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EXPERIENCE OF EXPLOITING THE RADIOACTIVE WASTE RECYCLING COMPLEX AT THE SMOLENSK NPP

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The article explores the experience from the operation of RW processing complex at Smolensk NPP fully commissioned in 2015. The paper presents a brief description of its facilities and overviews the operational results. It describes further tasks on the improvement of RW management system such as, reaching the capacity specified in the designs and increasing the efficiency of RW processing technologies considering further RW transfer for disposal.

Keywords: *radioactive waste, RW processing complex, radioactive waste processing, RW ion-selective treatment, RW cementation, RW compaction, RW incineration.*

Introduction

Given the availability of RW processing facilities and relevant operational experience, Smolensk NPP is considered to be one of the most equipped NPPs of Rosenergoatom Concern (table 1). However, long-term operational life of the NPP resulted in a big amount of RW accumulated due to the RW management strategy implemented in the past. This strategy involved advanced processing of RW accumulating in specialized storage facilities located at the NPP site. RW registration campaign revealed that the past operation of Smolensk NPP resulted in significant solid RW (SRW) inventory. To date, some 85 % of this inventory have been assigned to VLLW category, some 15 % — to LLW and ILW, < 1 % accounts for HLW. The accumulated inventory also involves a significant amount of liquid RW (LRW).

Rosenergoatom Strategy approved in 2013 [2] provides for a wide scope of activities — starting from those resulting in decreased RW generation up to the development of RW processing systems enabling to process the whole inventory of generated and accumulated RW, also suggesting their conditioning in accordance with particular waste acceptance criteria [3]. In order to address these issues, as well as due to almost complete exhaustion of available storage capacities, RW processing complex (RW PC) was constructed and commissioned at Smolensk NPP. Its task was not only to process annually generated RW inventory, but also enable gradual processing of the earlier accumulated one.

The paper briefly overviews the issues associated with Smolensk NPP RW PC operation enabling to identify the technologies considered the best and most suitable for their implementation at other sites. It also summarizes operating boundaries and limitations requiring further elaboration and research to be conducted.

RW processing flow chart at Smolensk NPP's RW PC

In general, RW management flow chart involves pre-treatment, storage and processing operations.

Pre-treatment is carried out at relevant units where the waste has been previously generated. These operations performed by personnel working in relevant industrial divisions and the radiation safety department, involve:

- Segregation of common industrial (non-radioactive) waste from SRW based on dosimetry inspections;

The translation is done by N. S. Cebakovskaya

Table 1. Available RW processing equipment at NPPs [1]

NPP	Installations								
	LRW				SRW				
	Ion-selective treatment	Strong evaporation	Cementation	Bituminous grouting	Incineration	Compaction	Cutting, grinding	Cementation, SRW	Heat insulation and aluminum melting
Balakovo	×	✓	×	✓	✓	✓	×	✓✓	×
Beloyarsk	2022	×	2022	×	✓	2020	2020	×	×
Bilibino	×	×	×	×	×	2017	×	×	×
Kalinin	×	×	×	✓	✓	✓	✓	✓	×
Kola	✓	×	✓	×	✓	✓	✓	×	×
Kursk	2019	×	2019	×	✓	✓	2019	×	✓
Leningrad	2019	×	2019	✓	✓	✓	✓	×	×
Novovoronezh	×	✓	×	×	×	✓	×	×	×
Rostov	×	×	✓	×	✓	✓	×	✓	×
Smolensk	✓	×	✓✓	×	✓	✓	✓	×	×
ODITs	×	×	×	×	✓	×	×	×	×

✓ – Operating
✓ – On standby
2017 – Under construction (commissioning date indicated)
2020 – Design development (planned commissioning date indicated)
× – Not needed

- Segregation of SRW based on their morphology, suggested processing approaches, segregation of SRW based on activity level (dosimetry measurements);
- Surface decontamination (if possible);
- Cutting of large-size SRW (to a size of no more than 300×300×300 mm);
- SRW primary packaging (polyethylene or multilayer paper bags);
- Transportation of RW packages to the place of their storage and processing.

