A SYSTEM FOR SORTING RADIOACTIVE WASTE OF THE CHERNOBYL EXCLUSION ZONE

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This work is extending the research started in 1998, which are directed on development of a Chernobyl origin radioactive waste sorting system. In this paper the principal scheme and possible engineering solutions of the system for sorting the waste placed in temporary localization dumps of the Chernobyl Exclusion Zone are described.
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1. INTRODUCTION

In works [1,2] the problems of sorting the solid radioactive waste (RW) were considered and the scheme of sorting the Chernobyl origin RW by physical features, activities and lifetime was proposed. Urgency of these researches are caused by the fact that now in Ukraine so large amount of the RW are accumulated that the necessity of its centralized collection and disposal has come to a head. It is concerned both to the RW that have aroused owing to the accident at the Chernobyl Nuclear Power Plant (ChNPP) and to those that are constantly produced as a result of activity of atomic power stations and other objects of nuclear industry, scientific and medical establishments. The structure and amount of the solid RW of Ukraine are presented in Table 1 [3].

At the present time the particular attention is focused on the RW, which are located in the Chernobyl Exclusion Zone (ChEZ). There in the object "Shelter", ChNPP industrial site, stations of temporary localization of RW (STLRW) and stations of RW storage (SSRW) (objects of the state plant "Complex") accumulated are ~2.4x10^6 m^3 of radioactive materials [3] of different activity groups and of a very broad nomenclature. These RW, consisting 98.6% of solid RW of Ukraine, in many cases are placed under conditions not adapted for long-term storage. Inspections of some STLRW have shown [4], that their design and RW storage conditions do not satisfy the requirements of the normative documents regulating RW management in Ukraine. The RW are placed in STLRW without screening from atmospheric precipitation and ground waters. Some of them (e.g. "Neftebaza") are flooded by ground waters so they are uncontrollable radionuclide suppliers to environment.

Such huge badly controlled amounts of RW produce potential danger and require a urgent way for transformation them into a reliably controlled safety state. The ways of solution this problem are designed in the Complex Program of RW Management [5]. According to the Complex Program it is planned to realize the technical design and construction of a RW treatment and disposal center (TDC), with storehouses of low and intermediate activity waste [6]. Also, it is planned to perform a gradual dismantling of STLRW, extraction and moving of waste concentrated in them into TDC storehouses. Therewith, according to the developed scheme of management with RW at TDC [6], RW will be taken for storage in a selected state. The sorting must be done by physical features (pressed, burned, metal, waste non-requiring treatment), activity groups (high (HLW), intermediate (ILW) and low (LLW) active waste) and by their lifetime (long lived (LL) and short lived (SL) radioactive waste). The process of sorting is strongly complicated owing to a broad and non-standard nomenclature of the RW, which are in ChEZ. The developed detailed strategy of management with such RW is not produced yet. In this paper one of the possible variants for solving a part of this large problem is considered.

2. CHARACTERIZATION OF THE RW OF THE CHERNOBYL EXCLUSION ZONE

RW of ChEZ have arisen due to the accident at ChNPP-4 Unit and so by their characteristics (relative nuclide mixture and nomenclature) they are waste of nuclear power. Therefore management with such RW should be regulated by the normative documents adopted in this branch one of which is a document [7]. Pursuant to this one, firstly, solid waste are active if they satisfy one of the criteria listed in Table 2,

Table 1. *Solid RW of Ukraine (m^3) [3].*

Supplier of RW	Waste groups						Total	Fraction (%)
	1 (LLW)	2 (ILW)	Including					
			Burn	Pressed	Non treat	Metal		
NPP of Ukraine	26856	1497	4021	7369	10287	5179	28353	1.2
UkrSP "Radon"	4731		-	-	-	-	4731	0.2
ChEZ:	2384000		-	-	-	-	2384000	98.6
SP "Complex"	1980000		400000	30000	1550000	-	1980000	81.9
Object "Shelter"	345700	58300	160	4840	340700	-	404000	16.7
Total			404181	42209	1900987	5179	2417084	

secondly, by activity RW are divided on three groups: HLW, ILW, LLW.

At present, the main sites of RW accumulation in ChEZ are: object "Shelter", ChNPP industrial site, nine STLRW, three SSRW and some sites, which are not registered as temporary or constant dumps. The study of some of ChEZ RW dumps was undertaken within the framework of some Ukraine and international projects (see [8] and refs.).

