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TECHNOLOGY OF RW MANAGEMENT IN DECOMMISSIONING OF MR AND RFT RESEARCH REACTORS

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The paper describes the technologies of management of RW generated in decommissioning of research reactors of National Research Center "Kurchatov Institute". The choice of technologies was justified by their safety, limited number of qualified personnel, personal and collective annual dose limits for personnel and population, threshold values of environment contamination parameters, and location of the reactors in a densely populated area of Moscow. All specified features were considered in the project of decommissioning of the MR and RFT research reactors. Safety issues of the applied technologies, the difficulties, which arose in the course of work on the project are discussed. Technologies of use of remotely controlled mechanisms jointly with means of remote radiometry and spectrometry are presented. These technologies were used both during dismantling the large-size equipment, and at the stage of management of high level waste. The main results of works are summarized and recommendations are made concerning radiation safety in process of RW management.

Keywords: *radioactive waste, decommissioning, personnel exposure doses, radiometry, spectrometry, remotely controlled mechanisms.*

Introduction

In 2008 NRC "Kurchatov Institute" started the process of decommissioning of MR and RFT research reactors in the framework of the Federal Targeted Program "Nuclear and Radiation Safety Assurance for 2008-2015". The works were carried out in compliance with the decommissioning project, which was approved by the State Expertise of the Russian Federation in 2009. The project in terms of radioactive waste (RW) management was based on the results of comprehensive engineering and radiation survey of equipment and compartments, initial data on the results of operation of MR and RFT reactors and the level of knowledge, technologies and regulatory requirements available at the end of 20th — beginning of 21st centuries. Low and intermediate level waste was packed in concrete and metal containers for subsequent long-term storage.

High-level waste was packed in airtight casks and transported to the high-level waste storage pad of the Centre. Remote radiometric instrumentation and remotely controlled mechanism were widely used in combination with dust suppression techniques in the compartments. This made possible to complete the required large scope of dismantling and decontamination works while at the same time minimizing the radiation impact on the personnel and environment.

RW Management in Decommissioning of MR and RFT Research Reactors

The following principles were incorporated in the procedure of decommissioning works:

- implementation of works by a limited number of personnel: insufficient number of workers was the result of rising radiophobia following the Chernobyl accident, decrease of hiring new staff in nuclear industry due to political changes in

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the country (the number of workers was within 40—45 people);
- conduct of works with individual dose limits set at 4 mSv/year in accordance with the thresholds set by regulatory documents and internal institute services;
- contamination of the environment outside the territory of the Center and in city districts should have been lower than the limits set for the population even in case of emergency situations;
- the RW generated must have been characterized, separated in accordance with their specific activity, conditioned, appropriately packed and sent for long-term storage outside of Moscow [1, 2].

The limitations listed above required the project to envisage use of technologies ensuring implementation of the overall scope of works without presence of personnel in the areas with high radiation background. The estimates made in the framework of the project suggested that ~ 1800 m^3 of solid radioactive waste (SRW) would be generated, including ~ 1500 m^3 of low-level, ~ 300 m^3 of intermediate-level and ~ 3.5 m^3 of high-level waste (in accordance with requirements to specific activity set by OSPORB-99). The total activity of SRW generated in process of reactor equipment and loop facilities dismantling was projected at $1.0 \cdot 10^{14}$ Bq (~ 2700 Ci). The duration of works on MR and RTF equipment dismantling was set at 4 years. Average annual dose loads on the personnel were limited to 4 mSv/year and collective dose was required to remain within 140 man·mSv/year.

According to the project, dismantling works were started at peripheral least contaminated compartments, then loop facilities equipment was dismantled, followed, at the final stage, by the in-vessel equipment of MR and RFT reactors located in the reactor hall with the highest values of exposure dose (up to 0.6 mSv/h) [3].

Such ideology of works required the use of remote characterization methods and use of remotely controlled mechanisms at all stages of works on decommissioning of research reactors. Experience of works on closure of radiation-hazardous facilities in the territory of NRC "Kurchatov Institute" demonstrated that radiometric and spectrometric automated characterization systems allow effective identification, categorization, conditioning of RW and selection of appropriate RW packages, and, consequently, provides reduction of waste volume [4].

Loop facilities equipment of MR reactor was located in underground compartments, and the total number of compartments was ~ 50, therefore works in each of the compartments included development of a work implementation plan (WIP), which included radiation characterization [5].

