there are no more unsolved problems in radioactive waste management – the only problem is cost” [2].

A breakthrough in eliminating the nuclear legacy of the Cold War has been achieved in the end of 1990ies with key decisions taken to dispose of the Russian Navy’s park of nuclear submarines formed by their mass withdrawal from operation. Impressive results have been achieved in the partnership with former Cold War adversaries initiated by the G8 at its Kananaskis Summit. By the beginning of 2013, almost all 198 decommissioned nuclear submarines have been defuelled and dismantled, and intensive work is underway to remove their nuclear fuel to PA Mayak. Long-term storages of submarine reactor compartments were deployed in the North and Far East of Russia. Construction of the Regional Radioactive Waste Management and Storage Center is nearing completion. All these activities are undoubtedly an outstanding example of international cooperation for the benefit of the whole global community [4]. It should be noted that all participants of this program acknowledge considerable scientific contribution provided by the Kurchatov Institute to support it.

"New" nuclear power development policy adopted by the Russian government in 2006 (with financing from the state budget re-opened for the first time since the USSR times) coupled with the works intensified on all fuel cycle stages, together have actually lead to a breakthrough in solving the issues of radioactive waste management.

Below follows the assessment of Russia's respective status based on the latest IAEA Nuclear Technology Review [5]. The country's government approved several fundamental documents on radioactive waste management to support activities in the field of nuclear energy, cleanup works, remediation of contaminated sites and the extraction and processing of mineral and organic materials with a high content of natural radionuclides. Work on the creation of radioactive waste disposal facilities has started. Design development is under way for the creation of an underground laboratory at the Nizhnekanskiy granitoid massif (at a depth of 500 m) in the Krasnoyarsk region, for research to be performed into the possibility of disposal of long-lived HLW (over $10^7$ kBq/kg for beta nuclides) and ILW ($10^3$–$10^7$ kBq/kg) on this site. In addition, preliminary design work (geological and engineering studies) has been done for a disposal facility for LLW (below $10^3$ kBq/kg) and short-lived ILW in the north-west of the Russian Federation. Phase I of the country's first commercial away-from-reactor dry storage facility began operation in 2011 on the Mining & Chemical Plant site, in Zheleznogorsk, Krasnoyarsk region. Several dozens of potential final disposal sites were also identified, in line with the decision to gradually withdraw from the practice of waste accumulation in temporary onsite storages.

The law "On Radioactive Waste Management" adopted after more than 10 years of development provides a regulatory framework for the unified national system of radioactive waste management. The Law applies to all radioactive waste types, including those generated by civil (which this paper deals with) and military uses of nuclear energy.

This law for the first time makes a distinction between two categories of waste: newly produced waste (whose reprocessing, conditioning and mandatory disposal are subject to strict requirements) and waste accumulated before the law came into force (this category allows "more flexible approach" [2]).

In particular, the law admits liquid radioactive waste disposal in deep underground layers, but limits it strictly to sites, which are already in operation (Seversk, Zheleznogorsk, Dimitrovgrad), where the total amount of accumulated waste exceeds 50 million cubic meters [3].

A dedicated company responsible for this final stage – national radioactive waste management operator, a subsidiary of Rosatom State Corporation – was established and made responsible for all waste disposal activities.

One can foresee many difficulties in implementing these decisions, including inevitable conflicts between local and national interests, but nevertheless, the results already achieved allow certain optimism, as concerns the future of radioactive waste issue, which (the future) largely depends on the nuclear power development strategy adopted by Russia.

## 2 RUSSIA'S NUCLEAR ENERGY STRATEGY: SHORT-TERM PROSPECTS

The energy strategy adopted by the Russian government considers nuclear energy though not a priority, but still an indispensable part of the country's energy mix for the foreseeable future.

In contrast to the global nuclear power output, which was decreasing over the last years, in Russia it is growing steadily, and this growth is supported by governmental plans and programs (Fig. 1).

The governmental program provides for the growth of the country's installed nuclear capacities to 50–60 GW by 2030. In the same period, Russia intends to build about 20 GW of nuclear capacities abroad.

