

**Dismantling of Loop-Type Channel Equipment of MR Reactor  
in NRC "Kurchatov Institute" – 13040**

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**ABSTRACT**

In 2009 the project of decommissioning of MR and RTF reactors was developed and approved by the Expert Authority of the Russian Federation (Gosexpertiza).

The main objective of the decommissioning works identified in this project:

- complete dismantling of reactor equipment and systems;
- decontamination of reactor premises and site in accordance with the established sanitary and hygienic standards.

At the preparatory stage (2008–2010) of the project the following works were executed: loop-type channels' dismantling in the storage pool; experimental fuel assemblies' removal from spent fuel repositories in the central hall; spent fuel assembly removal from the liquid-metal-cooled loop-type channel of the reactor core and its placement into the SNF repository; and reconstruction of engineering support systems to the extent necessary for reactor decommissioning.

The project assumes three main phases of dismantling and decontamination:

- dismantling of equipment/pipelines of cooling circuits and loop-type channels, and auxiliary reactor equipment (2011–2012);
- dismantling of equipment in underground reactor premises and of both MR and RTF in-vessel devices (2013–2014);
- decontamination of reactor premises; rehabilitation of the reactor site; final radiation survey of reactor premises, loop-type channels and site; and issuance of the regulatory authorities' deregistration statement (2015).

In 2011 the decommissioning license for the two reactors was received and direct MR decommissioning activities started. MR primary pipelines and loop-type facilities situated in the underground reactor hall were dismantled. Works were also launched to dismantle the loop-type channels' equipment in underground reactor premises; reactor buildings were reconstructed to allow removal of dismantled equipment; and the MR/RTF decommissioning sequence was identified.

In autumn 2011 – spring 2012 results of dismantling activities performed are:

- equipment from underground rooms (# 66, 66A, 66B, 72, 64, 63) – as well as from water and gas loop corridors – was dismantled, with the total radwaste weight of 53 tons and the total removed activity of  $5,0 \times 10^{10}$  Bq;
- loop-type channel equipment from underground reactor hall premises was dismantled;
- 93 loop-type channels were characterized, chopped and removed, with radwaste of  $2.6 \times 10^{13}$  Bq ( $^{60}\text{Co}$ ) and  $1.5 \times 10^{13}$  Bq ( $^{137}\text{Cs}$ ) total activity removed from the reactor pool, fragmented and packaged. Some of this waste was placed into the high-level waste (HLW) repository of the Center.

Dismantling works were executed with application of remotely operated mechanisms, which promoted decrease of radiation impact on the personnel. The average individual dose for the personnel was 1.9 mSv/year in 2011, and the collective dose is estimated as 0.0605 man×Sv/year.

## INTRODUCTION

For the last five years NRC “Kurchatov Institute” is performing decommissioning works on its research reactors – MR and RFT. The preliminary phase of these works (2008–2010) included: radiation survey; development of reactor decommissioning project; SNF removal from the MR reactor hall; licensing of decommissioning works; and inventory-taking in the HLW repository [1, 2]. The inventory was taken of repositories situated both in the MR reactor hall and on the special site (Repository #7 adjacent to the reactor buildings). In 2011, reactor equipment dismantling was launched, including: fragmentation and removal of loop-type channels from the reactor pool; elimination of under floor loop pipelines; dismantlement of loop-type cooling circuits in the central hall and basement of the MR building, etc. Dismantling operations were performed using remote-control Brokk robots, with the “dirtiest” equipment and pipeline sections identified with the help of systems such as “Gamma-Pioneer”, “Gamma-Locator” and “Gammavisor” applying radiometry and spectrometry methods [3–5]. For the purposes of waste sorting by its activity levels and shipping casks’ selection, dedicated equipment chopping technologies were developed, which involved the use of robots steered towards intensive gamma-sources following the data obtained from the “Gammavisor”. Use of remote-control mechanisms allows: considerable reduction of dose burden on the operating personnel by eliminating the need of people’s presence in areas with high radiation fields; monitoring of volumetric activity of aerosols in the air; and prevention of significant radionuclide releases in the environment. Support and productivity of works extended due to the application of robots reduce the duration of operations to be performed in radiation-hazardous conditions and considerably facilitate recurrent routine dismantling operations, thus making this work more interesting and creating opportunities for the involvement of young specialists.

