Prospects and Challenges in the Management of Non-Retrievable Radioactive Waste in the Russian Federation - 17212

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ABSTRACT

In 2011, the Federal Law "On the Management of Radioactive Waste" was enacted in the Russian Federation setting a framework for the Unified State System for Radioactive Waste Management and establishing a mandatory requirement for safe radioactive waste (RW) disposal [1]. Particular category of "non-retrievable RW" was defined given the amount of RW generated by that time, the issues associated with relevant sites, as well as the experience gained during the implementation of nuclear legacy programs. It was specified that in situ disposal is the preferred management option for this category of waste rather than RW retrieval and re-disposal due to relevant radiation and financial aspects [2].

In 2011 – 2015, a set of high-priority tasks on taking the inventory of accumulated RW was accomplished. This work also provided for demonstrating the feasibility and making key decisions on the final stages on their lifecycle and relevant end-state strategies. Facilities holding non-retrievable RW were divided into two categories:

- subject to transition into near-surface storage facilities by constructing additional safety barriers;
- subject to controlled long-term storage followed by remediation.

Efforts on a number of surface liquid RW storage water reservoirs falling under the first category launched back in the 20th century were completed. The new federal program provides for a set of follow-up efforts to be completed at 12 facilities.

As it comes to the second category, the main task was to develop a set of safety management options, as well as some computational methods to demonstrate the feasibility of the selected end-state strategies [3]. The most considerable efforts were made at the Techa Cascade of water reservoirs being the largest liquid radioactive waste (LRW) storage facility in the world that holds over 360 million m^3 of waste [4] with uncertain legal status, the lack of relevant computational models to predict its state.

The paper summarizes the data on defining the end states of non-retrievable RW, completed and scheduled efforts on implementing relevant long-term safety strategies. The paper focuses on subsurface repositories and near-surface LRW storage reservoirs considered as common types of facilities holding non-retrievable RW.

INTRODUCTION

Level of focus placed upon RW management issues in Russia varied significantly at different stages of nuclear technology development. During the arms race top priority was given to production of nuclear materials which led to adoption of various simplistic decisions in RW management. It resulted in a number of accidents including the so-called Kyshtym accident of 1957 [5, 6]. The desire to avoid environmental disruption at other sites prompted the development of a unique technology of LRW deep well injection [7]. Three Rosatom enterprises have been using this technology since the early 1960's. Later on, the system for state management and planning adopted in the USSR (The Union of Soviet Socialist Republics*)* allowed to postpone some fundamental decisions on RW disposal challenges. Therefore, enterprises had no incentives to reduce the amount of generated waste and the technologies used in the middle of the 20th century became widespread even after the nuclear arms race was over. As the result, a large number of near-surface RW storage and disposal facilities constructed according to some simplified designs was created as well as a number of surface LRW storage water reservoirs the capacity of which varied from one to several hundred million cubic meters.

The attitude that there were no fundamental difficulties associated with addressing the huge backlog of RW management problems prevailed until the end of the 20th century and even exacerbated due to a grave economic crisis following the break-up of the USSR.

By the early 21th century, the major effects of the crises had been mitigated, environmental consciousness became more widespread, and the full extent of RW management problems, finally, got acknowledged. Even though operational safety was assured at the overwhelming number of RW facilities, the long-term safety issues remained to be addressed almost in every case. However, at certain facilities the situation was close to critical even in relation to operational safety (for example, the Techa cascade of reservoirs which is discussed below) [8 – 10].

All major nuclear powers that were actively engaged in the nuclear arms race in the past have faced the challenges associated with nuclear legacy clean up. Large scale programs have been launched to address these challenges (for example, those discussed in [11 – 17].

