DOI: 10.25283/2587-9707-2019-2-6-17

UDC 621.039.009

OPTIMIZATION THE CONTAMINATED MATERIALS AND RADIOACTIVE WASTE MANAGEMENT WITHIN INDUSTRIAL SITES

Vedernikova M. V., Ivanov A. Yu., Linge I. I., Samoylov A. A.

Nuclear Safety Institute of the Russia Academy of Sciences, Moscow, Russian Federation

Article received on May 17, 2019

The paper discusses the ways in which the contaminated materials and low-level short-lived radioactive waste (LL-SL RW) management can be optimized. It considers different options allowing the reuse of contaminated materials and LL-SL RW during the remediation of nuclear legacy sites, including the conservation of liquid RW storage facilities, construction of engineered safety barriers in disposal facilities for non-retrievable RW, and decommissioning of nuclear- and radiation- hazardous facilities. Special attention is given to the issues associated with maintaining the adequate safety level of contaminated materials and waste management options while reducing relevant management costs.

Keywords: *optimization, low-level short-lived radioactive waste, contaminated materials, non-retrievable radioactive waste, disposal of radioactive waste, decommissioning, radiation safety.*

Introduction

Radioactive waste (RW) management process flow charts have been originally arranged according to a flowline principle: “from the generation source to the storage facility”. Subsequently, with the development of technologies, facilities enabling to process waste from several “sources” started to appear in RW management flow charts, including segregation, compaction, incineration and other complexes. Introduction of disposal requirements for RW conditioned to comply with relevant acceptance criteria for disposal, is likely to accelerate this process, also opening the door to arranging for larger scale RW processing using the capacities of specialized enterprises. Unfortunately, for the time being, “from the generation source to the storage facility” flow chart providing for no optimization as regards RW conditioning in accordance with waste acceptance criteria, is usually developed and has been already applied to new and incomparably mightier sources of RW generation such as nuclear decommissioning activities. Results of the initial RW registration in part of assigning the waste to the non-retrievable RW category seem to be quite regrettable. Decisions on categorizing RW storage facilities as facilities holding non-retrievable RW or non-retrievable RW conservation facilities were postponed for many sites either due to the regulatory framework imperfections [1] or relevant will of operating organizations. In a number of cases, even more radical unreasonable decisions were made suggesting that radioactive waste was assigned to retrievable RW category. A common feature of the setting described above is the failure to follow the existing and prospective operating mode of an industrial nuclear site. Whereas such mode suggests that the radiation safety of personnel and the environment should be ensured to the fullest extent possible by using relevant solutions not involving collection and isolation of all radioactively contaminated materials. This article discusses the possibilities and prospects allowing more efficient arrangement of RW management activities within the boundaries of one or more industrial nuclear sites.

The requirement on increasing the efficiency of RW management is laid down in the provisions of the Law [2], along with the cost-effective arrangements for implementing waste disposal. At present time, certain excesses can be already observed in the practical implementation of these requirements suggesting that the implemented radiation protection measures go beyond of reasonably sufficient ones stated internationally in ICRP [3] and IAEA publications [4]. Manifestations of this kind of excesses have already been generally analyzed in [5, 6]. This is also the case for the data on low RW activities being emplaced into repositories [7] and already put into RW disposal facilities (RWDF) [8]. This paper is manly focused on reduction of waste amounts and activity subject to disposal at the sites run by the National operator as a way allowing to increase the efficiency. In a number of cases, to implement some of the abovementioned opportunities, it will be necessary to adjust certain regulatory provisions. For such cases, rationale behind such adjustment was given. But in the first place it seems reasonable to discuss the general concept of RW disposal in centralized disposal facilities (run by the National Operator).

As regards the safe RW management, the rationale behind relevant reasonable sufficiency requires multicomponent argumentation. This applies in particular to the most hazardous category of waste, namely, long-lived high-level waste. Many countries have chosen the option suggesting direct disposal of spent nuclear fuel, assuming it to be sufficient enough to ensure the safety, while a number of countries are implementing SNF reprocessing strategies. Preamble to the Joint Convention [9] clearly states (Preamble, section vii) that recognition of SNF as a valuable resource that may be reprocessed is seen as a decisive factor in RW disposal strategy. If SNF is recognized as a valuable resource, various strategy options can be also implemented, including those suggesting various types of reprocessing, fuel and reactor technologies, REMIX fuel technologies [10], etc. At the same time, economic efficiency is set as the main priority in the overwhelming majority of cases with powerful tools being developed and applied [11]. And only in particular cases, when the emphasis is placed on minor actinides burning, the feasibility of a technological option is demonstrated based on disposal safety considerations [12]. In general, it can be argued that radiation safety considerations, especially regarding the final life cycle stages (decommissioning and RW disposal) played quite a minor role in the feasibility evaluation of fuel cycles and nuclear technologies [13].