WIP included preliminary examination of the work area using an unmanned gamma-visor and gamma-locater, which scanned the equipment and compartment surfaces. The characterization results included gamma-image of the facility and spectrum and flux of gamma-quanta in the selected direction [5—7]. Measurement results processed using specially developed methods and data display software were used to obtain distributions of either surface or specific activities of the main γ-emitting radionuclide contaminants for equipment and compartment surfaces [8]. Fig. 1, for example, shows distributions of ^{60}Co and ^{137}Cs activities in the compartment of PVK loop facility. The results obtained were used to identify the sequence of dismantling works, characterization, sorting of RW generated, and selection of methods for waste packing and removal. Measurement results allow simulation of activity changes in process of dismantling and decontamination works (Fig. 2). In general, the measurement data were used to identify the most contaminated pieces which were the first to be removed in process of dismantling works. This ensured reduction of equivalent dose rate in the compartment and easier access of the personnel to the working areas.

RW management technologies included in the project

Equipment in loop facilities rooms was dismantled by remotely operated mechanisms Brokk-330. The most contaminated pieces of equipment were removed first, followed by dismantling, sorting and packing of the rest of RW.

At the final stage the containers were sent to a specially equipped temporary storage pad for subsequent transportation to FSUE RPA "Radon". All compartment surfaces were decontaminated after the dismantling of equipment. Only the remotely operated mechanisms entered the areas with high radiation fields, while the operators worked in radiation protected areas and in areas with much smaller equivalent dose rates (Fig. 3).

All the works were carried out with the use of dust localization and dust suppression techniques in order to reduce the volumetric aerosol activities in compartments and in operating personnel working areas.

Dust suppression techniques lead to considerable reduction of radioactive aerosols release to the compartments and to the environment. Air volumetric activity in the areas occupied by personnel did not exceed regulatory values.

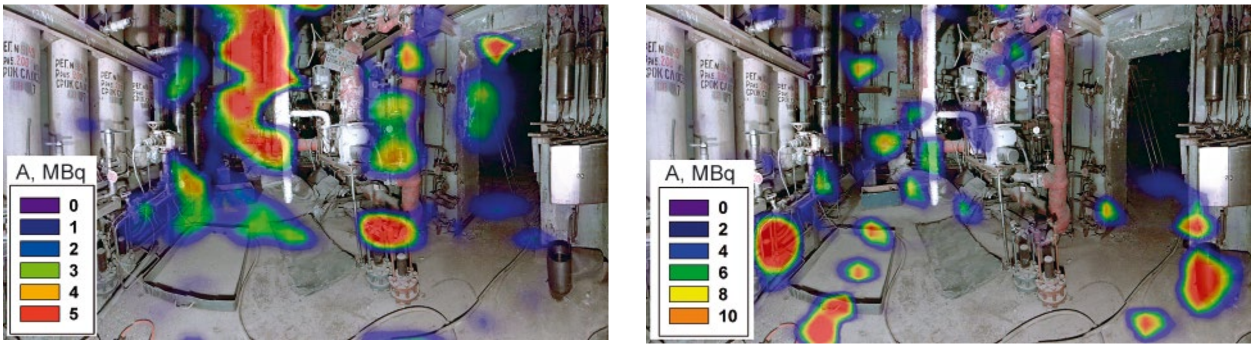
Technologies of RW characterization

Standard RW characterization and RW separation according to specific activity technologies were used in process of research reactors decommissioning works.

The standard procedure was scanning by gamma-locator and contamination visualization by gamma-visor, measurement of γ-radiation spectra of dismantled structures, sampling for spectrometric and radiochemical analysis. Radionuclide vector of the waste was identified in laboratory studies. On the

(a) Total activity of ^{60}Co: 2.1·10^{9} Bq *(b) Total activity of ^{137}Cs: 5.9·10^{9} Bq*

Fig. 1. ^{60}Co (a) and ^{137}Cs (b) activity distributions superimposed over photo image of the PVK loop facility compartment



(a) Total activity of ^{60}Co: 3.7·10^{8} Bq *(b) Total activity of ^{137}Cs: 2.6·10^{8} Bq*

Fig. 2. ^{60}Co (a) and ^{137}Cs (b) activity distributions as a result of simulation of removal of most contaminated pieces

