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# Radioactive Waste Activity Resources Estimation at "Ecores" Storage Facilities

M. L. Zhemzhurov,* N. D. Kuzmina,† A. V. Kuzmin,‡ and K. A. Yarashevich§
*Joint Institute for Power and Nuclear Research – Sosny of NAS of Belarus, 220109, Minsk, BELARUS*
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In this paper, an estimation of radioactive waste activity resources in mothballed and being decommissioned storage facilities of the special enterprise for radioactive waste management, Unitary Enterprise "Ekores" (The Republic of Belarus), has been carried out taking into account the results of work on their comprehensive engineering and radiation research. At the same time, activity resources are differentiated by radioactive waste categories, what will serve as the basis for development of conceptual technological solutions for their extraction from storage facilities and long-term safety case.

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## 1. Introduction

The specialized enterprise for radioactive waste management UE "Ekores" (hereinafter - "Ekores") is located 2 km away from Minsk city. The facility was created in 1963 to locate radioactive waste resulted from the activities of the research reactor of the former Nuclear Energy Institute of the Academy of Sciences of BSSR. Later on, being the only enterprise of its kind, the facility provided the reception of a wide range of radioactive waste resulting from radioactive isotopes usage in the territory of the Republic of Belarus.

Currently "Ekores" is a complex radiation-hazardous facility that houses:

two near surface radioactive waste storage facilities of the "first generation" buried type (operation from 1963 to 1978, in 1979 they were mothballed);

two near surface radioactive waste storage facilities of the "second generation"buried type (underground monolithic blocks of 8 tanks each, operation from 1978 to 2013, now one of them is mothballed, the second one is at the stage of decommissioning), in which there are four mothballed wells (2 in each) for spent sealed radionuclide sources (hereinafter - SRS) placement;

storage facility for spent SRS with 11 well-type containers (in operation since 2003);

ground-type conditioned solid radioactive waste storage facility (in operation since 2013);

radioactive waste reprocessing facility with laboratories (in operation since 2013).

In the initial period, radioactive waste was disposed of in near surface storage facilities of a trench type, and then - in special structures of a buried type, which are monolithic structures (tanks) made of reinforced concrete. In the CIS and Eastern Europe similar structures performed according to the Moscow Design Institute standard design are referred to near surface radioactive waste storage facilities of the "Radon" type. Radioactive waste was placed in storage facilities in manufacturer's packaging

*E-mail: Jema@sosny.bas-net.by
†E-mail: ndkuzmina@sosny.bas-net.by
‡E-mail: avkuzmin@sosny.bas-net.by
§E-mail: subprogr_3@sosny.bas-net.by

without prior sorting and processing.

Since 1997, for the purpose of bringing the object into a state that meets modern safety requirements, its reconstruction is being carried out. As a result of the “Ekores” reconstruction project implementation, the construction and commissioning of the radioactive waste processing facility as well as the new radioactive waste storage facility for new incoming to the enterprise radioactive waste were completed in 2013, that allows radioactive waste (solid and liquid) receiving, reprocessing and conditioning, as well as long-term storage of solid conditioned radioactive waste at a level that meets current requirements. Existing capacities of “Ecores” will ensure storage of radioactive waste being generated in organizations of the Republic of Belarus until about 2030. However, further storage of radioactive waste in the near surface storage facilities of the “first” and “second generation” may cause deterioration of the radioecological situation in the region [1].

In 2019 in order to determine the objective level of radiation and environmental safety, as well as to obtain initial data for the development of a radioactive waste extraction project Stock company “Logistics Center of NFC” (Russian Federation) together with Stock company "PDC UGR Limited liability company AP “KVARK”, FSUE “RADON” (Russian Federation) carried out works on a comprehensive engineering and radiation research (hereinafter – CERR) of mothballed and being decommissioned “Ekores” storage facilities [2].

The state scientific institution “JIPNR – Sosny” of NAS of Belarus carried out scientific and methodological support of mentioned works on CERR.

One of the tasks of CERR was determination of the total and specific activity of radionuclides in the storage facilities [2], that is one of the most important parameters necessary for estimation of the radiation situation at the industrial site, in the sanitary protection zone and the monitoring zone of radiation facilities, as well as potential danger of near surface radioactive waste storage facilities estimation [3].

Specificity of the so-called “historical” radioactive waste storage facilities is the lack of reliable information about the characteristics of the radioactive waste placed in it, including specific activity of the radioactive waste (at the best case, information about radioactive waste is limited to information about the total alpha and beta activity and the radionuclide composition of radioactive waste). The specific activity of radionuclides, as a rule, is determined by an expert method based on knowledge of the technologies that were used at different time periods [4].

In this paper, taking into account the CERR results, data on radioactive waste activity in the mothballed and being decommissioned “Ekores” storage facilities necessary for the development of conceptual technological solutions for their extraction from storage facilities and long-term safety case, have been obtained.

## 2. Information about radioactive waste buried in the near surface radioactive waste storage facilities of the “first generation” buried type

From 1963 to 1979 on the territory of “Ekores”, radioactive waste was being buried in trench-type storage facilities (canyon No. 1 and canyon No. 2). In this case, the spent SRS were placed together with the rest of the radioactive waste nomenclature. Until 1998, reliable data on the delivery and disposal of radioactive waste and SRS in tanks were absent.

During the filling of canyons, the characteristics of radioactive waste in the certificates were not given fully enough. For this reason, it is difficult to establish a reliable picture of what is located in these storage facilities.

The main sources of radioactive waste

formation at that time were the Institute of Nuclear Energy of the Academy of Sciences of the BSSR with the IRT-2000 reactor and the V.I. Lenin Minsk Instrument-Making Plant, that was producing dosimetric instruments and special-purpose equipment for the Ministry of Defense and the Navy. In canyons No. 1 and No. 2, a large volume of building materials contaminated with $^{226}$Ra, cleaning materials (cotton, rags, paper) contaminated with residual phosphorus residues based on $^{226}$Ra, light-weight peeling are buried; bubblers with residues of radium salt are also buried.

The bulk of spent SRS were sources for gamma-ray inspection based on $^{152}$Ir, $^{170}$Tm, $^{75}$Se, which were mainly disposed of in improvised containers. Most of the radioisotope technological control devices were buried entirely in the form of a block of gamma sources without preliminary discharge. Medical sources were also buried - the head of a cobalt gun with a source, applicators and needles for gamma therapy.

In 1998, in the MS Access-97 database management system a computer database with special software applications for solid radioactive waste and spent SRS buried in "Ekores" storage facilities and wells was created in order to improve the monitoring system for life cycle of radioactive sources and substances. Simultaneously with data bank, a system for automating the accounting of radioactive waste was created. The initial data for creation of a data bank were the primary documents (protocols) for delivery of radioactive waste and SRS to "Ekores". In total, more than 10,000 deliveries have been processed with participation of specialists from the State scientific institution "JIPNR – Sosny".