Actually, the same considerations are stated in the provision of a key document on radiation protection of population [3]. Relevant quote can be found in ICRP publication 103: *“The Commission recommends that, when activities involving an increased or decreased level of radiation exposure, or a risk of potential exposure, are being considered, the expected change in radiation detriment should be explicitly included in the decision-making process. The consequences to be considered are not confined to those associated with the radiation — they include other risks and the costs and benefits of the activity. Sometimes, the radiation detriment will be a small part of the total. Justification thus goes far beyond the scope of radiological protection. It is for these reasons that the Commission only recommends that justification require that the net benefit be positive. To search for the best of all the available alternatives is a task beyond the responsibility of radiological protection authorities.”*

Following the gradual shift with more focus placed on less hazardous radioactive waste classes (low-level, short-lived), the principles of radiation protection, namely justification and optimization, should play an increasingly important role in choosing relevant waste management options. Ultimately, the latter suggests a decrease in the number of safety barriers providing waste isolation with simultaneous enhancement of safety case quality. Practical experience of such countries as France, Sweden and many others demonstrates the positive effect offered by this approach [14].

Anticipating possible criticism of the proposed approaches, it can be stated that the justified use of radioactively contaminated materials within the boundaries of an industrial site can be considered as a testimony of rationality, soundness and culture. Conversely, options suggesting that expensive packages containing scanty activity are subject to disposal for hundreds of years reveal mismanagement approach, which may be accompanied by more stringent formulations. To illustrate the above, a comparison of the main conditions suggested for the disposal of specific packages containing similar radioactive waste in our country and abroad is presented below (table 1).

Table 1. Key disposal parameters for low-level RW

Characteristics		Sweden	France	Russia
Type of disposal structure		Mound type at NPP site	Centralized trench type	Permanent structure
Package type		compacted plastic bags, drums, transport freight containers	plastic bags, drums, large equipment, etc.	NZK-RADON, KMZ, KRAD 3.0, KRAD 1.36
Cost of conventional packaging, thousand rubles/m^3		0.5	0.5◆	More than 50⅄
Disposal cost, thousand rubles/m^3		15–40	15	55 (class 4)
Dose rate at the surface of RW package, mSv/h		Less than 0.5	-	0.1
Maximum specific activity in the package✦, Bq/g	α	<0.1 % of the total activity	<10^2	<10^2
	β	<$3\cdot10^2$ (radionuclides with a half-life of over 5 years)		<10^3
Average specific activity in the package✦, Bq/g	α	6.8–49.5 [14]		~15★
	β			$2.5\cdot10^2$✶

Note:
◆In Russia, the cost of big-bag "packaging" does not exceed 0.5 thousand rubles/pcs. VAT included
⅄The cost of the container ranges from 72 thousand rubles/pcs. (useful capacity of KRAD 1.36 — 1.4 m^3 of radioactive waste, package volume 1.6 m^3) + 55 thousand rubles/m^3 (disposal tariff for RW class 4)
✦Assessment based on actual disposal practice
★The average value for the radioactive waste retrieved from the facilities of the Grozny branch of the Federal State Unitary Enterprise "RosRAO"
✶Data of FSUE Atomflot

It is worth noting that various approaches can be applied to minimize RW amounts subject to disposal. For example, for accumulated low-level short-lived RW, pre-processing segregation seems to be quite effective which is due to rather long storage times and insufficient attention paid to the procedure allowing to categorize waste as radioactive during its generation with no financial incentive being in place providing for waste amount minimization.

This article considers an approach aimed at recycling the contaminated materials. It's argued that such opportunities may turn to be extremely ample. For example, slightly contaminated dismantled building structures may be used in the construction of drainage layers or as secondary crushed stone in the concrete production and applied in new nuclear facilities construction. Also, radioactively contaminated materials can be used to build roads under various conditions (within the boundaries of settlements and beyond, depending on their specific activity [15]).

A more detailed discussion of other options involving the use of contaminated materials in nuclear decommissioning activities is presented below. Relevant optimization opportunities have been evaluated for three types of facilities considered in terms of contaminated material recycling (surface reservoirs for liquid radioactive waste (LRW) storage, near-surface storage facilities for solid RW, including near-surface disposal facilities, and facilities under decommissioning). Considered as source materials were both radioactively contaminated materials and those already categorized as radioactive waste.

Near-surface LRW storage reservoirs

A total of 17 facilities of this type were operated in the territory of the Russian Federation (FSUE PA Mayak, JSC SCC, FSUE MCC) containing a total of over 420 mln m^3 of waste (table 2). Regarding two of these, decisions were made and relevant activities were started to retrieve the waste (facilities of FSUE MCC holding over 29,000 m^3 of waste). Water surface capping activities have been completed or started at seven reservoirs (B-2, B-1, B-25, sludge storage facility at JSC SCC, V-9, V-17 at FSUE "PA Mayak", 354 at FSUE MCC). In the future, water area and reservoirs V-3, V-4 of FSUE "PA Mayak", 354a at FSUE "MCC" and others will be capped. It should be noted that according to the TCR Strategic Master Plan [16] the water area of the largest reservoirs (V-10, V-11) is not going to be capped.

Data presented in table 2 demonstrates that all the cases suggesting water area capping deal with moving large (V-17, PKh-1 and PKh-2, etc.) and very large amounts (V-3, V-4) of material required to build the screen covers.

