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Research Article

Ensuring radiation safety during temporary storage of solidified radioactive waste in light hangar-type facilities*

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Abstract

Expensive permanent storage facilities with massive engineered structures are used traditionally to ensure safe temporary storage of solidified radioactive waste at the NPP sites. Such approach is dictated by the need to comply with the regulatory requirements for limiting the gamma background in the area adjacent to the storage facility.

The costs involved in temporary storage of solidified RW can be optimized by using light hangar-type storage facilities. At the same time, the safety of storage, including radiation protection of the personnel, the public and the environment, is undoubtedly ensured through the use of special organizational and engineering solutions.

The Novovoronezh NPP, a branch of JSC Concern Rosenergoatom, operates successfully light hangar-type facilities for temporary storage of solidified RW classified as medium-level waste in accordance with OSPORB-99/2009. In the process of operation, a methodology and a method for conditioning and temporary storage of solidified RW were developed to ensure the RW removal for final disposal with no extra process operations and unreasonable costs.

A methodology has been developed to assess the radiation situation around storage facilities during temporary storage of RW, as well as a software package for predicting the radiation situation when deciding on the arrangement of the storage facility's peripheral rows.

Keywords

Radioactive waste, temporary storage, hangar-type storage facilities, radiation package, optimization of radiation protection

Introduction

Permanent storage facilities with massive engineered structures are used traditionally to ensure safe temporary storage of solidified radioactive waste (RW) at the NPP sites. Such approach is dictated by the need to comply with the regulatory requirements for limiting the gamma background in the area adjoining the temporary storage facility.

With regard for the fact that the global volume of low- and medium-level waste to be conditioned exceeds 6 000 thsd. m^3 (Sorokin and Pavlov 2018, Sobolev 2019), the temporary storage costs for the above waste are expected to amount to billions of dollars.

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The optimization of costs during temporary storage of solidified RW can be achieved through the use of light storage facilities of a hangar type. And the safety of storage, including radiation protection of the personnel, the public and the environment, is undoubtedly ensured through specific organizational and engineering solutions.

Since the mid-2000s, a number of casks have been developed in the Russian Federation to ensure safe conditioning of radioactive waste fully in compliance with regulatory requirements (Sorokin et al. 2013, Radchenko et al. 2017, Sorokin 2019).

Reinforced-concrete casks of the NZK-150-1,5P type have been used extensively in the Russian nuclear industry to condition different types of radioactive waste (Gataullin et al. 2011). Due to high density, apart from isolation of the radioactive content from the environment, these casks can be looked upon as the biological shielding component for protection against the effects of gamma fields during handling operations and in the process of temporary storage at the facility site (Shvedov et al. 2008, Gataullin et al. 2012).

Since 2008, light storage facilities of a hangar type have been used successively by the Novovoronezh NPP, a branch of JSC Concern Rosenergoatom, for the interim storage of solidified RW classified, in accordance with OSPORB-99/2009, as medium-level waste. A methodology has been developed and tested in the process of service for conditioning and interim storage of solidified RW, which results from the operation of the Novovoronezh NPP units, to ensure the minimization of costs, the safety of temporary storage, and the RW removal for final disposal without extra process operations (Nalivayko and Rosnovsky 2010).

The following practical tasks have been solved as part of the undertaken activities:

- a methodology and a method for the solidified RW conditioning and temporary storage have been developed to ensure the RW removal for final disposal while avoiding extra process operations and unreasonable costs;
- a methodology has been developed to assess the radiological situation around storage facilities during temporary storage of RW;
- procedures have been developed to measure the RW activity and radionuclide composition using analytical methods without cask opening and sampling;
- a dedicated software package has been developed to calculate the optimal loading of the temporary storage facility for casks so that to ensure the minimization of the radiation fields in the adjoining area.

The results obtained in the process of investigations make it possible to arrange for the interim storage of solidified waste at the NPP site using NZK casks and unheated light storage facilities of a hangar type. The developed models and procedures allow assessing the in-situ radiological situation.

As part of the developed conditioning technology, primary waste in the form of the evaporation-to-the-maximum-salt concentration plant's saline product is placed into steel drums which are packed into prismatic concrete casks of the NZK-150-1,5P type with the free space inside of these being filled with a substance that attenuates ionizing radiation (sand, concrete, etc.) (Rosnovsky and Bulka 2014).

For temporary storage, pending the shipment to the national operator, concrete casks are accommodated on a concreted platform above the ground level. At the top, the storage facility is covered with a light-weight steel structure that protects the contents from atmospheric phenomena, while providing little radiological protection.

The protection against ionizing radiation is achieved through dedicated procedures with waste placed inside a secondary package and through a particular arrangement of such packages within the storage facility.

