Radioactive Waste Management Strategy at the Production Association «Mayak»

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The main approaches in current radioactive waste management at the Production Association «Mayak» (PA «Mayak»), has been examined. The description of the properties of high-, medium-, and low-level radioactive wastes is given, together with a brief description of the methods of storage and reprocessing.

The Production Association «Mayak» (the former Chemical Engineering Plant «Mayak») was founded in the late forties with the aim to produce plutonium for military purposes and to process fissionable materials in order to reach parity in the sphere of nuclear weapons. Later on, the well-developed infrastructure of the enterprise allowed to start non-military production of nuclear fuel cycle, radioactive sources and radioactive preparations. In 1955, a radioisotope plant was put into operation, in 1976 a radiochemical engineering plant dealing with reprocessing of spent nuclear fuel from nuclear power stations, transport and research plants was put into service. In 1986, the radiochemical engineering plant stopped to reprocess irradiated fuel and to produce plutonium, and some time later 5 industrial uranium-graphite reactors and a number of other production facilities of defensive character were removed from operation. To approach the problems of radioactive waste management and environmental restoration, the Production Association «Mayak» developed a comprehensive program covering the entire range of the problems accumulated during the past and current activities, with due regard to the new perspective spheres of operation.

High-Level Liquid Radioactive Wastes (HLW)
In the course of defence program performance about 19000 m^3 of high-level radioactive wastes and high-level radioactive suspensions with total radioactivity 135 million Ci were accumulated at the PA «Mayak». The chemical and radionuclide composition of the suspensions is rather complicated, as concentration by sedimentation was applied to the solutions obtained as a result of reprocessing of different types of irradiated units and fuel assemblies (hydrate, sulfide, ferrocyanide sediments). Part of the wastes (about 8000 m^3) remaining after the reprocessing of fuel assemblies by extraction methods is stored in reservoirs as high-level radioactive nitrate solutions with total radioactivity 200 million Ci. The above solutions with nitric acid concentration up to 3 mole/l were obtained by evaporation (concentration by boiling) and contain the following chemical elements: aluminum (1-3 g/l), natrium (2.5-3 g/l), fermium (1-10 g/l), nickel (1-5 g/l), chromium (0.3-2.0 g/l), calcium (0.2-2.0 g/l), sulfate ion (1-3 g/l), platinoides and rare-earth elements. Besides, about 2,000-3,000 m^3 of HRW with total radioactivity up to 100 million Ci is produced annually at the radiochemical engineering plant in the course of reprocessing of spent nuclear wastes from Navy power facilities and reactors. The aqueous tailing solution remaining after reprocessing of enriched fuel assemblies contains salts- up to 200 g/l and nitric acid- up to 250 g/l. The radioactivity of the solution reaches 30 Ci/l. The solution obtained in the result of reprocessing of the fuel assemblies of nuclear power reactors contains salts- up to 10 g/l and nitric acid- up to 250 g/l, with radioactivity -up to 60 Ci/l. Some information on the volumes of high-level radioactive liquid wastes (for 01.03.95.) is given in Table 1.

Table 1. The volumes of high-level radioactive wastes accumulated at PA «Mayak»

Type of wastes	Volume, m^3	Total radioactivity, million Ci
Suspensions	19000	135
Nitrate solutions	11700	249
Vitrified wastes	1974	246

