Safety assessment of near surface disposal facilities in Russia

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Abstract:
Former “Radon” facilities were designed and operated as disposal facilities in early 60-s. The initial assessment performed recently shows the overall picture of the situation with the legacy disposal facilities in the Russian Federation. General results of the assessment are presented in the paper.

1 WASTE DISPOSAL IN THE RUSSIAN FEDERATION

For today there are no disposal facilities for solid radioactive waste in the Russian Federation. There are only three disposal sites in Russia for the deep well injection of low and intermediate level liquid radioactive waste into geological media. This option is very specific and needs specific and separate study. From the other side when looking in the past not only in Russia but in many other countries one coud see a lot of legacy facilities that were sited, designed and operated as disposal facilities. A good example of such case is the former “Radon” system in the former Soviet Union which gives the name of the “Radon-type facilities” in the IAEA documents.
The “Radon” System was established in the early 60-s for collection, transportation, treatment and near surface disposal of low and intermediate level institutional radioactive waste and disused sealed radiation sources. There were 35 facilities in the USSR including 16 facilities in the Russian Federation. The Moscow and Leningrad “Radon” facilities were the largest. Moscow “Radon” played the leading role assisting other facilities in solving scientific and technical issues. It still remains the only “Radon” facility in Russia while the others were incorporated into the new system and are operated under supervision of the Federal State Unitary Enterprise "RosRAO".
No one from the former “Radon” facilities has now the license for radioactive waste disposal, while the immobilisation technology implemented in the past didn’t suppose waste retrieval. They do not dispose the waste now but still have the old vaults filled with the waste and closed. They are still waiting for the desision.
One of the internationaly accepted options for the legacy facilities in case when now disposal facility exist, nor plan for waste retrieval exist, no financial and other guaranties for the waste retrieval, reconditioning and disposal exist is to assess such facilities as disposal facilities. And this task was performed using the ISAM methodology adopted to the conditions of the actual Russian Safety Requirements and Guides.

2 TYPIFICATION OF GEOLOGICAL AND HYDROLOGICAL CONDITIONS OF THE FSUE "ROSRAO" SITES

According to its geological and hydrological conditions the sites of operating branches of the Federal State Unitary Enterprise "RosRAO" where radioactive waste is located can be classified into four types. The first type is characterized by a favorable hydrological conditions that prevent the spread of radionuclides. This includes areas that are composed of a thick layer (15 m) low permeability rocks (loam and clay) from the surface that prevent the

spread of radionuclides out of the facilities with enough deep occurrence of the aquifer (30 - 72 m)
On such sites migration of radionuclides in the rocks underlying the facility will be carried out mainly by molecular diffusion. In case of flooding and destruction of engeneered barrier systems of the facility possible release of radionuclides to the surface and their migration with the surface runoff is likely to take place.
This type includes the sites of Volgograd, Samara, Blagoveshensk, Novosibirsk branches of the FSUE “RosRAO” and FSUE "Radon"/
The second type is characterized by a relatively favorable hydrogeological conditions. This includes the sites, stacked from the surface of low permeable rocks (loam and clay) that prevent the spread of radionuclides out of the repository, but with a high water table (9 – 15 m). Total thickness of loam rocks ranges from 7 - 14 to 18 m - 40 m. Groundwater located sufficiently close to the repository bottom, nevertheless , do not have direct contact with it. However, there is a possibility of radionuclides to migrate both in groundwater and in surface runoff.
On such sites migration of radionuclides in the rocks underlying the facility can be carried out mainly by molecular diffusion.
This type includes Rostov, Khabarovsk, Sverdlovsk and Chelyabinsk branches of FSUE "RosRAO."
The third type is characterized by a less favorable hydrological conditions. It includes the sites composed from the surface of permeable rock (sandy clay and sand with a permeability of 0.5 m / day), but with sufficiently deep bedding aquifer (below 15 m). Total thickness of highly permeable host rocks range from 10.2 to 43 m/
On such sites migration of radionuclides in the rocks underlying the facility can be carried out mainly by convective transport through the degraded walls and bottom of the facility, and subsequent transfer to the aquifer.
This type includes the sites of the Saratov , Irkutsk and Nizhny Novgorod branches of FSUE "RosRAO."
The fourth type is characterized by unfavorable hydro-geological conditions. The main difference from the other three types is the presence of perched water at depths corresponding to the placement of waste into near-surface repository (0.1-3.0 m). This includes the sites, formed from the surface of low permeable rocks (loam, boulder clay, heavy loam) with interbedded sands and sandy loams and bedding of the aquifer at a depth of 13 - 30 m. On such sites migration of radionuclides in the underlying repository rocks mainly occurs by convective transport in groundwater. For such conditions the periodic flooding of repository, contamination of surface runoff and perched water is likely to take place.
This type includes the sites of Kazan and the Murmansk branches of FSUE "RosRAO."

