Design solutions for the creation of VLLW disposal facilities in the RF North-West region

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Abstract

The report discusses key aspects having an effect on shaping design solutions in the creation of very low-level waste (VLLW) disposal facilities (DF).

Presented is a brief description of urgent VLLW management problem in the Russian Federation in view of the existing and recently developed sanitary regulatory documents.

An analysis has been made of the VLLW characteristics arising in the Andreev Bay at different rehabilitation stages to generate design solutions.

An evaluation has been carried out of various VLLW DF design approaches for the Andreev Bay site.

Based on the general site selection criteria for the VLLW DF the site and the DF design have been identified.

A review of key aspects (DF capacity, package types, operation period etc.) having an effect on DF design solutions has been done.

Presented are the preliminary results of economical assessment to create the VLLW DF at the Andreev Bay and a preliminary analysis of economical efficiency for LLW and VLLW separate disposal.

List of abbreviations

N/SM	–	nuclear submarine
LRW	–	liquid radwaste
LLW	–	low-level radwaste
VLLW	–	very low-level radwaste
SNF	–	spent nuclear fuel
TSF	–	temporary storage facility
LTSF	–	long-term storage facility
DF	–	disposal facility
VLLW DF	–	very low-level waste disposal facility
RW	–	radioactive waste
ILW	–	intermediate-level waste
SRW	–	solid radwaste
FS	–	feasibility study

1 Urgent problems

The North-West region of Russia hosts many enterprises of defense and national importance which are potential sources of nuclear and radiation danger.

Of special concern are facilities of nuclear legacy, namely: former coastal technical bases of the USSR atomic fleet at the Andreev Bay and village of Gremikha and a lot of other defense facilities. Nuclear fuel and radwaste at those facilities are stored within unfit structures and even at open pads.

Geology at the radwaste storage locations is mainly presented with loose rock having a high permeability and, as a result, the territory got contaminated and now is subject to rehabilitation.

Currently a complex of activities is carried out at the main facilities of nuclear legacy – the Andreev Bay and Gremikha village – to rehabilitate the territory, move off the SNF for reprocessing, create radwaste treatment systems and to send radwaste to the Saida Bay dedicated facility for long-term storage.

Up to now conservation, superconservative and costly approaches were used when creating the RW management systems which were based on the available RW classification. Currently a new group of waste – "very low-level waste" is being singled out in the RF classification.

The very low-level waste does not meet the exempt criteria but it does not require a high degree of isolation and radiation shielding which allows to dispose of them in the near-surface disposal facilities.

The very low-level waste has a comparatively short period of potential hazard, on the average up to 100 years, which allows to place the VLLW disposal facilities on the facility site under rehabilitation.

Creation of the VLLW disposal facilities carries a "key" to optimize the RW long-term storage and treatment as the singling out of the VLLW category from the general RW stream will reduce VLLW volumes coming to the RW long-term storage facilities.

At the present time OJSC "Leading institute "VNIPIET" is being developed the project for the VLLW disposal facility – a first in the RF North-West region within the Andreev Bay TSF.

2 Regulatory baseline and VLLW characteristics

Till now no VLLW category was available in the RF classification system and, consequently, no VLLW management and disposal regulation was available. The OSPORB-99 [1] was the only document which vaguely mentioned this waste group.

In March 2008 a regulatory document the "Hygienic requirements for industrial waste management at the Federal state unitary enterprise "North Federal radwaste management enterprise: was introduced. The document has been developed specially for the FGUP "SevRAO" enterprises and sets requirements to assure safe management of **production waste** with low-levels of toxic materials and man-made radionuclides historically accumulated and arising during rehabilitation of the SNF and RW temporary storage facilities at the SevRAO enterprises and also sets requirements for design, maintenance and operation of the disposal landfill.

In line with this Regulation to the VLLW refer waste, if:

<u>at an unknown radionuclide content</u>

– the inequality satisfied:

$$P_1 < P \leq P_2, \qquad (1)$$

where P – dose rate near the waste surface (0,1 m); P_1 - dose rates due to the natural radiation background characteristics of a given locality; P_2 - dose rate near the waste surface (0,1 m) with an unknown radionuclide content with the increase of which it is treated as a solid radwaste - in line with SPORO-2002 [3]

$P_2 =$ 1 μSv/hr.