Fig. 1 shows an example of the asymmetrical secondary package loading. Due to the varying thickness of the absorbing substance layer, provided primary casks with close radiation parameters are arranged as shown in Fig. 1, we obtain a diagram of radiation on the secondary package's outer walls (Fig. 2).

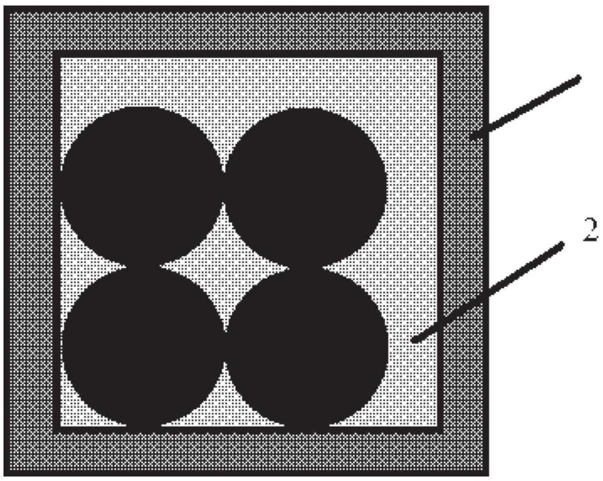

Figure 1. An example of the asymmetrical NZK-150-1,5P cask (secondary package) loading pattern: 1 – concrete cask wall, 2 – filler (extra biological shielding).

An analysis of the pattern shows that the equivalent dose rate differs greatly at different points of the concrete casks. Therefore, one can control the radiological safety parameters through a particular arrangement of outer casks in the storage facility. Fig. 3 shows an example of the layout.

To improve the efficiency of this approach, mathematical tools and software have been developed to calculate the optimal loading for the storage facility to ensure the smallest possible radiation impacts on the environment (Sorokin et al. 2013).

Procedures were adopted during the commissioning of hangar-type storage facilities for pilot operation to find

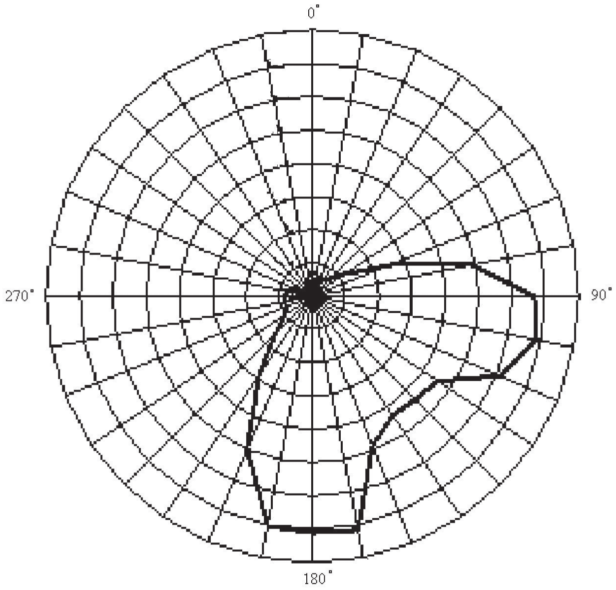

Figure 2. Directional pattern of gamma radiation from a filled NZK-150-1,5P cask.

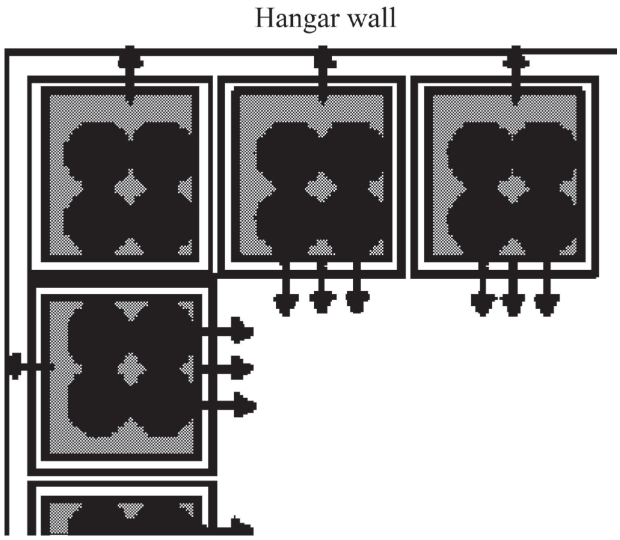

Figure 3. Diagram of the external cask orientation in the storage facility's peripheral rows.

out if it is possible to fill these based on determining the allowable equivalent dose rate values.

The following values were used as the reference maximum allowable levels during operation of hangar-type storage facilities based on radiation safety rules and internal regulations:

- 6.0 μSv/h, in the controlled access area;
- 1.2 μSv/h, at the buffer area boundary.

