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TECHNOLOGICAL DEVELOPMENT OF FSUE "RosRAO" AS A PART OF THE INDUSTRY-SPECIFIC INFRASTRUCTURE FOR PROCESSING, CONDITIONING AND STORAGE OF RADIOACTIVE WASTE*

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This article describes promising technological solutions for the processing, storage and transportation of radioactive waste (RW) implemented by a leading Russian enterprise specializing in the field of radioactive waste management. Federal State Unitary Enterprise "RosRAO" performs national-level tasks to ensure nuclear, radiation and environmental safety in the treatment of all types of radioactive waste. To date, FSUE "RosRAO" has a number of ready-made solutions aimed at saving resources while maintaining the radiation and environmental safety by reducing logistics costs due to using large containers for transportation and storage; maximum recycling of waste at the site of its formation or interim storage with the help of mobile systems; creation and operation of easily erected facilities for temporary storage of solid radioactive waste before transferring it for conditioning or disposal. In recent years, we completed a number of major projects focused on improving the radioecological situation on the territory of Russia. The Regional Centre for conditioning and long-term storage of radioactive waste, largest in Russia, was put into operation in Sayda Guba in Murmansk region. Works for state needs were performed to bring radiation-hazardous objects to a safe state and to reclaim territories of the Russian Federation subjects exposed to radiation as a result of past activities in the Trans-Baikal and Stavropol territories, Kirov, Moscow, Ivanovo and Orenburg regions.

Keywords: *processing waste, large-capacity containers, mobile facilities, utilization of nuclear submarines, easily erected storage, decommissioning of nuclear facilities, rehabilitation of radiation-contaminated areas, cleaning of oil-producing equipment from sediments from natural radionuclides.*

Being the largest operator professionally operating sites with radioactive waste (radwaste) storages and providing a full complex of radioactive waste management services in the territory of the Russian Federation, Federal State Unitary Enterprise RosRAO aims at creating a branch infrastructure for processing, conditioning and storage of radioactive waste before transfer to the National operator. To do this, the following prospective activities of the enterprise are being implemented:

formation of a complete production cycle for the management of radioactive waste of any level (very low – VLLW, low – LLW, medium – MLW, high – HLW) based on modern scientific and

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technological achievements for radioactive waste management and optimization of the existing process designs and operation of new mobile complexes;

- development of transport and technological infrastructure and integration into the uniform state system of radioactive waste management;
- complex works for the disposal of nuclear-power submarines (NPS), vessels for nuclear technological maintenance (NTM) and rehabilitation of former Russian Federation Navy objects;
- active promotion of services for removing from operation (RO), control and disposal of nuclear power objects (NPO) and rehabilitation of polluted territories (RPT) including promotion of services to the new markets for removing chemical enterprises from operation;
- entry into new markets of services in the management of materials polluted by natural radionuclides (NRN) above the level of release from under the regulating control according to the radiation factor, but lower than the level of rating them as radioactive waste (creation of disposal sites for low-level radioactive waste);
- active promotion of services for the management of waste polluted with NRN accumulated in the fuel and energy complex: processing of deposited oil slimes, purification and return of equipment and pump and compressor pipes (PCP) of internal deposits with NRN.

The enterprise competitiveness is based on key aspects: the highly skilled personnel, the constantly developing engineering and manufacturing base, the existence of specialized approval documents and licenses.

The introduction of long-run process designs is focused on resource saving while preserving radiation and ecological safety by:

– decreasing logistic costs due to the use of **large-capacity containers** for transportation and storage;

– refusal of power-intensive technologies and technologies leading to large volumes of secondary radioactive wastes;

– maximum processing of radioactive wastes at the site of their formation or at the site of intermediate storage by means of **mobile complexes**;

– creation and operation of e**asily built constructions** for temporary storage of solid radioactive wastes (SRW) before transfer for conditioning or disposal.

So far FSUE “RosRAO” has a number of ready designs [1, 2].

Large-capacity containers based on unified 20-feet containers with a certified internal polymer coating allow increasing 3–5-fold the efficiency of transport and logistic operations. Containers (Figure 1) are designed:

– for collecting and temporarily storing SRW in places of their formation or location in conditions excluding direct impact of subsoil waters or any aggressive environments on the container (in open storage areas under sheds, in pavilions and hangars);

– for transporting by automobile, railway and sea (only UKTN-24000) transport from collecting points to a specialized organization.