Reservoir B-9 was the first industrial reservoir regarding which relevant solutions for capping its water area were proposed. Due to many reasons considered in [18], purpose designed hollow blocks PB-1 and rocky soils were used for capping. In 2005, a permit was given allowing to use purpose designed packing kits of VT, ZhT type to

Table 2. Main characteristics of near-surface LRW storage reservoirs [17]

	FSUE PA Mayak	TCR	JSC Siberian Chemical Combine				FSUE MCC
Characteristic	V-17	V-3,4	B-1	B-25	PKh- 1,2	VKh-3, 4	354a
Year of construction	1949	1952	1961	1962	1961	1958	1966
Surface area, km^2	0.13	2.05	0.08	0.01	0.056	2.71	0.066
Volume, mln m^3	0.27	4.96	0.08	0.0043	0.174	3.63	0.76
Main radionuclides essential in terms of the accumulated activity	^{137}Cs, ^{90}Sr	^{137}Cs, ^{90}Sr, ^{239}Pu	^{137}Cs, ^{90}Sr, ^{239}Pu	^{239}Pu, ^{241}Am	^{137}Cs, ^{90}Sr	^{238}U, ^{235}U, ^{137}Cs, ^{90}Sr	^{137}Cs

perform capping. Since 1993, staged efforts were implemented to construct 4 sections of the landfill designed to accommodate solid very low-level and low-level radioactive waste (activities were performed in 4 stages: first stage — 1993—1996, second stage — 1997—2009, third stage — 2009—2013): it covered part of the capped water area of the shutdown V-9 reservoir. The waste being packed into primary packaging was placed in bulk. After closure, the sections were covered with a protective soil layer (stony and loamy) with a thickness of 0.5—1 m at the first stage of closure, a 1 m thick layer with an interlayer composed of crushed stone having a thickness of 0.2 to 0.3 m was placed at the second stage. This method of reservoir closure was selected based on many factors, including the need of constructing a covering safety barrier, taking into account the optimization principle when placing newly generated solid radioactive waste. In addition, preliminary safety evaluations considering the option of SRW final disposal in a landfill were performed involving relevant calculations enabling to assess the migration of the main radionuclides. The calculations showed that the landfill operation both at present time and in the future will produce no significant impact on the open hydrographic network [19].

The general practice applied with respect to other water bodies (B-2, B-1, B-25, facility 354) provided mainly for the use of clean materials. The use of contaminated materials having either a potential stabilizing effect on the accumulated waste or materials potentially not being able to produce any significant negative effect on waste were not investigated in detail, although relevant ideas and intentions were considered by a number of organizations.

The unacceptability of the existing situation suggesting no direct indications and no opportunities for using the potential of placing additional volumes of radioactive waste and other contaminated materials both under operation and conservation of facilities holding non-retrievable radioactive waste was indicated in [20]. Currently, some improvement was achieved due to the enactment of NP-103-17 [21]. According to its provisions, facilities holding non-retrievable RW are allowed to accept RW generated during:

- operation or nuclear decommissioning providing for the generation of RW accumulated in non-retrievable RW facility;
- operation of non-retrievable RW facility itself;
- activities performed to change the status of the facility to "a conservation facility for non-retrievable RW";
- remediation of non-retrievable RW facility's site.

Nevertheless, significant restrictions remained. The same section of the regulation states that the emplacement of other radioactive waste in non-retrievable RW facility shall be prohibited. However, it should be assumed that in this section of NP-103-17 the "radioactive waste" notion is used in its strict sense, i.e. materials subject to no further use and, thus, completely devoid of any useful properties.

Provisions regarding the general procedure providing for additional radioactive waste disposal in such facilities are presented in NP-103-17. The key features that should be reflected in the safety analysis report are as follows: analysis and accounting of the morphological, chemical and radionuclide composition, amount and activity of the radioactive waste subject to disposal; allowable total and specific activity, etc. As it comes to V-17 reservoir, the prospects regarding the use of radioactive materials of various types and morphological composition (metal waste, building materials, shredded vegetation, contaminated soil) were considered in [22]. In particular, it examined the influence produced by contaminated materials on the general level of activity in V-17 reservoir, the economic feasibility associated with the use of contaminated materials, radiation protection of personnel during work execution, and the impact associated with the use of contaminated materials while performing activities enabling to ensure the long-term safety of the facility itself.

However, one cannot state that the optimization topic has been put behind completely. JSC SCC experts have also discussed the application of similar approaches with regard to PKh-1 and PKh-2 closure. However, on the whole, similar experience can be extended to cover other materials, including non-radioactive ones, in particular waste generated by mining and metallurgical enterprises.

Given the existing practice, it seems more difficult to use materials that were previously categorized as radioactive waste. It is worth reminding that earlier, materials were categorized as radioactive waste based on completely different rational with no consideration given to their possible reuse or extraction of useful components in the future, often without proper segregation procedure. Issues associated with additional extraction of useful materials (uranium, metals, etc.) and relevant economic feasibility were examined with respect to the old tailings of JSC ChMZ, tailings of PJSC PIMCU and other facilities. In addition, as it was shown above, in some cases the generated radioactive waste is also used to perform activities enabling to ensure the long-term safety (term referred to as conservation in Russian literature) of legacy sites (tailing No. 1 at JSC ChMZ [23] and others).

On the other hand, the process of putting new records into the accounting documents of the System for State Registration and Control of Radioactive Substances (RS) and RW (SGUK RV&RAO) currently provides for some operations implicitly conforming with RW changing over into RS. For example, the following codes of operations were entered into [24]: "15" — to reflect information on the generated radioactive substances during RW processing in the form of a spent sealed radiation source, "49" — to deregister RW during segregation (with subsequent registration of new RW), etc.