Computer database contains information on delivery and disposal of radioactive waste and SIR for the entire period of operation of the "Ekores" storage facilities. Database data is differentiated by:

burial date;

location (wells, mothballed burial places, containers in existing repositories with their numbers, storage in protective containers, etc.);

size and type of activity (neutron, gamma, beta, alpha sources, isotopic composition);

types and conditions of waste (spent SRS, plastic, glass, metal, rags, paper, etc.).

Special software applications make it possible to recalculate the activity of wastes at any given date, determine their isotopic composition, differentiate quantitative characteristics at the place of waste disposal, etc. The created database allows to make an accurate analysis of the nomenclature of buried solid radioactive waste and SRS with a detailed definition of quantitative characteristics to develop recommendations for the extraction and recycling of waste from existing storage facilities.

Quantitative characteristics of radioactive waste located in mothballed canyons No. 1 and No. 2, specified basing on the use of information from a computer database, are presented in Tables I and II. In total, 123,484 kg of solid radioactive waste with total activity of $1.08 \cdot 10^{14}$ Bq are buried in canyons No. 1 and No. 2 of "Ekores".

## 3. Information about radioactive waste buried in the near surface radioactive waste storage facilities of the "second generation" buried type

Until 1998, there were no reliable data on the delivery and disposal of radioactive waste and SRS in the storage facilities tanks No. 1 and No. 2 for the entire period of operation since 1979, their quantity and nomenclature. The quantitative characteristics of radioactive waste and SRS buried at "Ekores" between 1963 and 1995 were approximate and, it is very significant, that there was no data on the isotopic composition of radioactive waste and SRS, and activity was estimated based on certificate data for the time of the burial of the waste lot.

Table 1. Characteristics of the radioactive waste placed in the mothballed canyon No. 1 (as of the time of disposal).

| **No.** | Isotope composition | Half-life, yr | Activity, Bq | Volume activity, Bq/m$^3$ | Life time, yr |
|---|---|---|---|---|---|
| 1 | $^{14}C$ | 5730.0 | $3.7 \cdot 10^5$ | $1.64 \cdot 10^3$ | 0 |
| 2 | $^{45}Ca$ | 0.449 | $3.7 \cdot 10^8$ | $1.64 \cdot 10^6$ | 1.36 |
| 3 | $^{36}Cl$ | $3.01 \cdot 10^5$ | $5.6 \cdot 10^8$ | $2.49 \cdot 10^6$ | $1.22 \cdot 10^6$ |
| 4 | $^{60}Co$ | 5.271 | $5.1 \cdot 10^{12}$ | $2.27 \cdot 10^{10}$ | 100.6 |
| 5 | $^{137}Cs$ | 30.17 | $1.2 \cdot 10^{12}$ | $5.3 \cdot 10^9$ | 573.8 |
| 6 | $^3H$ | 12.28 | $5.6 \cdot 10^{12}$ | $2.5 \cdot 10^{10}$ | 143.3 |
| 7 | $^{192}Ir$ | 0.2023 | $5.6 \cdot 10^{12}$ | $2.49 \cdot 10^{10}$ | 3.63 |
| 8 | $^{147}Pm$ | 2.62 | $2.2 \cdot 10^8$ | $9.8 \cdot 10^5$ | 2.32 |
| 9 | $^{210}Po$ | 0.379 | $3.37 \cdot 10^{10}$ | $1.5 \cdot 10^8$ | 7.7 |
| 10 | $^{239}Pu$ | 24313.0 | $1.1 \cdot 10^{11}$ | $4.92 \cdot 10^8$ | $4.8 \cdot 10^5$ |
| 11 | $^{226}Ra$ | 1608.0 | $4.9 \cdot 10^{11}$ | $2.19 \cdot 10^9$ | $3.55 \cdot 10^4$ |
| 12 | $^{75}Se$ | 0.328 | $1.2 \cdot 10^{10}$ | $5.3 \cdot 10^7$ | 3.27 |
| 13 | $^{90}Sr$ | 28.6 | $1.5 \cdot 10^{10}$ | $6.7 \cdot 10^7$ | 500 |
| 14 | $^{204}Tl$ | 3.784 | $2.2 \cdot 10^9$ | $9.8 \cdot 10^6$ | 24 |
| 15 | $^{170}Tm$ | 0.325 | $1.7 \cdot 10^{12}$ | $7.6 \cdot 10^9$ | 5.23 |
| 16 | Mixed radioactive waste | | $2.6 \cdot 10^{12}$ | $1.15 \cdot 10^{10}$ | |
| 17 | Composition is not determined | | $1.9 \cdot 10^{10}$ | $8.44 \cdot 10^7$ | |
| | TOTAL | | $8.214 \cdot 10^{12}$ | | |

The radioactive waste loaded in the storage facilities tanks No. 1 and No. 2 of "Ekores" are characterized by great diversity. The entire array of storage facilities cells contents can be represented as consisting of the following types of radioactive waste, differing in source material, distinctive dimensions of individual units, and method of containerization:

- radioactively contaminated consumables (rags, cover-up, personal protective equipment, etc.);

- bulk radioactive waste (furnace cinder, soil, soil samples, cleanings from hot chambers);

- spent SRS: long sources of $\gamma$-radiation with $^{60}$Co isotopes, blocks of $\gamma$-sources with various radioisotopes, $\beta$-sources, radioactive smoke detectors of premises, etc.;

- biowaste (corpses of experimental animals, underlying materials, radioactive solutions ampoules);

- small-sized solid metallic and nonmetallic radioactive waste (elements of metal structures, pipelines, plastic parts, laboratory chemical glassware);

- waste of Chernobyl origin (mainly household items);

- large-sized metal radioactive waste (reactor vessel with bioprotection and structural elements of the transportable NPP "Pamir-630D", large-sized facility equipment, 200-liter metal barrels with cemented liquid waste).

Allocation of individual cells for disposal of one type of radioactive waste until 1999 was not practiced. The sequence of loading tank cells was determined in the established order: at the beginning, the longest cells were filled, and lastly - the nearest cells. During loading, radioactive waste lot was not sorted by activity level, and each successive cell was loaded as the radioactive waste entered. An inventory of radioactive waste buried before 1992 was absent.