It is taken into account in assessing the radiological situation that, due to a low activity of the waste in storage, the casks in the outer row are the only contributor to radiation beyond the storage facility.

No radiation from casks in the inner rows penetrates the outer cask row in practically significant amounts. Therefore, the outer row of casks isolates the ionizing radiation from the casks in the storage facility's inner rows.

To calculate the values of the equivalent dose rate from the outer casks within and beyond the specialized facility area, we shall present the outer cask row as a portion of the spherical radiator surface with a certain radius, R_{equ} (Fig. 4). It is evident that the highest value of the equivalent dose rate is observed along the perpendicular that originates from the center of the hangar face (the radiation at point 1 in the figure will be higher than that at points 2 and 3).

The dose rate at the given distance from the wall center is expressed by the dependence

$$D = A / (x + R_{equ})^2 + D_b, \quad (1)$$

where D is the dose rate at the given point from the monitored hangar wall, μSv/h; R_{equ} is the equivalent radius of the spherical source computed experimentally; A is the constant that characterizes the power of the radiation source as reduced to its center (found experimentally); x is the distance from the hangar wall to the point under consideration, m; and D_b is the background value of the dose rate at the measurement point, μSv/h.

Calculated constants A and R_{equ} were determined based on experimental data as the result of which the expression has taken the following form

$$D = [3.6 \times D_0 / (x + 20.3)^2 + 0.13] \pm 7\% \; [\mu Sv/h], \quad (2)$$

where $A = 3.6 \times D_0$; D_0 is the average background dose rate on the hangar wall surface as shown by the radiation monitoring data; and $D_b = 0.13$ μSv/h.

For the equivalent dose rate on the outer surface of the specialized facility enclosure not to exceed a value of 1.0 μSv/h, in accordance with D_b, the average dose rate from the cask sides facing the enclosure must not exceed 4.5 μSv/h. For the equivalent dose rate within the specialized facility not to exceed 6.0 μSv/h, the average dose rate from the cask sides facing the hangar wall must not exceed 10.8 μSv/h.

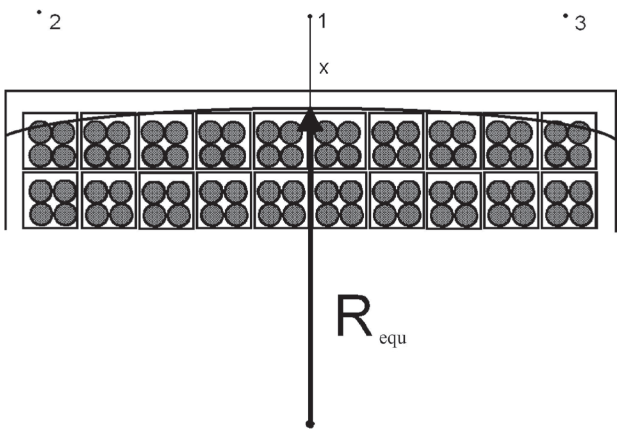

Figure 4. A model to assess the radiological situation around a hangar-type storage facility.

As a result of the activities in 2014, a patent of invention has been registered for JSC Concern Rosenergoatom (Povarov et al. 2012).

In practice, to decide on if it is possible to accommodate a cask in the hangar's peripheral row, a more suitable criterion is often that based on the value of the saline product activity rather than on the gamma dose rate value. To reduce the earlier developed criteria to the permissible value of the waste activity in the peripheral row, we shall use a model of a spherical source with the activity distributed over the sphere surface (Fig. 5).

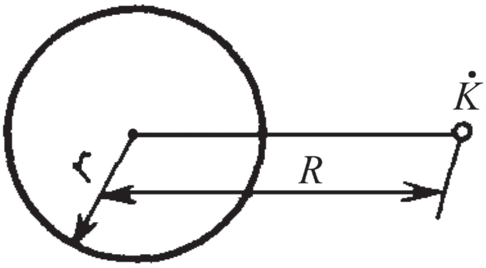

Figure 5. A model to calculate the permissible activity of radioactive waste in NZK-150-1,5P casks in the hangar's peripheral rows.

For the above source, the surface activity value relates to the dose rate as

$$K = 2\pi A_s \Gamma_\delta r \times \ln[(R + r) / (R - r)] / R, \quad (3)$$

whence

$$A_s = KR / \{2\pi \Gamma_\delta r \times \ln[(R + r) / (R - r)]\}. \quad (4)$$

For the cask layer facing the specialized facility enclosure, $R = r + 17 = 37.3$ m, and permissible $K = 1$ μSv/h.

For the cask layers facing the specialized facility, $R = r + 1 = 22.3$ m, and permissible $K = 6$ μSv/h.

Then, from relation (4), we have the following specific surface activity values per the cask surface area unit for the row facing

- the enclosure: $A_s = 2.22 \times 10^6$ μm^2;
- the potential contamination area: $A_s = 3.16 \times 10^6$ Bq/m^2.

