RADIATION SAFETY IN RADIOACTIVE WASTE MANAGEMENT: RADIATION DOSES AND PROSPECTS FOR REGULATORY FRAMEWORK DEVELOPMENT

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Based on the evaluation of data on public exposure from various sources, the paper demonstrates that the contribution of nuclear power and nuclear industry into individual and total collective doses in Russia is minor compared to the exposure from natural radiation sources and medical treatment even in regions with sites run by Rosatom. The personnel are exposed to a level being considered common for the nuclear industry. Public exposure associated with RW management is practically absent with the same exposure levels being forecasted in the long run. Based on the above and considering the objectives of USS RW development, the paper presents relevant proposals on further elaboration of basic radiation safety regulations: NRB, OSPORB and SPORO.

Keywords: *radioactive waste, radiation safety, radioactive waste management, federal norms and regulations, radiation safety standards.*

The article focuses on controversial issues related to the radiation safety of radioactive waste (RW) management.

As it comes to the safety of nuclear facilities (NF), current regulatory framework that has been put in place a long time ago consists of several elements with the federal norms and rules in the field of atomic energy use (FNR), as well as sanitary rules in the field of radiation safety considered as the key regulations.

In a large number of cases, requirements concerning the non-exceedance of established dose limits for workers (personnel) and the public, standards on discharges and releases of radioactive substances (RS), RS maximum content in the environment and relevant restrictions in the event of beyond design basis accidents (in particular, those indicated in paragraph 1.2.1 of NP-001-15[1] and paragraph 3.2 of N-016-05[2], etc.) are stated in FNRs as safety criteria. Indicators related to the radiation safety of workers and the public and the associated limits and standards are directly specified under the sanitary-hygienic framework.

It should be noted that both frameworks assume some precaution when making decisions on radiation protection. In particular, Article 24 of the

[1] General Safety Provisions for Nuclear Power Plants (NP-001-15), approved by the Order of the Federal Service for Ecological, Technical and Nuclear Supervision of December 17, 2015 No. 522.

[2] General Safety Provisions for Nuclear Fuel Cycle Facilities (NP-016-05 (OPB NFCF)) approved by the Order of the Federal Service for Ecological, Technical and Nuclear Supervision of December 2, 2005 No. 11.

Federal Law No.170-FZ On Atomic Energy Use specifying more general safety regulations on the whole indicates that safety measures implemented by state regulatory bodies should commensurate with potential risks associated with nuclear facilities and relevant activities. Radiation protection principles, including the optimization principle are viewed as essential theoretical concepts in radiation protection. However, in practice, precaution of a different conservative kind implying that various restrictions are imposed to prevent some hypothetically possible exposure situations is inherent to both of these systems. This situation is typical for most types of activities associated with the industrial use of nuclear power. Moreover, it accentuates to a certain extent due to some historical reasons, which also affects the evolution of modern RW management system.

In 2020, the task of upgrading the sanitary and hygienic framework in the field of RW management is believed to be urgent due to the following circumstances:

1. Updating of basic radiation safety regulations (NRB [1], OSPORB [2], SPORO [3]) was somewhat halted, in particular, due to discussions around regulatory guillotine matters [4]. The proposal declared in late 2018 within the framework of the Scientific and Technical Council No. 10 of the State Corporation Rosatom on the development and simultaneous enactment of a harmonized regulatory package is still considered as a promising idea only.

2. Over a long time, sanitary standards have been specifying most part of safety requirements on RW management, as well as on the management of industrial waste with high RS content. Accelerated FNP development was somewhat typical for the period following the enactment of the Federal Law On Radioactive Waste Management ... (No. 190-FZ).

At the same time, documents of the two regulatory frameworks sometimes do not constitute to a complementary and balanced system providing for no proper interaction between the two state bodies responsible for the radiation safety regulation.

