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Regulatory Cooperation Program between the Norwegian Radiation and Nuclear Safety Authority and the Federal Medical Biological Agency of Russian Federation

Results and Review of Progress from 2015 to 2019

DSA

Norwegian Radiation
and Nuclear Safety Authority

Reference
Siegien K, Sneve M K, Strand P, Shandala N K, Romanov V.Semenova M. Regulatory Cooperation Program between the Norwegian Radiation and Nuclear Safety Authority and the Federal Medical Biological Agency of Russian Federation. Results and Review of Progress from 2015 to 2019

Key words
Regulation of legacy, radiation and nuclear safety, Andreeva Bay, spent nuclear fuel, radioactive waste, contaminated land, emergency preparedness and response, environmental monitoring, radiological environmental impact assessment, worker protection, public protection, protection of the environment, regulatory compliance.

Abstract
This report describes work carried out between 2015 and 2019 within the regulatory cooperation program of the DSA and the Federal Medical Biological Agency of Russia, with support of the Burnasyan Federal Medical Biophysical Center. The work is set into the context of the long-term regulatory cooperation program that began in 2001.

Referanse
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Emneord
Regulering av avfall, utbedring, strålevern, historisk radioaktivt avfall, brukt kjernebrensel, radioaktivt avfall, forurenset jord, beredskap og respons, miljøovervåking, radiologisk konsekvensutredning, beskyttelse av miljøet, overholdelse av regelverk.

Resymé
Rapporten beskriver resultatene av prosjektene som ble utført mellom 2015 og 2019 under myndighetssamarbeidsprogrammet mellom DSA og Federal Medical Biological Agency of Russia, med støtte fra Burnasyan Federal Medical Biophysical Center. Arbeidet settes i sammenheng med det regulatoriske samarbeidsprogrammet som begynte i 2001.

Approved:

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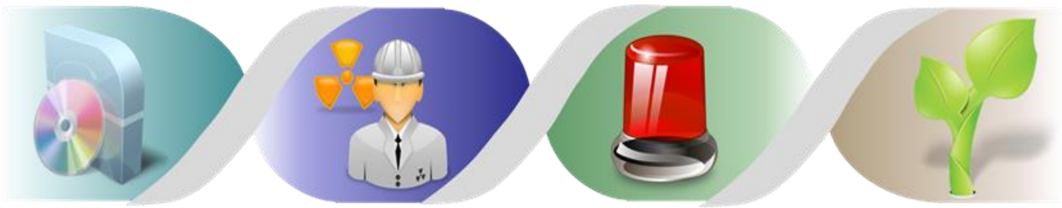

Preface/foreword

This report describes work carried out between 2015 and 2019 within the regulatory cooperation program of the Norwegian Radiation and Nuclear Safety Authority and the Federal Medical Biological Agency of Russia, with technical support of the Burnasyan Federal Medical Biophysical Center. The work is set into the context of the long-term regulatory cooperation program that began in 2001.

The most recent activities have focused on reduction of hazards and regulatory supervision of hazardous operations at the Site for Temporary Storage (STS) for spent nuclear fuel and radioactive waste at Andreeva Bay as preparations for recovery of spent nuclear fuel (SNF) from degraded stores and transfer to PA Mayak are completed and the first transfers have commenced.

A major achievement of the last five years has been to see a significant reduction in the hazard at STS Andreeva, due to retrieval from interim storage facilities and transfer off-site of substantial amounts of SNF.

The first substantial transfers took place in 2017 and it was acknowledged that international cooperation had resulted in the work being carried out safely and more quickly than otherwise possible. Continued progress is reported as being in line with or better than expected. The work is not complete and continues in the context of recovery and shipment of the more problematic degraded SNF.

The significant progress demonstrates the advantages of a stable long-term policy of hazard reduction and a strategy to implement it, in line with the Norwegian Plan of Action. Regulatory cooperation is a vital adjunct to international support for engineering projects, working within a flexible framework that makes it possible to address newly recognized challenges while still maintaining strict control over all risks.

Sharing of the experience internationally has been of significant mutual benefit and I would like to commend all colleagues within the program who have contributed so effectively.

Per Strand

Director of DSA

The following people were responsible for the tasks summarised in this report:

Organisation	Person, role
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Federal Medical Biological Agency of Russia (FMBA of Russia)	Romanov Vladimir - MD, Deputy Head, Federal Medical Biological Agency
SRC Burnasyan Federal Medical Biophysical Center of Federal Medical Biological Agency of Russia (SRC-FMBC)	Samoylov Alexander - Director General Corr.member of RAS, Dr.Sci.in Med.,Prof.,
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Contents

Executive summary

The Norwegian Radiation and Nuclear Safety Authority (DSA) has worked in a regulatory cooperation program with Federal Medical Biological Agency of Russia (FMBA) for the past 18 years. FMBA is the regulatory authority in Russia responsible, beyond others, for protection of workers and the population from radiation hazards.

The cooperation is financed by the Norwegian Ministry of Foreign Affairs under the Norwegian Action Plan for Nuclear Safety, where one of the main objectives is cooperation with relevant authorities and organizations to reduce the risk of serious accidents and radioactive contamination. The program has therefore focussed on regulatory enhancement of the nuclear safety culture and radiation protection at legacy sites in the area of the Barents Sea coastline, in particular, the Site for Temporary Storage (STS) of spent nuclear fuel (SNF) and radioactive waste (RW) at Andreeva Bay.

The projects have been performed by experts from the FMBA and the Burnasyan Federal Medical Biophysical Center of FMBA (FMBC) with active support from DSA experts.

The program of work has been designed to address a comprehensive range of radiation and nuclear safety issues, and to promote effective and efficient regulatory supervision. The method of work has been flexible, so as to support practical solution of specific and atypical safety problems. This involves discussion among relevant stakeholders and sharing of information during the preparation and review of draft regulatory documents and other materials. The program has also been promoted and supported through discussions in wider international fora.

Cooperation between FMBA and DSA in the period up to 2015 supported improved understanding of the radiation situation at STS Andreeva from a regulatory perspective and, in parallel, enhancement of the regulatory basis for operations at the site. It was important to update documents and procedures to be in line with latest developments in international recommendations and guidance, as adopted within the Russian regulatory framework, and to address the particular challenges associated with the complex radiation situation.

Results of the cooperation program provided the regulatory basis for progress to be made with refurbishment of the technical infrastructure at the significantly degraded stores for SNF and RW, and the other facilities at STS Andreeva. It also provided for necessary preparations to be made for recovery of the SNF and RW, allowing the work to proceed in a comprehensively regulated and safe manner, in terms of protection of workers, the public and the environment. Over 30 regulatory documents and procedures were developed and approved, giving comprehensive coverage of all radiation protection issues, including reconstruction and engineering work on site, personnel and environmental monitoring, emergency preparedness and response in case of accidents and overall improvement in safety culture. Innovative visualization tools were developed as well as techniques for monitoring personnel reliability. In addition, independent monitoring of the radiation situation and its dynamics was carried out.

This report describes work performed under the regulatory cooperation program in the period 2015 to 2019. In this period, operational activities at the site progressed to include completion of new buildings and installation of technical equipment, initial SNF recovery operations, re-packaging in containers for transfer off-site and completion of initial transfers. The regulatory cooperation program has followed these activities, based on the results of an updated regulatory threat assessment, to ensure compliance with the enhanced regulatory framework and the practical application of the new tools and techniques. The results can be summarized as follows.

Radiation protection of workers and the public

Regulatory review has been carried out of the Environmental Impact Assessment (EIA) of the proposed process for extraction of SNF from dry storage units (DSUs) and transport operations. Experts of FMBC made more than 60 comments and suggestions. After many discussions and meetings, and relevant amendment and supplementation, the EIA was approved by FMBA.

The proposed technological plan and safety justification for management of normal and abnormal SNF at STS Andreeva was analysed and approved following discussion and amendment. Regulatory documents on safe management of normal SNF have been developed on:

- Radiation monitoring;
- Planning of radiation hazardous operations;
- Implementation of the personnel protection optimization principle;
- Established reference levels;
- Selection of workers to carry out radiation hazardous operations;
- Arrangement of education and training of the personnel; and
- Enhancing safety culture.

Radiation parameters have been checked during test removal of SNF and occupational doses assessed.

Monitoring and optimization of doses for workers during SNF and RW management

Independently obtained gamma dose rate measurements confirm the stability of the radiation situation and doses to workers have been below the established reference levels.

The first generalized indicator of the radiation situation, the ambient equivalent dose rate (AEDR) integral over the technical site of STS Andreeva, demonstrated its effectiveness and convenience for evaluating the radiation situation in combination with the procedure for decomposition of time series. There has been a sevenfold decrease in the AEDR integral due to technical and engineering improvements.

The information and analytical system on radiation protection of workers (IAS RBP) software system developed within the cooperation program, and its efficient algorithms in effective analysis of past and possible future radiation situation data, provide clear benefits in radiation control planning for future hazardous operations, and in the context of emergency preparedness and response.

Emergency preparedness and response in case of a radiological accident

Two emergency exercises have been held that have demonstrated the operation of controls and the emergency response system of Northwest Center for Radioactive Waste Management “SevRAO” and institutions under FMBA in case of a radiological accident. In combination, the exercises have improved arrangements for closer cooperation between operator and regulator when developing urgent decisions and recommendations on taking protective measures. In particular, the exercises tested:

- expert assessment of the radiation situation and potential radiological consequences, to prepare recommendations for the management bodies, including the necessary counter-measures;

- → activation of the emergency preparedness system of FMBA in the region and, based on the findings of the exercise, to improve the preparedness of institutions under FMBA;
- → capabilities of forces and means of the responding bodies to the public of the region; and
- → procedure of the International Atomic Energy Agency (IAEA) and Scandinavian countries for notification of a radiological accident in real time mode in accordance with the current agreements at local, territorial and federal levels.

Results indicate that there is a high level of cooperation between emergency teams under FMBA and Rosatom, and preparedness of institutions under FMBA for medical care of injured persons. The exercises have confirmed improvement in emergency medical care indicators at the SevRAO facilities in comparison with previous exercises. Response times were reduced and there was improvement in the technical base of medical institutions and departments, serving as a basis for minimization of health effects in case of emergency exposure combined with other hazardous factors.

Valuable experience was obtained in the use of computer simulation methods for the purpose of radiation scenario and radiation situation assessment as well as visualization of radiation situation data and planning radiation hazardous operations, AndreevaPlanner and EasyRad.

Measures on psychological training of the personnel involved in the aftermath of a radiological accident were taken and experience in assessment of psychological training has been accumulated.

The “Docking-2018” video shows the practical activities and processes in the exercise, and can be used in sharing experience with other specialists but also with other relevant bodies and with the public.

Personnel reliability monitoring and training for hazardous operations

The system of personnel reliability monitoring, TIBUR_TSP, has been implemented in pre-shift monitoring and in training in hazardous operations. Testing has shown that the newly applied vibro-image data technique compares reasonably with conventional methods. The duration of this test is about one minute compared to 2-3 hours by conventional methods, which is a significant practical advantage.

Laboratory tests in FMBC have been carried out to assess the abilities of the students/testees to develop self-regulation skills. The relation between the parameters of electro-physiological signals with those of the speed and quality parameters of the trained activity has been revealed and described. The data obtained so far are preliminary, so it is reasonable for studies in this area to be continued.

Environmental monitoring of STS Andreeva

The environmental monitoring program has provided key data on the continuing situation with regard to both chemical and radiological contamination and their dynamics. The results indicate that, overall, the radiation situation has improved, while Cs-137 and Sr-90 continue to be the radiologically dominant radionuclides.

Gamma dose rates over the site have changed little over the period of surveillance. The main changes in dose rate have been temporary and are connected with identified planned operations, such as the installation of the biological shields at DSUs. Measurements of chemical forms indicate the potential for mobilization of Cs-137 and Sr-90; however, the results of time series monitoring indicate that contamination remains largely localized.

Analysis of groundwater samples from wells across the site indicate a range of chemical contaminants is present, with some contaminants being in excess of maximum permissible concentrations. Activity concentrations of Cs-137 and Sr-90 are also in excess of intervention levels in some samples. Both cytotoxicity and genotoxicity of groundwater samples has been demonstrated. However, the lack of double chromosome aberrations, frequently seen as radiation-induced biomarkers, indicates that chemical pollutants are likely responsible for the effects observed.

The analysis of fluctuating asymmetry of the birch leaves sampled on the site indicates a significant change in the state of plants. This could be due to their growing within the territory, but also because the site is on the edge of the species range.

Assessment of the Jaccard coefficient of floristic similarity in different areas indicates that species diversity across the site is small. Future changes to the coefficient could indicate a change in relative environmental quality, or just that they have evolved differently following the previous industrial or other disturbance. However, any such changes could be considered as a basis for further investigation as to the cause.

Continued monitoring will ensure that any changes to the radiation and environmental situation during continued SNF and RW activities are detected and any changes indicating ecological impacts detected, e.g. through changes in biodiversity indices.

Engagement with wider international cooperation.

Information from the regulatory program has been shared widely with the international community, through participation in workshops and conferences, and publication of program results in peer reviewed journals. In the period covered by this report, 9 papers have been prepared describing aspects of the program and published in peer reviewed international journals. In addition, contributions have been made to three major workshops on nuclear legacy management and to a Nuclear Energy Agency of the Organization for Economic Co-operation and Development (OECD NEA) report entitled, ***"Challenges in nuclear and radiological legacy management: Towards a common framework for the regulation of nuclear and radiological legacy sites and installations"***. This report shared substantial experience on the application of international recommendations and guidance and challenges at the site-specific level. Such sharing is considered of great mutual benefit to those participating and the timely publication by OECD NEA supports an even wider community.

This collective sharing and engagement also provide input to regulatory developments in Norway as well as wider information on strategic issues and examples of good practice how to deal with nuclear legacy problems. It also informs the strategy for related research activities carried out by CERAD.

The conclusions and recommendations from the workshops and the OECD NEA work provide a strong basis for continued international engagement in bilateral programs, helping to build strong and trusted working relationships and build confidence among all stakeholders.

A major achievement of the last five years has been to see a significant reduction in the hazard at STS Andreeva, due to retrieval from the old stores and transfer off-site of substantial amounts of SNF.

The first substantial transfers of SNF took place in 2017 and it was acknowledged that that international cooperation had resulted in the work being carried out safely and more quickly than otherwise possible[1]. Continued progress is reported as being in line with or better than expected[2]. The work is not complete and continues in the context of recovery and shipment of the more problematic degraded SNF.

The significant progress demonstrates the advantages of a stable long-term policy of hazard reduction and a strategy to implement it, in line with the Norwegian Plan of Action. Regulatory cooperation is a vital component, working within a flexible framework that makes it possible to address newly recognized challenges while still maintaining strict control over all risks.

[1] https://www.youtube.com/watch?v=s91OV_e8j8Y
[2] https://bellona.org/news/nuclear-issues/2018-06-andreyeva-bay-nuclear-fuel-removal-going-faster-than-planned-rosatom-says

List of acronyms

AEDR	–	Ambient equivalent dose rate
ALARA	–	As low as reasonably achievable
CAA	–	Controlled Access Area
CERAD	–	Centre for Environmental Radioactivity
CH&E-120	–	Center of Hygiene and Epidemiology-120 under FMBA of Russia
CMSU-120	–	Central Medical Health Unit 120 under FMBA of Russia
CTF	–	Close Territorial Formation
DSA	–	Norwegian Radiation and Nuclear Safety Authority
DSU	–	Dry Storage Units
EIA	–	Environmental Impact Assessment of technological operations on SNF extraction from DSU cells, loading to canisters and transport containers, loading at the Andreeva Bay pier, convey to and unloading at the pier of FSUE “Atomflot” in Murmansk
Emercom of Russia	–	Ministry of the Russian Federation for Civil Defense, Emergencies and Elimination of Consequences of Natural Disasters
EMRDC	–	Emergency medical radiation dosimetry center of SRC-FMBC
EROUW	–	Emergency rescue and other urgent works
ERT	–	Emergency rescue team
FA	–	fluctuating asymmetry
FMBA	–	Federal Medical Biology Agency of Russia
FMBC	–	Burnasyan Federal Medical Biophysical Center
FSUE ETC SPb.	–	Federal State Unitary Enterprise “Emergency technical center of Minatom of Russia (Saint-Petersburg)”
FSUE RosRAO	–	Federal State Unitary Enterprise for Radioactive Waste Management
HBS	–	horizontal biological shielding
HPZ	–	Health Protection Zone
IAEA	–	International Atomic Energy Agency
IAS RBP	–	Information and analytical system on radiation protection of workers
IBRAE RAN	–	Institute of safe development of nuclear power engineering of the Russian Academy of Science
INES	–	International Nuclear Event Scale
IRM-120	–	Interregional Management-120 under FMBA of Russia
MPC	–	Maximum Permissible Concentration
NWC SevRAO	–	Northwest Center for Radioactive Waste Management “SevRAO”
OECD NEA	–	Nuclear Energy Agency of the Organization for Economic Co-operation and Development
REE	–	Research Emergency Exercise
RL	–	Reference Level
Rosatom	–	Nuclear and Radiation Safety Department of the SC “Rosatom”
RW	–	Radioactive waste
SA	–	Supervision Area
SCC	–	Situation Crisis Center
SIC “Typhoon”	–	Scientific industrial society “Typhoon” under Roshydromet
SFA	–	Spent Fuel Assemblies
SNF	–	Spent Nuclear Fuel
SRC	–	State Research Center
STS	–	Site for Temporary Storage
TPC	–	Transport Package Container

1 Introduction

The Norwegian Radiation and Nuclear Safety Authority (DSA) has worked for over 18 years with the Federal Medical Biology Agency of Russia (FMBA) as part of a wider regulatory cooperation program between Norway and the Russian Federation within the Norwegian government action plan for nuclear activities and the environment in northern areas [5]. Technical support is provided by the State Research Center - Burnasyan Federal Medical Biophysical Center (SRC-FMBC). The overall objective has been to improve radiation and nuclear safety in the Russian northwest.

Based on international analysis for the priorities for hazard reduction in that area [12], [10], the DSA/FMBA cooperation has focused on the site of temporary storage (STS) for spent nuclear fuel (SNF) and radioactive waste (RW), at Andreeva Bay, located 40 km from the northern Norwegian boarder.

DSA and FMBA decided from the beginning to take an innovative and holistic approach to the challenges associated with the STS. It was important to recognize the wide range of issues to be addressed in achieving effective and efficient regulatory supervision, to provide comprehensive the protection of workers, the public and the environment. Priorities for project activities within the program were based on analysis of the different threats from a regulatory perspective [3].

This threat assessment report covered the full range of radiation protection issues:

→ Emergency preparedness and response.

→ Operational safety and optimization.

→ Site characterization and environmental monitoring.

→ Control of discharges and public exposure during remediation.

→ Radiological Environmental Impact Assessment for: planned releases; accidents; transport; and treatment and storage of waste.

→ Contaminated land management and support for long-term site restoration and waste management strategies.

Cooperation project activities covered all these areas [8]. Over time, further projects have been introduced, including the development of visualisation tools for dose control and remediation planning [1] and for analysis and monitoring of personnel reliability [7].

The outputs include a range of drafted norms, standards, regulatory guides and procedures that address the unusual circumstances at the STS. They also include technical information on the radiation situation that supports independent evaluation of safety, as well as training and emergency exercises and the practical application of new technologies in challenging radiological situations. The program includes engagement with all relevant regulatory authorities in Russia and dialogue with operator organizations.

The results and technical outputs have been routinely published, most recently, prior to this report, in [9]. In addition, information from the program has been shared widely with the international community, through participation in workshops and conferences and in the successful publication of program results in peer reviewed journals, e.g. [11]. Engagement with this wider community benefits the DSA/FMBA cooperation program as well as the other participating organizations, all learning from shared experience [4], [6].

In accordance with progress on infrastructure improvements, plans were developed for large-scale operations at Andreeva Bay for SNF and RW recovery and preparation for transfer to PA Mayak [2]. Plans were divided into 3 stages:

1. SNF removal from the Dry Storage Units (DSU).
2. Removal of 6 spent fuel assemblies (SFA) from Building number 5.
3. Removal of RW accumulated during the previous operation of the site as well as other waste being generated at the stage of SNF removal.

The regulatory control of the above activities is a natural progression of projects developed within the DSA/FMBA cooperation program. The initial threat assessment [3] was updated through 2014 and results reported in [9]. The update took into consideration progress with stabilization of the radiation safety situation, the newly prepared regulatory documents, progress with the program of industrial projects, including hazardous operations to recover SNF, and developments in international recommendations and guidance.

Given the identified updated priorities, five projects were developed and implemented from 2015 to 2019 within the DSA/FMBA regulatory cooperation program. With support from DSA and FMBA experts, the projects were undertaken by the FMBC.

Radiation protection support during SNF and RW removal operations at STS Andreeva

This project aimed at enhancing the regulatory functions of the territorial bodies under FMBA of Russia. The findings and results of the project were intended to support radiation protection of workers and the public during the planned radiation hazardous operations.

Tasks of the project included:

- Analysis of the proposed solutions and operational technology procedures for the SNF and RW removal and the compliance of these solutions and procedures with the current regulatory documents.
- Assessment of the radiation parameters in the main working areas.
- Assessment of doses to workers.
- Development of the activities to optimize protection of workers and the public.

Scientific support of IAS RBP in regulatory supervision of STS remediation works at STS Andreeva

In order to monitor the changing exposure conditions and to improve capabilities in radiation protection of workers, in 2012-2014, under DOSEMAP-3 project the information and analytical system on radiation protection of workers (IAS RBP) was developed. IAS RBP consists of components compatible with each other:

- Mazur Interface – interface to input initial measured data;
- EasyRAD – to analyze the radiation situation;
- TesnovKML – to input routes of the personnel.

Using this software, it is possible to solve tasks associated with regulatory control of workers radiation exposure and efficient regulatory supervision of STS remediation works connected with accumulation of measured data, calculation of radiation fields, input of the personnel routes and basic radiation situation analysis. Crucial to safety in future hazardous operations is the effective implementation of the software at STS Andreeva, which is the main objective of the ongoing project.

Improvement and implementation of the soft/ hardware training complex for workers involved in hazardous SNF and RW operations

This project is the third in the series concerning professional reliability monitoring. The main outputs have been the pilot version of an expert-and-diagnostic information system for risk monitoring of the performance reliability violation and a soft/hardware system to train and perfect motor skills, taking into account the psycho-physiological price control of the activity. The main objective of the continuing project is to generate the testing model for soft/hardware training and introduce it into the system of training or retraining of workers involved in hazardous SNF and RW operations.

Organization of emergency exercises with international participation on the assessment of the preparedness and response in the event of a radiological accident at STS Andreeva

This project was to arrange and conduct an emergency exercise with international participation. The main objective was to assess the effectiveness of actions between all participants using computer methods for simulating the radiation situation as well as to assess the technical and psychological preparedness of the medical team personnel and groups to mitigate and minimize consequences of a radiation accident.

Ecological assessment of the environment during remediation of STS Andreeva

Evaluation of the environmental conditions around STS and ecological assessment of the terrestrial ecosystems is an important feature of regulation of remedial activities at STS Andreeva. A growing trend in the recent development of radiation protection principles includes the concept of supporting both protection of human health and the environment, through maintenance of stable functioning of ecosystems and biodiversity. Output of the project also included information on dynamics of monitored parameters of STS Andreeva radio-ecological situation.

This report describes the results of these projects, set in the context that shows continued support to regulation of radiation safety at STS Andreeva during the process of staged hazard reduction. The work is presented in the following five areas of activity, in sections 2 to 6:

- → Regulatory support of radiation protection of workers and the public during SNF operations
- → Monitoring and optimization of doses to workers during SNF and RW operations
- → Emergency preparedness and response in case of a radiological accident
- → Personnel reliability monitoring in hazardous operations
- → Environmental monitoring of the STS area

Section 7 presents examples of how the sharing of the output contributes to wider international discussion, and how that combined shared experience in turn helps to guide the next steps in FMBA/DSA cooperation. References are listed at the end of each section. Section 8 draws overall conclusions on the importance and continued relevance of the regulatory cooperation program as industrial operations proceed through some of the most hazardous activities.

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2 Regulatory support of radiation protection of workers and the public during SNF operations

2.1 Introduction

SNF storage at Andreeva Bay consists of three separate DSUs: 2A, 2B and 3A, half-buried in soil cylindrical containers that were originally designed and designated as a special water treatment complex (Fig. 1). Each DSU has a diameter of 18 meters and volume of approximately 1000 m^3. They are located inside the newly constructed sheltering building 153.

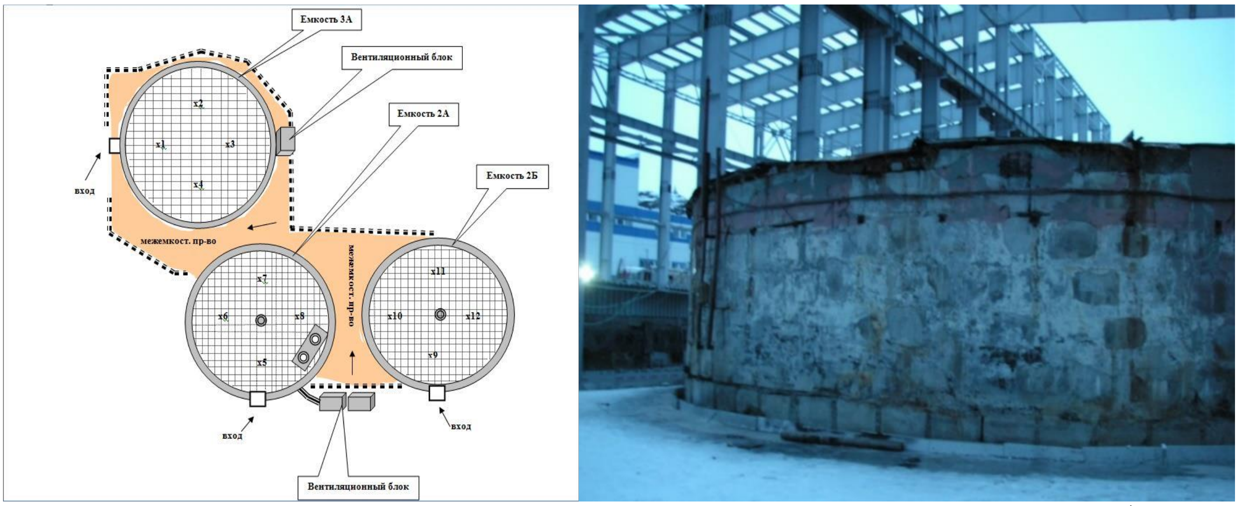

Fig. 1. Left- Building 153 and positioning of DSUs, right- DSU 3A and a part construction of Building 153 in 2012 (source: FMBC)

Spent fuel is stored in metal, vertically installed pipe storage cases, grouped within cells. The space between the cells is filled with concrete. Some of the SNF assemblies, as well as storage cases, have various defects. The defects do not allow for unloading using regular processes and equipment.

The developed technological regulations envisaged a staged approach to SNF recovery and its transportation to PA Mayak:

- 1st stage – removal of normal SNF[3] from DSU 2A and 2B prior to commissioning of Building 153 – the sheltering above the DSU – 2015.
- 2nd stage – removal of SNF from DSU 3A and of abnormal SNF using the infrastructure of Building 153 – 2016.

The main task was to study and assess the special features of operational activities of workers involved in management of normal SNF at STS Andreeva Bay. However, the State Corporation Rosatom made Decision No. 1-2/17339 – VK “On termination of work for the federal state needs in 2015 under the state defense order within the state contract of 27 March 2015 - Preparing for unloading and unloading of SNF from DSU at the Andreeva Bay facilities of Murmansk region”. According to this Decision, retrieval of SNF located in DSU containers and transportation to Federal State Unitary Enterprise (FSUE) PA Mayak was not to be implemented prior to the installation and commissioning of appropriate infrastructure and technical equipment in the complex to support SNF

[3] “Normal SNF”- SFA, without damage hampering recovery, loading and unloading into containers, i.e. no significant deviation from the regular geometric shape and dimensions; no damage to lifting catches, and no structural integrity violations, such as significant leaks, breaks, cropping, scaling, etc. Abnormal fuel presents damage of some sort that requires modification of work procedures.

and RW management at Andreeva Bay. This decision required the time schedule to be adjusted, transferring the due dates of “Assessment of work conditions of the personnel of the Andreeva Bay facility during SNF removal from DSU 2A and 2B” to 2017-2018.

The scope was also revised to focus on assessment of preparedness of the complex for SNF and RW management with the appropriate infrastructure and technical equipment. The plan was to analyze compliance of the accepted design solutions and operational technology (procedure) for SNF removal with the current regulatory documents and radiation parameters in the main working areas, together with assessment of doses to workers. As an outcome of the analysis and the performed studies, 120 recommendations were developed jointly with the North-West Centre for Radioactive Waste Management (NWC SevRAO) and Interregional Management 120 of FMBA (IRM-120) on how to optimize the protection of workers and the public during the management of normal and abnormal SNF.

The main tasks were as follows:

1. Assessment of preparedness of the complex for SNF and RW management with the appropriate infrastructure and technical equipment.
2. Evaluation of the working conditions at the Andreeva Bay facility during removal of normal and abnormal SNF from DSUs.
3. Development of regulatory recommendations on safe management of normal SNF.