In addition, the code "98" is also provided for deregistration of radioactive waste "for other reasons." Thus, within the framework of reporting under SGUK RV&RAO, it is possible to reconsider a decision regarding waste categorization as radioactive waste. No requirements regarding the procedure for changing the status of radioactive waste into RS are provided in relevant regulatory provisions, including federal norms and rules, which is obviously due to the fact that until now no such cases have been identified and should be regarded only as a matter of time.

Near-surface RW storage and disposal facilities

It seems necessary to reconsider the issue with respect to a number of large facilities that were not categorized as sites holding special (non-retrievable) RW. The rationale behind this statement can be confined to the fact that decisions during the initial registration of RW were made by operating organizations and commissions with no proper evaluation of the following factors: up-close opportunities regarding RW disposal funding, waste characteristics, comparation of dose and radiation risks for personnel and the public given various waste management options. It could be considered quite remissible for the stage of preliminary data acquisition. Moreover, in most cases to categorize RW as retrievable waste, the criteria associated with "non-defense" origin of the waste and the "unfortunate" location of the facilities were considered solely [25]. Today, when the data are completely compiled and RW retrieval operations have started [7], it seems obvious that the retrieval of all accumulated retrievable RW will be a long and expensive process.

Even among large RW storage facilities whose waste was categorized as retrievable, some facilities mainly containing short-lived radionuclides can be identified (Table 3).

Among the facilities listed in Table 3, two are located in the territory of the Novovoronezh NPP. It should be noted that the period of potential hazard for more than 70% of the RW accumulated at the site of the Novovoronezh NPP accounts for less than 150 years. The cost associated with the disposal of such waste amount, including packaging cost, may exceed 2 billion of rubles. As regards the facilities belonging to JSC "PDC UGR", it seems obvious that the radioactive waste will be removed from SGUK RV&RAO register before the start of relevant retrieval operations. It should be noted that the above calculations are based on data filled in by organizations to SGUK RV&RAO. Thus, during the development of a detailed strategy for the management of accumulated radioactive waste and decommissioning of RW storage facilities, consideration should be given to determining the expanded radionuclide composition of the waste [20, 26].

Table 3. Examples of the largest storage facilities for retrievable radwaste

Organization	Name of RW storage facility	Main radionuclide	Potential hazard time, years	Amount, thousand m^3
Novovoronezh NPP	KhTRO № 6	Cesium-137	Less than 150	9.97
Novovoronezh NPP	KhTRO № 7	Cesium-137	Less than 30 years	10.0
JSC "PDC UGR"	Trench type storage facility № 3 site 11	Cesium -137, Cobalt-60	Less than 20	10.0
JSC "PDC UGR"	Trench type storage facility № 4 site 11	Cesium -137, Cobalt-60	Less than 20	9.93

Issues associated with the future fate of the radioactive waste held in long-term storage facilities have already been considered several times. Under the initial RW registration campaign, decisions regarding waste categorization as retrievable were postponed both due to obvious safety losses and expenses, as well as due to the lack of already developed justification materials.

For a number of facilities (for example, GMZ tailings the long-term safety of which has been ensured under the Federal Target Program for Nuclear and Radiation Safety hold over 10.6 million m^3 of radioactive waste), rational decisions regarding RW categorization as non-retrievable waste practically do not raise any questions [1]. For example, in-situ disposal of radioactive waste at JSC "MSZ" (over 410 thousand m^3) will reduce dose commitments by more than 25 man·Sv and allow to save more than 90 billion rubles. To date, some progress can be distinguished in terms of reviewing pending decisions (facilities of FSUE RosRAO Kirovo-Chepetsk branch).

Particular in-depth consideration should be also given to facilities the feasibility studies regarding RW categorization as non-retrievable for which were done under the initial RW registration campaign (facilities of FSUE RFNC-VNIIEF, JSC SSC RIAR, JSC SSC RF-IPPE, branch of JSC NIFCHI named after L. Ya. Karpov, etc.). It should be noted that the dates for reviewing the deferred decisions were set in relevant acts of initial RW registration. It was assumed that by this time materials demonstrating the feasibility of RW in-situ disposal, as well as evaluations of relevant exposure, radiation risks and costs considering both the option of waste retrieval and in-situ disposal are to be developed by operating organizations. A point to note is that a delay in making relevant decisions on a number of facilities, such as storage facilities of FSUE "RADON" (43 facilities holding a total of over 132 thousand m^3 of RW) and Bilibin NPP (4 facilities holding a total of over 4 thousand m^3 of RW), allows to assess not only the doses, risks, costs and long-term safety, but also take into account some other aspects of relevance.

The use of contaminated materials and radioactive waste in the case of non-retrievable RW disposal facility conservation is regulated using the same approaches as it comes to LRW storage reservoirs. The main difference is that generally additional materials cannot be placed inside. However, slightly contaminated materials, in comparison with the main radioactive waste disposed of in the repository, may still be used, especially in the cases suggesting that additional safety barriers performing some new functions can be constructed. For example, intrusion safety barrier made of containers holding low-activity short-lived radioactive waste (or waste contaminated with radionuclides, but not falling under RW classification criteria) can be constructed over a landfill type repository (Figure 1). Apparently, quite a big amount of such packages was formed in the past [8]. Among such candidate facilities, the complex of soil landfills of plant 235 at FSUE PA Mayak site seems to be the top priority one to consider.

