NO0000004

Problems Related to Final Disposal of High-level Radioactive Waste in Russia

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1. RW types and quantity, stored at different departments.
All types of radioactive wastes (RW), considered in IAEA (1994) classification, are accounted for in the different Russian organizations and enterprises:

- unprocessed liquid high-level wastes (HLW) from nuclear weapons production;
- liquid and solid low-(LLW), intermediate-(ILW) and HLW from nuclear power industry operations in the framework of the closed nuclear fuel cycle and from the transport nuclear reactors;
- liquid (LRW) and solid (SRW) radioactive wastes from ionization sources.

Total RW volume, accumulated in Russia to date, ranges about $6 \cdot 10^8$ m^3. Its bulk radioactivity reaches $1.5 \cdot 10^9$ Ci. RW distribution analysis on different departments and enterprises, illustrated in table 1, shows, that 99.9% of wastes are accumulated at the enterprises of Minatom of the Russian Federation.

Table 1 *(from data of N.N.Egorov, 1998).*

1 in order	RW source	RW type	RW volume (m^3)	Activity (Ci)	Storage type
Minatom enterprises					
1.	Radioactive ore mining and processing.	Sludge's and barren rock heaps.	$1.0 \cdot 10^8$	$1.8 \cdot 10^5$	Surface storages, open plots.
2.	Atomic power plants.	LRW, SRW	$2.72 \cdot 10^5$	$4.4 \cdot 10^4$	Storages, containers.
3.	Radiochemical enterprises.	LRW, SRW, solidified RW	$5 \cdot 10^8$	$1.47 \cdot 10^9$	Containers, storages, reservoirs, basins
Sum			$\mathbf{6 \cdot 10^8}$	$\mathbf{1.47 \cdot 10^9}$	
Ministry of Defence (Navy)					
4.	Exploitation of Nuclear Submarines (NS).	LRW, SRW	$2.7 \cdot 10^4$	$9.8 \cdot 10^2$	Storages, land storage facilities and mother ships.

5.	Exploitation of atomic icebreakers.	LRW, SRW.	$1.9 \cdot 10^3$	$2.0 \cdot 10^4$	Land storage facilities.
Sum			**$2.9 \cdot 10^4$**	**$2.1 \cdot 10^4$**	
Former Goskomoboronprom of Russia					
6.	NS construction and utilization.	LRW, SRW.	$4 \cdot 10^3$	$6 \cdot 10^2$	Land storage facilities and mother ships. Storages.
Ministry of Russia					
7.	Utilization of ionizing radiation sources (IRS).	LRW, SRW, solidified RW, IRS in ampoules.	$2 \cdot 10^5$	$2 \cdot 10^6$	Storages, 16 special combines «Radon».
Sum total			**$6 \cdot 10^8$**	**$1.47 \cdot 10^9$**	
Spent fuel (SF) quantity					
8.	Fuel mounting of RBMK, VVR, of transport and research reactors.		$8.5 \cdot 10^3$ t	$4.45 \cdot 10^9$	APP storages, PA «Mayak», mother ships of Research Institutes.

8 500 t of spent nuclear fuel (SF) with total radioactivity of $4.5 \cdot 10^9$ Ci (Table. 1), is accumulated also in APP and temporary storages of Minatom radiochemical enterprises, of which 6000 t with activity $3.0 \cdot 10^9$ Ci ranges SF from reactors RBMK and 2 500 t SF from reactors VVR – with activity $1.5 \cdot 10^9$ Ci. Last mentioned are to be processed and represent an additional potential RW source.

2. Practice of RW management in Russia.

Russia develops its nuclear energetic on the base of closed nuclear-fuel cycle concept, providing SF processing. However, there is no consensus in the country concerning practice of RW management for all nuclear-radioactive enterprises. A method of liquid LRW and ILW injection into the deep-seated reliably isolated aquifers is employed from the early 1960s at the Siberian Chemical Combine (SCC, Tomsr-7), at the Mining Chemical Combine (MCC, Krasnoyarsk-26) and at the State Scientific Centre of the Scientific Research Institute of Nuclear Reactors (SSC SRINR, Dimitrovgrad). At the PA «Mayak», because of the absence of the appropriate geological conditions of liquid wastes disposal, liquid LLW and ILW were released into the artificial reservoirs and Karachay lake, respectively. Liquid HLW at all radiochemical enterprises are stored in special tanks in the interim storage facilities. At PA «Mayak» a part of these wastes (more then 2 000 t of solidified HLW with total activity near 300 mln. Ci was solidified in alumophosphate matrices which are stored in special engineering facilities. In locations of nuclear fleet bases at the north-western region and at the East of Russia, about 150 nuclear submarines (NS), 60% of which with the not unloaded spent fuel (SF), are by now forced out of operation and require safe management. RW and SF interim storages of these regions are filled practically up to project levels. Enterprises on RW conditioning are absent.