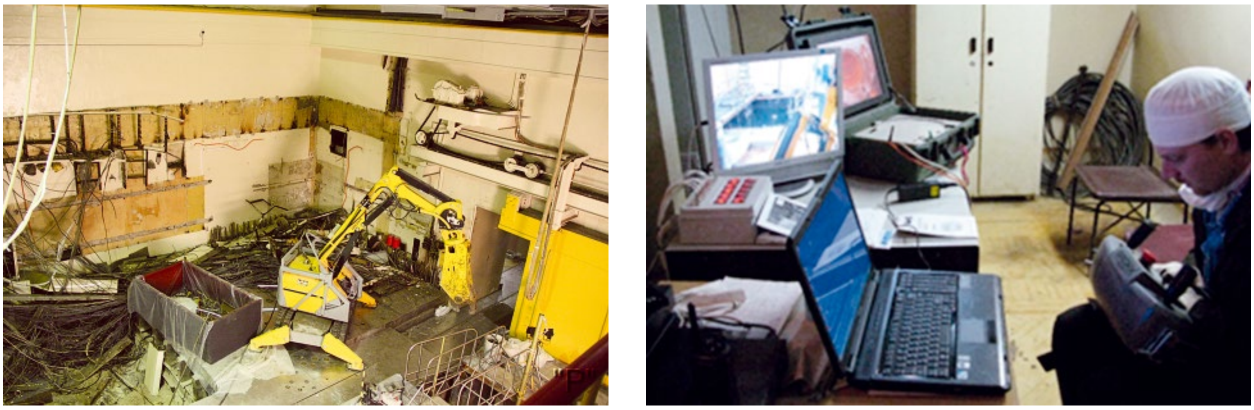


Fig. 3. Position of remotely operated mechanisms and their operators in process of implementation of radiation-hazardous works

basis of this procedure activities of radionuclides, which were earlier measured in laboratory analysis can be evaluated based on the measurements of activities of the main γ-emitting radionuclides. In particular, extensive measurements were performed to identify the nuclide composition of contaminated water in the storage pool and reactor pool [9].

A radiometric express-method was developed for in-situ measurements of ^{90}Sr activity in the presence of such γ-emitting radionuclides as ^{137}Cs and ^{60}Co [10].

Filters of aspiration equipment used to control volumetric activity of aerosols in the working areas were also thoroughly analyzed in addition to RW samples. Filters were subjected to γ-spectrometric, β-radiometric measurements and radiochemical analysis to determine the activity of α-radiating radionuclides. Such measurements were a good assessment of the radionuclide vector of waste contamination, as the filters captured dust from the surfaces of dismantled equipment and microparticles generated in process of cutting and dismantling.

Logic of RW separation

As mentioned above, there was a need for separation of waste in process of characterization. This was connected to the lack of storage space for high-level waste and waste containing long-lived radionuclides in the storage facilities locate in the neighbouring regions. Due to long-standing cooperation between NRC “Kurchatov Institute” and FSUE “Radon”, it was possible to send most of RW to the storage facilities of FSUE "Radon". Nevertheless, fragments of high-level waste (equipment) had to be left at the temporary high-level waste storage pad of the Centre (storage facility #7) for storage and decay of contaminating radionuclides. The location of high-level waste storage pad in the immediate vicinity of the reactor building was a significant simplification of the process. Inventory of HLW storage facility was carried out at the preliminary stages of works on decommissioning of MR and RFT reactors [11].