Repositories were constructed as engineered trenches and pits, or excavations the soil from which was excavated while constructing the enterprise. The depth of trenches and pits ranges from 0.5 to 8 m. The repositories are covered with stony and loamy soil (up to 2 m high), however, some outcrops of waste and scrap metal from the backfill, as well as surface dips can be observed. Moreover, hardy-shrub species have overgrown most part of such repositories. About 230 thousand m^3 of solid radioactive waste with a total α-activity of $1.7 \cdot 10^{12}$ Bq and β-activity of $2.4 \cdot 10^{13}$ Bq [17] were placed into these repositories [17]. Solid RW were disposed of in bulk without packaging. Their inventory is mainly composed of stainless steel, non-ferrous and ferrous metals, including bulky equipment, laboratory

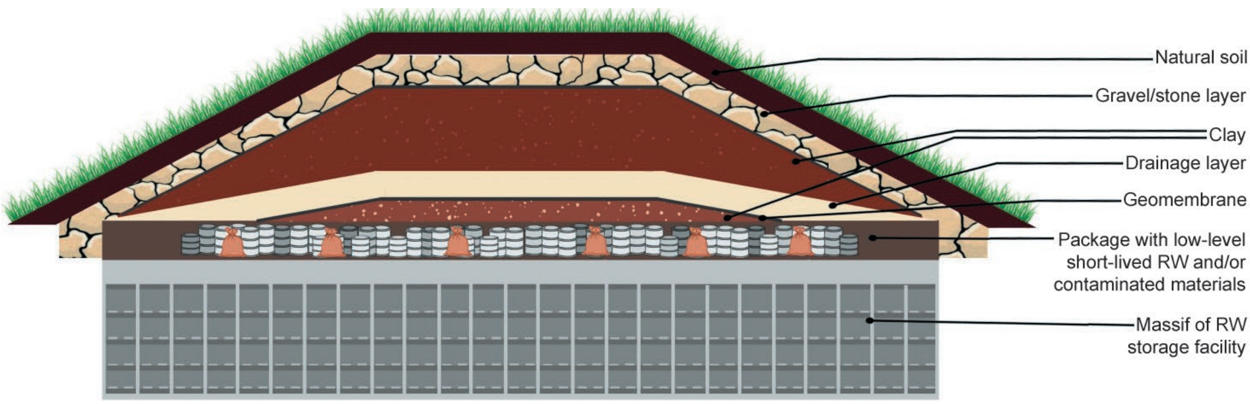

Figure 1. Conservation technology for solid RW trench type storage facility

dishes, plastics, special protective clothing, cleaning materials and construction waste. According to specific activity level, the waste stored in landfills corresponds to the categories of very low, low- and intermediate-level RW.

Current setting within the site boundaries can be described as a quite complex one with some prospects for natural improvement in 50-100 years. Obviously, activities enabling to achieve the long-term safety of the repository complex are required to be performed. During their execution, it also seems advisable to construct a covering safety barrier made of solid materials, for example, made of a number of NZK-type containers containing low-level short-lived radioactive waste, or contaminated concrete slabs from the dismantlement of buildings and structures. This layer will provide: protection from intrusion and bio-interference [27], make it easier to monitor the state of the repository and etc.

The total area of the site accounts for over 80 thousand m^2. Given occasional flooding of some facilities at the site and the need for arranging a denser setting, it can be halved. But even in this case, the potential capacity can amount to only 15 thousand NZK-type containers. Allowed added activity of short-lived radioactive waste for this repository can be limited to 0.1 % of the accumulated RW β-activity. Which is approximately equal to $2.4{\cdot}10^{10}$ Bq resulting in a value of $2{\cdot}10^{7}$ Bq per container. According to [8], the portion of such packages may reach 50 % of those being disposed of in near-surface disposal facilities.

A similar amount of "weak" radioactive waste already accumulated and packaged into containers may be not available. But in this case, various types of reinforced concrete slabs from nuclear decommissioning activities, etc. can be applied.

In case of near-surface RWDFs with some structures located on the ground level (RW disposal facilities located above natural ground surface level, for example, specialized buildings, etc.), such packages may be used to arrange a buffer zone increasing the stability of the structure, while bunding the structure with soil after completion of RW emplacement operations can be considered as a typical engineering solution applied at such facilities both in Russia and abroad (Figure 2). This will reduce the consumption of clean materials and eliminate the need for placing RW packages with extremely low-level waste or contaminated materials in near-surface disposal facilities or other types of facilities.

Facilities under decommissioning

All previously described proposals and approaches are fully valid for the decommissioning activities providing for the entombment option. Under the first project of this kind implemented in Russia aimed at upgrading industrial reactor EI-2 into a storage facility for special (non-retrievable) RW, these were partially implemented to address the issues associated with graphite stack and individual reactor metal structures [28]. However, many components of the optimization potential remained untapped, including the following: no need for removing part of the metal structures, possibility of using packages with radioactive waste formed during nuclear decommissioning operations to build upper covering screen layer considered as an important element preventing intrusion in the distant future, optimization of monitoring systems, etc.

Papers [5, 6] provide a detailed evaluation of best RW management and decommissioning technologies under the dismantlement option. Furthermore, backfilling of pits remained after the dismantlement of the underground part of decommissioned buildings and structures can be noted as an additional opportunity for optimization. In these cases, it also seems acceptable to use contaminated materials, the specific activity of which will reach clearance levels in some 30—50 years.