- its content of *β-emitting* radionuclides amounts to 0,3 – 100 kBq/kg, *α- emitting* radionuclides amount to 0,3 – 10 kBq/kg, *transuranic radionuclides* amounts to 0,3 – 1 kBq/kg.

if two conditions are satisfied at <u>a known radionuclide content of waste</u>:

$$0{,}3 \text{ kBq/kg} < a_i < SL \quad (2)$$

$$\sum_i^n \frac{\grave{a}_i}{SL_i} \leq 1, \quad (3)$$

where a_i is a specific activity of i-th radionuclide within the waste;
SL - screening limit Bq/g.

The SevRAO waste feature is that, as a rule, their activity and personnel exposure dose are mainly contributed by ^{60}Co, ^{90}Sr, ^{137}Cs (up to 95 %).

Table 1 in the Regulation presents reference criteria to VLLW with an average waste composition of ^{90}Sr (20%) and ^{137}Cs (80%) and a negligible content of α-emitters (<0,1%).

Table 1 - Industrial waste sorting criteria at the SevRAO with isotopic composition: ^{90}Sr (20%) и ^{137}Cs (80%)

Waste category	Specific β-activity, kBq/kg	Surface contamination, β-part/m*sm^2	Dose rate 0.1 m off package surface, μSv/hr
Exempt waste	≤ 0,3	≤ 50,0	Not to exceed natural radiation background characteristics of this locality, more than by 0.1
VLLW	0,3 – 12,0	50,0 – 500,0	0,1 – 1,0
Note: *Specific activity and surface contamination are used simultaneously and do not rule out each other.*			

These criteria should be recalculated in line with formulae (2) and (3), if waste with another isotopic composition is available.

When sorting the historical waste with an unknown isotopic composition and impossibility to determine it the waste may be sorted by γ-radiation levels (see formula 1).

More over, the γ-emitting waste *of the unknown radionuclide composition* may be exempted, if: dose rate 0.1 m (P) off its surface does not exceed top boundary of the dose rate measurement range (P1) from the natural background characteristic of a particular locality:

$$P \leq P_1 \quad (4)$$

Waste *of the known radionuclide composition* with any mass is exempted, if the following condition is satisfied:

$$\sum_i^n \frac{a_i}{a_{0i}} \leq 1 \quad (5)$$

where: a_{0i} - the value of maximal specific activity of nuclide *i* within the waste with which it is exempted, if no other radionuclides are available, kBq/kg. In line with OSPORB-99 the a_{0i} values for all radioniclides are 0,3 kBq/kg.

Specific activity of up to 30,0 kBq/kg is allowed in the analysis of disposal system's radiation safety for the public, personnel and environment in view of site characteristics, design features and landfill barrier characteristics and radionuclide composition of waste to be sent to the TSF disposal landfill. Water whose specific activity reaches 100,0 kBq/kg (table 2) may be disposed of in individual packages (no more than 10% of the total disposal volume).

Table 2 Permissible VLLW characteristics to be sent to the SevRAO disposal landfill, (isotopic composition: ^{90}Sr (20%) and ^{137}Cs (80%)

Very low-level radwaste	A_{SP} in package, (kBq/kg)	Max A_{SP} in package, (kBq/kg)	Surface β-contamination (part/m*smм^2)	EDR, (μSv/hr)	α - content (%)
	0,3-30,0	< 100,0	50,0-500,0	< 1,0 0.1 m off	< 0,1

Exempted waste and materials may be sent to the industrial waste landfills for disposal outside the "SevRAO" industrial sites or may be used in economy without any restriction.