These growth targets naturally involve considerable uncertainties and depend on old units' decommissioning time, nuclear machine-building capabilities, market conditions, etc. However, the essential idea [6] is that Russia, despite its huge hydrocarbon resources, is strategically interested in accelerated development of its nuclear power industry to assure its energy security, preserve and efficiently use its resources, and improve its opportunities in exporting natural gas and hi-tech machine-building products.

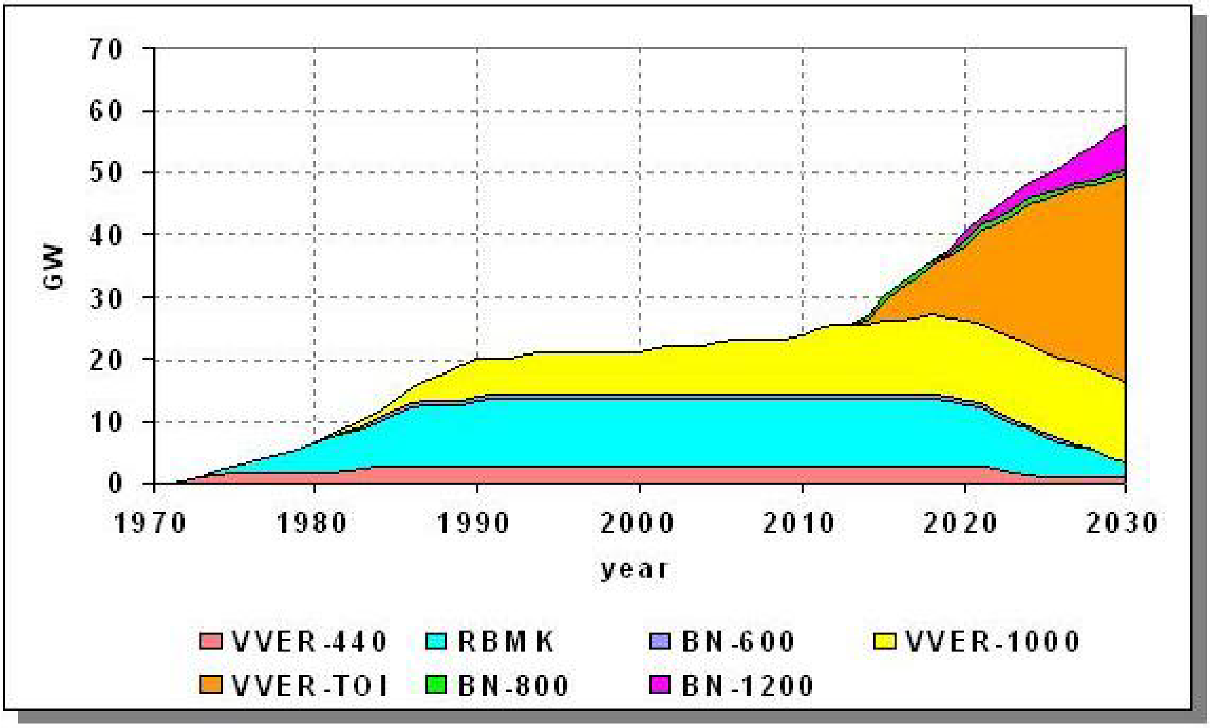


*Fig. 1. Installed nuclear capacities in Russia: Short-term perspective*

Currently the country is constructing nine large nuclear units and a floating nuclear power plant. Surveys are also underway on several potential sites. Russian nuclear specialists are in consensus about two basic provisions put forward by the Kurchatov Institute long ago:

- large-scale nuclear energy would inevitably involve the deployment of closed fuel cycle, including spent fuel reprocessing and safe disposal of radioactive waste;
- at the first stage (to ~2030), the only technology available as a basis for capacity growth would be pressurized water reactors (VVER). In this period, fast reactors could be present as a single unit – or, at best, a small series (BN-800 – BN-1200).