SRW's of low specific activity – metal parts of equipment, pipelines, polluted glassware, ceramics, polymers, rubber, construction garbage, soil, ion exchange resins, cardboard, wood, biowaste – are placed in containers in primary packings. Types of primary packings and containers used to transport SRW's in large-capacity containers are as follows: soft containers like "Big-Bag" up to 1.3 m^3, metal barrels of 200 dm^3, certified metal containers KMZ, KRAD-1,3, KRAD-1,36; KRAD-2,7MO; KRAD-3,0; KM-RAO-2,8; KTO-800.

Container PU-2STK-SK enables horizontal loading and unloading through side doors, and vertical loading and unloading − through a removable roof.

The design of all large-capacity containers provides durability and resistance to the effect of static and dynamic stress arising upon transportation, loading and unloading and upon store handling subject to loading capacity and rules of load fastening; the possibility of repeated deactivation of outer and inner surfaces.

a *b*

c *d*

e *f*

g

Figure 1. Large-capacity containers for SRW used in FSUE “RosRAO”:

a, *b* − PU-2ETs-SKh; *c*, *d* − PU-2ETs-SS; *e*, *f*, *g* − PU-2STK-SK.

Container PU-2STK-SK has a number of advantages as compared to similar large-capacity containers for transportation and temporary storage of radioactive waste, such as UKTN-24000, PU-2ETs-ST and PU-2ETs-SS:

– the convenience of repair, technical inspection of the container and its components;
– the possibility of free assembly/disassembly (extraction) of components of the system for fastening containers, receptacles, packings with SRW;
– the possibility of stacking loaded PU-2STK-SK with the maximum load of 942 kN at each top angular fitting;
– the lever design for fixing and unblocking the removable roof provides fast carrying out operations and safe fixation;
– the mechanism for the fixation of the removable roof is placed in the container, which prevents the possibility of access to the load and allows quickly fixing the roof or its unblocking;
– the floor of the container is covered with stainless steel 08Kh18H10 providing mechanical strength and deactivation.

The mobile complexes for processing radioactive waste allow to process quickly radioactive waste decreasing their volumes up to 1.5–7 fold directly at the site of their formation [3].

Radioactive wastes have various aggregate states and morphologies (dry, metallic, moldable, burning, liquid, heterogeneous, exhausted closed sources of ionizing radiation, soils etc.), and they are placed in all regions of the country. To create a corresponding set of stationary technologies for processing and conditioning all forms of radioactive waste considering their uneven concentration at the enterprises of the country, as well the inexact forecasts of the formation of different types of radioactive waste (first of all, when removing nuclear power objects from operation) is an extremely difficult technical and economic task. In the modern regulatory conditions the cycle of creation of such stationary objects takes from 3 to 5 years, which does not enable flexible and quick adjustment according to the needs of the industry sector.

Considering the best international practices, FSUE “RosRAO” is oriented to the operation of mobile installations for radioactive waste management for the purpose of maximum processing of wastes at the sites of their formation. This allows increasing considerably ecological safety at all stages of radioactive waste management, to decrease logistic expenses, to establish quickly the management at the sites.

In 2014–2015 a mobile complex for sorting, fragmenting and prepressing SRW in 200 dm^3 barrels (Figure 2) was developed, made, tested at start-up and put into operation. The mobile complex with a productivity of 270 m^3/year is based on three containers of standard size 1CCC. Its basic technological element is a 25 t press providing 2–4-fold SRW volume reduction.

Figure 2. Mobile complex of FSUE "RosRAO" for sorting, fragmenting and prepressing SRW in 200 dm^3 barrels.

FSUE "RosRAO" created a mobile installation for treating liquid radioactive wastes (LRW) within the framework of cooperation with the JSC "V. G. Khlopin Radium Institute". The installation includes an ultrafiltration block, a reverse osmosis block, a block for evaporating salt concentrate formed on reverse osmosis membranes and a cementation block. The modular complex productivity is 1 m^3/h (calculated for initial LRW), a 200 dm^3 barrel per shift (calculated for the final cement compound). Water purified according to discharge regulations is discarded into soil. Monitoring and control of the technological process is made by means of an automated system. Auxiliary systems include radiation control, ventilation, lighting and emergency power supply.