On the whole, two options can be considered when it comes to addressing nuclear legacy challenges. In the overwhelming majority of cases cleanup efforts can be performed according to a standard workflow: retrieval of nuclear materials and radioactive waste followed by facility dismantlement and environmental cleanup.
However, the task of complete elimination and remediation can't be accomplished "in general" for a small number of large nuclear legacy facilities. This is due to the fact that feasibility, competitiveness and cost efficiency of the projects ensuring long-term safety can be evaluated only when they are considered as a part of specific strategies. Whereas, in a certain timeframe a strategy on its own can prove to be not the cheapest one or, on the contrary, the safest one. Generally, the flawless safety solutions prove to be the most expensive ones and, moreover, are associated with

significant management risks as the process involves a large number of interested parties.

On the contrary, the projects involving more cost effective and less “elegant” solutions not associated with any infrastructural benefits often turn to be the optimal ones as they can be performed more easily. Past experience has shown that even the strategies deemed to be passive can eventually turn to be more beneficial than the active ones.

Enactment of a framework act “On the Management of Radioactive Waste” in 2011 was a major milestone that marked the transition to completely new radioactive waste management practices in Russia. Russian nuclear industry faced the challenge of establishing a unified state RW management system [1]. A set of tasks was set out to address this challenge:

- to make the inventory of all accumulated radioactive waste and storage facilities (the so-called program of RW initial registration) and to define relevant long term safety strategies;
- to establish a system of available large disposal capacities for low-level and intermediate-level waste;
- to provide certain engineering solutions required to retrieve the retrievable radioactive waste, to ensure its pre-disposal management and conditioning to meet specific acceptance criteria;
- to advance the practice of very low-level waste disposal, in particular VLLW in situ disposal practice;
- to perform certain efforts ensuring safe storage configuration of facilities holding non-retrievable radioactive waste (the process commonly referred to as “conservation” in Russian literature).

The overriding concern was given to the initial registration of radioactive waste that involved the implementation of a specific approach suggesting that all the accumulated RW were split into two categories: retrievable RW and non-retrievable RW (also called “special” RW). Relevant decisions were made based on the evaluation of risks and costs associated with certain waste management options. These activities as well as practical efforts addressing the most challenging RW management issues were carried out under the first state nuclear legacy program – the federal target program “Nuclear and Radiation Safety in 2008 and until 2015” (hereinafter – FTP NRS).

SPECIAL AND RETRIEVABLE RW

Since 2011, in accordance with the Federal Law “On the Management of Radioactive Waste” all radioactive waste in Russia are categorized either as retrievable or non-retrievable (special) radioactive waste. Relevant decisions are made based on the optimal waste management option involving minimal risks and costs.

It was a strategic decision to specify the category of non-retrievable RW which was taken with account of specific nature of nuclear legacy facilities and the state responsibility for RW management. This new category of radioactive waste enables the implementation of significantly less expensive but none the less safe approach to the final isolation of earlier accumulated RW inventory – mothballing RW storage facilities (or in other words ensuring safe storage configuration of facilities holding non-retrievable radioactive waste) with their subsequent transition into RW disposal facilities provided that the long-term safety is ensured.

Decisions on attributing the waste to the category of non-retrievable RW are made based on qualitative and quantitative criteria set up in 2012 (Government of the Russian Federation Resolution № 1069 dd. 19.10.2012): “Non-retrievable RW are RW generated during the implementation of special state programs, the use of nuclear devices for peaceful purposes or due to a nuclear and (or) radiation accident, as well as liquid (water) and solid (bottom sediments) radioactive waste stored in surface water reservoirs in cases when:

a) collective effective dose during the entire period associated with RW potential hazard and the risk of potential exposure associated with RW retrieval exceed relevant values in case of RW in-situ disposal;
b) costs associated with RW retrieval (including the costs associated with retrieval operations, RW treatment, conditioning, shipment to the disposal site and disposal itself) exceed costs associated with RW in-situ disposal, including the overall potential environmental damage determined in accordance with the special Acts of Ministry of Natural Resources and Environment of the Russian Federation;
c) RW storage facility and the sanitary protection zone are located outside the boundaries of settlements and nature conservation areas.”

