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Large Surface Storage Facility for Liquid Radioactive Waste: Addressing Safety Justification Challenges

Utkin SS* **and Linge II**

Nuclear Safety Institute of the Russian Academy of Sciences (IBRAE RAS), Bolshaya Tulskaya Ul, 52, Moscow, Russia

***Corresponding author:** Utkin SS, Head of Department, Nuclear Safety Institute of the Russian Academy of Sciences (IBRAE RAS), Bolshaya Tulskaya Ul, 52, Moscow, Russia, Tel: +7(495)955-23-77; E-mail: uss@ibrae.ac.ru

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Abstract

The Techa Cascade of water reservoirs (TCR) is one of the most environmentally challenging facilities resulted from FSUE "PA Mayak" operations. Its reservoirs hold over 360 mln m^3 of liquid radioactive waste with a total activity of some 5·1015 Bq which is about 0.1% of the total radioactivity released from the Chernobyl accident and occupy an area equivalent to roughly the size of 7,000 football fields.

A set of actions implemented under a special state program involving the development of a strategic plan aimed at complete elimination of TCR challenges (Strategic Master-Plan for the Techa Cascade of water reservoirs) resulted in considerable reduction of potential hazards associated with this facility.

The report summarizes the key elements of this master-plan: defining the facility's final state, feasibility study of the main strategies aimed at its attainment, evaluation of relevant long-term action plans, development of computational tools enabling the long-term forecast of TCR behavior depending on various engineering solutions and different weather conditions.

Keywords: Techa cascade of water reservoirs; TCR; Strategic master plan; SMP; Liquid radioactive waste; Long-term safety; Safety justification

Introduction

The Techa Cascade of water reservoirs (TCR) at FSUE "PA "Mayak", the world largest near-surface LRW storage reservoir, is associated with a huge number of engineering, scientific and legal challenges that should not be addressed separately [1,2]. The year 2014 saw the completion of a large integrated interdisciplinary R&D project aimed at justifying and ensuring TCR safety. This R&D project is briefly discussed below, whereas much more detailed and specific information is presented in Ref [3].

The mid-20th century attitude towards radio ecological issues did not interfere with creation of similar to TCR facilities. Moreover it somewhat smoothed the way for it [4]. It was strongly believed that environmental medium, in the first place, and human body, in particular, has sufficient resistance to radiation exposure. This firm conviction paved the way for unconditional application of this principle in the development of nuclear technologies without extensive discussions or debate. Furthermore the lack of time and unbiased knowledge in the early years of nuclear development resulted in somewhat simplistic decisions that nevertheless were believed to be rather effective according the RW management priority system of the day. This practice resulted in a number of legacy facilities varying in nature (near-surface LRW storage reservoirs, repositories without proper designs, deep LRW disposal facilities and etc.) and timeframes representing their potential hazard (from hundreds to tens of thousands of years). These facilities were often managed based on ad hoc decisions. A quite detailed discussion of these facilities, as well as relevant approaches and methods designed to ensure their safety and perform the required cleanup is presented in Ref [4-7].

On the whole, all major powers previously engaged in rapid nuclear weapons development have complex and diverse nuclear legacy facilities. However, due to a number of reasons (geographical setting being the most important one) Russian nuclear legacy facilities are considered to be more challenging both in terms of RW amounts and the accumulated activity.

Until mid-1990's these issues have been set aside by nuclear industry, and the true extent of accumulated challenges became evident only by the early XXI century.

Comprehensive Action Plan on Addressing Environmental Issues Associated with Current and Past Operations at FSUE "PA "Mayak" approved in 2003 by Atomic Energy Minister of the Russian Federation was a first example of applying strategic approach to addressing RW management challenges. More detailed information on "PA "Mayak" is given in Ref [8].

Another major milestone in adjusting domestic RW management approaches according to the international ones was the development of a Strategic Master-Plan on Disposition and Environmental Cleanup of Decommissioned Nuclear Navy Facilities, the project led by member of the Russian Academy of Sciences A.A. Sarkisov [9].

Therefore, the launch of the first large-scale state nuclear legacy program (FTP NRS), setting up a framework for the activities discussed below, was an obvious next step aimed at living up to the potential accumulated by the mid-2000's.