In 2000 the storage facility tank No. 1 was full. Radioactive waste was filled with an inert material (sand) after the cells of storage facilities

Table 2. Characteristics of the radioactive waste placed in the mothballed canyon No. 2 (as of the time of disposal).

| **No.** | Isotope composition | Half-life, yr | Activity, Bq | Volume activity, Bq/m$^3$ | Life time, yr |
|---|---|---|---|---|---|
| 1 | $^{110m}Ag$ | 0.70 | $7.4 \cdot 10^5$ | $3.29 \cdot 10^3$ | 0 |
| 2 | $^{133}Ba$ | 10.535 | $2.2 \cdot 10^8$ | $9.8 \cdot 10^5$ | 35.8 |
| 3 | $^{14}C$ | 5730.0 | $4.3 \cdot 10^{10}$ | $1.9 \cdot 10^8$ | $5.52 \cdot 10^4$ |
| 4 | $^{57}Co$ | 0.745 | $1.3 \cdot 10^7$ | $5.8 \cdot 10^4$ | 0 |
| 5 | $^{60}Co$ | 5.271 | $2.6 \cdot 10^{13}$ | $1.16 \cdot 10^{11}$ | 113 |
| 6 | $^{134}Cs$ | 2.062 | $1.9 \cdot 10^8$ | $8.4 \cdot 10^5$ | 14.1 |
| 7 | $^{137}Cs$ | 30.17 | $1.6 \cdot 10^{13}$ | $7.1 \cdot 10^{10}$ | 687 |
| 8 | $^{3}H$ | 12.28 | $2.6 \cdot 10^{12}$ | $1.16 \cdot 10^{10}$ | 130 |
| 9 | $^{192}Ir$ | 0.2023 | $2.8 \cdot 10^{13}$ | $1.24 \cdot 10^{11}$ | 4.1 |
| 10 | $^{32}P$ | 0.0391 | $6.7 \cdot 10^9$ | $2.98 \cdot 10^7$ | 0.352 |
| 11 | $^{147}Pm$ | 2.62 | $1.6 \cdot 10^{10}$ | $7.1 \cdot 10^7$ | 18.5 |
| 12 | $^{210}Po$ | 0.379 | $3.7 \cdot 10^9$ | $1.64 \cdot 10^7$ | 6.47 |
| 13 | $^{238}Pu$ | 87.75 | $2.57 \cdot 10^8$ | $1.14 \cdot 10^6$ | 956 |
| 14 | $^{239}Pu$ | 24313.0 | $8.9 \cdot 10^{10}$ | $3.96 \cdot 10^8$ | $4.7 \cdot 10^5$ |
| 15 | $^{226}Ra$ | 1608.0 | $5.9 \cdot 10^{10}$ | $2.62 \cdot 10^8$ | $3.06 \cdot 10^4$ |
| 16 | $^{35}S$ | 0.24 | $1.1 \cdot 10^{10}$ | $4.89 \cdot 10^7$ | 1.31 |
| 17 | $^{124}Sb$ | 0.164 | $2.5 \cdot 10^{10}$ | $1.1 \cdot 10^8$ | 1.8 |
| 18 | $^{75}Se$ | 0.328 | $3.2 \cdot 10^{12}$ | $1.42 \cdot 10^{10}$ | 5.9 |
| 19 | $^{119m}Sn$ | 0.802 | $1.2 \cdot 10^6$ | $5.33 \cdot 10^3$ | 0 |
| 20 | $^{90}Sr$ | 28.6 | $3.2 \cdot 10^{11}$ | $1.42 \cdot 10^9$ | 626 |
| 21 | $^{232}Th$ | $1.4 \cdot 10^{10}$ | $3.7 \cdot 10^6$ | $1.64 \cdot 10^4$ | $6.7 \cdot 10^{10}$ |
| 22 | $^{204}Tl$ | 3.784 | $1.8 \cdot 10^9$ | $8 \cdot 10^6$ | 22.9 |
| 23 | $^{170}Tm$ | 0.352 | $1.8 \cdot 10^{13}$ | $8 \cdot 10^{10}$ | 6.86 |
| 24 | $^{65}Zn$ | 0.668 | $3.5 \cdot 10^{11}$ | $1.564 \cdot 10^9$ | 10.3 |
| 25 | Mixed radioactive waste | | $4.5 \cdot 10^{12}$ | $2 \cdot 10^{10}$ | |
| 26 | Not determined | | $3.4 \cdot 10^{11}$ | $1.51 \cdot 10^9$ | |
| | TOTAL | $9.95 \cdot 10^{13}$ | $4.42 \cdot 10^{11}$ | | |

tanks were fully loaded. By now, storage facility No. 1 has been mothballed without dismantling the protective ground structure.

The storage facility tank No. 2 was been filled from October 1992 to 2013. Currently there are: a detailed inventory of its contents in the database; cell systematization of the characteristics of radioactive waste buried in this tank; information was collected on the characteristics of the radioactive waste buried in the tank, whose attachment to any of the cells is not documented.

Sand filling of the filled cells of storage facility tank No. 2 was not performed. The exception is cells No. 1 and 8, that, after loading, were concreted. Cells of storage facilities No. 1 and 2 are closed with concrete slabs of 20 cm thick. The isotopic composition of radioactive waste buried in these storage facilities varies significantly.

An enlarged systematization of information on loading storage facility cells by type of radioactive waste for storage facilities No. 1 and No. 2 is presented in Tables 3 and 4, respectively.

The quantitative characteristics of radioactive waste located in mothballed storage

Table 3: Brief description of archival information on radioactive waste burial in cells of storage facility No. 1.

| | |
|---|---|
| **Cell No.1** Radioactive waste burial was carried out before 1986. Presumably it was mainly small-sized solid radioactive waste and consumables. | **Cell No. 8** It was filled in 1986 - 1988 with wastes of Chernobyl origin (clothing, military uniforms, household items, etc.). |
| **Cell No. 2** Similar to cell No. 1. | **Cell No. 7** It was filled in 1986 - 1988 with wastes of Chernobyl origin (clothing, military uniforms, household items, etc.). |
| **Cell No. 3** Similar to cell No. 1. | **Cell No. 6** There is no reliable information on the loaded radioactive waste. |
| **Cell No. 4** Burial of small and large radioactive waste - metal structures of the transportable NPP "Pamir-630D", (turbine-generating unit). | **Cell No. 5** There is no reliable information on the loaded radioactive waste. |

Table 4: Brief description of archival information on radioactive waste burial in cells of storage facility No. 2.

| | |
|---|---|
| **Cell No. 1** It is divided into two compartments, currently not in operation and concreted. It contains a diverse nomenclature of radioactive waste and SRS. | **Cell No. 8** It was loaded in the post-Chernobyl period with contaminated clothing, synthetic wrapping material, rags, etc. It is completely filled, paved with asphalt. Under stove 8-4, the burial of small lots of control sources was organized. |
| **Cell No. 2** Basically, SRS were buried here (blocks of gamma-ray sources, extended sources, sources in containers, etc.), due to the availability of free space, temporary storage of SIR was carried out. | **Cell No. 7** It is almost full, contains significant amounts of contaminated consumables. |
| **Cell No. 3** By the nature of burials - the same as in cell No. 2; a large barrel – a special container for alpha sources – is additionally placed here. | **Cell No. 6** In the lower part – mainly furnace slag containing radium salts, higher in volume – biowaste, extended sources, cemented bottles with liquid radioactive waste, consumables, etc. |
| **Cell No. 4** Radioactive waste of CJSC "Isotope technologies". | **Cell No. 5** The reactor block of the transportable NPP "Pamir-630D" with neutron sources and a few small lots of radioactive waste and SRS were buried here. |

facilities No. 1 and No. 2, updated based on the use of information from a computer database, are presented in Tables 5 and 6. The total activity of radioactive waste loaded into storage facilities No. 1 and No. 2 is $9.175 \cdot 10^{15}$ Bq.

