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STRATEGIC MASTER-PLAN FOR RESEARCH DEMONSTRATING THE SAFETY OF CONSTRUCTION, OPERATION AND CLOSURE OF A DEEP GEOLOGICAL REPOSITORY FOR RADIOACTIVE WASTE

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The paper concentrates on the factors defining the current state of the project on establishment of a deep radioactive waste disposal facility from the scientific support perspective. The paper overviews the general principles and the key areas of the research program, including the activities to be performed in the underground research laboratory, and required for the safety assessment and the development of a safety case covering all life cycle stages of the facility.

Keywords: *radioactive waste, deep disposal facility, underground research laboratory, strategic master-plan, safety assessment and safety case.*

International experience shows that construction of deep RW disposal facilities (DRWDF) is an extremely complex problem requiring long-term comprehensive efforts on development of scientific and technological foundations and tools for the long-term safety case and safety assessment and inevitable optimization of DRWDF characteristics [1—6]. Implementation of such projects usually gives rise to serious concerns of the public and other stakeholders, caused by both traditionally acute perception of radiation risks, and virtual irreversibility of decisions regarding the disposal of long-lived RW. These concerns have resulted in a number of high-level decisions to cease the operation of such facilities in a number of countries (the USA, Germany and other) or to declare the concept of reversible RW disposal (France, etc.).

Probably due to this fact, as well as due to the lack of an urgent need to intensify the efforts on SNF and HLW disposal (compared to LLW, which has been accumulated in much larger volumes), the first IAEA document on the subject was published only in 2001 after more than 40 years of research in the area of geological disposal [1], and the second one — a handbook on experience of research and interpretation of the results obtained in URLs — is currently under development. The logic of this draft document reflects the way that IAEA perceives the place and role of research in the development of DRWDF (Fig. 1).

This paper will take a closer look at the areas covered by the Project Research Program and the URL Research Program. They specifically reflect the broad scope of research tasks and the stepwise approach aimed at building trust in the results of relevant safety assessments. The respective programs include relevant activities falling under various aspects of RW pre-disposal management, safety assessment and safety case development, feasibility of facility construction. The most important and laboursome part of the activities shall be done in-situ under URL conditions.

In 1990—2015 a set of research and design efforts was performed in the Russian Federation under the DRWDF project (Fig. 2).

Before 2007, the progress achieved was continuously reviewed by the scientific community. However, the conditions of work implementation in 2008—2013 did not envisage, and, moreover, even eliminated a possibility of engaging a wide audience of experts in the design decisions review and quality assurance.