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Strategic master-plan for the Techa Cascade of water reservoirs

TCR size (surface area of over 50 km^2) and the strong dependence of its state on precipitation make it really hard to manage. Unlike common water reservoirs, any event of TCR overflow is highly undesirable, whereas uncontrolled overflow is totally unacceptable. Since the early 2000's the most high-level officials have been discussing TCR challenges: TCR overflow threatened the environment whereas no credible management options existed at the time. Urgent management actions taken at TCR and favorable water conditions in the mid-2010's enabled the development of TCR Strategic Master-Plan (SMP TCR). Its overall objective was to justify and select the most suitable TCR management strategy covering the whole time period associated with TCR potential hazard. Based on it relevant organizational and technical arrangements have been developed.

The project launched in 2008 involved a large number of experts from 5 organizations whose expertise covered the whole range of the envisaged challenges (Figure 1): IBRAE RAS- the main contractor, FSUE "Gidrospecgeologiya"-hydrogeological and geochemical support, FSUE "PA "Mayak"-TCR operation, initial data; LLC "Gidrotech"-engineering design of LRW treatment technologies, construction and testing, LLC "NIEP"-feasibility study on the availability of water resources for a power reactor unit.

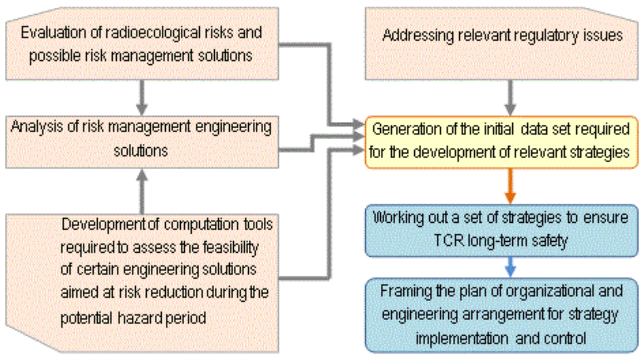

Figure 1: Research flow sheet used in the development of SMP TCR.

New research tasks for SMP TCR development

It became clear that the scope of previously conducted research is far not enough to enable maximum management options and develop a well-defined long-term action plan. A number of new tasks were added on the agenda, in particular:

To evaluate the TCR, being on its own a complex facility (water reservoirs V-3, V-4, V-10, V-11, hydraulic engineering structures, including by-pass channels), as an integral part of a wider system involving a large number of different facilities inside and outside the industrial site, including Irtyash-Kaslinsk lake system, water reservoirs V-9 and V-17, water reservoir V-2, ground water and the river Techa.

To address all regulatory matters: the extent of the problem was so high that in late 2010's it almost caused the radiochemical plant shutdown.

To organize all available monitoring data.

To gain full understanding of TCR state at each step of its lifecycle. The top priority task was to evaluate TCR water balance and its isotope inventory.

To define the whole range of engineering solutions enabling TCR integrated management, considering the possibility of gradual lifting the restrictions imposed on the use the Techa river resources, including its floodplain.

To define TCR final state, as well as relevant strategies and timeframes.

To develop a roadmap and a plan of organizational and engineering arrangements for each and every strategy.

This work was completed in 2014. In keeping with the best strategic management practice, several editions of the final report were made available for different stakeholders: a small pamphlet discussing in brief the major achievements, a multipage volume describing all the results achieved, and a more detailed report containing all relevant supporting materials.

Based on thorough analysis of ways enabling to justify and ensure TCR safety, the outlook on its final state has been shaped, 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 the associated effects on human and the environment were identified; the most relevant processes influencing the entire system behavior were outlined.

All necessary historical data was acquired and organized (long-term hydrogeological, meteorological, radiation and chemical monitoring surveys).

Specific calculation models and techniques used to predict TCR state and the environmental settings in the region based on modern methods of space-time series analysis were developed, enabling 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.

Sr-90 specific activity fluctuations in waters and bottom sediments of the TCR reservoirs (given sediment detachment 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 "TCR-Prognoz" (Figure 2) It enabled to evaluate over 60 different TCR operation scenarios involving various natural (mainly precipitation) and anthropogenic (primary discharged LRW amounts and activities, as well as weir sill level) influences.

