REMOTE SEARCH FOR GAMMA SOURCES AT THE DRY STORAGE UNIT 3A IN ANDREEVA BAY AND THE DETERMINATION OF THEIR DOSE RATES DURING ACTIVITIES FOR IMPROVEMENT TO THE RADIOLOGICAL ENVIRONMENT

by

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The remotely controlled replacement of the concrete covering of the spent fuel dry storage unit 3A with a new iron horizontal biological shielding was carried out during works aimed at the improvement of the radiological environment at the NWC "SevRAO" – Branch of FSUE "RosRAO", Andreeva Bay, Murmansk Region. Video control systems, a BROKK robotic manipulator, HIAB manipulator crane, gamma detectors of the ASCRO radiation monitoring system, and a CARTOGAM gamma camera were employed. A CARTOGAM gamma camera was used in all stages of the work involving high radiation levels for the remote location of the most dangerous gamma radiation sources and the evaluation of their dose rates. Gamma detectors of the ASCRO radiation monitoring system were located at several spots of the dry storage unit 3A in order to control the radiation situation. The use of the ASCRO and CARTOGAM has allowed us to avoid unauthorized exposure of the staff involved in the operations at the dry storage unit 3A site.

Key words: improvement to the radiological environment, dry storage unit gamma camera

INTRODUCTION

The widespread use of nuclear technologies has led to the accumulation of spent nuclear fuel (SNF) and radioactive waste (RAW). Long-term storage of SNF and RAW requires radiological monitoring around the storage sites in order to avoid environmental problems. Waste management may involve high radiation fields dangerous for the involved personnel. The employment of remotely controlled equipment and machinery, as well as remote monitoring of γ-radiation equivalent dose rates (EDR) at the RAW management site, are important. According to the strategic master plan, SNF dry storage units (DSU) in Andreeva Bay, Murmansk Region, Northwestern Russia, were qualified as especially dangerous. In 2005, the highest γ-radiation EDR at the DSU-3A above the concrete covering was found to be 3.2 mSv/h, while that under the covering was 38 mSv/h. Over one third of the concrete covering area, the EDR was found to exceed 1 mSv/h. Systematic work on the improvement of the radiological environment (IRE) at the SNF storage facilities in Andreeva Bay commenced in 2004. Our work has been financially supported by foreign donors and the State Corporation "Rosatom".

In the interval between 2009 and April of 2012, Russian experts from the NRC "Kurchatov Institute", NWC "SevRAO" – Branch of FSUE "RosRAO", FSUE FCNRS, OJSC RDTB "Onega" *etc*, carried out the IRE work at the DSU 3A in Andreeva Bay. The work was financially supported by Nuvia Ltd., UK. The old concrete covering was replaced with new iron horizontal biological shielding segments. By the end of the IRE operations, the mean EDR at the DSU 3A shielding surface did not exceed 7.44 Sv/h.

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EXPERIMENTAL

A remotely controlled BROKK robotic manipulator, HIAB manipulator crane and video control systems were employed in the IRE work at the DSU 3A. Radiation monitoring at the DSU 3A was carried out using the Automatic System for Radiological Environment Monitoring (ASCRO) system, a CARTOGAM gamma camera, portable γ-radiation detectors, and an air sampling system (radiation monitor). The CARTOGAM gamma camera was used in all stages of the work involving high-energy radiation levels for remote location of the most dangerous gamma radiation sources and the evaluation of their dose rates. The use of the ASCRO system and CARTOGAM gamma camera made it possible for us to avoid unauthorized exposure of the staff involved in the operations at the DSU 3A site. We had previous experience in this field at the temporary solid radioactive waste (SRW) storage site (open pad) in Gremikha, NWC "SevRAO" – Branch of FSUE "RosRAO" [1, 2]. Also, the isotopic composition of the sources detected by the CARTOGAM was established using the ISOCS γ-spectrometer [3]. The objective of this work was to implement the remotely controlled replacement of the old concrete covering at the DSU 3A in Andreeva Bay, Murmansk Region. The DSU 3A tank containing concreted spent fuel assemblies (SFA) was covered by iron biological shielding segments and lead sheets (fig. 1).

Figure 1. DSU 3A tank site at the NWC "SevRAO" – branch of the FSU "RosRAO", Andreeva bay, Murmansk region (27. 12. 2011)

RESULTS AND DISCUSSION

Remotely controlled replacement of the DSU-3A concrete covering. Since high radiation levels were expected at the DSU 3A site in the course of the operations, the staff was not supposed to be present there (fig. 2). Therefore, before the start of the works, an 8-10 m high temporary concrete block structure and metal modules (SRW module, HIAB module, BROKK module, control module) were erected over the DSU 3A tank (fig. 3). A trolley on rails was located in the SRW module for the removal of SRW such as concrete slabs and blocks, girders, containers with debris, soil, *etc*. from the DSU 3A. The HIAB manipulator crane was located in the HIAB module. It traveled on rails to/from the DSU 3A transfering heavy SRW and containers with debris to/from the trolley. The BROKK robotic manipulator was located in the BROKK module. It climbed onto the DSU 3A surface and conducted the work (moving concrete slabs and blocks, cutting reinforcement bars, battering, drilling, *etc*.), using the attached implements.