Analysis results of the research performed before 1998 are submitted in the final report on inventory RW of ChEZ [9] where data about the volume, weight and activity of main accumulations of RW in ChEZ are presented. Accordingly to [9], RW in STLRW are placed in trenches (≥498) and mounds (≥15). The total area of STLRW is of about 7.97 km^2. The size of explored trenches widely varying: length from 7 to 315 m, width from 5 to 75 m and depth from 0.5 to 3.7 m. Thus, the RW volume in trenches can change from tens to tens of thousands of cubic meters. RW accumulated in STLRW differ by the structure very much. They include trees, metal, metal designs, stones, concrete, ground, sand, petroleum, building scraps, machines. Also, there is a probability of existing small amounts of special fissile materials (SFM). In some STLRW predominating is one kind of RW. So, in the STLRW "Sand Plateau" sand and ground, in the "Red Forest" trees, bushes, ground, in the "Strojbaza" concrete, steel designs predominate.

According to estimation [9] the total waste volume in STLRW is of about 4.69×10^6 m^3 (~2.8×10^6 tons), their total activity ~1.9×10^{15} Bq, average specific activity ~500 Bq/cm^3 (~700 Bq/g). Thus, RW accumulated in STLRW are the RW of the 1-st and 2-nd groups. The RW volume in SSRW ("Podlesny", "Kompleksny", "Buryakovka") is ~5.7×10^5 m^3 (~3.7×10^5 tons) with a total activity of ~5.5×10^{15} Bq [9]. Their average specific activity is ~15000 Bq/g, thus the waste, disposed at these sites are the RW of the 1-st, 2-nd and 3-rd groups.

As follows from report [9] ~90% of RW are in STLRW that agrees with the data of Table 1 (~82%). They produce ~25% of all ChEZ RW activity (except RW of the object "Shelter"). But estimations of the total RW volume in ChEZ given in [9] are nearly as twice more than in [3]. This difference may be due to the difference in methods of RW estimation on the one hand, and reflects a lack of knowledge that compels to resort to different and rough extrapolations, on the other hand. Therefore the results of [9] can be considered as an upper limit of RW amount and can be used for policy making of RW management**.** Some results of the analysis from [9] are shown in Table 3.

This is a special question about possible absence of HLW in STLRW. Such conclusion (and also evaluations of volume, structure, specific activity of RW, which were widely used in [9]) was made on the base of data obtained during investigations of some STLRW by the method of γ-probing [10]. According to this method, downhole measurements of the exposure dose rate (EDR) in volume of a trench containing RW using a special probe have been carried out. The sounding was performed on the grid (5x5, 2x2 or 2x1 m) in depth up to 3 m. In each point EDR was measured by steps of 0.2 m from the surface and up to the bottom.

To evaluate the reliability of this method for revealing small active fragments (some cm), which can accidentally fall into the RW and lie down separately, the mathematical simulation was carried out [8] in geometry of γ sounding used in [10]. The simulation was executed with the help of the program complex CYCLONE [1] based on using the Monte-Carlo method. The spectra of γ-rays in places of the detector position for fragment of activity 0.001 mSv/h, 0.3 mSv/h, 10 mSv/h (lower limit of LLW, ILW, HLW, respectively) were calculated. It was supposed that the fragment is in ground (sand) on different distances from the point of detecting.

The calculation has shown that the method of γ-sounding practically can not warrant HLW revealing in trenches with RW even if the grid step is 1 m due to the background from surrounding LLW and ILW and also because of errors of measuring instruments (~20%). Thus it is impossible to be sure, that during extraction of RW from trenches (for which the method of γ- sounding has shown the absence of highly active fragments) only LLW, ILW and the waste, which are exempted of control, will arrive for sorting [8]. Such chance should be taken into account when designing the sorting system.

Table 2. *Classification of solid RW by the group activity [7]. EDR is the exposure dose rate*

№	Dimensions	Type of activity	Waste groups			
			Exempt of control	1 group (LLW)	2 group (ILW)	3 group (HLW)
1	EDR, mSv/h.	γ	$<1 \cdot 10^{-3}$	$1 \cdot 10^{-3}$–0,3	0.3–10	>10
2	Volume activity, Bq/kg	β	$<7.4 \cdot 10^4$	$7.4 \cdot 10^4$–$3,7 \cdot 10^6$	$3.7 \cdot 10^6$–$3,7 \cdot 10^9$	$>3.7 \cdot 10^9$
		α	$<7.4 \cdot 10^3$	$7.4 \cdot 10^3$–$3,7 \cdot 10^5$	$3,7 \cdot 10^5$–$3,7 \cdot 10^8$	$>3.7 \cdot 10^8$
3	Surface contamination activity, particle/(cm^2·min.)	β	<500	500–$1 \cdot 10^4$	$1 \cdot 10^4$–$1 \cdot 10^7$	$>1 \cdot 10^7$
		α	<5	5–$1 \cdot 10^3$	$1 \cdot 10^3$–$1 \cdot 10^6$	$>1 \cdot 10^6$

Some conclusions following from the above should be kept in mind on elaborating the scheme of sorting the RW, which will be extracted from STLRW.