3 General approach in decision-making on VLLW DF construction

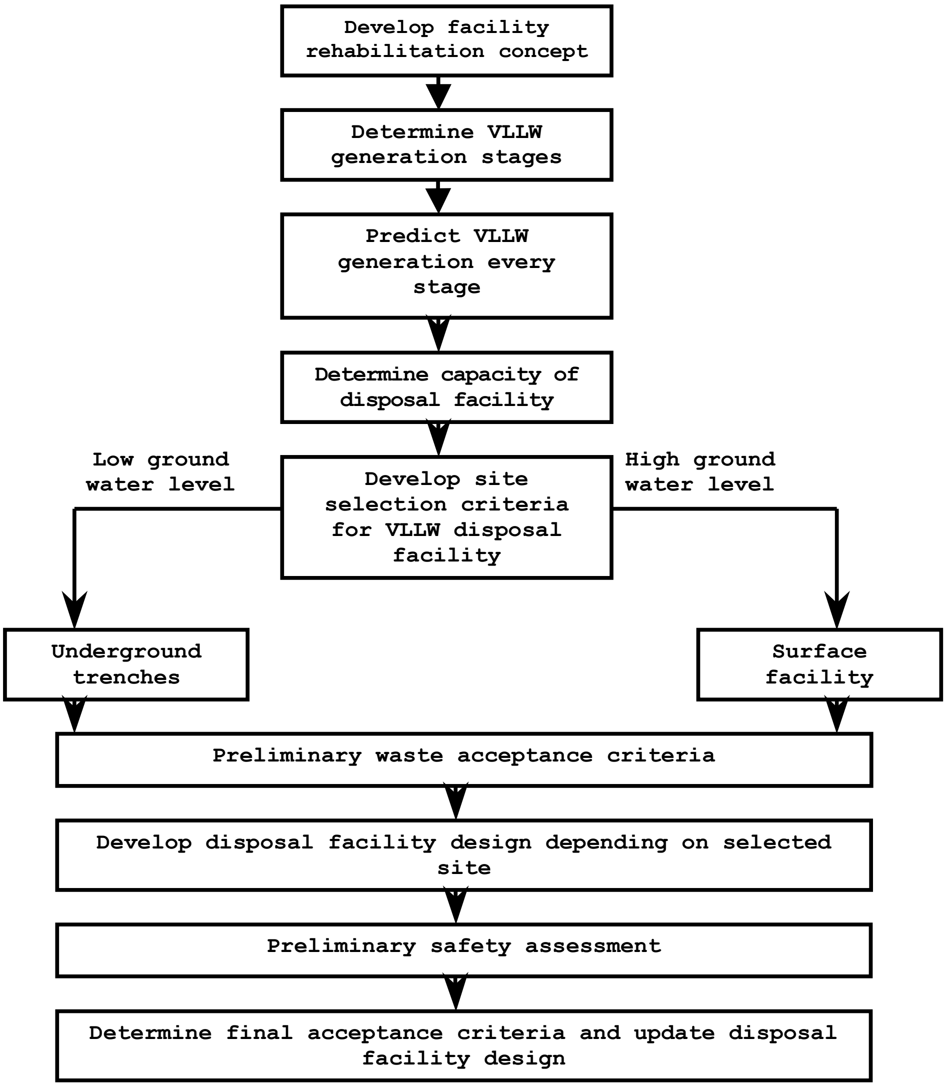
In line with P 2.6.5.04-08 the VLLW is allowed to be disposed of in the near-surface disposal facilities.

In decision – making on VLLW DF construction a certain algorithm may be used or a general approach which takes into account specific conditions of the facility and its rehabilitation concept. Fig. 1 presents an algorithm for the Andreev Bay facility.

The adopted rehabilitation concept to identify working conditions and phases for that facility is the starting point in decision – making on the necessity to construct the VLLW DF at the Andreev Bay TSF. Then to be determined are main VLLW sources and generation phases, projected evaluation of VLLW generation at every work stage (for instance, preparation for construction, construction, decommissioning etc.). Based on the obtained data the disposal facility capacity to be determined for each VLLW generation stage. The number of disposal facilities on the site to be determined by the availability of vacant areas, VLLW generation stages and waste volumes.

The choice of a disposal method (surface, shallow, deep), disposal depth, the number and properties of barriers as well as their purpose to be determined in the land fill project depending on:

- waste form;
- waste quantity;
- radionuclide composition;
- total and specific activity;
- hazard category;
- host rock properties;
- geological and hydrogeological characteristics of the region and the disposal facility site (in particular, ground water level).