Should RW are categorized as retrievable they are retrieved from the storage facility and transferred to the National Operator for disposal.

The initial registration campaign of 2013-2014 covering the accumulated RW inventory generated prior to the enactment of RW management law had to address a number of issues associated with each facility claiming the status of a facility holding non-retrievable RW:

- To evaluate the period of potential hazard associated with each RW facility.
- To evaluate the technical feasibility of ensuring RW in-situ confinement during this whole period, or in other words to demonstrate that the impacts associated with radioactive materials won’t result in the exceedance of regulatory dose limits during normal operation. In this respect, geomigratory and geochemical problems had to be addressed in the first place at certain level of detail.
- To evaluate collective personnel and public exposure both in case of constructing additional safety barriers in RW storage facility (obtaining a new status of an RW in-situ disposal facility) and RW retrieval. The in-situ RW disposal scenario had to provide for a number of project implementation stages up to facility’s release from regulatory control, whereas RW retrieval scenario involved certain steps – from the initial state of the facility and up to RW transfer for disposal, storage facility decommissioning and site cleanup. In the latter case, the most urgent challenge was to evaluate operational doses to personnel. No designs had been developed

for RW retrieval from existing storage facilities so it was often impossible and not necessary to define in detail relevant technical features which prompted the use of already existing knowledge accumulated by the industry. It shall be noted that Nuclear Research Center "Kurchatov Institute" can be listed among other leading Russian organizations possessing such valuable knowledge [18, 19].

- To evaluate risks of potential exposure. Activity release caused by tornado is one of the most important formally describable scenarios. For RW retrieval scenarios, the most detailed evaluation of risks was made for accidents associated with handling operations and transportation of packages within the facility's site and on public roads.
- To evaluate the costs associated with in-situ disposal and RW retrieval.
- To evaluate the overall potential environmental damage in case of in-situ disposal, which was made based on calculations of dose rates to reference wildlife features within the territory affected by RW storage facilities; followed by comparison of the values obtained with conservation and radioecological safety criteria. A number of simplifying assumptions were taken and conservative calculations were performed to overcome obvious methodological difficulties. Nevertheless, there is no doubt that this issue is relevant in itself even outside the scope of the initial registration.

As the result, relevant safety justifications required to define RW facilities as non-retrievable were developed for over 150 facilities.

To date, the uncertainties that existed prior to 2011 and were associated with RW management strategies are almost completely resolved. Fig. 1 presents the key groups of facilities that were subject to the initial registration:

- Storage facilities holding retrievable RW (light green) – the number of such facilities will constantly decrease as the waste is retrieved and transferred to the National Operator.
- Final decisions on facilities marked with red were postponed. Further on they will be attributed either to the "green" or to the "brown" group.
- Disposal facilities (dark green) ensuring adequate level of safety for people and the environment (three deep LRW disposal facilities).
- Storage facilities for special (non-retrievable) RW (brown) refers to those cases when the final goal is to upgrade them to disposal facilities. These facilities require additional activities and safety justifications.

In addition to that the initial registration campaign enabled to identify the sites contaminated due to the peaceful use of nuclear devices that were defined as storage facilities holding non-retrievable RW.