Research and development works aimed at creating mobile installations for SRW compaction, deactivation and burning were started. A promising project in this area is the creation of a mobile hot chamber for recharging/discharging exhausted closed sources of ionizing radiation according to foreign analogs.

One of components of the mobile complex for SRW deactivation that is being developed in collaboration with JSC “VNIIHT” is the air-ice installation “Gradoboy” (which means “hail damage” in Russian – *translator's note*) intended for deactivating surfaces with the use of cryotechnologies. In Russia there are no analogs of such a mobile installation: only installations for dry abrasive processing using sand or pellets are known. An essential shortcoming of such installations is dusting and, therefore, considerable formation of secondary liquid LRW. Installations for cryogenic blasting (ASCOJET, BUSE, Cold Jet, Cool Blast, Trivintek and Wickens Dry Ice Blasting) using accelerated solid CO_2 granules are known abroad. However, cryogenic blasting cannot be applied to deactivate radioactive pollution of SRW because of the necessity of additional apparatus implementation for obtaining dry ice. Besides, the hardness of CO_2 granules is insufficient: it enables only removing slight superficial pollution. One more reason for cryogenic blasting inapplicability is the formation of radioactive acidic fog polluting the vicinity as a result of interaction of CO_2 granules with the polluted surface.

The developed “Gradoboy” installation uses monodisperse ice granules. When the granules hit the object surface, their kinetic energy in the impact point turns into surface microcompression energy. Reverting to the original state the surface “rejects” the pollution from itself along with the remainder of the ice granules. As a result of heat exchange the granules break up and heat up passing into a liquid and gaseous state. The formed liquid and gas having high potential energy get into the space between the pollution particles and deactivate the surfaces.

The mobile complex for deactivation includes a system of compressors and nozzles (blasters) for obtaining and accelerating ice granules; a block for SRW deactivation with recirculation of polluted melt-water subjected to mechanical purification and directed again for freezing; and a block for preliminary fragmentation of SRW by a unified hydrocutting tool. The complex will be placed in unified 20-feet containers, which will enable transporting it with any transportation vehicles and preparing it for work at the facility as soon as possible.

Easily built storages (buildings of hangar type) enable placing wastes of the VLLW and LLW (MLW) categories for temporary storage in containers. An advantage of such storages (Figure 3) is the simplicity and low cost of their removal from operation.

In regions of the Russian Federation, large-scale actions are planned within the Federal target program "Ensuring nuclear and radiation safety for 2016–2020 and for the period till 2030" in order to remove facilities from operation. This inevitably results in the formation of large volumes of low level (LLW) and very low level (VLLW) radioactive wastes. These are metallic and concrete fragments of buildings and constructions, of pipelines, air ducts, equipment, polluted soil, construction waste. Before creation of disposal points in regions an alternative option of transferring such waste to the specialized organization FSUE “RosRAO” is only placing waste on platforms of

the industry sector enterprises. This will require from the enterprises increasing staff for providing radiation safety, which will complicate and slow down works for removing nuclear objects from operation and will make them more expensive. In addition, there are almost no free containers for SRW storage in regional branches and offices of FSUE “RosRAO”.

Figure 3. Temporary storage of containerized SRW in easily built constructions.

Putting in operation the easily built storages for temporary (up to 15 years) placement of containerized SRW upon the condition of competent logistic decisions in regions will allow optimizing specific costs of radioactive waste storage, reducing the shortage of storage volumes before transferring radioactive waste for disposal to the National operator, ensuring the radiation safety of regions and satisfying the need of the industry sector enterprises for transferring and placing radioactive waste.

Integrated works for the **disposal of nuclear submarines**, nuclear technological service ships and for the rehabilitation of former objects of the Russian Federation Navy are conducted in branches of FSUE “RosRAO”: the Northwest center for radioactive waste management (SZTs "SEVRAO") and the Far East center for radioactive waste management (DVTs "DALRAO").