3. Prospects associated with the elaboration of regulatory requirements concerning the operation of the Unified State System for RW Management (USS RW) [5] have been actively discussed, including by means of amending certain provision of the RF Government Resolution No. 1069[3] and the Federal Law No. 190-FZ. Unfortunately, feasible proposals on RW categorization as non-retrievable RW and RW classification for disposal purposes are discussed along with obviously unproductive ideas suggesting the expansion of the Federal Law No. 190-FZ provisions to cover the management of industrial waste with a high RS content [6] the feasibility of which is alleged by an insufficient level of radiation safety provided during the management of such waste [7].

Under these circumstances, what should be specifically seen as the basis for further development of USS RW regulatory framework is now considered as an essential issue.

Firstly, ***international practice.*** Harmonization of Russian regulatory framework is a relevant task to be addressed. However, along the way one should not forget that this harmonization shall always (which is reflected in international documents) take into account particular national aspects associated with the development and operation of nuclear industry in a particular country.

Secondly, ***available data on radiation exposure of personnel, public and the environment,*** since all numerous requirements are ultimately aimed at preventing personnel and public exposure in keeping with the established standards. Data of this kind are quite sizeable and convincing, but are extremely rarely considered under relevant discussions. Commonly, preference is given to conservative estimates based exclusively on the existing concerns, as, for example, discussed in [7], or to the past experience. Given the above, a brief overview of the events triggered by RW or RW storage facilities seems worth to be provided.

These include a case study of the Techa River contamination due to the accident of 1957, contamination of areas around lake Karachay and much more localized cases of contamination in the vicinity of other nuclear legacy facilities. These events have been studied in sufficient detail: relevant radiological consequences and the effectiveness of implemented protective measures on accident mitigation were investigated as well [8]. Negative radiological impacts produced on the population and the environment on the banks of the Techa River were scientifically established [8]. The extent of radiological effects associated with the accident of 1957 seems to be a much more controversial matter. Very extraordinary pathways of human exposure associated with the operation of near-surface LRW storage facilities, including studies focused on bats residing in the vicinity of lake Karachay and the Techa cascade of water reservoirs (TCR), are also known and were evaluated [9]. Nevertheless, it was in the distant past that these events resulting in such effects occurred. All the drawbacks of such engineering solutions have been recognized, and most prominent facilities were upgraded with qualitatively different state achieved

[3] Resolution of the Government of the Russian Federation of October 19, 2012 No. 1069 On Criteria Used to Assign Solid, Liquid and Gaseous Waste to the Radioactive Waste Category, Criteria for Radioactive Waste Categorization as Non-retrievable Radioactive Waste and Retrievable Radioactive Waste and Classification Criteria for Non-retrievable Radioactive Waste

[10, 11]. As for the rest of similar facilities, relevant measures will be completed in the coming years (decades) or are planned to be implemented under federal target programs.

*Thirdly, **scientifically founded forecasts,*** since it's in the distant future that RW safety should be specifically provided. The Joint Convention [12] provides a most concise indication with the goal being defined as: "to ensure that during all stages of spent fuel and radioactive waste management there are effective defenses against potential hazards so that individuals, society and the environment are protected from harmful effects of ionizing radiation, now and in the future, in such a way that the needs and aspirations of the present generation are met without compromising the ability of future generations to meet their needs and aspirations."

Therefore, it seems worth considering two aspects of the situation: current radiation doses and radiation doses in the future in the post-disposal period.

To date, a large number of site-level and facility-level assessments and measurements [13] is available providing convincing evidence on the compliance with the requirements: non-exceedance of population exposure levels and risks is observed in all regions and at all sites of Russian nuclear sites with some negligible values being recorded in practice. The number of similar estimates for the entire territory of Russia is much lower, which is associated with the methodological complexity of their implementation.

In Russia, such an assessment system has been basically evolving for 20 years already. Radiation-hygienic certification is carried out in Russia and the Unified State System for Monitoring and Accounting Individual Public Exposure Doses (ESKID) has been put in place [14, 15]. We believe that these systems have become a reliable source of sound and complete data on radiation safety in constituent entities of the Russian Federation. A large-capacity data source has been actually established, which can and should be used to provide general radiation safety assessments and to identify the areas for further elaboration of the requirements.