The staff stayed in the control module (fig. 3). Radiological control via ASCRO detectors, as well as the control of the BROKK and HIAB operation, was done using the video control system. Radiological control inside the building was provided by dosimeters, in order to create maps of the EDR levels at the DSU 3A site during operations (fig. 4). The BROKK and HIAB were used to remove debris from the concrete slabs (fig. 5) covering the cells with SFA in the DSU 3A tank, including the loading and removal of containers with concrete debris, bricks, wire, *etc*., vacuum cleaning of the surface and dismantling of the

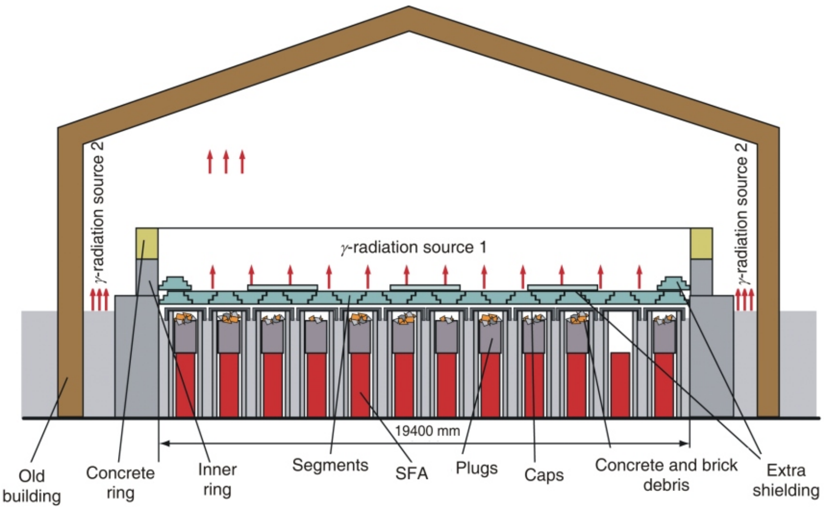

Figure 2. γ-radiation source at the DSU 3A under the cover (27. 02. 2012)
(a) – γ-radiation source 1 (mean EDR   7.44 μSv/h),
(b) – γ-radiation source 2 (mean EDR   20-60 μSv/h)

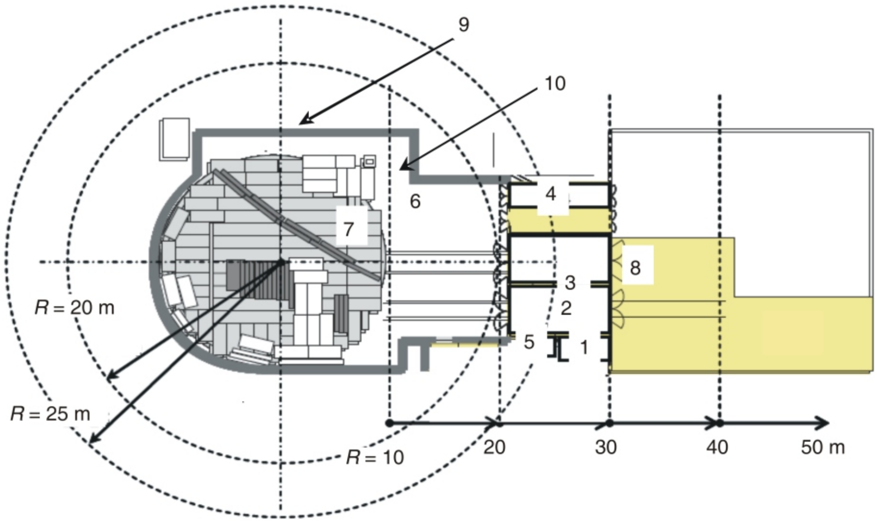

Figure 3. Layout of the DSU 3A tank, modules, and workplaces
1 – control module, 2 – SRW management module, 3 – HIAB module, 4 – BROKK module, 5 – changing and decontamination rooms, 6 – process extension, 7 – 3A tank enclosed with concrete walls under rhe roof, 8 – open pad, 9 – concrete wall, 10 – CARTOGAM gamma camera, R – distance to the DSU 3A