Further RW management performed by personnel working in RW management workshop (RW MW) involves waste storage in a storage facility (SF) and processing at RW PC if the waste is assigned to the category of processible waste and is characterized by an appropriate activity level. It should be noted that RW PC can process solid very-low level waste covering over 80 % of the total RW inventory.

LRW pre-treatment is performed in a chemical workshop with the resulting bottom residues being transferred for temporary storage to LRW and SRW storage facilities or LRW storage facilities and further on for RW processing to RW PC.

At Smolensk NPP, SRW and LRW processing takes place in the same workshop being part of purposely designed RW PC. The complex was designed to process and condition most part of RW enabling their further transfer to the National Operator. As most of the RW generated and accumulated at the site pertain to the categories of VLLW (SRW), LLW and ILW (LRW) the complex was designed specifically for their processing.

Relevant decisions on the selection of processing technologies, equipment and installations were based on the available experience accumulated in Russia and abroad. For each RW category, most high performance and well-proven technologies were selected, also based on the best practices applied at other NPPs.

In general, SRW inventory can be divided into the following groups of materials (based on particular features associated with their management):

- Compactable (metal items, heat insulation, rubber tools and parts of equipment, cable jackets, etc.);
- Disintegrable (PVC);
- Incinerable (rags, paper);
- Subject to decontamination (metal).

According to RW PC designs, most part of RW can be processed at 9 facilities. Given the planned scope of industrial operations, these facilities were subject to staged commissioning (involving 2 phases). The first phase implemented in 2011 involved the commissioning of auxiliary and infrastructure facilities (laboratories, central control unit, center for documentation and RW accounting, storage facility for already processed RW), as well as a number of RW processing facilities. In 2015, the site was completed after the second part of RW PC facilities was commissioned (table 2).

Table 2 presents all the facilities of RW PC and their key characteristics.

A more detailed discussion of SRW stream processing flow chart is presented below (figure 1).

The first stage involves RW segregation. Relevant installation enables to control the quality of preliminary RW segregation, as well as to perform additional radiation control. The former control process involves additional waste segregation based on RW morphology with due account of the supposed further uses. Additional radiation control eliminates the occurrence of situations when LLW are transferred for processing — if such waste is detected, it is transferred for storage.

Table 2. List of RW processing facilities (RW PC)

#	Installation (supplier)	Designation (design capacity)	Capacity, m^3/year (as for 2017)	RW characteristics after processing, m^3
		First unit		
1	LRW cementation facility (JSC SverdNIIkhimmash)	Immobilization of LRW resulting from the operation via cementation (18,000 drums per year)	57 m^3	54.6 m^3 of cemented RW (RW class 4) in 200 l drums
2	Incineration facility for solid and liquid inflammable RW	Incineration of solid and liquid inflammable VLLW (SRW – 600 m^3/year, LRW – 65 m^3/year)	547.6 m^3	18.8 m^3 of ash residues (RW class 4)
3	Cementation facility for ash residues (JSC SverdNIIkhimmash)	Ash residues resulting from incineration confined into cement matrix (11.4 t/year)	26.4 m^3	26.4 m^3 of cemented ash residues (RW class 4) in 200 l drums
4	SRW segregation facility (JSC Atomenergoproekt)	Control segregation of RW (820 m^3/year)	827,4 m^3	Generation of inflammable RW – 291.2 m^3; compactable RW of class 4 – 536.1 m^3
		Second unit		
5	SRW segregation and compaction facility (JSC SverdNIIkhimmash)	SRW controlled segregation and compaction (by force of 95 t.s.) – 980 t/year	755.03 m^3	252.4 m^3 of compacted RW (class 4) in 200 l drums
6	Grinding facility (JSC SverdNIIkhimmash)	Cutting (grinding) of flexible sheet PVC to a predefined particle size (21.5 t/year)	108.2 m^3	52 m^3 of grinded PVC (RW class 4) in 200 l drums
7	Automatic manipulator for liquid deactivation of contaminated metal items (JSC SverdNIIkhimmash)	Decontamination of metal items (300 m^3/year or 1,000 tons per year)	52 m^3	Materials were released from regulatory control after the treatment
8	LRW Ion-selective treatment facility (JSC SverdNIIkhimmash)	Supernatant cleaning from radionuclides (3,600 m^3/year)	88 m^3	5.6 m^3 of sludge generated; brine solutions released from regulatory control
9	Super-press FSC004 (Netherlands, "FontijneGrotnes")	SRW compaction (5 drums per hour, 3,920 tons per year)	443 pcs, 200 l drums (with 88.6 m^3 capacity)	51 containers (SRW volume not accounting for package geometry – 59.1 m^3) with RW class 4

