

GEOLOGICAL AND HYDROGEOLOGICAL CONDITIONS OF "RADON" STORAGE SITES IN THE RUSSIAN FEDERATION

Andrey V. Gooskov, Serguei L. Speshilov, Lev B. Prozorov, Alexey V. Tkachenko,
Svetlana A. Korneva

Moscow State Enterprise "Radon" (Mos SIA "Radon")
Russia, Moscow 119121, 7-th Rostovsky Lane, 2/14
7(095) 248-1941, mcgoose@cityline.ru

ABSTRACT

Safety assessment for near surface radioactive waste disposal facilities starts with collecting and analyzing data. Geological-and-hydrogeological conditions of storage sites are of great importance for such investigations as well as facility design. The analysis of these conditions allows determination of the most probable migration pathways and scenarios that should be done for facilities safety assessment.

INTRODUCTION

The management of low and intermediate level radioactive waste (excepting fuel-and-nuclear) is carried out in Russia by the "Radon" system, that was established in the beginning of 60-th in the Soviet Union and included 35 enterprises. There are now 16 specialized enterprises located in various regions of the Russian Federation. They were designed for transportation, preliminary processing and storage of solid, liquid waste and spent sealed sources.

"Radon's" specialization is science, industry, agriculture and medicine wastes as well as the aftermath of the Chernobyl accident. Waste storage facilities accumulated about 100000 m³ of LLW/ILW with total activity more than 1 million Ci and a lot of spent ionization radiation sources with total activity more than 1.5 million Ci.

The most part of waste volume (about 85%) is presented by solid and solidified waste contaminated with ¹³⁷Cs. More than 90% of sealed sources activity is formed out of ⁶⁰Co. The Moscow State Enterprise "Radon" accomplishes processing and deposition of RAW in central region of Russia and is leading organization in the system of 16 similar enterprises in Russia. It renders scientific-and-methodical and technical support to these enterprises. Not long ago Moscow "Radon" started investigations aimed to develop safety assessment methodology and to help regional "Radon" facilities to make safety assessment.

"RADON" TYPE DEPOSITORIES

During more than 30 years significant information about processes happening within RAW storages and in geological environment was accumulated. At first we tried to collect and to analyze all available information.

The most of oldest "Radon" facilities were built according to typical design and correspond to one of two types (except two largest - Moscow and Leningrad):

- 500-1000 m radius Sanitary Protective Zone with rectangular Regime Zone in the center;
- rectangular Sanitary Protective Zone with the Regime Zone on the far end.

All depositories always are located in the Regime Zone. Dimension and the form of disposal site depend on the surface morphology, annual waste income and other conditions.

Spent sealed sources containerless disposal is effected into special designed boreholes and needs to be considered separately later.

Liquid waste are accepted by "Radon" enterprises only for interim storage and following processing, so they may be not taking into account while concerning long term safety assessment.

Solid waste are usually placed in vaults of different volume and structure. Eight facilities have old 200 m³ near surface rectangular vaults of monolithic reinforced concrete covered with concrete plates of 30 cm thickness. They are divided into sections by concrete or wooden partition. Wall and bottom thickness are usually about 30-50 cm. They have outer dump course cover of bitumen or asphaltic felt and as a rule additional brick cover to prevent the waterproofer damage. The bottom is usually on the depth of 3,5-5 m. Six facilities have 600 m³ under surface rectangular vaults of monolithic reinforced concrete and three more facilities have 940 m³ vaults of similar structure. They are sectioned and have the same waterproofing as 200 m³ vaults. In some cases we have similar non monolithic vaults of cement blocks.

Three facilities have similar vaults of 640 m³, 900 m³ and more volume but constructed over-ground.

On the one site we have situation when new over-ground cement block vaults were built on the top of closed under-ground vaults.

In two cases solid waste are disposed in conversed under surface liquid waste storage. They are 200 m³ cylindrical vaults of monolithic reinforced concrete covered inside with all-welded 4 mm stainless steel plate.