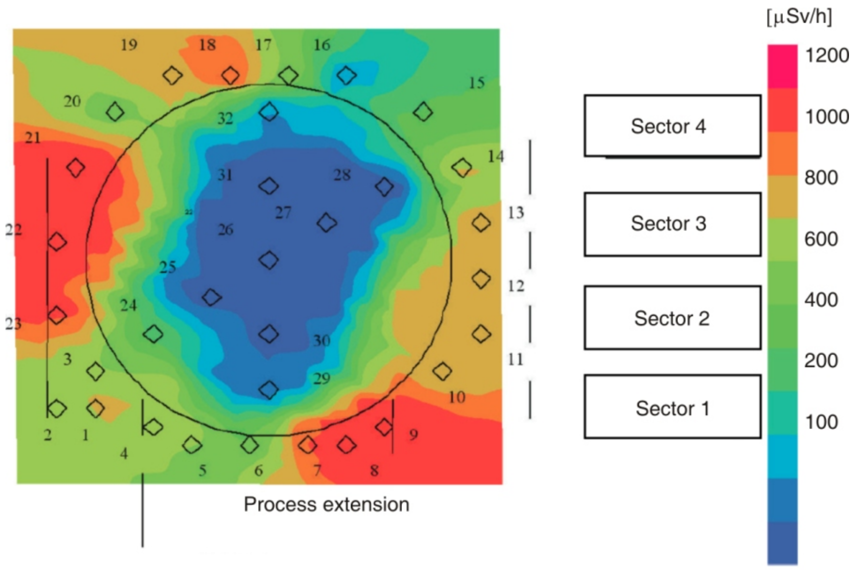

Figure 4. γ-dose rate distribution at 0.10 m above the DSU 3A tank

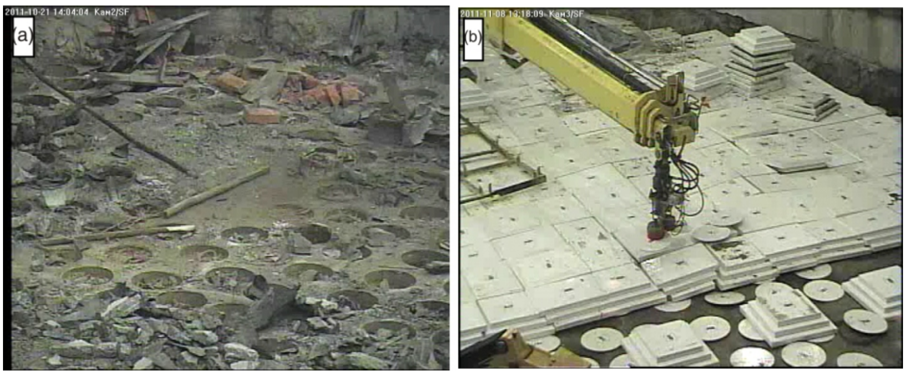

Figure 5. DSU 3A surface
(a) – concrete slabs and blocks removed (20. 11 2011), (b) – HIAB lays the caps and biological shielding segments (20. 12. 2011)

concrete slabs and blocks. All the slabs and containers were loaded onto the trolley and transferred to the SRW module where they were checked with dosimeters, separated into low- and intermediate-level waste, marked, wrapped in polyethylene film, and moved out of the site. They were then loaded onto trucks and transferred to the storage areas.

At all stages of the operations, radiological monitoring using the ASCRO system and the CARTOGAM was carried out. The CARTOGAM was mounted on a wall 3 m above the DSU 3A surface (fig. 3).

After concrete slabs had been removed from Sectors 1 and 2 of the DSU 3A surface, the concrete base with the SFA cells was exposed, figs. 4, 5(a), and the radiation level increased significantly. Then the DSU 3A surface was vacuum cleaned. After that, the HIAB covered the SFA cells with marked metal caps. Above the caps, 15 cm thick puzzle-shaped biological shielding segments weighing 380 kg were laid, fig. 5(b). As a result, the radiation level was reduced.

It would have been easier, technologically speaking, to remove all the concrete slabs and blocks from the entire DSU 3A tank surface and to install the biological shielding segments afterwards. But, in this case, the radiation level would have increased to dangerous values, even for the operators in the control module. Therefore, this was done in two stages: first, the concrete covering of Sectors 1 and 2 was dismantled and the sectors covered with metal shielding segments; afterwards, the same was done for Sectors 3 and 4 (fig. 5).