1) The large volumes of RW and distribution of dumps on the vast space require that the sorting system was highly producing and mobile. The probable availability of a suitable amount of the RW, which are removed from the control, causes utility to place the sorting system near the places of RW extraction for decreasing the cost of their transportation.

2) At present only a part of dumps in ChEZ are investigated in details. In the majority of works the data about the waste physical characteristics are submitted very commonly, a significant part of the information is based on approximated and estimated data and does not reflect the actual situation and has numerous errors. Such a situation requires an additional research to specify the dumps, determine the RW physical structure and select the most effective sorting methods providing necessary treatment and management of RW.

3) Information about the waste α activity in many cases is not submitted. However, for many dumps (if not for all) it is necessary to take into consideration a probable availability of a significant amount of transuranium radionuclides or high active fragments. Uncertainty of RW nuclide composition causes necessity of additional control, necessity to have a more broad set of sorting schemes, that complicates and rise the price of a system.

4) Very large oscillations of the RW activity from HLW which are exempted of control, wide scattering by physical features, forms, sizes, humidity complicate the selection of the most effective and economic methods of sorting which besides would allow to automate the process. These circumstances do economically unprofitable creation of a universal system, which would be applied for all possible conditions.

3. SPECIALITIES OF THE RW ChEZ SORTING BY ACTIVITY AND LIFETIME

Existing national and international classifications and technology of management with RW allow one to classify ChEZ RW depending on:

- level of activity and degree of contamination by groups LLW, ILW and HLW;
- time of exemption of control- by SL and LL waste;
- contents of SFM;
- physical features- by liquid and solid;
- physical-chemical characteristics.

The sorting system must segregate RW according to the adopted classification. As was mentioned above the RW of ChEZ under their characteristics are waste of nuclear power, therefore their segregation by activity groups (LLW, ILW, HLW) should be regulated accordingly to criteria listed in Table 2. Their classification by lifetime is regulated by the law- "*The management with radioactive waste*". In accordance with this law the long -lived waste (LL) belong to the RW exemption of control which is achieved in three hundreds or more years. This waste must be disposed in stable geological formations.

A direct determination of the nuclear composition of RW and the partial activity of nuclides, especially, α active ones, with the purpose of determining their lifetime is a very difficult task. However, Chernobyl origin of RW allows to essentially simplify the process of RW sorting by lifetime. As is well known, the RW of ChEZ arose owing to expansion of radionuclides, which were accumulated in the nuclear fuel of the working reactor into the environment as a result of the accident. The average fuel radionuclide composition in 2000 year, which is determined by conditions of the reactor work, is listed in Table 4 [11], where the expected activity (A) of these radionuclides calculated for 2300 year is also listed. One can see that at present more then 90% of the Chernobyl origin RW activity is caused by the ^{137}Cs but after 300 years the activity of these RW will be determined by the α-activity of transuranic radioisotopes. The criteria of RW decontrol are the values of activity listed in Table 2. For α-active radionuclides this criterion is equal to 7.4 Bq/g of the specific activity. After 300 years the α activity of the waste will decrease approximately on 8%. Therefore to decontrol the Chernobyl origin RW in 2300, it is necessary that in 2000 year the specific α activity of this waste would be of about 8 Bq/g. Waste with α activity exceeding this value must be referred to the LL category.

In 2000 year the value of ^{137}Cs specific activity, corresponding to the criterion determined by the Ukraine law for the lower limit of volumetric α- activity of LLW is ~220 Bq/g for ChEZ RW with the average fuel concentration. Then by measuring the specific activity of ^{137}Cs in 2000 it is possible to make evaluations of RW nuclide composition, if the relative contents of radionuclides (correlation relations) and the concentration of fuel in waste are known. Accuracy of these evaluations depends on errors with which the correlation relations of a given accumulation are determined. It should be noted that in accordance with the IAEA recommendations, [12], for definition of the level of LL waste one uses criterion of the waste specific α-ctivity in 400 Bq/g for one package. This results in that the level of a specific ^{137}Cs activity for the lower limit of LL waste equals to 1.1x10^4 Bq/g in 2000 year for the average fuel composition of ChEZ RW.