Progress against each of these tasks is described below.

2.2 Preparedness of the complex for SNF and RW management with the appropriate infrastructure and technical equipment

2.2.1 Building 151

The construction of Building 151 and installation of the main technological equipment was completed in December 2016. The building was constructed for the “buffer” storage of containers, both loaded with or empty of SNF, and consisting of not more than 48 items Transport packages containers (TPC) with SNF are delivered to Building 151 from Building 153 by special transport vehicles (Fig. 2).

The movement of TPCs from Building 151 to the pier in forward and reverse directions is carried out via double gates number 1 using a rail transfer truck of 50 tons carrying capacity (Fig. 2). To perform loading and unloading operations in Building 151, a bridge crane of 50 tons lifting capacity (Fig. 2) is provided.

Fig. 2. Left: Transporter container carrier for TPC-108/1 (TC-18) transportation from Building 153 to Building 151, right: rail transfer truck and bridge crane.

2.2.2 Building 153

Building 153 is for the sheltering of DSUs [2]:

- To ensure safe working conditions for personnel during the discharge of SNF from DSU cells, loading of SFA in cases and forming packages TPC-108/1;
- To support operation of the re-loading unit, bridge cranes, re-loading trucks and special equipment for SNF discharge from the DSU cells, overload of SFA in cases CT and forming packages TPC-108/1 (TPC-18);
- To prevent the penetration of atmospheric fallouts to the DSU, containers and cases;
- To limit release of radioactive material and ionizing radiation resulting from routine operations and in case of accidents to the environment.

The building consists of a technological hall containing a SNF storage facility and facilities for TPC loading operations (Fig. 3 and 4A, B and C).

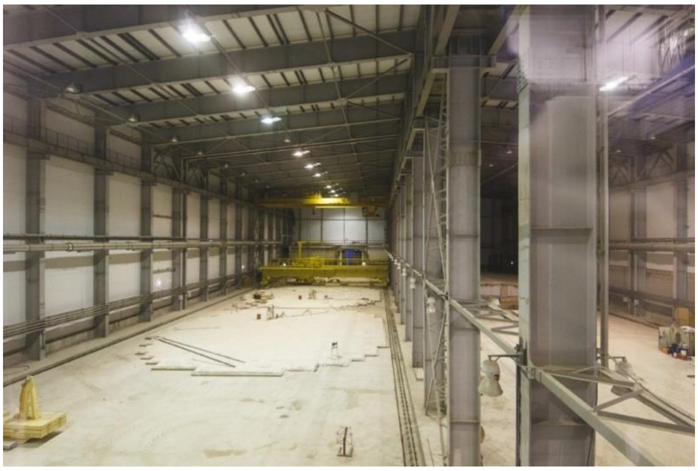

Fig.3 Technological hall of Building 153 (DSUs 2A and 2B, on the background – reloading unit)

Fig. 4A Technological hall of Building 153 (in the foreground - DSUs 2A and 2B, in the background – DSU 3A

Fig.4B Technological hall of Building 153 (February 2019)

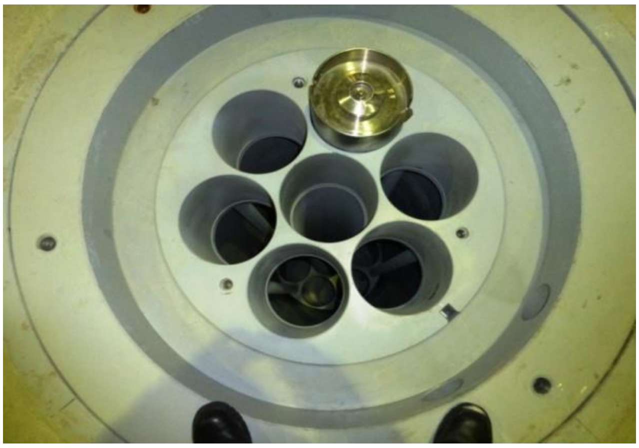

Fig. 4C The unit of the case loading (changing the cases) consists of cells for 7 cases

2.2.3 SNF storage conditions

DSU 3A was fully filled with SFA by mid-1985. The radiation situation here was the most severe. Damage to cases resulted in water penetration and its contact through fuel cladding directly with the fuel.

DSU 2A and 2B have an enclosing concrete wall of 600 mm thickness around the perimeter of the storage facility and shed made of steel removable. However, some storage cells of DSU 2B are filled with water.

SNF consists of submarine SFA in canisters of the following types:

- → T-21, T- 22 and T-22M (with SFA from reactors of the first generation of nuclear submarines);
- → T-24 and T-24M (with SFA from reactors of the second generation of nuclear submarines);
- → T-25, T-25M, T-26, T-26M, T-34M, T-35M and T-36M (with SFA from reactors of icebreakers).

The precise number of cases of each type, and the number of SFA in the cases is not finally established due to the lack of documentary support processes of the case overload.

Some stored SFAs are defective and are jammed in the case pipe or have damage to the outer casing of SFA and cladding that hampers safe extraction and reloading. Some SFAs also have various defects in the upper part and plugs, such as deformation or the absence of case plug clip, jamming plug screw clamp or plugs, which does not allow for use of regular tools for opening and extracting plugs.

During the examination of DSUs in 2003 - 2005 high dose rates were recorded above the surface of the storage facilities [2].

Much of the DSU work has been to bring the radiation situation into normal operating conditions, including removal of the old plugs from the cells and the installation of horizontal biological shielding (HBS), to provide acceptable conditions for the work of the personnel on the surface of containers (Fig. 5)

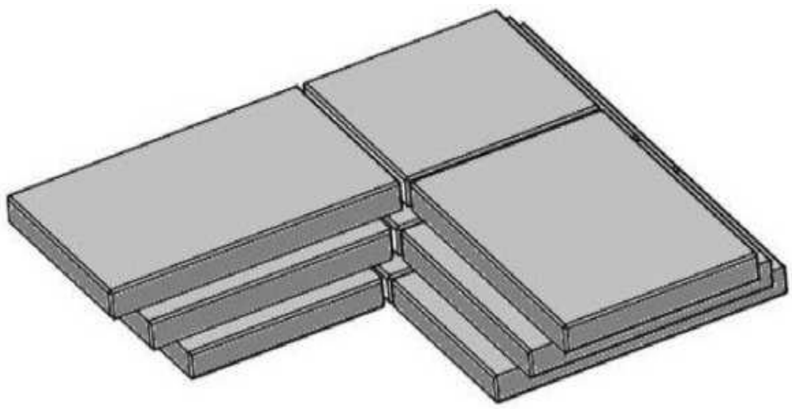

Fig.5 Segments of the horizontal biological shield [2]

It was expected that the dose rate would increase during the following operations:

- → water removal from the cell;
- → case plug dismantlement;
- → SFA condition test;

- → SFA removal from the cell to the reloading container;
- → case removal from the cell to the reloading container; and,
- → SFA lifting for the purpose of repair or inspection.

The completed analysis of the accepted technological and organizational decisions to protect workers against ionizing radiation during SNF management in DSU showed that implementation of the envisaged measures should ensure non-exceeding of the main dose limits established by NRB-99/2009 [3] for workers.

2.2.4 Radiation situation at the Andreeva Bay SevRAO Facility

At the end of 2015, dose rates were measured by FMBC jointly with the radiation safety service of the SevRAO, measured gamma dose rates at the sites of DSUs 2A, 2B and 3A, as well as inside DSUs 2A and 2B. Example result are shown in Fig. 6 and 7.

Obtained gamma dose rate measurements confirm the stability of the radiation situation when the SNF cells are not being extracted. Doses to workers over the calendar months of construction operations at the contaminated site around Building 153 were recorded as substantially below the reference levels (RL) established in the Order of 12.01.2015.

More detailed records have been maintained and used in the database for the visualization software tools, discussed in Section 3.

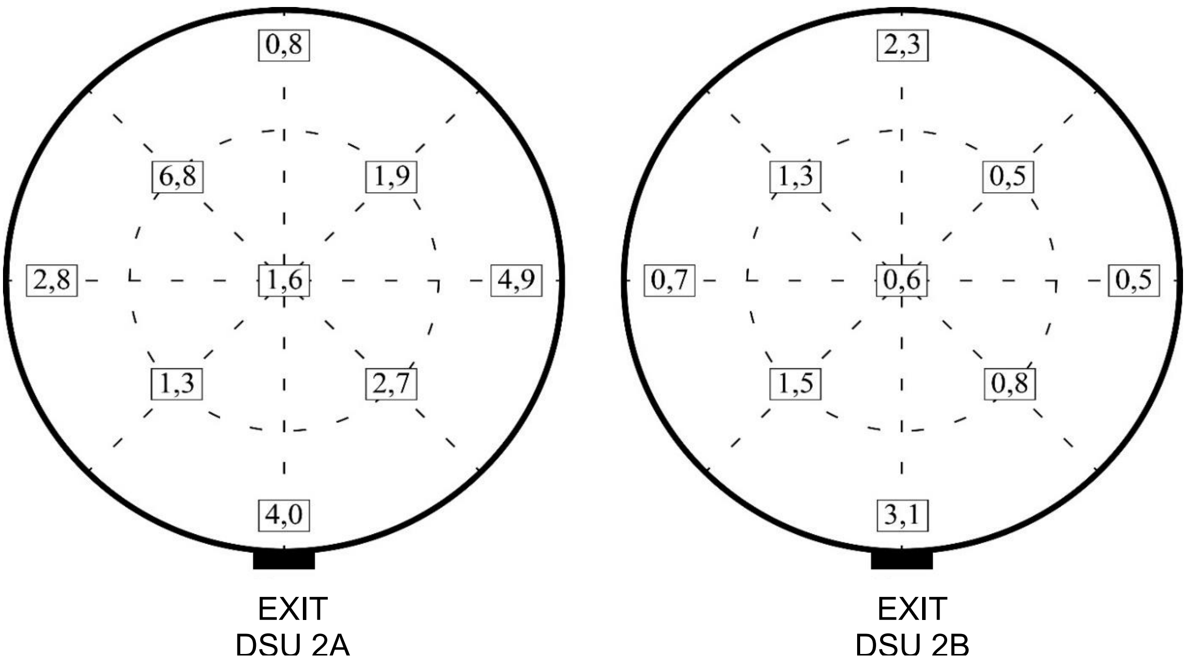

Fig. 6 Gamma dose rate inside DSU's 2A and 2B, μSv/h.

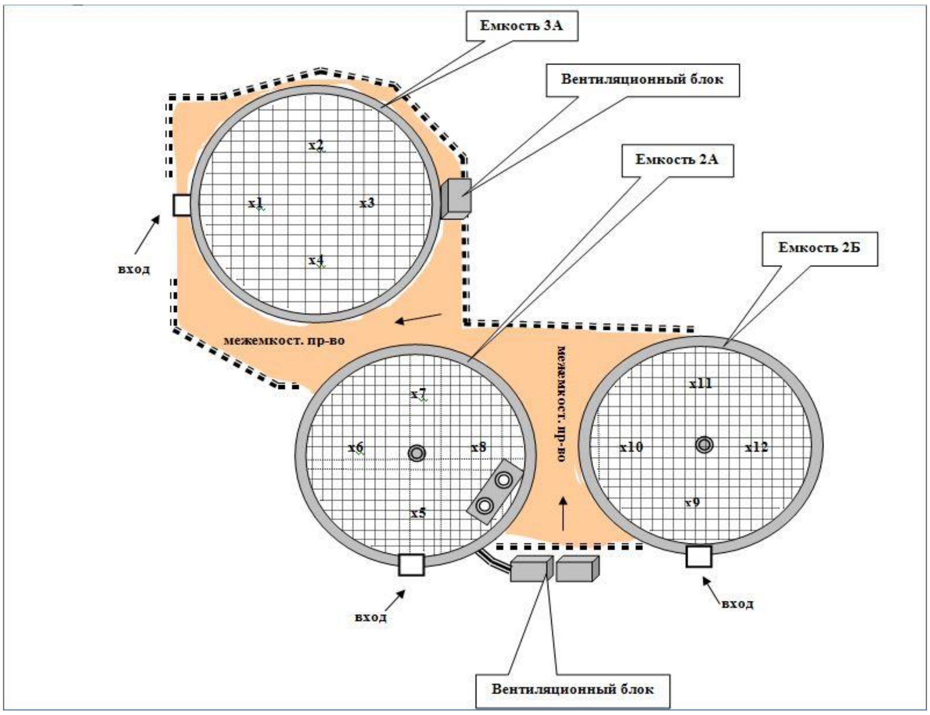

Fig.7 Location of points of measurement of gamma dose rate at the site of DSU location

2.3 Environmental Impact Assessment of Technological Operations

The objective of this task was to assess together with "JS "Atomproect" impact on the environment and the population from SNF extraction from DSU cells, reloading to cases and transport containers, loading transport containers at the Andreeva Bay Pier, transportation to the "Atomflot" Pier in Murmansk and unloading at the "Atomflot" Pier. The Environmental Impact Assessment [11] was financed through the Norwegian Nuclear Action Plan and with the Office of the County Governor of Finnmark

Work included analysis of documents on physical and geographical, climatic and meteorological characterization of the area, technological documentation on SNF management and social-and-economic and medical-and-demographic conditions of the public living in Zaozersk and Murmansk cities. An assessment of impact of hazardous chemicals and radionuclides to the environment during SNF extraction and management on-site was done. Finally, consequences/effects of potential accidents were analyzed.

The development of the technology for SNF and RW management is based on the following key principles:

- nuclear and radiation safety during SNF discharge and removal from Andreeva Bay, in accordance with the requirements of the relevant regulatory and legal documents;
- prevention of the spreading of radioactive materials in workshops and to the environment;
- the use of 'as low as reasonably achievable' (ALARA) principles (radiation exposure to workers, the public and environment, as low as it is technically feasible and economically reasonable);
- the use of physical barriers to prevent spreading of ionizing radiation and radioactive materials to the environment (the defense in depth principle);

- → the use of various control/monitoring measures;
- → optimization of transport-technological and re-loading operations;
- → minimization of generation of the secondary RW;
- → physical protection (security) at each stage of SNF management, accounting and control of nuclear materials and radioactive substances at each stage of SNF and RW management;
- → monitoring of the radiation situation during management of SNF and generated RW within technological buildings, Health Protection Zone (HPZ) and supervision area.

Bearing in mind the application of these principles, the performed calculation of the spreading of hazardous chemical materials during extraction and removal of SNF at the Andreeva Bay STS showed the highest concentrations at the HPZ borders and in the settlements near Nerpichiya Bay, Bolshaya Lopatka Bay and Zaozersk city. However, the assessed levels do not exceed the highest permissible concentrations in atmospheric air and releases during operations on-site are not expected to result in significant exposure to the population living in the area.

Analysis did not reveal any negative impact of Building 153 on surface and groundwater, off-shore water area, soils and geological environment, plants and animals in case of normal operations.

Assessment of consequences of design-basis accidents when using the infrastructure of the SNF management complex has demonstrated that the individual effective dose to the public will be significantly lower than 10 μSv/year. The highest effective dose to the public following the maximum design-basis accident (fall of the guiding device to the TPC-108/1 container being loading to the “Serebryanka” tanker) without the use of infrastructure of Buildings 153 and 151 ranged from 0.45 mSv/year to 0.037 mSv/year.

The maximum beyond-design-basis accident assumed the fall of an aircraft on the TPC-108/1 while being loaded within Building 153 or in the loading post at “Serebryanka” tanker. In this case, the highest committed dose to the public under the least favorable weather conditions can reach 41 mSv in the nearest settlement over the first year following the accident, i.e., exceeds the annual dose limit of 1 mSv. This situation would require measures to be taken to protect the public.

2.4 Analysis of technological plan and safety justification for management of normal and abnormal SNF at STS Andreeva

The anticipated radiation situation during works required development of organizational measures and technical means to assure the radiation protection of workers. Considering this, Joint Stock Company NIKIET developed technological documents concerning SNF removal from DSUs and from Building 5:

- → “Transport-and-technological plan of SNF discharge and removal from DSU cells of Andreeva Bay STS to the container storage site of FSUE “Atomflot”.
- → “Technical justification of safety and protection during management of normal and abnormal SNF at the Andreeva Bay NWC SevRAO sites”.
- → “Technological regulation for management of normal and abnormal SNF at the Andreeva Bay NWC SevRAO Facility”.
- → Technological regulation. The detailed technology of SFA removal.

→ Transport-and-technological plan of SFA preparation and discharge from the right small basin at Andreeva Bay.

→ Terms of Reference for manufacturing the irregular equipment and simulators.

The compliance of the accepted technological plan prepared by JSC NIKIET and a set of safety measures during SNF management and existing regulations in this respect was assessed.

2.4.1 Technological sequence of SNF management

The general procedure of the preparation of normal and abnormal SFA for removal for processing involves the following sequence of measures (Fig. 8, 9, 10):

4. Preparation of cases of "secondary"[4] and special canisters for SNF loading;
5. Dismantling of biological protection segments of DSU capacity;
6. Dismantling light cover from DSU cell;
7. Removing water from the volume of the opened DSU cell;
8. Correction of the defects of the upper casing cover (for abnormal cases);
9. Dismantling the "primary"[5] cover plug;
10. Condition test SFA (for abnormal cases);
11. Correction of the defects of abnormal SFA;
12. Overload of recoverable SFA in "secondary" cases and special canisters;
13. Removal of water from the interior of the "primary" cover;
14. Recoverability test of "primary" boot from DSU cell;
15. Overload of recoverable "primary" covers with jammed SFA into modernized TPC;
16. Installation of biological shielding segments of DSU capacity;
17. Loading cover of "secondary" and special canister with SNF into TPC;
18. Transportation of TPC with SNF by a special motor transport from Building 153 to the accumulation site of Building 151 (Fig. 8);
19. Transportation of TPC with SNF by a special motor transport from Building 151 to the pier;
20. Loading of TPC with SNF from the special motor transport to the cargo compartment of the ship.

[4] Secondary case- new case, where normal SFA should be reloaded from the primary case.
[5] Primary case- case filled with SNF and located in the DSU cell, from which normal SFA should be unloaded.

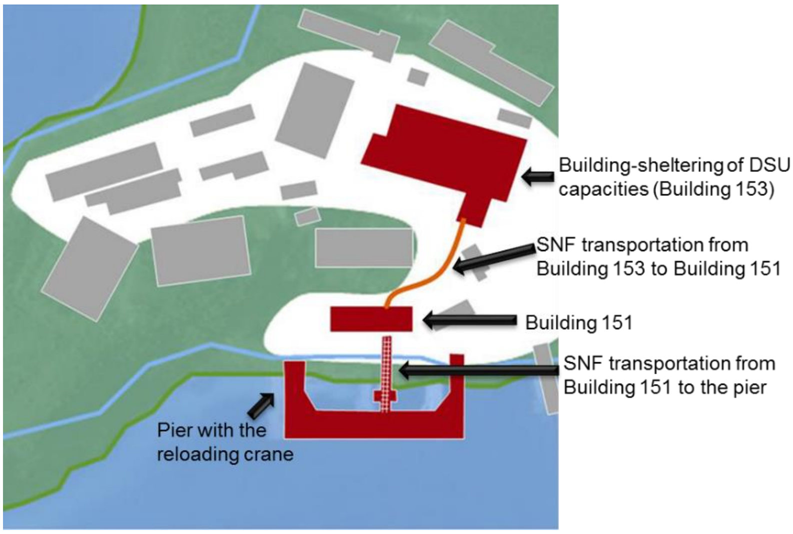

Fig.8 Technological plan of the SNF removal from the Andreeva Bay NWC SevRAO site [1]

Fig 9. Reloading unit (RU) installed in Building 153, Reloading protective container for SFA, Transport package container

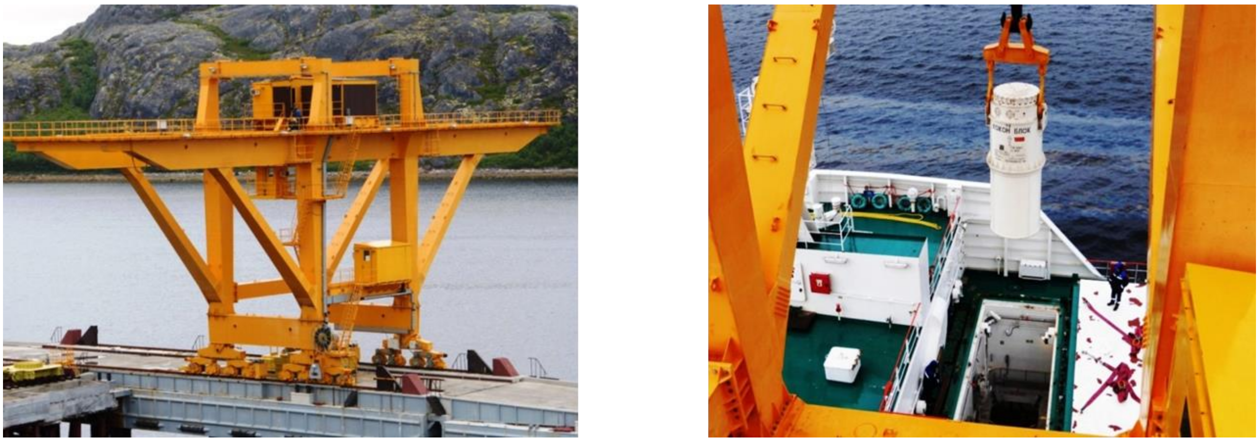

Fig. 10. Overhead crane with lifting capacity of 50 tons, installed on the pier, loading of the TUK into the cargo compartment of the "Rossita" ship

2.4.2 Procedure for preparing the infrastructure and facilities for discharge and removal of spent fuel from the DSU at the first stage (from DSU 2A and 2B)

The Provision regulates the organization of work on preparation for discharge and on discharge of normal SFA from the cells of DSU 2A and 2B, including transportation to the pier, transfer to the "Serebryanka" tanker and loading in TPC-108/1 containers. Radiation safety is assured by:

- → monitoring of radiation factors during SNF discharge and removal;
- → envisaged measures to normalize radiation situation in case of its change for worth;
- → compliance with the established rules, standards and technological instructions relating to SNF discharge;
- → implementation of the plan of organizational and technical measures to assure radiation safety during discharge and removal of regular SNF from the cells of DSU 2A at the first stage; and
- → establishing RL for radiation factors.

2.4.3 Technical justification of safety during management of normal and abnormal SNF at STS Andreeva

The "Technical Justification of Safety and Protection during Management of Normal and Abnormal SNF at the Premises of the Andreeva Bay NWC SevRAO Facility" includes:

- → operator-specific information;
- → general description of the facility;
- → list of regulatory documents used at the stage of designing;
- → technological sequence of SNF management at STS Andreeva;
- → justification of nuclear safety;
- → justification of radiation safety.

The "Technical Regulation for Management of Regular and Damaged SNF at the Andreeva Bay NWC SevRAO Facility" was developed to:

- → identify the sequence and composition of operations;
- → identify the list of the necessary newly designed equipment;
- → extract single SFAs from covers being stored in DSU;
- → load SFA in other (new) covers and preparing for transportation as a part of TUK.

Prognostic assessments were made, based on the highest dose rate values, to determine the time needed for dose rate to reach the control level of 20 mSv, e.g. 900 h for removal of damaged SFA from the damaged covers.

2.4.4 Technological Regulation for Management of Normal and Abnormal SNF

The "Technological Regulation for Management of Normal and Abnormal SNF at STS Andreeva" includes:

- → description of the operational facility (where operations are carried out);
- → technological sequence of normal and abnormal SFA management;
- → measures for nuclear and radiation protection during SNF management under conditions of normal operation, and in case of irregular (abnormal) and pre-emergency situations;
- → functions and composition of facilities;
- → description, characterization and functions of existing equipment and tools;
- → description, characterization and functions of equipment and accessories under development;
- → technological sequence of operations (procedure) of normal and abnormal SNF management; and
- → analysis of the compliance of the technological sequence for SNF management.

Radiation protection during SNF management should be assured due to:

- → zoning of workshops and the site of the facilities in accordance with the requirements of the regulatory documents and depending on the specific radiation situation, based on the measurement and analysis of radiation factors;
- → the use of collective and personal protective equipment;
- → prompt decontamination and localization of centers of radioactive contamination;
- → the use of tested/verified stationary and portable equipment for radiation monitoring and means for analytical control;
- → determination and account of individual doses to workers;
- → organization of work according to the appropriate permit depending on the particular radiation situation.

2.5 Development of regulatory documents on safe management of normal SNF

The recommendations on safe management of normal SNF were developed following regulatory review and assessment of a set of technological documents to support operations on SNF discharge and removal from the DSU cells. These recommendations were developed taking into account the following documents prepared jointly with DSA under the Norwegian Regulatory Cooperation Program:

- → The Guidance "Public Health Requirements for Ensuring Personnel and Population Radiation Safety during SNF and RW Operations Planning and Management at SevRAO's Facility No. 1 (R GTP SevRAO-07)". R 2.6.1. 29–07;
- → The Guidelines "Procedure for Radiation Monitoring at SevRAO's Facility No. 1", MUK 2.6.5. 7–08;
- → The Guidelines "Requirements for Individual Dosimetric Monitoring of SevRAO's Facility No. 1 Personnel", MU 2.6.5. 6 – 08;
- → The Guidelines "Instructions on ALARA Principle Application to SNF and RW Management at SevRAO's Facility No. 1", MU 2.6.5. 05 – 08; and

- The Guidelines "Application of Analytical Information System for the Forecast of Radiation Doses for the Regulation of Radiation Safety of the RosRAO Enterprise SevRAO's Personnel MU 2.6.1. 064–2012.

An important component of the organizational measures to assure radiation safety is the prediction of doses to workers involved in radiation hazardous operations. Within the DSA collaborative projects, FMBC has developed an information and analytical software system, which serves as a tool for the optimization principle implementation (DOSEMAP series). Recommendations envisage the wide application of this pack to assure radiation protection of the NWC SevRAO workers during radiation hazardous operations on SNF management.

The developed regulatory recommendations are intended for use by:

- IRM-120 under FMBA of Russia when implementing its regulatory functions to control radiation protection of the NWC SevRAO workers;
- Radiation safety service of the NWC SevRAO at Andreeva Bay when planning radiation hazardous operations;
- Joint development (IRM-120 of FMBA of Russia and NWC SevRAO) of protective actions to reduce radiation exposure to workers during the management of normal SNF.

2.5.1 Radiation monitoring

The operation of the databases on the radiation situation and on individual doses to control safety of the personnel is based on database data being obtained in the course of the radiation monitoring, including:

- individual dose monitoring of personnel;
- radiation situation monitoring in workshops and at the industrial site;
- radiation situation monitoring in the HPZ and at the supervision area,

and during radiation hazardous operations:

- gamma dose rate;
- beta fluency density;
- contamination with alpha – and beta - emitters;
- activity concentration of aerosols in air; and
- neutron dose rate.

2.5.2 Planning of radiation hazardous operations

When planning radiation hazardous operations, various procedures of these operations should be considered. The procedures implying the lowest predicted collective and individual doses to workers are preferable. Based on data of the radiation situation database and taking into account the good practice or the relevant design decisions, the NWC SevRAO asses the occupational doses and determines:

- the personnel sequence of actions in the specific workplaces during the technological operations;

- → the radiation situation parameters in the specific workplaces;
- → the number of workers required to carry out the technological operations; and
- → the duration of the technological operations.

When analyzing and assessing the proposals of the NWC SevRAO management, IRM-120 should use the calculated values of the predicted external and internal doses or the assessed doses obtained using the radiation situation database and evaluate against:

- → the permitted dose for the given operation;
- → the permitted duration of work under the given conditions; and
- → the set of protective actions.

2.5.3 Implementation of the personnel protection optimization principle

The development of and actions taken to implement the optimization principle is supervised by the chief engineer, addressing in particular:

- → ways for personnel involvement in the work planning;
- → preparation for work under radiation hazardous conditions;
- → prediction of doses to workers;
- → justified selection and preliminary planning of actions to increase safety;
- → supervision and control of protective actions; and
- → analysis and assessment of outcomes, taking the accumulated experience into account.

2.5.4 Establishing reference levels

Reference levels are established for those radiation factors, which are monitored in compliance with the current NWC SevRAO "Procedure of individual dose monitoring", approved by the management of the facility and agreed with IRM-120 of FMBA of Russia. The following criteria should be used when establishing RL of external and internal exposure to workers:

- → Annual effective dose to workers, which cannot lead to the exceeding of the dose limit, taking into account the highest uncertainties of measurement of individual components of the effective dose;
- → Annual equivalent dose to the lens of the eye, skin, hands and feet of workers, which cannot lead to the exceeding of the relevant dose limit, taking into account the highest uncertainties of measurement of individual components of equivalent doses to individual organs and tissues.

2.5.5 The selection of workers to carry out radiation hazardous operations

The main requirement when selecting workers to carry out radiation hazardous operations in case of normal operation of the radiation facility is the strict observance of:

- → effective and equivalent dose limits;
- → RL of doses;

- → permitted dose, which can operatively be determined using the hardware and analytic system.

In case of operations connected with especially hazardous operations, the hardware and analytical system (discussed in section 5) should be used to identify some group of qualified male workers of the required specialization, having a margin of any doses at that moment, and preferably above 30 years old.