Two facilities have old non typical depositories. In one case we have five exposed trenches of 150 m³ total volume filled with low level ²²⁶Ra contaminated ground. In other case there are four 200 m³ concreted trenches without partitioning.

All depositories, that are now under operation, and some closed depositories have hangar to protect them against precipitation.

Except for exotic depositories the most of solid waste is stored in near surface rectangular multiple vaults of monolithic concrete or cement blocks on the depth down to 4.5 m or above ground. Every section is covered from above with cement plate. After section is filled up with waste all hallows between waste packages usually (but not always) are filled with cement. After the hole vault is filled up it is usually covered with asphalt and clay cap of 1.5-2 m thickness.

Such construction have several engineering barriers:
waste package;

cement vault backfill (if presents);

reinforced concrete or cement block walls and bottom (concrete plates on the top);

bitumen or asphaltic felt (if presents);

wall brick cover (if presents);

waterproofer cap (only on the top).

Admitting engineering barrier significance we consider that natural barriers are more important for long-term RAW disposal safety. But the knowledge of depository design

and its erection technology is very helpful for identification of possible migration form while geological surrounding analyzing.

GEOLOGICAL AND HYDRO-GEOLOGICAL SURROUNDING

In view of geological and hydrogeological conditions, disposal sites of the “Radon” enterprises may be referred to four categories (types).

First type has the most favourable hydrogeological conditions, which prevent environment from the radionuclide migration. The top of the cross-section of the sites consists of low permeable rocks (loam and clay) from 15 to 57 meters in thickness. The first aquifer occurs at depths 30-72 meters. In such conditions radionuclide migration through the underlying rocks happens due the molecular diffusion. In a case of water flood or destruction of the repository during a water flood, radioactivity carry-over on the surface is possible and, after that, the radionuclide migration may happen by surface-water flow.

This type may be seen on sites of the “Radon” facilities in Volgograd, Samara and Moscow.

Hydrogeological conditions for storage sites of the second type are not so good. Although the top of the geological structure is composed of low permeable rocks (loam and clay), which prevent from the radionuclide spreading outside storage buildings, the first aquifer occurs not deep from the surface – at depths 9-20 meters. So, the underground water is not far from the bottoms of storage reservoirs, but it is not in contact with the storage buildings. Total thickness of loamy rocks varies from 7-14 to 18-40 meters.

In these conditions the radionuclide migration will occurs by molecular diffusion. But there is a rather high possibility of radionuclide ingress into the aquifer and their carry-over in surface water flows.

Sites of Bashkir, Novosibirsk, Rostov, Habarovsk and Chelyabinsk facilities refer to this type.

Hydrogeological conditions of the third type sites are characterized with permeable rocks from 4.1 to 18 m in thickness down from surface and the first aquifer occurrence at the depth down 50 meters. Surrounding storage buildings the permeable rocks are presented with loamy and clay sands with filtration coefficient more than 0.7 m/day.

In the sites of this type radionuclide migration through underlying rocks may occur by convection transfer with seepage from the storage buildings in case of its destruction and, then, by diffusion transfer into the aquifer.

Saratov and Irkutsk facilities belongs to this type.

The fourth type differs from the mentioned above types with presence of irregular temporary groundwater in the depths (0.1 – 3.0 m), where RAW are located. There are the sites, composed of low permeable rocks (loam, boulder clay, heavy loamy sand) with layers of sand and loamy sand and with aquifer occurrence at the depths 13 – 30 m, which are referred to the type.

In the sites radionuclide migration through underlying rocks may occur by convection transfer with groundwater flow. In this conditions there is a possibility of a periodic storage underflooding and, as a result, contamination of surface and underground waters. For safety assessment predictive analysis of diffusion radionuclide transfer through the low permeable rocks, underlying the irregular temporary water, should be done.

Kazan, Leningrad and Nizhny Novgorod facilities refer to the fourth type.