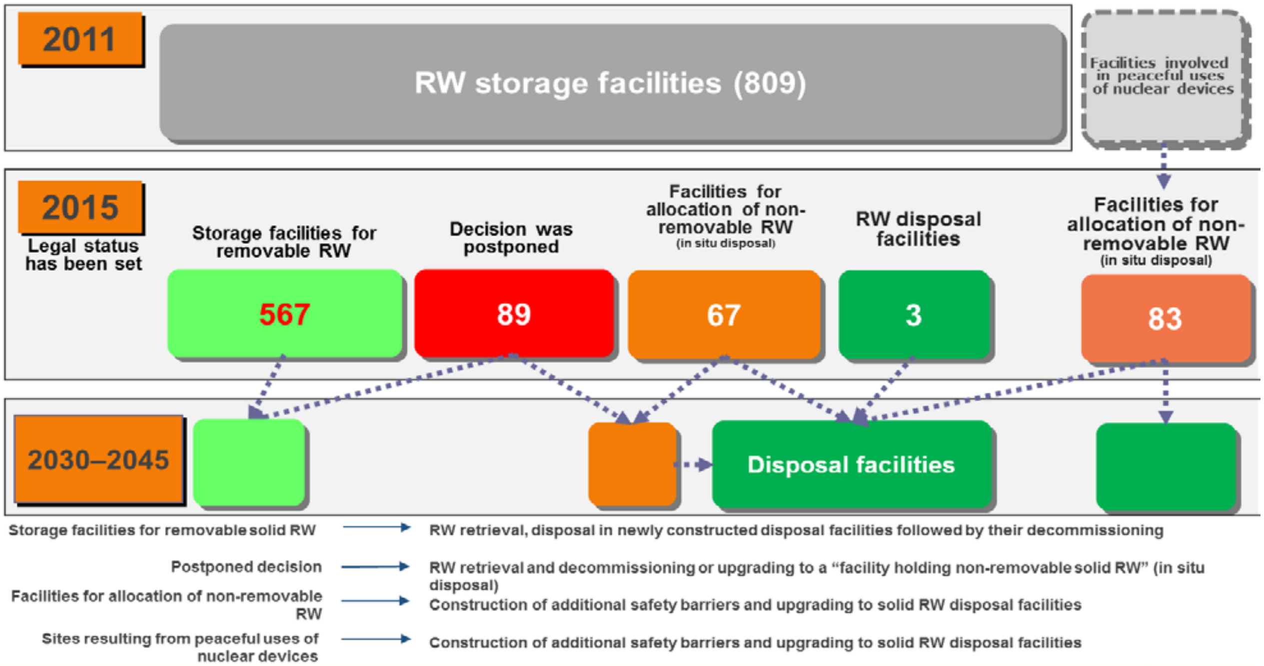

Fig. 1. Changes introduced to the status of RW storage facilities following the “legacy” RW initial registration [20]

The initial registration is considered to be a key step in the development of a unified state system for RW management. The following activities have been scheduled based on the evaluation of its results [21, 22] and the altered status of storage facilities:

– Retrieval of retrievable RW followed by its conditioning and treatment in accordance with the acceptance criteria and transfer to the National Operator responsible for RW disposal in the newly created centralized disposal facilities.
– Construction of additional safety barriers at storage facilities holding non-retrievable RW thus ensuring the long-term safe storage configuration followed by their eventual upgrading to in-situ RW disposal facilities.
– Development of RW management strategies for the waste that due to various reasons was defined neither as retrievable nor non-retrievable during the initial registration campaign.

On the whole, the initial registration campaign required the assessment of a safety level ensured in different conditions. The key issue was to demonstrate that the decisions made provide an adequate level of safety. Although the complexity of issues associated with the development of safety cases covering a period of a hundred or some hundreds of thousand years varies significantly, the implemented solutions should be equally reliable. Otherwise, the low degree of public confidence in RW management safety as it is at the moment can decrease swiftly.

DEMONSTRATING THE SAFETY OF NEAR-SURFACE RW DISPOSAL FACILITIES

Near-surface repositories, a most common type of disposal facilities in Russia. They accumulate several hundred cubic meters of waste. The potential hazard period associated with this waste exceeds 300 years.