Fig, 1 - Design-making algorithm for VLLW disposal facility construction

Then to be determined are the preliminary acceptance criteria and the disposal facility design depending on DF site features.

Following up the preliminary safety assessment the need for updating the acceptance criteria and the DF design should be evaluated.

4 Launching of VLLW disposal at the Andreev Bay TSF

At the present time, OJSC "Leading institute "VNIPIET" have completed the technical and economical feasibility study (TEF) for the VLLW disposal options at the Andreev Bay TSF and started to develop the design.

The TEF contains and analysis of VLLW generation sources, VLLW DF construction phases, the construction site and an analysis of optimized VLLW DF specifications.

4.1 VLLW generation sources

Sources of VLLW generation in the sources of Andreev Bay TSF rehabilitation are:

- buildings and structures to be dismantled when constructing the SNF and RW management shops,
- solid RW stockpiled within the "old" RW storages and at open pads,
- facility area to be improved.

The following VLLW will be generated in performing these works:

- building structures (concrete, bricks, rebars etc.),
- soil,
- individual protection means, packaging materials.

In line with «Regulation…» [2] the VLLW to be collected close to places of their generation.

The VLLW should be classified and collected into different packages depending on:

– specific activity and chemical characteristics;
– fire and explosion hazard;
– size (fine- and large-sized);
– waste treatment procedures;
– type of disposal or economic use.

No RW mixing with VLLW is allowed when collecting the VLLW.

4.2 Disposal facility construction phases and projected VLLW phases

Construction phases of the VLLW disposal facilities are governed by the facility rehabilitation phases at the Andreev Bay and waste generation in time allows to classify the VLLW into 3 waste streams:

– 1-st stream – VLLW generated during ~2- 4-x years before and in the course of SNF, SRW and LRW management shops construction;
– 2-nd stream – VLLW generated during 10 - 15 years in operation of the SNF, SRW and LRW management shops and in dismantling the existing SRW storages;
– 3-rd stream - VLLW generated in decommissioning of the Andreev Bay TSF and territory rehabilitation. The stream includes decommissioning of the existing SNF and RW management buildings and structures and the conditioned RW storage as well as territory rehabilitation.

Fig. 2 presents VLLW generation phases and projected volumes in the course of Andreev Bay TSF rehabilitation.

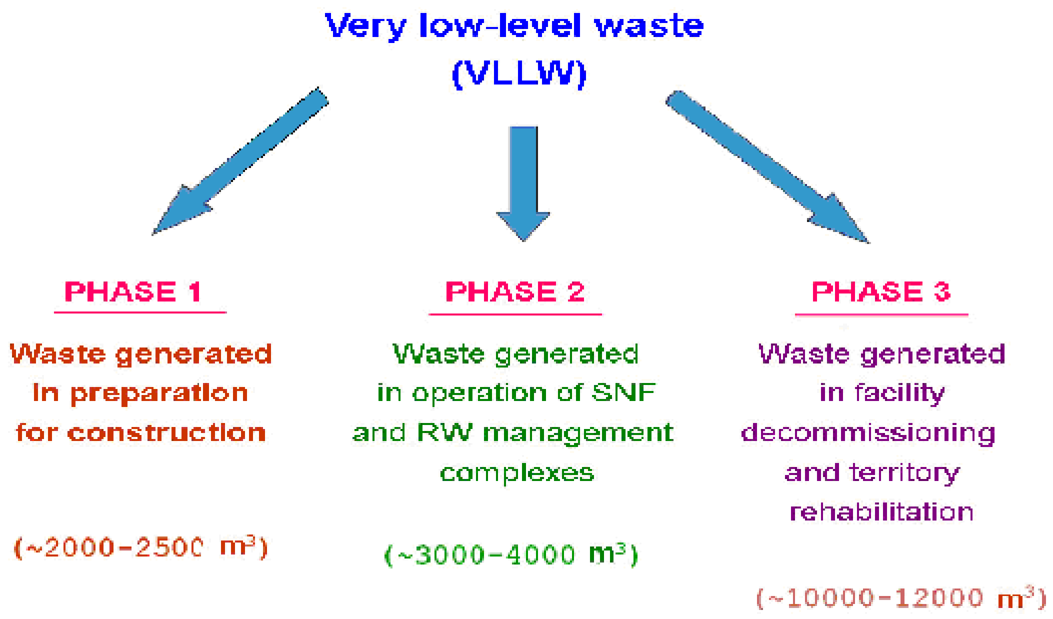


Fig. 2 – Phases and projected amounts of VLLW generation at the Andreev Bay TSF

Due to phase 2 and 3 remoteness in time and the lack of vacant areas in the TSF technical territory to arrange the disposal facilities in these phases a 2000 m^3 VLLW design is being now developed for phase 1.