2.5.6 Arrangement of education and training of the personnel

The Administration of NWC SevRAO and its departments is required to provide:

- → radiation safety specific training and evaluation of work leaders and performers, radiation safety specialists, and other persons, who are permanently or temporarily involved in radiation sources management;
- → instruction and examination of workers in the field of radiation safety; and
- → scheduled emergency exercise for personnel.

The personnel training and instruction program is supported by the hardware and analytical system, which allows the development of training programs in each area of radiation safety and the specific procedures of technological operations.

2.5.7 Enhancing safety culture

Safety culture is a component of the general culture of the facility designed to assure safety of radiation hazardous facilities. To maintain and improve the safety culture, the following actions are to be taken:

- → to identify the responsibilities of the administration, work and task leaders and the personnel;
- → to organize the quality assurance and safety control of the working process;
- → to confirm the qualification skills and to train the personnel;
- → to organize a system of rewards and punishments; and
- → to perform revisions, analytical reviews and comparisons.

The safety culture principles should cover the personnel not only in the course of their occupational activities, but also the behavior beyond the facility, including the observance of a pre-shift relaxation regime by workers.

2.6 Assessment of radiation parameters during testing removal of normal SNF from DSU 2A

During the test removal of SNF the main attention was paid to monitoring of the following radiation factors:

- → gamma dose rate;
- → neutron dose rate;
- → radioactive contamination of surfaces.

Table 1 includes the highest recorded values of gamma ambient equivalent dose rates (AEDR) during specific operations in 2017 and 2018. Values of neutron AEDR were lower than the limit of measurement during the full duration of work.

Table 1 – Highest values of AEDR during SNF unloading (remotely measured levels):

Number of Unit	Maximum AEDR, μSv/h	Location of measurement
2017		
1	4500	at height of 0.1 m after the opening of biological shielding
1	540	at height of 1.0 m after the opening of biological shielding
1	3300	in the direct vicinity when extracting and loading the SFA
1	1100	at distance of 1.0 m from the case when extracting SFA
2	10.0	when loading the case into the container - in the direct vicinity
2	8.0	when loading the case into the container – at distance of 1.0 m
3	3200	at 0.1 m from the TUK
3	1100	at 1.0 m from the TUK
3	14.0	after the cases loading – in the direct vicinity of the TUK
3	7.0	after the cases loading – at distance of 1.0 m
2018. Stage 1 - from 16.01.2018 to 02.03.2018		
1	1200	at 0.1 m above the cell after the opening of biological shielding and extraction of the case plug
1	720	At 1.0 m height over the opened cell
1	3400	Close to the SFA when loading to assembly 02
2	17.0	Close to the case when loaded into the container
2	14.0	At 1.0 m distance from the case
3	2200	Above the TUK cell
3	2400	Over the coordinate device
3	19.0	Close to the TUK after loading the cases
3	10.0	At 1.0 m distance from the TUK
2018. Stage 2 - from 26.03.2018 to 24.05.2018		
1	2700	at height of 0.1 m above the cell after the opening of biological shielding and extraction of the case plug
1	3000	At 1.0 m height over the opened cell
1	3100	Close to the SFA when loading to assembly 02
1	11.0	At 1.0 m distance from the case
1	27000	At 0.1 m height above the cell when extracting 22m-type cases during the period 11.05 to 24.05.2018
2	720	Close to the case when it is loaded into the container
2	120	At 1.0 m distance from the case
3	2800	Above the TUK cell
3	3200	Over the coordinate device
3	19.0	Close to the TUK after loading the cases
3	9.0	At 1.0 m distance from the TUK
2018. Stage 3 - from 27.07.2018 to 22.10.2018		
1	8200	at height of 0.1 m above the cell after the opening of biological shielding and extraction of the case plug

1	2300	At 1.0 m height over the opened cell
1	7300	Close to the SFA when loading to assembly 02
1	25	At 1.0 m distance from the case
1	100000	At 0.1 m height above the cell when extracting 22m-type cases during the period 27.08 to 11.09.2018
2	1300	Close to the case when it is loaded into the container
2	580	At 1.0 m distance from the case
3	8000	Over the coordinate device
3	22.0	Above the TUK cell
3	13.0	At 1.0 m distance from the TUK

2.7 Assessment of occupational doses during normal SNF management

The radiation monitoring system at the NWC SevRAO regulates the measurement of the individual gamma dose equivalent per work shift using individual dosimeters. Averaged data obtained during the SNF removal in 2017-2018 are given in Table 2, mean individual monthly doses are given in Table 3 and Table 4 the highest individual doses to workers during the removal of normal SNF. The highest monthly dose does not exceed 0.7 % of the established RL, 5 mSv; the highest value of individual dose over the whole period of the SNF removal did not exceed the established RL.

Table 2 Mean doses to workers per work shift during normal fuel management, mSv.

Time of work	Occupation			
	Dosimetrist	Decontaminator	Operator of the SNF storage facility	Crane driver
05.2017	0.0029	0.0044	0.0040	0.0021
06.2017	0.0031	0.0063	0.0050	0.0032
07.2017	0.0024	0.0082	0.0048	0.0020
08.2017	0.0033	0.0128	0.0073	0.0020
09.2017	0.0053	0.0172	0.0146	0.0026
01.2018	0.0066	0.0105	0.0128	0.0035
02.2018	0.0071	0.0138	0.0124	0.0020
03.2018	0.0061	0.0139	0.0102	0.0026
04.2018	0.0058	0.0110	0.0111	0.0018
07.2018	0.0062	0.0143	0.0188	0.0027
08.2018	0.0103	0.0133	0.0180	0.0005
09.2018	0.0102	0.0144	0.0128	0.0021
10.2018	0.0072	0.0109	0.0125	0.0002

Table 3 Mean monthly occupational doses during the normal fuel management, mSv.

Time of work	Occupation			
	Dosimetrist	Decontaminator	Operator of the SNF storage facility	Crane driver
05.2017	0.0410	0.0674	0.0531	0.0206
06.2017	0.0627	0.1170	0.1081	0.0508
07.2017	0.0435	0.0802	0.0880	0.0294
08.2017	0.0648	0.1968	0.1483	0.0480
09.2017	0.1022	0.3260	0.2000	0.0438
01.2018	0.0836	0.1125	0.1172	0.0411
02.2018	0.1356	0.2445	0.2410	0.0268
03.2018	0.0272	0.0762	0.0546	0.0128
04.2018	0.1106	0.2108	0.2300	0.0417
07.2018	0.0151	0.0333	0.0489	0.0082
08.2018	0.2289	0.2453	0.3451	0.0006
09.2018	0.2383	0.1464	0.1889	0.0287
10.2018	0.0813	0.1180	0.1190	0.0133

Table 4 The highest individual occupational doses during operations in 2017-2018.

Time of work	The personnel group	The highest dose, mSv/month	Proportion of RL, %	The highest dose per shift, mSv/shift
03.07.2017 - 25.10.2017	A	2.50	50.0	0.26
	B	0.21	4.2	
16.01.2018 - 02.03.2018	A	1.94	38.8	0.16
	B	0.06	3.0	
26.03.2018 - 24.05.2018	A	1.70	34.0	0.21
	B	0.12	6.0	
27.07.2018 - 22.10.2018	A	3.09	61.8	0.59
	B	0.12	6.0	

2.8 Discussion

Independently obtained gamma dose rate measurements confirm the stability of the radiation situation in DSUs when the SNF cells are not being extracted. Doses to workers over the calendar months of construction operations around Building 153 were substantially below the established reference levels.

The completed analysis of the Environmental Impact Assessment (EIA) document [5,11] demonstrated that the process of extraction from the DSUs and transport operations will not have negative impacts on the public or environment. However, the experts of FMBC made more than 60 comments and suggestions. After many discussions and meetings, and after relevant amendment and supplement, the EIA was approved by FMBA. DSA experts also made comments to the report.

The proposed technological plan and safety justification for management of normal and abnormal SNF at STS Andreeva was analysed and approved following discussion and amendment.

Regulatory documents on safe management of normal SNF have been developed on:

- → Radiation monitoring;
- → Planning of radiation hazardous operations;
- → Implementation of the personnel protection optimization principle;
- → Established reference levels;
- → selection of workers to carry out radiation hazardous operations;
- → Arrangement of education and training of the personnel, and
- → Enhancing safety culture.

Radiation parameters have been checked during test removal of normal SNF from DSU 2A and occupational doses assessed.

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11. Environmental Impact Assessment Of The Removal of Spent Nuclear Fuel (SNF) From Andreeva Bay./ Shilov, V.V., Lazarev A.L., Krakhmalev, S.Yu., Kolobaev, A.A., Novikov, V.P., Timofeev M.S., Ivanova, A.S., Ivanova, M.L. Editors: Dowdall, M.J., Standring, W.J.F., Amundsen I.B. StrålevernRapport 2017:9. Østerås: Statens strålevern, 2017

3 Monitoring and optimization of doses for workers during SNF and RW operations

3.1 Introduction

Joint DSA/FMBA projects on optimization of radiation protection of workers during remediation work in Andreeva Bay began in 2008. The aim was to monitor the changing radio-ecological situation and to improve capabilities in radiation protection of workers, as well as to enhance regulatory supervision performed by FMBA of Russia.

In the first stage of work (2008-2010) efforts were focused on development and optimization of the regulatory and methodical basis for radiation protection of SevRAO workers. This stage included also design of the information and analytical system on radiation protection of workers (IAS RBP). The objective was to monitor the situation during construction and operation of the new complex of buildings for SNF management and RW treatment and later in the remediation phase. Between 2010 and 2012, the information and analytical system was introduced into NWC SevRAO practice.

Between 2011 and 2014, improvements were made to the interface for initial data input (Mazur Interface), route calculation tool (Tesnov Interface) and the tool for management of data, EasyRAD, see Fig. 11.

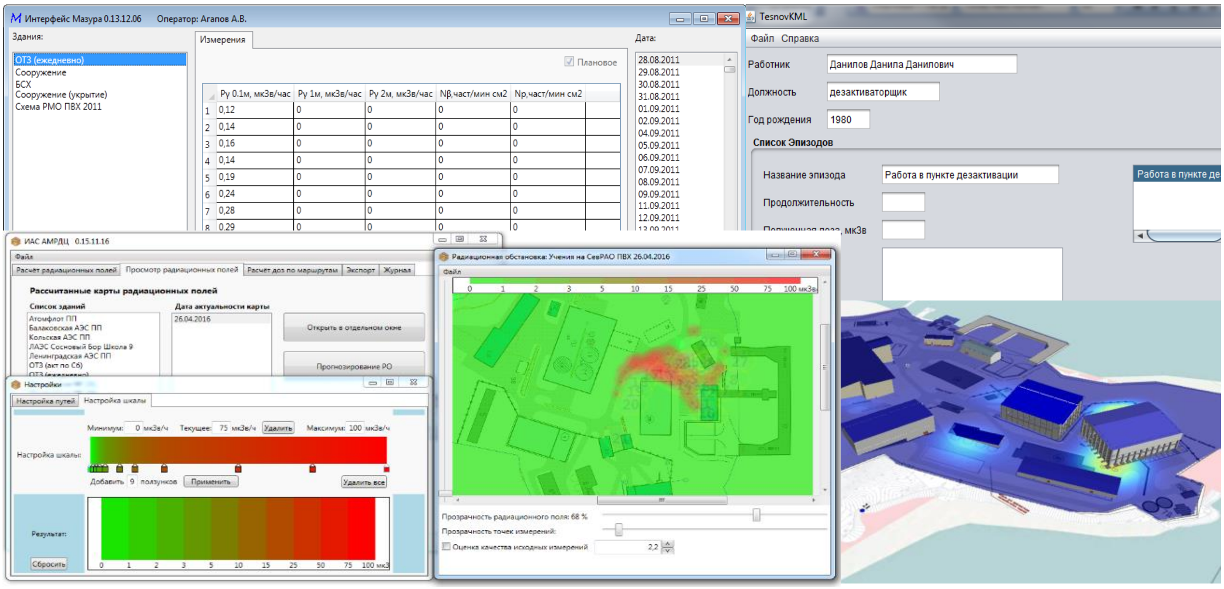


Fig.11. Screen shot from the IAS RBP system (top row: Mazur Interface and Tesnov Interface, bottom row: IAS RBP)

In the next step, in-situ supervision of software application and comprehensive technical support of the regulator in his workplace were the priorities. The project team participated in meetings on technical decisions on enhancing radiation safety and protection and development of methods and procedures for supervision and control.

The database was completed with historic data and this enabled analysis of the change of radiation situation in Andreeva Bay and discussion on its dynamics over the years since 2000. Analysis was based on a suitable generalized index, the AEDR. This allowed identification of key operations affecting the ambient radiation around the site.

3.2 Organization of retrospective data input and technical support for IAS RBP

Technical support and close cooperation with the radiation safety department of the Andreeva Bay NWC SevRAO and IRM-120 was crucial for proper and effective implementation of the IAS RBP system into everyday use at Andreeva Bay. Meetings were held in Murmansk with personnel of NWC SevRAO to discuss how to improve the reliability and efficiency of the system, such as how to deal with increased amounts of data.

Joint discussions led to the development of input routes by personnel without the use of external programs and to supplement IAS RBP with a module for radionuclide concentrations in the environmental media, i.e. alongside AEDR, to supplement the radiation situation picture.

Technical support was connected to the fieldwork at STS Andreeva to verify the procedure of data input into IAS RBP. During the fieldwork it was revealed that the schemes of survey in the IAS RBP (location and number of measurement points) were not always changed in line with changing conditions and actual measurements. Inappropriate data input was corrected, and personnel were trained to change the amount and location of points in Retrospective data introduced in the database concern period from January 2000 to November 2016.Was developed dedicated procedure for data input and created additional schemas required inputting data on buildings, which are demolished at this moment. Data related to these buildings are important for the purpose of the radiation situation analysis. The list of required schemas includes:

- → Old pier and a spot near PMK67 (new pier);
- → ATT site (motor vehicle parking) near Building 5 + specialized laundry (today, Building 154 is located instead these sites);
- → Controlled Access Area (CAA) of DSU and Building 1;
- → Site 3;
- → Building CAA 5

Another improvement was to introduce time dependent values of RL. This issue was considered, and the software structure was revised to accommodate this. Retrospective data from January 2000 were introduced in the database. Fig. 12 illustrates the changing radiation situation over the whole STS from 2011 to 2015.

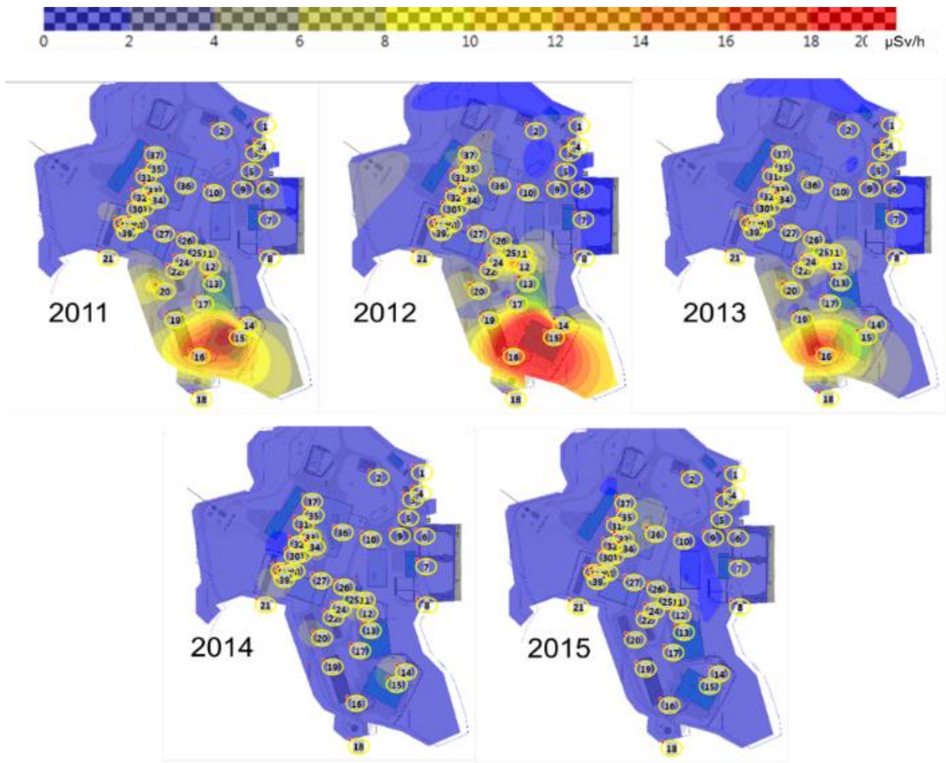


Fig.12 Dynamics of the radiation situation 2011-2015, AEDR in µSv/h

3.3 Understanding dynamics of the radiation situation for control of worker dose

Using retrospective data being input into the IAS RBP database was performed analysis of the radiation situation over 2003-2015 and extended to present day.

Initially, the highest dose rate values were being registered around DSUs; at 7, 7A, 7B, and 7E sites; and near Building 67A. By 2004, the dose rate around the DSUs, near Building 67A and at 7 and 7A sites decreased significantly; while around sites 7B and 7E these values remained high. After 2005, high dose rate values were registered around sites 7, 7A, 7B, and 7E. Since 2009, after the first emplacements of HBS, the dose rate values began to reduce significantly. In 2012, HBS work was completed and by 2013 and the beginning of the construction of Building 153, the dose rate at the DSUs was 30 times lower than in 2003. The construction of shelters 201 and 202 in 2012 also changed the radiation situation for the better. By 2015, the dose rate around shelter 201 was more than 50 times lower than in 2003.

The dynamics of the Andreeva Bay situation between and 2016 can be presented using a so-called AEDR integral µSv.m^2/h (Fig. 13). Each time point corresponds to the integrated radiation situation across the site. Presented values were calculated based on retrospective data introduced to the IAS RBP database under the DSA/FMBA cooperation program.

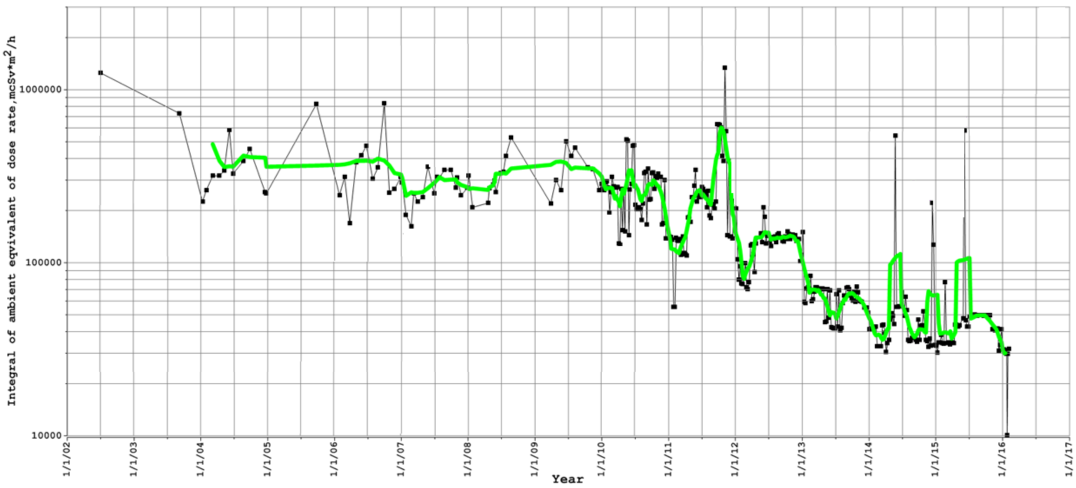


Fig.13 Time dependence of the AEDR integral by the Andreeva Bay site since 2002 to 2016.

The green line shows a 9-point smoothed version of the AEDR integral. The integral behavior can be divided into two periods. From 2004 to the end of 2010, the function has a very stable, almost constant value. In the second period, from 2011 to the end of 2015, there is a 5-6 times decrease with 4 strong peaks. The biggest change can be noticed right after the first peak, in November 2011.

To better understand this result, decomposition of the time series of the ADER integral was undertaken (Fig.14). The upper diagram shows the original time series. On the other three - the multiplicative decomposition of the original time series: trend, seasonal and random components. The last dependence is most correctly called a component that does not fit into the trend and seasonal components.

Consistent with the AEDR integral function, the dose rate function and remainder function have 4 peaks, marked on Fig. 14 with colored rectangles. The peaks can be linked to implementation of hazardous operations that caused sudden, temporary increases in radiation dose rates. Most infrastructure operations were finished before 2011, so these peaks, which should be taken under closer analysis, were associated with clean-up operations. In Table 5 the peaks are matched to specific operations carried out at the site.

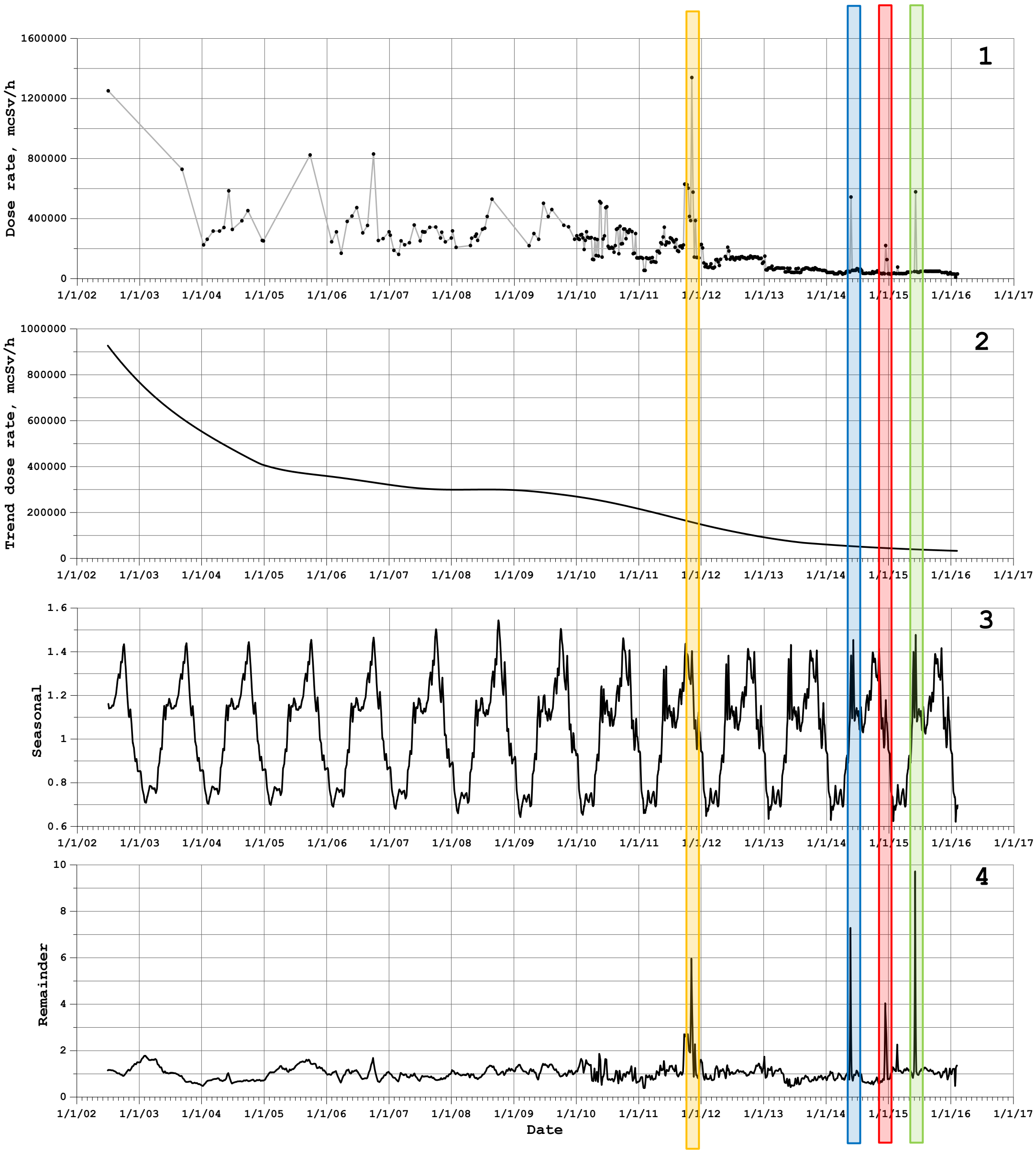


Fig. 14 Decomposition of the time series of the AEDR integral over the technical site at Andreeva Bay over the period 2002-2016. 1- initial time series, 2- trend, 3- season, 4- remainder components of the initial time series.

Table 5 Radiation hazardous operations over the period from 2011 to 2015 on-site and link to peak doses

Peak	Time of the peak occurrence	Operation being carried out at that time
orange	October-December 2011	Bring the radiation situation in normal condition at DSU 3A[6]
blue	April-May 2014	Extraction of soil nearby DSU 3A
red	December 2014-January 2015	Drilling operations in the area of DSUs 2A and 3A, soil operations (relocation-removal) on the construction site of Building 153.

[6] Operations to bring the radiation situation at DSU 3A in normal condition are connected with the removal of concrete slabs – as preliminary work for installation of HBP (horizontal biological protection made of three-layer steel slabs). There was no concrete covering at DSUs 2A and 2B.

green	May-June 2015	SNF inventory at DSU 2A (April-May), main operations, June – bringing to initial state (restore order).

3.4 Minimizing external exposure while moving in radiation hazardous areas

Minimizing doses to workers was taken into consideration and included as one of the purposes for developing the IAS RBP. The system allows for the estimation and planning of personnel dose during radiation hazardous operations, for example: SF and RW recovery, radiation monitoring and clean-up of radioactive contamination. For this purpose, graph theory has been used.

The IAS RBP allows for input and interpolation of measured AEDR linked to site coordinates. In the situation when a worker is not put into any constraints or restrictions regarding his route e.g. being restricted to existing roads, a graph in the form of a regular grid is created based on the input data set (Fig. 15). The dose that a worker receives during movement along an edge of such grid taking into account probable speed of movement of a worker, the grid spacing and the interpolated values of the dose rate is assigned to the weight of that graph's edge.

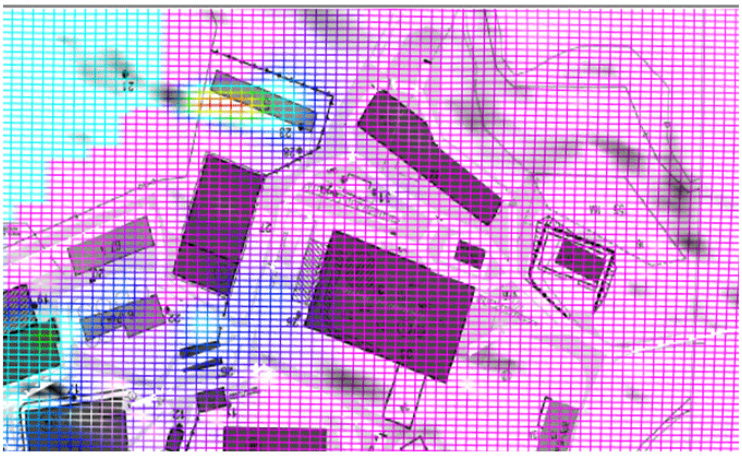


Fig. 15 An example of a graph of the radiation situation at a given time

Paths can be identified so that the worker may move only along existing roads, bypassing particular fixed points, passing each road only once, etc. Minimizing the dose for the route under certain constraints can be included as input conditions. Such conditions might be formulated for specific tasks, such as radiation monitoring in the contaminated area, decontamination of the area, etc. The IAS RBP tool solves the non-trivial task of identifying the route with minimal received dose for any given radiation situation.

When the condition of using only existing roads is added (Fig. 16), the software creates a graph with nodes according to the crossroads and lines of existing roads. The weight of each graph's line is also equal to the dose that worker may receive during movement along this line in radiation field chosen by the user for a specific date or radiation situation.

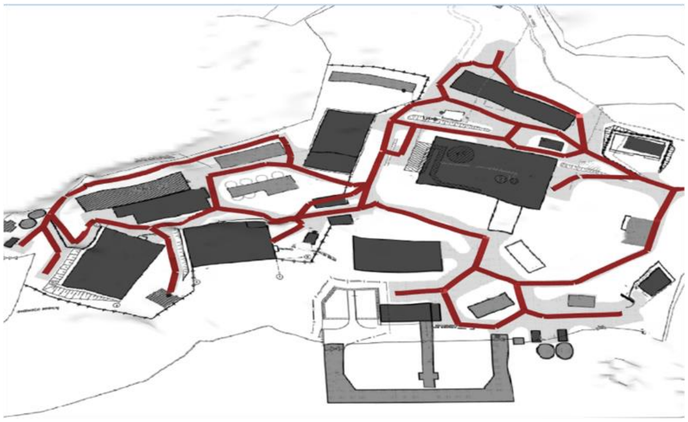


Fig. 16 Graph of Industrial Site transport network, Enterprise transport network graph

There are usually a few solutions for one task. Those are results with different variants of possible routes in radiation field, which are associated with different doses (Fig. 17).