The accumulated high-level radioactive nitric solutions are stored in 18 special reservoirs with the total capacity 316 m^3 and the effective capacity 285 m^3, diameter 9 m. and height 5 m. The reservoirs are made of stainless steel X18H9T in the form of cylinders with covers and bottom. The reservoirs are supplied with measuring instruments of the level, pressure and temperature control, overflow indicators, blow-off gas collectors, air feed collectors for dilution of the evolved radiolytic gases. For heat abstraction purposes, the reservoirs are fitted with coil pipes (made of three sections) with cooling surface 60 m^2. Each reservoir is incorporated into a canyon of stainless steel. The canyons are fitted with indicators and pipe-lines located in special pits and serving for identification of possible leaks and for collection of the liquid. Evaporated nitric solutions are stored in 3 reservoirs made of stainless steel X 18H10T with the effective capacity 1500 m^3 each. The diameter of the reservoir is 22 m., height - 4.25 m., total capacity-1553 m^3 Each reservoir is located in a separate canyon lined with stainless steel. For heat abstraction the reservoirs are fitted with 16 sectional coil pipes uniformly distributed over the area. The total area of the cooling surface is 300 m^2. 20 storage reservoirs are used for storage of the suspensions. The reservoirs are the concrete compartments as big as 19.5 x 9.5 x 7 m., lined with stainless steel, with effective capacity 1170 m^3. 12 reservoirs are fitted with the internal cooling system and with the meters checking level, pressure, temperature and gas emission. In order to remove or dilute the hydrogen and methane released in the process of radiolysis, the air over the surface of the solution is blown off. Inside the vitrification compartment there is a storage facility designed for storage of the vitrified wastes with maximum heat release -5 kW/m^3. The storage facility is divided into 7 compartments, each supplied with independent ventilation. Each of the compartments has 338 pockets (racks). Each bed is designed to accommodate 2 cases containing three cans of vitrified mass (200 l each). The first compartment contains 13 control racks that hold the cases which are to be monitored for leakproofness. In accordance with the concept of closed-circuit water-supply system and safe radioactive waste management, a basic process scheme for handling the liquid radioactive wastes of any radioactivity level was developed at the PA «Mayak» (Fig. 1).The scheme consists of three process chains intended for processing of the solutions with high-, medium-, and low-level of radioactivity, respectively. In accordance with the requirements of safe radioactive waste storage the phosphate glass is used as matrix for HRW, while bitumen or concrete matrixes are used for LRW.

The liquid HRW obtained during spent fuel assembly reprocessing are evaporated (boiled down). The boiled residues first partly mix with the HRW accumulated at the earlier stages, and then, upon fluxing with phosphoric acid and Na nitrate, are vitrified in the electric furnace(ЭП-500) of direct heating with the furnace capacity (output) up to 500 l/hour (Fig. 2). Information on the volume of vitrified wastes is given in the Table 2. The produced vitrified mass is cast into special containers (cans) holding 200 liters. The cans are packed into the cases (3 in each one) and are placed in the temporary storage pockets. The designed specific radioactivity of the vitrified mass is 2500 Ci/l, the specific radioactivity of the produced glass-200-600 Ci/l. The condensed matters produced as a result of the above process, merge with medium-level radioactive wastes. At the present time, all the current HRW are reprocessed in this way. Further reprocessing of the accumulated HRW can be fulfilled only after special treatment of the wastes according to one of the following techniques: e.g. fractionation in the operating electric furnace or using some other alternative plants (electric furnace with insulated electrodes and bottom discharge, induction melter with cold melting pot). A new type of fractionation plant UE-35 for fractionation of HRW has been recently produced at the enterprise. It is designed for strontium and cesium extraction from the wastes by chlorinated Co dicarbide. The technology is in the stage of development.

Fig. 1. The scheme of HRW management.