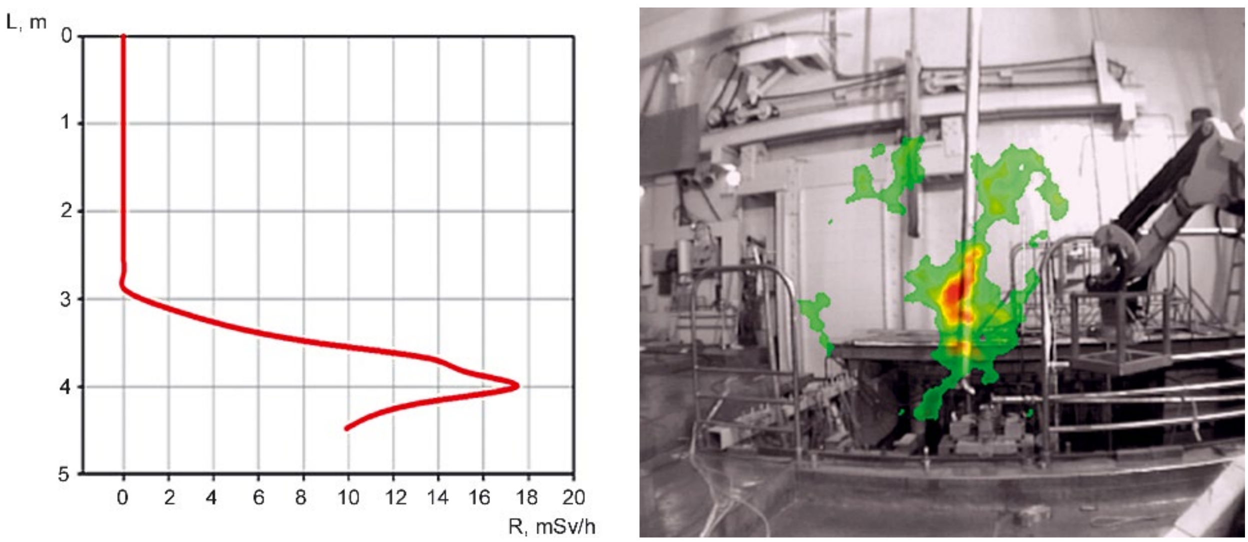
Prior to the start of works all the storage facility cells were nearly completely filled with waste and required sorting, repacking and removal of some of the waste for subsequent use of cells for storage of high-level waste generated in process of dismantling equipment of MR reactor. Waste placed in storage facility cells were stored in metal cases packed into special protected containers. The temporary storage facility was a subsurface concrete monolith building with steel channels 95—416 mm in diameter and 4 m deep used as storage cells. The total number of cells was 127. All of them were sealed by concrete plugs. The storage facility was equipped with a protective structure. The walls were constructed of concrete blocks 600 mm thick, the roof was constructed of concrete plates 170—200 mm thick providing biological protection in process of work with highly hazardous cases and a removable metal roof for precipitation protection.

Examination of the contents of storage facility cells was carried out by remotely controlled mechanisms and included removal of the cases from the cells and measurement of activity distribution along the case length. Remotely controlled mechanisms were also used for packing of low- and intermediate-level waste removed from the storage facility cells into containers. Assessment of total activity of the cases was done in an assumption of its uniform distribution along the case volume. In case of measurements at distances of at least quadruple maximum linear dimension of the source the heterogeneity of activity distribution introduces a small error to the calculation of case activity. When the activity of the case and container parameters are known, the type of the container can be selected that would comply to the transport standards of equivalent dose rate in transportation.

The result of the work was complete characterization of the cases stored in the cells of the storage facility. The cases were sorted into three groups with respect to γ-radiation dose rate at the distance of 1 m. In accordance with the data acquired, the cells were reloaded in order to free up the maximum number of cells for subsequent storage of RW generated in dismantling of MR and RTF reactors. As a result, 40 large-diameter cells were completely unloaded and 9 cells were partially unloaded. A part of radioactive waste unloaded from the cells corresponded to the 2-nd class, while those corresponding to the 3-rd class were packed into KRAD 2.7 and NZK-150-1.5 containers and sent for storage to FSUE "Radon".

2-nd class RW consisting of reactor elements were subsequently repacked and also sent for long-term storage.

Due to the limited storage space at the high-level waste storage pad of the Centre, extensive measurements were performed in process of removal of high level objects, cleanup of the storage pool and dismantling the in-vessel equipment of MR reactor [11]. Results of spectrometric measurements of in-vessel structures and loop channels demonstrated that the main γ-emitting radionuclide was ^{60}Co, activity of ^{137}Cs was 4—10 times lower than the activity of ^{60}Co [11, 12]. This activity ratio suggests that there is a chance for considerable reduction of specific activity after 10—15 years of storage. Activity distribution along the length of loop channels and beryllium blocks of reactor core was highly heterogeneous (Fig. 4) in accordance with the distribution



a *b*

Fig. 4. a) Equivalent dose rate distribution along the channel, b) gamma-image combined with a photo of the channel

of neutron flux in the core of MR reactor. The following measurement instrumentation was used for identification of the most radiation-emitting parts of loop channels: "Gamma-pioner" system, remotely controlled spectrometric system and portable gamma-camera "Gamma-vizor" [6—8].