Well type storage facilities inv. No. 369, No. 422 as part of storage facility No. 1 began to be operated in the early 1980s. In accordance with the data of archival records in the storage facility of spent SRS, inv. number 369, 3578 sources buried with a total activity of $44.29 \cdot 10^{12}$ Bq. The main contribution to the activity is made by $^{137}$Cs ($34.74 \cdot 10^{12}$ Bq). Due to an emergency during loading, technological channel of the storage facility, inv. No. 369 was covered up with metal shot; reception of sealed radionuclide sources was discontinued. The storage facility of SRS, inv. No. 422 since 1982 was used mainly for the disposal of neutron sources. Information on the number of buried neutron sources has not been preserved. At the same time, 93 sources of $^{226}$Ra with an activity of $3.7 \cdot 10^9$ Bq were placed in this storage facility.

Well type storage facility inv. No. 423, No. 423 as part of storage facility No. 2 had been in operation since the early 1990s and were used

Table 5. Characteristics of radioactive waste disposed of in mothballed storage facility tanks No. 1 (at the time the radioactive waste delivered to the "Ekores").

| **No.** | Isotope composition | Half-life, yr | Activity, Bq | Volume activity, Bq/m$^3$ | Life time, yr |
|---|---|---|---|---|---|
| 1 | $^{241}Am$ | 432.2 | $3.37 \cdot 10^{10}$ | $4.1 \cdot 10^7$ | $6.86 \cdot 10^3$ |
| 2 | $^{133}Ba$ | 10.7 | $3.40 \cdot 10^7$ | $4.1 \cdot 10^4$ | 0 |
| 3 | $^{207}Bi$ | 38 | $3.7 \cdot 10^8$ | $4.5 \cdot 10^5$ | 77.3 |
| 4 | $^{14}C$ | 5730.0 | $4.37 \cdot 10^9$ | $5.3 \cdot 10^6$ | $2.56 \cdot 10^4$ |
| 5 | $^{144}Ce$ | 0.778 | $3.7 \cdot 10^{10}$ | $4.5 \cdot 10^7$ | 8.33 |
| 6 | $^{57}Co$ | 0.745 | $3.7 \cdot 10^{12}$ | $4.5 \cdot 10^9$ | 9.49 |
| 7 | $^{60}Co$ | 5.271 | $5.22 \cdot 10^{13}$ | $6.4 \cdot 10^{10}$ | 109 |
| 8 | $^{51}Cr$ | 0.076 | $5.0 \cdot 10^8$ | $6.1 \cdot 10^5$ | 0 |
| 9 | $^{134}Cs$ | 2.06 | $3.7 \cdot 10^6$ | $4.5 \cdot 10^3$ | 0 |
| 10 | $^{137}Cs$ | 30.17 | $1.65 \cdot 10^{14}$ | $2.0 \cdot 10^{11}$ | 732 |
| 11 | $^{152}Eu$ | 13.2 | $2.78 \cdot 10^{12}$ | $3.4 \cdot 10^9$ | 199 |
| 12 | $^{55}Fe$ | 2.68 | $5.55 \cdot 10^9$ | $6.8 \cdot 10^6$ | 10.8 |
| 13 | $^{153}Gd$ | 0.663 | $3.7 \cdot 10^8$ | $4.5 \cdot 10^5$ | 0 |
| 14 | $^{3}H$ | 12.28 | $3.77 \cdot 10^{12}$ | $4.6 \cdot 10^9$ | 113 |
| 15 | $^{192}Ir$ | 0.202 | $2.45 \cdot 10^{14}$ | $3.0 \cdot 10^{11}$ | 4.35 |
| 16 | $^{85}Kr$ | 10.72 | $1.11 \cdot 10^9$ | $1.4 \cdot 10^6$ | |
| 17 | $^{54}Mn$ | 0.857 | $3.7 \cdot 10^9$ | $4.5 \cdot 10^6$ | 3.85 |
| 18 | $^{22}Na$ | 2.6 | $5.14 \cdot 10^8$ | $6.3 \cdot 10^5$ | 10.1 |
| 19 | $^{63}Ni$ | 96 | $4.63 \cdot 10^5$ | $5.6 \cdot 10^2$ | 0 |
| 20 | $^{32}P$ | 0.039 | $4.55 \cdot 10^8$ | $5.6 \cdot 10^5$ | 0.13 |
| 21 | $^{147}Pm$ | 2.62 | $7.84 \cdot 10^8$ | $9.6 \cdot 10^5$ | 2.25 |
| 22 | $^{210}Po$ | 0.379 | $1.85 \cdot 10^{10}$ | $2.3 \cdot 10^7$ | 6.65 |
| 23 | $^{210}Po + Be$ | 0.379 | $1.8 \cdot 10^{11}$ | $2.2 \cdot 10^8$ | 7.89 |
| 24 | $^{238}Pu$ | 87.75 | $9.95 \cdot 10^{11}$ | $12.1 \cdot 10^8$ | $1,84 \cdot 10^3$ |
| 25 | $^{238}Pu + Be$ | 87.75 | $2.03 \cdot 10^{12}$ | $2.5 \cdot 10^9$ | $1.93 \cdot 10^3$ |
| 26 | $^{239}Pu$ | 24313.0 | $7.53 \cdot 10^{11}$ | $9.2 \cdot 10^8$ | $5.02 \cdot 10^5$ |
| 27 | $^{226}Ra$ | 1608.0 | $1.2 \cdot 10^{12}$ | $1.5 \cdot 10^9$ | $3.46 \cdot 10^4$ |
| 28 | $^{124}Sb$ | 0.165 | $1.25 \cdot 10^{12}$ | $1.5 \cdot 10^9$ | 2.98 |
| 29 | $^{75}Se$ | 0.329 | $1.32 \cdot 10^{13}$ | $1.6 \cdot 10^{10}$ | 7.08 |
| 30 | $^{119m}Sn$ | 0.803 | $1.40 \cdot 10^9$ | $1.7 \cdot 10^6$ | 1.65 |
| 31 | $^{90}Sr$ | 28.6 | $1.05 \cdot 10^{12}$ | $1.3 \cdot 10^9$ | 622 |
| 32 | $^{204}Tl$ | 3.784 | $8.88 \cdot 10^{10}$ | $10.8 \cdot 10^7$ | 37 |
| 33 | $^{170}Tm$ | 0.353 | $4.37 \cdot 10^{13}$ | $5.3 \cdot 10^{10}$ | 6.67 |
| 34 | $^{238}U$ depleted | $4.47 \cdot 10^9$ | $3.7 \cdot 10^8$ | $4.5 \cdot 10^5$ | $3.21 \cdot 10^{10}$ |
| 35 | $^{88}Y$ | 0.292 | $3.7 \cdot 10^8$ | $4.5 \cdot 10^5$ | 0.59 |
| 36 | $^{65}Zn$ | 0.668 | $2.51 \cdot 10^{10}$ | $3.1 \cdot 10^7$ | 6.51 |
| 37 | Mixed radioactive waste | | $1.27 \cdot 10^{14}$ | $1.6 \cdot 10^{11}$ | |
| 38 | Radioactive waste composition is not determined | | $5.4 \cdot 10^{12}$ | $6.6 \cdot 10^9$ | |
| 39 | Special material | | $3.52 \cdot 10^{13}$ | $4.3 \cdot 10^{10}$ | |
| | TOTAL | $7.05 \cdot 10^{14}$ | | | |