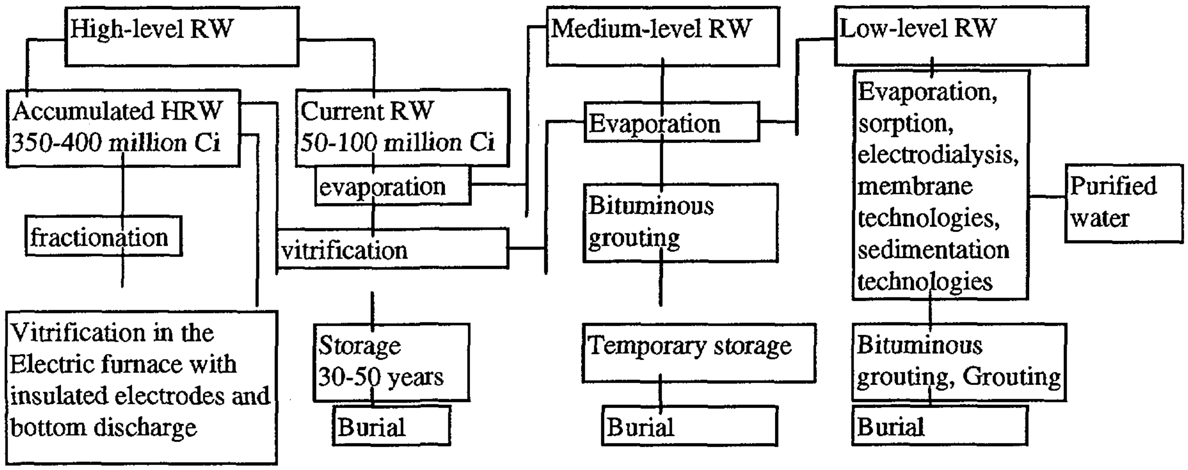
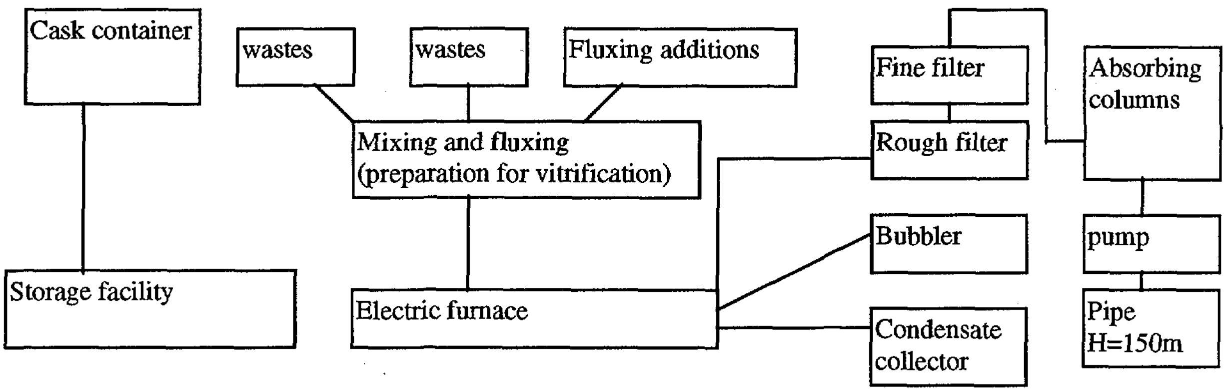


Fig. 2. The scheme showing radioactive waste vitrification process in the electric furnace EP-500



It is planned to complete the development of the plant IPHT (induction melter with cold melting pot) within 1998.

Table 2. The quantity of vitrified wastes.

Year	Wastes mass, t	Wastes radioactivity, million Ci
1987-1990	162	3.96
1991	178	28.2
1992	563	77.7
1993	448	46.8
1994	407	57.4
1995	216	31.7
Total:	1974	245.76

Further steps in HRW management are connected with the development of matrixes of mineral origin suitable for long-term storage and burial.

Intermediate - Level Liquid Radioactive Waste (ILW)

The MRW are usually discharged into open reservoirs (basins) # 9 and # 17 (Table 3)
About 2.5 million m^3 of liquid wastes has been discharged into the basin #9 (Karachay lake) since the start of operation in 1951. The total radioactivity accumulated during this period is about 120 million Ci. Radionuclides are distributed among the mobile bottom sediments (60%), the loam bed of the basin (35%) and the water phase (5%). In the recent years the disposal of the wastes to basin #9 reached approximately 20000 m^3/per year. Specific radioactivity is 104 Ci/l

Table 3. Parameters of the basins # 9 and #17

Index		Basin	
		# 9	# 17
Area, .km2		0.16	0.17
Volume, million m^3.		0.3	0.3
Concentration in water, Ci/l	Strontium-90	$1.7x10^3$	$7x10^{-4}$
	Cesium-137	$1.2x10^2$	$4x10^{-4}$
	Total α-sources		
	Strontium-90		
Concentration in bottom sediments, Ci/l	Cesium-137	1.4	$3.3x10^{-2}$
	In the water	$8.4x10^6$	$4.5x10^3$

At present, the MRW are represented with desorbent solutions from drainage, solutions obtained in the result of washing and deactivation of equipment, solutions from washing of extragents and extractors, solutions from deactivation of covers and cases, condensates obtained in the result of special gas cleaning. The total annual MRW volume is 16-20 thousand m^3per year (less than 1 million Ci). Specific radioactivity of the wastes is 2 x 10^{-2} Ci/l.
In order to stop discharge of MRW into the basin # 9 a new industrial MRW reprocessing complex is under construction. The complex will contain the facilities necessary for preparation, evaporation and bituminous grouting of the solutions, as well as for storage of the accumulated product, ie. the bitumen compound.