The decisions on attributing the waste held in these facilities to the category of non-retrievable RW were made in consistence with all national and international [2] recommendations based on relevant long-term radionuclide migration forecasts. Scenario considering normal evolution of a disposal system was of the main concern due to the evaluative nature of these forecasts and the institutional control arrangements currently introduced at the sites, thus, minimizing the possibility of inadvertent immediate contact of public with RW. In near-surface repositories, radionuclide migration occurs with seepage of precipitation water into facilities and further on to the unsaturated zone. Due to convective transfer, radionuclides reaching the aquifer with the seepage flow migrate with groundwater flows while some part of radionuclides is retarded by the host rocks. Standard conceptual model presented in Fig. 2 enabled to consider all the properties, processes and events relevant for the disposal sites. A most conservative approach was used in these calculations.

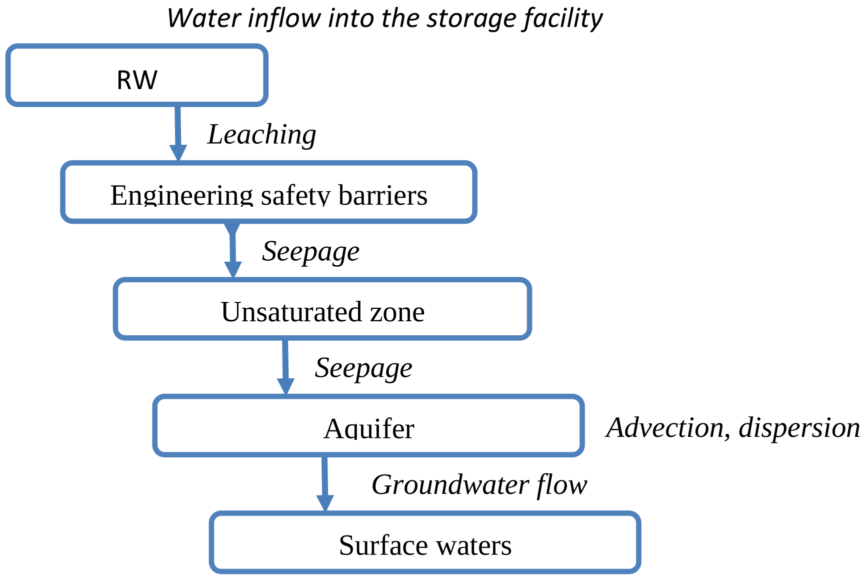

Fig.2 Conceptual model for a storage facility under a normal evolution scenario

The forecasts performed to evaluate the migration of major dose contributing radionuclides as well as the public exposure for all critical groups were aimed to demonstrate that in situ disposal won't result the exceedance of the public dose limit of 10 µSv/year [23].

Therefore, migration forecasts show the potential feasibility of in situ RW disposal and should be followed by comparison of possible RW management options. Such comparison, being part of the decision-making process on assigning certain RW to the category of non-retrievable waste, is based on such factors as personnel exposure (collective effective dose rate), cost and risks of potential exposure.

A specific approach suggesting the consideration of already existing knowledge and data was introduced to assess personnel exposure due to different operational activities. For example, a data bank on personnel exposure was used to complete the retrieval of radioactive waste from repositories of the National Research Center "Kurchatov Institute" located inside the boundaries of the Moscow city in the intermediate vicinity of residential area [2].

The safety demonstration process involved the consideration of certain external impacts that could result in additional exposure of public and personnel, namely: earthquake, flooding, naturally occurring fire, strong winds (including tornados and whirlwinds), airplane crash and etc. Furthermore, a distinctive feature of in situ disposal activities is that they suggest that additional protection of personnel shall be ensured by already existing safety barriers (the capping structures), whereas RW retrieval activities involving the breach of the capping structures may result in additional exposure of personnel. Moreover, considering the large amounts of accumulated RW, in situ disposal involves lower risks associated with contamination of adjacent areas (spills, dust and etc.) and transport accidents [2].