Table 6. Characteristics of radioactive waste disposed of in filled storage facility tanks No. 2 under the assumption of a uniform homogeneous distribution of the activity of radioisotopes in volume (at the time the radioactive waste delivered to the "Ekores").

| **No.** | Isotope composition | Half-life, yr | Activity, Bq | Volume activity, Bq/m$^3$ | Life time, yr |
|---|---|---|---|---|---|
| 1 | $^{110m}Ag$ | 0.685 | $1.32 \cdot 10^8$ | $1.79 \cdot 10^5$ | 1.26 |
| 2 | $^{241}Am$ | 432.2 | $2.41 \cdot 10^{11}$ | $3.27 \cdot 10^8$ | $8.15 \cdot 10^3$ |
| 3 | $^{199}Au$ | $8.6 \cdot 10^{-3}$ | $7.40 \cdot 10^4$ | $1.00 \cdot 10^2$ | 0 |
| 4 | $^{133}Ba$ | 10.7 | $5.59 \cdot 10^7$ | $7.58 \cdot 10^4$ | 0 |
| 5 | $^{14}C$ | 5730.0 | $3.71 \cdot 10^{10}$ | $5.03 \cdot 10^7$ | $4.42 \cdot 10^4$ |
| 6 | $^{45}Ca$ | 0.449 | $1.85 \cdot 10^6$ | $2.51 \cdot 10^3$ | 1.64 |
| 7 | $^{109}Cd$ | 1.27 | $2.49 \cdot 10^{10}$ | $3.37 \cdot 10^7$ | $1.56 \cdot 10^1$ |
| 8 | $^{144}Ce$ | 0.778 | $3.85 \cdot 10^9$ | $5.22 \cdot 10^6$ | 5.91 |
| 9 | $^{36}Cl$ | $3.01 \cdot 10^5$ | $1.20 \cdot 10^8$ | $1.63 \cdot 10^5$ | $3.61 \cdot 10^4$ |
| 10 | $^{244}Cm$ | 18.1 | $4.00 \cdot 10^3$ | 5.42 | 0 |
| 11 | $^{57}Co$ | 0.745 | $7.51 \cdot 10^{10}$ | $1.02 \cdot 10^8$ | 5.42 |
| 12 | $^{60}Co$ | 5.271 | $3.00 \cdot 10^{15}$ | $4.07 \cdot 10^12$ | $1.40 \cdot 10^2$ |
| 13 | $^{51}Cr$ | 0.076 | $1.47 \cdot 10^{11}$ | $1.99 \cdot 10^8$ | $4.37 \cdot 10^{-1}$ |
| 14 | $^{134}Cs$ | 2.06 | $6.48 \cdot 10^8$ | $8.78 \cdot 10^5$ | $1.42 \cdot 10^1$ |
| 15 | $^{137}Cs$ | 30.17 | $4.90 \cdot 10^{15}$ | $6.64 \cdot 10^{12}$ | $8.84 \cdot 10^2$ |
| 16 | $^{152}Eu$ | 13.2 | $1.73 \cdot 10^5$ | $2.34 \cdot 10^2$ | 0 |
| 17 | $^{55}Fe$ | 2.68 | $8.25 \cdot 10^{10}$ | $1.12 \cdot 10^8$ | $2.16 \cdot 10^1$ |
| 18 | $^{153}Gd$ | 0.663 | $4.40 \cdot 10^8$ | $5.96 \cdot 10^5$ | $1.49 \cdot 10^{-1}$ |
| 19 | $^3H$ | 12.28 | $6.18 \cdot 10^{13}$ | $8.37 \cdot 10^{10}$ | $1.65 \cdot 10^2$ |
| 20 | $^{203}Hg$ | 0.128 | $7.03 \cdot 10^{10}$ | $9.53 \cdot 10^7$ | 1.75 |
| 21 | $^{125}I$ | 0.162 | $4.75 \cdot 10^{10}$ | $6.44 \cdot 10^7$ | 2.07 |
| 22 | $^{131}I$ | 0.022 | $1.17 \cdot 10^9$ | $1.56 \cdot 10^6$ | 0.18 |
| 23 | $^{192}Ir$ | 0.202 | $4.39 \cdot 10^{14}$ | $5.95 \cdot 10^{11}$ | 4.55 |
| 24 | $^{40}K$ | $1.28 \cdot 10^9$ | $2.41 \cdot 10^4$ | $3.27 \cdot 10^1$ | 0 |
| 25 | $^{85}Kr$ | 10.72 | $2.02 \cdot 10^{10}$ | $2.74 \cdot 10^7$ | |
| 26 | $^{54}Mn$ | 0.857 | $1.01 \cdot 10^9$ | $1.37 \cdot 10^6$ | 2.38 |
| 27 | $^{99}Mo$ | 0.0075 | $7.36 \cdot 10^{10}$ | $9.97 \cdot 10^7$ | $6.57 \cdot 10^{-2}$ |
| 28 | $^{22}Na$ | 2.6 | $9.98 \cdot 10^7$ | $1.35 \cdot 10^5$ | 4.29 |
| 29 | $^{63}Ni$ | 96 | $8.65 \cdot 10^{10}$ | $1.17 \cdot 10^8$ | $6.70 \cdot 10^2$ |
| 30 | $^{32}P$ | 0.039 | $1.04 \cdot 10^4$ | $1.41 \cdot 10^1$ | 0 |
| 31 | $^{147}Pm$ | 2.62 | $4.74 \cdot 10^9$ | $6.42 \cdot 10^6$ | 9.43 |
| 32 | $^{210}Po$ | 0.379 | $1.85 \cdot 10^{10}$ | $2.51 \cdot 10^7$ | 6.70 |
| 33 | $^{236}Pu$ | 2.85 | $2.03 \cdot 10^2$ | $2.75 \cdot 10^{-1}$ | 0 |
| 34 | $^{238}Pu$ | 87.75 | $1.03 \cdot 10^{12}$ | $1.40 \cdot 10^9$ | $1.86 \cdot 10^3$ |
| 35 | $^{238}Pu + Be$ | 87.75 | $8.99 \cdot 10^{10}$ | $1.22 \cdot 10^8$ | $1.55 \cdot 10^3$ |
| 36 | $^{238}Pu + B$ | 87.75 | $1.55 \cdot 10^{13}$ | $2.10 \cdot 10^{10}$ | $2.20 \cdot 10^3$ |
| 37 | $^{239}Pu$ | 24313.0 | $2.14 \cdot 10^{12}$ | $2.90 \cdot 10^9$ | $5.42 \cdot 10^5$ |
| 38 | $^{242}Pu$ | $3.76 \cdot 10^5$ | $2.15 \cdot 10^2$ | $2.91 \cdot 10^{-1}$ | 0 |
| 39 | $^{226}Ra$ | 1608.0 | $1.25 \cdot 10^{12}$ | $1.69 \cdot 10^9$ | $3.49 \cdot 10^4$ |
| 40 | $^{103}Ru$ | 0.108 | $9.62 \cdot 10^4$ | $1.30 \cdot 10^2$ | 0 |
| 41 | $^{106}Ru$ | 1.01 | $5.88 \cdot 10^9$ | $7.97 \cdot 10^6$ | 8.73 |
| 42 | $^{125}Sb$ | 2.77 | $2.02 \cdot 10^7$ | $2.74 \cdot 10^4$ | 0 |