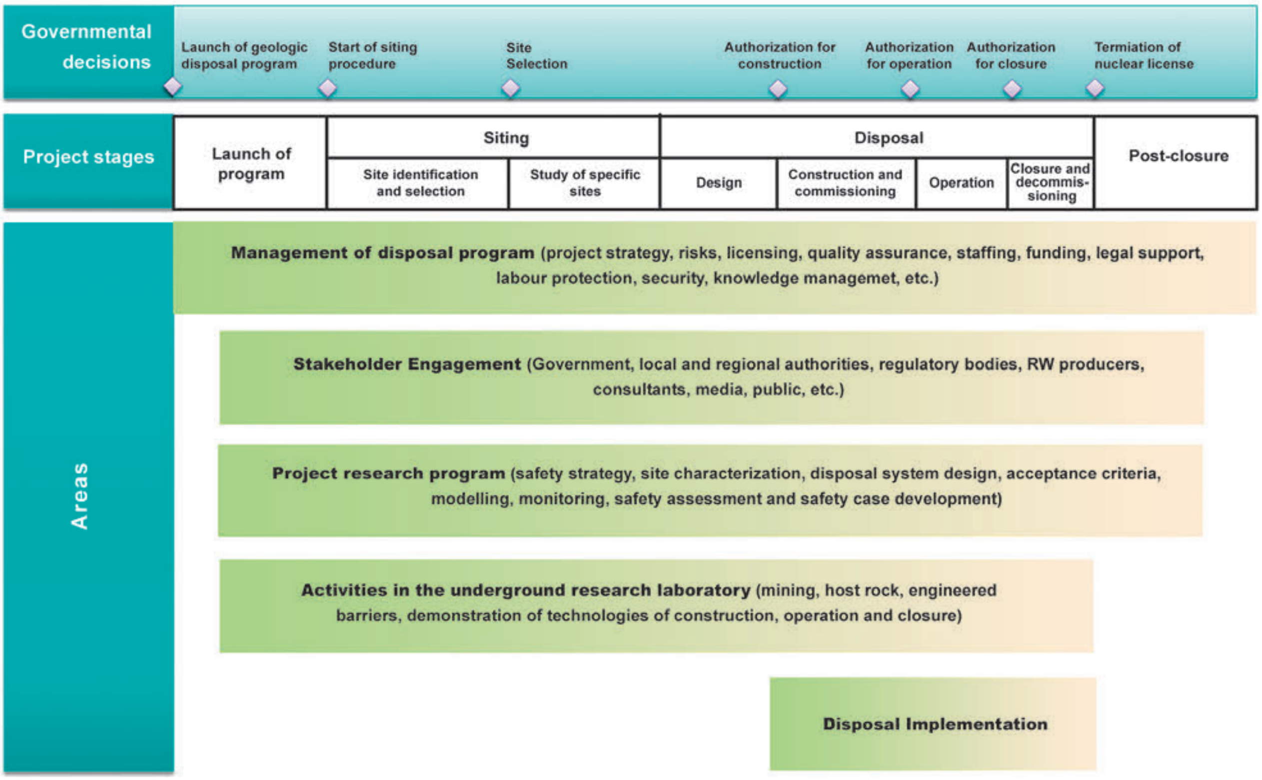

Fig. 1. General logic of arranging activities on the development of a deep geological RW repository

In the recent years, the situation has changed drastically. In 2016, FSUE NO RW developed a key document — Report on Demonstrating the Safety of Siting and Construction of RW Storage Facility Being a Non-nuclear Installation Developed in Accordance with the Design Documentation for Construction of RW Final Disposal Facilities (Krasnoyarsk Krai, Nizhnekansk Rock Massif) as a Part of an Underground Research Laboratory. In spring 2016, these materials were reviewed at the Session No. 10 of the State Corporation "Rosatom" Scientific and Technical Council, and then submitted to Rostechnadzor as part of license application process. In both cases, the review resulted in extensive remarks. The current state of the project reflects the following:

- there is a need for a rational fragmentation of the project, since its current form suggests that one can not specify the components that could be viewed as completed construction structures;
- the project involves a number of engineering solutions, which have not yet been duly tested;
- the project does not envisage traditional investigation excavations and wells being part of the URL.

In light of the existing situation, there is a need to define a more flexible strategy suggesting some corrections to be introduced to the project and some major decisions regarding DRWDF layout, safety and construction put off until the research stage at the URL (at the same time, some studies will be performed outside the URL).

It should be noted that this approach is in line with the international practice: if there are clear strategic goals for construction of deep RW disposal facilities and decision-making milestones, there is also a considerable variability in the actual implementation of specific activities.