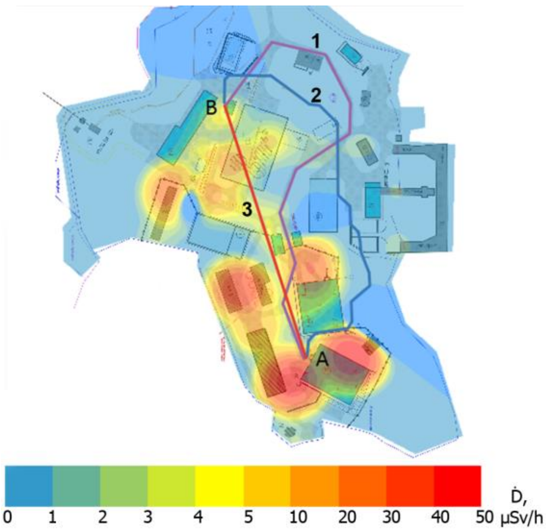


Fig. 17 Search for the shortest route. 0.081, 0.043 and 0.032 mSv

3.5 Discussion

In the period from 2002 to 2016, there was almost no additional SFA deposition to the STS. On the other hand, only a small amount of SFA and RW was removed during this period of time. Therefore, over the reported period, the total activity of radionuclides on-site and in the Andreeva Bay STS buildings decreased mainly due to radioactive decay and very limited off-site releases via surface and groundwater.

In this light, it can be concluded that the sevenfold decrease in the AEDR integral on the technical site is due to the actions of the Andreeva Bay NWC SevRAO personnel, on the compartmentalization of RW in the storage facilities of SevRAO and works on the creation of infrastructure. The average individual dose to personnel in the period from 2008 to 2012 did not exceed 1.2 mSv, and annual collective dose was not higher than 110 mSv·person. In the following years, the picture of occupational exposure did not change.

Accurate assessment of the reduction of the AEDR integral over the Andreeva Bay technical site became possible due to the implementation of the procedure for decomposition of time series of the AEDR integral. Attempts to evaluate the decrease in the integral of the AEDR for the period from 2002 to 2016 based directly on the time dependence of the AEDR integral would lead to significant uncertainty in the estimates. The generalized indicator of the radiation situation, the AEDR integral over the technical site of the Andreeva Bay STS, demonstrated its effectiveness and convenience for evaluating the radiation situation in combination with the procedure for decomposition of time series.

The IAS RBP and its efficient algorithms in efficient analysis of past and possible future radiation situation data provide clear benefits in radiation control planning for future hazardous operations, and in the context of emergency preparedness and response, discussed further in section 4.

4 Emergency preparedness and response in case of a radiological accident

4.1 Introduction

For many years cooperation with DSA, SRC-FMBC carried out four full-scale exercises on various aspects of emergency preparedness and response of institutions under FMBA of Russia at radiation hazardous facilities (2006 and 2016: exercise at the interim storage facility in Andreeva Bay, 2009: exercise at NWC SevRAO Ostrovnoy, 2018: emergency exercise on the interaction between rescue services of State Corporation “Rosatom” and FMBA of Russia in case of an accident during the management and transportation of SNF at Andreeva Bay SevRAO Facility) in the North-West of Russia.

4.2 Research Emergency Exercise (REE) at the site of temporary storage for spent fuel and radioactive waste in Andreeva Bay (2016)

4.2.1 Objectives and conduct of the exercise

In 2016, DSA together with FMBC and support from FMBA and State Corporation “Rosatom” jointly organized and conducted a Research Emergency Exercise (REE) at STS Andreeva.

The REE was aimed at providing a comprehensive solution to the issues of emergency response and cooperation of Rosatom and FMBA of Russia during a radiological accident. The objectives of the REE were:

- To enhance cooperation arrangements between the State Corporation “Rosatom” and FMBA of Russia.
- To improve the preparedness of FMBA’s institutions to render medical care to patients and taking health measurements.
- To review and assess methods, techniques and procedures of health-care provision.

A key feature of the REE was the use of visualization and simulation software developed within the on-going regulatory cooperation program and psychological training of involved personnel.

According to the exercise scenario, the initiating event of the radiological accident was a helicopter falling on a TPC being conveyed across the STS Andreeva Bay industrial site (Fig. 18). A fire occurs at the site of the helicopter crash, sensors of the automated radiation monitoring system record a sharp increase in ambient radiation, indicating breach of containment of the TPC and release of radioactive material into the environment. There are four victims of the accident (the members of the helicopter crew and workers involved in the TPC transportation) with varying degrees of severity of traumatic injuries, as well as internal and external radioactive contamination.

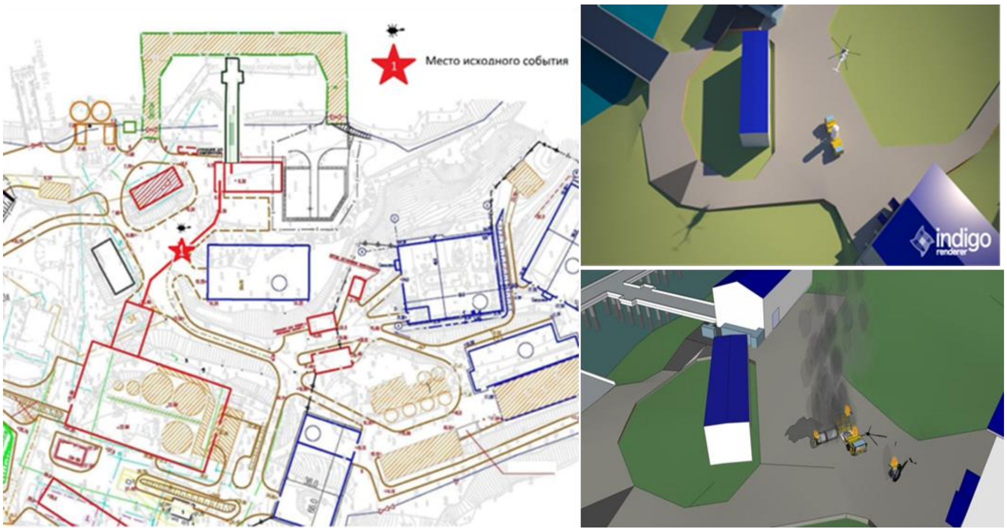


Fig.18 Left: Location of the initiating event (the helicopter fall) in the STS map. Right top: The helicopter flying over the STS area. Right bottom: The helicopter fall on TPC 108/1 and the fire occurring.

Tasks of the REE included:

- Working out of the procedure and forms of notification of the IAEA and Scandinavian countries (in accordance with the current agreements with Rosatom involvement) about the radiological accident in real time mode, including early notification.
- Organizing and providing medical assistance to the patients and provision of health care.
- Activities during the radiological accident aftermath work at the STS.
- Arrangement and working out of cooperation between emergency teams of medical institutions under FMBA and emergency rescue teams of Rosatom during emergency rescue and other urgent works (EROUW).
- Improvement of techniques for assessment of the radiation situation by computer simulation.
- Psychological training of the personnel involved in the radiological accident work.

Altogether, 150 people from the following organizations were involved in arranging the REE:

- FSUE “RosRAO”, (Moscow);
- The Andreeva Bay NWC SevRAO facility – branch of FSUE RosRAO (Close Territorial Formation (CTF) Zaozersk);
- Nuclear and Radiation Safety Division of the State Corporation Rosatom (Moscow);
- Situation Crisis Center (SCC) under the State Corporation Rosatom (Moscow);
- FSUE “Emergency Technical Center under Minatom of Russia” (FSUE ETC SPb), Saint-Petersburg;
- Institute of safe development of nuclear power engineering of the Russian Academy of Science (IBRAE RAN), Moscow;
- Scientific industrial society “Typhoon” under Roshydromet (SIC “Typhoon”), Obninsk;
- Emergency medical radiation dosimetry center of FMBC (EMRDC) (Moscow);

- → CMSU-120 under FMBA of Russia (Snezhnogorsk);
- → IRM-120 under FMBA of Russia (Snezhnogorsk);
- → CH&E-120 under FMBA of Russia (Snezhnogorsk);
- → Special Fire Department N10 under Emercom of Russia (CTF Zaozersk).

4.2.2 Conducting the REE

The REE took place from 1st to 3rd June 2016 and consisted of 3 stages. The objective of the first stage was to work out cooperation between the Emergency Commissions of NWC SevRAO and SCC Rosatom in real time mode. There was training in notification, real time assessment of the radiation situation and EROUW communication by videoconference. Participation involved:

- → Rosatom SCC (Moscow);
- → NWC SevRAO – Branch FSUE RosRAO (Murmansk);
- → Andreeva Bay NWC SevRAO facility - Branch FSUE RosRAO (CTF Zaozersk);
- → FSUE RosRAO (Moscow);
- → FMBC (Moscow)
- → IBRAE RAN (Moscow);
- → SIC “Typhoon” (Obninsk).

The key practical actions were carried out at STS Andreeva on 2 June 2016. The objective was to train practical actions on preparedness and EROUW performance by staff of STS Andreeva and FSUE ETC SPb, and delivering medical treatment to victims. The 3rd stage consisted of discussion and assessment of the exercise.

The early warning of the conventional radiological accident of the IAEA and neighboring Scandinavian countries, including the Kingdom of Norway, was performed for training purposes in real time. In compliance with Russia's international obligations under the Convention on Early Notification and the Assistance Convention, as well as Russia's obligations in the area of physical protection of nuclear materials, FSUE SCC Rosatom provided the national point of contact (communication) functions. Information about the Exercise was posted on the IAEA website and information exchange was conducted in compliance with the established EMERCON-forms with IAEA (Fig. 19).

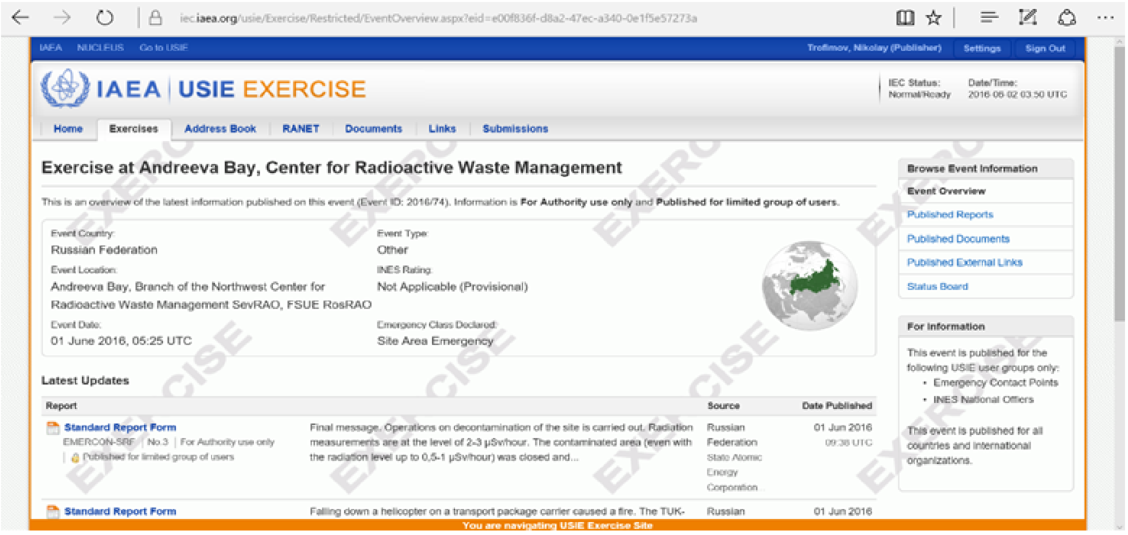


Fig. 19 The REE specific information at the IAEA website.

Expert and analytical tasks were solved through exchange of operative information on the radiation situation and health effects between the scientific and technical supporting centers: IBRAE RAN, FMBC and SIC “Typhoon” under Roshydromet. The results of assessments were the basis for proposals on the EROUW tactics and management decision making to minimize consequences of a radiological accident. Assessment of radiological consequences was carried out on the basis of measurements of dose rate and radioactive contamination of surfaces. The numerical values of these parameters are quantitatively related to each other on the basis of model calculations performed by IBRAE RAN.

For radiation situation visualization the computer codes “EasyRAD” and AndreevaPlanner were used. Both of these codes been developed previously within the FMBA/DSA cooperation program, With the help of “AndreevaPlanner” dynamic three-dimensional simulation of radiation hazardous operations with the radiation situation visualization in real time, calculation of doses to the work participants and search for optimal routes of workers was prepared.

Based on measurements of gamma dose rates and density of radioactive fallout, IBRAE RAN assessed parameters of the activity release from the damaged TPC into the environment. The experts of the scientific and technical supporting centers, jointly with the radiation safety service of the facility, predicted the dissemination of the release onto the adjacent area. This prediction was procedural, taking into account that the scale of consequences of this accident (according to International Nuclear Event Scale (INES) – level 2) was limited to the area of the STS and had no radiological consequences on the population and environment.

Experts of SIC “Typhoon” simulated and evaluated the transboundary transport of radioactive discharge to the territories of neighbor countries based on data of the hydro-meteorological monitoring and surveillance data.

EMRDC as scientific and technical supporting center, obtained all required operative information from the Rosatom SCC and supported permanent communication with the operational duty person in FMBA, CMSU-120 and IRM-120. The main attention of the expert and analytical group under EMRDC was on the conservative assessment of internal doses of the injured pilot of the helicopter, who was in the direct vicinity of the damaged TPC without any protection equipment of breathing organs for 10 – 15 minutes. The presence in the discharge of fission products, such as Cs-134, Cs-137 and plutonium isotopes could lead to significant internal doses.

During the 2^{nd} day, training and practical actions of EROUW and medical treatment of victims were carried out at the industrial site of the Andreeva Bay NWC SevRAO facility, as illustrated in Fig. 20.

Fig. 20 Second stage of the REE, practical activities (Andreeva Bay, 02.06.2016).

The key health care provision components included:

- → medical care of victims at the stage of medical evacuation;
- → health physics activities and execution of regulatory functions on monitoring and compliance with the occupational radiation protection requirements.

The three-stage system of treatment and evacuation measures was used during the training (Fig. 21-22):

- → 1^{st} stage (pre-hospital) – was organized in-situ (the site of the accident);
- → 2^{nd} stage (qualified medical treatment) – was launched in the departments of CMSU-120;
- → 3^{d} stage (specialized medical treatment) – was organized conventionally in the specialized stationary hospital of the FMBC.

According to the scenario, at the first stage of medical evacuation activities, the victims were evacuated from the potentially hazardous area of radioactive contamination and smoke with participation of the personnel of the facility special emergency team and rescuers of the fire department. The victims have a high probability of internal exposure due to inhalation. At the collection site, victims were provided with the first treatment and preliminary measurements of radioactive contamination of clothes and open skin were carried out.

In the distribution unit (the sorting site) the first pre-hospital and first medical treatment by the medical staff and health unit of the facility and medical team under CMSU-120 (site IV) was organized. For medical personnel working at the sorting site, the input messages were prepared, which required quick decision-making and the application for emergency care skills. The sanitization of light victims was arranged in the decontamination facility (sanitary pass), while for the severe ones – at the sorting site.

Fig. 21 Evacuation and first medical treatment.

Fig. 22 Medical activities at the sorting site.

The 2nd stage was worked out at the subsidiary of CMSU-120 (CTF Zaozersk), where, according to the scenario, one of the victims with multiple soft tissue injuries and secondary damage of the main blood vessel has been delivered. At the premises of the subsidiary of CMSU-120 specialized reception department was deployed and work on receiving and providing medical assistance to the victim was organized.

The 3rd stage was worked out conventionally. According to the scenario, after the health stabilization in the territorial clinics of the Murmansk region, all the victims were conveyed to the clinic of FMBC (Moscow), because of their radiation exposure, for the purpose of their survey (conventionally).

Capabilities of FSUE ETC SPb mobile communication unit, mobile complex unit for equipment decontamination, facility for decontamination of workers and mission control complex facility for unmanned aircrafts were demonstrated.

4.2.3 Assessment of the exercise. Research tasks of REE

4.2.3.1 Preparedness of FMBA's medical institutions to work in case of a radiological accident

Based on practical measures, the capability of timely application of medical protective equipment by the personnel of the facility was assessed. Kits of individual medical and civil protection to provide preliminary medical treatment and health care approved by the Russian Ministry of Health in 2013 are optimal in their composition of drugs and ensure fast and effective protection of people affected by emergency exposure.

Emergency exercises completed within the previous cooperation with DSA (Andreeva Bay, 2006, Gremikha, 2009) stressed the close dependence of the effectiveness of medical treatment activities at the pre-hospital stages on the conditions of the infrastructure of the region and remoteness of the main base CMSU-120 (Snezhnogorsk) from the NWC SevRAO facilities. Since then, significant improvement of the emergency medical assistance availability in the event of radiation incidents is indicated as follows:

- → own medical center and ambulance service under FMBA of Russia appeared in Zaozersk, which reduces the time of arriving of FMBA's medical staff to the NWC SevRAO from 2 hours to 25 minutes;
- → new medical equipment for emergency medical services including a vehicle with capacity for up to 4 injured.

Within this project, training of medical staff of CMSU-120 was conducted on issues of medical treatment of injured at the stage of medical evacuation. Reserves of medical equipment and special drugs for emergency medical treatment were updated and refreshed. Ambulance teams under CMSU-120 mastered the use the of antishock suit "Kashtan" (Fig. 23).

Fig. 23 The anti-shock suit "Kashtan" was delivered for possibility of immobilization in case of combined trauma and complex radiation injuries.

Operational communication, including videoconferencing between relevant management bodies, was established and tested.

4.2.3.2 Computer simulation methods. Radiation situation and dose rate estimation.

At the stage of project planning, the decision was made to use the special software developed with support of DSA for the radiation situation visualization - EasyRad and AndreevaPlanner.

The software EasyRad facilitates the dose rate interpolation based on points of measurement and helps to build the radiation situation maps. The software AndreevaPlanner can be used for the purpose of dynamical three-dimensional simulation of radiation hazardous operations with the radiation situation visualization in real time, calculation of doses to persons involved in these operations and search for optimal routes of workers.

For the purpose of the REE, 3D-models of constructions (buildings, facilities) and the relief of STS Andreeva were developed and imported into AndreevaPlanner. To visualize the calculation results, a map including 3D-models of buildings and constructions at the SevRAO industrial site was developed (see Fig. 24), and a dose map was developed with EasyRAD (Fig. 25). Additionally, especially for the exercise were developed algorithms to solve tasks of:

- → transition from the surface activity to ambient dose rate;
- → simulation of dose rate due to surface precipitation;
- → planning the radiation survey and inspection of damages;
- → building radiation situation maps, their analysis and identification of vulnerabilities;
- → planning additional radiation survey;
- → planning the aftermath activities;
- → calculation of doses to workers involved in emergency works and search for optimal routes of workers.

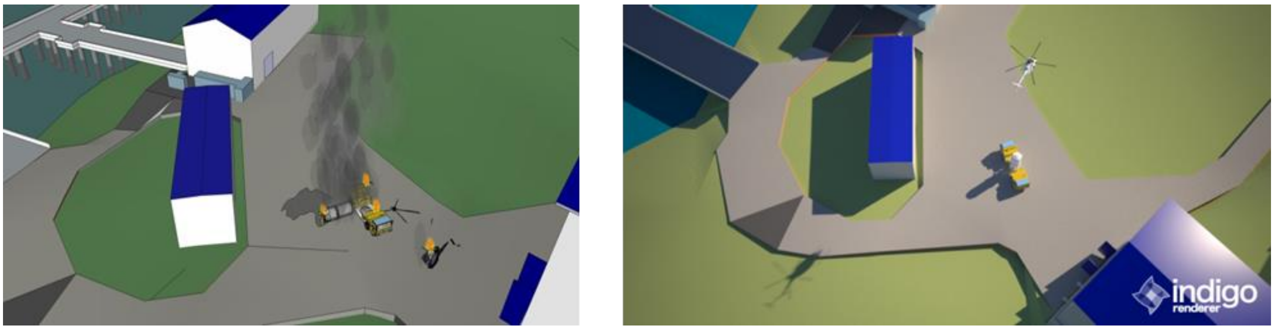


Fig. 24 3D visualization of the accident.

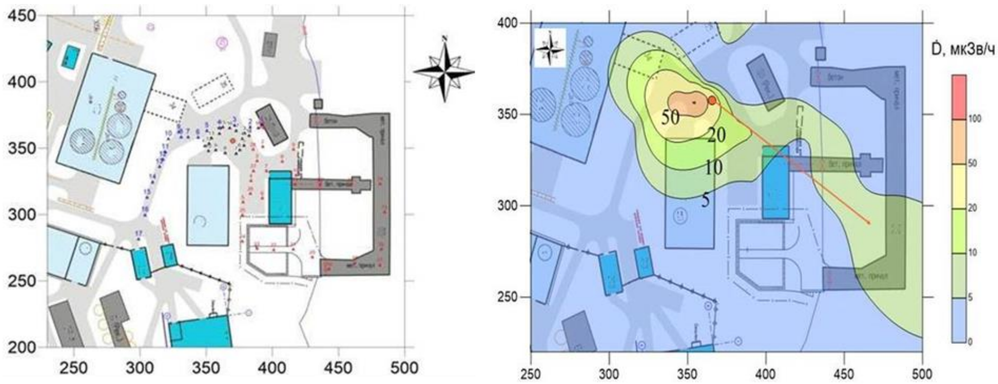


Fig. 25 Building the dose rate map in EasyRAD.

Outcomes of the radiation situation prediction made by IBRAE RAN served as input data for the computer simulation. These data included:

- → Contamination of the Andreeva Bay SevRAO industrial site with radioactive materials;
- → Concentration field of radioactive materials at 1.5 meter height;
- → Dose rate field at time 1000 sec after release start.

IBRAE RAN made its calculations using the specialized software intended for the assessment of the radiation situation within the industrial site of the nuclear and radiation hazardous facility during radioactive releases into atmosphere taking into account impact of industrial building and environmental conditions (different stratification, wind strength).

In accordance with the REE plan, the AndreevaPlanner and EasyRAD were used jointly to solve the analytical tasks for:

- → Planning the personnel evacuation (EasyRAD);
- → Planning the radiation survey (EasyRAD);
- → Planning the road cover decontamination (EasyRAD);
- → Planning local decontamination (AndreevaPlanner);
- → Dose assessment (EasyRAD, AndreevaPlanner).
- → Comparison of various scenarios of the radiation hazardous operations (AndreevaPlanner).

Time dependence of dose rates received by specific individuals through the event are illustrated in Fig. 26.

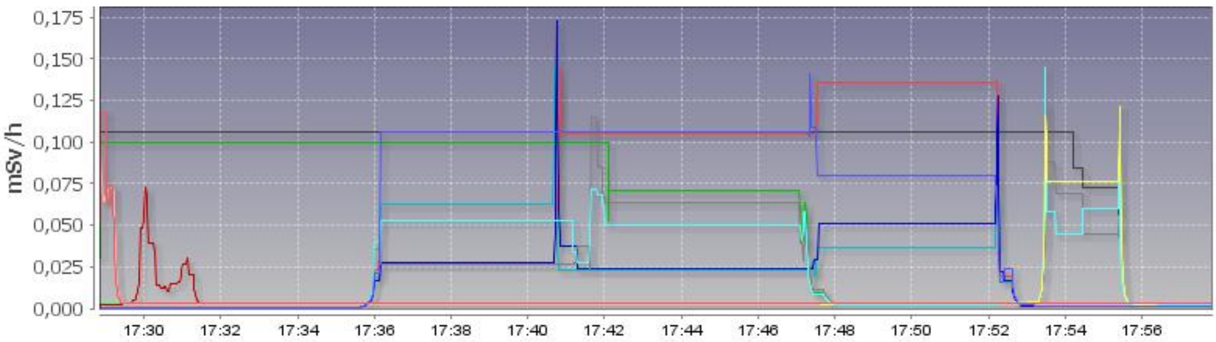


Fig.26 Time dependence of the dose rate for each person involved in emergency work

Based on the experience in application of the VR software during REE, the conclusion was drawn that both AndreevaPlanner and EasyRAD can be used in practice both by regulator and operator. By regulator for:

- → coordination of the RLs of radiation situation at the technical area and at the facilities;
- → Expert review of projects on implementation of radiation hazardous operations;
- → Coordination of dose orders to carry out radiation hazardous operations;
- → Investigation of cases of the occupational exposure above the established levels;
- → Minimization of doses to workers.

By chief of the radiation safety service for:

- → Generation of training scenarios;
- → Monitoring of doses to workers.

By personnel of the facility for:

- → Maintenance of the database on dose rate measurements;
- → Maintenance of the database on radiation sources;
- → Participation in drills and exercises.

Evaluation of use of the radiation situation visualization software at the stages of preliminary work and during REE allowed for preparation of a range of recommendations on the training of users.

- → The software required a user should be qualified sufficiently is PC management, while, as a rule, ordinary employees of the enterprise does not possess this qualification and, therefore, while implementing the software, additional training is required.
- → For the software operation, the advanced powerful computer is required (processor intel I7 at least of the fifth generation) and large-scale monitor/projector (at least 21 inches).
- → The software is unable to cope with the scenarios including a large number of 3D-models. It is reasonable to subdivide scenario into several scenarios for each group of premises or for individual workshop. With increasing computer performance and development of the software this problem will be solved.

- → Calculations being performed using the software, were in line with calculations by other methods; this fact confirms the applicability of the software for dose assessment.
- → The scenario in the software allows more accurate pre-work activities in the aftermath of the accident, through the work within a 3-dimensional virtual environment.
- → The calculated data can be exported to GIS.
- → Training video based on the generated scenarios can be prepared for the personnel.
- → The software is applicable for the decision making support during the aftermath of the accident.

4.2.3.3 Psychological training

The relevance of psychological training and assessment of psychological preparedness of the staff for especially hazardous work conditions including EROUW is explained by:

- → a real hazard to the life and health of workers in the performance of aftermath tasks;
- → negative impact of radiological accidental factors and other types of emergencies on the psyche and behavior of workers; and
- → inadequate attention to issues of psychological training of specialized medical teams.

Special training materials were prepared in the form of lectures, presentations, working notebooks with cards-tasks and conducted practical lessons on "The acute stress response in a radiation accident" and "Features of emergency psychological assistance and self-help". Also developed were documents on psychological training: "Methods and techniques of psychological assistance and self-assistance in case of aftermath of a radiological accident" and as a practical guide "Emergency psychological assistance and self-assistance in the aftermath of a radiological accident".

To examine the psychological readiness of the personnel of emergency, rescue and medical teams for the aftermath of a radiological accident, criteria were developed for self-assessment of psychological training to work in the case of an emergency in the form of questionnaire "Self-assessment to work in case of emergency". 36 staff participated and results are given in Table 6.

Table 6 Assessment of psychological readiness of the personnel

Indices	SevRAO emergency personnel	Medical staff CMSU-120
Method of self-assessment of psychological readiness:		
- knowledge increase, %	6.0	13.0
- skills increase, %	0.3	0.25
- motivation increase, %	2.9	0.4
Method of analysis of projective measurement "Three vectors":		
- knowledge	5.5	20.2
- skills	4.7	2.5
- motivation	2.6	11.8

Data show that NWC SevRAO staff are oriented to practical application of skills and methods of urgent psychological assistance and self-assistance, while the medical personnel of CMSU-120 have higher motivation to the theory of emergency psychological assistance (getting knowledge) but not so sufficient readiness to use it in practice. Medical personnel should improve psychological training in respect to objectives, tasks, methods and ways of emergency psychological assistance to victims.

Special attention during the psychological training should be paid to post-stress violation in victims survived after psychologically traumatic events.

4.2.4 Discussion

This REE was comprehensive and generally demonstrated the effectiveness of procedures and technical means of notification about a radiological emergency at the local, territorial and federal levels. Cooperation was worked out between participants in Zaozersk, institutions and management bodies under Administration of the Murmansk region and institutions, which carry out functions of authority of the Federal level. During the exercise, the participants and observers used for communication: teleconference mode, satellite, mobile and internet.

Conducting the REE demonstrated operation of controls and emergency response system of NWC SevRAO and institutions under FMBA of Russia in case of a conventional radiological accident and contributed to:

- closer cooperation between operator and regulator when developing urgent decisions and recommendations on taking protective measures with respect to the personnel;
- expert assessment of the radiation situation and potential radiological consequences, to prepare recommendations for the management bodies including the necessary counter-measures;
- activation of the emergency preparedness system of FMBA of Russia in the region and, based on the findings of the exercise, to improve the preparedness of institutions under FMBA of Russia; and
- demonstration of forces and means of the responding bodies to the public of the region.

A summary of achievements and recommendations is as follows:

1. The procedure of the IAEA and Scandinavian countries for notification on a radiological accident in real time mode in accordance with the current agreements was tested. The REE showed the effectiveness of procedures and equipment for notification at local, territorial and federal levels.
2. There is a high level of cooperation between emergency teams of institutions under FMBA of Russia and emergency rescue teams under the Rosatom during EROUW and preparedness of institutions under FMBA of Russia for medical care of injured persons.
3. The results of studies confirmed improvement in the available emergency medical care indicators at the SevRAO facilities in comparison with studies performed during the 2006 Andreeva Bay and 2009 Gremikha training exercises. Response times were reduced and there was improvement in the technical base of medical institutions and departments.
4. According to the assessments, joint work of rescuers, dosimetrists and medical staff serves as a basis for minimization of health effects in case of emergency exposure combined with other hazardous factors (fire, smoke, mechanical injures).
5. A model of simultaneous implementation of medical treatment recommendations and care of injured, including special treatment of wound areas, was developed. This model and the training of staff reduces treatment time and increases capacity to

provide medical treatment. The trained actions of the ambulance teams to accept victims directly from the sorting site supports the continuous process of medical treatment at the pre-hospital stage, even under conditions of a complicated radiation situation.