Table 6: continued

| No. | Isotope composition | Half-life, yr | Activity, Bq | Volume activity, Bq/m$^3$ | Life time, yr |
|---|---|---|---|---|---|
| 43 | $^{75}Se$ | 0.33 | $7.29 \cdot 10^{12}$ | $9.88 \cdot 10^9$ | 5.78 |
| 44 | $^{113}Sn$ | 0.315 | $8.96 \cdot 10^4$ | $1.21 \cdot 10^2$ | 0 |
| 45 | $^{119m}Sn$ | 0.803 | $1.17 \cdot 10^9$ | $1.59 \cdot 10^6$ | 1.57 |
| 46 | $^{90}Sr$ | 28.6 | $1.20 \cdot 10^{12}$ | $1.63 \cdot 10^9$ | $6.31 \cdot 10^2$ |
| 47 | $^{232}Th$ | 1.4 1010 | $2.01 \cdot 10^6$ | $2.72 \cdot 10^3$ | $7.71 \cdot 10^{10}$ |
| 48 | $^{204}Tl$ | 3.784 | $3.10 \cdot 10^9$ | $4.20 \cdot 10^6$ | $1.94 \cdot 10^1$ |
| 49 | $^{170}Tm$ | 0.353 | $2.34 \cdot 10^{11}$ | $3.17 \cdot 10^8$ | 4.06 |
| 50 | $^{238}U$ depleted | 4.47 109 | $1.51 \cdot 10^9$ | $2.05 \cdot 10^6$ | $4.19 \cdot 10^{10}$ |
| 51 | $^{88}Y$ | 0.293 | $2.00 \cdot 10^8$ | $2.71 \cdot 10^5$ | $3.81 \cdot 10^{-1}$ |
| 52 | $^{65}Zn$ | 0.668 | $1.54 \cdot 10^5$ | $2.09 \cdot 10^2$ | 0 |
| 53 | $^{95}Zr$ | 0.175 | $3.00 \cdot 10^6$ | $4.07 \cdot 10^3$ | 0 |
| 54 | Radioactive waste composition is not determined | | $2.19 \cdot 10^{10}$ | $2.97 \cdot 10^7$ | |
| 55 | Mixed radioactive waste | | $3.75 \cdot 10^{13}$ | $5.08 \cdot 10^{10}$ | |
| 56 | Special material | | 0 | | |
| | TOTAL | | $8.47 \cdot 10^{15}$ | | |

mainly for storing gamma sources. In accordance with the data of archival records in the storage facility of spent SRS, inv. No. 423, 7198 sources with a total activity of $2.84 \cdot 10^{15}$ Bq were buried. The main contribution to the activity is made by $^{137}$Cs ($2.81 \cdot 10^{15}$ Bq). In the storage facility of spent SRS, inv. No. 424, 66 sources of $^{60}$Co and $^{137}$Cs with a total activity of $56.98 \cdot 10^{13}$ Bq were buried. The main contribution to the activity is made by $^{137}$Cs sources ($56.98 \cdot 10^{13}$ Bq).

## 4. Estimation of the radionuclide composition and activity of radioactive waste disposed at "Ekores" mothballed and being decommissioned storage facilities, taking into account the results of CERR

During the CERR work on the "Ekores" storage facilities that were mothballed and are being decommissioned, the Stock company "Logistics Center of NFC" specialists using field spectrometry method using the ISOCS complex, investigated the radionuclide composition and estimated the activity of radionuclides in the storage facilities. For field gamma spectrometric measurements, "Methodology" for measuring the activity (specific activity) of radionuclides in closed containers with compacted solid or solidified radioactive waste using a CANBERRA semiconductor gamma spectrometer with ISOCS software was used.

Investigation of the radionuclide composition and estimation of the radionuclides activity in the storage facilities were carried out sequentially throughout the volume of storage facilities, so that the investigated and simulated areas intersected edges with each other and went beyond the limits of interest. This approach made it possible to estimate radiation parameters of the entire storage facilities volume and to avoid accidental loss of required information due to the presence of uninvestigated parts of them.

In the trench-type storage facilities (canyon No. 1 and canyon No. 2), five measurements were taken at equal distances (3 m) along the longitudinal axis of the storage facility. To ensure spectrometric equipment access to their floors, pits of 1.5 m were dug along the longitudinal axis along the entire length of the storage facilities in the embankment (Figure 1). At storage facilities No. 1 and No. 2, all cells were individually examined sequentially (eight in each of the storage facilities). Measurements were taken through the geometric center of the cell overlap surface. Access to the floors of storage facilities No. 1 and No. 2 is free, that did not require preparatory work for their gamma-spectrometric examination (Figure 1).

The filling level of all radioactive waste storage facilities in the segments models of storage facility and cell was taken based on the results of a previous research of the degree of filling of the storage facilities (storage facilities compartments) and measuring of the equivalent dose rate distribution during logging in drilled vertical penetrations. The active layer of radioactive waste in the storage facilities during the calculations was modeled by two levels - the distribution of activities and the results of the dosimetric examination of the side walls of the storage facilities.

Schematically diagrams of the distribution of activity of the main dose-generating radionuclides along the length of the storage facilities are presented in Figures 2,3 [2].

The radionuclide composition of the "first generation"storage facilities (canyon No. 1 and No. 2) determined by direct gamma-spectrometric measurements mainly corresponds to the data of preserved archival records on location in these radioactive waste storage facilities provided by the operating organization.