## INVENTORY-TAKING IN HIGH-LEVEL REPOSITORIES

At the preliminary work phase, high-level waste were characterized and removed from repositories, on the one hand, to reduce the dose equivalent rate in the MR reactor hall and, on the other hand, to provide free space for accommodation of high-level waste to be produced in the process of reactor equipment dismantlement. For instance, a radiation survey of radwaste and spent nuclear fuel (SNF) repositories in the reactor hall was performed in view of subsequent removal of SNF and high-level sources [6]. MR decommissioning project framework also included high-level waste inventory taking in Repository #7 intended for interim storage of intermediate- and high-level waste of R (reactor) Group until its shipping to MosNPO “Radon” for long-term storage. Waste in this repository is packaged into metallic canisters installed in concrete cells. HLW Repository #7 is situated on the MR reactor site and consists of an underground concrete monolith with 127 four-meter-long embedded steel channels (repository cells).

Data from archive indicated that this repository comprised over 200 canisters with diameters of 190–400 mm containing high-level waste of over  $10^{15}$  Bq total activity. The works were primarily intended to characterize this waste, remove intermediate-level waste to long-term disposal facility, and prepare repository cells for storage of HLW to be produced in the process of MR/RFT decommissioning activities. Survey of the repository contents included canisters’ extraction from cells and their lengthwise activity distribution measurements, in order to identify the canisters eligible for shipping to MosNPO “Radon” for long-term storage.

A canister containing high-level waste was removed from its storage cell, delivered to the measuring devices and slowly lowered into the selected empty cell (# 122) for lengthwise scanning of its radiation parameters. “Gamma-Locator” and “Gammavisor” measuring systems were installed at a distance of 4.5 m from the cell, in order to identify the radiation parameters of waste contained in canisters. “Gamma-Pioneer” radiometry

system – a collimated detector installed on Brokk-90 remote-control robot – was installed at a distance of 0.5 m from the cell.

“Gammavisor” produced gamma-images of canisters superposed with respective video-images [3]; the dose equivalent rate distribution over the collimator space angle was measured by “Gamma-Pioneer”, and gamma-spectra of individual canisters were measured using the “Gamma Locator” with a spectrometric semiconductor detector based on CdZnTe (CZT). Depending on results measured, canisters were either transferred to free repository cells, or chopped and packaged in KRAD or NZK shipping casks for subsequent removal to MosNPO “Radon” site. Canisters’ extraction from cells, measurements and packaging of low- and intermediate-waste were performed using remote-control robots – Brokk-330. According to the existing Russian standards for solid radioactive waste transportation, the dose equivalent rate at 10 and 100 cm distances from the shipping cask walls should not exceed 100 and 10 mR/h (about 1 and 0.1 mSv/h), respectively. The main goal of radioactive waste sorting was to identify the type of container to accommodate the next portion of waste. Towards this end,  $^{60}\text{Co}$  and  $^{137}\text{Cs}$  (basic dose-forming nuclides in waste) activity ratios were determined using a specifically-developed methodology, and dose rates were measured at a certain distance from the portion of waste being reloaded. Depending on the above parameter ratios, the type of containers to accommodate radwaste canisters was identified in accordance with a special chart. Radwaste are transported in two container types: metallic casks (KRAD and KMZ) and concrete casks (NZK). The latter allows some modifications to improve HLW loading security.

These works resulted in comprehensive inventory taken in the operating HLW repository, as well as in characterization of canisters available in its cells. The contents of canisters were divided into three groups on the basis of their gamma-radiation levels at a distance of 1 m. In accordance with this waste grouping, the optimal sequence was developed regarding radwaste reloading operations, in order to empty the highest possible number of cells to be subsequently loaded with radwaste resulting from MR and RFT reactor decommissioning.

## **BERYLLIUM BLOCKS ACTIVITY MEASUREMENTS**

MR core and reflector were assembled from 76 beryllium, 106 graphite and 46 aluminum blocks with characteristic size of 130×130×1000 mm. Graphite blocks were part of the reflector, while the beryllium ones were structural elements of the reactor core. During reactor operation, some of them have been removed from the core and placed in the storage pool. The storage pool connected with the MR reactor pool by a hatch was intended for interim storage of spent fuel assemblies, as well as of loop-type channels, graphite and beryllium blocks unloaded from the reactor core. Figure 1 shows the beryllium blocks stored in the storage pool in the central reactor hall.