Table 3. *Volume, mass, activity of RW from the Chernobyl Exclusive Zone located in stations of temporary RW localization (STLRW) and stations of RW storage (SSRW) [9]*

STLRW and SSRW	Vol. (m^3)	Mass (ton)	Activity (Ci)
Strojbaza	398000	539000	35583
Red Forest	250000	400000	8400
Yanov Station	18686	29897	78
Neftebaza	122118	192705	1494
Sand Plateau	100000	180000	5000
Purifying build.	200	200	1
Pripyat	16000	11000	700
Chistogalovka	160000	150000	100
Kopachi	110000	390000	900
Living house	2900000	880000	200
Podlesny	11000	22000	70000
Kompleksny	26196	41914	12727
Buryakovka	533574	825560	65596

There is a very large volume of RW in the ChEZ therefore it is necessary to construct a productive sorting system for RW processing. A key problem for solving this problem is the choice of a method, which allows obtaining a high sorting output. As follows from the above there is a relation between the activity of the Chernobyl origin RW, which is caused mainly by ^{137}Cs and the classification of these RW by lifetime, which is determined by α-active radionuclides. (The same relation is also between EDR, which is created by RW loaded in the container fixed by the form and volume and RW lifetime). This relation can be used for sorting and then the 1-st criterion of Table 2 must be used. To apply this, the EDR at the distance 0.1 m from the surface of the package with RW must be measured. In the present time ^{137}Cs is the most promising radionuclide for practical determination of the RW category, because it has the characteristics convenient for EDR measurements, and produces 90% of RW activity.

We performed calculations of EDR created by containers of various volumes with RW having the specific activity of ^{137}Cs 1000 Bq/g at a distance of 0.1 m from their surface, Fig. 1. The calculations were made by the Monte Carlo method with using the program complex CYCLONE [1]. The EDR value is equal to 9.6×10^{-2} mSv/h for 200 l packages (which are widely used in the world practice, especially for LL and HLW) and for the given specific activity. If one uses the calculated value of specific ^{137}Cs activity corresponding to the LL waste criterion under the Ukraine laws (220 Bq/g) it is possible to evaluate EDR from such a package when LL is placed in it. For 2000 year this limit EDR value equals 2.1×10^{-2} mSv/h. Using the same approach for the criterion recommended by IAEA (1.1×10^4 Bq/g) we shall get a value of ~1.1 mSv/h.

Analyzing the results obtained and comparing them to criteria listed in Table 2, one can to conclusion that, according the Ukrainian laws being in force now (under condition of loading in 200 l packages) the most part of LLW, and of all ILW and HLW should be referred to LL. Fig. 2 shows the correlation between the RW classification by activity (and lifetime) and the fuel concentration, which unambiguously determines the level of Chernobyl origin waste activity. In the case of transition to the specifications recommended by IAEA only a part of ILW and all HLW should be referred to LL waste that is in 10-100 times less.

Table 4

Isotope	Type of radiation	$T_{1/2}$, years	A, MBq/g UO^2,	
Years	–	–	2000	2300
^{90}Sr	β	28.6	850	0,6
^{106}Ru	β, γ	1.057	0.46	-
^{134}Cs	β, γ	2.06	8.0	-
^{137}Cs	β, γ	30.17	1015	1,0
^{144}Ce	β, γ	0.779	0.08	-
^{154}Eu	β, γ	8.8	24	-
^{238}Pu	α	86.4	6.1	0,5
^{239}Pu	α	24110	5.0	5,0
^{240}Pu	α	6553	8.2	7,9
^{241}Pu	β	14.4	490	$2{,}6\cdot10^{-4}$
^{241}Am	α, γ	432.5	16.4	20,5
^{244}Cm	α	18.11	1.3	-

As follows from the above due to the relation between the activity and lifetime the most promising method for RW sorting is the method of passive gamma analysis based on EDR measurement of waste γ-radiation and the using of the correlation relations between isotopes which are in RW ChEZ. This method is cheap and rather fast, because the waste activity group and the lifetime are determined simultaneously in one measurement and the intensity of the RW γ radiation is rather high. It does not require large and expensive arrangement. The accuracy of the method depends on the accuracy of EDR measurement and errors with which the correlation relations are known for the RW accumulation.