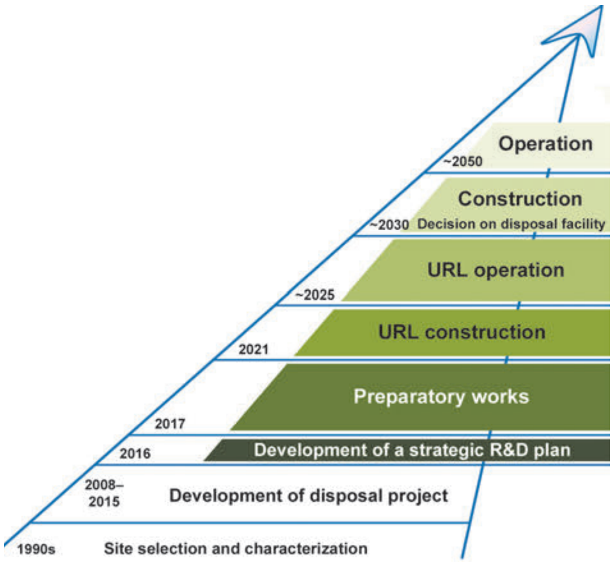

Fig. 2. Main Stages of Deep RW disposal facility lifecycle (implemented and planned)

It should be noted one more time that a strategy is required enabling to specify the time schedule for specific stages, as well as some key infrastructure requirements. For example, characterization of accumulated waste inventory may result in some corrections to be introduced to the current RW classification system for disposal purposes and relevant acceptance criteria [7].

In 2016, due to the specific nature of research required for decision-making (scope, scientific intensity, diversity and interconnection) suggesting that it would be impossible to select a single organization possessing all the required competences, the Director for State Policy in the Field of RW and SNF Management and Decommissioning of Nuclear Facilities of the State Corporation "Rosatom" acknowledged the advantage of having an integrated view of scientific and technical support challenges associated with the DRWDF development project (hereafter referred to as the Project) in the form of a strategic master-plan (SMP NKM).

It should be noted that the methodology of strategic planning has proved to be successful during the implementation of such comprehensive and long-term projects as decommissioning of nuclear submarine fleet facilities in the North-West of Russia [8] and achieving the safe configuration of the Techa Cascade of water reservoirs at FSUE PA "Mayak" [9].

The format of the overall Project management system and the place of SMP NKM within the system are currently being discussed. One of the preferred options would be an industry-level strategic planning document (in terms of the federal law [16] (paragraph 27, article 3)) with a unique planning time-frame and a type of costs that is defined as a "departmental non-investment integration targeted program". The document is to define the priorities, goals and tasks for the state management of the 1st and the 2nd hazard class RW disposal and assurance of national security of the Russian Federation, means of effective implementation of these goals and decisions addressing the challenge of ensuring the long-term safety of RW disposal.

SMP NKM within the planning timeframe of 2070 (being the minimal reasonable timeframe for making decisions on DRWDF closure) will allow for: stepwise optimization of the design and operational parameters of URL and DRWDF (as needed); development and support of the research program and the program for RW pre-disposal management, development of long-term DRWDF safety cases both for Russian regulatory bodies and international peer reviews.

A prototype of the future knowledge base, a special system named PULSE (Project of the Underground Laboratory Scientific Escort) is currently being developed (para 3.15 [11], para 3.12 and 6.83 [12], para 4.98[13]). PULSE encompasses:

- Information about the design (disposal concept and safety functions; documentation; review comments and remarks; relevant support).
- 907 features, events and processes (FEPs) recommended by NEA/OECD [10] and/or considered in various foreign projects: Tono, Kamaishi, MIU, Honorobe (Japan), KURT (Korea), ONKALO (Finland), Aspo HRL, Stripa (Sweden), Grimsel TS, Mont Terri URL (Switzerland), Fanay-Augeres, Amelie, Tournemire RT, Bure (France), Climax, G-Tunnel, Busted Butte, WIPP, ESF (USA), etc. (Fig. 3).