3 SCHEMATIZATION FOR ASSESSMENT PURPOSES

To assess the potential radiation hazard of facilities for human and environment the following common normal evolution scenario was considered: accumulation of ground or atmospheric water in the repository, transfer of radionuclides from the waste into the liquid phase, migration of radionuclides out of the repository into the host rocks, contamination of groundwater or surface water, transport of radionuclides to the area of human activity (the border of Sanitary-protective Zone or the nearest settlement).
Using the graded approach at the first stage of assessment each separate repository (constraction) concidered as a source term of contamination with the known geometric parameters, conventional porosity and other specific features. No waste packages or sells were concidered in details. Initial data on waste activity was taken from the official Reports on the Status of Radiation Safety (in accordance with the RB- 054- 09), submitted annually by the operator to the Rostehnadzor.
Host rocks are considered as one or more unsaturated layers with different geological-and-hydrogeological and sorption characteristics. The bottom of unsaturated layer is considered as the roof of the aquifer, characterized by the presence of the natural groundwater flow.

Three main mechanisms of radionuclide transport were concidered: convective-and-dispersive transport, diffusive transport and the transport of radionuclides in surface runoff.
The modelling of radionuclide migration were performed using simulation software tool Ecolego 4.2 [3], that is often used for creating compartment dynamic models and performing deterministic and probabilistic simulations.
To calculate the annual effective dose for human, typical “farmer” models based on use of contaminated water for domestic purposes were adapted to specific conditions of each site.

4 ANALISYS OF RESULTS

Conservative calculations performed for all objects have shown that already in decades after the engineered barrier degradation the concentration of tritium in groundwater in the nearest settlement can go beyond the safe level even at considerable distances from the repository. After several thousand years the ground water contamination will be formed by long-lived α-emitting radionuclides (and their decay products), the most significant of which are ^{238}U, ^{235}U, ^{232}Th and their daughter radionuclides ^{231}Pa, ^{226}Ra and ^{210}Pb. The maximum contamination of aquifers in nearby settlements (at a distance of several kilometers) can be reached in a few tens of thousands up to hundreds of thousands of years and can several times exceed the “Intervention Level for Drinking Water” (Table 1)

Table 1 – Maximal concentration of radionuclides in groundwater in ILDW (Conservative assessment)

Facility	Distance to the nearest settlement, km	Maximal concentration of radionuclides in groundwater in ILDW / Time in years			
		α-emmiters	^{3}H	^{14}C	^{90}Sr
Kazan	0,6	640/2,9·105	89/11	-	0.3/267
Saratov	2	74/6,2·104	71/5	0.2/2,6·103	-
Nizhniy Novgorod	5	1863/4,7·104	-	-	27/201
Samara	2	31/1,5·105	79/10	-	0.8/250
Blagoveshensk	2	20/1,3·103	-	-	-
Irkutsk	3	2205/4·104	-	-	1665/141
Novosibirsk	1,5	0.2/4,9·105	-	-	-
Khabarovsk	3,8	1063/5,2·104	263/7	18/819	-
Volgograd	5	655/9·105	-	1.0/1,3·104	-
Rostov	1,5	4375/9·105	-	-	-
Sverdlovsk	2	643/2·105	24/26	2/4,2·103	-
Chelyabinsk	5	5510/3,1·105	-	-	-
Leningrad	2,5	700/4,5·104	6/4	-	12/47
Murmansk	10	97/1,3·103	0.9/2	-	147/43
FSUE «Radon»	4	1121/1,4·105	4/42	5/3,4·103	-