It should be noted that cesium has a high mobility, which depends on temperature conditions. So, those materials, which in the greater degree undergone to the temperature influence, have lower cesium content while the samples taken further of the accident place contain a higher quantity of cesium, than it would be possible to expect. Therefore divergence in the relative activity of nuclides (correlation relations) for different tests of the RW is observed. However, one can use the average values of correlation relations, which in accordance with data of [13] within a factor of 2, coincide with real ones independently from the place of RW location. This conclusion is confirmed by results of the research at the industrial site of the object "Shelter" [14] and in ChEZ [10]. The average values of correlation relations obtained by different organizations are rather close [11] that justify a possibility of using such data with an error of 30-40%.

Proceeding from the results of EDR measurement performed at a distance of 0.1 m from the surface of a 200 l package with RW, the values of correlation relations of which corresponds to the average fuel composition, one can determine the radionuclide activities in these wastes.

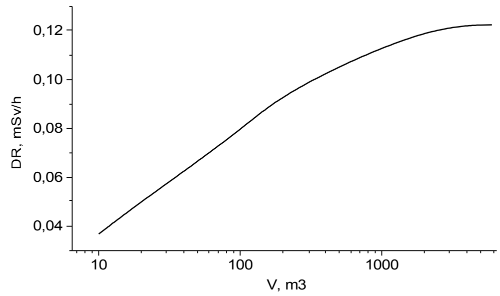

Fig. 1. *The EDR at 0.1 m distance from the surface of package with RW having specific activity ^{137}Cs 1000 Bq/g as a function of package volume*

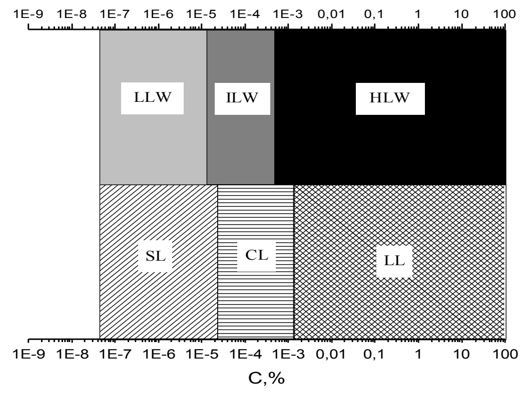

Fig. 2. *Connection RW classifications and concentration of fuel in waste*

4. SCHEME OF SORTING ChEZ RW

Results of the analysis of dumped RW displacement waste nomenclature and expected activity, results of the simulation of sorting ways and techniques are used as a basis for elaboration of the principal scheme of sorting RW located in STLRW. As follows from the above, the system assumes the sorting of RW extracted from STLRW in two stages.

1. The main sorting of RW is made near STLRW.

2. The additional sorting is made in TDC after RW processing and, in the case of necessity to sort LL waste, it is done with the use of active neutron analysis.

The advantage of RW sorting near STLRW is caused by such reasons:

- RW should come to TDC in a sorted kind;

- sorting near the place of extraction reduces the amount of RW which goes to TDC, because at once one separates and direct into the dump the waste which are exempted of the control;

- mixing of HLW and LL with the waste of other activity groups is not admitted, due to their separation at stage 1 of sorting.

In Fig. 3 the block scheme of the system for sorting RW (by physical features and activity), which are located in STLRW, is shown (dark color marks technological operations which do not concern to the system).

At the first stage the RW are sorted by:

a) activity groups and time of decontrol- into LLW, ILW, SL waste, waste which are exempted of control, HLW and LL waste;

b) physical features- into RW in the bulk-form (ground, sand, road metal, small pieces of metal, tree etc.) and RW in the object form (metal designs, machines and gears, bulky concrete units, trees, etc.).

Partially, the sorting can be produced already during RW extraction from STLRW, and this should be provided when designing the RW extraction system. Though a noticeable amount of HLW in STLRW is not expected, however it is necessary already at preliminary sorting to carry out the control for probable appearance of HLW in the radioactive waste and their separation. As was shown in [8], it is impossible to find active fragments in trench with RW, and unambiguous identifying HLW in the dredge ladle during their extraction also is not always possible. Thus under the data of a mathematical simulation the scheme of the management with RW, which are extracted from STLRW, should take into account possible appearance of high active fragments and the sorting should be made using techniques allowing to reveal and to sort out HLW. The further operations with HLW are conducted in accordance to the plan of management with waste of this group, (see, e.g. [1,2]) and here are not considered in details. However, since their amount in STLRW is expected to be small, their processing and detailed sorting should not be performed near the place of extraction, but at the special place and with special equipment in TDC.