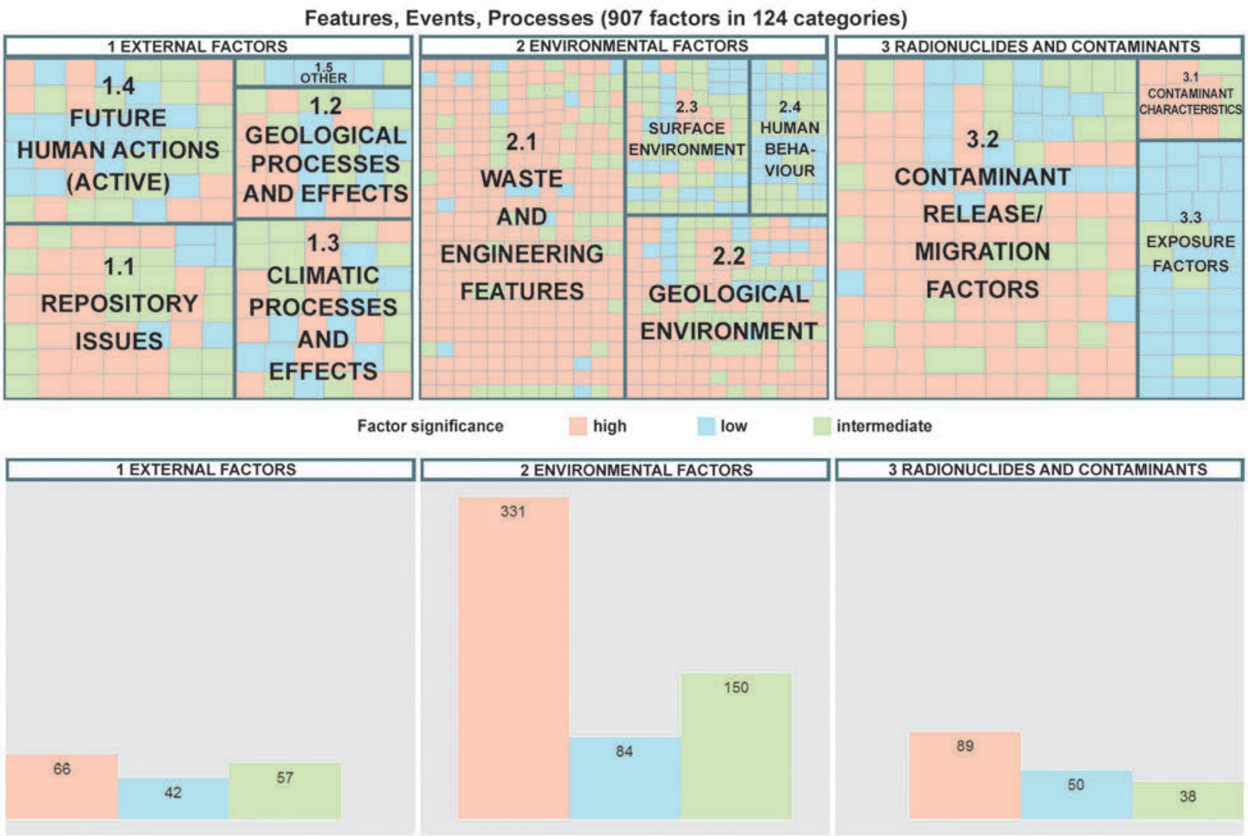

Fig. 3. Relevance analysis of features, events, and processes

- 50 IAEA requirements and recommendations reflected in key documents [11—13] (Fig. 4), which were directly referred to during the IAEA peer review on assessing the LRW deep well injection practice in the Russian Federation [14].
- Over 1000 references and other documents associated with the Project (Fig. 5).
- Over 160 research tasks of various levels (table 1) classified both by relevant elements (components) of the disposal system to which they belong (table columns) and relevant types of research performed (table rows).

Each research task is presented as a work breakdown and constitutes an input to the PULSE system with the following data: name of the research task and unique identification code specifying the place where the research is to be conducted (e.g., URL), the goal and prerequisites (e.g., IAEA recommendations, including the need to consider specific FEPs; comments expressed in Rosatom and Rosnedra reviews, design documentation, safety case etc.); estimated duration of the research activity; preceding research task and the "customer" of the research; research methods and their rationale; expected results; terms of reference.