5 Justification of VLLW DF specifications

5.1 Site selection

In line with "Regulations…" [2], geological, hydrogeological and seismic features should be taken into account in site selection for the disposal facility. The site should have access roads for vehicles with materials, equipment and waste. The site should not be promising for economic activities, These requirements are satisfied by VLLW DF arrangement at the Andreev Bay TSF technical territory. However, due to the shortage of vacant areas in the technical territory all the possible options have been studied in the analysis of VLLW DF constructability. Five candidate sites were considered at the TEF stage: a site within the fuel oil tanks area, a site within the boiler-house area, a site near the former SNF storage, a site near the substation, a site near the wharf.

The VLLW DF site was selected based on the following principles:

- not to disrupt the SNF and RW traffic;
- unattractiveness to use areas for construction of primary facilities.

Following up the study, the site within the fuel oil tanks area has been selected. A preliminary analysis of the engineering and geological survey data within the Andreev Bay TSF technical territory has shown the feasibility to construct surface (hill-type) facility but not an underground (trench-type) one. A high level of underground water within the Andreev Bay TSF area does not allow to implement the underground facility [4].

5.2 Options for the VLLW disposal facility

Different options have been discussed while performing the TEF [4]: trenches, hill-type facilities, the available items.

The safety assessment results have shown an inexpedience to place waste into available the fuel oil tanks which is connected with difficulty to seal the old tanks, to provide the underlying shields and with a high permeability of the tank walls which ultimately will result in radionuclide migration, if precipitation gets into the disposal area.

Different options for the near-surface facility designs have been also elaborated within the TEF: of rectangular and square form with no reference to the site and with the retaining wall and a reinforced base with reference to the site.

Following up the options analysis a surface disposal facility (hill-type) has been recommended for further design. The design of a similar VLLW disposal facility in the Oskarshamn (Sweden) has been adopted as a basis.

5.3 Types of packages to come to the VLLW DF

In line with the "Regulation" [2] the VLLW should come to the DF as-packaged on special vehicles. Packages to be disposed of are:

- large-sized containers for large-sized waste and debris;
- big-bags for soil and small debris;
- compacted soft VLLW briquettes.

The VLLW bags and containers coming to the DF perform only the shape-forming function when placed in the disposal facility.

5.4 VLLW preparation for disposal

The VLLW do not require special preparation for disposal.

VLLW distribution into packages is envisaged depending on the waste nomenclature (soil, debris, compactable waste, large-sized waste).

A 70 t precompaction is envisaged for compactable (soft) VLLW to reduce volume (~2.5 –fold reduction). 1 m^3 VLLW briquettes come for disposal as a result of precompaction

5.5 VLLW facility specifications

One of the main components of the VLLW facility is a reinforced steel-concrete slab of an intricate configuration 0.3 m thick in the basic part and 0.5 m thick within the retaining wall area (see fig. 3). An option for the VLLW facility with a stepwise base slab is being elaborated at the design stage.

The slab should be laid down on the underlying shield consisting of the following layers (from bottom upwards):

- compacted base;
- sand;
- crushed stone;
- concrete bed.

A system grooves in the slab is envisaged to drain precipitation off the slab. The slab has a 2-3 % inclination to building. Water runs off through the grooves into the sorption layer and then comes into the areaway where sampling is performed to monitor water contamination. After monitoring the water runs by gravity to the terrain.

A 0.5 m thick steel-concrete retaining wall is erected on the west side (rock side) to provide stability and waterproofing. The wall is 0.5 m high in the middle part and downsized to 1.5 m towards the edges.