Other RW are divided into the waste in the object form and in the bulk-form. RW in the bulk-form, if necessary, are processed to required size (some cm) and are sorted by features of required processing. Necessity of processing RW in the bulk-form can arise when on sorting waste of mainly one type (metal or those, which are burned) is arrived. These RW are loaded in 200 l packages and transported in TDC.

The RW in the bulk-form which do not require the processing, go onto the conveyor for sorting by activity, where their separation into groups and categories of activity, time of exemption of control is performed with the use of the passive gamma-method and correlation relations. Simultaneously the total weight of RW after conveyor sorting is determined. Proceeding from the volumes of RW to be sorted, the efficiency of the conveyor system should be no less than 4 m^3/h. After sorting, RW exempted of control are directed in dumps, and SL and LLW are loaded in suitable containers and are transported to TDC. The LL waste is loaded in 200 l packages accordingly with the scheme of management with RW.

RW in the object form are, as a rule, surface-contaminated constructions or gears. After determination of level of their contamination the materials exempted from the control are directed in dumps, and others are divided in those, which require or do not require processing, and then are transported in TDC.

The processes of containerization and transporting do not concern to the system of sorting and are not considered in details.

At the second stage of sorting after RW arriving into TDC, the kind of processing is determined for those one, which require treatment. The treatment (burning, pressing etc.) decreases the RW volume. Before treatment RW, which are in the bulk-form are certified with the purpose of determining their element composition and activity. After treatment RW will be undergo to the additional control because in the result of processing and compacting the transition of these RW in other group (HLW or LL) is possible. The sorting system must separate such waste by activity into groups LLW, ILW, HLW and by lifetime into conditionally LL (CLL) and purely LL waste with the purpose of separate storage of CLL (CLL are waste, which