SAFETY JUSTIFICATION FOR THE TECHA CASCADE OF WATER RESERVOIRS

In the past periods major nuclear facilities used to discharge large LRW amounts into open hydrographical networks. Such discharges into large rivers and seas enabled to mitigate some grave environmental problems considering the total activity that was released. A case in point, the Sellafield nuclear reprocessing plant in the UK that has discharged over 9.0E+16 of long-lived radionuclides since 1952. Some water reservoirs were contaminated as well, namely, Par Pond [24-26], L-Lake [24, 27] and White Oak in the USA [28], as well as Link Lakes [29] in Canada.

In general, for a contaminated water objects four alternative strategies aimed to decrease the hazard level associated with the reservoir are possible:

1. Draining, breaching the dam, and converting the lakebed to forest or other vegetation cover.
2. Draining, breaching the dam, and excavating and removing the sediments.
3. Draining and attempting to fix the sediments in place.
4. Repairing the dam and refilling the reservoir to cover the ^{137}Cs-contaminated sediments.

The lessons learnt from Par Pond (Savannah River) project shows that option 4 is feasible even though water and bottom sediments were not categorized as radioactive waste.

This adds another point in favor of the fact that was confirmed many times by calculations during the initial registration campaign and the decision-making process on attributing RW to the category of non-retrievable waste [2]: in situ disposal is a much more pragmatic and safe strategy rather than waste retrieval and re-disposal when it comes to relatively large facilities.

However, Russia has faced a much more challenging situation. The key nuclear legacy facility here is the Techa cascade of reservoirs (TCR) being the world's largest surface LRW storage reservoir [30]. This cascade is a complex hydrogeological natural and human-made facility isolated from open hydraulic system involving four water reservoirs and dams, a system of bypass channels and a number of hydro-technical structures (Figure 3). TCR holds over 350 million m^3 waste containing about 4.6 PBq of radioactivity mostly coming from Sr-90 and Cs-137. The main challenge for TCR was associated with uncontrolled water level increase in V-11 reservoir [31].

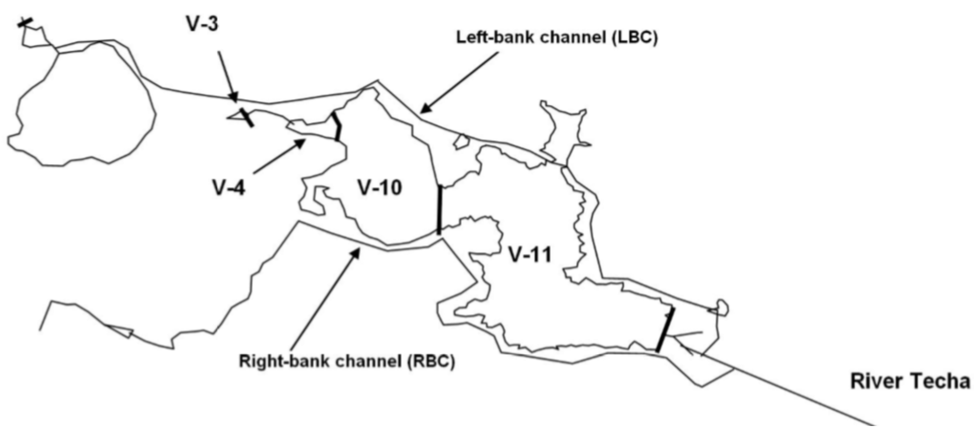

Fig. 3. TCR layout: water reservoirs V-3, V-4, V-10, V-11

Based on thorough analysis of ways enabling to justify and ensure TCR safety, the outlook on its final state has been formed, as well as a comprehensive vision of its life cycle followed by the development of tools required for the safety assessment and strategy analysis, in particular:

- Pathways and associated impacts on human and the environment were identified, the most relevant processes influencing the behavior of the entire system were outlined.
- All necessary historical data was acquired and systematized (long-term hydrogeological, meteorological, radiation and chemical monitoring surveys).
- Specific calculation models and techniques used to predict TCR state and the environmental setting in the region based on modern methods of space-time series analysis were developed, allowing to forecast:
    - Volumes and levels of water in TCR reservoirs induced by natural and anthropogenic influences.
    - Seepage flows in the hydrodynamic system "reservoirs – groundwater – bypass channels".
    - Rate of Sr-90 infiltration into the environment allowing for various scenarios of regional changes in water level and performance of various engineering and technical activities.