Despite largely positive general outlook on the efforts considered, the statements provided in [14] about the reliability and completeness of the data seem excessive to us which can be evidenced by the below reasons. Firstly, the considered efforts deal exclusively with dose estimates done based on a multistage procedure characterized by its own errors (of various kinds) at each stage with apparent setbacks in a number of accounting components over the years. This explains significant fluctuations in the average annual doses over time that could not be reasonably explained. In this case changes accounting for some fractions of a percent should be recognized as requiring some elucidation. Secondly, the classification system has some flaws and is somewhat detached from the nuclear power and industrial entities operating hazardous facilities. These remarks have been already stated in [16]. Nevertheless, the latest certification data and ESKID reveals practically no difference between the accounting features and the actual processes and phenomena affecting such accounting. Although more precise indications on the fluctuations in the estimates and not in the doses themselves appear more and more often. Nevertheless, ESKID data provide very important information evidencing steady increase in the public exposure due to medical treatment and relevant steadily minor contribution of the nuclear power in Russia. The breakdown of constituent entities of the Russian Federation (Table 1) covers all regions with large nuclear sites operated by the State Atomic Energy Corporation Rosatom. For comparison purposes, it presets two entities providing specific contribution associated with contamination of territories (Bryansk region) and natural exposure (Stavropol Territory). In all entities, average doses to the population resulting from operations with sources of ionizing radiation do not exceed 10 μSv and are mainly associated with occupational personnel exposure. The highest values are observed in regions with RBMK-type reactor units. Similar pattern is observed when it comes to collective dose estimates: contribution of RI sources accounts for 0.1—0.7 % of the total collective dose. Moreover, in the Bryansk region, consequences of Chernobyl accident appear to be more noticeable amounting to almost 7% of the total contribution. In all other territories these figures account for 0.1—0.2% of the total collective doses in the corresponding regions.

It's considered important that all data presented reflects the reporting from thousands of non-nuclear organizations operating sources of ionizing radiation. These are also listed in a more detailed collection [15] as organizations with highest levels of personnel exposure. Under the above circumstances, one can state that, in general, inherent task of existing regulatory framework on occupational exposure and operation of nuclear facilities is addressed quite effectively, therefore, its further elaboration should be focused not only on the reduction of radiation doses, but on the adequacy of regulations also addressing local and specific tasks, implying, first of all, professional exposure for medical purposes, and relevant cost reductions.

Obviously, against the background of prevailing natural and medical exposure and given the barely noticeable contribution of nuclear sector, it seems impossible to identify the exposure associated with RW management. Nevertheless, RW challenges are

Table 1. Average doses to the population residing in regions with Rosatom enterprises (according to [15] for 2018) associated with operations involving RI sources (OS), industrial exposure (IE), naturally occurring radionuclides (NR) and medical sources (MS)