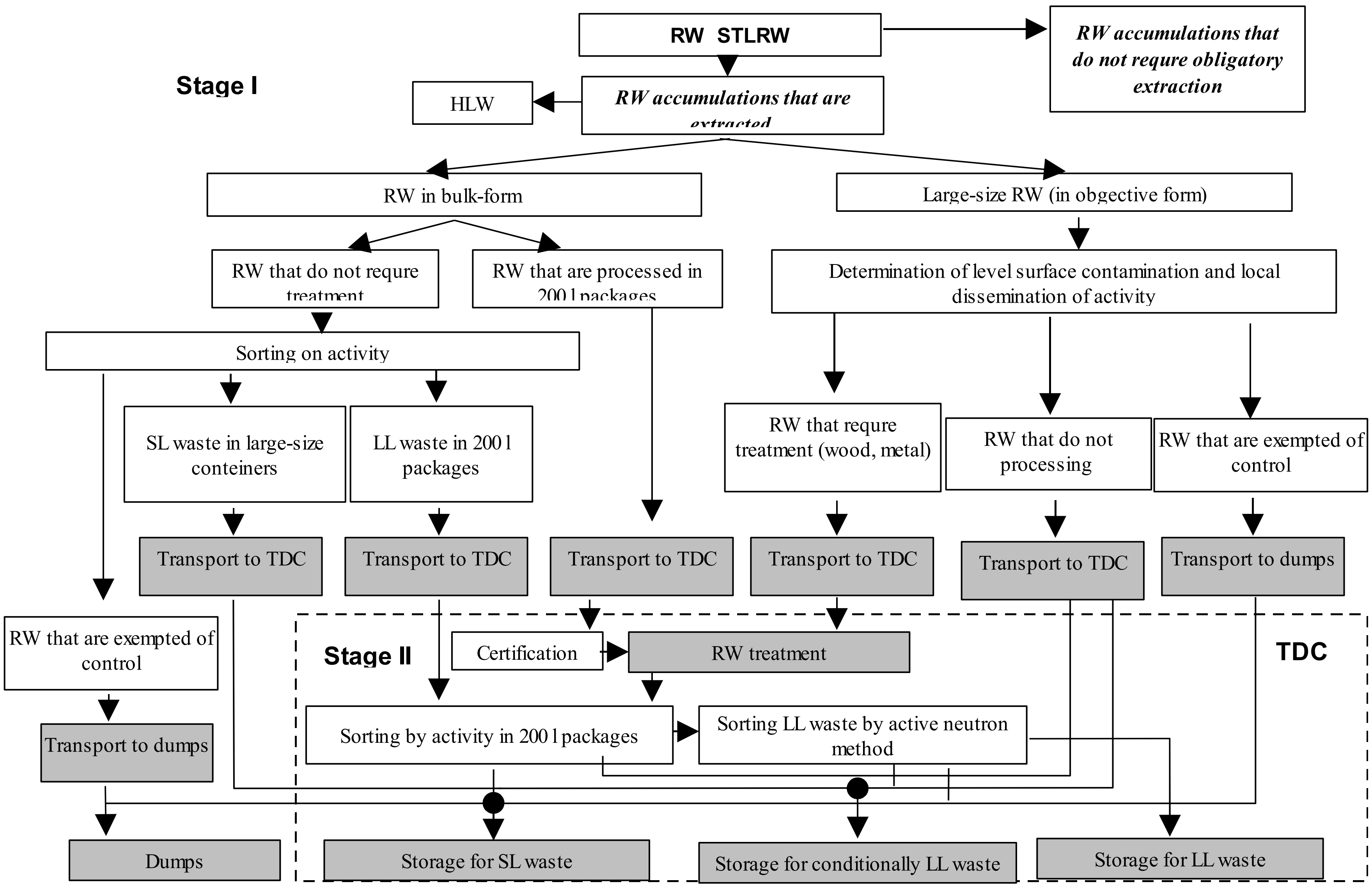

Fig. 3. Structure of the sorting scheme RW of Chernobyl Exclusive Zone on physics features and activity

belong to LL grope only according to the Ukrainian low and are not LL according to norms recommended by IAEA). Such approach, in view of the expected transition of the Ukraine legislation to the international standards, enables one to transfer storehouses of CLL into subsurface disposals without repeated sorting and large economic expenses. The RW sorting in TDC is supposed to be carried out in standard 200 l packages, with using, if necessary, the active neutron method for determination of SFM availability. RW in the object form and the containers with RW, which do not require treatment, as well as the containers with the processed RW are transported to the storehouses specified for definite groups and categories of waste.

5. ENGINEERING SOLUTIONS OF MAIN UNITS OF SORTING SYSTEM

In accordance to the submitted block scheme two basic systems are engaged for sorting: the system of conveyor sorting of RW in the bulk-form and the system of sorting the waste in 200 l packages.

Conveyor sorting RW in the bulk-form. The system of conveyor sorting RW in the bulk-form by activity is placed near the site of RW extraction from STLRW and is aimed on express waste sorting into groups LLW, ILW, waste exempted of the control, and category SL and LL waste. Also, the separation of HLW will be produced if they fall into the RW that are extracted. Simultaneously with the determination of groups and categories of activity the system determines the total weight of the RW, which have passed conveyor sorting. RW sorting is based on the method of passive gamma analysis considered above.

The sorting system includes a subsystem for forming portions of RW for analysis, conveyor line, measuring facility and sorting arrangement. If necessary the radioactive waste before sorting are treated to obtain a required size of pieces (no more than 5 cm). The volume of the RW portion entering for passive γ analysis is of about 0.04 m^3 (10x50x80 cm^3). The distance between RW portions on the conveyer is of about 50 cm. It is chosen of necessity for the system productivity and task of decreasing the measurement error.

A measurement facility is destined for EDR measurements of RW portions. As detectors for this facility one can use detectors on the base of NaJ or CsJ crystals. To estimate time required for measurements with this arrangement we have carried out the simulation of this process with the NaJ detector (4x4 cm) placed at a distance 10 cm from the surface of RW. It has been found that the minimal time required for getting necessary number of counts (no less than 100) for RW belonging to HLW, ILW, LLW groups is $5x10^{-7}$, $5x10^{-4}$, $2,5x10^{-2}$ s, respectively. For detector with the crystal sizes of 1,13x1 cm these times are 10^{-5}, 10^{-2}, $5x10^{-1}$ s. From results obtained it follows that the sorting productivity will depend, first of all, on the speed of conveyor movement but not on the time of measurement of RW portion activity. If productivity of the conveyer is planned to be not less than 4 m^3/h it means that the conveyer must pass up to 100 portions with RW per hour. If the distance between them is 50 cm, one portion will be under processing during ~18 s. To obtain such a high productivity of the conveyor its construction should be designed with high technical requirements and conditions.

The calculations, which have been made for detectors (with NaJ crystals volume of 1 cm^3), placed at the distance of 1 m from RW surface, have shown that the statistical errors of EDR measurements during processing time is no more than 7% for measurements at the lower limit of LLW. The calculations show also that the detection device will work with a great loading. To decrease the load the detectors should be shifted at a distance providing necessary loading. Besides, one should use fast electronics.