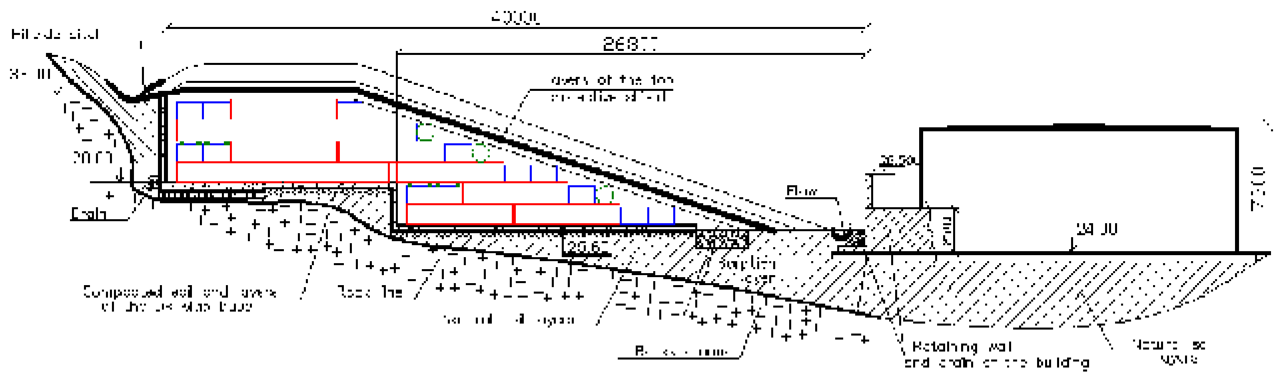


Fig. 3 - VLLW disposal facility design with the stepwise base

Large-sized metal VLLW containers stacked in 3 tiers in height with 0.1 m spacing between the containers form the base of the DF con figuration. Compacted waste briquettes and big-bags (touch polyethylene bags) are placed round the periphery of each stack and in the 4th tier.

The VLLW packages form a dome-shaped section of the facility.

Spacing between the containers and briquettes are filled up with grit rock (sand) to create the vertical filtering section

The following covering shield layers are created over the located portion of the facility:

- stone crumbled layer (very fine gravel-sand) to fill up spacing between the containers and briquettes and to erect a 0.5 m layer over the VLLW packages;
- 2 layers of waterproofing material (total thickness of 3 mm) laid on grit rock;
- ~0.5 m layer of grit rock over the waterproofing material;
- layer of crushed stone and boulders. Total thickness of the layer is ~1.5 m.

Observation wells are located round the facility for environmental monitoring .

5.6 Preliminary VLLW disposal criteria

The preliminary criteria allow to approach by iteration those waste characteristics which will be accepted for disposal at each particular landfill with specific technical parameters (see fig. 4).

The preliminary waste acceptance criteria are developed based on the international experience and requirements of the RF regulatory documents. Then preliminary estimates of safety analysis should be made relying on the adopted waste management concept and the disposal facility design as well as taking into account composition of the underlying and covering shields, the natural and engineered barriers.