Fig. 1. Beryllium blocks stored in the storage pool in the central MR hall.

Radiation parameters and activity of beryllium blocks were measured using the same measuring instrumentation as that applied during inventory-taking in the HLW repository. Positioning of this measuring equipment in the MR reactor hall is shown in Figure 2.

Blocks were extracted from the pool by the overhead crane equipped with electric hoist, and hanged above the storage pool, where their radiation parameters were measured (including spectrometry measurements). All blocks are measured on the same geometry basis, in a predetermined spot at a fixed distance from detectors. These works are performed remotely by the operating personnel staying beyond the reactor hall behind the biological shield.

Measurement of radiation parameters of beryllium blocks included: the measurements of dose rate in the block center at a 100-cm-distance from it; spectrometry measurements taken by “Gamma-Locator”; and gamma-images of blocks produced by “Gammavisor”.



Fig. 2. Positioning of measuring equipment during beryllium blocks' characterization:  
1 – Dosimeter; 2 – “Gammavisor”; 3 – “Gamma-Pioneer”.

Eleven blocks from the storage pool and 7 blocks from the reactor core were examined. Their spectrometry has shown that the basic gamma nuclide was  $^{60}\text{Co}$ , while the activity of  $^{137}\text{Cs}$  was an order of magnitude lower than that of  $^{60}\text{Co}$ . Cumulative  $^{60}\text{Co}$  activity of all blocks from the storage pool measured by “Gamma-Locator” varied from 0.7 to 6.6 GBq, and the dose equivalent rate measured at a 1-m-distance from the block center varied from 0.1 to 5 mSv/h. For blocks extracted from the core, activities were in the range of 7.0–30.0 GBq.

Block-lengthwise activity distribution was found out to be uneven, with maximum radiation emitted by the central sections of blocks. Figure 3 shows an example of a block gamma-image produced by “Gammavisor”.

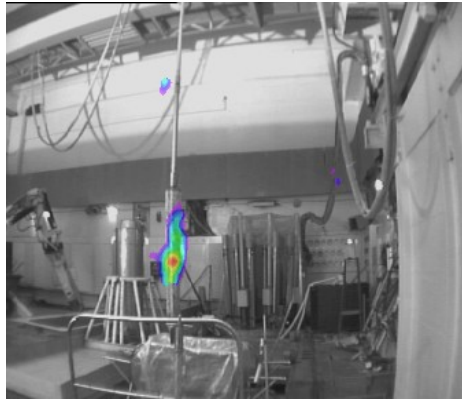


Fig. 3. Beryllium block gamma-image produced by “Gammavisor”.

Such activity distribution is consistent with the neutron flux distribution in the core. Lower activities of blocks from the storage pool compared to those from the core are consistent with their actual decay times. Data obtained from beryllium blocks survey form the basis for the MR decommissioning solutions, as concerns selection of technologies and methods for handling these beryllium blocks.

### **DISMANTLEMENT OF EQUIPMENT AND PIPELINES OF MR LOOPS**

The MR/RFT decommissioning license has been received in 2009, and in 2011 direct dismantling works were launched under the respective decommissioning project. Works were performed in technological rooms of loop-type facilities. These premises:

- had plenty of equipment inside;
- accommodated some large-sized equipment weighing up to 5 tons;
- showed high gamma-levels – up to 20 mSv/h;
- had complex removal routes for containers with dismantled equipment fragments inside.

Rooms of these loop-type facilities are situated in the basement of Building 37/1. The following works were performed there:

- chopping of loop-type channels stored in the central hall’s storage pool;
- extension of doors and hatchways in Building 37/1 basement premises;
- dismantlement of equipment and pipelines in water pipelines corridors 1–3 (including mezzanine pipelines);
- dismantlement of underfloor pipelines of the MR central hall;
- dismantlement of PG, POV and PVO loops equipment and pipelines [7].