6. Valuable experience was obtained in the use of computer simulation methods for the purpose of radiation scenario and radiation situation assessment as well as visualization of radiation situation data and planning radiation hazardous operations (AndreevaPlanner and EasyRad).
7. Measures on psychological training of the personnel involved in the aftermath of a radiological accident were taken and experience in the use of methods to assess its psychological training has been accumulated.
8. The required activities on the occupational health care provision at the early stage of the radiological accident at Andreeva Bay can be provided by CMSU-120, IRM-120 and CH&E-120 under FMBA of Russia in cooperation with emergency teams of NWC SevRAO, Emercom of Russia and management bodies of the CTF Zaozersk Administration. The effectiveness of these activities depends on the timeliness of decision-making on protective measures, the availability of adequate resources, knowledge, skills, personnel and operational management.

4.3 DOCKING Exercise: 2018

4.3.1 Objectives and conduct of the exercise

This exercise was jointly organized with Rosatom under the DSA/FMBA cooperation program. The main goal was to test decision-making in the event of a radiological accident during the management and transportation of SNF and the implementation of the necessary radiation-hygienic and medical measures in the early phase of the accident.

Specific objectives included:

1. Working out interactions and enhancing skills of managerial authorities and organizations of the Rosatom and FMBA on prevention and elimination of radiation emergencies with health consequences.
2. Improving skills of personnel of the emergency rescue team of Rosatom and emergency response organizations of FMBA in case of a radiation accident during SNF management and transportation.
3. Analysis and evaluation of preparedness of the Rosatom ERT personnel and organizations of FMBA of Russia to actions under conditions of radiation accident at SNF management and transportation.

In addition, interaction with mass media was also exercised, for provision of information to the population of Zaozersk on risks and threats in the case of an accident.

The exercise was carried out in two stages:

→ 1st stage -The main activities took place on the territory Andreeva Bay site, Northwest Center SevRAO 17 October 2018.

→ 2nd stage, 18 October 2018, was focused on summarizing and discussing the results of the exercise.

Participation included 73 employees from 11 organizations and 25 observers from 8 organizations. Fig. 27 gives the general scheme of the exercise participants interaction. An observation point (site) was prepared for the exercise observers. Operations of the exercise participants were commented out through loudspeakers.

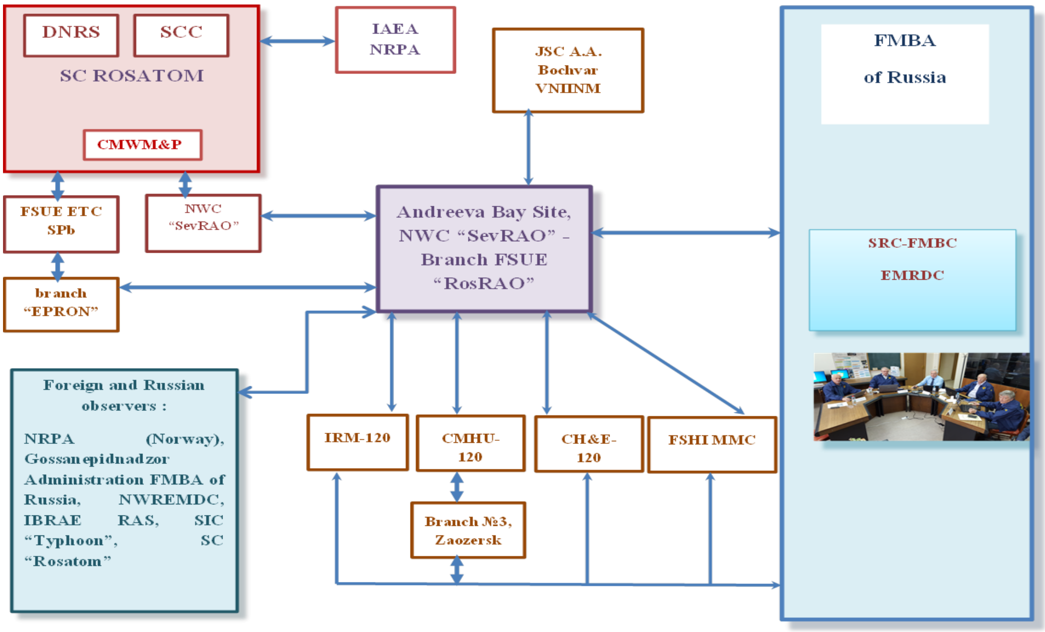


Fig.27 General scheme of the exercise participants interaction

4.3.2 Technological scenario and sequence of activities for the participants

According to the exercise scenario, a natural rock fall results in generation of a rump wave that hits the loading pier at STS Andreeva. This results in an uncontrolled rapid descent of the TPC onto the pier concrete bed. Because of a welding joint defect, a split occurs in the base of the TPC and radioactive substances are released into the environment. To carry out the exercise, a cylindrical metal simulator was used as the damaged TPC on the pier (Fig. 28). Due to the accident, two car handling personnel are injured and need urgent medical aid.

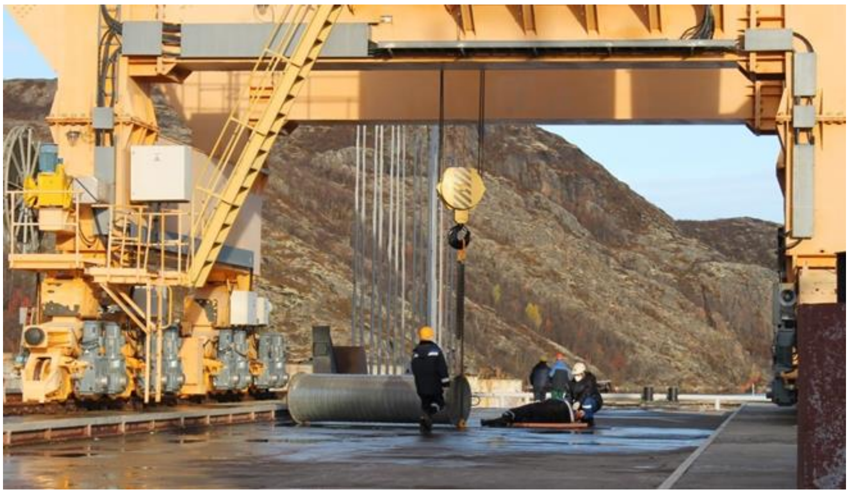


Fig.28 Simulated accident at TPC loading

On command of the exercise leader, the participants started the emergency response measures. The “radiation danger” signal was announced on the facility, the warning siren was activated and the Personnel Protection Plan was initiated. Administrative bodies and emergency response forces were notified. The special emergency brigade at STS Andreeva was brought into Emergency Situation mode. Activities on evaluation of the radiation and medical situation were organized and primary emergency-rescue works (including first aid to the injured persons) were carried out.

The Sectoral Comission for Emergency Situations of Rosatom was gathered and a decision was made to send emergency response forces of FSUE ETC SPb to the accident site for emergency-rescue and emergency-technical operations, including diving works, use of robotics and monitoring of radioactive contamination in the marine area.

The medical section of STS Andreeva Bay site were notified of the state of injured persons and the medical team of Branch CMSU-120 was called.

Prompt notification and information exchange measures were implemented:

- within frameworks of interdepartmental interaction: EMRDC with FSUE SCC of Rosatom;
- organizations of FMBA EMRDC with Northwest Emergency Medical Radiation and Dosimetric Center and territorial body of FMBA of Russia in Murmansk region (IRM-120);
- under international interaction: FSUE «SCC of Rosatom» with IAEA, Nordic countries (Norway, Sweden, Finland), as well as with Armenia and Belarus.

The information exchange with IAEA was carried out according to established procedures in EMERCON form (SRF format); two messages have been sent, and each of them was verified by IAEA. Employees of STS Andreeva who were in the vicinity of the accident site (witnesses of the accident), rendered first aid to persons injured due to the accident (Fig. 29). Personnel of the medical team that arrived to the accident site continued rendering first aid to the injured persons in a safe area (Fig. 30).

Fig.29 First aid (in the form of mutual assistance) to persons injured due to the accident

Fig.30 Personnel of medical team render first aid

Dose monitoring technicians of STS Andreeva carried out an initial radiation survey and assessment of the radiation environment in the simulated accident site. The pier area, where the γ-gamma dose rate was more than 100 μSv/h, was immediately fenced off, and radiation control points established. The largest AEDR (point Nr.5, 38 mSv h) was recorded in the immediate vicinity of the damaged TPC. Personnel of FSUE ETC SPb carried out repeated radiation surveys around the pier.

To further understand the circumstances within framework of the exercise, the radiation situation was simulated using software and calculation tools. Specialists of the radiation safety service of the enterprise and an expert group of EMRDC (working remotely) took part in the simulation of the radiation situation, which worked in the mode of remote access.

The ERT of FSUE ETC SPb carried out radiation monitoring of water near the pier using a mobile laboratory, and a small-motor boat. When performing the radiation monitoring, the motor boat moved in the water area around the pier on the route “small circle” (at a distance of 20-30 m from the pier) and on the route “big circle” (200-300 m from the pier). Figure 62 shows the chart of γ-irradiation ADRE during the water area monitoring. Average ADE was about 0.04 μSv/h; the value corresponds to natural background radiation. Since this was just an exercise, the results only reflect the current radiation status, but the work demonstrated the capacity to carry out measurements in the marine environment in an emergency situation.

Water sampling was carried out and spectrometric measurements of natural radionuclides and Cs-137 activity concentrations in water were performed by means of the immersion-type instrument SKS-99 “Sputnik” at several points located close to the pier.

4.3.3 Radiation environment assessment

The specialists of radiation safety service of STS Andreeva and the expert group of EMRDC of FMBC developed conclusions and recommendations based on the radiation environment assessment:

1. The simulated radiation accident is of a local nature and restricted by the boundaries of the industrial site of the facility.
2. The INES level of the radiation accident is estimated as 2 (incident - inadequate packaging of a highly radioactive sealed source).
3. The nature of the radioactive contamination is mainly determined by the release of radioactive materials (Cs-137) in solid form and the formation of a local contamination site.
4. Spread of radioactive substances in the atmospheric air is insignificant and depends on secondary wind transfer.
5. Areas of Cesium-137 radioactive contamination would have been as follow:
6. 5E+4 kBq/m^2 (100 μSv/h) ~ 100 m^2
7. 5E+3 kBq/m^2 (10 μSv/h) ~ 500 m^2
8. 5E+2 kBq/m^2 (1 μSv/h) ~ 900 m^2
9. Radioactive contamination of the water area adjacent to the pier (from the outside) would not have exceeded the level of intervention for drinking water according to NRS-99/2009.
10. Additional dynamic studies may be required to assess contamination of water and bottom sediments adjacent to the pier.
11. For the entire period of EROUW in the areas with AEDR up to 100 μSv/h, personnel dose rates would have been be limited to 2 mSv.
12. When working in the immediate vicinity of the damaged TPC, personnel dose rates should be limited to 10 mSv (considering the use of robotics).

During the exercise, works were carried out to survey the underwater part of the vessel "Rossita" and to assess the condition of the berthing structure with the help of divers. Upon completion of the underwater works, samples of bottom sediments and seawater were transferred to the radiation safety service of the NWC SevRAO for analyses. During the exercise, the observers had opportunity to see emergency-rescue equipment, diving equipment and instruments, as well as diving supporting systems.

Specialists of JSC A.A. Bochvar VNIINM (decontamination team) took part in the exercise and carried out decontamination of areas of the fixed berth and TPC to avoid further spread.

They successfully solved the task with the help of a state-of-the-art mobile complex of airless application of deactivating polymer coatings developed by JSC "VNIINM". The complex makes it possible to carry out decontamination and containment of the contamination. The compositions used for decontamination operations were selected to be effective at low temperatures.

Although the accident scenario suggested no radiation consequences off site, radiation monitoring was carried out in the territory of CTF Zaozersk (γ-survey from a car with use of mobile radiation monitoring laboratory of FMBC for conservative reasons. At the same time, specialists of CH&E-120 in Zaozersk performed γ-survey on the territory of the sanitary protection zone of STS Andreeva on foot.

4.3.4 Discussion

Thanks to this project, the overall level of preparedness of the SevRAO enterprises and FMBA institutions in the North-Western region to conduct rescue operations, radiation measures and provide medical assistance to injured persons has increased.

Actions on radiation contamination survey and monitoring have been worked out on coastal water areas, diving works have been carried out and the technology of eliminating the consequences of an accident and preventing environmental contamination into the wider marine areas has been trialed.

A set of measures has been taken to organize and provide medical assistance to the injured persons. Now, a center named after N.I. Pirogov of FMBA is becoming a specialized medical institution providing medical aid in case of accidents and emergencies at radiation-hazardous facilities in the Murmansk region.

Participation in the exercise Branch of FSUE ETC SPb «EPRON» allowed the center’s staff to enhance the level of preparedness in EROUW, including diving and engineering operations.

Information activities planned within the framework of the exercise increased awareness of the public in case of radiation accidents, including radiation safety issues. During the implementation of the project, a video film about the exercise “Docking-2018” was made. This shows the practical activities and discussions and can be used in the exchange of practical experience with specialists and in working with the public. Russian and foreign participants noted the value of the “DOCKING” exercise.

5 Personnel reliability monitoring for hazardous operations

5.1 Introduction

The FMBA-DSA cooperation program has previously recognized as highly important the development and arrangement of an organizational and technical system for assurance of the performance reliability of workers involved in SNF management.

Following the recognition of human failure as a major residual risk factor, i.e. once effective engineering and safety procedures are in place, the TIBUR_TSP software system was developed as part of the DSA/FMBA cooperation program, in order to develop physical control skills, and robust and optimal behavioral responses to hazardous or stressful situations. The system generates, in a virtual environment, a 3D model corresponding to real work activities. Parameters that reflect degradation of a worker's reliability (psycho-physiological price (PPP)) are measured during training or exercises with the simulator, providing measures for performance reliability assessment. The results support early identification of degrading performance reliability, support in optimization in design of working procedures (e.g. through recognition of stressful tasks) and training of workers involved in SNF and RW handling. The process also helps to reduce the chance of psychosomatic disorders associated with long-acting stressors / radio-phobia of the workers.

The development of the SHC "TIBUR_TSP" was based on the following generalizations and conclusions:

- → In the technical-organizational systems, the human is the weakest link, whose errors in the work can cause a variety of incidents and accidents.
- → When performing important tasks, in most cases the human error probability is determined by the severity of mental and emotional stress state of regulatory mechanisms of functional systems that implement specific activities.
- → Increasing mental and emotional stress causes additional mobilization and energy resources; this is reflected in the increase in psycho-physiological prices of activities performed.
- → High level of PPP, on the one hand, increases the risk of psychosomatic disorders, on the other - is accompanied by a decrease in functions of perception, attention, memory, and, in general, reduced cognitive abilities, spatial-and-temporal coordination and motor-and-coordination interaction.

The system has applied in two ways:

- → Training to implement jobs, which are the most difficult for the particular person, that require updating of the same psycho-physiological functions, promoting the formation of an optimal strategy for the implementation of activities under difficult conditions.
- → Training to apply methods ensuring the removal or reduction of mental and emotional stress through the use of self-regulation mechanisms in normal and stress regimes.

The main activities of the work carried in the current period included:

- → development of a testing pattern for the soft/hardware training complex based on interactive simulation training games with biological feedback in the virtual environment and concurrent registration of psycho-physiological indexes and behavioral responses;
- → development of technical documentation;
- → transfer installation testing of the TIBUR_TSP at NWC SevRAO premises;
- → analysis of findings of the testing and making associated improvements; and
- → development of the procedure/method of education/training of the NWC SevRAO personnel.

5.2 Development of the testing pattern of TIBUR_TSP

Software improvement included:

- → development of stress modes;
- → adding the new ways of presenting results; and
- → development of tools for video recording and database for video information storage.

The stress mode option takes the form of time limiting for disassembling of one container, the back-timing is displayed in the left upper corner (fig. 31). Thirty seconds before the time limit, the timer starts to blink and a sound signal is continuous until the end of the attempt. If a player manages to completely disassemble the container (i.e., reset the last component in the tank) before the end of time, the screen displays the inscription: “You have successfully coped with the task. Try to improve it”. Otherwise, the screen displays the inscription: “You do not have coped with the task. Try again”.

Fig.31 Screen shoot from TIBUR_TSP software in stress mode

The time limiting parameter for discharge of the container is settable. It is determined individually for each tested depending on the results of background investigations.

Results of training session are presented in a graphic form (Fig. 32), where are shown paths which crane has come during recovery and handling operations. Paths of movement (trajectories) are built for each compartment of the container and have different colors. Also provided are travel time, distance traveled, average velocity, inactivity time and percentage of inactive time.

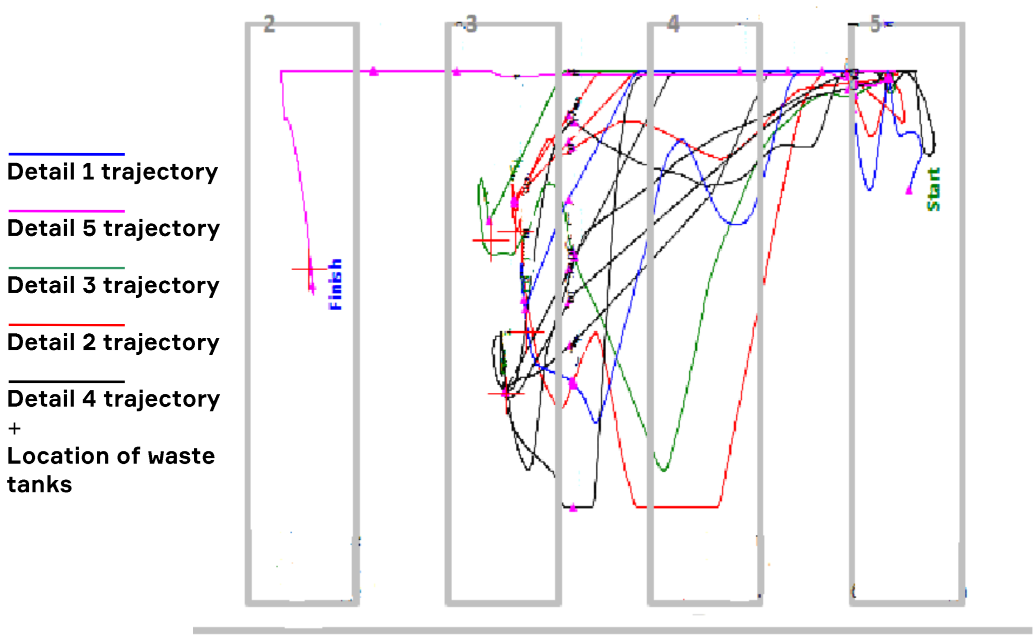
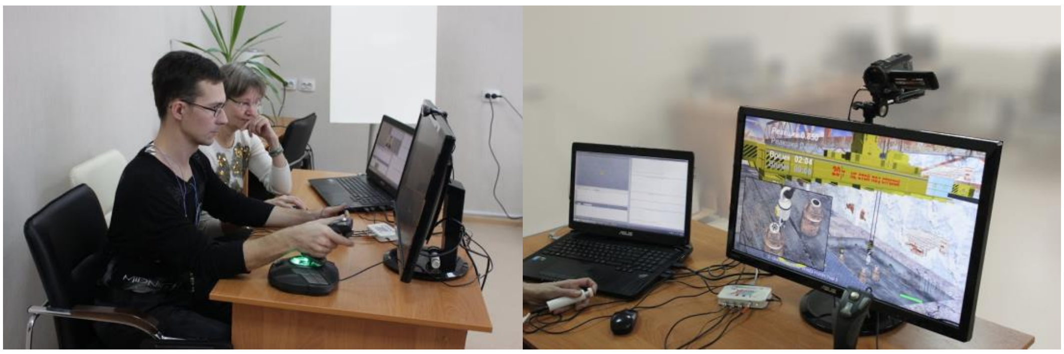


Fig. 32 Path of movement of the crane. Sign "+" shows the position of barrels containing waste.

Training session is each time recorded with focus on the face of the trainee, using a web-camera and external video camera. Recordings are analyzed using VibroMed software, also implemented through the FMBA/DSA cooperation program. At the same time there are measured physiological data, including: electromyogram, sensor of electrical conductivity of the skin, breath sensor, electrocardiogram, each synchronized with the video recording, see fig. 33.



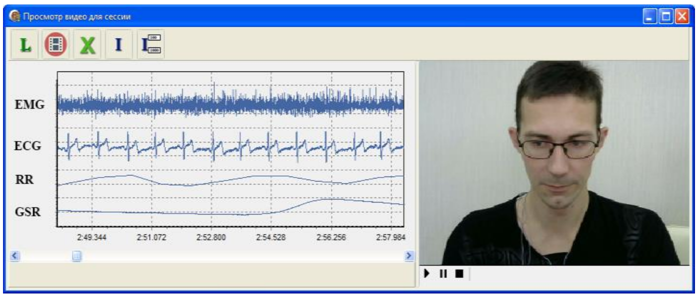


Fig. 33 Physiological signals and video image in time and precise characteristics during manipulations with objects in virtual space.

5.3 Testing of "TIBUR_TSP" at the premises of NWC SevRAO and analysis of results

"TIBUR_TSP" was transferred to Zaozersk. In the studies were involved 12 NWC SevRAO experts. The following functions of "TIBUR_TSP" were tested:

- the ability to complement the database with new students / testee;
- the ability to generate the required cyclogram to train / testing the personnel;
- the ability to change parameters of the gaming model (jobs, number of containers to disassembly, time to limit the simulated activity);
- the ability to setup physiological signals to achieve a desired quality of registration;
- the ability to respond properly to manipulation of the joystick when disassembling containers and moving parts in storage capacity;
- the ability to save results of training / testing.

The training and testing procedure included:

1. Explaining the basic operations and actions of the student / testee using the demo video.
2. Background mode of training / testing to develop skills in using the gaming model of activity (container disassembly).
3. Stress mode of training / testing. The basic number of containers for disassembling was 6.
4. The feedback mode, when the crane speed depends on the ability of the student / testee to reduce his heart rate.

The average time of the training / testing procedure was 2 hours.

5.4 Analysis of the TIBUR_TSP test results

Analysis of findings of the test of the testing pattern of TIBUR_TSP consisted of three stages:

1. Comparative analysis of results of the assessment of psycho-physiological conditions in terms of the conventional (traditional) parameters and in terms of

video image parameters, obtained using the VibraMed software, including the development of new integral parameters of the vibro image assessment.

2. Analysis of vibro image of the NWC SevRAO specialists participated in the TIBUR_TSP tests.
3. Comprehensive assessment of the findings of training / testing of the NWC SevRAO personnel in respect to the precision and rate indicators of the performed activity, parameters of the recorded physiological signals and vibro-images.

Vibro-image technology is based on the real-time transformation of video image of the light image of the object into the image formed by accumulated frame difference. Vibro-image systems are used to solve a wide scope of problems, from the public safety / protection assurance to medical diagnostics. The advantages include speed of analysis , which is of great assistance in practical application.

To assess the relationship between the vibro-image parameters and traditional methods of psycho-physiological state assessment, an examination of the personnel of one of the nuclear facilities (47 workers in total) was carried out, using both conventional methods and face video-registration. Results show that the highest psycho-emotional stress occurs at the start. This is due to the lack of skills in the activity and the novelty of the situation. With repeated testing, parameters improved, indicating a decrease in the level of emotional stress. To assess the probability of the individual psycho-physiological adaptation violations, a probabilistic nomogram was constructed (Fig. 34). The ordinates represent the values of the risk function, while abscises represent the probability of identifying the psycho-physiological disorders. The decision-making rule is as follows. The risk function value being calculated for the particular worker is put on the abscise axis. From the resulting point perpendicular to the intersection with the decision-making curve is built. The intersection point is projected to the y-axis at which the risk probability of psycho-physiological adaptation violations is estimated. For example, if R_ind=1.5, the probability of violations is 0.95 (95%).

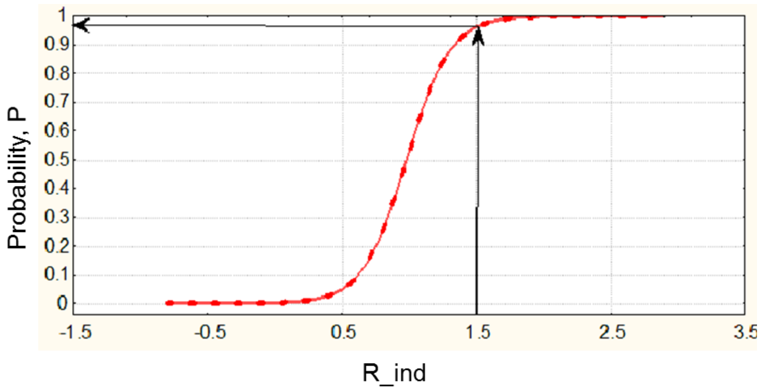


Fig. 34 Nomogram of probabilistic assessment of the psycho-physiological adaptation violations

5.5 Analysis of the vibro-image parameters of SevRAO staff

The vibro-image was recorded using the external camera and data matrix was formed for 431 cases. The STATISTICA pack was used for data analysis.

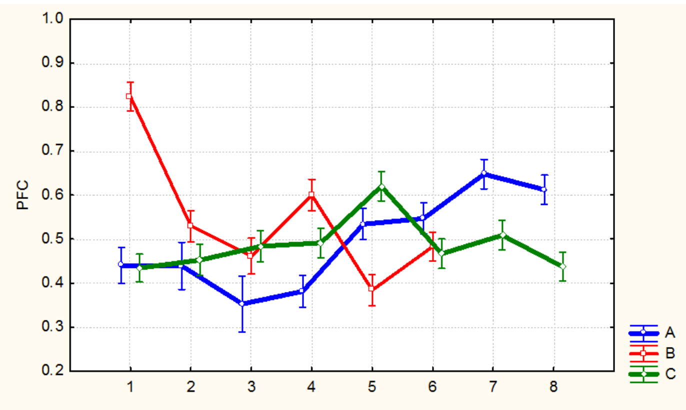
Vibro-image data shows that the highest psycho-emotional stress is at the start stage of the SHC work. This is due to the lack of skills in the SHC use, the novelty of the situation. In the process of the learning of the activity model, vibro-image parameters improved, indicating a decrease in the level of emotional stress.

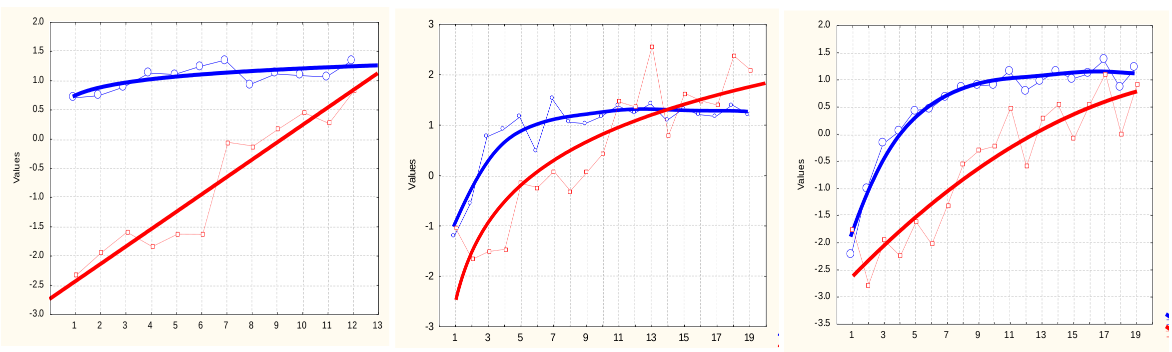
To evaluate the relationship between speed and precision parameters of the simulated activity with vibro-image parameters, automated classification of the surveyed persons was carried out. The parameters include:

- → duration of work;
- → mean time between the cellars;
- → mean time of response;
- → joystick control quality; and
- → false reactions, e.g. pressing the joystick trigger when there is no objective reason.

Based on the speed and precision data for the simulated activity, low efficiency in completing the simulated work task is accompanied by higher psycho-emotional stress for the testee. Given this result, the development of self-control skills of testees was investigated.

The objective was to improve stress resistance and self-control of the NWC SevRAO workers under complex working situations, which can arise during SNF management. Results of studies from 2015-2016 were used, in which FMBC played the roles of the testees. Fig. 35 illustrates the assessment of the psycho-physiological “price” of three testees, day-by-day of the examination.





A B C

Fig. 35 Dynamical change of the speed and quality parameters of the activity depending on the number of containers disassembled, according to data of the background studies (blue curve – speed (OS), red – quality (QA) of the activity)

According to Figure 35, speed-specific individual plateau is being generated during the disassembling of 11-12 containers and the quality parameter continuously increases. Figure 36 shows the dynamics of the speed and quality parameters by stages of the study.