RF Constituent Entity	OS, µSv	IE, µSv	NR, µSv	MS, µSv	Total, mSv
Udmurtia	0.7 (0.0 %)	5 (0.2 %)	2,600 (85.0 %)	450 (15.0 %)	3
Krasnoyarsk Territory	1.9 (0.1 %)	5 (0.1 %)	3,000 (73.2 %)	850 (20.7 %)	4.1
Stavropol Territory	0.7 (0.0 %)	5 (0.1 %)	5,800 (93.5 %)	450 (6.3 %)	6.2
Bryansk Oblast	0.6 (0.0 %)	222 (6.8 %)	2,600 (78.9 %)	400 (12.1 %)	3.3
Voronezh region	1.6 (0.1 %)	6 (0.2 %)	2,600 (81.3 %)	650 (20.3 %)	3.2
Irkutsk Oblast	1.8 (0.0 %)	5 (0.1 %)	5400 (85.7 %)	900 (14.3 %)	6.3
Kaluga Region	3.8 (0.1 %)	23 (0.5 %)	3,900 (81.3 %)	900 (18.8 %)	4.8
Kursk Region	8.2 (0.2 %)	14 (0.4 %)	3,100 (85.1 %)	500 (13.9 %)	3.6
Leningrad Region	9.7 (0.3 %)	6 (0.2 %)	3,300 (91.7 %)	300 (8.3 %)	3.6
Moscow Region	1.5 (0.1 %)	5 (0.2 %)	3,000 (93.8 %)	200 (6.3 %)	3.2
Murmansk region	8.8 (0.2 %)	5 (0.1 %)	3,000 (81.1 %)	700 (18.9 %)	3.7
Rostov Region	1.1 (0.0 %)	5 (0.1 %)	4,000 (87.0 %)	400 (8.7 %)	4.6
Sverdlovsk Region	2.2 (0.1 %)	5 (0.1 %)	4,000 (87.0 %)	600 (13.0 %)	4.6
Smolensk region	10 (0.3 %)	5 (0.2 %)	2,600 (83.9 %)	500 (16.1 %)	3.1
Tver Oblast	1.9 (0.1 %)	5 (0.2 %)	2,600 (86.7 %)	400 (13.3 %)	3
Tomsk Region	5 (0.1 %)	5 (0.1 %)	2,800 (80.0 %)	700 (20.0 %)	3.5
Ulyanovsk Region	5.5 (0.2 %)	5 (0.2 %)	2,300 (76.7 %)	600 (20.0 %)	3
Chelyabinsk Region	7.5 (0.2 %)	5 (0.1 %)	3,800 (88.4 %)	500 (11.6 %)	4.3
Trans-Baikal Territory	11 (0.1 %)	5 (0.1 %)	7,300 (92.4 %)	550 (7.0 %)	7.9
Moscow	2 (0.1 %)	5 (0.1 %)	3,000 (75.9 %)	950 (24.1 %)	3.95
Chukotka Autonomous Okrug	54.8 (1.8 %)	5 (0.2 %)	2,400 (80.0 %)	500 (16.7 %)	3

discussed under the ESKID framework, even though these discussions are limited to impracticalities accounting. In [15], for example, 23 organizations involved in RW disposal activities were mentioned as accounting subjects. At the same time, National Operator for Radioactive Waste Management was established in keeping with provisions of Federal Law No. 190-FZ being the only authorized organization responsible for RW disposal in Russia. Currently, 4 RW disposal facilities (RWDF) are operated in Russia. Published data [17, 18] indicate a very small number of involved personnel and very moderate radiation exposure. At operating RWDF for RW class 3 and 4, annual personnel exposure did not exceed 1/4 of the established exposure limit for the corresponding groups of personnel (A, B). Normal operation of RWDF commonly suggests no reason for discrepancies between the dose loads associated with RW management and exposure conditions for the majority of professional workers.

Post-disposal radiation doses in modern RWDF

Existing system of RW disposal requirements virtually excludes the possibility of additional population exposure. [19] provides a detail overview of the main components of the methodology used to demonstrate the long-term disposal safety. The key component suggests that an extensive list of events and phenomena potentially causing deviations from normal RWDF evolution scenario should be considered at timeframes of tens and hundreds of thousands of years. Long-term safety demonstration is considered as painstaking, time-consuming task regardless of RWDF types, nevertheless, quite accomplishable if no unnecessary obstacles are imposed, such as, for example, an unconditional restriction of 10 µSv/year stipulated in OSPORB provisions.

Considering a quite favorable situation with the radiation exposure of personnel and population due to RW management operations, provided below is a summary evaluation of the prospects for further elaboration of basic regulations referring to the radiation hygiene standardization framework. An important point should be noted as well: many of these requirements have been put in place a long time ago and have proved their reliability. However, some requirements were somewhat theoretical in their nature, since some processes, including RW disposal assuming currently approved concept, were practically absent. Relevant proposals on regulatory framework upgrading are aimed at abolishing such norms, as well as those indicating some technical means.