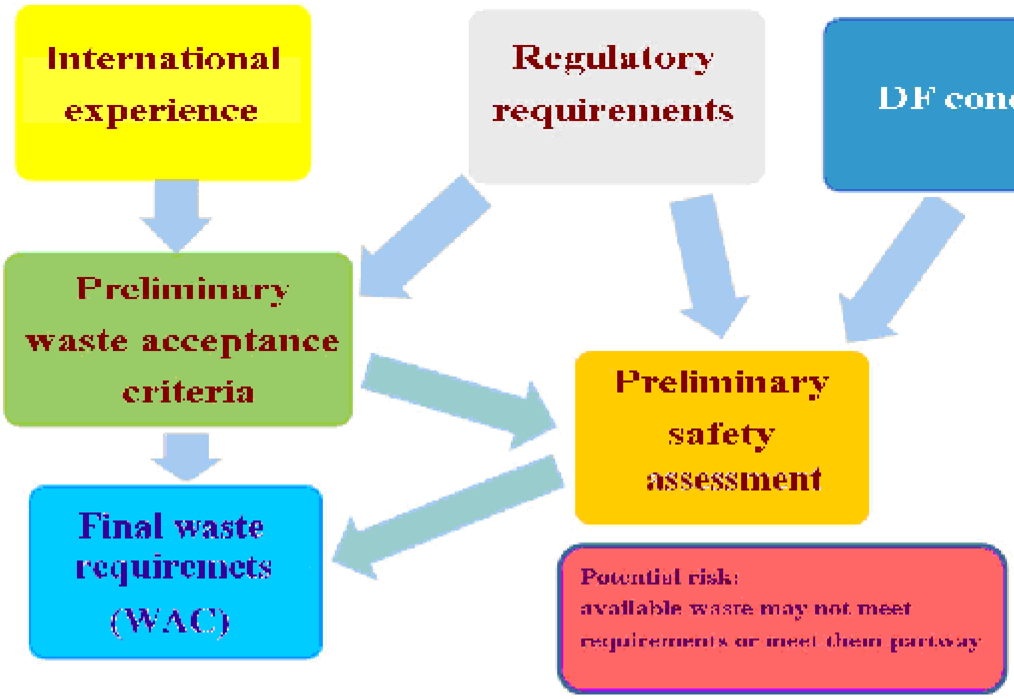


Fig. 4 – Development approach to waste acceptance criteria.

Table 3 presents preliminary waste acceptance criteria for disposal in the VLLW DF.

Table 3 – Preliminary VLLW acceptance criteria for disposal

Parameter/requirements		Value	Note
VLLW package requirements			
Specific activity of in-package radionuclides, kBq/kg		0,3-30,0	
Maximal specific activity of in-package radionuclides, kBq/kg		100	
Surface β-contamination level of VLLW contamination, part/sm^2 min		50-500	
Equivalent dose rate, μSv/hr		<1,0	0.1 m off package
Maximal content of long-lived α-active radionuclides, %		0,1	
Large-sized containers		3-tier stacking	
Mass	Large-sized containers, t	No more than 24	
	Big-bags, t	No more than 1,5	
	Briquettes, t	0,5	
Moisture content		Natural	

Table 3 - Continue

Parameter/requirements	Value	Note
Potential hazard period for VLLW	100 years	
Waste form requirements		
Solid or solidified waste		
Compactable VLLW compacted in briquettes		
Toxicity grade - IV-III		

6 Economic indicators for different VLLW DF designs

Economic evaluation of the VLLW disposal cost made for the Andreev Bay pilot project has shown that the total unit cost of disposal amounts to 17.3 thousand rouble/m^3 of VLLW (470 €).

The estimated cost is more than two times higher than that of VLLW projects have been implemented.

Table 4 presents unit cost of VLLW disposal for countries where the VLLW DF projects have been implemented.

Table 4 - VLLW disposal cost in Lithuania, Sweden, Russia

Country	Disposal facility specifications	Disposal cost of 1 m^3
Sweden	Hill-type disposal facility for 10000 m^3 of waste	154 €
Lithuania *(design values)*	Hill-type disposal facility for 12000 m^3 of waste	190 €
Russia *(design values)*	Hill-type disposal facility for 2000 m^3 of waste 10000m ^{3} - basis	470 € ≈ 295 €

Analysis of the estimated data and methodical approaches to the VLLW disposal cost estimate for different countries has shown that the high VLLW disposal cost for the Andreev Bay TSF as compared with the Swedish and Lithuanian disposal facilities is attributed by the following causes:

- *difference in methodical approaches to the estimate of operating and capital expenses.*. If the covering shield and container costs are charged to operating expense, then the unit cost of VLLW disposal will amount to 9,6 thousand rouble/m^3 (260 €/m^3) . If these costs are charged to the capital expense then the unit disposal cost will amount to 17,3 thousand rouble/m^3 (470 €/m^3);
- *complexity of the facility governed*, by the site terrain: a need for the retaining wall, reinforced base and intricate configuration of the slab;
- *restricted capacity (2000 m^3)*, governed by sizes of the available site - instead of 10000 m^3 or 12000 m^3 as it done in Sweden and Lithuania respectively.
- *need for the construction of a detached building* to accommodate bays for waste precipitation for disposal (VLLW compaction bay).