With the start of operations at the site, including drilling and mining, as well as relevant research at the URL, there will be an ever-growing increase of the amount of actual data to be taken into consideration during the long-term process modelling.

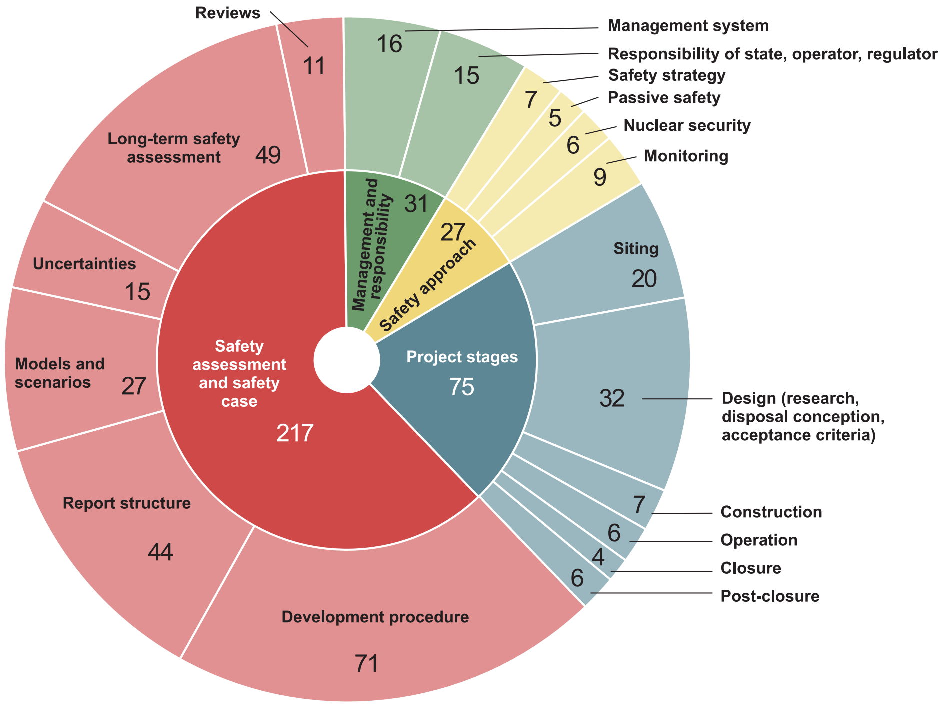

Fig. 4. Decomposition of IAEA requirements and recommendations (the numbers indicate their quantity for the relevant area)