Radiation Safety Standards (NRB) and practice

Most fundamental contradictions between actual situation with the exposure and NRB provisions are discussed below. Firstly, these are related to intake and exposure standards. All cases associated with increased exposure occurred under conditions that did not correspond to the standard ones. Moreover, for many parameters regulated under these considerations the values did not exceed the established standards which has been recorded for decades in all constituent entities of the Russian Federation. Secondly, this accounts for a problem of one Bq stemming from the "should not exceed" concept. In most cases, the specified values correspond to the performance margin of low-cost measurement methods or beyond. As a result, a bunch of contradictions evolved. Most detailed regulations have been specified regarding the exposure from man-made radionuclides under industrial conditions providing less than 0.5 % of the collective dose to the population of Russia. Instrumental control mostly addresses the measurements related to purely secondary characteristics of the radiation environment. Exceedance of the standardized values by at least 1 Bq appears to be a problem. Although the latter actually evidences that a conservatively calculated intervention parameter gives a weak signal on a potential exceedance of the control level established with the greatest care based on a linear dose-response relationship, which is on its own considered as a product of excessive precautions. A simple way to get rid of these flaws is seen in softening the wording.

Radiation Safety Standards and RW Management

No references to RW management as a particular area of hygienic regulation can be found in NRB provisions. However, it's believed that the requirements stipulated in the basic radiation safety regulation produce an important impact on the considered areas and some other activities as well which does not always advance safety. Here are a few examples demonstrating the unreasonable use of numerical values from NRB under some regulatory provision. Criteria used to categorize solid waste not subject to any further uses as RW fully reproduce the values from NRB Appendix No. 4. Waste assignment to RW category means that this waste should not be released into the environment, nevertheless, this requirement does not suggest immediate waste disposal, since after being held in storage facilities some waste will be no longer categorized as RW (short-lived waste with a half-life of less than 1—5 years). This is the case of a large waste inventory containing approximately 2/3 of the radionuclides specified in the above Appendix. This case demonstrates the disregard of the target USS RW assignment function: long-term safety ensured via RW disposal. A more dramatic or even rather absurd is the case of criteria established to categorize waste as gaseous RW suggesting that all relevant points are ignored: firstly, hygienic principles that underlie the establishment of Allowable Volumetric Activity levels for population; secondly, analytical problems associated with the measurements of similar activity levels; thirdly, the need to ensure physical localization of such a volume, since it is highly unreasonable to attribute atmospheric air to waste; fourthly, short-lived radionuclides, etc. Unfortunately, these simple considerations have not been acknowledged by regulatory authorities. The same is true for the arguments suggesting that RW management and radiation safety should be considered as separate tasks and should be addressed individually by different means. Another case in point is that at the outset of USS RW infrastructure establishment, which is seen as a complex task in itself, the requirements should refer only to VLLW. Moreover, often expressed [7] are the proposals on the incorporation of even less hazardous industrial waste with a high content of technogenic radionuclides into the RW management system. What is even worse is that these proposals are supported by some experts in radiation hygiene. Due to their incorrect interpretation of the goal being pursued in this area (prevention of VLLW accumulation) actual principles of radiation protection are virtually disregarded, since the high cost of RW disposal is completely neglected.

RW management issues in OSPORB [2]

First of all, extensive duplication of regulatory material presented in Section 3.12 of OSPORB should be noted. At the same time, unlike FNP, no references to other regulatory frameworks are provided. This remark mainly concerns subsection 3.12.1 with its semantic content that has been defined in the recent years based on relevant provisions of a Government Resolution of the Russian Federation [20].

Considering the radiation safety of workers, RW classification system presented in Section 3.12.3 of OSPORB, which again duplicates the text of the above Resolution [20], is considered substantial. However, the concepts introduced in the subsequent text are used only in the LRW disposal context. We have already noted the fundamental differences between RW classification system for radiation safety purposes and the one for RW disposal purposes [21, 22]. It should be also noted that basic sanitary rules could provide some indications of basic radiation protection methods for personnel working with different categories of waste, including the use of exclusively remote methods during HLW management. These provisions are completely absent in OSPORB, and regulatory requirements are either linked to dosimetric (3.12.9) or volumetric characteristics (3.12.10). In some cases, safety requirement can refer to all waste categories or demonstrate a simplified concept associated with the opportunities for storing the entire RW inventory in waste containers (3.12.12), and in some cases, some clarification of the wording is clearly required, as, for example, in clause 3.12.18 mentioning tenacious packaging.