3. Conceptual essentials of underground RW disposal strategy on the base of new technologies.

Underground RW disposal is accepted as the most ecologically, technically and economically reasonable way for the safe RW isolation from the ecosphere for the whole period of its potential radiobiological hazard. This way dependably allows to guarantee a socially-acceptable risk at all cases of radionuclides escape to the environment independent of the. Preparation of liquid LLW and ILW for disposal is accomplished by LLW solidification in cement and bituminous matrices and ILW – in glasslike compositions. Two new technologies, which will allow to alter fundamentally common strategy of RW underground disposal, are planned. The first – a technology of synthesization from mineral mixtures, containing titanates, zirconium-titanates and alumosilicates, new high-stable mineral matrices, which include radioisotopes in its crystallic structure on the base of isomorphic replacement mechanism. Mineral matrices, containing zirconolite and murataite are very effective for actinides immobilization, These matrices are three orders of magnitude more stable than alumophosphatic glasses, used so far at RW solidification. They firmly confine from 10-12% up to 18-20% of Uranium and Cerium, imitating in experiments presence of transuranic radioisotopes (Laverov e.a., 1997). The second «know how» is a technology of all liquid RW types grading, whereby radionuclides fractions, which characterized by different duration of existence, dissimilar toxicity, specific radioactivity and physical volumes, are selectively separated from the bulk of wastes. This technology is elaborated in pilot variant at PA «Mayak» (Dzekun e.a., 1996). Extractive-sorptive-industrial method of liquid RW separating at actinide, caesium-strontium, rare earth and palladium fractions makes its basis. Industrial assimilation of this technology will allow to solve customary a problem of appropriate safe localization of new-formed RW fractions, which contain:

- long lived high toxic radioisotopes (actinides and radionuclides, close to them on its protraction of existence), containing a less part of RW common volume and characterizing by half-decay periods at tens-hundreds of thousands of years and more;
- medium lived high toxic and heat releasing caesium-strontic and similar half-life radioisotopes, dominating in RW common volume and having half-decay periods of a fear tens of years;
- last, short lived, less toxic radionuclides with half-decay periods up to 10-20 years.

Thus, for prevention of toxic action on ecosphere of liquid RW fraction, containing long-lived radionuclides, its reliable isolation is required on many thousands of years. Such isolation conditions may be created by including long-lived radioisotopes in previously named high stable mineral matrices and by disposal of these latter in the Earth crust at the depth not less than 2-3 km. Geoblocks, which are in a state of long-term tectonic rest and are formed by rocks, possessing of effective protective properties, are suitable for construction of deep-seated repositories. Liquid RW of caesium-strontium fraction demand reliable isolation from the environment at a term of 500-1000 years. For providing its secure localization it is necessary to transform radionuclides to glass-like forms and to dispose these matrix materials in underground repositories at the depths of the first hundreds of meters. Geological medium may consist vulcanites of basic composition, clays, salts and other rocks, ensuring required isolation. For providing secure localization of short-lived LLW and ILW, it is worthwhile to condition it and dispose at subsurface ferroconcrete repositories, constructed in clays.