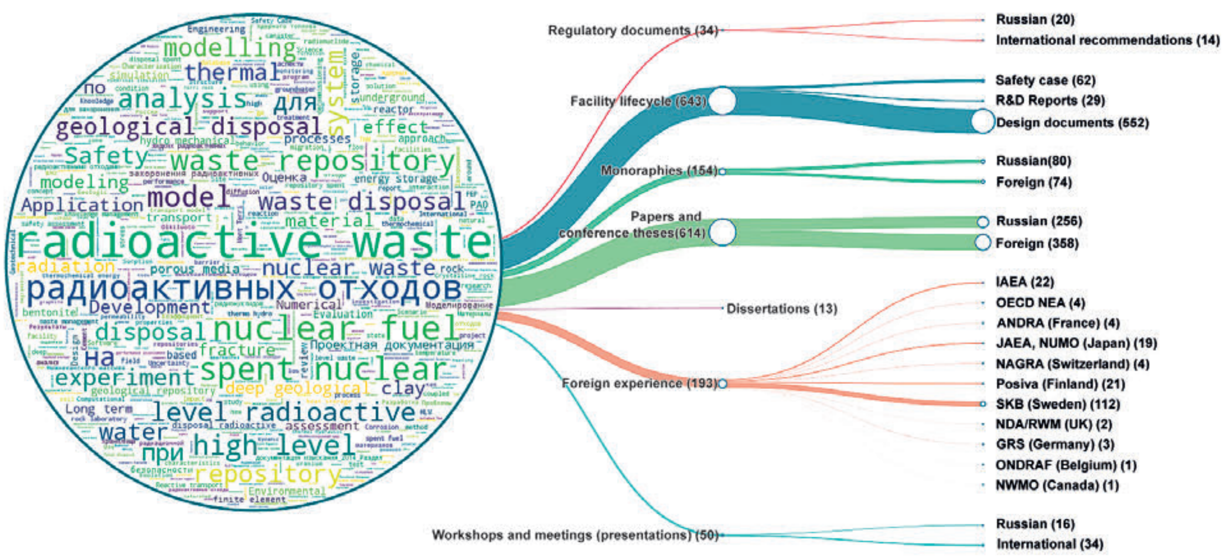

Fig. 5. SMP NKM Library

Table 1. Principle of categorization and main areas of research

	Geosphere	ESB	RW	Equipment	Biosphere
Monitoring	**Hydrogeology** • hydrodynamic observations in wells and shafts • URL impact on environmental medium		**Waste inventory** (accumulated RW, new types of RW)		**Monitoring observations**
	Geochemistry (chemical composition of ground waters)				
	Geodynamics and SS (stress state) • contemporary movement of • earth's crust • geodynamics monitoring • seismic acoustic monitoring				
Technology demonstration	**Excavations** • scientific support • optimization of methods • isolation of faulted zones	**Production** • analysis ofcapabilities of Russian resource suppliers • selection of barrier materials composition • production of materials • production of Confining Containers (CC) • materials quality control	**Preparation for disposal** • placement of packages of class 2 RW in cells • placement of a simulator of class 1 RW package • in CC • package acceptance control • RW registration • optimization of technological processes	**New equipment** • network of automatic hydraulic pressure monitoring; • regular sampling of ground waters; • posts of seismic monitoring; • instrumentation for measuring of water permeability of fractures; • equipment for disposal of CC with RW in wells • laser 3D-mapping of the surface of underground shafts	
		Backfilling • remote backfilling with barrier materials • introduction of thixotropic slip to the wells • sealing of areas with high water permeability • allocation of barrier and backfilling material in chambers		**Disposal:** • non-standard equipment; • potential retrieval of packages	
				Sealing	
Field studies	**Geological structure:** • areas of high crackling • tectonic disturbances • lithological non-uniformities of geological medium	**Operation modes:** bentonite behaviour, change of tensions in ESB		**Demonstration of technological operations**	
	Hydrogeology: • water behaviour in construction • filtration characteristics • water permeability properties of fractures	**Chemical processes and conditions:** • interaction of materials, barriers and underground water • change of chemical properties barriers materials and underground water • oxidation-reduction conditions			
	Migration properties	**Microbiologic conditions** • microbiologic degradation • gas generation			
	Geothermal mode: • thermal physics characteristics • thermal monitoring				