- Decreasing levels (both due to a radioactive decay and time dependent sedimentation) of Sr-90 specific activity in waters and bottom sediments of TCR reservoirs (given sediment disturbance as well) and in the river Techa.
- Probability and effects of emergencies involving TCR activity release into the environment (eolian entrainment, emergency overflow).

The models developed were integrated into a unified calculation complex shown in Fig. 4 and Fig. 5.

The most feasible strategy enabling TCR transition into environmentally sound state was selected based on multiple-option calculations involving various key factors determining its overall hazard level [32].

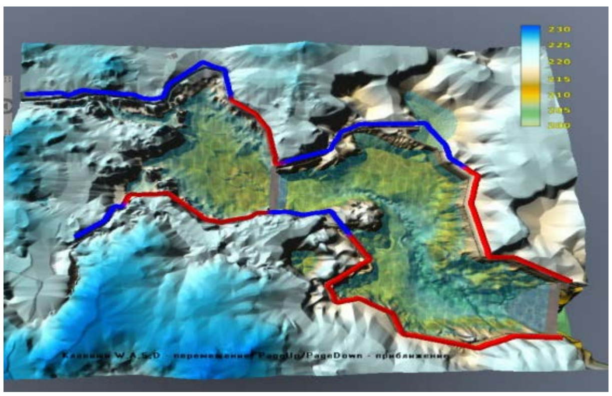

Fig. 8. Evaluation of filtration between TCR channels and reservoirs

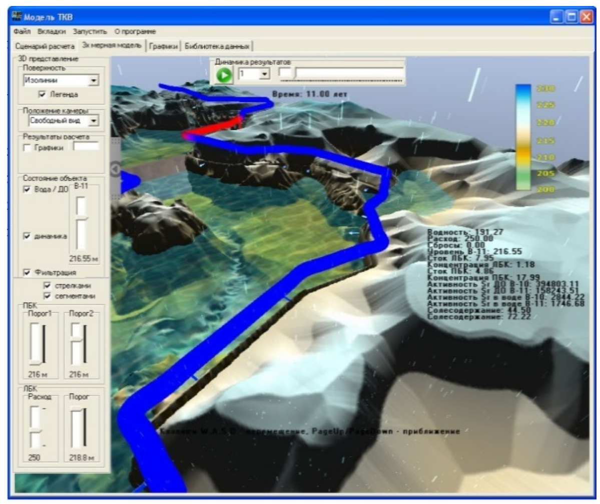

Fig. 9. Demonstrating the dynamics of changes in forecasted TCR parameters

The efforts performed to date enabled a complete transformation of the initial TCR challenge that had been associated with a large number of uncertainties (regulatory status, forecasts on TCR future states, management engineering solutions) – from now on adequate knowledge is available to ensure safe operation and staged decommissioning of this complex facility. The TCR management concept was presented in the TCR Strategic Master Plan (TCR SMP) approved in 2016 by the CEO of the State Corporation “Rosatom”. All the activities scheduled under the Master Plan have been performed under the federal target program “Nuclear and Radiation Safety in 2016 – 2020 and until 2030”.

According to TCR SMP provisions, two possible options are considered for TCR water reservoirs depending on their specific features: bogging (formation of a waterlogged swampy area) followed by subsequent transition into RW disposal facilities (reservoirs v-3 and V-4) or controlled storage for decay combined with water level controls in water reservoirs and bypass channels (V-10 and V-11). In 30-40 years, these management options will allow to release reservoirs V-10 and V-11 from regulatory control according to the radiation factor, which means that the water contained in these reservoirs will no longer be regarded as LRW, and the bottom sediments – no longer regarded as SRW.