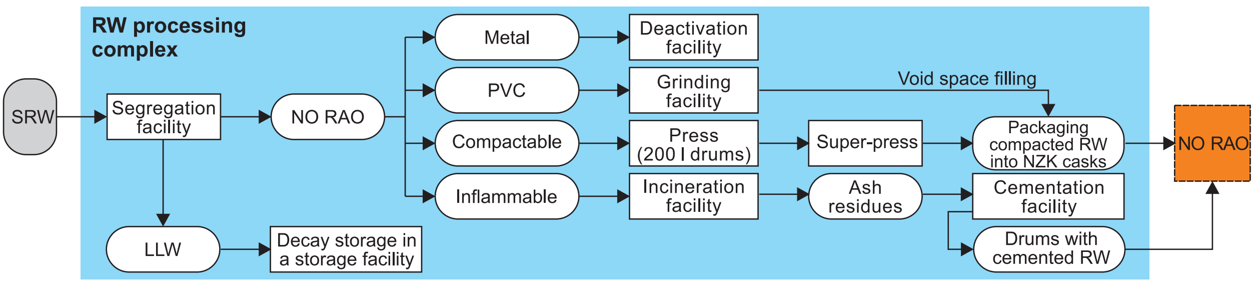

Figure 1. SRW processing flow chart (RW PC

An average of up to 1% of waste are segregated after this stage with relevant decisions taken on their further management or transfer for storage.

It should be noted that the selected SLW management option for LLW and higher-activity waste (long-term storage) is quite feasible, as for specific waste categories (up to 99%), the major part of activity at the time of their generation accounts for short-lived radionuclides with half-lives of less than 6 years (Co-60, Mn-54, Nb-95, Zr-95, Cr-95 and other). Moreover, activity level associated with radionuclides with half-life of less than 1 year may account for up to 70% of the inventory even after several years of decay storage.

Different waste management approaches are used for different RW categories depending on their characteristics. Thus, metal RW may be subject to decontamination, compaction or transferred for processing performed by specialized organizations.

Super-compaction unit (figure 2) deserves particular attention to be paid as it is the only installation of this kind operated in Russia — it has a compaction capacity of up to 1,500 tons per second and was specially designed by experts from Netherlands. The compaction device was purchased under the TACIS international program for technical cooperation.

Super-press facility has been successfully operated in Europe for many years. Since early 90's, a similar facility has been operated by NPO Radon [5]. To manage RW from Russian NPPs, a similar facility is also operated at Balakovo NPP. Super-press capacity enables 10-fold reduction in RW volume. This facility can be applied to treat a wide variety

Figure 2. Super-compaction facility FSC004

of RW items (cables, electrical scrap, construction waste, heat-insulation and rubber products) packaged in drums with compacted disks as end-product of compaction process. Robotic system determines their size and weight to ensure most effective packaging of such waste.

Super-compaction efficiency is also ensured through RW pre-treatment performed at a separate facility for segregation and compaction. Following RW segregation, they are packed into thin-walled metal drums. These drums are subject to pre-compaction process ensuring that any void space is eliminated. Subsequently these drums are delivered to super-press facility where they are compacted till maximum. Compacted waste in form of disks (some 20 cm in height) are packaged into NZK casks [6] (figure 3). Voids are filled with grinned PVC produced by a grinding facility.

In theory, higher efficiency of RW treatment can be achieved at least for RW class 4 if thinner walled containers are used.

LRW (bottom products) are treated at ion-selective and cementation facilities. General flow chart of these operations is presented at figure 4.