After sorting RW by activity they are delivered to suitable transport channels with subsequent loading into transport containers of a suitable type.

The system of RW sorting by activity in 200 l packages. The system of RW sorting by activity in 200 l packages is placed in a technological building of TDC where separation of RW into groups HLW, ILW, LLW and categories SL, LL and CLL is executed. It is planned to use this system in such cases:

-more precise determination, if necessary, of LL activity waste in the bulk-form, which do not require processing and arrived to TDC in 200 l packages after preliminary conveyor sorting on place of extraction, with the purpose of separating them into CLL and LL. These RW are arrived on the control in a fragmented form and are sorted by physical properties;

-sorting RW by activity and lifetime after treatment in TDC and, consequently, possible transition them into others groups (HLW or LL waste). In this case it is supposed to carry out the control of SDM presence in such RW with using active neutron analysis.

The system operates with standard 200 l containers KSTA-02 developed by STC CMRW [15]. It includes a transport subsystem (conveyer line) and a measuring subsystem. The conveyer line is made on the base of a roller conveyer and is used for transport of packages with RW up to 400 kg weight into a measurement facility. After measuring the weight and activity of RW they are transported to other sites. Containers have marks necessary for automatic information processing and tracking.

The RW enters onto the control in 200 l containers in the fragmented form and sorted by physical properties and with a known weight. As it has been shown by simulation, to inspect the most part of container volume with using the passive γ-method it is necessary to scan the container. A maximum rotation rate of the container at scanning is of about 1 turnover in minute.

The EDR measurements are made in the range of activity from 0.1 mkSv/h to 1 Sv/h for RW with a maximal specific activity of ~100 MBq/g. The preliminary calculations show, that the necessary number of detectors is of about 5. They may be produced on the base of NaJ, CsJ or BGO crystals. The detectors are placed into the lead shield and equipped with collimators. They have such sizes that the container KSTA-02 can be scanned during one rotation that essentially accelerates the measuring.

The expected values of detector counting rates were got by simulation of the γ radiation spectrum, which is radiated from the given container with RW of definite groups and which is produced by ^{137}Cs. It is supposed that ^{137}Cs are uniformly distributed in the container volume in a substance with an average density of 2 g/cm^3 and average atomic number Z=14 (sand).

Results of the counting rate calculations for one of the possible variants of the measuring system placement are shown in Table 5. In this variant the detectors are placed behind the 30 cm long collimators, the front edge of which is at a distance of 10 cm from the container surface. The dimensions of the collimator hole are 10x1 cm. The detector registration efficiency is supposed to be 100%. The calculations have shown that the scattered γ quanta increase the loading of detectors in 3 times. The counting rate may control by changing the distance between the detectors and container or collimator hole. The time required for obtaining the minimal necessary statistics (~100 counts) is no more than 10 s.

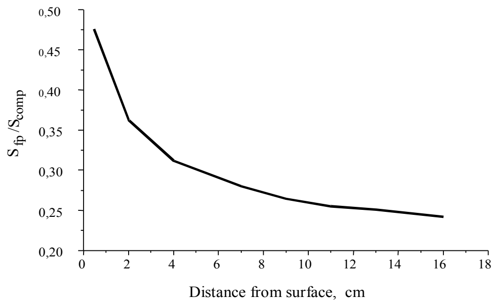

***Fig. 4**. Ratio of the fotopeak and the total γ spectrum areas as a function of depth of active fragment localization from side face of cylindrical container*

***Table 5.** Flux of γ-quanta from the 200 l cylindrical container with RW at a distance of 10 cm from the side face*

C-ng rate, s^{-1}	RW groups		
	LLW	ILW	HLW
Photopeak	11-1100	1100-38000	≥3.8×10^4
Total	33-3300	3300-110000	≥1.1×10^5

A photopeak proportion in the total counting rate output decreases with the depth position of the active layer, Fig. 4. So, the control of high-activity small fragments, which can exist in the package, by the passive γ- method will be effective up to depth of ~ 15 cm from the package surface. In the case of the container KSTA-02 it consists ~85% of the volume. For uniform distribution of RW in the container and their density ≤2 g/cm^3, a possible error of evaluation by the total ^{137}CsJ activity is expected no more than 20%.

This system operates in the automatic mode. The maximum output is up to 10 containers in hour (2 m^3). More detail engineering solutions concerning these systems are considered in [8].

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