4. Selection of sites and conditions of RW disposal.

Subsurface repositories of short-lived LLW and ILW is worthwhile to construct near sites of production and temporary storage of these wastes. For disposal of Cs-Sr fraction of vitrified RW it is proposed to construct regional repositories, which are to be placed in the regions of radiochemical Minatom combines location; these combines are actual (PA «Mayak») or potential (MCC Krasnoyarsk-26) liquid RW producers. Production Association (PA) «Mayak» is located at the Eastern slope of Ural mountain ridge in Chelyabinsk oblast (Fig. 4). Enterprise was founded at 1948. Prior to the year 1986 it produced weapons plutonium and since 1976 spent nuclear fuel processing (plant RT-1) is underway. Accumulated and producing RW are solidified to glass-like alumo-phosphatic matrices. In immediate prospect all RW types are to be fractionated with separating caesium-strontium and actinides solo fractions (Glagolenko e.a., 1996, 1997). RW repository construction is projected on the area of PA «Mayak» sanitary-protective zone (SPZ); having regard to structure, composition and state of geological medium, it is worthwhile to use this repository for disposal of fractionated RW, containing radioisotopes of Cs and Sr. Vulcanites of basic composition with total thickness near 2 km serve as the most suitable medium for localization of mentioned RW in the limits of PA «Mayak» site. This thickness is formed by andesite-basaltic porphirites, by its tuffs and lavas, which possess low (~0.2-0.3%) effective porosity and high mechanical and thermal stability. As a whole, vulcanite's thickness is characterized by relatively homogenous chemical composition. According to experimental investigations data, porosity in vulcanites at temperature ~200 C and elevated pressure leaves unchanged. Primary vulcanites minerals (Ca-Na plagioclases, pyroxenes, olivines) in the presence of heated water are subjected to replacement by secondary minerals (epidote, chlorite, hydromicas of Fe, Mn, mixed-layered and clayey minerals); last named possess high sorption properties in relation to radionuclides and therewith «heal» porosity and rocks microcracks, since they occupy more volume than primary minerals. Recorded vulcanites properties characterize these rocks as suitable for RW disposal. At the same time PA «Mayak» site shows intensive but uneven tectonic disturbance. Regional fault zones of various orientation and thickness are separated. Inside it rocks are subjected to intensive schistosity, cracking, are dissected by tectonic seams, complicated by the shifts of post-Quaternary age. These zones possess high permeability and are a main medium in a rock basement of underground water transport. Considering its high water conductivity, as well as, probability of its alteration by the late tectonic movements, areas, occupied by fault zones, are considered as unsuitable for locating there engineering facilities of repositories (Velichkin e.a., 1997). Essentially less disturbed blocks are located between outlined zones. In those which are in the limits of PA «Mayak» SPZ and formed by volcanogenic rocks of basic composition, possessing, as was shown above, by dependable isolating properties, three plots were selected, which may be recommended for further more detailed examination with the purpose of site selection for construction of underground laboratory and subsequently – RW repository. Taking into account relatively small dimensions of separated sites (from 1.5 up to 3 km^2) it is evident that it is impossible to position there the complex of engineering facilities, necessary for construction of shaft type repository. Using for disposal of wells of large (not less than 600 mm) diameter, experience on heading which is in Russia, represents more actual. Based upon peculiarities of territory SPZ geological structure, formed by suitable for disposal volcanogenic rocks, the most optimal level of proposed repository deeping is depths interval 500-1000 m, in which limits it is possible to provide dependable isolation of Cs-Sr RW fraction on demanded 500-1000 years. One further regional RW repository is designed to create at the region of Mining Chemical Combine (Krasnoyarsk-26). On the territory of this enterprise underground radiochemical plant, which processes SF and therewith produces RW, acts, as well as, construction of even larger plant RT-2 of similar profile was began. At placing it in operation, RW quantity at MCC will rise sharply. Taking into account this situation, investigations on the selection of sites, suitable for underground RW disposal, in Nizhnekanskyi granitoide massif, located in the immediate vicinity of MCC SPZ, were began. Complex of required geologic-geophysical investigations were conducted, on which results two sites were selected with the area near 7 km^2 each (Anderson e.a., 1998), recommended for the further more detailed investigation with the purpose of revealing polygon for creation of underground laboratory and then – RW repository. Both sites are formed by biotic granites and granodiorites, which in undisturbed state possess by only a slight porosity (~ 10^{-7} Md) (Anderson e.a., 1998). Taking into account high isolating properties of noted rocks and location of marked prospective sites in the lateral part of vast Eastern-Siberian platform, characterized by resistant tectonic stability during last hundreds of millions of years, it is possible to realize, in the limits of investigated territory of Nizhnekanskyi granitoide massif, of underground disposal of fractionated and then solidified RW just as of caesium-strontium, so of actinidic fractions. Disposal depth in interval of 500-1000 m from the present surface is quite sufficient for Cs-Sr-containing matrices. For providing dependable isolation of actinide-containing RW and exception of probability of subjection at repository of regional erosion, disposal depths not less that 2-3 km are necessary. Taking into account possibility of noted RW fractions disposal at different depths, a variant of location of two repositories in the limits of the sole site, represents to be quite realizable.

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