However, already at this stage, a bud of new technology should be gradually developed, with reactors using fuel of recycled U and Pu, as well as the corresponding pilot and industrial closed fuel cycle infrastructure. In this process, thermal and fast reactors are not to compete, but to complement each other's functions in energy generation and fuel breeding, with their optimal shares to be determined by economy and safety criteria. The estimated scale of nuclear energy sufficient to justify the fuel cycle closing from economic viewpoint is about 30 GW.

Today Russia has a nuclear fuel cycle, which is partially closed for uranium. RT-1 plant operating on PA Mayak site – Russia's only operating plant reprocessing spent fuel – jointly processes spent fuel from research reactors, VVERs-440, ship reactors and BN-600. Then the recovered U further goes to RBMK fuel fabrication, while the separated Pu is accumulated in stockpiles. In the last years the plant reprocesses about 70 tons of spent fuel per year.

In Zheleznogorsk, Mining & Chemical Plant – a recognized center of fuel cycle development in Russia – has extended its the centralized wet (pool-type) spent fuel storage facility and launched the first phase of a dry spent fuel storage with enough capacity to accommodate all RBMK spent fuel and some part of VVER spent fuel currently stored on NPP sites.

Basic milestones were identified for the fuel cycle back-end roadmap (Fig. 2), and their step-by-step implementation has already started.

Trial & Demonstration Centre (TDS) capable to reprocess 250 tHM of nuclear fuel annually is currently under construction on Zheleznogorsk Mining & Chemical Plant site. The key mission of this Center will be to develop new technologies of spent fuel reprocessing to the industrial level and to separate reusable fuel components in order to minimize the resulting amount of radioactive waste. The TDS is also intended to rehearse an advanced wet technology including gas purification ($^3$H etc.) at the initial process stage and generating considerably less intermediate- and low-level waste compared to traditional processes. The TDS will also include research chambers for innovative processes' testing (e.g., experiments with dry technologies) [7].