As an example, Figure 1 shows a graph of the concentration of radionuclides in the aquifer in the time of the migration of radionuclides from the vaults of Volgograd branch of the branch "Southern Territorial District" FSUE "RosRAO."
The results of effective dose calculations for the Blagoveshensk, Samara, Saratov, Kazan, Volgograd, Leningrad, Murmansk, and the Khabarovsk branches of FSUE "Radon" show that the potential exposure in short terms (less then 100 years) is formed by entering of tritium in the human body along with water and milk.
For Kazan, Saratov, Samara, Khabarovsk branches of FSUE "RosRAO" the dose for public exceeds the basic dose limit for the effective dose to the public (1 mSv / year) already during the first ten years after the EBS degrades and the control over the source term is lost.
During the follow-up period and up to several thousand years, the major nuclides determining the contamination level are ^{90}Sr and ^{14}C. The consumption dose is determined by intake of ^{90}Sr with water and ^{14}C – with plant foods. After several thousand years the human exposure is determined by the long-lived α-emitting radionuclides (and their decay products). For

almost all considered sites the limit of the effective dose for the public (1 mSv / year) is likely to be exceeded.

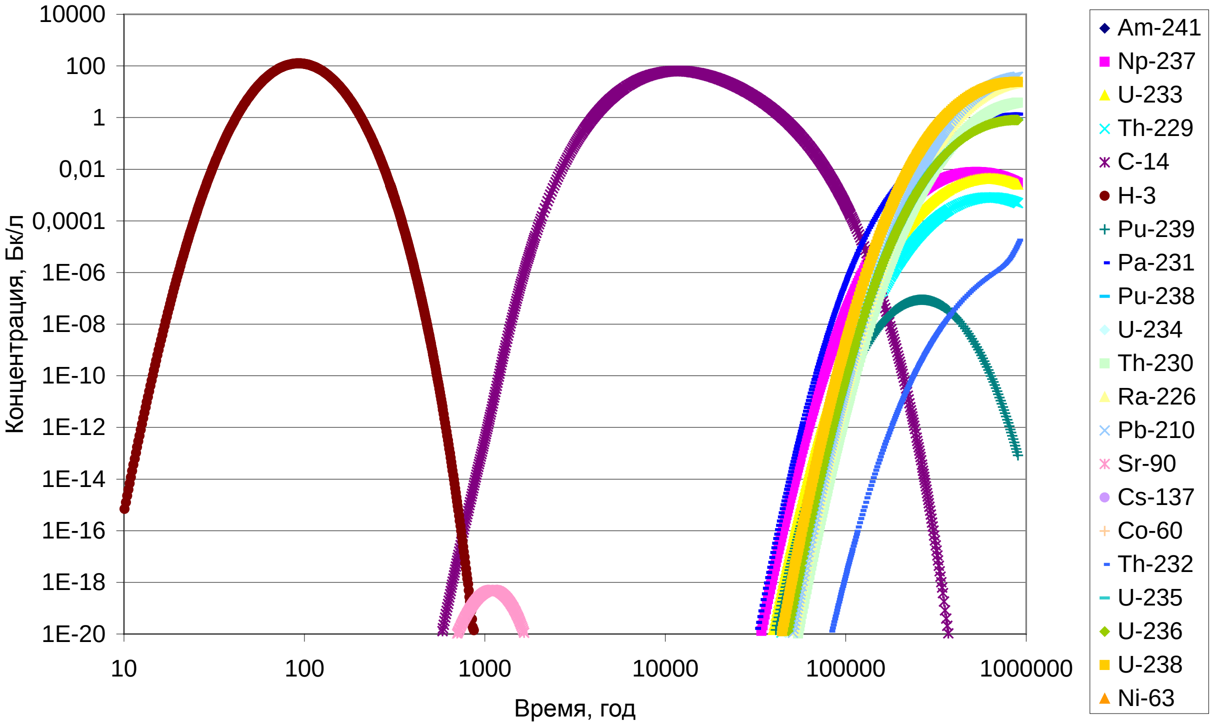

Figure 1 – The radionuclide concentrations in the aquifer for the Volgograd branch of FSUE "RosRAO" in time.