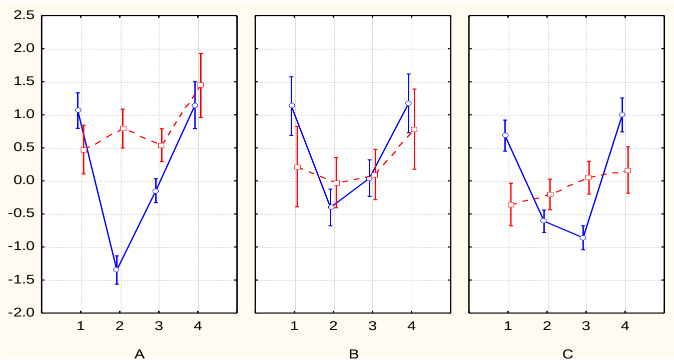


Fig. 36 Dynamics of the speed and quality of the activity by stages of the study (blue curve – speed (OS), red – quality (QA) of the activity). 1 - Background (before the load), 2-3 - STRESS+BF, 4 – After the load.

According to these data, after the load, parameters return to the background values. The operation speed of the testee A confidently decreases during the first load STRESS+BF.

Figure 37 illustrates the dynamics of the direct indicator of the ability to form the self-regulation skills – heart rates – day-by-day of training/testing.

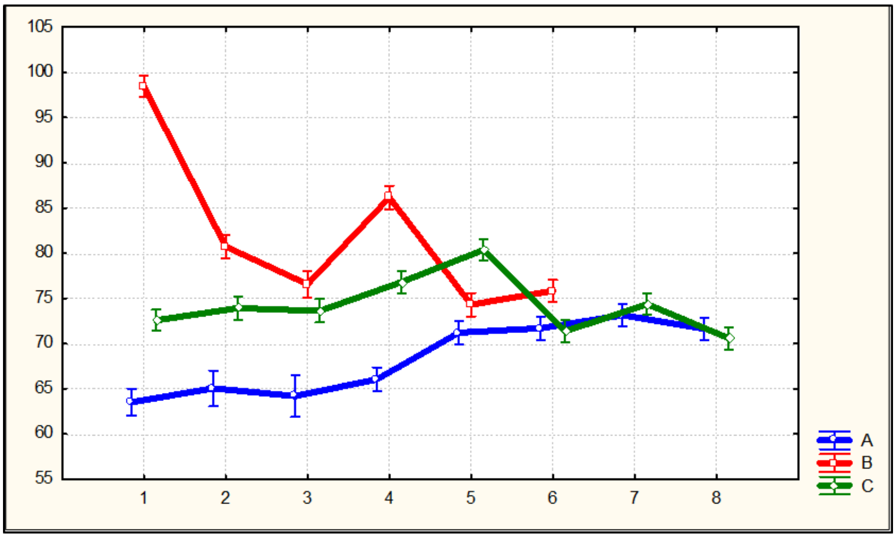


Fig. 37 Dynamics of the heart rate by days of training/testing

According to the results, testee B had the best formed self-regulation skills, for testee A there was not reducing in his HR. The reducing HR of student C has not been registered before the 5th day of the training/testing. This effect has occurred since the 6th day.

Psycho-physiological “price” is often interpreted as psycho- physiological “expenditures” of internal resources, which enable individuals to accomplish certain activities. Fig. 38 illustrates the assessment of the psycho-physiological “price” of the testee by days of the examination.

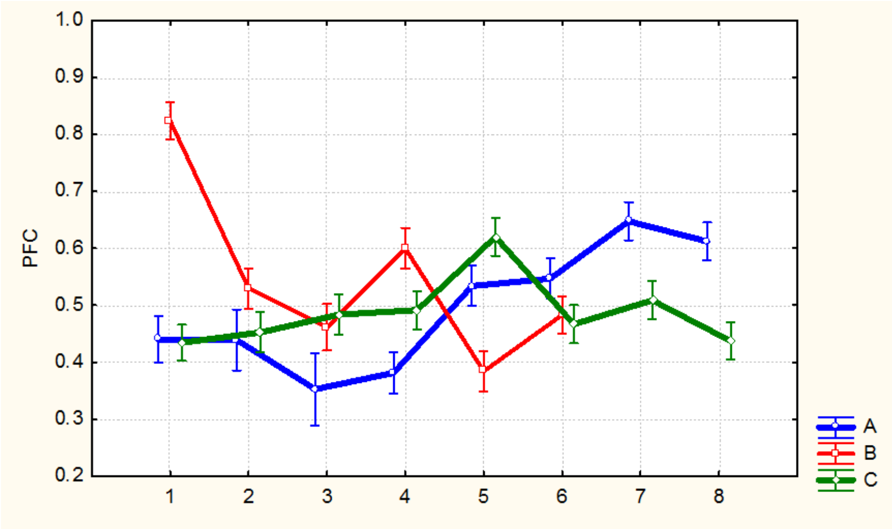


Fig. 38 Dynamics of the psycho-physiological “price” (PFC) of the training/testing

Comprehensive assessment of SHC “TIBUR_TSP” tests concerning the ability of the testees to form the self-regulation skills helped to ascertain that the disassembling of 11-12 containers is required to form skills of the activity model handling. The dynamics of psycho-physiological “price” shows that motivated persons capable of self-regulation achieve the effect rather quickly – by 3-4 day of the training. The motivated and lower capable persons – about twice later. If the testee has low motivation level to learn the self-regulation skills, the learning process can be more long-term and testee requires individual explanatory work.

5.6 Discussion

Trial work with VibraMed showed that allocated characteristics of vibro-image are not directly related to the psycho-physiology, therefore, examination of workers of one of the nuclear facilities was carried out. Both traditional methods of assessment of the psycho-physiological state and psycho-physiological adaptation of individual, and examination including video registration of faces of the persons under examination were used.

Based on the mathematical analysis of the vibro-image parameters, new characteristics of the vibro-image have been developed. The comparison of these characteristics with traditional methods of psycho-physiological state assessment revealed that the vibro-image parameters reflect the individual system reaction at psychic, psycho-physiological and physiological levels. Criteria were developed to find persons with violated psycho-physiological adaptation based on their face vibro-image parameters. This allows in one minute, in a contactless manner, to obtain information that required 2-3 h by conventional methods.

Result raises the question of whether to include vibro-image assessment, as an additional technique, developed by FMBC within the PRM1 project "EDIS_STS", and to perform, jointly with CMSU-120, psycho-physiological examinations as part of the periodic medical examination of the personnel of the Andreeva Bay SevRAO facility.

The laboratory tests of TIBUR_TSP in FMBC helped to assess the abilities of the students/testee to develop self-regulation skills. The psycho-physiological “price” was used as a criterion. The relation between the parameters of electro-physiological signals with those of the speed and quality parameters of the activity has been revealed and described. It was shown that to form skills of the model application, the student/testee should disassembly 11-12 containers. The dynamics of psycho-physiological “price” show that the motivated and capable to self-regulation persons achieve the effect rather quickly – by 3-4 day of training. The motivated and lower capable persons – about twice later. If the student/testee has poor level of motivation for self-regulation, learning of skills can occur significantly later. The received data are preliminary and estimative, so the studies in this area are reasonable to be continued.

The macro-image analysis is relevant when assessing the behavioral responses in workplaces and during solving the occupational tasks. If work is carried out in normal mode, the vibration spectrum of different parts of the worker’s body would be certain and match his temperament, individual manners of occupational activities. In case of freelance activity, behavioral reactions will inevitably change, which will affect the range of body vibrations. This may be a signal to identify the causes of behavioral changes and take appropriate organizational decisions.

6 Environmental monitoring of the STS area

6.1 Introduction

Large amounts of data on contamination of soil, vegetation, bottom sediments and other environmental media with manmade radionuclides has been gathered under FMBA/DSA collaboration projects since 2012. The data have been entered into the site environmental database, along with data from other sources and applied in the DATAMAP and DOSEMAP software systems, to visualize the current distribution of radionuclides and understand their dynamic behavior. This in turn supports the control of radiation exposure of people at the site as well as the planning of future activities. The crucial task in the last few years was to continue monitoring during the removal of SNF and RW and STS remediation, to collect data before, during and after the removal of SNF and RW from the site. The supervision and field measurements were extended to monitoring of the offshore marine water area. In addition, work was done to understand the possible impact of contamination on biodiversity at the site, alongside other measures of ecological health. This section sets out the work carried out under the DSA/FMBA cooperation program in the last 5 years to support ecological assessment and understanding of the radiation status of STS Andreeva, and the monitoring work linked to recent SNF handling activities.

6.2 Ecological assessment and radiation status of the environment

Samples have been taken of soil, well water, plants (moss, motley grasses), seawater and aquatic environmental media (bottom sediments, seaweeds), from the industrial site and from within the STS supervision area. Sampling was carried out in accordance with “The Guidelines for health monitoring of concentrations of radioactive materials in the environmental media” [1,2] .

The primary preparation (drying, filtering, and homogenization) of samples was carried out in the laboratory of the environmental monitoring section of STS Andreeva. All measurements were made in the laboratory of FMBC.

During the field work (25-31October 2015) outdoors gamma dose rate was measured within the industrial site HPZ and CAA. Gamma dose rates were measured by foot gamma survey , using portable spectrometric complex MKS-01A “Multirad-M”[7], DKG-02U “Arbitr” dosimeter and searching dosimeter-radiometer MKS/SRP-08A. Gamma dose rate on-site varies over the range 0.5-98 μSv/h (Fig. 39, prepared through DATAMAP).

The highest gamma AEDR values (up to 2.807 μSv/h) were registered at the border between theHPZ and CAA near Building 5. Generally, within the HPZ, where the STS serviced facilities are located, the dose rate varies over the relatively narrow range 0.08-0.25 μSv/h and average values do not exceed significantly the mean values typical for whole region, of 0.9 -0.2 μSv/h [7]. High variability of this value was observed in 2015 within the CAA, which is under remediation today, see Table 7

[7] Detector NaI 63x63, range of AEDR measurement 0.03-60 μSv/h; uncertainty ±25%, activity 1-5·104 Bq; uncertainty 10%.

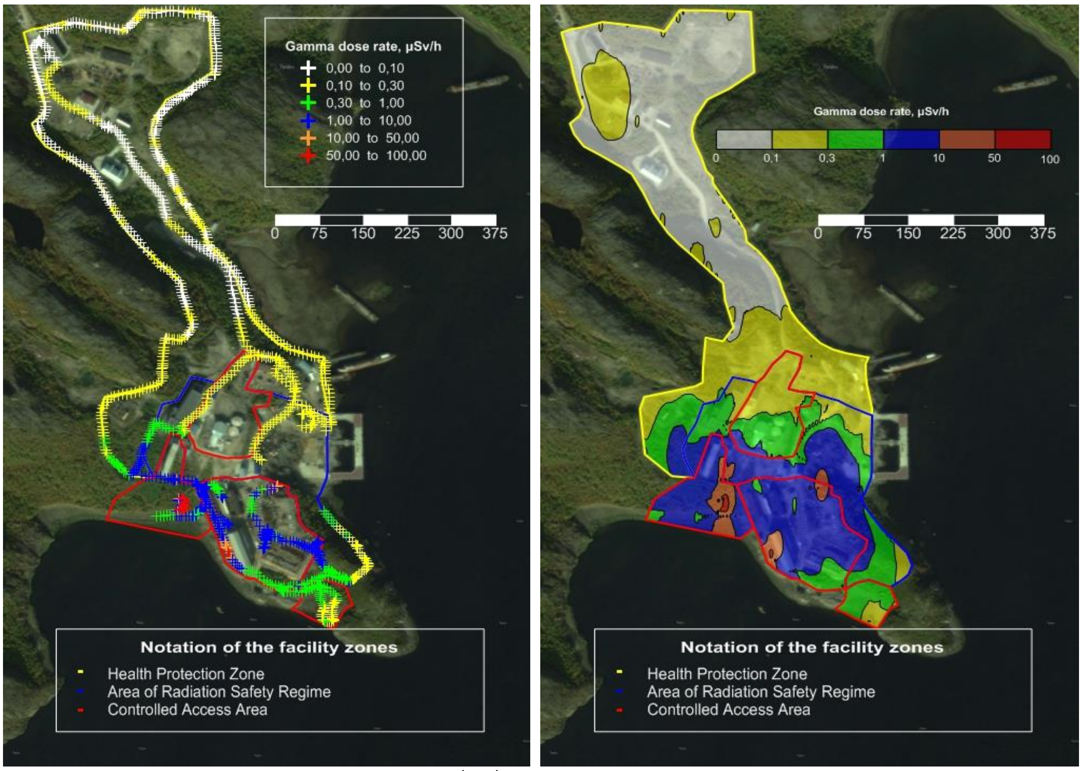


Fig. 39 Dot map of gamma survey results over 2015 (left). Contour map of gamma survey of the Andreeva Bay SevRAO site over 2015 (right).

Table 7 Data of gamma survey at STS Andreeva Bay over 2015.

Area	Number of measurements	Gamma AEDR, μSv/h		
		Minimum	Maximum	Average
HPZ	517	0.082	2.8	0.18
Radiation Safety Area	180	0.101	4.8	0.5
CAA, DSU	21	0.109	0.18	0.13
CAA, former location for drying the floating units	62	0.142	0.6	0.34
CAA, site 3	200	0.420	98	3.6
CAA, area around Building 5 and mouth of the former brook	66	0.508	91	18

The gamma dose rate dynamics over the site are shown through DATAMAP software in Fig, 40. The main changes were registered around the DSU and are connected with the installation of the horizontal shield and other preparation activities (see Section 2 and discussion at subsection 3.2).

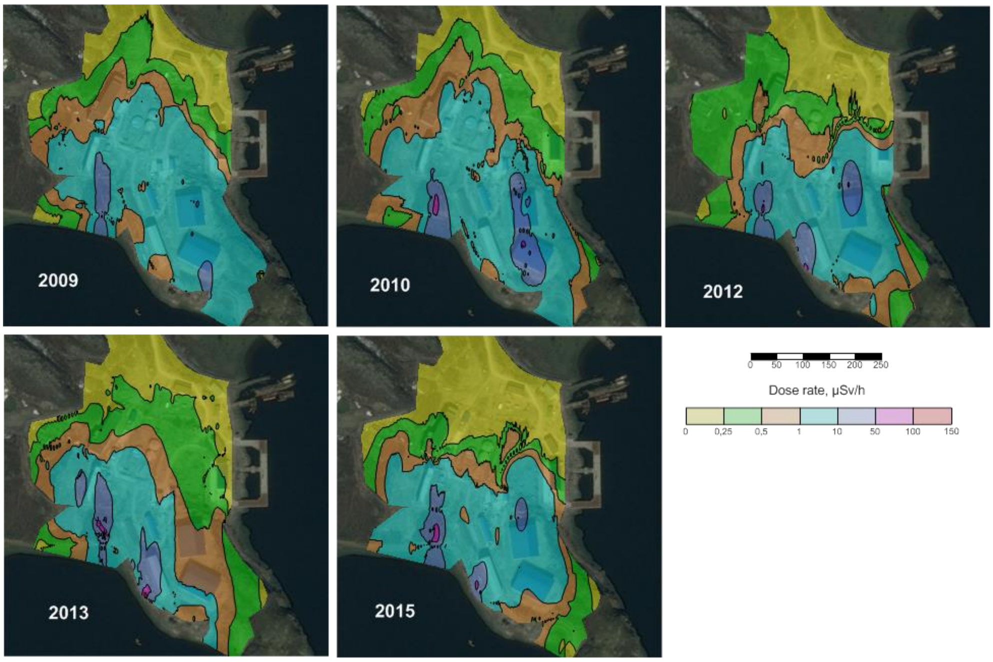


Fig. 40 Dynamics of gamma dose rate at the industrial site over 2009-2015.

6.2.1 Terrestrial gamma dose rate and radionuclide contamination

Samples of soil and well water were studied using gamma spectrometry and radiometry methods. ^{137}Cs, ^{60}Co, ^{241}Am in samples were determined using semiconductor germanium “CANBERRA” gamma spectrometer with detector N28-TP20099 №400301. Data measurement and treatment using gamma spectrometer was carried out in accordance with “The Method for Activity Measurement of Gamma Emitting Radionuclides in the Counting Samples using Gamma Spectrometry System LabSOCS” (certified by SRC FSUE “Mendeleev All-Russian Scientific Research Institute of Metrology”[5].^{90}Sr was determined in accordance with the Guidelines [6].

Results from 2015 are presented in Table 7. The time for spectrum selection was up to 24 hours. Comparing with the data obtained in previous years, it can be concluded that the preparatory stage for the removal of SNF up to 2015 generated no additional contamination on the industrial site and adjacent supervision area. In addition, no marked trend towards the spread of existing contamination within the health protection zone and beyond was registered.

Outdoor gamma dose rate was measured within the industrial site HPZ and Controlled Access Area (CAA). Table 8 summarizes the gamma survey data in 2015. The highest values (up to 2.8 µSv/h) were registered at the border of the HPZ and CAA near Building 5. Generally, the values do not exceed significantly the mean values typical for whole region, of 0.9 -0.2 µSv/h [7].

Table 8 List of samples collected in 2015, during the site visit, and results of measurement

Sample code	Type of sample	Location of sampling	Mass, kg (l)	Sr^{90}, Bq/kg (l)	Cs^{137}, Bq/kg (l)	Co^{60}, Bq/kg (l)	Am^{241}, Bq/kg (l)
A-15-01	Birch juice	Brook behind Building 5	1.25	$1.3 \cdot 10^{3} \pm 0.2 \cdot 10^{3}$	$3 \cdot 10^{2} \pm 0.2 \cdot 10^{2}$	-	
A-15-02	Soil 5-10 cm	Brook behind Building 5 under the tree	0.0046	$7.9 \cdot 10^{4} \pm 1.3 \cdot 10^{4}$	$6.7 \cdot 10^{6} \pm 3.3 \cdot 10^{5}$	-	
A-15-03	Soil 10-20 cm	Brook behind Building 5 under the tree	0.0043	$9.9 \cdot 10^{4} \pm 1.6 \cdot 10^{4}$	$4.6 \cdot 10^{6} \pm 2.3 \cdot 10^{5}$	-	
A-15-04	Soil 0-5 cm	Brook behind Building 5 under the tree	0.0028	$9.5 \cdot 10^{4} \pm 1.6 \cdot 10^{4}$	$6.5 \cdot 10^{6} \pm 3.2 \cdot 10^{5}$	-	
A-15-05	Soil 0-5 cm	Near borehole 6090	0.85	3.6±0.6	89.9±4.5	-	0.92±0.17
A-15-06	Soil 0-5 cm	Near borehole 4080	0.845	18.4 ±3.1	$1.3 \cdot 10^{2} \pm 0.1 \cdot 10^{2}$	-	1.2±0.28
A-15-07	Soil 0-5 cm	Near borehole 6091	0.52	66.3±11	$8.4 \cdot 10^{2} \pm 0.4 \cdot 10^{2}$	-	
A-15-08	Soil 0-5 cm	Near borehole 6092	0.615	26.9±4.5	$7.8 \cdot 10^{2} \pm 0.4 \cdot 10^{2}$	-	
A-15-09	Soil 0-5 cm	Near borehole 4085	0.995	$1.2 \cdot 10^{2} \pm 0.2 \cdot 10^{2}$	$4.4 \cdot 10^{2} \pm 0.2 \cdot 10^{2}$	-	
A-15-10	Soil 0-5 cm	Near borehole 4098	0.65	$2.4 \cdot 10^{3} \pm 0.4 \cdot 10^{3}$	$1.2 \cdot 10^{4} \pm 6 \cdot 10^{2}$	7.3±0.48	9±4.4
A-15-11	Soil 0-5 cm	Near borehole 6095	0.17	$2.4 \cdot 10^{3} \pm 0.4 \cdot 10^{3}$	$2 \cdot 10^{4} \pm 1 \cdot 10^{3}$	18.9±0.8	$1 \cdot 10^{2} \pm 0.1 \cdot 10^{2}$
A-15-12	Soil 0-5 cm	Near borehole 6096	0.2	$1.7 \cdot 10^{2} \pm 0.3 \cdot 10^{2}$	$2.9 \cdot 10^{2} \pm 0.2 \cdot 10^{2}$	-	
A-15-13	Soil 0-5 cm	Near boreholes 4092a, 4092b	0.135	86.3±14.5	$9.6 \cdot 10^{2} \pm 0.7 \cdot 10^{2}$	-	2.3±1.4
A-15-14	Soil 0-5 cm	Near the birch at the CAA behind Building 5	0.35	$21 \cdot 10^{4} \pm 3.6 \cdot 10^{4}$	$6.4 \cdot 10^{6} \pm 5.2 \cdot 10^{5}$	$8.2 \cdot 10^{2} \pm 3.3 \cdot 10^{2}$	
A-15-15	Bottom sediments	Mouth of the former brook behind Building 5	0.541	40.2±6.5	$3.6 \cdot 10^{2} \pm 0.2 \cdot 10^{2}$	-	
A-15-17	Bottom sediments	Section of drying of the floating units	0.34	$2.4 \cdot 10^{2} \pm 0.4 \cdot 10^{2}$	$5.3 \cdot 10^{2} \pm 0.4 \cdot 10^{2}$	16.4±0.9	40.3±2.5
A-15-18	Soil 0-5 cm	Above the section of drying of the floating units	0.305	$1.5 \cdot 10^{2} \pm 0.3 \cdot 10^{2}$	$3.9 \cdot 10^{2} \pm 0.2 \cdot 10^{2}$	0.93±0.05	3.7±0.37
A-15-20	Soil 0-5 cm	Above the section of drying of the floating units	0.215	$4.8 \cdot 10^{2} \pm 0.8 \cdot 10^{2}$	$1.1 \cdot 10^{3} \pm 78$	1.39±0.5	
A-15-22	Soil 0-5 cm	Montejuce site	0.345	$1.1 \cdot 10^{3} \pm 0.2 \cdot 10^{3}$	$2.2 \cdot 10^{3} \pm 1.1 \cdot 10^{2}$	28.5±0.9	32±3.2

A-15-23	Soil 0-5 cm	Near borehole 4097	0.95	7.2±1.2	95.6±4.5	-	0.6±0.24
A-15-24	Soil 0-5 cm	Near boreholes 6093. №6093a	0.7	6.7±1.13	73±3.8	-	
A-15-25	Soil 0-5 cm	Near the corner of Building 5	0.625	18.9±3.2	$3.1{\cdot}10^2 \pm 0.2{\cdot}10^2$	-	

Results were added to the visualization database to allow visualization to support dose planning, as discussed in section 2, and understanding of the radiation situation dynamics, discussed in section 3.3 and section 6.2

6.2.2 Marine gamma dose and radionuclide contamination

Gamma survey of the off-shore area was carried out using the spectrometric installation MKS-01A “Multirad-M”, scintillation gamma spectrometer “Multirad gamma-aqua” (Fig.41).

Fig. 41 Measurement by the near bottom gamma spectrometry method aboard a boat.

Locations of measurements were fixed using portable GPS related equipment. The distance between measurements varied depending on the activity measured. In case of a significant (>10 times) difference of readings in neighboring points, the step between two measurements was reduced. This allowed the boundaries of areas with increased radioactive contamination to be identified and defined. The dominant radionuclide was Cs-137.

The dose rate in bottom sediments varies over the range 0.05-3.5 μSv/h. The extent of bottom sediment contamination with Cs-137 varies over the range 100-200 kBq/m^2 in the area near the PMK-67 pier and the section of the drying of floating units (Fig. 42). Elsewhere, the extent of contamination with Cs-137 varies over the range from 0.1 to 100 Bq/m^2. According to echo-sound data, the contaminated area is at the depth of about 18 meters. Table 9 includes data of gamma AEDR measurement on the seabed and the surface activities of ^{137}Cs in bottom sediments.

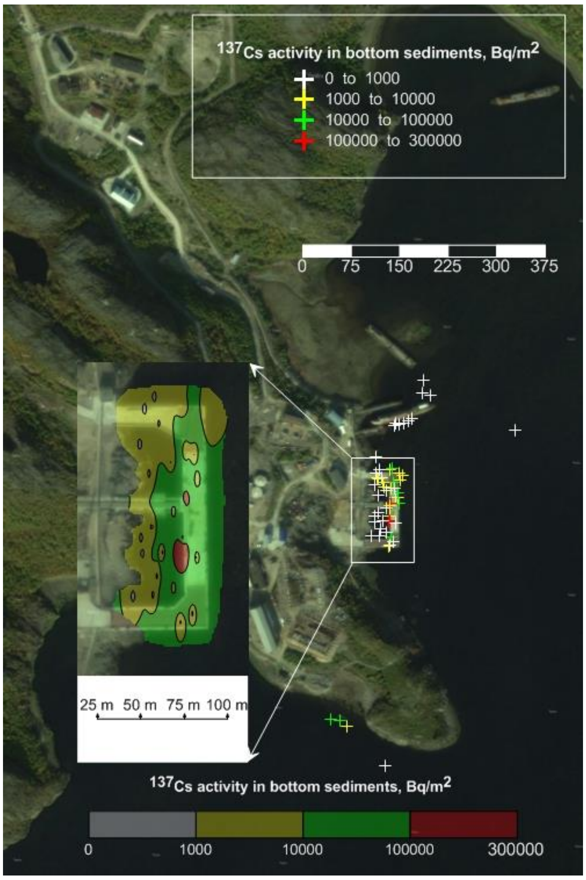


Fig. 42 Dot and contour map of distribution of ^{137}Cs in off-shore bottom sediments, 2015

Table 9 Data of gamma AEDR measurement on the seabed and surface activity of Cs-137 in off-shore marine bottom sediments in 2015.

Part of off-shore water area	Number of points	Gamma dose rate on the seabed, range and mean value, Sv/h	Surface activity of Cs-137 in bottom sediments in the layer 0-10 cm, range and mean value, Bq/m²
Around of emergency wooden piers and floating caissons	11	(0.050 – 0.069) / 0.05	(0 – 100) / 0.1
PMK-67	43	(0.057 – 0.343) / 0.1	(0 – 257000) / 19700
Area of the drying of floating units	4	(0.051 – 0.104) / 0.08	(0 – 23800) / 10600

6.2.3 Radionuclide and chemical analysis of groundwater

Table 10 includes results of physical and chemical analysis of water samples from the monitored wells of the STS. Investigated ground water meets the health physical requirements for composition and properties of water from water bodies of water protection zone and areas of drinking, household and recreational water supplying (*SanPiN 2.1.4.1074-01; GN 2.1.5.1315-03*) [8,9] by hydrogen index – pH=6.5-8.5 and mineralization level – up to 1 g/L.

The maximum permissible concentration (MPC) for the level of mineralization was exceeded in sampled water from wells number 4077 and 4085-b. Although the hygienic requirements are not applicable in this case (for groundwater) directly, they can help to characterize the studied water samples as brackish water.

Table 10 Physical and chemical parameters and macroelement concentrations in water samples

Sample	Na	K	Ca	Mg	Mineralization, g/L	pH	Chromaticity	Odor
	mg/l							
Control	37.8	4.74	72.0	7.05	0.690	8.2	Colorless	Neutral
4077	250[1*]	10.6	2.68	22.75	1.276[1]	7.1	Off-green, turbid	Strong smell of ether
4085-a	109.5	17.6	73.2	14.7	0.839	7.9	Light yellow, hazy	Neutral
4085-b	176.5[3]	10.5	42.3	22.16	1.015[1]	7.9	Light brown, precipitate	Slight smell of ether
4092-a	229.6[13]	18.3	64.9	25.7	0.669	8.1	Light yellow, with red sediment	Neutral
4092-b	243[13]	30.6	84.2	27.84	-	8.3	Light yellow, hazy	Neutral
4098	102.3	8.7	82.9	16.66	-	8.2	Light red, cloudy	Strong smell of ether
6091	100.9	14.5	87.5	26.24	0.935	8.2	Light yellow, brown precipitate	Slight smell of ether
6092	156.5[3]	26.5	58.2	48.88[3]	-	8.1	Light brown	Slight smell of ether
6093-a	47.9	8.4	53.4	17.2	0.510	8.1	A bright yellow, precipitate	Slight smell of oil
6093-b	155.3[3]	13.9	78.6	19.64	-	8.3	Auburn, muddy	Neutral
6095	248.6[13]	8.3	84.0	19.4	-	8.1	Colourless with sediment	Slight smell of ether
6096	220.4[13]	20.5	25.2	17.32	-	8.3	Light yellow, hazy	Neutral
6097	184.4[3]	7.5	41.9	10.26	-	7.8	Light grey, sediment	Neutral
6099	96.2	33.8	21.7	35.53	-	6.9	Brown, turbid	Neutral
MPCdw	*200*	-	-	-	*1.0*	*6.0 - 9.0*	-	-
MPCwb	*200*	-	-	*50*	-	*6.0 - 9.0*	-	-
MPCf	*120*	*50*	*180*	*40*	-	*6.5 - 8.5*	-	-

Note: [1]MPC_{dw} *– for drinking water (SanPiN 2.1.4.1074-01)*
[2]MPC_{wb} *– for water bodies of economic and culture-domestic water use (GN 2.1.5.1315-03)*
[3]MPC_f *– for fishery water bodies [7]*
*[*1,2,3] – deviation from the appropriate MPC*

For potassium (K), calcium (Ca) and magnesium (Mg) there are no set regulatory limits of the concentrations in drinking water. Nevertheless, the favorable situation in terms of the content of these elements can be observed based on standards for fishery water bodies: the excess of MPC is noted only on the content of Mg in the sample from the well number 6092. On the other hand, in many cases, the sodium (Na) concentration was above MPC standards for drinking water (Table 10) in wells 4077, 4092-a, 4092-b, 6095 and 6096. As the tap water used as a laboratory control, the contents of macroelements meet hygienic and fishery standards.