Table 1. Continued

<table>
<tr><th></th><th>Geosphere</th><th>ESB</th><th>RW</th><th>Equipment</th><th>Biosphere</th></tr>
<tr><td></td><td>Geodynamics and SS
• determination of tension field, direction of highest tension, value and directions of main tensions
• study of tension fields of surrounding rock
• determination of physical and mechanical properties</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="5">Laboratory experiments</td><td>Filtration properties
• effective diffusion components
• water conductivity and gas conductivity</td><td>Physical and mechanical properties
• bentonite-based buffer materials
• concrete-based materials (concrete, slip and etc.)
• dependence on the thermal field and humidity</td><td rowspan="2">New methods of RW composition monitoring</td><td rowspan="5"></td><td rowspan="5"></td></tr>
<tr><td>Migration properties
• adsorption and sedimentation of radionuclides
• radionuclide solubility limits
• role of biocolloids</td><td>Chemical properties
(change of composition of pore waters)</td></tr>
<tr><td>Properties of underground waters
• ground waters age
• colloid fractions
• microbiologic composition</td><td>Migration properties:
• parameters affecting the transport and their relation to temperature and humidity</td><td rowspan="3">Release
• release rate
• corrosion layer of the glass matrix
• release from the irradiated graphite</td></tr>
<tr><td rowspan="2">Rock properties
• thermal physical, mechanical and strength
• chemical and mineral composition
• fracture filling</td><td>Processes
• rate of container corrosion
• gas generation due to corrosion processes
• evolution of material properties
• biodegradation</td></tr>
<tr><td>Colloids and pseudo-colloids</td></tr>
<tr><td rowspan="3">Theory and modelling</td><td>Structural geological model
• 3D geological and tectonic model
• 3D model of lithological differences and fracture areas
• SS thermal impact</td><td>Evolution model
• SS of the rock mass and ESB system
• corrosion of metal components
• gas generation
• change of composition of underground waters and material properties
• change of barrier properties at thermal impacts
• colmatation process in fractured rock mass
• impact of radiolytical hydrogen on the safety</td><td>Release of radionuclides (change of RW material properties)</td><td>Optimization models for the operational period (dynamic 3D model)</td><td>Scenarios</td></tr>
<tr><td>Geofiltration and geomigration model
• 3D two-phase geofiltration model
• chemical model of interaction with geologic medium
• geologic evolution</td><td rowspan="2">Migration model
• adsorption and sedimentation parameters
• two-phase flow
• colloids</td><td rowspan="2">Calculations for optimization of acceptance criteria</td><td rowspan="2"></td><td rowspan="2">Impact on the population and the environment</td></tr>
<tr><td>Hydrogeological model</td></tr>
<tr><td>Project Management</td><td colspan="5">Knowledge base, data analysis, research programs, regulatory framework</td></tr>
</table>

Therefore, the SMP NKM clearly defines the tasks for the first years. In accordance with the decision of STC No. 10 [15], the following activities are being considered as high-priority ones for 2017—2019:

1. Development and maintenance of (knowledge) DRWDF database.

2. Development of a comprehensive standing model enabling to demonstrate DRWDF safety, which shall include the following interrelated models:

- thermal impact of RW and SS of the engineered barriers system within the near field of the facility;
- evolution of engineered safety barriers and radionuclides transport in the near field;
- far field, including geological, geomechanical, geomigrational and geofiltration models;
- technological simulation model of the RW management systems in DRWDF;
- integral model enabling to evaluate the long-term DRWDF impact on the population and biota (including FEPs, evolution scenarios, transport of radionuclides in the near field and in the far field, reference biosphere, etc.).

3. More precise categorization of facility systems and elements with account for external and internal processes, phenomena, and natural and man-caused factors.

4. More detailed estimates regarding RW volumes and characteristics affecting the long-term DRWDF safety.

5. Development of a scientific support program for mining operations performed during URL and DRWDF construction.

6. Scientific support and development of recommendations regarding the project management during URL and DRWDF construction.

7. Justification and development of a comprehensive DRWDF monitoring system.

8. Additional studies of the region and DRWDF site:

- Continuous geodynamic monitoring studies.
- Geophysical investigations of faults.
- Drilling of new well clusters enabling to refine the parameters of host rock and ground water flows to the discharge area.
- Studies in the existing deep wells.
- Water balance studies.

9. Laboratory studies to define types, mechanisms and kinetics of physical and chemical processes resulting from the interaction of radionuclides and DRWDF engineered safety barriers, ground waters and host rock.

In 2017, practical efforts were started for the majority of the areas mentioned above. It is critical to understand their stepwise manner which is typical for the majority of activities aiming to demonstrate the long-term safety.

In the future, the plan of research should regularly be updated based upon the results obtained. The plan shall be used for coordination and optimization of activities carried out by various design and scientific organizations, development of detailed plans of specific actions, and as a basic tool arranging for the continuous process enabling the integration of the results and their reviews.