PAST EXPERIENCE AND THE PROSPECTS FOR NON-RETRIEVABLE RW MANAGEMENT

A number of efforts scheduled under FTP NRS were performed in order to improve the safety level at over 30 facilities holding non-retrievable RW. The overriding concern was given to water reservoirs holding LRW considered as the most potentially hazardous facilities. The following tasks associated with storage facilities holding liquid non-retrievable RW were addressed under FTP NRS:

1. Final states of these facilities were defined under the initial registration campaign as well as the management strategies enabling their attainment: most facilities are to be put into safe storage configuration pending their subsequent transition into RW disposal facilities; several facilities are to be released from regulatory control after decay storage according to radiation levels.
2. Efforts enabling to achieve safe storage configuration have been completed at three large facilities (relevant projects had been launched before FTP NRS was started).
3. Safe operation is ensured for five largest water reservoirs (installation of new systems and reconstruction).

Efforts enabling to achieve safe storage configuration of facilities holding non-retrievable liquid waste are to be continued under the second federal target program. Practical efforts are also scheduled for near-surface disposal facilities. Planned RW management activities will obviously require the development of relevant technologies that would enable such operations at legacy facilities that are often unique in nature and hold different types of radioactive waste. It will also prompt a large number R&D, calculations and safety assessments as well. Thus, the decision-making process on attributing storage facilities to the category of non-retrievable waste facilities can be regarded as an optimization task resulting in decreased decommissioning costs. This also involves critical evaluation of already performed projects, monitoring activities at the sites of facilities placed under safe storage configuration and continued research enabling the optimization of relevant engineering solutions.

Conducted evaluations have shown that the engineering solutions aiming to enhance nuclear and radiation safety level are often too conservative which is mainly due to the insufficiency of calculations regarding specific issues. Thus, the optimization process could potentially focus on:

- Elements and properties of the engineering barriers system used to ensure safe storage configuration of nuclear facilities holding non-retrievable RW (conservation);
- Potential of placing additional amounts of radioactive waste generated during conservation and decommissioning into such facilities;

- Potential reuse of contaminated materials during conservation;
- Cleanup criteria for radioactively contaminated areas.

If conservation activities are postponed due to financial or other reasons a reasonable assurance should be provided that this will not result in the exceedance of the established personnel and public exposure limits and that the safety enhancement decisions will be applicable in the future.

From the engineering point of view, such calculations correspond to the tasks that were previously addressed during the elaboration of RW management strategies and safety demonstrations performed to select the preferred end-state option. The only difference is the level of detail: in some cases, more advanced computational tools and models were required, as well as additional evaluation of conditions at the site and the adjacent territories [33, 34]. Relevant activities have been scheduled under the new nuclear legacy program.

CONCLUSION

Definition of decommissioning strategies for all RW storage facilities based on comparative risk and cost evaluations was carried out during the development of the unified state system for RW management.

A category of non-retrievable waste that are supposed to be disposed of in situ have been specified under the current legislation. Two end-state options are provided for such facilities: either release from regulatory control according to radiation level or upgrading to a disposal facility following the construction of additional safety barriers. Such a management concept is consistent with the nuclear legacy management practices widely used abroad, namely, in the USA.
These strategies have been implemented under federal target programs on nuclear legacy since 2008. Several facilities were completed under the first federal target program (these efforts had been started before FTP NRS was launched). A number of projects aiming to decrease the intolerable risks associated with some other nuclear facilities (including the TCR) have been completed as well. The increased work scope scheduled under the second federal target program requires detailed evaluations of costs and risks associated with the suggested engineering solutions that should be made based on the knowledge gained during the implementation of the first FTP NRS.

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