The majority of dismantled equipment and pipeline fragments were converted into radwaste, while the rest was returned into the process cycle in form of scrap metal. During some operations in these rooms, gamma dose rates achieved the following levels:

- (1÷1.5) Sv/h – for channels' chopping, fragmenting and packaging into radwaste casks;
- (1÷10) mSv/h – for underfloor pipelines' dismantling in the MR central hall;
- (1÷10) mSv/h – for mezzanine water loop pipes' dismantling in water pipelines corridors 1–3 (pipeline corridors);
- up to 20 mSv/h – for loop-type equipment dismantling.

Effective regulatory documents prescribe the admissible gamma-dose of 12  $\mu$ Sv/h. In the same time, actual gamma-doses during the works in the immediate vicinity to contaminated equipment exceeded this admissible level by 3–6 orders of magnitude. That means that one might receive the annual dose within an hour while working in loop-type facility rooms, and within 5 minutes while chopping the loop channels. Due to these high dose rates, these works required application of remote-control mechanisms and radiation monitoring by additional remote-control means and methods. Moreover, these works required application of dismantling technologies including preliminary survey of rooms by “Gamma-Locator” and “Gammavisor” in order to detect the equipment surfaces with the highest radiation levels. Measurements have shown varying contamination of the equipment, with some areas contaminated with  $^{137}\text{Cs}$  not coinciding with those contaminated mainly with  $^{60}\text{Co}$  [5]. Nevertheless, it should be noted that these identified surfaces and equipment with the highest contamination levels weren't the main contributors to the room's average dose equivalent rate, i.e. their removal caused no significant reduction of this rate in the room as a whole. Due to this circumstance, step-by-step dismantling of equipment accessible for remote-control Brokk robots was selected as the easiest option of equipment dismantlement in the basement rooms of PG, POV and PVO loop-type facilities. A family of these mechanisms – from Brokk-90 to Brokk-400 – was applied, allowing a wide range of operations to be performed very efficiently and with varying specific forces applied. Use of a large set of easily-replaceable attachments allowed all possible dismantling operations to be performed promptly enough and without any direct personnel involvement. Operators worked in external decontaminated premises, while all operations in the technological premises were performed by remote-control robots.

Access to technological rooms required arrangement of hatchways to allow the above mechanisms to penetrate there, i.e. involved considerable amounts of construction activities. During the works these hatchways were used for radwaste casks' removal. All radwaste management operations were performed in the rooms accommodating the equipment being dismantled – there the waste was dismantled, fragmented, packaged into containers and removed in the form suitable for subsequent shipment to long-term storage facility. Large components were sometimes extracted in bulk form and then chopped in the radwaste processing shop. Figure 4 shows an example of this work result for room #66, which initially contained the equipment of the PG gas-cooled loop-type facility. Remote-control mechanisms in these rooms were used in order to increase the efficiency and productivity of personnel's work. Dismantlement of loop-type facility equipment involved dose rates reaching 20 mSv/h, so the personnel could control the operation of these mechanisms from corridors, through the doorways opening into these rooms, and even enter these rooms for a short time. Polymer coatings preventing the dust from rising were also used to reduce the volumetric activity of aerosols.



Fig. 4. Use of remote-control mechanisms during equipment dismantlement in room #66.

Quite a different situation was faced while dismantling and chopping loop-cooling circuits in the storage pool and in the MR reactor hall. During these works, dose rate levels turned out to be several orders of magnitude higher than those registered in the basement, thus making it impossible for the personnel to be present in the working area while the cooling circuit equipment components were being extracted, chopped, sorted and packaged, so all these operations were performed by remote-control robots. These works included handling of long fragments of reactor and loop equipment (namely loop channels), which differed by their configurations and structural materials. Parts of these elements from inside the reactor core were subject to intensive neutron irradiation, while the rest was contaminated with fission and activation products. All this equipment – over 150 items total – was situated in the reactor storage pool. Uneven irradiation of these elements considerably complicated their extraction from the reactor pool, fragmentation and removal from the central hall. In view of their specific activity, irradiated parts of these channels belonged to the category of high-level waste.

As before, the loop equipment elements emitting the highest radiation were identified using the radiometry system installed on Brokk-90 (“Gamma-Pioneer”), the remote-control spectrometry system and the portable gamma-camera (“Gammavisor”).