Taking into account these reasons the following solutions may be used in the detail design to reduce the unit cost of VLLW DF construction:

- maximal use of the existing buildings and hardware available on the site;

– maximal increase of the total DF capacity within the allotted area;

– make changes in the methodical approach to the estimate of investments.

7 Analysis of economic efficiency to create the VLLW disposal facility

RW management cost as well as decommissioning cost for radiation facilities are evaluated by many experts in different countries and the cost diversity is rather high. An accurate evaluation can be given only by actual expenses for a particular facility in view of its special features and after design materials have been completed.

References [6] and [7] contain RW management cost up to the final disposal based on documents received from Sweden, England and Holland. The Russian data have been derived from the "LI "VNIPIET" - designed project for the regional near-surface RW disposal facility in the Leningrad region

Table 5 - Cost comparison for RW long-term storage and disposal in different countries ($/m^3)

Country	LLW	ILW	HLW	Note
Holland	6 500		13 000	Surface storage during ~100 years
Sweden	~ 3 500 (1 000÷5 000)		-	Underground disposal
England	1 900	19 000	-	Underground disposal ILW and HLW long-term storage (~100 years)
Russia	~ 1500		-	Surface disposal

Table 6- Low-level SRW management cost [6]

Country, facility	Construction cost of 1 m^3 (SRW storage)	Total cost (conditioning, long-term storage/disposal of 1 m^3)
Germany	~ 4 000 €	~ 10 000 €
Sweden	1 700 $	~ 4 000 $
England	~ 4 000 €	~ 10 000 €
USA	3700 $	5 000-10 000 $
Russia LSK «Radon» MosNPO «Radon»	~100 000 rouble	134 000 rouble 402 000 rouble

Reference [8] carries an evaluation of LLW disposal at Drigg at a level of £3000/m^3 which corresponds to ~ 5400 $/m^3.

Reference [9] carries an analysis of LLW disposal costs which are within the range from 1000 $/m^3 to more than 8000 $/m^3.

The average cost evaluation of intermediate LLW storage within the conventional surface storage facilities and of final disposal within the near-surface disposal facilities in the form of concrete vaults amount to at least 3000 €/m^3.

A new VLLW disposal facility sized for 10 000 m^3 (6000 t) was constructed in Sweden at Oskarshmn in 2004. Total activity of < 300 GBq, Cs-137 content below 10% and below 1% of α-emitters. The cost including design, licensing, construction and disposal amounts to 154 €/m^3 (257 €/t).

The average evaluation of VLLW disposal cost within simplified near-surface disposal facilities make up ≈ 300 €/м^3.

Simple estimates show that saving of € 2,7 M pre each 1000 m^3 of VLLW can be reached, if a new group of VLLW is singled out from the RW category and in individual disposal flowsheet is applied for that group.

As a rule, 30-60 % of RW arising in decommissioning the facilities of atomic energy utilization may be treated as very low-level waste.

VLLW disposal immediately at the facility site allow to save more than half the funds spent for RW management.

Such a saving justifies all expenses needed to introduce this RW category and create a near-surface disposal facility for it. Probably, just these reasons have played an important role for Sweden to make the decision on funding the surface VLLW disposal facility at the Andreev Bay.

The disposal facility for the VLLW at the Andreev Bay and later on at the Gremikha village will promote and make less costly the whole SRW management flowsheet.

A wide use of the VLLW category in RW management and the construction of simplified disposal facilities for this category will allow to reduce expenses needed to place 1 m^3 of waste by at least 10 times. This will allow to reduce LLW and ILW quantity on account of the scale-up of the VLLW share which, in turn, will allow to strive for the reduction of total expenses including cost for decontamination and SRW placement in storage facilities of different types.

Nevertheless, currently, the construction of intermediate LLW and ILW storage facilities is the common practice in the RF which is attributed to the uncertainty in commissioning dates of disposal facilities due to the lack or insufficiency of funding the design. Taking into account that the prime cost of intermediate RW storage in facilities which satisfy current requirements is comparable with that of the near-surface disposal the use of stopgap solutions is economically inefficient since it leads to double expenditures.

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