According to the results of gamma-ray field spectrometry, $^{226}$Ra radionuclides (with a total activity of $4.8 \cdot 10^{11}$ Bq), mainly concentrated at a depth of 1.5 m, and $^{137}$Cs (with a total activity of $4.5 \cdot 10^{11}$ Bq), mainly concentrated in the bottom of the store, were found. Determining factor is $^{137}$Cs (total activity $2.96 \cdot 10^{12}$ Bq) in the entire volume of canyon No. 2. The difference in the radionuclide composition is determined by the presence in the canyon No. 2 of a small amount of the $^{152}$Eu isotope, that may be due to the lack of necessary records of the burial or secondary activation of its materials by neutrons from sources located inside the storage facility and not having the necessary protection.

The information received does not correspond to the data of archival records on the location of radioactive waste in mothballed canyons No. 1 and No. 2 at the time of the disposal, where a significantly larger range of radionuclides is reported, and the resulting total activity of radioactive waste in both storage facilities (canyon No. 1 – $9.3 \cdot 10^{11}$ Bq; canyon No. 2 – $2.96 \cdot 10^{12}$ Bq) turned out to be an order of magnitude less archival, shown in Tables 1, 2. The obtained deviations can be explained by the natural decrease in activity and the imperfection of the field spectrometry technique, that cannot take into account the activity of ionizing radiation sources enclosed in protective packaging.

According to the results of gamma-ray field spectrometry, of the detected radionuclides, the determining factor is $^{137}$Cs (with a total activity of $1.18 \cdot 10^{14}$ Bq) and $^{60}$Co (with a total activity of $4.48 \cdot 10^{10}$ Bq) through the entire volume of storage facility No. 2. The main dose-generating radionuclides in storage facility No. 2 are $^{137}$Cs, $^{60}$Co (compartments No. 2, 3, 4, 6, 7, 8), $^{241}$Am (compartment No. 2) and $^{152}$Eu (compartment No. 6).

The information obtained does not correspond to the data of the archival records on location of radioactive waste in the mothballed storage facilities No. 1 and No. 2 at the time of “disposal where a significantly larger nomenclature of radionuclides is reported, and the resulting total activity of the radioactive waste for both storage facilities (storage facilitiy No. 1 – $1.18 \cdot 10^{14}$ Bq, storage facility No. 2 – $2.98 \cdot 10^{13}$ Bq) is slightly lower than the archival given in Tables 5, 6.

Table 7 presents expert estimates of the

FIG. 1. Measurements on the overlap between canyons No. 1, No. 2 (left) and on the overlap between storage facilities No. 1, No. 2 (right).

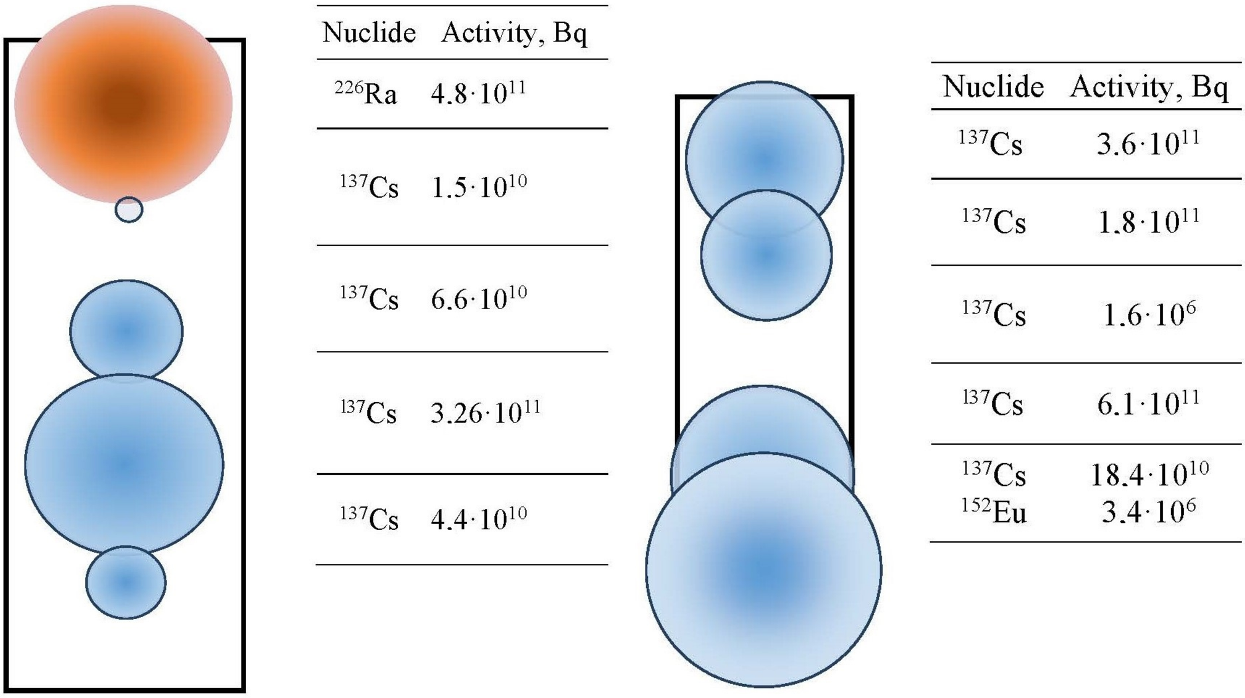
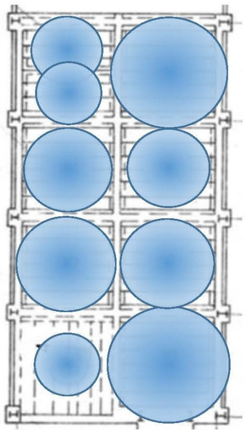



FIG. 2. Activity distribution diagrams of the main dose-generating radionuclides along the length of canyon No. 1 (left) and of the main dose-generating radionuclides along the length of canyon No. 2 (right).

specific and total activities of radioactive waste located in the mothballed and decommissioned "Ekores" storage facilities taking into account the results of CERR [2]. Since the spent sealed radionuclide sources located in the well-type storage facility, inv. No. 369, were not conditioned due to obstruction of the technological channel, it was not possible to determine their specific

| Compartment | Nuclide | Activity, Bq |
|---|---|---|
| 1.1 | $^{137}$Cs | $4.1 \cdot 10^{12}$ |
| 1.2 | $^{137}$Cs | $3.8 \cdot 10^{12}$ |
| 2 | $^{137}$Cs | $5.9 \cdot 10^{12}$ |
| 3 | $^{137}$Cs | $7.4 \cdot 10^{12}$ |
| 4 | $^{137}$Cs | $3.7 \cdot 10^{12}$ |
| 5 | $^{137}$Cs | $11.7 \cdot 10^{12}$ |
| 6 | $^{137}$Cs | $6.8 \cdot 10^{12}$ |
| 7 | $^{137}$Cs | $5.2 \cdot 10^{12}$ |
| 8 | $^{137}$Cs | $10.6 \cdot 10^{12}$ |
| | $^{60}$Co | $4.5 \cdot 10^{10}$ |



