

Safety Assessment for a Surface Repository in the Chernobyl Exclusion Zone - Methodology for Assessing Disposal under Intervention Conditions – 13476

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ABSTRACT

The Radioactive Waste Disposal Facility (RWDF) Buryakovka was constructed in 1986 as part of the intervention measures after the accident at Chernobyl NPP (ChNPP). Today, RWDF Buryakovka is still being operated but its maximum capacity is nearly reached. Plans for enlargement of the facility exist since more than 10 years but have not been implemented yet. In the framework of an European Commission Project DBE TECHNOLOGY GmbH prepared a safety analysis report of the facility in its current state (SAR) and a preliminary safety analysis report (PSAR) based on the planned enlargement. Due to its history RWDF Buryakovka does not fully comply with today's best international practices and the latest Ukrainian regulations in this area. The most critical aspects are its inventory of long-lived radionuclides, and the non-existent multi-barrier waste confinement system. A significant part of the project was dedicated, therefore, to the development of a methodology for the safety assessment taking into consideration the facility's special situation and to reach an agreement with all stakeholders involved in the later review and approval procedure of the safety analysis reports. Main aspect of the agreed methodology was to analyze the safety, not strictly based on regulatory requirements but on the assessment of the actual situation of the facility including its location within the Exclusion Zone. For both safety analysis reports, SAR and PSAR, the assessment of the long-term safety led to results that were either within regulatory limits or within the limits allowing for a specific situational evaluation by the regulator.

INTRODUCTION

The Radioactive Waste Disposal Facility (RWDF) Buryakovka was designed and built in 1986 as a major element of the infrastructure created during the acute phase of the radiation accident at Chernobyl NPP (ChNPP) to eliminate the accident consequences. The trench-type facility was dedicated for the disposal of solid - mostly bulk - waste generated as a result of decontamination activities in the Exclusion Zone (EZ) around ChNPP. Today, the RWDF Buryakovka is still being operated but its capacity of approximately 700,000 m³ is nearly reached: Out of the total 30 trenches, about 29 were filled at the end of 2012, and at the current pace of disposal the remaining capacity might be filled in 2013. Plans for reconstruction and enlargement of the facility exist since more than 10 years but mainly for financial reasons they have not been technically implemented yet.

In December 2010 the contractor Consortium consisting of consortium leader DBE TECHNOLOGY GmbH, (Germany) together with ANDRA (France) commenced activities in cooperation with experts of the Radioenvironmental Centre at the Presidium of the National Academy of Sciences of Ukraine on implementation of INSC-Project U.04.01/08-B “Improvement of infrastructure for management of radioactive waste in the Chernobyl Exclusion Zone. Stage I: Safety Assessment” financed by the European Commission.

The overall project goal is the reconstruction of RWDF Buryakovka to improve its safety controls and expand its capacity. To this end DBE TECHNOLOGY GmbH prepared a safety analysis report of the facility in its current state (SAR) and a preliminary future-state safety analysis report (PSAR) based on the planned reconstruction activities.

The existence of RWDF Buryakovka as well as its past and future operation has to be regarded as result of intervention measures following the Chernobyl NPP accident about 25 years ago and cannot be expected to fully comply with today’s best international practice and the latest Ukrainian regulations in this area. The most critical aspects comparing the characteristics of RWDF Buryakovka with regulatory requirements are the total content of long-lived alpha- and beta-emitting radionuclides in the waste and their specific activity, as well as the fact that RWDF Buryakovka does not correspond to the concept of a multi-barrier waste confinement system.

A significant part of the project was dedicated, therefore, to the development of a methodology and procedure for the safety assessment of RWDF Buryakovka taking into consideration the facility’s special situation and to come to an agreement with all stakeholders involved in the later review and approval procedure of the safety analysis reports.

This paper focusses on the results of the post-closure safety assessment of RWDF Buryakovka and here on the assessment of the facility in its planned extended state as this also covers its existing state.

DESCRIPTION OF THE REPOSITORY SITE

Geographic Location

RWDF Buryakovka is located in Ivankov district in the Kiev region, 12 km to south-west of the ChNPP at 51°19'00" N and 29°54'70" E. Its location lies in the southwestern sector of the 2600 km² zone of special radiation hazard, established to monitor the most radioactively contaminated areas around the “Shelter” facility and ChNPP within the larger Exclusion Zone (Fig. 1).