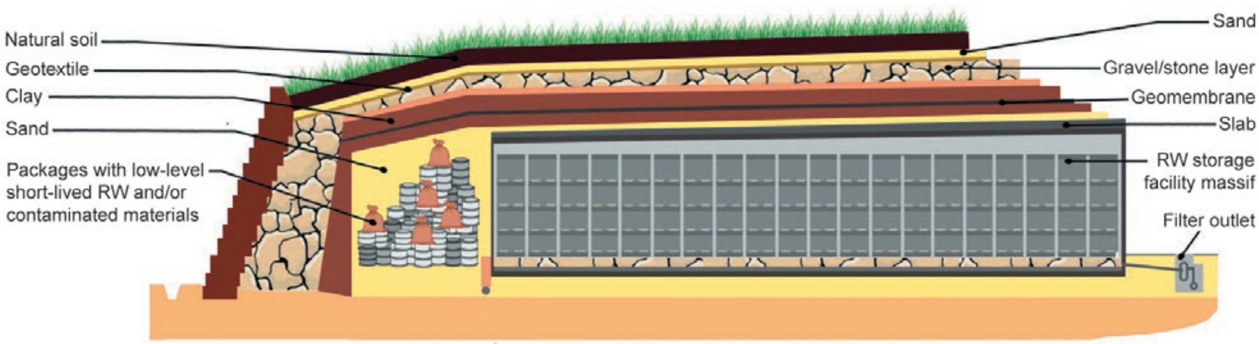

Figure 2. Proposal suggesting the use of packages containing low-level short-lived RW or contaminated materials during RW disposal facility closure

Conclusion

The approaches considered on rearranging the management of contaminated materials and radioactive waste within the boundaries of an industrial site are aimed at achieving a significant reduction in costs while maintaining or even increasing the safety level. In all cases, the proposed measures will require some efforts and funding, including those associated with safety demonstration. In some cases, additional studies on the compatibility of materials and substances are to be done. But these additional costs will pay off many times. On the whole, the following is true - the more thorough is the safety demonstration and the more is the number of conducted independent expert reviews, including those required to obtain operating licenses, the more effective are the activities.

The positive effects may be even higher in the case of a wider optimization of operations, including the consideration of opportunities for moving materials between the sites of different enterprises.

The proposed solutions suggesting the use of packages with low-level RW will make possible a manifold speed up in the removal of accumulated RW from industrial sites and dispense the disposal system for RW class 3 and 4 with the necessity of placing packages with very low-level short-lived waste into relevant facilities.

The proposed solutions may be cautiously perceived as manifestations of a simplified safety approach. However, the authors consider and will insist on the contrary: at the moment more complex solutions in terms of their planning and safety demonstration are proposed, especially given the extended planning time for RW management from regular 20 years to 50 and more years. At the same time, they fully comply with the basic principles of radiation protection. Their implementation requires a shift from facility-level planning and work arrangement to a comprehensive one, taking into account the development of the entire industrial site and the industry as a whole. This means that decommissioning activities should be planned and arranged for in strict coordination with the program on the establishment of RW final disposal system (not limited to formal references stating the obligation of the national operator to accept radioactive waste conditioned according to the acceptance criteria) with full transparency ensured for the projects providing for the management of slightly contaminated materials.

References

1. Linge I. I., Vedernikova M. V., Savkin M. N., Samoilov A. A. Perspektivy obrashcheniya s osobymi radioaktivnymi othodami [Special Radwaste Management Prospects]. *Atomnaya energiya — Atomic Energy,* 2017, vol. 122, no 6, pp. 396—399.

2. Federal'nyj zakon ot 11 iyulya 2011 g. No 190-FZ «Ob obrashchenii s radioaktivnymi othodami i o vnesenii izmenenij v otdel'nye zakonodatel'nye akty Rossijskoj Federacii» [Federal Law of 11 July 2011 No. 190-FZ "On the management of radioactive waste and amending separate legal acts of the Russian Federation"].

3. ICRP, 2007. Recommendations of the International Commission on Radiological Protection (Users Edition). ICRP Publication 103. Ann. ICRP 37 (2—4).

4. Safety Standards for protecting people and environment. Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards. General Safety Requirements. Part 3. Vienna, 2014.

5. Abalkina I. L., Linge I. I., Panchenko S. V. K voprosu obrazovaniya i obrashcheniya s RAO pri reabilitacii zagryaznennyh territorij [On the Issue of Generation and Management of Radioactive Waste from Remediation of Contaminated Territories]. *Radioaktivnye othody — Radioactive Waste,* 2018, no 1 (2), pp. 7—14.

6. Abalkina I. L., Linge I. I. Osobennosti obrashcheniya s RAO ot vyvoda iz ekspluatacii [Peculiarities of Decommissioning Waste Management]. *Radioaktivnye othody — Radioactive Waste,* 2018, no 3 (4), pp. 6—15.

7. Abramov A. A., Dorofeev A. N. Sovremennoe sostoyanie i perspektivy razvitiya sistemy obrashcheniya s RAO v Rossijskoj Federacii [Current State and Prospects of Development of the RW Managements System in the Russian Federation]. *Radioaktivnye othody — Radioactive Waste,* 2017, no 1, pp. 10—21.

8. Pron I. A., Konovalov V. Y. Opyt ekspluatacii pripoverhnostnogo punkta zahoroneniya radioaktivnyh othodov 3 i 4 klassov [The Near-Surface Disposal Facilities of Radioactive Waste: Operational Experience]. *Radioaktivnye othody — Radioactive Waste,* 2018, no 4 (5), pp. 8—14.