Most serious remarks concern the final paragraphs of the section (3.12.18—19). The first one denotes a simplified interpretation of the siting conditions for RW disposal facilities, and the second indicates the groundlessness of the proposed standards. One can somehow agree with the limitation on the annual effective dose for a critical group of population considering all types of RW management operations prior to its disposal. This is mainly explained by its widespread practical implementation and the inability of providing the instrumental control, including within the ESKID framework. However, as it comes to limitations imposed on the annual effective dose for a critical group of population associated with RW management prior to its disposal (0.01 mSv), the situation seems to be much more complicated. This norm contradicts the international practice and indeed complicates the process of disposal safety demonstration, i.e. RWDF development and actual RW disposal therein. It can be argued that by implementing relevant efforts aimed at mitigating the corresponding negative consequences for distant descendants, we place certain burden on the current generation. IBRAE RAS performed a most painstaking research and demonstration addressing this issue, namely, the research group led by A. A. Samoilov [23, 24]. International approaches and Russian requirements suggest the need of considering reference and alternative scenarios of RWDF evolution at its post-closure stage. Moreover, the latter refers to both unlikely catastrophic scenarios and scenarios implying human intervention due to the loss of a great part of safety important knowledge. Considering the above, much milder restrictions are implemented under such scenarios (Table 2).

Table 2. Annual effective dose to a critical group of population in the event of an alternative scenario evolution. International practice

Regulation	Dose, mSv
ICRP, publ. 81 [25]	10–100
IAEA (SSR-5) [26]	1–20
US (classification) [27]	5
NEA OECD [28]	5

The Russian limit of 10 μSv is largely explained by the lack of proper practice in the field of RWDF safety demonstration. Apparently, this should be changed based on a transfer to a graded approach:

- a dose limit of 0.3 mSv/year specified for a time period while the uncertainties in the simulated processes are viewed as negligible (up to ~ 300 years) and 1 mSv/year for a longer period considering a reference RWDF evolution scenario, as recommended in [25];
- a dose limit of 5 mSv for a longer period providing for the implementation of alternative scenarios, as assumed in [27].

RW Management Issues and SPORO [3]

For a long time, predecessors of these regulations and then the SPORO themselves were considered as the main source of safety requirements in the field of RW management. To date, the situation has changed fundamentally, and most of the required safety standards, if not all, are provided under key FNP provisions. For this reason, two scenarios are deemed possible: its abolishment, which has already happened in fact, or its substantial revision and reduction with the former option being viewed as a more rational one.

Conclusion

For decades, operation of nuclear power and production facilities have demonstrated an acceptable level of radiation safety. Compliance with personnel exposure restrictions, including those associated with RW management, is ensured assuming its high reliability.

Public exposure associated with the operation of nuclear power and production facilities is not identified by instrumental methods. Conservative calculations evidence its minor contribution to the total exposure. Public exposure due to RW management operations is almost absent.

Sanitary rules and hygienic standards on radiation safety, namely, their provisions dealing with RW management require upgrading and, in particular, actual interfacing with FNPs, focusing on the subject of regulation — radiation doses, and not on technical and organizational measures implemented to limit the exposure. Radiation protection principles, including the costs required to implement the considered restrictions, the scope and time needed to achieve the positive effect should not be neglected during the development of radiation exposure restrictions.

Abolishment of a single 10 μSv/year limit on the public exposure suggested by OSPORB provisions for all scenarios of RWDF evolution and establishment of more flexible and scientifically sound criteria is viewed as a most important task for USS RW development.

The stance of operating organizations should play a decisive role in the identification of relevant concept and structure of a SPORO-type document.

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