As an example, the Figure 2 shows a graph with the contribution of different radionuclides to the calculated total effective dose for public in Volgograd Branch of FSUE "RosRAO." The graph shows that the main contribution to the total effective dose is defined by tritium, carbon and long-lived alpha-emitting radionuclides with their daughters.

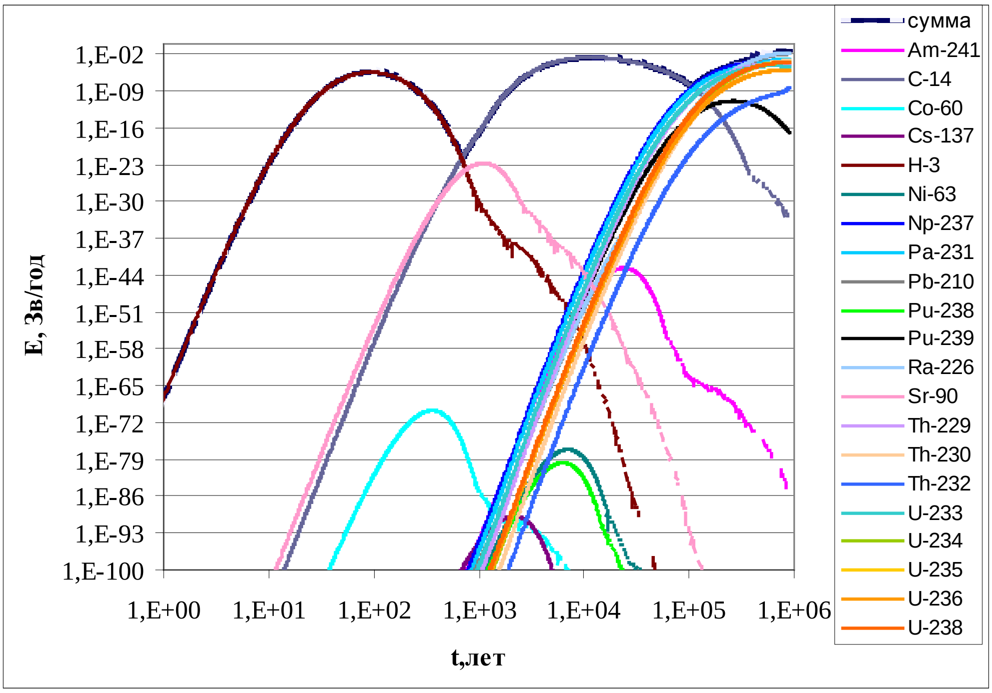

Figure 2 - The contribution of different radionuclides into the total effective dose for public in time (the Volgograd branch of the FSUE "RosRAO")

A general sensitivity analysis of the models to the input parameters performed using the Ecolego function has demonstrated that the distribution coefficient has the greatest influence on the results. The models are much less sensitive to the filtration parameters of the natural and engineered barriers.