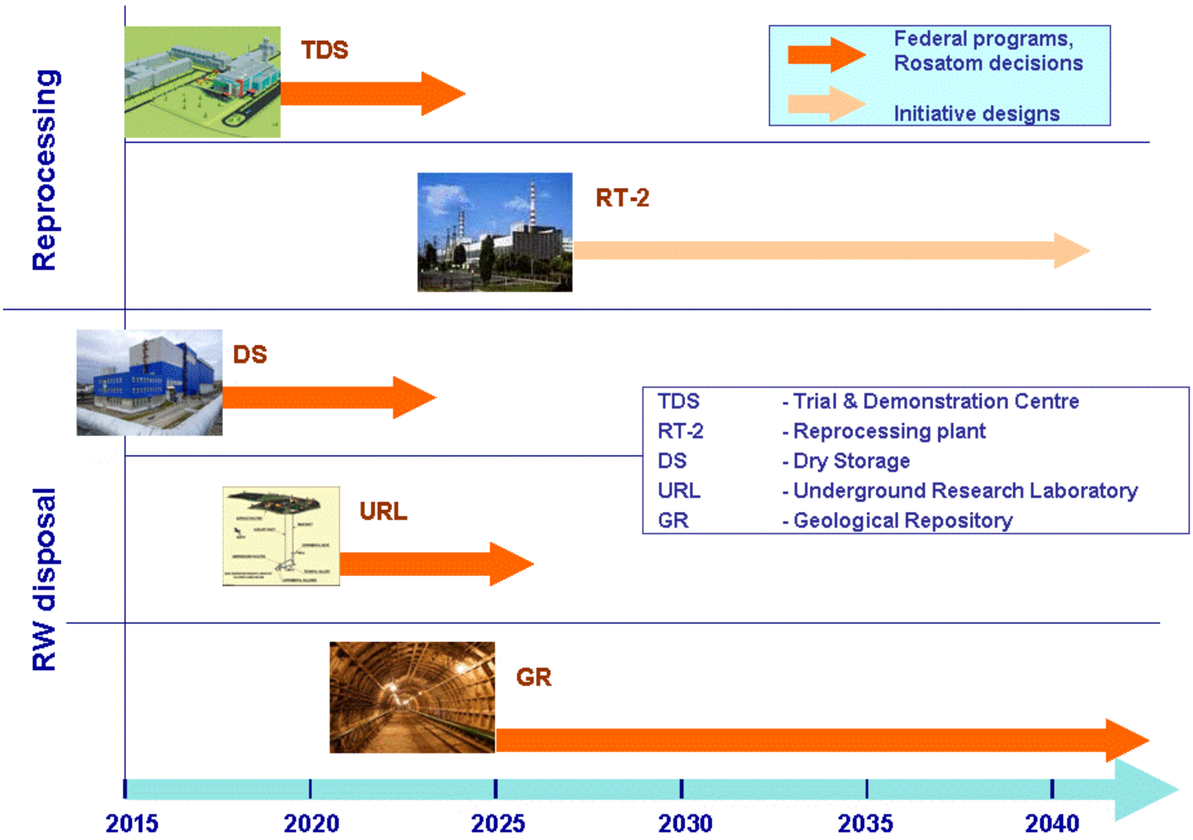


*Fig. 2. Nuclear fuel cycle back-end roadmap*

New industrial reprocessing technologies to be developed at TDS would create a basis for adopting the decision to build a large spent fuel reprocessing plant RT-2 with intended capacity of up to 1000 tons per year).

By today Russia has accumulated about 20 000 tons of spent nuclear fuel. If its accumulation continues within once-through cycle, by 2030 the amount of spent fuel in storage facilities may reach 25 000 tons. However, the optimistic scenario of implementation of the first fuel cycle closing stage provides for the amount of spent fuel in storages (with account of VVER-440 spent fuel reprocessing by RT-1) to start decreasing around 2025 (Fig. 3).

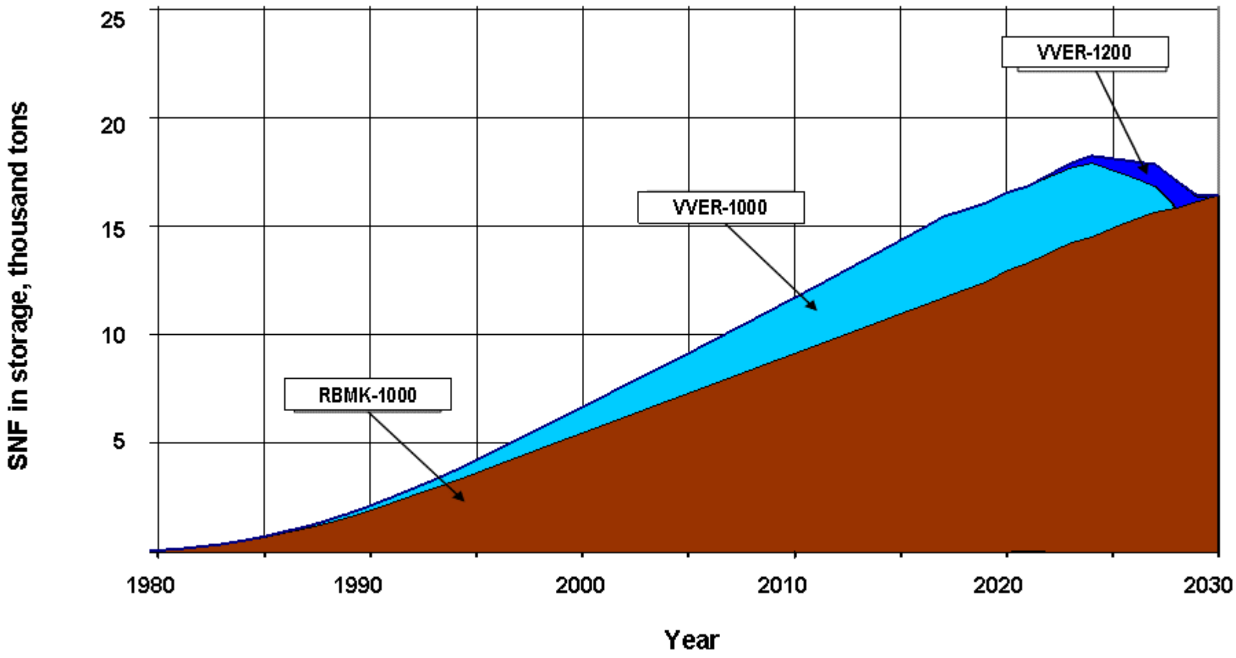


*Fig. 3. Accumulation of spent fuel in Russian storage facilities during the transition to nuclear fuel cycle closing*

In parallel with spent fuel reprocessing capacities' deployment, it will be necessary to solve the issue of reliable final isolation of high-level waste containing long-lived radionuclides.