When evaluating the organoleptic characteristics, it should be noted that, except for the control, all test water samples had different shades of color from light yellow to brown, and are characterized by varying degrees of turbidity and precipitate (Table 10). For seven water samples, the odor of ether was recorded.

Arsenic (As) and heavy metal concentrations (mercury (Hg) and beryllium (Be)) in the water samples were determined by atomic-absorption spectrometry (flame and electrothermal methods) with the use of Quant-2A and Quant Z.ETA (CORTEC, Moscow) spectrometers with a typical uncertainty in measurements of 25% depending on the element under examination.

Table 11 includes data on the concentrations of As and of the 1^{st} class of hazard chemicals (Hg, Be). The As content in all test samples is much lower than the health physics standards. Concentrations of Hg and Be for the majority of the studied samples are much lower than the established standards. The exceptions are: 1) water samples from wells number 4077 and 6093-b, in which the content of Hg and Be, respectively, reached their MPC, and 2) water samples from wells number 6092 and 6099, where double MPC_{dw} excess of Be content was measured.

Table 11 Concentration of arsenic and chemicals of the 1^{st} class hazard in water samples, mg/L

Sample	As	Hg	Be
Control	0.0008	<0.0001	0.0001
4077	0.0025	0.0005[3]	0.00012
4085-a	0.0025	0.0001	0.0001
4085-b	0.0025	0.00005	0.0001
4092-a	0.0025	0.00005	0.0001
4092-b	0.0025	0.00005	0.0001
4098	0.0025	0.00005	0.00005
6091	0.0025	0.00005	0.0001
6092	0.0025	0.00005	**0.0004**[123]
6093-a	0.0025	0.00005	0.00005
6093-b	0.0025	0.00005	0.0002
6095	0.0025	0.00005	0.00005
6096	0.0025	0.00005	0.00005
6097	0.0025	0.00005	0.00005
6099	0.0025	0.00005	**0.0004**[123]
MPC_{dw}	***0.01***	***0.0005***	***0.0002***
MPC_{wb}	***0.01***	***0.0005***	***0.0002***
MPC_{f}	***0.05***	***0.0001***	***0.0003***

Note: Abbreviations are similar to those of Table 10

For 2nd class hazardous chemicals (cadmium (Cd), lead (Pb), nickel (Ni), strontium (Sr), barium (Ba) and lithium (Li)), multiple violations of hygienic standards have been recorded (Table 12). In particular, Pb may require special attention; the concentrations were higher than MPCs in 12 of 14 cases – for each of three types of health physics standards. The lowest number of violations was observed for Cd.

Table 12 Concentration of the 2nd class hazard chemicals in water samples, mg/L

Sample	Cd	Pb	Ni	Sr	Ba	Li
control	<0.0001	0.005	**0.032[23]**	**8.05[123]**	0.043	0.017
4077	**0.0013[1]**	**0.095[123]**	**0.038[23]**	0.29	**0.70[1]**	0.030
4085-a	0.0003	**0.094[123]**	**0.038[23]**	**0.46[3]**	**0.15[1]**	0.030
4085-b	0.0003	**0.023[23]**	**0.035[23]**	0.28	0.05	0.027
4092-a	0.0001	**0.049[123]**	**0.032[23]**	**0.45[3]**	0.07	**0.036[1.2]**
4092-b	0.0002	**0.037[123]**	**0.061[23]**	**0.44[3]**	0.03	**0.041[1.2]**
4098	0.0003	**0.105[123]**	**0.069[23]**	**0.44[3]**	0.05	0.011
6091	0.0003	**0.014[23]**	**0.03[23]**	**0.64[3]**	0.06	**0.050[1.2]**
6092	0.001	**0.394[123]**	**0.146[123]**	**0.87[3]**	**0.52[1]**	**0.050[1.2]**
6093-a	0.0002	**0.046[123]**	**0.038[23]**	0.31	0.08	**0.055[1.2]**
6093-b	0.0004	**0.592[123]**	**0.017[3]**	**0.65[3]**	**0.50[1]**	**0.037[1.2]**
6095	0.00005	**0.048[123]**	**0.015[3]**	**0.47[3]**	0.09	**0.036[1.2]**
6096	0.0003	**0.043[123]**	**0.018[3]**	0.26	0.04	**0.073[1.2]**
6097	**0.0018[1]**	**0.095[123]**	**0.018[3]**	0.15	0.09	0.023
6099	**0.0018[1]**	**1.763[123]**	**0.022[23]**	**0.58[3]**	**0.38[1]**	**0.042[1.2]**
MPC_{dw}	***0.001***	***0.03***	***0.1***	***7.0***	***0.1***	***0.03***
MPC_{wb}	***0.001***	***0.01***	***0.02***	***7.0***	***0.7***	***0.03***
MPC_{f}	***0.005***	***0.006***	***0.01***	***0.4***	***0.74***	***0.08***

Note: Abbreviations are similar to those of Table 10

MPC for the 3d class hazardous chemicals (aluminum (Al), copper (Cu), manganese (Mn), iron (Fe) and zinc (Zn)) have been exceeded in many cases (Table 13). The highest levels were observed for Fe in sample numbers 4077 and 6099. For other chemicals, the standards for drinking water and economic activities, in some cases is exceeded three or four times.

Table 13 Concentrations of the 3d class hazard chemicals in water samples, mg/L

Sample	Al	Cu	Mn	Fe	Zn
control	0.022	0.019	0.07[3]	0.374[1]	0.96[3]
4077	2.6[123]	3.29[123]	1.27[123]	311.5[123]	1.70[124]
4085-a	0.77[123]	0.5[3]	0.22[123]	21.9[123]	0.64[3]
4085-b	0.26[23]	0.2[3]	0.14[123]	75.5[123]	0.11[3]
4092-a	0.57[123]	0.34[3]	0.20[123]	28.9[123]	0.14[3]
4092-b	0.36[23]	0.66[3]	0.12[123]	120.0[123]	0.09[3]
4098	0.51[123]	0.11[3]	0.53[123]	70.6[123]	0.13[3]
6091	0.46[23]	0.37[3]	2.0[123]	131.6[123]	0.09[3]
6092	2.7[123]	4.04[123]	0.86[123]	158.3[123]	1.42[123]
6093-a	0.11[3]	0.27[3]	0.47[123]	116.3[123]	0.08[3]
6093-b	2.61[123]	3.63[123]	0.51[123]	39.8[123]	4.90[123]
6095	0.13[3]	0.17[3]	0.14[123]	94.3[123]	1.13[123]
6096	0.86[123]	0.19[3]	0.23[123]	114.2[123]	0.12[3]
6097	1.1[123]	0.24[3]	0.06[3]	87.5[123]	0.04[3]
6099	2.67[123]	2.1[123]	2.73[123]	415.1[123]	1.54[123]
MPC_{dw}	*0.5*	*1.000*	*0.1*	*0.3*	*1.0*
MPC_{wb}	*0.2*	*1.000*	*0.1*	*0.3*	*1.0*
MPC_{f}	*0.04*	*0.001*	*0.01*	*0.1*	*0.01*

Note: Abbreviations are similar to those of Table 10.

Table 14 includes data on concentrations of the main radionuclides in water samples from monitoring wells located on the NWC SevRAO site. Radioactive contamination of the studied water samples is due to the presence of manmade radionuclides, Cs-137 and Sr-90. The specific activity concentration of Cs-137 in water samples from eleven wells exceeded the intervention level established by *SanPiN 2.6.1.2523-09 [11].* The highest concentration of Cs-137 was registered for water samples from wells number 4092-a, 6092, and 6097.

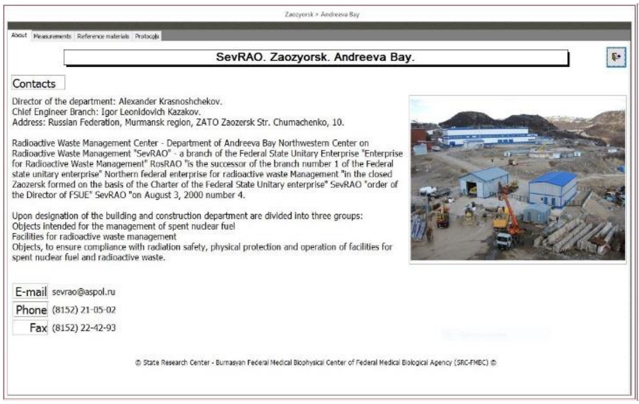
The presence of Sr-90 in the studied water samples is negligible, except for two wells: number 4092-a and number 4092-b, in water of which the concentration of Sr-90 radionuclide was two orders of magnitude higher than the IL. This can be explained by the proximity of sources of contamination in the area of these sampling points.

Table 14 The specific activity of the main manmade radionuclides in water of the monitoring wells

Sample	**Specific activity, Bq/l**	
	^{137}Cs	**^{90}Sr**
control	-	-
4077	1.5	0.5
4085-a	1.5	0.5
4085-b	1.5	0.5
4092-a	**154***	**899***
4092-b	**33.5***	**885***
4098	**33.5***	0.5
6091	**51.9***	0.5
6092	**80.2***	0.5
6093-a	**50.5***	0.5
6093-b	**33.4***	0.5
6095	**36.3***	0.5
6096	**23.5***	0.5
6097	**66.7***	0.5
6099	**32.7***	0.5
IL	***11***	***4.9***

6.2.4 Environmental monitoring database

All information on environmental monitoring is stored in the database developed within the DSA/FMBA regulatory cooperation program. The database has a graphic user interface with four tabs: information, measurement data, background information and protocols (Fig. 43).



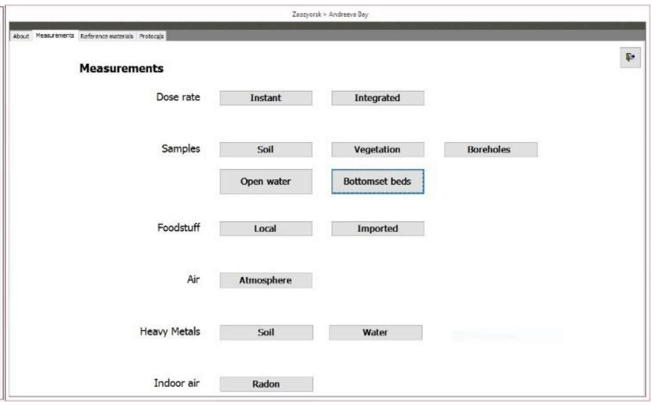


Fig. 43 left: Screen form “card of the facility”, right: Screen form with open tab “Measurement data”.

The “measurement data” tab allows to call screens to view the data for different types of measurements, such as the dose rate, activity concentrations in the soil, vegetation, water, atmospheric precipitation, as well as measured radionuclide content in local and imported foods.

The forms “Contents of heavy metals in the water” and “Contents of heavy metals in the soil” allows identification of the exceedance of regulatory MPCs.

The system provides the ability to create, store and edit protocols by the following sets of activity measurements in samples of soil, vegetation, water, sediments.

The designed single informational complex on the radio-ecological situation at STS Andreeva Bay is used for optimization of radiation control and monitoring, as well as for information support of regulation and decision-making systems to assure radiation safety during the remediation process.

6.2.5 Evaluation of biodiversity, environmental quality and water quality

Biodiversity

Biodiversity[8] is considered a key parameter characterizing the state of supraorganism[9] systems. Measures of biodiversity should be described quantitatively allowing comparison either by counting the species and measuring their relative abundance, or by a measure combining these two components. Only a few species of any phytocenosis[10] are dominant, having a large biomass and productivity. Most species are present in moderate or small quantities, but their occurrence is essential for the sustainable ecosystem condition. Industrial disturbance can influence the disappearance of the most sensitive species within phytocenoses, which leads to creation of impoverished and unstable forms.

A study was conducted at three sites within the HPZ and Supervision Area: former area to dry the floating units, area around the Dosimetry Control Post and the area near the stadium.

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[8] "Biological diversity" means the variability among living organisms from all sources, including terrestrial, marine and other aquatic ecosystems and the ecological complexes, which include them as a part; this term includes diversity within species, between species and ecosystems [11].
[9] Supraorganism is a group of synergistically interacting organisms of the same species.
[10] Phytocenosis is a community of plants; all of the plant species found at a site, considered collectively.

To identify the species composition systematic multi-scale photographing was performed (Fig. 44).

Fig.44 Examples of general form, medium and macro plan of the studied vegetation

A convenient way to measure biodiversity is to establish a coefficient of similarity using the Jaccard formula [17]. The Jaccard coefficient characterizes the isolation of one phytocenosis from another taking into account the number of species in each of the two compared phytocenoses and the number of common species within them. In all three studied phytocenoses, 28 species of vascular plants belonging to 18 families were found. The richest representation was among families: *Ericaceae* – 5 species and *Rosaceae* – 3 species. The species composition of the first of these two phytocenoses differ by six species. The Jaccard coefficient of floristic similarity in areas near the former floating unit drying location, the Dosimetry Control Point and the stadium has the value of 0.52. Changes to this value in future could indicate a change in relative environmental quality between the three sites, or simply indicate that they have (since 2015) evolved differently following the previous industrial disturbance. However, any such changes might be considered as a basis for further investigation as to the cause.

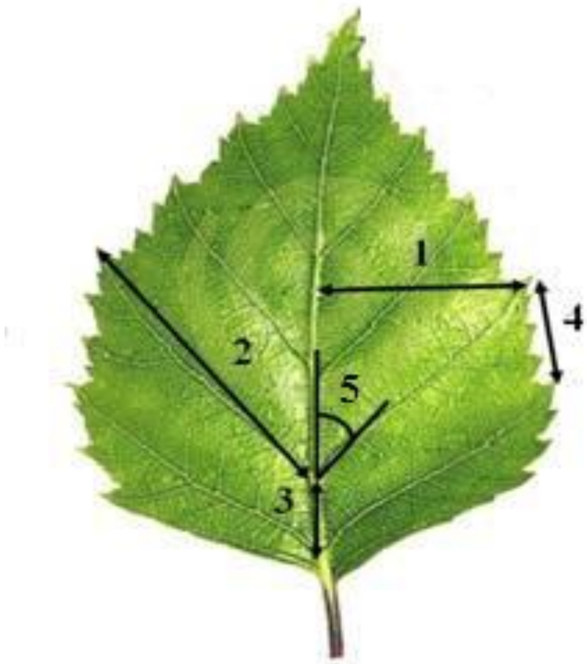
Environmental quality

Biological indicators can be used as a criterion for the assessment of dynamic changes in an anthropogenically influenced ecosystem [18]. Plants in particular can be good bio-indicator organisms since their presence and growth fully depend on the quality of the environment.

For this study, a morphogenetic method was used that evaluates the stability of organism development in morphological parameters with fluctuating asymmetry (FA[11]) being used as the main criterion. The FA level reflects the general state of the body and is characterized by high correlation with other indicators of homeostasis [24]. The FA was evaluated for the *Betula* (Birch) family [25], including weeping birch (*Betula pendula).* The *Betula* family grow widely in Eurasia and they are particularly suitable as bio-indicators due to having a distinct bilateral symmetry, which is the main requirement of this method [26, 27-29]. Studies have shown that the weeping birch responds to chemical and radioactive contamination in the environment by changing FA index [29-30] (Fig. 45).

Material for assessment was collected in August-September 2015, with sample size: 223 leaves from the Supervised Area (SA), and 540 leaves from around Building 5. Leaves were scanned using MFToolbox 4.9 software at MFU Canoni-SENSYSMF3010, and measured using ImageProPlus software.

[11] FA is a small omni-directional deflection of living organisms from a strict bilateral symmetry.



1. width of left and right half of the leaf: in the middle of the leaf plate, from the boundary of the midrib to the border of the leaf;
2. length of the rib of the second kind, the second from the base of the leaf;
3. distance between the bases of ribs of the first and second kind;
4. distance between the ends of the same ribs;
5. angle between the main rib and the second (from the base of the leaf) rib of the second kind

Fig. 45 Measured parameters on one side of the leaf plate

The FA parameter was calculated as described in reference [30]. Assessment of the FA index showed, that the condition of the SA is on the border of "significant deviations from the norm" and "critical". The FA index in the most contaminated area near Building 5 corresponds to the "critical state" (0.059 ± 0.003). This could be due to their growing within the territory, but also because the site is on the edge of the species range. The Student t-test did not reveal significant differences in the control area of observation.

Water quality

To evaluate the toxicity of water samples, the *Allium*-test method was used [8, 9]. In case of the normal growth without acute toxic effects, the roots of onions have a light shade of visually observed tissues and classic straight shape. Anomalies include a change of typical color, necrotic damage, annularly and helically twisted roots, tumor-like bulges, thickening at the tip, forming a hook shape or wavy-curved (wavy) form.

For this study, the onion roots (3 – 10 units from each bulb) of 10-15 mm length were fixed in a mixture of alcohol and glacial acetic acid in a ratio of 3: 1 for a day. Analysis of genotoxicity and cytotoxicity of water samples was carried out following the standard methodology [31-33]. The mitotic index and count of cells with chromosomal aberrations at the stage of ana-telophase were selected as indexes for analysis.

Toxicity is an integral index of an organism's reaction to exposure from external factors. Cytotoxicity demonstrates the ability of the test factor to induce disorders of biological processes at the cellular level. The process of cell division is an important step in the growth and development of a living organism so the assessment of the intensity of cell division is an informative indicator of the cytotoxic effect. The cytotoxicity was evaluated based on changes in the number of dividing cells of onion roots. Quantitatively, the mitotic activity was determined by the value of the mitotic index.

Genotoxicity means the ability of the environment to impact on the structure and function of the genetic apparatus in the test object. The genotoxicity of water is presented as the frequency of aberrant ana- and telophases in the first mitosis of onion root cells. The aberration spectrum was analyzed through separation of chromatid and chromosome bridges and fragments, tripolar mitosis and gaps in chromosomes (genome mutations) [31-33]. To determine the frequency and spectrum of chromosomal aberrations 8672 ana-telophases in 180 specimens were analyzed.

Calculation of phytotoxicity of the aquatic environment I_{tox} was based on the changing the length of the Allium root relative to the control sample. The phytotoxicity is classified in accordance with the toxicity scale (GOST R ISO 22030-2009 [35]):

1. < 0.2 – phytotoxicity does not occur;
2. 0.2-0.4 – slight phytotoxicity;
3. 0.4-0.6 – medium (moderate) phytotoxicity;
4. 0.6 – heavy phytotoxicity.

Results of the study and analysis are presented in table 15.

Table 15 The morpho-metric indicators of onion (*Allium cepa L.)* bulb germinated roots and assessed phytotoxicity factor.

Sample	Root length, mm	Number of adventitious roots, un.	Root modifications, % of the total number of roots		I_{tox}
			hook-shaped	curved	
control	26.4 ± 0.7	13 ± 1	5.6	-	
4077	16.0 ± 0.5*	12 ± 1	5.3	-	**- 0.39**
4085-a	19.4 ± 0.7*	13 ± 1	3.8	-	**- 0.27**
4085-b	24.1 ± 0.6*	12 ± 1	5.2	4.2	- 0.08
4092-a	17.7 ± 0.5*	14 ± 1	3.3	1.5	**- 0.33**
4092-b	21.2 ± 0.7*	12 ± 1	5.4	1.2	**- 0.20**
4098	25.2 ± 0.8	11 ± 1	5.8	0.3	- 0.05
6091	22.5 ± 0.9*	10 ± 1*	11.1	-	- 0.15
6092	20.4 ± 0.7*	13 ± 1	7.4	1.3	**- 0.23**
6093-a	25.2 ± 0.7*	13 ± 1	6.4	2.6	- 0.05
6093-b	26.8 ± 0.8	12 ± 1	14.7	0.8	0.02
6095	18.1 ± 0.8*	13 ± 2	4.0	4.4	**- 0.31**
6096	19.6 ± 0.8*	11 ± 1	13.1	3.1	**- 0.26**
6097	21.0 ± 0.8*	12 ± 1	7.4	0.6	**- 0.21**
6099	23.7 ± 0.8*	12 ± 1	15.5	0.6	- 0.10

I_{tox} – phytotoxicity factor;
* – statistically significant difference from the control sample at p<0.05;
Samples with low toxicity are in bold

On this basis, water samples from the NWC SevRAO site can be described as non-toxic (water from wells number 4085-b, 4098, 6091, 6093-a, 6093-b, 6099) or slightly toxic (water from wells number 4077, 4085, and, 4092-a, 4092-b, 6092, 6095, 6096, 6097).

Figure 46 illustrates the assessment of variation in the onion root length during germination in water samples from the NWC SevRAO site. In twelve samples an inhibition effect was observed with significant reduction in the length of the root, from 5% up to 30% in comparison with the control sample (onion germinated in the tap water control).

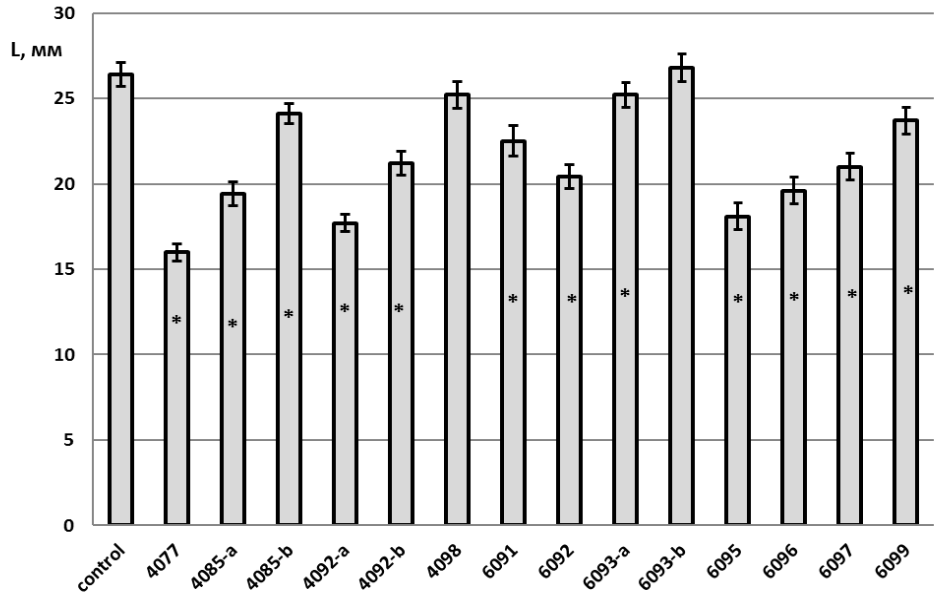


Fig. 46 Length of germinated onion roots (Allium cepa L.)

* Statistically significant difference with the control sample is observed at $p<0.05$ (Student *t*-test)

Abnormalities in terms of color and structure of the roots were examined according to the Allium-Test procedure described in [32]. The bulk of the considered roots had classic straight shape and light shade of all visually observable tissues. However, changes in the shape, such as curved roots and the appearance of the hook like tips were observed.

In bulbs germinated in water samples from wells 6096, 6093-b, and 6091 there was a visible increase in the number of roots with a hooked tip, i.e. 10 to 15% compared with 5% in the control, indirectly indicating the manifestation of a toxic effect from the components present in the well water samples.

Root-undulating curved modifications were noticed for 11 water samples. The proportion of roots with this type of disorder was much lower and not more than 4% of the total number of roots. The highest number of curved roots was registered for onions germinated in wells number 6096, 6095, 6093-a, and 4085-b.

Endogenous processes can cause changes in form and thickening, such as non-uniform cell division around the perimeter of the axis of the root, a violation of the cell differentiation process during the formation of the main root tissues. Analysis of morpho-metric parameters does not provide any full assessment of the toxicity of the tested aquatic environment because of the short-term duration of the testing procedure. This study can be considered as a supplement to the assessment of natural waters by the cytotoxicity and genotoxicity criteria.

Analysis of endogenous processes occurring in the body of the test-object at the cellular and genetic level, was carried out taking into account the dynamics of mitosis, disorders were recorded via aberrant cells frequency. The mitotic index of onion root cells varied over the range from 10 to 13%, with a control value 12.6±0.2%. When sprouting ordinary onions in water from monitoring wells from the NWC SevRAO site, a statistically significant inhibitory effect on mitotic activity in the samples of water from wells number 4077, 4085-a, 4085-b, 4092-a, and 4092-b was found. The reduction of the index of less than 50% of the benchmark (cytotoxicity threshold) is considered as a sub-lethal effect on the test organism [36]. In this case the deviation of the mitotic activity from the reference level did not exceed 10-20% so this may be considered a negligible cytotoxic effect.

The genotoxic impact of water samples on the test object was considered at the level of morphological analysis of chromosomes during ana-telophase stages of mitosis with the definition of aberrant cells and the separation of the spectrum of observed disorders. In the control sample the aberration frequency was 1.2±0.3%, consistent with data on the spontaneous level of cytogenetic disorders in cells of the onion meristem, being registered during other studies [37-41]. The frequency of aberrant cells for those samples from wells number 4077, 4085-a, 4085-b, 4092-a, and 4092-b were 2 to 4 times higher than the spontaneous level, suggesting a statistically significant inhibitory effect on mitotic activity of the onion root.

Under the analysis of the spectrum aberrations three groups of abnormalities have been revealed: chromatid (m1+f1), chromosomal (m2 + f2), genomic (g and 3p). The frequencies for various types of aberrations are compared in Fig. 47.

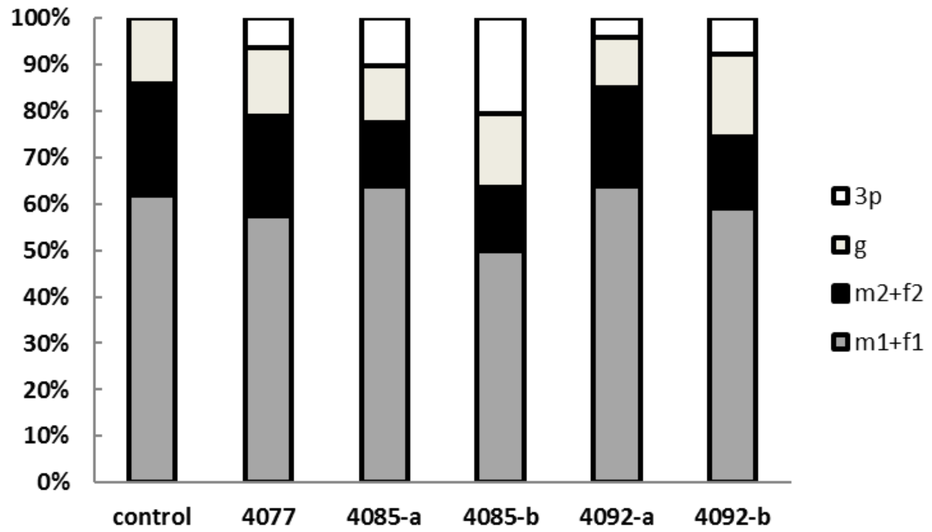


Fig. 47 Aberration spectrum in the onion root meristem

The bio-testing procedure showed statistically significant change in the level of mitotic activity of root meristems and the frequency of aberrant cells. These two biological indicators are consistent with each other in the degree of inhibitory effect. In the spectrum of cytogenetic disturbances, chromatid aberrations prevail. The presence of a significant proportion of genomic disorders in the general spectrum of aberrations indicates a potential biohazard environment, which can be expressed, inter alia, as the risk of occurrence of mutagenic biomarkers in organisms. The frequency of chromosome (double) aberrations, which are frequently seen as radiation-induced biomarkers, in all cases, do not differ from the control level confirming the leading role of chemical pollutants in the observed genotoxic effect.

6.3 Radiation monitoring during recent SNF handling activities

6.3.1 Radiation situation assessment prevailing by 2019

Gamma dose rate

During the field work in February 2018 and September 2019, outdoor gamma dose rates were measured within the HPZ and CAA. Table 16 and Fig. 48 illustrate results of studies of September 2019 and locations of the gamma dose rate measurements, respectively. Figure 49 shows interpolated data. Figure 50 then illustrates the dynamics of gamma dose rate over the period between 2009 and 2019.

Table 16 Results of a gamma survey of the Andreeva Bay NWC SevRAO site of 2019.