After that, a new and complete map of the dose rate distribution (like the one in fig. 4) was drawn. It indicated that the background radiation levels had reduced significantly, but that a number of spots with γ-radiation dose rates higher than the target level of 10-12 Sv/h still remained. Therefore, extra biological shielding segments, ~180 kg 1.9 m 1.8 m × 0.05 m steel sheets, ~30 kg ~0.8 m × 1 m × 0.05 m lead sheets, and ~5 kg sacks with 2-3 mm lead shot, were laid above such spots. Following this, another dose rate distribution map was drawn.

We have come to the conclusion that a substantial contribution to the radiation level was coming from outside the DSU 3A tank, in particular, from between the tank with the SFA cells and the outer wall, as well as from the process extension (fig. 3). Therefore, the soil and debris were removed from these places and the highest level spots covered with steel and lead sheets. As a result, the background radiation levels reduced down to the target level of 10-12 Sv/h.

Following the completion of the planned IRE, the concrete walls, machinery and equipment (HIAB, BROKK, trolley and the modules) were dismantled, wrapped in polyethylene film and transported to storage areas. The roof was lowered and installed on the DSU 3A tank wall.

Remote dose rate measurements at the DSU 3A site. The rapid remote (tens of meters) γ-radiation source search and dose rate evaluation at the DSU 3A site employed the CARTOGAM gamma camera with special software, GammaView 4.03, by CANBERRA. The technique that we had developed earlier [1-3] permitted quick γ-radiation source location, even in the presence of other sources.

As a part of the IRE operations at the DSU 3A site, the γ-dose rate acquisition by the CARTOGAM was carried out within the framework of scientific and technological activities defined by the "Development of techniques of remote integral and differential measurements of radiation background and its structure". The objective was to assemble, install, set up and adapt the CARTOGAM gamma camera to the site conditions; take radiation measurements at the DSU 3A in order to conduct the monitoring and to analyze changes in the radiation situation at the site throughout 2011-2012; evaluate relative γ-dose rates from the major sources.

The gamma camera was mounted on the wall at a height of ~3m above the tank surface (fig. 3). The first step in the measurements consisted of producing a visual image (photograph) and an γ-image of objects being examined (exposure time, 5 minutes). Both high and low count rate modes were employed. Then the visual and the γ-images were superimposed. The dose rate was evaluated by variation of certain parameters like segmentation (separation of sources of different γ-intensity), radiation discrimination threshold (0 to 0.9), energy of the standard line for dose rate calculation (in this work, it was ^{137}Cs – 662 keV). The error in dose rate determination was 30%-50% [1]. When the measurements are done from the same gamma camera position and under the same conditions, the obtained data can be compared and qualitative conclusions on the changes in the radiological situation at the DSU 3A be drawn. In the course of our measurements, detector temperature varied between +10 °C and –10 °C. All dose rate measurement results are presented as composite images in the form of distributions by count rates (figs. 6-8). The variation in the discrimination threshold licensed the determination of γ-activity peaks and shapes of the sources.

To evaluate dose rate P_0 at the source, one has to use the formula $P_0 = P R^2$, where P is the dose rate at the gamma camera, and R – the distance between the gamma camera and the source [1]. This evaluation was done in our work. Dose rates obtained by the CARTOGAM were compared with the results of the dosimeter measurements. In the international system of units (SI), the unit of absorbed dose is Gray (Gy), and that of the equivalent dose is Sievert (Sv). Since for ã-radiation in the air the Sv/Gy ratio is ~1, the CARTOGAM data [Gyh^{-1}] can be compared to the dosemeter results [Svh^{-1}] [4].

Results and discussion. The dose rate measurement results at the DSU 3A are presented in figs. 6-8. They show the integral dose rates at the detector for the discrimination thresholds of 0.5 and 0 (in parentheses). The numbers of γ-quanta registered by the detector (counts per second, cps) are given in the upper right corner of each figure. The value in the parentheses shows the total detected dose rate, while the value at the discrimination threshold of 0.5 gives the dose rate at half maximum. The color gradations in the color figures reflect the γ-dose rate gradients not expressed numerically.

Before the start of IRE activities in the initial state of the DSU 3A tank, the background distribution was practically uniform (30 Sv/h ~ 30 Gy/h). In this picture, one can see the HIAB boom end with the grab