The regional Center "Sayda-Guba" (SZTs "SEVRAO") is an example of successful international interaction for solving serious radioecological problems. Sayda-Guba is a fishing settlement in Murmansk region on the Barents Sea coast. It is included in an urban district of the Closed Administrative-Territorial Entity Skalisty. In 1990 it was transferred to the Northern Fleet, and its pier zone started to be used for parking laid-up nuclear submarines. In 2003 the Ministry of the Russian Federation for Atomic Energy (nowadays Rosatom State corporation) and the Federal Ministry of Economics and Work of the Federal Republic of Germany concluded an agreement in order to implement the arrangement reached at the summit the Group of Eight. The agreement included the following items: to create a coastal point for long-term storage of reactor compartments of nuclear submarines; to accelerate nuclear submarines disposal and create

conditions for safe management of radioactive waste; to put the environment in Sayda-Guba in ecologically safe state (Figure 4).

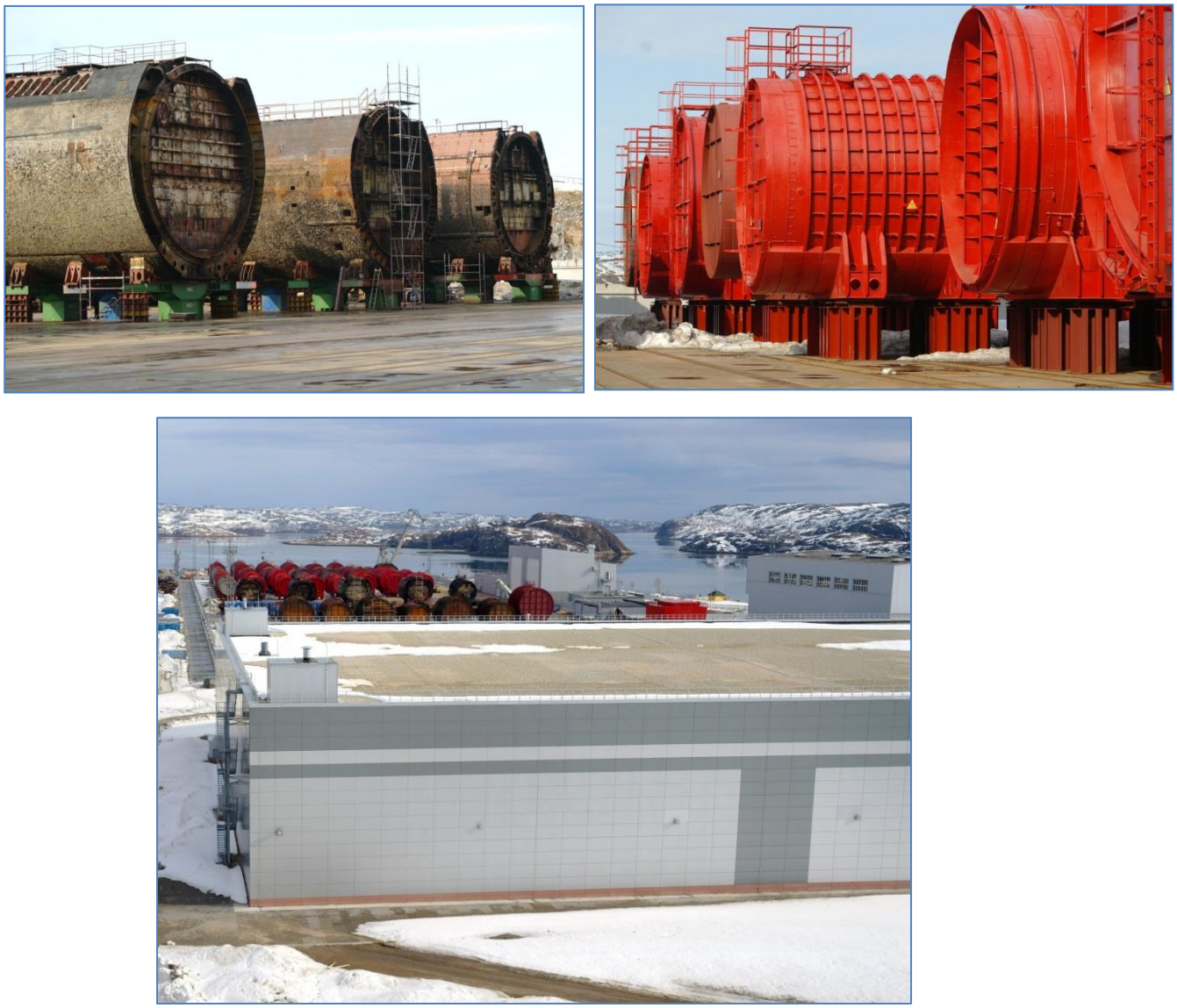

Figure 4. One-compartment blocks of nuclear submarines in Sayda-Guba.