9. Joint Convention on the safety of spent fuel management and on the safety of radioactive waste management, Vena. — URL: https://www.iaea.org/sites/default/files/infcirc546.pdf.

10. Ignatiev V. V., Kormilitsyn M. V., Kormilitsyna L. A., Semchenkov Yu. M., Fedorov Yu. S., Feinberg O. S., Kryukov O. V., Khaperskaya A. V. Zhidkosolevoj reaktor dlya zamykaniya yadrenogo toplivnogo cikla po vsem aktinoidam [Molten-Salt Reactor for the Closure of the Nuclear Fuel Cycle for All Actinides]. *Atomnaya energiya — Atomic Energy,* 2018, vol. 125, no. 5, pp. 251—255.

11. Van Den Durpel L. On the value of recycling fuel cycles in competitive and uncertain energy markets. Atomespo. 2018. Sochi.
12. Ivanov V. K., Chekin S. Yu., Menyajlo A. N., Maksioutov M. A., Tumanov K. A., Kashcheeva P. V., Lovachev S. S., Adamov E. O., Lopatkin A. V. Urovni radiologicheskoj zashchity naseleniya pri realizacii principa radiacionnoj ekvivalentnosti: risk-orientirovannyj podhod [Application of the radiation equivalence principle to estimation of levels of radiological protection of the population: risk-oriented approach]. *Radiaciya i risk — Radiation and Risk,* 2018, vol. 27, no. 3, pp. 9—23.
13. Bol'shov L. A., Arutyunyan R. V., Linge I. I., Vorob'yeva L. M., Kazakov S. V., Pavlovskiy O. A., Kobrinskiy M. N., Osip'yants I. A. Yadernye tekhnologii i ekologicheskie problemy v Rossii v XXI veke [Nuclear Technologies and environmental problems in Russia in the XXI century]. *Byulleten' po atomnoj energii — Byulleten' po atomnoy energii.* 2003. no. 5. pp. 15—19.
14. Abalkina I. L. Opyt zahoroneniya ONAO: perspektivy dlya Rossii [Disposal Experience: Perspectives for Russia]. *Radioaktivnye othody — Radioactive Waste,* 2018, no. 4 (5), pp. 15—23.
15. SanPiN 2.6.1.2800-10. Trebovaniya radiatsionnoy bezopasnosti pri obluchenii naseleniya prirodnymi istochnikami ioniziruyushchego izlucheniya [Radiation safety requirements for population exposure to natural sources of ionizing radiation].
16. Strategicheskiy master-plan resheniya problem Techenskogo kaskada vodoyemov FGUP «PO «Mayak» [Strategic Master-Plan for solution of the problems of Techa water reservoir range of FSUE "PA "Mayak"] / IBRAE RAN i dr. Utverzhden gen. direktorom Goskorporatsii «Rosatom» ot 15.02.2016.
17. Osobyye radioaktivnyye otkhody [Special radioactive waste]. Pod obshch. red. I. I. Linge. Moscow, "SAM poligrafist" Publ., 2015. 240 p.
18. Mokrov Yu. G., Alexakhin A. I. Monitoring — osnova obespecheniya bezopasnosti pri vypolnenii rabot po konservacii vodoema Karachaj [Monitoring as the Basis for Ensuring Safety of Karachay Lake Closure Implementation]. *Radioaktivnye othody — Radioactive Waste,* 2018, no. 3 (4), pp. 60—68.
19. Obosnovyvayushchiye materialy «Otneseniye radioaktivnykh otkhodov, razmeshchennykh v poligone PZ TRO V-9, k osobym radioaktivnym otkhodam [Justification materials "Designation of radioactive waste located SRW disposal site V-9 as special radioactive waste"]. Utv. gen. direktorom FGUP «PO «Mayak». Ozersk 2014, FGUP «PO «Mayak». 45 p.
20. Dorofeev A. N., Linge I. I., Samoylov A. A., Sharafutdinov R. B. K voprosu finansovo-ekonomicheskogo obosnovaniya povysheniya effektivnosti normativnoj bazy EGS RAO [Feasibility study on enhancing the efficiency of USS RW regulatory framework]. *Radioaktivnye othody — Radioactive Waste,* 2017, no. 1, pp. 22—31.
21. Federal'nyye normy i pravila v oblasti ispol'zovaniya atomnoy energii «Trebovaniya k obespecheniyu bezopasnosti punktov razmeshcheniya osobykh radioaktivnykh otkhodov i punktov konservatsii osobykh radioaktivnykh otkhodov (NP-103-17)» [Federal codes and standards in the field of use of atomic energy "Safety requirements for special radioactive waste storage and conservation facilities (NP-103-17)"]. Utv. prikazom Federal'noy sluzhby po ekologicheskomu, tekhnologicheskomu i atomnomu nadzoru ot 10 oktyabrya 2017 g. № 418.
22. Samoylov A. A., Boldyrev A. K., Mokrov Yu. G. Podkhody k optimizatsii konservatsii vodoyema-khranilishcha V-17 [Approaches to optimization of conservation of V-17 storage pond]. *Voprosy radiatsionnoy bezopasnosti — Issues of radiation safety* 2019, no. 1 (93).
23. Obosnovaniye dlya prinyatiya resheniya ob otnesenii radioaktivnykh otkhodov k osobym radioaktivnym otkhodam (ob"yekt – konserviruyemoye khvostokhranilishche №1 OAO «CHMZ») [Justification of radioactive waste designation as special radioactive waste (facility — conserved tailing dump No. 1 of JSC "TchMZ")]. Utv. gen. direktorom OAO «CHMZ» ot 03.07.2014. Glazov. 2014. 48 p.
24. Prikaz "Goskorporatsii Rosatom" ot 28.09.2016 g. № 1/24-NPA «Ob utverzhdenii form otchetov v oblasti gosudarstvennogo ucheta i kontrolya radioaktivnykh veshchestv, radioaktivnykh otkhodov i yadernykh materialov, ne podlezhashchikh uchetu v sisteme gosudarstvennogo ucheta i kontrolya yadernykh materialov, aktivnost' kotorykh bol'she ili ravna minimal'no znachimoy aktivnosti ili udel'naya aktivnost' kotorykh bol'she ili ravna minimal'no znachimoy udel'noy aktivnosti, ustanovlennoy federal'nymi normami i pravilami v oblasti ispol'zovaniya atomnoy energii, poryadka i srokov predostavleniya otchetov» [Order of State Corporation "Rosatom" of 28.09.2016 No. 1/24-NPA "On approval of reporting forms in the field of state accounting and control of radioactive materials, radioactive waste, and nuclear materials not subject to accounting in the state system for nuclear material accounting and control,and having activity in excess of or equal to minimum significant activity, or specific activity in excess of or equal to minimum significant activity as stipulated by the federal codes and standards in the field of nuclear energy use, procedures and dates of reporting"].
25. Postanovleniye Pravitel'stva Rossiyskoy Federatsii ot 19 oktyabrya 2012 g. № 1069 «O kriteriyakh otneseniya tverdykh, zhidkikh i gazoobraznykh otkhodov k radioaktivnym otkhodam, kriteriyakh otneseniya radioaktivnykh otkhodov k osobym radioaktivnym