Geological and hydrogeological conditions of Ekaterinburg and Murmansk facility sites differ from the mentioned above types and may be referred to the fifth and sixth types if they would not so specific and solitary.

Ekaterinburg site is composed of low permeable rocks (loam and clay) with 0.8-7 m in thickness under which original volcanogenic rocks occur. Crevice underground water without pressure is spread at 5-10 m depth. Due the small thickness of the loam-and-clay layer and its sporadic area distribution, radionuclide migration may happen in the underground water flow. In lack of real initial data it is not correct to predict radioactive contamination distribution in the seamy rocks.

Murmansk facility site is composed of original metamorphic rocks. Crevice underground water occurs at depths of 1-5 meters. These conditions do not fit requirements for storage facilities in the present. For assessment of the radionuclide migration through the gneiss strata, complex set of exploration and laboratory studies should be done.

The classification of the "Radon" facility's sites into the hydrogeological types was made on a basement of library material. Necessary geological-and-hydrogeological researches of the migration were implemented only on Volgograd, Moscow, Novosibirsk and Saratov sites.

(Surface morphology and location)

Beside geological surrounding there are also additional natural barriers such as surface morphology and site location.

All territories were selected to prevent precipitation accumulation on the site. The distance from site to nearest village is in the range from 1 to 9 km. The distance to the nearest town is in the range of 3-55 km. It's important to note that all distances are from the Sanitary Zone border (not from the depositories).

In most cases sites are rounded with farmlands.

PRELIMINARY ASSESSMENT

The analysis of RAW storage conditions allows to determine the most probable migration pathways and scenarios that should be done for Russian "Radon" facilities safety assessment.

From our point of view there are three main migration forms in considered conditions:
diffusion in clay and heavy loam;
convection-and-dispersion migration with ground or infiltrated water;
surface run off.

Thus, for long-term safety assessment it's necessary to predict ground and water contamination according to these three migration paths. This will allow to predict external irradiation and possible doses from eating contaminated vegetables, milk and meat from animals eating contaminated plants or drinking contaminated water, inhalation of dust, drinking water, eating freshwater fish, swimming, bathing, irrigation.

According to these migration forms and scenarios, mathematical models are determined for next consideration. Valid data play an important role for the model determination and prediction calculations. Generally, it is better not to use complex mathematics models, where parameters are unknown or are taken from literature sources. For the best accuracy of the assessment it is much better to use models, where it is possible to determine real values of all required parameters.

The use of the solutions, which are already known, allows to make the results of the researches more "transparent" for supervisory authority and population and let them checking the results.

By this Moscow "Radon" made preliminary prediction for 13 Russian "Radon" facilities. It was supposed that solid waste vault contains precipitation water. Engineering barrier was expected to be totally destroyed. Three main radionuclides were considered as contaminants: ^{137}Cs , ^{90}Sr and ^{60}Co . Specific activity was taken equal to 10^6 Bq l^{-1} for calculations according to inspected contaminated water real value ten times surplus. According to investigations carried out at Moscow and Saratov enterprises special activity for ^{90}Sr • ^{60}Co is several degrees less than for ^{137}Cs , but it was taken for predictive calculation as 10^6 Bq l^{-1} too.

In such situation maximal width of contaminated surrounding rock will not exceed 2 m and will not come to the sphere of human activity. It means that according to preliminary prediction the specific concentration of considered radionuclides will not exceed the limits determined by the Radiation Safety Standards on distances more than indicated above. These results can be considered only as preliminary safety assessment from geological-and-hydrogeological point of view and "Radon" is going to continue investigations giving more attention to geological barrier protective properties studying. From the other hand the analysis of accumulated information has allowed us to note some features concerning radionuclide migrations from the vaults and to make a conclusion that geological barrier protective properties play the most important role for RAW isolation and safety.