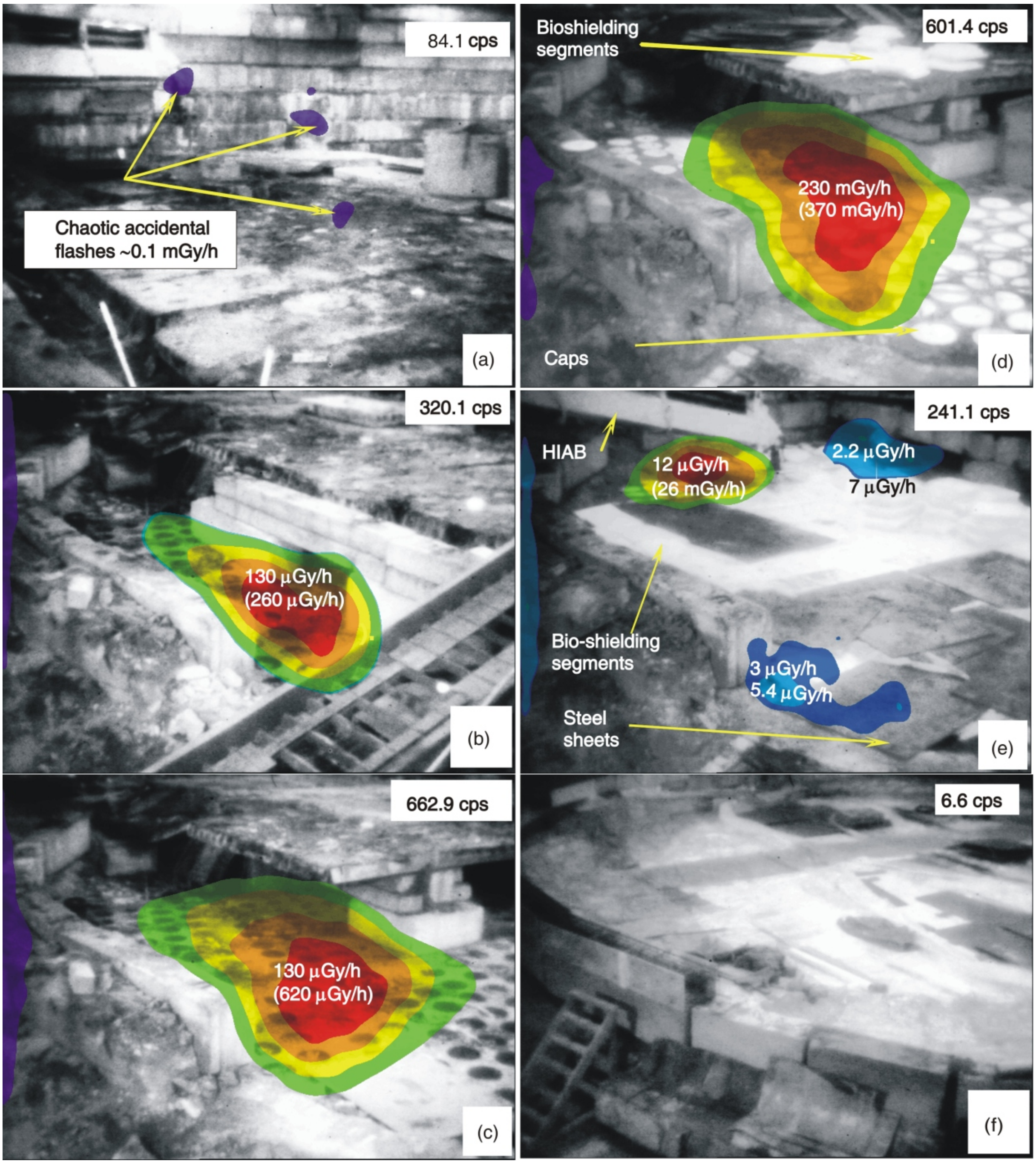

Figure 6. γ-dose rates fom the sources at the DSU 3A surface measured by the CARTOGAM
(a) – June 2011. Initial state, (b) – August 2011. Concrete slabs and blocks partially removed from sector 1, (c) – September 2011. Concrete slabs and blocks removed from sector 1 and 2, (d) – September 2011. Cells of sector 1 and partially of sector 2 covered with caps, (e) – September 2011. Biological shielding segments laid on the surface of sector 1 and 2, (f) – February 2012. Final state. DSU 3A covered by the biological shielding segments. Steel sheets and lead sheet laid over insufficiently shielded spots

in the process of work. According to the formula $P_0 = P\,R^2$, as noted, the dose rates in some spots of the DSU 3A at ~10 m from the gamma camera can be evaluated as ~10 Gy/h, fig. 6(a). Taking into account the mean background of ~30 Gy/h, one can get the total value of ~40 Gy/h for the radiation background. It agrees satisfactorily with data from the radiometric survey of the DSU 3A surface with dosimeters.

Immediate CARTOGAM readings allow instant evaluation of the actual dose rate at the source. It is extremely important, because the ASCRO detectors show only the increase in the overall radiation level and cannot locate the source in order to secure it by screening with lead or steel sheets using the HIAB.