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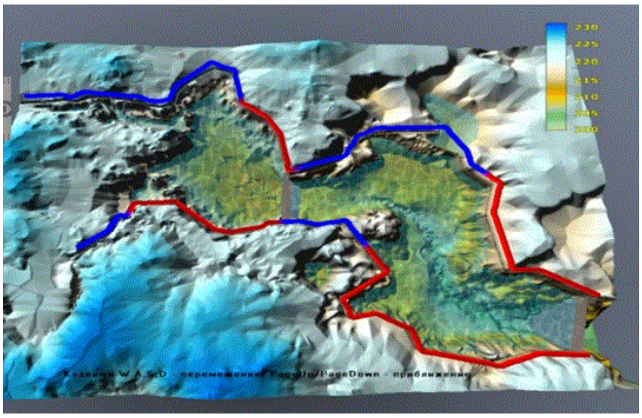

Figure 2: Calculation-monitoring complex "TCR-Prognoz" (evaluating filtration between bypass channels and TCR reservoirs).

Thereafter, for the first time ever TCR was granted the status of a nuclear facility. Acceptable limits for radionuclide discharges from TCR into the environment were set for this nuclear facility based on a specially developed technique which was also a novel practice for Russian nuclear industry.

To date, treatment technologies for TCR LRW, both already stored therein and the discharged ones have been developed, relevant facilities have been constructed and tested.

Comparison of alternative TCR management strategies

Three main strategies aimed at reaching TCR final state were considered (1-facility management using hydro-engineering structures; 2-construction and operation of a treatment facility designed to process the water from V-11 reservoir with a capacity of more than 10 mln m^3/year; 3-construction and operation of a nuclear power unit using TCR water as coolant) (Figure 3).

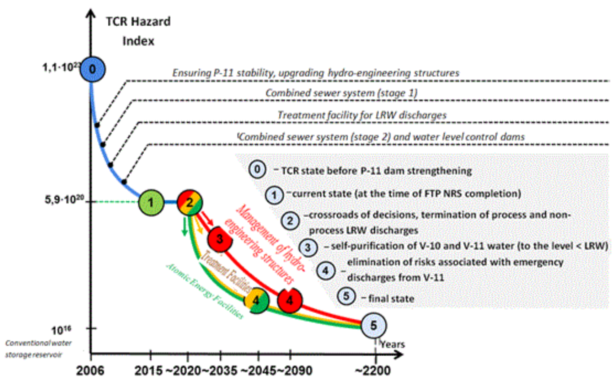

Figure 3: Comparison of risks associated with the implementation of different strategies (red-strategy 1, yellow-strategy 2, green-strategy 3).

The long-term program developed is aimed at most prompt cleanup of V-11 water (20-30 years).

The above presented dependencies used to compare different strategies are fundamental, whereas relevant numerical data can be presented in different forms (for example, the amount of radionuclides discharged annually from TCR or V-11 overflow potential).

Integrated hazard and environmental damage index widely used in the literature was used in this evaluation [10-12]. For the purpose of this research, the following equation was used to calculate TCR hazard index (HI) (or the Safety and Environmental Detriment Score as referred to NDA [12]): $HI=RHP \times (FD \times WUD)^4$, where RHP-Radiological Hazard Potential, FD-Facility Descriptor, WUD-Waste Uncertainty Descriptor. It should be noted that the initial NDA SED calculation approach and relevant coefficient values have been substantially elaborated and its functional capabilities have been greatly improved in Ref [13-15] so that they could better respond to individual efforts and facilities listed under the FTP NRS.

Results

TCR Strategic Master-Plan (SMP TCR) aimed at justifying and selecting the most suitable management strategy covering the whole time period associated with its potential hazard was developed. Based on it, a list of relevant organizational and technical arrangements was elaborated. The experience gained form SMP TCR development and its subsequent application showed the advantages of SMP approach aimed at planning and managing the life cycle and safety of key legacy facilities, as well as nuclear legacy as a whole.

Conclusions

Efforts launched in 2016 under the TCR Strategic Master-Plan are to ensure:

TCR conformity with all regulatory safety requirements both in the short run and until its release from regulatory control;

Maximum reduction of emergency risks until their complete elimination;

Ongoing operation of "PA "Mayak" production facilities;

Minimum direct costs to ensure TCR safety;

Complete radiological restoration of ecosystems covering the watersheds of rivers Techa, Iset, Tobol and Irtysh;

Socioeconomic impact associated with active infrastructure development in the FSUE "PA "Mayak" area.

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