CURRENT INVESTIGATIONS

Generally adopted principle of safety insurance during RAW isolation is now the principle of multibarrier cover. The essential role is played by artificial engineering barriers, preventing radionuclides to get in the sphere of human's activity, but one must take into account that they are not eternal and their efficiency is limited in time. The climate of central Russia can be described by raining and snowing seasonal periods, with freezing and thawing of the ground. Because of thermal conduction is various for concrete and clay ground, such alternation results in deformation processes on such contacts as clay - concrete. The walls of RAW disposals (e.g. the vault) are gradually deformed under the operation of temperature, dynamic pressure and leaching. Taking into account that period of RAW potential danger is about 300-500 years, it is very probable, that engineering barriers will be crippled (infringed) during this time. Therefore a natural geological barrier from our point of view just plays the most important role and needs for special attention.

From the other hand most of site characteristics and ground properties are usually obtained by laboratory or field tests before building the vault. A set of surrounding rock parameters obtained for siting, constructing and building is not the same as for safety assessment. Usual methods for ground parameter obtaining in constructing and building differ from these in researches of migration, and data are not the same too.

Besides this, the technology of near surface RAW storage construction proposes platform preparation on ground surface or foundation ditch shaping, in which the storage itself is placed. After the vault is built all cavities are usually filled with excavated ground. So it can be said that near the vault (on concrete-ground border) we really have infringed

structure ground with properties differing from obtained earlier. According to our investigations infringed clay ground porosity can increase in 1.5 times and hydraulic conductivity (filtration coefficient) can increase in 50-500 times. In such case not only values of migration parameters are changed but also migration pathways and even scenario may be changed too.

Building objects, transport exploration and another human activity on site during facility operation cause some changes in geological and hydro-geological situation so that protective properties of geological barrier change in time. After vault filling and cementation it is usually covered with natural material - earlier excavated ground. During this operation heavy building mechanisms usage can affect to the vault and surrounding rock and also may result into natural ground layer properties change down to the depth of 1.0 - 1.5 m.

In most cases we can not use data obtained earlier for another purposes and have to make hydro-geological complex researches of geological barrier protective properties for near surface RAW disposal facilities safety assessment.

The data obtaining

Last years some laboratory and field researches of geological barrier protective properties have been started on three "Radon" enterprise sites. The main objective of researches was to control geological and hydro-geological situation on inspected sites in postclose period and to obtain data for safety assessment of near surface solid RAW disposal facilities.

The complex of researches for an evaluation of geological-and-ecological safety of LLW/ILW isolation in specific geological-and-hydro-geological conditions has been developed and tested by the authors.

This complex includes:

- exploratory wells drilling;
- monitoring drilling for radiation and hydro-geological control of surrounding rock;
- the obtaining of filtration properties of surrounding rock in natural conditions;
- contaminated water analysis (chemical and radionuclide);
- laboratory study of real radioactive solution interaction with containing rock in static conditions and in dynamics (on filtration or diffusion models);
- field experiments for geological barrier protective properties clarification.

All these stages differ for different sites depending on geological and hydro-geological conditions, storage construction and available data. Prospecting drilling is for clarification of rock variability in the top of a geological section. During this stage surrounding rock is sampled to determine rock humidity, bulk weight, granulometric distribution and use in laboratory experiments. Number of wells, their siting, number of samples depends on geological structure simplicity.

Monitoring drilling is carried out as close to vaults as possible for sampling surrounding rock. Samples are tested for radioactive contamination and for rock humidity. Comparing this test results with the same for prospecting wells one can evaluate possibility of water flow into the vault and out of it and to determine the most probable migration type (diffusion or water flow).

It is very important to obtain filtration properties of surrounding rock in natural conditions. Depending on rock permeability, well tests or dug hole filling can be used.

Such properties as porosity, hydraulic conductivity (filtration coefficient), factor of hydrodispersion and so on have to be determined in these field tests.

Radionuclide conversion from solid or solidified waste into movable form usually is determined mathematically. There are a lot of uncertainty in determining release rate for solid RAW. We think that it may be more useful to analyse real contaminated water from closed vaults. In any case it's very important for the next stage.