The first stage involves Co-60 extraction ensured through mechanical removal of bottoms resulting from solution ozonization. The second stage provides for selective absorption of Cs-137 using purposely designed container type filter filled with absorbent. Solution flows through this filter (one or several times) enabling to reduce its activity to the required level. Subsequently, the solution is evaporated. This process results in distillate and salts. In terms of the specific activity levels, these products are not considered as radioactive waste. Current plans suggest that the container type filter will be later transferred to FSUE NO RAO for disposal. The sediment, containing Co-60, washed off from mechanical filters, is subject to immobilization and, thus, transferred to LRW cementation facility. Immobilized RW is placed into 200-liter metal drums.

It should be noted that during the whole life time of RW PC, no major faults occurred requiring some maintenance to be performed by contractors. At pre-commissioning stage close attention has to be paid to the analysis of possible issues and the development of relevant countermeasures. This can be exemplified by stagnant zone formation in LRW cementation facility. Occurrence of such zones has required some periodic control and well-timed maintenance operations to be introduced into work schedule.

Figure 3. Drum filled with RW – before and after compaction

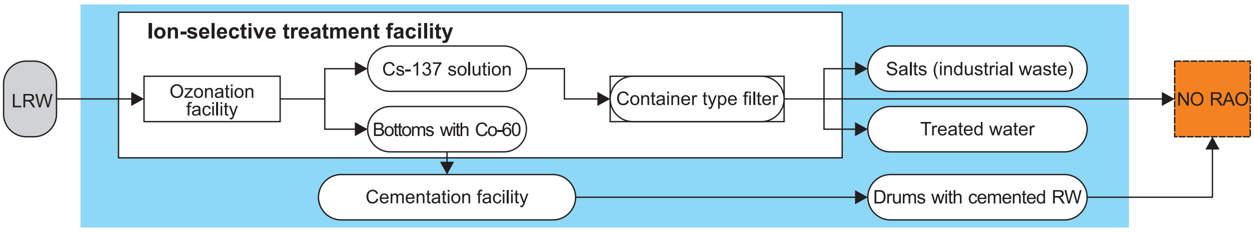

Figure 4. LRW processing flow chart at RW PC

Quality control for RW conditioning process

Quality control system operated at RW PC deserves some special attention to be paid. This is a multi-level system involving: control of initial material, control of flow chart parameters and control of conditioned RW. Analytic and spectrometric laboratories are in charge of these operations.

The first stage ensures that all initial materials used for RW conditioning are subject to quality control inspections. This stage also provides for relevant controls to be applied to initial RW characteristics to identify the required parameters for relevant technological processes (for example, solution-cement rate for LRW cementation).

The second stage is aimed to monitor operational process parameters. RW PC is managed through computer management and control systems. All parameters recorded are automatically saved in the system. Most important parameters are also backed up in workbooks by RW PC personnel. If the process control system reveals some discrepancies from predefined values, it ensures automatic data transfer to the personnel using alarm signalization.

Additional, third quality control stage is provided for cemented RW – final cement compound is subject to a quality control procedure. After cemented RW are poured into containers, cement samples are collected. Consolidated cement samples are subject to a series of tests (strength and leaching), including those performed following multiple freezing/thawing cycles (more than 30 times) (figure 5). Quality control results are also recorded.

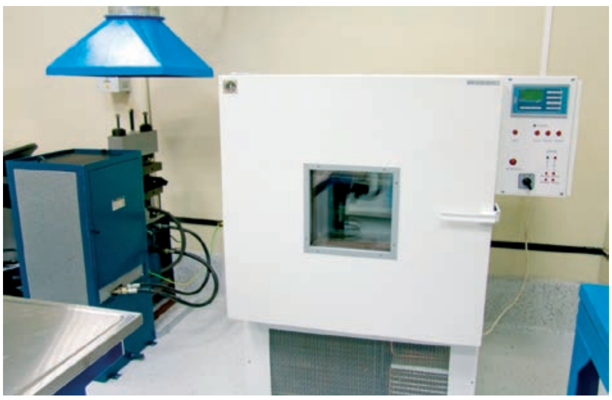

Figure 5. Refrigerating unit

Experience gained in this field shows that if process parameters and the quality of initial material are met, product resulting from cementation process is fully consistent with all specified standards.

RW package certificates are developed based on the data from RM and RW accounting and control system, analytical laboratories, as well as quality control performed. These certificates contain all necessary information, that, for instance, can be submitted to the National Operator sometimes well in advance (to schedule relevant RW disposal activities).