Optimal locations for cutting away the highest level fragments from the lesser contaminated equipment parts were identified according to the measurement results.

Cutting of loop channels and separation of highly active fragments was carried out underwater by remotely controlled robotic systems Brokk-180 and Brokk-330 with relevant rigging in accordance with a specially developed technology that excluded heating of zirconium channel claddings.

A special water-filled bench located in the reactor hall was developed. High-level parts of channels were placed inside cases and sent for storage to the high-level waste storage facility, while intermediate- and low-level waste was placed inside containers and sent to the accumulation pad for subsequent transportation to FSUE "Radon".

A similar method was used to examine the 216 beryllium, graphite and aluminum blocks removed from the reactor core. As a result:

- about 40 of them were placed in cases and loaded to temporary storage cells of high-level waste storage facility of the Centre;
- 70 beryllium blocks were loaded inside NZK-150-1.5P containers with additional protection of filling with low-level radioactive soil;
- the rest of graphite and aluminum blocks corresponded to low-level waste and were packed inside KRAD-3.0 containers.

Some aspects of RW management

Decommissioning of reactors, especially the research reactors, which have much higher contamination levels compared to commercial reactors at all stages of works, is connected to management of large volumes of RW, and the RW problem was a key one in conduct of works. The main and the most dose-intensive operations in process of decommissioning nuclear facilities include radiation survey, equipment dismantling, conditioning, sorting, packing and transportation for long-term storage.

RW volumes identified at the stage of characterization are mainly assessed based on the volume of contaminated equipment. The state regulatory bodies do not include other contaminated objects or materials in the project. However, other contaminated objects, such as compartment floors and walls, hidden abandoned special sewage pipelines and auxiliary pipelines were identified in process of works on dismantling of equipment. For example, dismantling the equipment of MR loop facilities uncovered contamination previously hidden under the thick concrete floor cover. This contamination was generated by RFT loop facilities LRW collection system, which was earlier located in these compartments. In several cases the radionuclide impregnation depth reached tens of centimeters and the contamination levels increased with removal of material layers. Compartment No. 49 of AST loop facility, shown in Fig. 5 may be considered as an example.

Fig. 5. Pipelines of abandoned special sewage system in compartment No. 49 of AST loop facility

Exposure dose rate was 10 μSv/h before the start of floor dismantling, and reached 1500 μSv/h after the removal of concrete floor and soil filling. Such a situation could not be envisaged in the project, and RW volumes planned in the project turned out to be greatly underestimated. It should be noted that this is a fairly typical situation for research reactors.

The final volume of RW generated, packed and sent for long-term storage in process of project implementation were higher than the values anticipated in the project.

The presence of a temporary high-level waste storage facility and RW accumulation pad in the territory of the Centre was very helpful from the point of view of assuring uninterrupted conduct of works. Sending containers with RW for long-term storage was an irregular and, in some cases, unpredictable process, and, therefore, the presence of packed RW ready for transportation allowed timely correction of the schedule of transportation. Temporary RW storage facilities should be constructed directly in the territory of NPP in process of decommissioning commercial reactors as there currently are no operational regional disposal facilities, and such a solution will greatly support the logistics of decommissioning operations if sufficient storage capacity would be constructed.

Issues of re-use of the reactor equipment elements

Another problem worth discussing is the problem of RW re-use. Large quantities of metallic waste corresponding to low-level waste is generated in the course of works. Due to the lower cost of reprocessing of such RW compared to long-term storage of RW, a decision was made to send such waste for reprocessing to "Ekomet-S". Metallic RW were separated in accordance with the level of specific activity and were loaded into 20-foot standard containers. Over 800 tons of radioactive metal was thus removed from the territory of the Centre. The problem of RW re-use has another aspect — the issue of categorization of contaminated reactor equipment elements generated in process of decommissioning as waste. This problem was encountered in process of works. According to IAEA classification, radioactive waste, from the legislative and regulatory point of view are the materials containing radionuclides or contamination above the clearance levels and for which no subsequent use is envisaged. From the point of view of NRC "Kurchatov Institute", all the equipment of MR reactor can be regarded as RW. Unique equipment, which currently is not produced anywhere in the world, was dismantled in process of decommissioning works. Specific nuclear facilities in the Russian Federation may need such equipment. In particular, main circulation pumps still used at the research reactors in Russia, were dismantled.