For several years, surveys and exploratory works have been performed in geological formations suitable for hosting such final HLW repositories. A site was finally selected in the Nizhnekansk granitoid rock massif. Long-awaited construction of the underground research laboratory is expected to start there in 2016.

The studies to be performed by this underground laboratory are supposed to confirm, before 2025, that it would be safe to convert it into a geological repository, which, when in commercial operation, is expected to provide enough space for geological disposal of over 150 thousand $m^3$ of ILW and HLW and to be filled around the mid-century [8]. Last year this ambitious project was submitted for public hearings.

## 3 LONG-TERM PROSPECTS

Russian nuclear scientists are extensively discussing the way of future nuclear energy development after 2030 (polemics in the country's leading nuclear magazine *Atomnaya Energiya*, a series of scientific seminars organized by Rosatom, etc.). Position of the Kurchatov Institute [6] is that only "a multi-component park of nuclear reactors (thermal and fast), with evolutionary development of both lines, would yield the most optimal combination of nuclear energy with the external energy system and minimize the risks caused by considerable uncertainties associated with resource supplies, as well as with the use of new materials and technologies". The multi-component structure of nuclear energy would enable sufficient flexibility of the nuclear fuel cycle industry, thus allowing it to compensate potential technology failures or deviations of actual development from anticipated scenario.

Other views of this issue also exist. For instance, a group of influential experts associate long-term prospects of nuclear energy development exclusively with the deployment of fast lead-cooled reactors, which, in the opinion of their developers, would have fundamentally higher safety and would be capable to replace all other reactors [9]. Development of the pilot demonstration lead-cooled reactor design coupled with onsite spent fuel reprocessing facility is financed from the budget of the Federal Target Program on New-Generation Nuclear Energy Technologies.

On the whole, the list of reactor systems, both already accepted for implementation and initiated (Fig. 4), impresses by its "unique diversity". Three very different designs are being developed only for fast reactors.