The overall results of the activities performed in 2017 and covering various topics of the research program indicate on the whole an increased need for establishment of a project management system, approval of a strategy for DRWDF construction allowing the required variability of decisions, concentration of efforts on correction of URL decisions and assigning R&D tasks under specific contracting arrangements.

References

1. IAEA-Tecdoc-1243. The use of scientific and technical results from underground research laboratory investigations for the geological disposal of radioactive waste. Vienna, 2001.
2. Study of granitoids of Nizhnekansk range for RW disposal: Materials of the Coordination scientific and technical council on scientific support of design and construction of RT-2 plant at MCC. — Zheleznogorsk, St-Petersburg, 1999. — 181 p.
3. Proceedings of Khlopin Radium Institute. — V. XI. — SPb, 2006.
4. Summary of foreign practices of SNF and RW disposal/ N. S. Tsebakovskaya et al; edited by I. I. Linge and Yu. D. Polyakov — M.: “Komtehprint”, 2015. — 208 p.
5. *Tsebakovskaya N. S., Utkin S. S., Linge I. I., Pron. I. A.* Foreign projects of SNF and RW disposal. Part I. The current condition of the projects of deep geological disposal facilities in European countries: Preprint of IBRAE, No. IBRAE-2017-03. — Moscow: IBRAE RAN, 2017. — 35 p.
6. *Tsebakovskaya N. S., Utkin S. S., Konovalov V. Yu.* Foreign projects of SNF and RW disposal. Part II. Current condition of the projects of deep geological disposal in the USA, Canada and Asian region: Preprint of IBRAE No. IBRAE-2017-04. — Moscow: IBRAE RAN, 2017. — 41 p.
7. *Linge I. I., Samoylov A. A.* Opportunities for optimization of regulation of the unified state system of radioactive waste management // Issues of radiation safety. — 2016. — No. 4 (84). — P. 12 — 20.
8. Order of Rosatom of 26.12.2007 No.686 “On the Strategic Master-Plan for decommissioning and environmental remediation of the nuclear fleet objects withdrawn from operation and the supporting infrastructure in the North-West Region of Russia”.
9. Strategic Master-Plan for solution of the problems of the Techa water reservoir range of FSUE “PA “Mayak” / IBRAE RAN et al. Approved by the Director General of the State Corporation “Rosatom” on 15.02.2016.
10. Features, Events and Processes (FEP) for Geologic Disposal of Radioactive Waste, NEA International FEP Database : Version 2.1. — NEA OECD, 2006.

11. Disposal of radioactive waste. Specific safety requirements. No. SSR-5. IAEA Safety Standards. - IAEA, Vienna. — 2011.
12. Geological Disposal Facilities for Radioactive Waste, Specific Safety Guide No SSG-14, IAEA Safety Standards. — IAEA, Vienna. — 2011.
13. The Safety Case and Safety Assessment for the Disposal of Radioactive Waste, Specific Safety Guide No SSG-23, IAEA Safety Standards. — International Atomic Energy Agency, Vienna, Austria. — 2012.
14. *Linge I. I., Utkin S. S., Khamaza A. A., Sharafutdinov R. B.* Experience of application of international requirements to long-term safety cases for radioactive waste disposal facilities: problems and lessons // Atomic energy. — 2016. — Iss. 120. P. 201 — 208.
15. Program of studies in the underground research laboratory (URL) in the Nizhnekansk range for confirmation of the design safety parameters for disposal of class 1 and class 2 RW: Decision of section No. 1 "Environmental and radiation safety of facilities for long-term storage, conservation and disposal of RW" of STC No. 10, the State Corporation "Rosatom", 06.04.2016.
16. Federal Law of 28.06.2014 No. 172-FZ "On strategic planning in the Russian Federation" // Rossiyskaya gazeta. — 2014. — No. 146.

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Bibliographic description

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