After the removal of a part of the concrete slabs and girders from Sector 1, an γ-spot of 1838.7

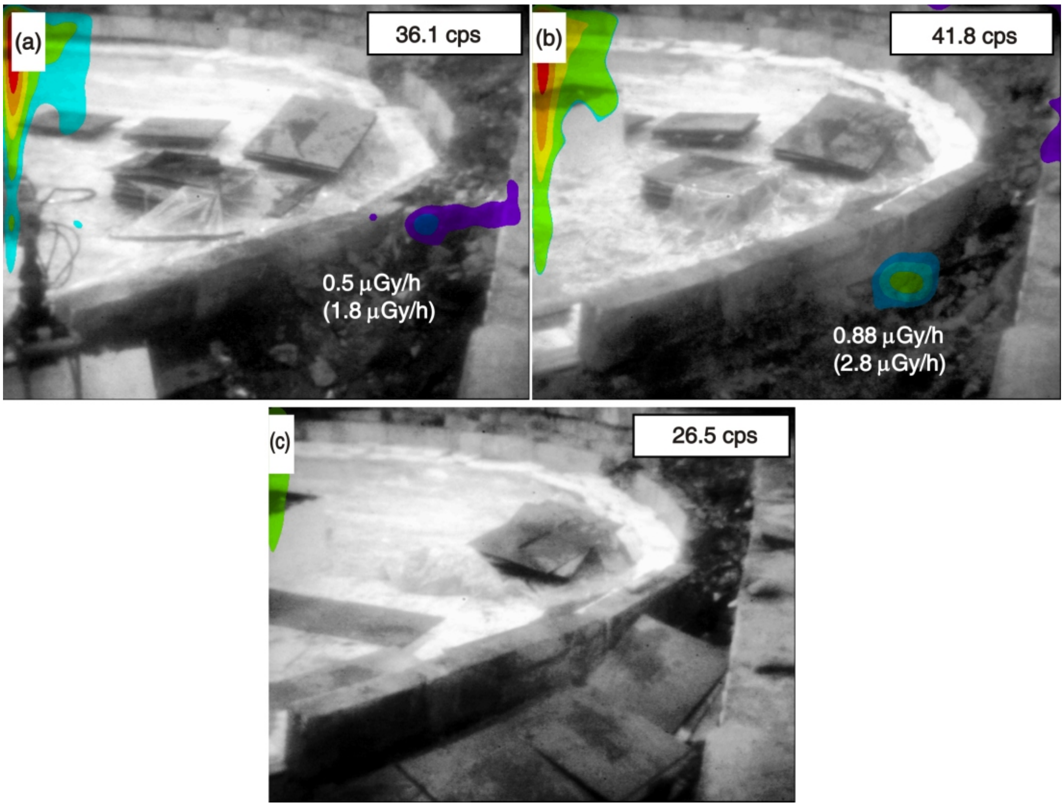

Figure 7. **γ-dose rates from the source at the side of the DSU 3A tank measured by the CARTOGAM (2011)**
(a) – the γ-radiation source detected, (b) – BROKK partially removed the soil, (c) – the γ-radiation source covered by the steel sheets