5 FINDINGS

Safety assessment calculation identified the following most dangerous radionuclides for concidered facilities:

- ^{3}H (half-life of 12.3 years) - the danger of tritium determined by the extremely high mobility of radionuclide in the environment. Potentially hazardous concentrations of tritium in groundwater in the nearest settlements can be found in about 10 years after the loss of EBS their waterproofing properties.
- ^{90}Sr (28,7 years) - the risk is associated with high mobility and radiotoxicity of the radionuclide . The maximum concentration of the radionuclide in the immediate locality can be observed after about 40-200 years after the degradation of the engineered barriers.
- ^{14}C (5730 years) - the hazard is determined by extremely high mobility of radionuclide in the environment and sufficiently long half-life, maximum concentration in the immediate locality may be reached in a few thousand years.
- Long-lived alpha emitters (^{238}U, ^{235}U, ^{232}Th and their daughter products) – the risk is determined by their long half-life and high radiotoxicity, but potentially hazardous concentrations of these radionuclides can be observed in the nearest settlement through decades or hundreds of thousand years because of their low migration ability.

The assessment results have shown that the long-term risk of the considered objects is determined, first of all, by the total activity of long-lived α-emitting radionuclides. For almost all considered sites the effective dose for public can exceed the limit of 1 mSv/year with the only exception in case of Novosibirsk Branch of FSUE "RosRAO."

With respect to the considered objects the following temporal regularitiesare identified:

1) In the short-term perspective (decades) the radiation safety is determined by the isolating properties of engineered barriers of operated and closed facilities that can contain tritium. The higher effective doses for the public (more than 1 mSv/year) due to the migration of tritium are calculated for the following branches of the FSUE "RosRAO" (in descending order of the danger): Khabarovsk , Kazan , Samara , Saratov , Sverdlovsk , Leningrad. For these branches the priority is to ensure that the operating organization follows the requirements of the paragraph 5.3.5 of NRB-99/2009 regarding mandatory monitoring of the specific activity of tritium in groundwater at the site and the buffer zone. Systematic monitoring of the tritium content in the samples taken from monitoring wells, would allow to identify signs of elevated concentrations of radionuclides in time and to take measures to restore the integrity of the engineered barriers.

2) In the medium term perspective (from tens to hundreds of years) the safety of facility is determined by engineered and natural barriers to limit the spread of the radionuclide ^{90}Sr. The higher effective doses for the public (more than 1 mSv/year) due to the migration of strontium calculated for the following branches of the FSUE "RosRAO" (in descending order of danger): Irkutsk , Murmansk , Nizhny Novgorod , Leningrad. This must be taken into account the operating organization in the implementation of conservation (closure) projects for that facilities. The priority in providing safety should be given to ensurance in adequate isolating properties of existing (and optionally additional) engineered barriers to prevent the spread of ^{90}Sr out of the repository, as well as the portional or complete retrieval of the most hazardous waste, which can not be reliably islated in citu.

3) In the long term perspective, the possibility to transfer the radioactive waste long-term storage facilities into the category of disposal facilities is determined by the accumulated activity of ^{14}C and long-lived alpha-emitting nuclides. The greatest danger such nuclides present for the following facilities (in descending order of danger): Chelyabinsk branch of FSUE "RosRAO", Rostov , Irkutsk , Nizhny Novgorod Branch, Federal State Unitary Enterprise "Radon" , Khabarovsk branch of FSUE " RosRAO ", Leningrad , Volgograd , Sverdlovsk , Kazan , Murmansk , Saratov , Samara and Blagoveshshensk branches. The potential danger of waste containing alpha-emitting nuclides will persist for hundreds of

thousands of years. The long period of the potential danger of such waste does not allow for their safe isolation from the environment in the near-surface disposal facilities. The priority in ensuring the long-term safety for these facilities is to enable the retrieval of the most dangerous part of the waste for subsequent disposal in deep geological disposal facilities.
The above results can be considered as the very conservative estimate of public radiation exposure in case of an administrative transfer of operating facilities into the final disposal facilities without substantial upgrading of safety barriers and other necessary measures to compensate for the deficiencies of safety. The results can also be used to determine priorities in decision making regarding the order of decommissioning of considered facilities.
The final decision on the fate of each object should take into account the specifics of the object and results of clarifying calculations for comparison of the radiation risks associated with the waste retrieval and disposal on-site, made on the basis of the results of the initial registration and inventory of accumulated waste (radionuclide composition, specific and total activity, physical form, placement, retriavability).