In 2004, design and construction of points for long-term storage of one-compartment reactor blocks of disposed nuclear submarines was started. At first, one-compartment blocks were produced at ship-repair plant “Nerpa”. The first seven of them were placed for 70 years’ storage in Sayda-Guba in 2006. By now, more than 70 one-compartment reactor blocks have been accepted for storage and maintenance. In 2014 SZTs "SEVRAO" – a branch of FSUE “RosRAO” – started forming independently one-compartment blocks. It is expected that the number of blocks produced at “Nerpa” plant per year will be exceeded by 2016. As provided by the “Concept of radioactive waste management in the Northwest region of Russia No. 2.3663k” approved by S. V. Kiriyenko in

2008, design and construction of the largest in Russia Regional Center for conditioning and long-term storage of radioactive waste (Figure 5) was started. The center was put in operation in 2015, and since 2016, the program for elimination of cold war legacy in the Northwest region of Russia will be in full force.

Figure 5. The Regional Center for conditioning and long-term storage of radioactive waste in Sayda-Guba.

FSUE “RosRAO” participates in the implementation of the Federal Target Program “Ensuring nuclear and radiation safety” within state contracts for **removal from operation**, elimination and disposal of nuclear power objects and **rehabilitation of polluted territories**.

Public service works for putting radiation-dangerous objects in a safe condition and recultivation of territories of the Russian Federation subjects that underwent radiation exposure as a result of past activity (the Stavropol and Zabaikalye Territories, the Kirov, Moscow, Ivanovo and Orenburg regions) were performed. The total area of recultivated lands is more than hundreds of thousands square kilometers [4]. The works for the rehabilitation of platforms of JSC Podolsk Plant of Non-ferrous Metals including sorting of the polluted soil on the platform of ash disposal area No. 1-5, transportation of radioactive waste for storage and rehabilitation of the territory of the refining department and ash disposal area No. 1-5 in order to use them for production purposes are complete. The experience of fulfilling state contracts for removal from operation and rehabilitation of polluted territories by FSUE “RosRAO” enables planning promotion of services for the removal of chemical enterprises from operation to new markets.

Large-scale actions within the FTP-2 for radiation safety are planned in regions of the Russian Federation in order to remove from operation radiation-dangerous objects. Such objects inevitably lead to the formation of large amounts of LLW and waste polluted by radionuclides above the level of release (hereafter referred to as VLLW, "very low level waste"). Polluted soil, construction garbage, metallic and concrete fragments of buildings and constructions, pipelines, air ducts, equipment are often VLLW. On one hand, the content of radionuclides in them does not enable rating them as radioactive waste (according to the criteria established by the decree of the Russian Federation government of October 19, 2012 No. 1069 "About criteria for rating solid, liquid and gaseous waste as radioactive waste, criteria for rating radioactive waste as special radioactive waste and as disposable radioactive waste and criteria for classifying disposable radioactive waste"). On the other hand, it is not possible to decontrol them taking into account the radiation factor according to Principal Sanitary Radiation Safety Rules 99/2010. The management of such waste is limited by the requirements of Principal Sanitary Radiation Safety Rules 99/2010. Meeting these requirements in practice is difficult, because the existing normative legal documents do not set rules of treating such waste, including their disposal. Actually, VLLW management nowadays is carried out by methods similar to those for radioactive waste management, which considerably increases the price of the works. The problem is pressing for many enterprises and organizations of the Russian Federation, where works for removing nuclear and radiation-dangerous objects from operation and rehabilitation of polluted territories are carried out. Foreign experience of the managing such waste is known.

FSUE "RosRAO" conducts work for the creation of grounds for storing VLLW. It also takes part in the development and approval of normative legal documents setting requirements and validating design and technological solutions for VLLW management. For 2016–2017 it is planned to carry out engineering and exploring works, to develop designing estimates and working documentation for the creation of points for placing production waste with high concentration of radionuclides in the Samara branch of Privolzhsky Territorial District of FSUE "RosRAO".