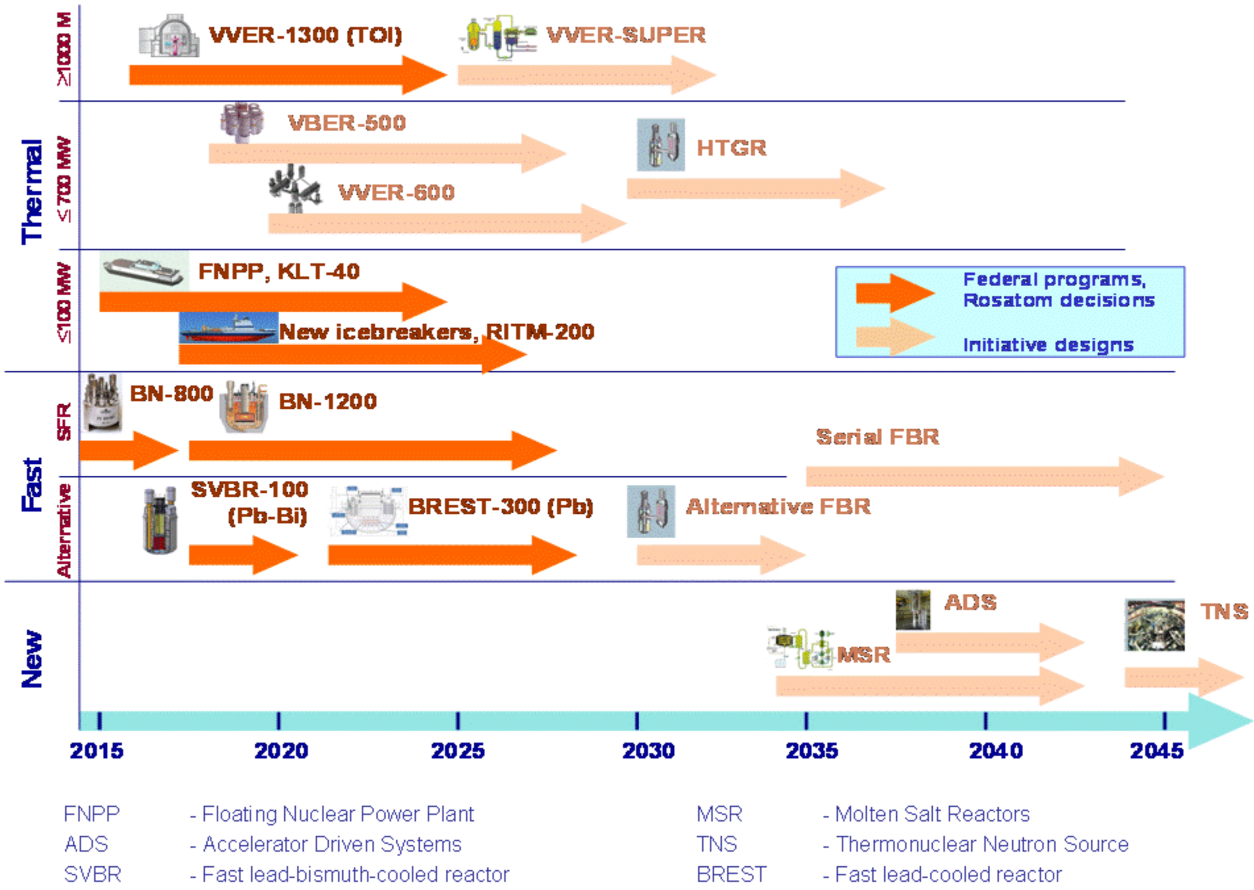


*Fig. 4. Nuclear reactors roadmap*

At the same time, calculations show that optional fuel cycle closing scenarios yield no essential difference as concerns the amount of waste to result from spent fuel reprocessing (certainly, assuming the same amount of energy produced), though it is possible and necessary to select processes and modes allowing the content of waste to be optimized.

We estimate the amount of radioactive waste from NPP operation and decommissioning to make respectively ~50 and ~30 thousand tons by the mid-century. The estimated amount of waste to be separated from spent fuel in the process of fuel cycle closing makes about 4000 tons. For different fuel cycle closing options, respective amounts of waste in each category would certainly also differ.

All fuel cycle stages are known to produce radionuclides, from their extraction from under natural barriers during uranium mining (radon and others), to their final disposal with fission and activation products, where the worst hazard is presented by nuclei having half-lives over 1000 years. Only a small share of waste, whose nuclide content obviously depends on the adopted nuclear generation option, belongs to this category of high-level materials.

Innovative technologies, such as molten salt minor actinide burners (or subcritical systems with electronuclear or thermonuclear neutron source), dry methods of spent fuel reprocessing (metallurgical, electrochemical, gaseous, etc.) can considerably improve the structure of wastes and minimize their amounts for reliable final disposal.

In recent years, nuclear specialists are back to discussing the prospects of development of thermonuclear neutron sources for purposes of fuel breeding in liquid-fuel blankets. If proven feasible, these sources would considerably influence the future fuel cycle and waste management structure.

The attitude of the Kurchatov Institute towards this variety of ideas quite correlates with the position of the report on America's nuclear future [10], which emphasizes the need "to pursue a policy of keeping multiple options open". This relates to alternative concepts, which have not yet achieved the proof-of-principle stage and "would require substantial investments of time and funding (and in some cases a number of revolutionary technical developments) to bring them to a level of maturity sufficient to evaluate their suitability for further development and potential implementation".

There is still enough time to choose our distant-future nuclear fuel cycle, which would meet the fundamental principles of safe radioactive waste management and, first of all, of keeping waste production as low as practically possible. However, in view of nuclear technology development inertia and decades-long lifecycles of nuclear power plants, some choices of principle should be made in the next few years.

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