Plan of the reservoir water area.
1962- the area of water basin is 51 hectare
1963- the area f water basin is 36 hectares
1995- the area of water basin is 16 hectare

Table 4. The stages of closing of reservoir #9

Year	Number of units PB-1, pcs	Rock volume, thousand m3
1984-86	1426	56,1
1987	1476+32 slabs	33,5
1988	977+12 slabs	36
1989	2188	165
1990	614	193
1991	1363	253
1992	1400	265,5
1993	-	270
1994	-	66
1995		
Total:	9444+44 slabs	1457,3

As a result of the fulfilled works, the area of the reservoir reduced from 36 hectares to 16 hectares by the end of 1995 (Fig. 3). The right selection of strategic and tactical solutions when dealing with the problem of closing of the reservoir, (e.g. arrangement of locks) allowed to reduce considerably the carry-over of radioactive aerosols from the water surface with the wind (through separation of drops from the wave crest) and reduce the hazardous impact of water-spouts' and whirlwinds' transit over the water surface of the reservoir. Nevertheless, it should be noted that complete elimination of the source of wind raise and radioactive aerosols in the air is possible only upon complete closing of the reservoir. In order to provide concrete, practical and scientifically proved recommendations concerning elimination of the source of radionuclide-polluted underground waters, we need to carry out the following work:

- to carry out comprehensive investigation of the geological and hydrological properties of underlying (bedding) rocks in the area of Karachai lake.
- to develop a predictive model of polluted water migration ways.

The above information allows to generalize the problems connected with Karachai lake. In 1995, the calculations were made for evaluation of the area polluted with radioactive substances. The forecasts will serve as a basis for concrete, practical recommendations and undertakings in this sphere. However, even now we can assume that practical measures for elimination of the area of pollution will depend on realization of the following steps:

- blocking the frontal zone of the polluted waters with a network of weep (release) holes;
- pumping-out and cleaning of the polluted drain water;
- discharge of purified water into the Mishelyak river

In this connection certain work was carried out for the development of underground water plume clearing technology. A comprehensive analysis of the reference (control) wells was carried out showing that such waters have the following properties: high salt content, presence of complex-formation elements, contamination with strontium-90 and actinides (uranium). The investigations carried out by means of sedimentation and sorption methods have not allowed to develop an effective technology of underground water cleaning. At the present time, the studies connected with the use of electric membrane technologies are being carried out.

Low-Level Radioactive Wastes(LLW)

Among the low-level radioactive wastes (at PA «Mayak) are the collected leaks (special plumbing system) arriving from the plants. The collected leaks (total volume 0.7-1.0 million m3/per year, specific radioactivity-1,5 x 10^{-5} Ci/l and average salt content -up to 1 g/l) are subjected to demineralization and radionuclide clearing by ion exchanger at the sewage works. The cleaning process includes the use of crystal (quartz) filters for mechanical cleaning, and the application of H- and OH- ion exchangers, connected in pairs.

For regeneration (recovery) of H-cation exchangers a 5% nitric acid solution is used, for OH-anion exchangers- a 3-4% sodium hydroxide is used. The purified water with radioactivity 2 x 10^{-7} Ci/l is discharged into the circulating water supply reservoir #2 (Table 4).

The regenerated purified water from the sewage works (up to 0,1 million m3/per year, specific radioactivity -10^{-4} Ci/l) is discharged into the reservoir #3- one of the series of storage reservoirs. At the present time, a series of reservoirs accepts annually about 2500 Ci/l of radioactive substances. During the entire period of operation of the PA «Mayak» about 1,8 x 10^{5} Ci of radionuclides was discharged into LRW reservoirs, the major part being accumulated in the reservoir #10.

Table 5. Brief summary of the reservoirs used at PA «Mayak»

Reservoir	Reservoir area, m2	Reservoir volume, million m3	Accumulated kCi
#3	0.5	0.17	44
#4	1.3	4.1	7.3
#10	19	76	230
#11	44	230	26
#2	19	83	22
#6	3.6	17.5	0.3
#9	0.16	0.3	120000
#17	0.17	0.3	2000

Solving LRW problems greatly depends on application of the efficient methods aimed at reduction of the volumes of starting (initial) solutions. We plan to test the method of repeated evaporation with further finishing of the process for the needs of industrial use. In the near future, the development of experimental plant DOU-10 will be completed. The still bottoms (residues) are supposed to be solidified by grouting methods.