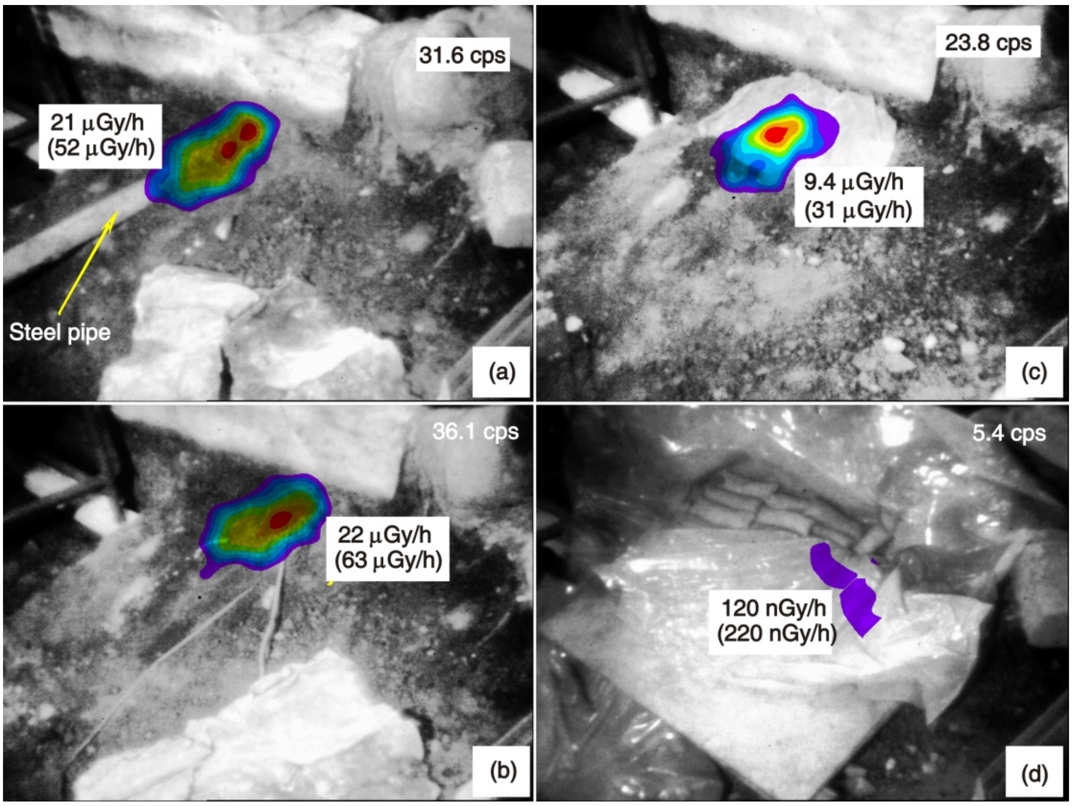

Figure 8. **An unknown γ-source detected at the entrance to the DSU 3A tank by the CARTOGAM**
(a) – the γ-radiation source detected, (b) – the steel pipe removed, (c) – the hole from the pipe screened with sacks of splintered iron, (d) – the hole covered by a lead sheet and 3 steel sheets

(4650.9) Gy/h, fig. 6(b), appeared at 10.4 m from the CARTOGAM. After all the concrete slabs and girders were removed from Sectors 3 and 4 and the biological shielding segments had been laid on Sectors 1 and 2, an intense γ-spot of 2717 (4576) Gy/h, fig. 6(c), appeared at 14 m from the CARTOGAM.

There were many γ-sources of the different dose rates at the DSU 3A site. The background radiation level at the site reduced after the shielding of the most intense ones, which allowed locating the next most intense γ-sources. Thus, γ-sources at 4.2 m, 7.6 m, and 9 m from the CARTOGAM, with the EDR of 65.3 (127.0), 57.8 (300.4), and 40.5 (137.7) Gy/h, fig. 6(d), respectively, were discovered after the biological shielding segments had been laid over the entire DSU 3A tank. After the extra biological shielding segments had been laid, new less intense sources were discovered, fig. 6(e). After further shielding, these sources vanished fig. 6(f).

The value of the total number of detected γ-quanta is also a qualitative characteristic of the radiological environment at the DSU 3A (fig. 6). Indeed, this value grows as new γ-sources appear and the value of 6.6 cps relates to the general background fig. 6(f).

Another example of CARTOGAM application was the monitoring of the dynamics of the γ-dose rate of the source discovered at the side surface of the DSU 3A tank (fig. 7). The distance to the source was about R = 8.1 m and its EDR at the detector was (1.8) Gy/h fig. 7(a). The dose rates (Gy/h) at 0.5 and 0 discrimination thresholds (in parentheses) are given in the picture. The numbers of γ-quanta registered by the detector (counts per second, cps) are given in the upper right corners. After the BROKK had removed a part of the soil, the dose rate increased up to 0.88 (2.8) Gy/h, fig. 7(b). Upon screening the source with steel sheets, the γ-spot disappeared, fig. 7(c). The numbers of the detected γ-quanta also reduced as expected. Taking into account the distance to the spot, the dose rates at 1 m from the spot can be found to be as follows: 32.8 (118.1) Gy/h for 0.5 (1.8) Gy/h at the detector, fig. 7(a), and 57.7 (183.7) Gy/h for 0.88 (2.8) Gy/h at the detector, fig. 7(b). Despite the fact that the spot had disappeared, the detector still counted the γ-pulses, fig. 7(c), at 26.5 cps, which could be attributed to the background. With this in mind, one can evaluate the background. Indeed, 36.1 cps – 26.5 cps = 9.6 cps, which corresponds to 1.8 Gy/h, fig. 7(a, c). Where from, 1 cps ~0.19 Gy/h. In the case of fig. 7(b), it was 0.18 Gy/h. So, one can evaluate the background at the CARTOGAM as 0.185 Gy/h 26.5 cps ~4.9 Gy/h. Since the gamma camera was located at 3 m above the DSU 3A tank surface (fig. 3), the background at 1 m from the surface can be evaluated as 4.9 Gy/h × 9 m^2 ~44.1 Gy/h, which agrees with the ASCRO detectors data for this situation.