An attempt to send the pump to RIAR encountered major financial and legal obstacles. On one hand, the pump is a contaminated piece of equipment, while on the other hand when operated as a part of reactor system, its contamination would not play any kind of role in operation of research reactor VK-50.

Unfortunately, transfer of contaminated equipment is not envisaged in the legislation. In accordance with the definition given by IAEA, the circulation pump is radioactive waste from the point of view of NRC "Kurchatov Institute", while at the same time it is a valuable piece of equipment from the point of view of RIAR. Sending several tons of equipment for long-term storage costs several hundreds thousands of roubles, therefore the Centre is interested to transfer this equipment free of charge. In turn, RIAR is interested in obtaining this equipment free of charge. However, this is a violation of anti-corruption legislation, although rational solution of the situation is in the interest of the society on the whole. Such situations need to be reflected in the legislation so that the management of relevant organizations would remain within the legal framework in such situations. Similar situations would continue to occur in decommissioning of commercial reactors due to standardization of the nuclear power plant equipment.

The problems highlighted here are only a small layer of problems occurring in process of decommissioning works, which need to be resolved at the following stages of works on remediation and cleanup of radiation legacy accumulated at previous stages of nuclear development.

At the current stage, further decommissioning works require development of regional RW disposal facilities. Decommissioning of commercial reactors would be impossible if this problem remains unsolved, as these works would result in generation of enormous quantities of RW of various classes.

Personnel exposure and environmental effects of RW management

Organization of works on decommissioning, application of remote radiation situation diagnostics methods, use of remote-controlled mechanisms and dust suppression systems all reduced the radiation impact on the personnel and environment.

External γ-radiation exposure dose was recorded on a daily basis for each worker. In spite of a complex radiation situation in most of technological compartments and a large scope of works, no dose standards were violated in process of dismantling of MR reactor systems, loop facilities and graphite blocks of RFT reactor by a limited number of personnel. Personnel exposure dose for the years of decommissioning works are given in Table 1.

Volumetric aerosol activities in the air was monitored both in working areas and in areas occupied by personnel. Personnel underwent annual examination at whole body counters at a specialized organization. Volumetric air activity in the areas occupied by personnel did not exceed regulatory values, and the maximum annual individual internal exposure dose in accordance with body counter data (for γ-radiating radionuclides) did not exceed 50 μSv/year. No cases of control levels being exceeded at the perimeter of NRC "Kurchatov Institute" were registered over the period of decommissioning works.

Table 1. Personnel exposure dose for the years of decommissioning works

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Average individual equivalent dose, mSv/year	1.5	1.5	2.0	1.9	2.7	3.5	3.6	3.7	3.8	3.6
Collective annual dose, man·mSv/year	84	84	76	65	97	123	129	134	136	126
Number of personnel, men	56	56	38	34	36	35	36	36	36	35

Conclusion

Works on decommissioning of MR and RFT research reactors at NRC "Kurchatov Institute" have identified a number of problems in RW management. First of all, the volume of conditioned RW turned out to be higher than anticipated in the project. In process of works over 1900 t of SRW and about 700 m^3 of LRW were removed from the territory of the Centre. The total activity of RW removed reached 113 TBq, with ~80 TBq being the activity of 170 channels of the loop facilities and ~3000 beryllium and graphite blocks of the storage pools and reactor core. A major portion of channels and blocks was packed in cases and left for long-term storage at the temporary storage facility in the territory of the Centre. The main radionuclides were ^{60}Co and ^{137}Cs, thus there is a chance of reduction of their activity and removal to FSUE "Radon" within several years of storage. Works on decontamination of MR reactor compartments are continued. 200 m^3 of RW are removed from the territory of the Centre annually as a result of these works. A decision on complete dismantling of the building was made due to the large volume of radioactive soil to be removed.

The logic of RW management operations and selection of the technologies used was aimed at performance of the works by a limited number of qualified workers with dose loads within 20% of individual annual doses for group A personnel with regards for both external and internal exposure. As a result of application of strict measures and additional radiation monitoring instrumentation, use of remote radiation examination methods and remotely controlled mechanisms the works on closure of MR and RFT reactors were carried out in full compliance with the design solutions. These solutions may form the basis for development of projects of decommissioning other nuclear- and radiation-hazardous facilities. The results of works, especially the use of intermediate RW storage facilities, need to be analyzed from the point of view of lessons learned for decommissioning commercial reactors and other nuclear facilities.

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