otkhodam i k udalyayemym radioaktivnym otkhodam i kriteriyakh klassifikatsii udalyayemykh radioaktivnykh otkhodov» [Decree of the Government of the Russian Federation of 19 October 2012 No. 1069 "On the criteria of designation of solid, liquid and gaseous waste as radioactive waste, criteria of radioactive waste designation as special radioactive waste and removable radioactive waste and criteria of classification of removable radioactive waste"].

26. Alexandrova T. A., Blokhin P. A., Samoylov A. A., Kuryndin A. V. Analiz dannyh po radionuklidnomu sostavu RAO v kontekste ocenki dolgovremennoj bezopasnosti ih zahoroneniya [Analysis of the RW Radionuclide Composition in the Context of Long-Term Safety of Its Disposal]. *Radioaktivnye othody — Radioactive Waste,* 2018, no. 2 (3), pp. 44—51.

27. Savkin M. N., Vedernikova M. V., Panchenko S. V. Vzaimnoe vliyanie ob"ektov zhivoj prirody i punktov zahoroneniya radioaktivnyh othodov: ekologicheskaya i tekhnicheskaya bezopasnost' [Mutual Influence of Non-Human Biota and Radioactive Waste Disposal Facilities: Environmental and Engineering Safety]. *Radioaktivnye othody — Radioactive Waste,* 2018, no. 3 (4), pp. 30—38.

28. Pavliuk A. O., Kotlyarevskiy S. G., Markov S. A., Shatrov M. V. Organizaciya i rezul'taty monitoringa punkta hraneniya radioaktivnyh othodov, sozdannogo pri vyvode iz ekspluatacii promyshlennogo urangrafitovogo reaktora EI-2 [Monitoring of RW Storage Facility Built as a Result of EI-2 Uranium-Graphite Reactor Decommissioning]. *Radioaktivnye othody — Radioactive Waste,* 2018, no. 3 (4), pp. 69—77.

Information about the authors

Vedernikova Marina Vladimirovna, PhD, researcher, Nuclear Safety Institute of the Russia Academy of Sciences (52, Bolshaya Tulskaya St., Moscow, 115191, Russia), e-mail: vmv@ibrae.ac.ru.

Ivanov Artem Yurievich, Head of Department for Information Support of Nuclear and Radiation Safety Programs, Nuclear Safety Institute of the Russia Academy of Sciences (52, Bolshaya Tulskaya St., Moscow, 115191, Russia), e-mail: aivanov@ibrae.ac.ru.

Linge Igor Innokentevich, Doctor of Technical Sciences, Deputy Director, Nuclear Safety Institute of the Russia Academy of Sciences (52, Bolshaya Tulskaya St., Moscow, 115191, Russia), e-mail: linge@ibrae.ac.ru.

Samoylov Andrey Anatol'evich, Senior Researcher, Nuclear Safety Institute of Russian Academy of Sciences (52, Bolshaya Tulskaya st., Moscow, 115191, Russia), e-mail: samoylov@ibrae.ac.ru.

Bibliographic description

Vedernikova M. V., Ivanov A. Yu., Linge I. I., Samoylov A. A. Optimization of Contaminated Materials and Radioactive Waste Management within Industrial Sites. *Radioactive Waste,* 2019, no. 2 (7), pp. 6—17. DOI: 10.25283/2587-9707-2019-2-6-17. (In Russian).