Perspectives for RW PC further development

Summarizing the preliminary results of RW PC operation, it can be noted that most of RW PC facilities have proven to be quite effective. The amount of secondary RW resulting from RW PC operations is considered to be quite insignificant and this waste is also subject to processing at RW PC. Several projects have been implemented under Rosatom Industrial System to increase RW processing capacities at NPPs, such as:

- Attaining the Design Capacity of RW PC;
- Process Optimization. Estimated RW Liabilities.

The first one is focused on decreasing the filled capacity of Smolensk NPP LRW storage facilities through the increase in LRW processing capacity. The second one enabled to reduce the cost of process operations by 18 % due to the use of cheaper containers and compaction process optimization (2 staged compaction).

Service life of 40 years specified in the designs for all containers will enable to cover NPP needs in terms of RW processing during the whole life time of NPP units.

Current RW processing rate suggests that the available capacities are sufficient (also taking into account future built projects) to address the challenge associated with the elimination of accumulated RW before new NPP units are commissioned. Further improvement in RW management efficiency can result from the use of some different types of RW containers. RW PC design development was started in the early 2000's. At this time the list of available certificated container types was quite short. For this reason, it was suggested to use non-retrievable shielding casks (NZK) to package compacted RW. Activity level of the compacted waste packed into these containers is low (VLLW), thus, it looks quite feasible to suggest the use of thin-walled metal container for this purpose. For example, KMZ containers similar in their size to NZK containers. It will enable to package a bigger number of compacted RW briquets into such containers due to its bigger effective capacity [7], thus, reducing the cost of container purchase and RW disposal [8]. Moreover, the number of containers required will decrease by over 20 %.

However, there are certain challenging issues that are to be addressed in order to increase the efficiency of RW processing. For example, as stated in effective standards specifying the classification of retrievable RW (Government Resolution [4]), container type filters containing absorbing material with Cs-137 can be attributed to RW class 2 (in case of maximum duration of use). This means that they are to be disposed of in the planned deep geological disposal facility (Nizhnekansk rock mass). However, this facility is not designed to accept such waste. Bearing in mind that similar RW packages are being produced at Kola NPP with similar facilities planned to be commissioned at Kursk, Leningrad and Beloyarsk NPP, necessary measures are to be scheduled to address this problem. As part of these efforts it seems also important to introduce relevant amendments to RW classification criteria for disposal discussed in [9].

We believe that further management of spent resins is yet another issue deserving particular attention. Experiments show that currently used cementation technology ensures that only some 11 % of the initial material are introduced into the cement matrix. New processing technologies are currently being developed, for example, those involving resin incorporation into polymer matrix. Its composition enables to envelope resin grains with no increase in its volume. Another new technology currently planned for Balakovo NPP suggests resin drying. Spent resin management entails some regulatory issues to be addressed as well. Acceptance criteria [3] specify that free liquid content in RW of class 2 and 3 shall not exceed 3 % which can be a rather challenging task both in terms of achieving these values and arranging for proper control of this parameter. Due to the challenges described above, spent resins are currently not subject to any processing.

Conclusion

In early 2000's RW PC design development was started. In 2011, the first unit of RW processing complex was commissioned. RW PC commissioning was finalized in 2015. RW PC is designed to enable RW processing, namely to treat solid VLLW and liquid RW (bottom residues) accounting for larger part of RW inventory generated by NPPs.

RW PC operational experience has shown that the engineering and technical solutions implemented can be considered effective for most of RW types. Commissioning of the second RW PC unit in 2015, enabled not only to process new annually generated RW inventory, but also some part of accumulated waste from previous operations. At present time, a number of projects is being implemented aiming to increase RW PC processing efficiency, as well as to enhance RW PC capacity.

Key solutions enabling to increase the efficiency of RW management are associated with:

- The use of lighter containers or casks;
- Development of LRW cementation technologies with higher gauging indicators;
- Arranging for VLLW disposal at NPP sites.

No major failures of process equipment have been registered requiring some maintenance to be performed by contractors.

Quality control system covering both the initial materials and conditioned waste has proven to be successful. During RW PC operational time, consistent operation of this system revealed no discrepancies in the quality of RW processing end-products from the specified standards.

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