Laboratory study of real radioactive solution interaction with surrounding rock in static conditions and in dynamics is carried out for approximate determination of migration parameters. It is known, that the interaction of actual contaminating solution with rock is rather complex. The migration of contaminants in layers is determined by convective transport (filtering), by longitudinal and transversal hydrodispersion, by difference between density of displacing and displaced liquids, by delay in deadlock (isolated) pores, by chemical interaction, by physical sorption, by diffusion, by natural decay etc. A quantitative evaluation of migration is rather difficult because of contaminated water, as a rule, contains a few migrants simultaneously. Besides, separate contaminants may be in several forms. The forms of migrants-contaminants can not always be determined rather precisely. The indicated features complicate studying of water contaminants migration very much. It is necessary to carry out tests for each object: for specific contaminated water and for specific rock.

Field experiments are fulfilled for geological barrier protective properties clarification and obtaining parameters for predictive calculation. Such experiments are planed on the base of both laboratory sorption test results and field filtration test results.

Methodology and Modeling

The other direction of "Radon's" efforts is the improvement of methodology and software. Traditionally safety assessment in Russia was based on the limits for ground and water contamination determined by Radiation Safety Standards (NRB) - "safety for environment". Actually "safety" is considered as "safety for human" and so the main safety criteria is to prevent individual human doze to overshoot the acceptable limit for all radiation sources.

"Radon" takes an active part in the IAEA Coordinated Research Program on Improvement of Long Term Safety Assessment Methodologies for Near Surface Waste Disposal Facilities (ISAM).

Attending the reliable data obtaining, "Radon" is looking for appropriate models and software for assessment predictions. The use of the model is determined by the purposes of calculations and by data reliability and availability. At the same time such data as geosphere properties are variable and there usually are some another data that are difficult or very expensive to obtain. In most cases there is uncertainty in some model parameters. In such situation computer programs for safety assessment have to satisfy two main demands: 1) they have to model the consequences of the disposal of radioactive waste in near surface repositories; 2) they have to take into account uncertainty in the model parameters by making a large number of model calculations, using randomly selected parameter values.

The first attempt of such safety assessment started not long ago for Moscow "Radon" site. This site was chosen as an object of investigation because about 80% of radwaste from scientific and industrial centers is collected by the Moscow "Radon" in the central

region of the Russian Federation. This work is carried out by the AEA Technology (The United Kingdom) and was funded by the European Community. The work is planned to be completed next year.

CONCLUSION.

More than 30-year experience of "Radon" type facilities operating shows that depository design and its building technology is very important for identification of possible radionuclide migration paths and forms. At the same time the geological barrier protective properties play the most important role for RAW isolation and safety. Their evaluation can be made only on the basis of empirical research of interaction of actual contaminated water with specific geological rocks. It is necessary to execute complex laboratory and field experiments for such researches. It is not possible to make the authentic prognosis of migration and reliable conclusion about natural barrier efficiency only on the grounds of some theoretical researches.

Such kind of complex researches of geological barrier protective properties for near surface RAW disposal facilities is most important for closed vaults especially because of these properties may be changed during facility operation. To compare site characteristics before facility building and in postclosed period it would be better to obtain the same protective properties by the same methods.

The researches carried out on one waste storage facility allowed not only to obtain reliable data for further investigations but also can necessitate to review scenarios and migration models.

The complex of researches developed and tested at some "Radon" facilities should be done to obtain reliable data for safety assessment on every site. Only after this it will be possible to carry out reliable prediction calculations according to full scenarios.

Besides this safety assessment needs "Radon" to improve the methodology and computer tools for its implementation. The usage of different ready to use computer codes for one specific object will allow to determine which of them is more suitable for considering conditions.

ACKNOWLEDGMENT

This work was funded by the Moscow Government and carried out by the Scientific Center of Geoecology and Territory Rehabilitation for Moscow State Enterprise "Radon" thanks to cooperation with the Applied Research Center and Saratov Zonal Special Enterprise "Radon".

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