First the loop equipment was scanned by the “Gamma-Pioneer” radiometry system, with relevant gamma-images being in the same time produced by the “Gammavisor”. Nuclide content in the contamination of the channels being scanned was determined on the basis of their radiation spectra measured by the “Gamma-Locator” spectrometry system. After that, lengthwise activity distribution was identified for each scanned channel, on the basis of scanning and spectra data analyzed using the specific methods developed [4].

Analysis of results has shown that activity was distributed along channels very unevenly, with the structural parts that have previously been in the core showing the highest activity levels. The main dose-forming nuclide was  $^{60}\text{Co}$ ; however, spectra measured in some other channels have also detected other radionuclides, such as  $^{94}\text{Nb}$ .

The results of channel-lengthwise activity distribution measurements were used to identify the optimal chopping spots in order to separate high-level parts from lower-level ones.

To prevent the channels' zirconium cladding from heating, all operations involving loop equipment chopping and high-level fragments' removal were performed under water using remotely controlled Brokk-180 and Brokk 330 robots equipped with relevant attachable tools. For this purpose a special bench was built in the reactor hall and filled with water; the equipment to be fragmented was placed on special supports submerged in water, and its high-level parts were then chopped with hydraulic shears (Fig. 5).



Fig. 5. A high-activity channel part being chopped off under water using remote-control Brokk mechanism.

High-level fragments were placed into special canisters and transferred to the Institute's HLW repository, while the rest was packaged into either concrete or metallic containers and shipped to MosNPO "Radon" for long-term storage. Underwater channel-chopping technology allowed significant reduction of radioactive aerosol releases during high-level waste chopping.

Releases of aerosols in the room air were estimated in the course of various dismantling operations. These data were used to assess the internal dose received by the personnel throughout the works. Aerosol activity levels in equipment-dismantling and radwaste-packaging areas, as well as the potential internal exposure doses, are presented in Table I.

Table I. Volumetric activity of aerosols in various dismantling areas.

Working area	Average volumetric activity, Bq/m <sup>3</sup>			Potential internal exposure dose, μSv			Total annual dose, mSv
	<sup>137</sup> Cs	<sup>60</sup> Co	<sup>90</sup> Sr	<sup>137</sup> Cs	<sup>60</sup> Co	<sup>90</sup> Sr	
Channel chopping	38.6	2.25	17.3	443.6	52.2	996.6	1.5
Underfloor rooms	20.9	11.84	12.3	240.7	272.3	708.5	1.2
Pipeline corridor	59.3	3.1	16.0	682.1	75.9	921.6	1.7
Room #66	6.5	2.4	0.49	75.1	55.2	28.3	0.19
Total:							5.6

Aerosol volumetric activity levels in dismantling operation areas was below the admissible levels prescribed by regulatory documents, but nevertheless made it impossible to assure the reference limits established for the personnel. Use of remote-control mechanisms allowed the operators to spend much less time in the reactor hall and limited their intake of radionuclides.



## MAIN RESULTS

Loop-type equipment dismantling has started on the MR research reactor site. Use of remote-control mechanisms allows these works to be performed in strict accordance with all relevant regulations by an optimal number of operating personnel (the basic team consists of about 20 workers). Brokk robots are used for supporting and enhancing the labor efficiency, as well as in the areas with high dose equivalent rates. This makes it possible to reduce the dose burden on the personnel and the duration of work in radiation-hazardous conditions. As a result of the MR/RFT decommissioning works performed in 2011–2012, 213 tons of equipment were dismantled in the basement rooms of PG, POV and PVO loop-type facilities (rooms # 66, 66A, 66B, 72, 64, 63), including near 156 tons prepared for removal as radioactive waste with total activity of about 150 GBq.

Over 150 channels with total  $^{60}\text{Co}$  and  $^{137}\text{Cs}$  activity exceeding 45 TBq were also extracted from the reactor pool, fragmented and packaged.

Reduction of radiation impact on the personnel was promoted by the use of remote-control mechanisms. Volumetric activity of air in working areas was below the standard limit; the average individual dose for the personnel in 2011 was 1.9 mSv/year, and the estimated collective dose – 0.0605 man-Sv/year.

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