Also, the gamma camera detected an intense γ-radiation source in front of the DSU 3A tank, fig. 8(a). As a rough approximation, this source can be treated as a point source. The distance to the γ-spot was R ~4 m. The dose rate and the number of γ-quanta detected by the CARTOGAM were 21 (52) Gy/h and 31.6 cps, fig. 8(a). After the BROKK removed the pipe, the CARTOGAM readings increased to 22 (63) Gy/h and 36.1 cps, fig. 8(b). After the source was screened with sacks of splintered iron and a lead sheet, the readings reduced to 9.4 (31) Gy/h and 23.8 cps, fig. 8(c). After the γ-source was covered by a lead sheet and 3 steel sheets, the readings further reduced to 0.12 (0.22) Gy/h and 5.4 cps, fig. 8(d). Taking into account the distance to the source, the dose rates at 1 meter from the source could be found as 336 (832) Gy/h for 21 (52) Gy/h at the detector, fig. 8(a), 150.4 (496) Gy/h for 9.4 (31) Gy/h at the detector, fig. 8(b), 352 (1008) Gy/h for 22 (63) Gy/h at the detector, fig. 8(c), and 1.92 (3.52) Gy/h for 0.12 (0.22) Gy/h at the detector, fig. 8(d). In this case, the value of 5.4 cps can be attributed to the background at the CARTOGAM location point. With this in mind, one can evaluate the background as 36.1 cps – 31.6 cps = 4.5 cps, which corresponds to 63 – 52 = 11 Gy/h, fig. 8(a, c), wherefrom 1 cps corresponds to ~2.44 Gy/h. In the second case, this value is ~2.69 Gy/h, fig. 8(a, c), and in the third case it is ~2.69 Gy/h. On average, 1 cps corresponds to ~2.73 Gy/h. Finally, one can evaluate the background around this specific γ-spot as ~2.73 5.4 = = 14.7 Gy/h, which reasonably agrees with the ASCRO data.

The γ-dose rate at the DSU 3A site depends on many factors that were not taken into account in this work. In the first stage of the IRE operations we made an attempt to draw a correlation between the CARTOGAM and dosimetry data. Unfortunately, a reliable correlation between these data has not been reached yet. This requires some model laboratory experiments. Such a correlation is only possible for point sources. The present work has made only a qualitative correlation between the CARTOGAM and dosimetry data at the level of evaluation and comparison.

CONCLUSIONS

The remotely controlled replacement of the concrete covering of the spent fuel dry storage unit 3A with a new iron horizontal biological shielding was carried out during operations aimed at the improvement of the radiological environment at the NWC "SevRAO" – Branch of FSUE "RosRAO", Andreeva Bay, Murmansk Region. Video control systems, a BROKK robotic manipulator, HIAB manipulator crane, gamma detectors of the ASCRO radiation monitoring system and a CARTOGAM gamma camera were employed in this work. The CARTOGAM gamma camera was used in all stages of the operations for the remote search of the most dangerous gamma radiation sources and the evaluation of their dose rates.

Gamma detectors of the ASCRO radiation monitoring system were located at several spots of the DSU 3A in order to control the radiation situation. This made a qualitative comparison of the ASCRO and CARTOGAM data possible. The data agree and describe the radiological situation at the DSU 3A site quite reasonably. The use of the ASCRO and CARTOGAM made the avoidance of unauthorized exposure of personnel involved in the operations at the DSU 3A possible. A comparative quantitative and qualitative analysis of the efficiency of the work done was performed. Further planning of SNF removal operations was also provided for.

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ДАЉИНСКА ПОТРАГА ЗА ИЗВОРИМА ГАМА ЗРАЧЕЊА И ОДРЕЂИВАЊЕ ЈАЧИНА ДОЗА ТОКОМ УНАПРЕЂЕЊА РАДИОЛОШКОГ ОКРУЖЕЊА У ЈЕДИНИЦИ ЗА СУВОГ СКЛАДИШТА У ЗАЛИВУ АНДРЕЈЕВА

У циљу унапређења радиолошке средине извршена је даљински управљана замена бетонског прекривача складишне јединице 3А ислуженог горива новом, гвозденом и хоризонталном, билошком заштитом. Складиште се налази у Заливу Андрејева, у Мурманској области. Коришћени су видео системи, BROKK роботски манипулатор, HIAB кран, гама детектори из ASCRO система за мониторинг зрачења и CARTOGAM гама камера. CARTOGAM гама камера коришћена је у свим фазама посла, укључујући високе нивое зрачења, за даљинско лоцирање најопаснијих извора гама зрачења и процену њихових јачина доза. ASCRO гама детектори били су постављени на неколико позиција око складишне јединице 3А за надгледање нивоа радијације. Коришћени ASCRO детектори и CARTOGAM камаре омогућили су да се избегне неовлашћено излагање зрачењу особља које је учествовало у раду.

Кључне речи: унапређење радиолошког окружења, суво складиште радиоактивног материјала, гама камера