Perspective projects of FSUE RosRAO in collaboration with inland and foreign producers of specific equipment are mobile installations for cleaning oil and gas equipment from internal alluvial pollution containing high concentrations of natural radionuclides, and also for purification of oil slimes deposited in ponds in oil extraction places. The integrated solution of radioecological problems of the Russian Federation fuel and energy complex proposed by FSUE "RosRAO" exhibits commercial benefit due to the transformation of waste into consumable goods and ecological advantage of the disposal of waste with high concentration of natural radionuclides. Large oil-processing enterprises of the Volga region and other oil-extracting regions of the country are interested in the results. Carrying out this work answers the purpose of Rosatom State

corporation associated to the diversification of services and entry into new markets of ecological services outside Rosatom State corporation. Besides, it conforms the technological strategy of greening of the oil-extracting complex, efficient use of resources and recycling of oil waste.

So far enterprises of the Russian Federation fuel and energy complex accumulated a considerable amount of oil slimes containing concentrated NRN impurities. For this reason they are classified as low-level radioactive waste. On one hand, their transfer for storage to FSUE "RosRAO" is inexpedient due to their huge amount and low level of radiation hazard. On the other hand, using them without additional purification is unacceptable.

In 2013 preliminary research of a sample of oil slimes having a high content of NRN was performed, and it was found that radiation pollution is typical of the inorganic component. The organic fraction is a mixture of various paraffin hydrocarbons. If it is separated from the inorganic fraction containing radionuclides, it can serve as a raw material for the production of various useful products (bitumens, fuel) or can be returned into the basic production cycle of the oil-processing enterprises. Its use should compensate the cost of radioactive waste separation and disposal. The radioactive impurities thus separated in the liquid or solid state can be transferred for storage and processing to FSUE "RosRAO". The proposed technological solution will enable carrying out controlled isolation of radionuclides from the three-phase system "water – organic phase – solid cake/slime" in mobile installations delivered to the places of oil slimes accumulation.

One of problems of ensuring radiation and ecological safety at the objects of the fuel and energy complex is the management of equipment polluted by deposits containing NRN. These are pumping and compression pipes, capacitive and technological equipment, fittings, pumps, tanks. Sources of radioactive pollution are the natural uranium and thorium radionuclides, radium and potassium-40 contained in the Earth crust and taken out to the surface as a result of oil production. As a result of coprecipifation, adsorption and cocrystallization with barium and strontium sulphate precipitates radium isotopes contained in stratum water, mainly in the ionic form, are deposited on the internal walls of the pipelines and equipment in the form of water-, acid- and alkali-insoluble salt sediments with a density of 3.0–3.9 g/cm^3 (Figure 6).

Figure 6. Pumping and compression pipes for oil production polluted by internal deposits of Ba(Sr, Ra)SO_4 with natural radionuclides coprecipitated from stratum water.

As time passes, ^{206}Pb isotope with its associated isotope ^{210}Po (from ^{226}Ra) and ^{228}Th with its associated products (from ^{228}Ra) accumulate in the precipitate. Thus, NRN's initially not contained in such quantities in stratum water accumulate in the precipitate.

Decommissioned equipment with radioactive deposits is stored with a view to be returned in the future to production, because pumping and compression pipes (PCP) and some equipment are in operable state and are the basic production assets of oil-producing enterprises. According to incomplete data the total of pumping and compression pipes can make some hundreds of thousands of tons. Cases are known when radioactive slime causing gamma radiation up to 500 μR/h on the exterior surface was found inside separating tanks. This is 50-fold higher than the level of natural radiation gamma background in the oil-field territory. FSUE "RosRAO" develops ecologically acceptable technologies for the purification of oil- and gas-extracting equipment from "radiobaryte" deposits. It offers services associated with SRW management and return of PCP for further operation.

The experience of FSUE "RosRAO" – the leading specialized enterprise of the Russian scale – is a technological basis for the creation of the branch infrastructure for processing and conditioning of radioactive waste and for its integration into the uniform state system of radioactive waste management. FSUE "RosRAO" fulfils national tasks of ensuring nuclear, radiation and ecological safety in the process of managing all types of radioactive waste. It forms public confidence in the nuclear industry and leadership of technologies and competences of Rosatom State corporation in the field of nuclear backend in the global market.

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