With the cask face area being equal to 2.27 m^2, we have the following average permissible activity of one unit for the row facing

- the specialized facility enclosure: $A_{nzk} = 5.04 \times 10^6$ Bq;
- the potential contamination area: $A_{nzk} = 7.17 \times 10^6$ Bq.

The calculations were conducted without taking into account the attenuation of the gamma radiation in the outer cask wall, and with no extra attenuating sand layer between the outer and inner cask walls. The total thickness of the protective layer is about 40 mm while the average density is 2 g/cm^3. The coefficient of the above screen attenuating the gamma radiation with the energy $E = 1$ MeV is equal to about 30.

Therefore, the final value of the average permissible activity for one outer cask is as follows for the row facing

- the enclosure: $A_{nzk} = 1.512 \times 10^8$ Bq;
- he potential contamination area: $A_{nzk} = 2.151 \times 10^8$ Bq.

To accommodate a new batch of classified casks, a decision is made based on the following rules as to the cask positioning.

- Low-level casks are accommodated in the storage facility's peripheral rows since the radiation dose from this class of casks is as small as possible.
- Casks with the maximum activity are accommodated in the central part of the storage facility. It is important that a rule is observed concerning the orientation of the wall with the radiation hazard sign applied to it – the respective cask shall be positioned with its wall with the minimum dose rate facing the peripheral row since positioning the cask otherwise will lead to increased radiation effects on the storage facility walls.
- Medium-level casks are placed between the peripheral rows and the central zone with extra-level casks.

A more accurate calculation of the radiation fields around the storage facility requires a procedure based on presenting each cylindrical cask with the EMSC plant's saline product as a standalone radiator using the field superposition principle and Monte Carlo method.

Software has been developed based on the obtained results in the form of specialized modules and in the form of a separate application for the hangar-type facility control.

Fig. 6 shows the result of operating a software module that determines the distribution of the equivalent dose rate from the outer package cask filled with waste with particular characteristics. As can be seen from the figure, the obtained results copy the diagram in Fig. 2 the data for which were obtained experimentally.

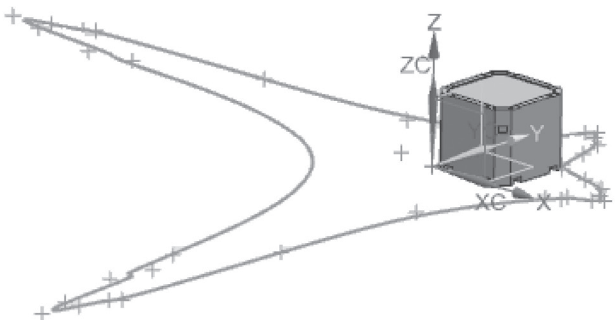

Figure 6. Software-predicted distribution of the gamma dose rate from a filled NZK-150-1,5P cask.

It is permitted to perform calculations by hand, as well as to develop specialized software based on the developed

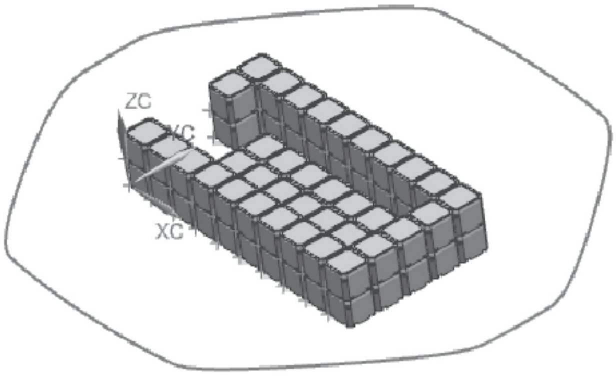

Figure 7. The result of using the model: a graphic representation of the region with the given gamma dose rate.

model. Fig. 7 shows the simulation result: a curve has been obtained that confines the region with the sanitary standards for equivalent dose rates being exceeded.

The simulation results were compared with the experimental data. The resultant difference was not more than 20%. The major reason for the discrepancy is expressed by the low accuracy of the input data that describes the contents of the storage facility.

Testing has shown the software to be satisfactorily serviceable and fit for being put into pilot operation at the Novovoronezh NPP. It was demonstrated in the course of testing that the research works considered in the paper had been practically confirmed [Rosnovsky et al. 2014, Parinov and Rosnovsky 2016, Rosnovsky and Parinov 2017).

The software for assessing the radiation situation during temporary storage of NZK casks in hangar-type storage facilities has been successfully integrated with the Novovoronezh NPP's Unified Automated Information and Analytical System for Accounting and Control of Radioactive Substances and Radioactive Waste (Bulka and Rosnovsky 2014).

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