| Compartment | Nuclide | Activity, Bq |
|---|---|---|
| 2.1 | $^{137}$Cs | $2.9 \cdot 10^{13}$ |
| 2.2 | $^{137}$Cs | $8.0 \cdot 10^{10}$ |
| | $^{60}$Co | $2.9 \cdot 10^{9}$ |
| 2 | $^{137}$Cs | $3.0 \cdot 10^{10}$ |
| | $^{60}$Co | $6.2 \cdot 10^{9}$ |
| 3 | $^{137}$Cs | $1.2 \cdot 10^{10}$ |
| | $^{60}$Co | $4.7 \cdot 10^{7}$ |
| 4 | $^{137}$Cs | $0.7 \cdot 10^{10}$ |
| | $^{60}$Co | $4.7 \cdot 10^{7}$ |
| 5 | ≤ MAA | - |
| 6 | $^{137}$Cs | $36 \cdot 10^{10}$ |
| | $^{60}$Co | $3.8 \cdot 10^{8}$ |
| | $^{152}$Eu | $8.0 \cdot 10^{8}$ |
| 7 | $^{137}$Cs | $6.4 \cdot 10^{9}$ |
| | $^{60}$Co | $3.8 \cdot 10^{9}$ |
| 8 | $^{137}$Cs | $2.4 \cdot 10^{10}$ |

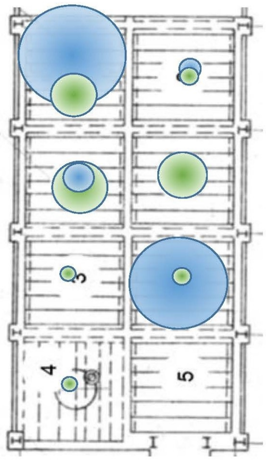



FIG. 3. Activity distribution diagrams of the main dose-generating radionuclides through the storage facility No. 1 compartments (left) and of the main dose-generating radionuclides through the storage facility No. 2 compartments (right).

activity. It was also not possible to clarify data on the total activity of sources buried in a well-type storage facility, inv. No. 422, within the framework of the CERR.

Thus, according to expert estimates, the total stock of radioactive waste activity in the mothballed and decommissioned "Ekores" storage facilities is $1.27 \cdot 10^{16}$ Bq.

It should be noted that in the above mentioned estimates of radioactive waste activities in "Ekores" storage facilities, based on archival data, the decay of radionuclides during the time after filling the storage facilities was not taken into account, since a significant proportion is radioactive waste of uncertain and mixed composition. This leads to overestimation of activity ratings. At the same time, incompleteness of the initial archival data leads to underestimation, and, thus, the indicated errors are leveled to a certain extent.

Taking into account the results of the CERR and based on the analysis of archival data on the history of filling storage facilities, it can be concluded that upon decommissioning of "Ekores" storage facilities all possible types of radioactive waste will be generated: very low-level, low-level, medium-active and high-level waste (Table 8).

The following comparisons are indicative of the obtained estimate of the total stock of radioactive waste activity in the mothballed and being decommissioned "Ekores" storage facilities ($1.27 \cdot 10^{16}$ Bq).

The Chernobyl decontamination waste isolated at 86 disposal sites on the territory of the Republic of Belarus has a total activity of about $3.7 \cdot 10^{12}$ Bq, that is three orders of magnitude lower than in the considered "Ekores" storage facilities.

As of 2019, the total activity of $^{137}$Cs radionuclides in the territory of 27.9 thousand km$^2$, estimated on the basis of the data [5] on contamination of the territory of the Republic of Belarus as a result of the Chernobyl accident, is about $6.2 \cdot 10^{15}$ Bq, that is, of the same order , as in the considered storage facilities. At the same time, the range of radionuclides in the "Ekores" storage facilities is much wider and is represented by more radiologically hazardous isotopes.

The given comparisons testify to the urgency of the problem of ensuring the radiation safety

Table 7. Expert estimates of specific and total activities of radioactive waste contained in the examined "Ekores" storage facilities.

| Name of the facility | Total activity, Bq | Specific activity, Bq/kg |
|---|---|---|
| Canyon No. 1 | $8.214 \cdot 10^{12}$ | $8.214 \cdot 10^{10}$ |
| Canyon No. 2 | $9.95 \cdot 10^{13}$ | $9.95 \cdot 10^{11}$ |
| Storage facility No. 1 | $7.05 \cdot 10^{14}$ | $7.05 \cdot 10^{12}$ |
| Storage facility No. 2 | $8.47 \cdot 10^{15}$ | $8.47 \cdot 10^{13}$ |
| Storage facility of the spent SRS, inv. No. 369 | $44.29 \cdot 10^{12}$ | Not determined |
| Storage facility of the spent SRS, inv. No. 422 | $3.7 \cdot 10^{9}$ | $3.7 \cdot 10^{7}$ |
| Storage facility of the spent SRS, inv. No. 423 | $2.84 \cdot 10^{15}$ | $2.84 \cdot 10^{13}$ |
| Storage facility of the spent SRS. inv. No. 424 | $56.98 \cdot 10^{13}$ | $56.98 \cdot 10^{11}$ |
| Total | $1.27 \cdot 10^{16}$ | |

Table 8. Expert estimates of distribution of volumes of radioactive waste disposed in the examined "Ekores" storage facilities by categories.

| Name of the facility | Distribution of radioactive waste by categories, % | | | |
|---|---|---|---|---|
| | very low-level | low-level | medium-active | high-level |
| Canyon No. 1 | 60-65 | 30-35 | 7-10 | – |
| Canyon No. 2 | 80-85 | 10-15 | 5-7 | – |
| Storage facility No. 1 | 70-75 | 20-25 | 5-7 | Less than 1 |
| Storage facility No. 2 | 60-70 | 30-35 | 5-10 | 1-2 |
| Storage facility of the spent SRS, inv. No. 369 | – | – | – | 100 |
| Storage facility of the spent SRS, inv. No. 422 | – | – | 100 | – |
| Storage facility of the spent SRS, inv. No. 423 | – | – | – | 100 |
| Storage facility of the spent SRS, inv. No. 424 | – | – | – | 100 |

of the "Ekores" radioactive waste management company.

## 5. Conclusion

According to the results of the CERR of the mothballed and being decommissioned "Ekores" storage facilities, it can be concluded that the used radiometric methods did not allow objective estimation of the qualitative and quantitative composition of the radioactive waste contained in the chambers of the examined storage facilities. Estimation of the total and specific activity of buried radioactive waste can be obtained from archival data on the history of filling storage facilities or during the extraction and certification of radioactive waste. According to expert estimates, the total stock of radioactive waste activity in the mothballed and being decommissioned "Ekores" storage facilities has amounted to $1.27 \cdot 10^{16}$ Bq.

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