RWDF Buryakovka is the only point of acceptance and disposal for radioactive waste in the Chernobyl Exclusion Zone. In its current state, RWDF Buryakovka comprises 30 near-surface trenches used for disposal of solid radioactive waste. By the end of 2012 about 29 of these trenches were filled. The remaining free volume will be filled in the near future, which is the

reason why reconstruction and enlargement of the facility are planned, which involves construction of additional capacities with a total volume of 120 thousand m³.

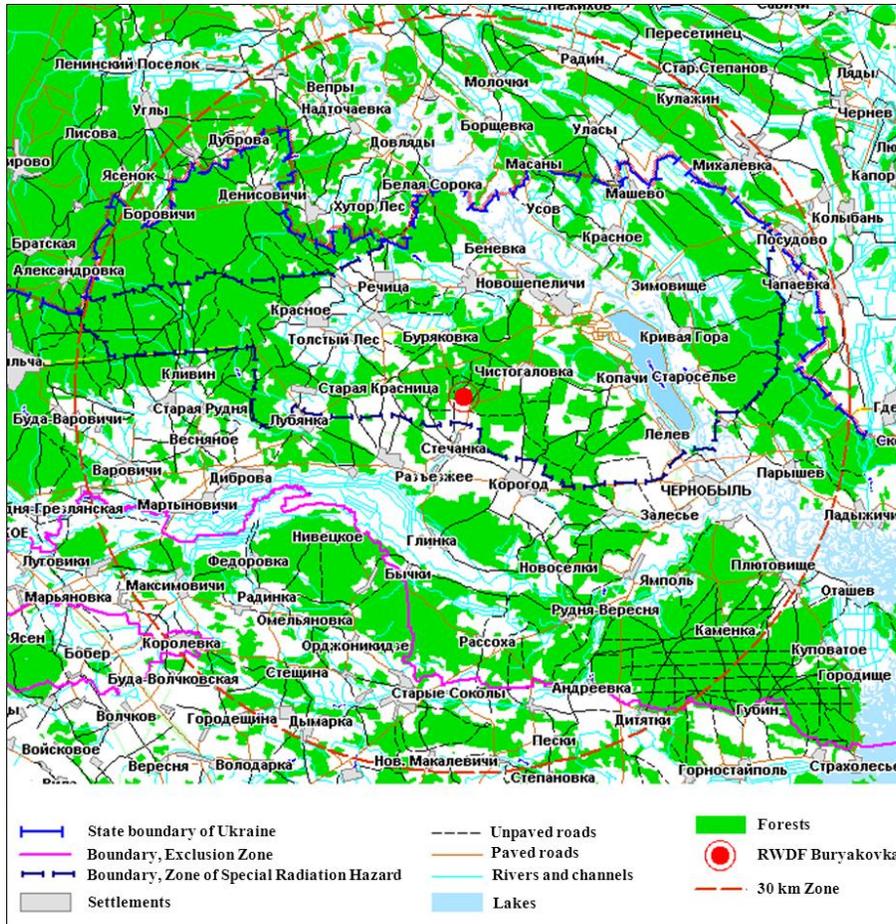


Fig. 1: Sketch map of the location of RWDF Buryakovka in the territory of EZ&ZAR.

RWDF Buryakovka accepts solid, low-level and intermediate-level radwaste for disposal that is generated as a result of decontamination work within the exclusion zone, at ChNPP, and at the "Shelter". These wastes consist of sand, soil, wood, concrete, bricks, metal structures, and other materials. RWDF Buryakovka contains more than 635,000 m³ of compacted radwaste with a total activity of about $2.92 \cdot 10^{15}$ Bq.

According to design each of the 30 trenches has horizontal dimensions of 58.8 by 150 m and a depth of 5.6 m. The trenches are located within the disposal site that covers an area of 1200 by 700 m. The flat bottom area of the trench measures 16 by 100 m.