Area	Number of measurements	ADER, μSv/h		
		Min	Max	Median (confidence interval border at P=0.95)
HPZ	678	0.03	0.19	0.07 (0.05-0.10)
HPZ, Building 5 impact area	102	0.06	10	0.28 (0.17-0.53)
Radiation Safety Zone	901	0.04	18	0.19 (0.11-0.25)
Dry storage units	23	0.07	1.8	0.23 (0.07-0.53)
Location for drying floating tanks	117	0.10	0.92	0.24 (0.16-0.33)
Site 3	319	0.15	>150	1.8 (1.2-2.6)
Coastal area behind Building 5	133	0.10	>150	1.0 (0.64-1.7)
Supervision Area	752	0.03	0.17	0.05 (0.03-0.07)

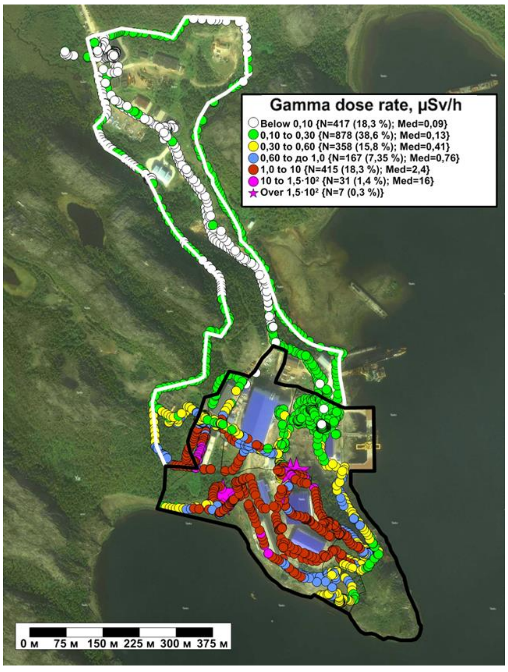


Fig. 48 Gamma point map of the Andreeva Bay NWC SevRAO site in 2019

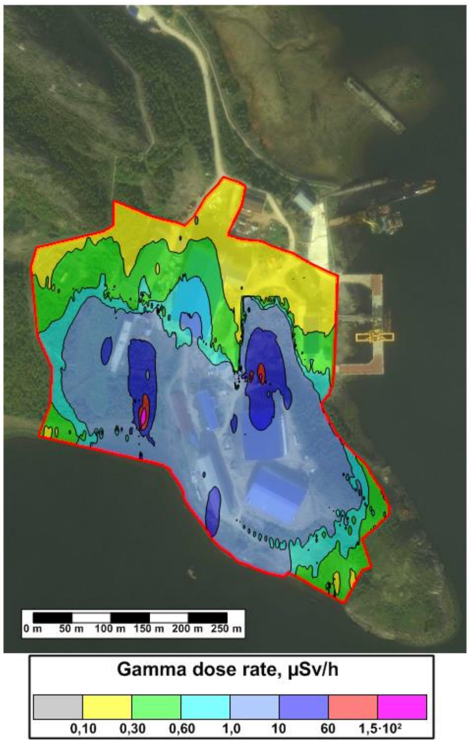


Fig.49 Contour map of gamma survey of the Andreeva Bay SevRAO site over 2019.

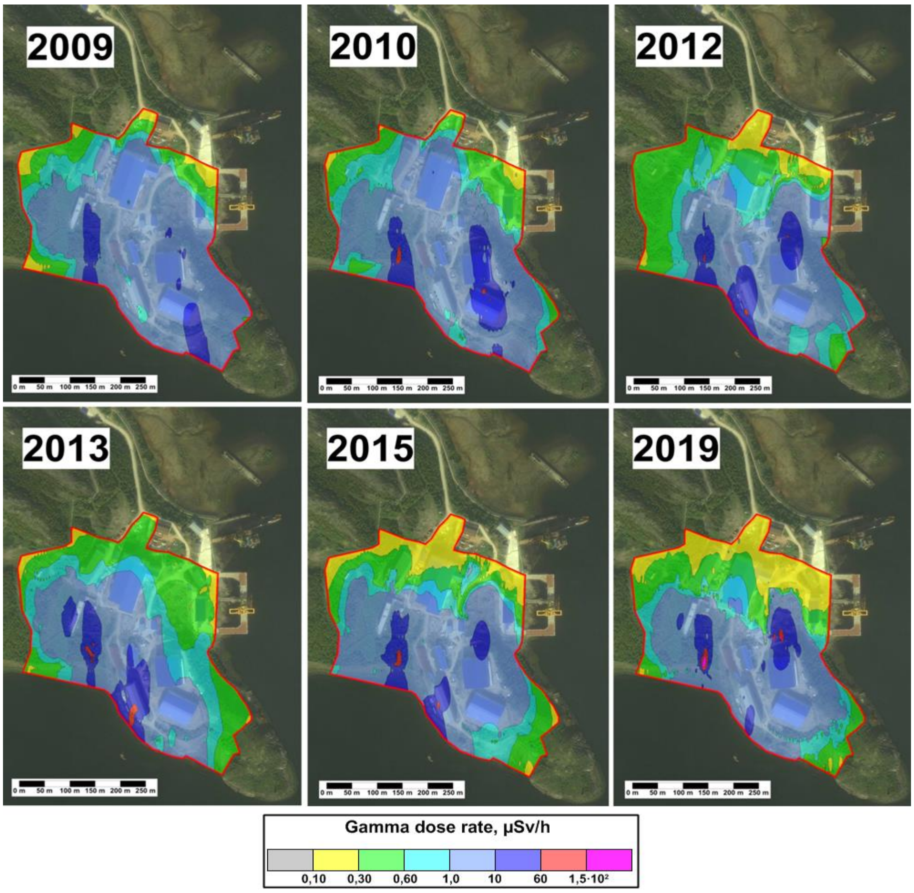


Fig. 50 Dynamics of gamma dose rate at the industrial site over 2009-2019.

According to Fig. 50, over the observation period, the radiation situation has changed in some areas. For example, in the area of the DSU the situation has improved significantly over time: contaminated soil was removed from the old slopes of the DSU; a new biological shield was arranged at the tanks, and Building 153 was built. In the course of remediation during construction of this new building over the DSU's and the removal of local contamination sites, it was possible not only to improve the radiation situation in this area, but also to prevent the creation of new contaminated sites in the adjacent areas. Relatively stable radiation conditions remain in the vicinity of Building 5 because large-scale remedial operations were not carried out in this area.

The appearance in 2019 of sites with increased dose rate were due to work carried out at the industrial site involving access to SNF. The areas involved are very small, and overall, the trend across the site is to lower dose rates.

To date, work on the unloading and removal of normal SNF has not led to the emergence of new foci of environmental contamination within the industrial site; there are no areas with an increased level outside the zones with limited access. It is important to continue monitoring, especially taking into account the fact that after the unloading of all normal fuel, work is planned to unload abnormal fuel.

6.3.2 Concentrations of manmade radionuclides in soil and plants in the HPZ

During field work, 35 soil samples, 15 plants samples, 7 bottom sediment samples, 7 seaweeds samples, 2 mollusk samples, 1 sample of mushrooms and 1 sample of fish were collected. Table 17 includes the results of the content determination of ^{137}Cs and ^{90}Sr. Results remain at similar level to those obtained in the previous years.

Table 17 List of samples collected in 2019 during the field work and data of gamma spectrometry.

Sample code	Sample	Location of sampling	^{90}Sr, Bq/kg (l)	^{137}Cs, Bq/kg (l)
A-19-1	Soil	Site 3	23.8±7.8	40.3±2.5
A-19-2	Soil	Site 3	176±17.6	1536±96.2
A-19-3	Soil	Site 3	104±16.7	1601±100
A-19-4	Seaweeds	Drying of floating tanks	5.6±1.9	10.9±1.2
A-19-5	Bottom sediments	Drying of floating tanks	201±24.1	385±27.4
A-19-6	Seaweeds	Behind Build.5	345±32.5	61.9±4.2
A-19-7	Bottom sediments	Behind Build.5	53.5±13.4	335±19.2
A-19-8	Soil	Near Build.151	59.6±9.6	919±57
A-19-9	Soil	Near the dose monitoring post	3.19±1.1	34.2±1.7
A-19-10	Plants	Near the dose monitoring post	1.3±0.4	2.8±0.3
A-19-11	Soil	Near the garage	0.75±0.2	8.9±1.1
A-19-12	Seaweeds	Near the pier	8.9±2.4	12.5±1.5
A-19-13	Bottom sediments	Near the pier	19.7±5.3	35.3±4.4
A-19-14	Mollusks	Near the pier	0.25±0.1	1.9±0.2
A-19-15	Soil	Near the locker room	2.2±0.7	55.8±6.9
A-19-16	Plants	Near Build. 5	4.4±1.3	7.9±0.49
A-19-17	Soil	Near Build. 5	28.4±5.1	102±6.4
A-19-18	Plants	Near Build. 5	16±7.1	103±6.0
A-19-19	Soil	Near the boiler room	26.4±7.9	910±6.7
A-19-20	Plants	Near the boiler room	2.5±0.3	2.1±0.23
A-19-21	Soil	On the road near Nicholas	44.5±7.9	99.6±6.2
A-19-22	Plants	On the road near Nicholas	23.3±7.7	48.7±4.3
A-19-23	Soil	Opposite Build. 151 near garage	7.5±2.2	21.2±0.19
A-19-24	Plants	Opposite Build. 151 near garage	14.6±1.5	23.1±1.8
A-19-29	Fish	Near the pier	0.99±0.15	2.7±0.33

To obtain data on the environmental impact of SNF unloading that began in October 2017, the Environmental Laboratory of STS Andreeva took soil and vegetation samples along the conveyor route for SNF from the storage facility to the container ship. Results are shown in Table 18. The results show that during the period of normal SNF unloading and its transfer on site, no additional contamination of the industrial site was revealed. However, it is reasonable to continue monitoring, especially for future work related to unloading of abnormal SNF, e.g. from DSU 3A.

Table 18 Samples collected along the SNF transport route

Sample code	Type of sample	Location of sampling	Mass. Kg (l)	Sr-90, Bq/kg (l)	Cs-137, Bq/kg (l)	Am-241, Bq/kg (l)
A-18-01	Soil 0-10 cm	to the right of Build.153, transport gateway	511	0.63±0.35	11.1±0.93	
A-18-02	Soil 0-10 cm	to the left of room 005 Build. 153, left butt	563	20.0±0.78	120.22±6.6	
A-18-03	Soil 0-10 cm	10 m from point 1 along the Nikolas route	418	7.3±1.0	39.62±2.56	
A-18-04	Soil 0-10 cm	10 m from point 2 along the Nikolas route, intersection with the OPM road	1234	31.3±2.6	13.96±1.09	

Sample code	Type of sample	Location of sampling	Mass. Kg (l)	Sr-90, Bq/kg (l)	Cs-137, Bq/kg (l)	Am-241, Bq/kg (l)
A-18-05	Soil 0-10 cm	10 m from point 3 along the Nikolas route	708	12.3±1.7	30.37±2.0	0.13±0.46
A-18-06	Soil 0-10 cm	10 m from point 4 along the Nikolas route	937	0.63±0.49	0.81±0.2	
A-18-07	Soil 0-10 cm	10 m from point 5 along the Nikolas route	667	0.91±1.42	5.97±0.75	0.11±0.31
A-18-08	Soil 0-10 cm	10 m from point 6	371	9.43±1.61	28.32±1.84	
A-18-09	Soil 0-10 cm	10 m from point 7	841	10.51±1.83	7.39±0.59	
A-18-10	Soil 0-10 cm	10 m from point 8	714	7.12±1.13	15.0±1.2	
A-18-11	Soil 0-10 cm	10 m from point 9 along the road opposite the well	180	8.58±1.83	18.99±1.44	1.07±0.62
A-18-12	Soil 0-10 cm	10 m from point 10	780	5.13±0.86	13.15±0.69	0.11±0.16
A-18-13	Soil 0-10 cm	near well 6091	623	24.5±0.65	291.83±15.15	
A-18-14	Plants	near well 6091, opposite Build. 50	106 (ash weight)	376.1±11.9	50.77±2.66	
A-18-15	Soil 0-10 cm	end of Build. 150	256	8.3±1.57	14.25±1.09	
A-18-16	Soil 0-10 cm	opposite Build. 151	637	4.92±0.76	16.59±1.18	
A-18-17	Soil 0-10 cm	Control Entry Post CEP-1	1062	0.63±0.31	4.19±0.67	
A-18-18	Plants	Control Entry Post CEP-1	77 (ash weight)	6.1±1.11	2.12± 0.24	
A-18-19	Soil 0-10 cm	Control Dosimetry Post	834	0.6±0.34	1.19±0.25	
A-18-20	Plants	Control Dosimetry Post	86 (ash weight)	70.76±4.07	5.27±0.39	
A-18-22	Plants	to the right of Build.153, transport gateway	17 (ash weight)	87.44±9.29	34.0±2.42	
A-18-23	Plants	to the left of room 005 Build. 153, left butt	20 (ash weight)	222.9±8.9	7.7±0.8	

6.3.3 Studies in the Supervision Area

In September 2019, measurements were made in the SA along the road from the STS to the landfill for construction waste, 6 km from the STS Control Entry Post.

Gamma dose rate in the SA varied over the comparatively narrow range from 0.06 to 0.17 μSv/h and did not exceed average regional background values.

In the SA samples of soil, plants and mushrooms were collected. Concentrations of Cs-137 and Sr-90 did not differ significantly from previous data.

No impact of the STS industrial site on the adjacent territory of the SA was indicated.

6.3.4 Radionuclide mobility in soils and marine bottom sediments

To determine the level of mobility of Cs-137 and Sr-90 in the environment and the strength of their binding to soil and bottom sediments, the chemical forms of these radionuclides present in soils and marine bottom sediments were determined.

For soils, on average, almost 90% of gross Sr-90 can be in mobile form and be available to plants or migrate along the soil profile. For Cs-137, the values were much lower at around 32%. The results indicate the potential for contamination to leach to the marine environment. This could be significant if the terrestrial contamination levels are high enough.

For marine bottom sediments the desorption coefficient[12] for Sr-90 was found to be 0.76 and 0.6 for Cs-137. This difference is explained by biological (the presence of organic material), mechanical and mineralogical (the presence of clay minerals) features of bottom sediments.

6.3.5 Study of the contamination of the marine offshore water area by the near bottom gamma spectrometry method

During the studies of 2015, some local contamination of the near-shore marine water area near the PMK-67 pier was found (see section 6.1.3).

Measurements made in 2019 made it possible to confirm the localization of Cs-137 contamination of bottom sediments revealed previously. According to measurement results (Fig. 51), the extent of contamination of bottom sediments with Cs-137 is about the same (1 to 40 kBq/m^2) as in the previous studies and remains in the same locations. Co-60 was also detected in approximately the same locations, in the range from 0.5 to 7 kBq/m^2.

[12] the ratio of the radionuclide content in mobile form to the total content of the radionuclide

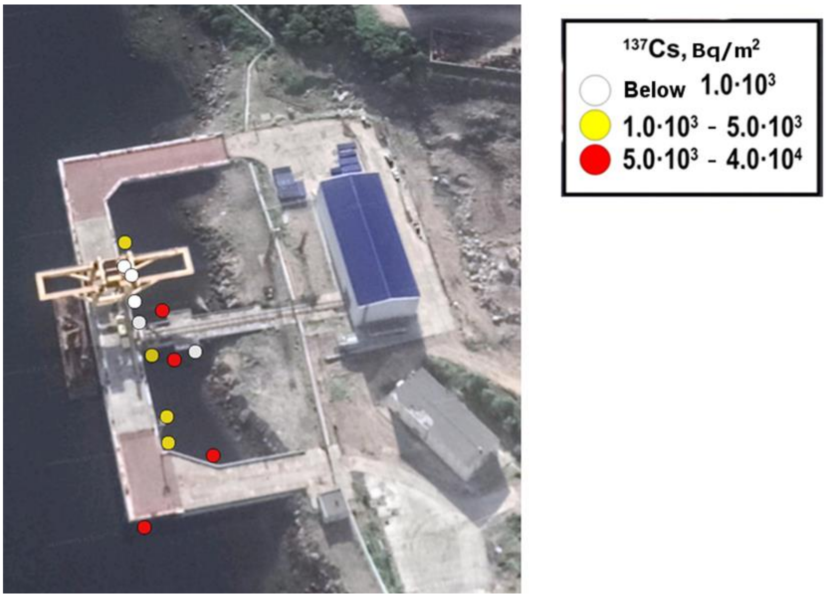


Fig. 51 Cs-137 activity distribution on the surface of bottom sediments near the PMK-67 pier (September 2019)

6.4 Discussion

The environmental monitoring program undertaken to support ecological assessment and understanding of the radiation status of STS Andreeva, and the monitoring work linked to recent SNF handling activities, have provided key data on the current situation with regard to both the chemical and radiological situation and their dynamics.

The results indicate that, overall, the radiation situation has improved at Andreeva Bay, both on-shore and in the marine environment close to pier PMK-67. Measurements of chemical form indicate the potential for mobilization of Cs-137 and Sr-90; however, the results of time series monitoring indicate that contamination remains localized.

Gamma dose rates over the site have changed little over the period of surveillance. The main changes in dose rate have been temporary and a connected with identified planned operations, such as the installation of the biological shield at DSUs.

Analysis of groundwater samples from wells across the site indicate a range of chemical contaminants is present, with some contaminants being in excess of MPCs. Activity concentrations of Cs-137 and Sr-90 are also in excess of intervention levels in some samples. Both cytotoxicity and genotoxicity of groundwater samples has been demonstrated. However, the lack of double chromosome aberrations, frequently seen as radiation-induced biomarkers, indicates that chemical pollutants are likely responsible for the effects observed.

The analysis of fluctuating asymmetry of the birch leaves sampled near to Building 5 and in the SA indicate a significant change in the state of plants. This could be due to their growing within the territory, but also because the site is on the edge of the species range.

Biodiversity was assessed within the STS industrial site and the SA based on determination of the Jaccard coefficient of floristic similarity in different areas. Results indicated that species diversity across the site is small. Changes to the coefficient in future could indicate a change in relative environmental quality between the three sites, or simply indicate that they have (since 2015) evolved differently following the previous industrial or other disturbance. However, any such changes could be considered as a basis for further investigation as to the cause.

Continued monitoring will ensure that any changes to the radiation and environmental situation during continued SNF and RW activities are detected and any changes with regards to ecological impacts detected, e.g. through changes in biodiversity indices.

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7 Engagement with wider international cooperation

As noted in the introduction, information from the program has always been shared widely with the international community, through participation in workshops and conferences, and publication of program results in peer reviewed journals. This approach has been continued over the last five years, supplemented by engagement with IAEA programs and coordination groups, and in activities of the Nuclear Energy Agency of the Organization for Economic Co-operation and Development (OECD NEA).

Journal papers covering the context and scope of the entire program include: [11], [5], [13], [6]. It is considered constructive that these include papers in English and Russian language journals.

Papers on specific topics cover dose control and visualization tools, environmental monitoring and protection of the environment:

- → Methods of minimizing doses incurred by external exposure while moving in radiation hazardous areas [2];
- → Practical radioecology support in the management and regulatory supervision of legacy sites [7];
- → Topographical classification of dose distributions: implications for control for worker exposure [1];
- → Radiation situation dynamics at STS Andreeva over the period 2002–2016 [3]; and
- → Radioecology as a Support to Regulatory Decision making on NORM and other Legacies, Related Waste Management and Disposal. Report of an International Workshop [4].

Substantial information has been shared at a connected series of widely attended international workshops on the regulatory supervision of legacy sites, firstly in Oslo 2016 [12], followed up in 2017, in Lillehammer [9] and then in 2019 at Tromsø . The last had a wider scope to include decommissioning and legacy management and was jointly organized with the OECD NEA and extensively documented in [7]. All three conferences included material related to the DSA/FMBA regulatory cooperation program and relevant corresponding experience in other countries.

Particularly valuable experience has been gained in the last several through participation by DSA and FMBC in the OECD NEA Expert Group on Legacy Management. This report of this group was published by the NEA in 2020 [8] and included 13 documented case studies, including the STS Andreeva but also of special interest, Sellafield (UK) and several sites in the USA, including Hanford.

The shared experience summarized above strengthens the development of international recommendations and guidance and also provides positive feedback into the bilateral work with FMBA and with other organizations. This collective sharing and engagement also provides input to regulatory developments in Norway as well as wider information on strategic issues and examples of good practice. It also informs the strategy for research activities carried out by the Centre for Environmental Radioactivity (CERAD).

The conclusions and recommendations from the workshops and the OECD NEA work provide a strong basis for continued international engagement in bilateral programs. The process also helps to build strong and trusted working relationships, building confidence and providing significant mutual benefits.

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8 Conclusions

Cooperation between FMBA and DSA in the period up to 2015 supported improved understanding of the radiation situation at STS Andreeva from a regulatory perspective and, in parallel, enhancement of the regulatory basis for operations at the site. It was important to update regulatory documents and procedures to be in line with latest developments in international recommendations and guidance, as adopted within the Russian regulatory framework, and to address the particular challenges associated with the complex radiation situation.

Results of the cooperation program provided the regulatory basis for progress to be made with refurbishment of the technical infrastructure at the significantly degraded stores for SNF and RW, and the other facilities at STS Andreeva. It also provided for necessary preparations for recovery of the SNF and RW to proceed in a comprehensively regulated and safe manner, in terms of protection of workers, the public and the environment.

Regulatory documents and procedures were developed and approved, giving comprehensive coverage of all radiation protection issues, including reconstruction and engineering work on site, personnel and environmental monitoring, emergency preparedness and response in case of accidents and overall improvement in safety culture. Innovative visualization tools were developed as well as techniques for monitoring personnel reliability. Independent monitoring of the radiation situation and its dynamics was carried out.

In the period from 2015 to 2019, operational activities at the site progressed to include completion of new buildings and installation of technical equipment, initial SNF recovery operations, re-packaging in containers for transfer off-site and completion of initial transfers. Norway has for more than two decades contributed significantly to build necessary infrastructure on site and preparatory work to ensure safety and security at the site, prior to and during SNF retrieval and transport. Other international partners has also cooperated significantly with the Russian side on these issues.The parallel regulatory cooperation program has followed these activities, based on the results of an updated regulatory threat assessment, to ensure compliance with the enhanced regulatory framework and the practical application of the new tools and techniques. The results can be summarized as follows.

Radiation protection of workers and the public

Regulatory review has been carried out of the EIA of the proposed process for extraction of SNF from the DSUs and transport operations. Experts of FMBC made more than 60 comments and suggestions. After many discussions and meetings, and relevant amendment and supplementation, the EIA was approved by FMBA.

The proposed technological plan and safety justification for management of normal and abnormal SNF at STS Andreeva was analysed and approved following discussion and amendment.

Regulatory documents on safe management of normal SNF have been developed on:

- Radiation monitoring;
- Planning of radiation hazardous operations;
- Implementation of the personnel protection optimization principle;

- Established reference levels;
- Selection of workers to carry out radiation hazardous operations;
- Arrangement of education and training of the personnel; and
- Enhancing safety culture.

Radiation parameters have been checked during test removal of normal SNF from DSU 2A and occupational doses assessed.

Monitoring and optimization of doses for workers during SNF and RW management

Independently obtained gamma dose rate measurements confirm the stability of the radiation situation and doses to workers have been below the established reference levels.

The first generalized indicator of the radiation situation, the AEDR integral over the technical site of STS Andreeva, demonstrated its effectiveness and convenience for evaluating the radiation situation in combination with the procedure for decomposition of time series. There has been a sevenfold decrease in the AEDR integral due to technical and engineering improvements.

The IAS RBP software system developed within the cooperation program, and its efficient algorithms in efficient analysis of past and possible future radiation situation data, provide clear benefits in radiation control planning for future hazardous operations, and in the context of emergency preparedness and response.

Emergency preparedness and response in case of a radiological accident

Two emergency exercises have been held that have demonstrated the operation of controls and the emergency response system of NWC SevRAO and institutions under FMBA in case of a radiological accident. In combination, the exercises have improved arrangements for closer cooperation between operator and regulator when developing urgent decisions and recommendations on taking protective measures. In particular, the exercises tested:

- expert assessment of the radiation situation and potential radiological consequences, to prepare recommendations for the management bodies, including the necessary counter-measures;
- activation of the emergency preparedness system of FMBA in the region and, based on the findings of the exercise, to improve the preparedness of institutions under FMBA;
- capabilities of forces and means of the responding bodies to the public of the region; and
- procedure of the IAEA and Scandinavian countries for notification of a radiological accident in real time mode in accordance with the current agreements at local, territorial and federal levels.

Results indicate that there is a high level of cooperation between emergency teams under FMBA and Rosatom, and preparedness of institutions under FMBA for medical care of injured persons. The exercises have confirmed improvement in emergency medical care indicators at the SevRAO facilities in comparison with previous exercises. Response times were reduced and there was improvement in the technical base of medical institutions and departments, serving as a basis for minimization of health effects in case of emergency exposure combined with other hazardous factors.

Valuable experience was obtained in the use of computer simulation methods for the purpose of radiation scenario and radiation situation assessment as well as visualization of radiation situation data and planning radiation hazardous operations, AndreevaPlanner and EasyRad.

Measures on psychological training of the personnel involved in the aftermath of a radiological accident were taken and experience in assessment of psychological training has been accumulated.

The "Docking-2018" video shows the practical activities and processes in the exercise, and can be used in sharing experience with other specialists but also with other relevant bodies and with the public.

Personnel reliability monitoring and training for hazardous operations

The system of personnel reliability monitoring, TIBUR_TSP, has been implemented in pre-shift monitoring and in training in hazardous operations. Testing has shown that the newly applied vibro-image data technique compares reasonably with the conventional methods. The duration of this test is about one minute compared to 2-3 hours by conventional methods, which is a significant practical advantage.

Laboratory tests in FMBC helped to assess the abilities of the students/testees to develop self-regulation skills. The relation between the parameters of electro-physiological signals with those of the speed and quality parameters of the trained activity has been revealed and described. The data obtained so far are preliminary, so it is reasonable for studies in this area to be continued.

Environmental monitoring of STS Andreeva

The environmental monitoring program have provided key data on the current situation with regard to both the chemical and radiological situation and their dynamics. The results indicate that, overall, the radiation situation has improved.

Gamma dose rates over the site have changed little over the period of surveillance. The main changes in dose rate have been temporary and are connected with identified planned operations, such as the installation of the biological shield at DSUs. Measurements of chemical form indicate the potential for mobilization of Cs-137 and Sr-90; however, the results of time series monitoring indicate that contamination remains localized.

Analysis of groundwater samples from wells across the site indicate a range of chemical contaminants is present, with some contaminants being in excess of MPCs. Activity concentrations of Cs-137 and Sr-90 are also in excess of intervention levels in some samples.

Both cytotoxicity and genotoxicity of groundwater samples has been demonstrated. However, the lack of double chromosome aberrations, frequently seen as radiation-induced biomarkers, indicates that chemical pollutants are likely responsible for the effects observed.

The analysis of fluctuating asymmetry of the birch leaves sampled near to Building 5 and in the SA indicate a significant change in the state of plants. This could be due to their growing within the territory, but also because the site is on the edge of the species range.

Assessment of the Jaccard coefficient of floristic similarity in different areas indicates that species diversity across the site is small. Future changes to the coefficient could indicate a change in relative environmental quality, or just that they have evolved differently following the previous industrial or other disturbance. However, any such changes could be considered as a basis for further investigation as to the cause.

Continued monitoring will ensure that any changes to the radiation and environmental situation during continued SNF and RW activities are detected and any changes indicating ecological impacts detected, e.g. through changes in biodiversity indices.

Engagement with wider international cooperation.

information from the regulatory program has always been shared widely with the international community, through participation in workshops and conferences, and publication of program results in peer reviewed journals. In the period covered by this report, 9 papers have been prepared describing aspects of the program and published in peer reviewed journals. In addition, contributions have been made to three major workshops on nuclear legacy management and to an OECD NEA report entitled, "Challenges in nuclear and radiological legacy management: Towards a common framework for the regulation of nuclear and radiological legacy sites and installations". This report shared substantial experience on the application of international recommendations and guidance and challenges in their application at the site-specific level. Such sharing is considered of great mutual benefit to those participating and the timely publication by OECD NEA supports an even wider community.

This collective sharing and engagement also provides input to regulatory developments in Norway as well as wider information on strategic issues and examples of good practice. It also informs the strategy for research activities carried out by the Centre for Environmental Radioactivity (CERAD).

The conclusions and recommendations from the workshops and the OECD NEA work provide a strong basis for continued international engagement in bilateral programs, helping to build strong and trusted working relationships and build confidence among all stakeholders especially in Russian Federation.

A major achievement of the last five years has been to see a significant reduction in the hazard at STS Andreeva, due to retrieval from the old stores and transfer off-site of substantial amounts of SNF.

The first substantial transfers took place in 2017 and it was acknowledged that that international cooperation had resulted in the work being carried out safely and more quickly than otherwise possible[13]. Continued progress is reported as being in line with or better than expected[14]. The work is not complete and continues in the context of recovery and shipment of the more problematic abnormal SNF.

The significant progress demonstrates the advantages of a stable long-term policy of hazard reduction and a strategy to implement it, in line with the Norwegian Plan of Action. Regulatory

[13] https://www.youtube.com/watch?v=s91OV_e8j8Y

[14] https://bellona.org/news/nuclear-issues/2018-06-andreyeva-bay-nuclear-fuel-removal-going-faster-than-planned-rosatom-says

cooperation is a vital component, working within a flexible framework that makes it possible to address newly recognized challenges while still maintaining strict control over all risks.

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