After excavation of the trenches, the bottom and side walls of each trench are isolated by a clay layer. The radwaste is placed into the trenches in bulk and then rolled over by heavy machines

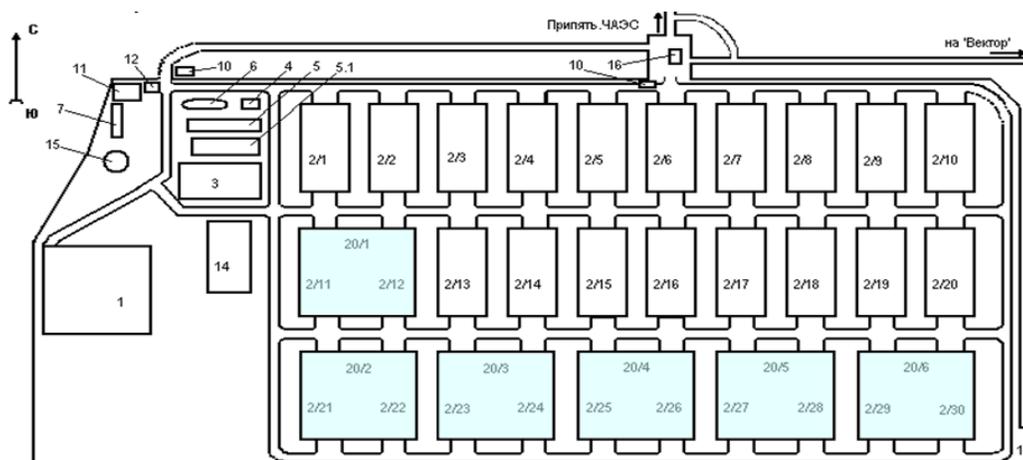
for compaction. The capacity of one trench is, depending on the technical realization of the design dimensions, approximately 20-35 thousand m^3 of compacted radwaste and may differ significantly from trench to trench. For sealing purposes, a levelling layer of local soil, a clay screen, and a layer of soil, on which grass is being cultivated, are placed on top of the radioactive waste. The radioactive waste pile inside the trenches is up to 6 m high. A drainage ditch is constructed along the contour of the closed trench.

Fig. 2 shows an older aerial view of the facility, where several of the trenches in the background of the picture are still empty or in operation.



Fig. 2: Aerial view of RWDF Buryakovka

RWDF Buryakovka enlargement design envisages the construction of six new near-surface trenches with a total capacity of $120,000m^3$. The new trenches will be located in the space between two adjacent existing trenches. The central part of the new trench will be located approximately at the surface level of the site between, and the side slopes of the pitched roof cover will end on the cover layers of the two neighboring old trenches. The layout of RWDF Buryakovka with its various facilities and existing as well as planned trenches is shown in Fig. 3.



Existing facilities and planned new trenches

1	Sludge pit	11	Fire-fighting equipment site
2/1-30	Existing disposal trenches	12	Transformer substation
3	Vehicle parking site	13	RW disposal site (contaminated)
4	Boiler House	14	Temporary storage site for clay
5/5.1	Special vehicles decontamination station	15	Water tower
6	Unit of fixative agent preparation	16	Automatic RW control station
7	Decontamination station	20/1-6	Planned new disposal trenches
10	Guard room with guard desk (2 units)		

Fig. 3: Layout of RWDF Buryakovka after its planned enlargement.

WASTE INVENTORY

In addition to the waste characterisation to be performed at the site of origin, up to 10% of the waste is checked randomly at RWDF Buryakovka by means of radiation control meters and by sampling for subsequent radionuclide composition analysis under laboratory conditions. Nonetheless, there is some uncertainty as regards the radionuclide content of radioactive waste buried at RWDF Buryakovka, especially for the waste delivered in the period before 1997.

Inventory Of Existing Trenches

Until 1997 measurement and calculation of total and specific activity were carried out by measuring the surface dose rate of the truck load of waste arriving at the facility and multiplying this value with the estimated mass of the waste load and a proportionality factor. The thus calculated activities are based on the assumption that 90 % of the surface dose rate is carried by Cs-137 and that Cs-137 contributes 50 % to the total γ - and β -activity. It was further assumed that α -emitting transuranium elements contribute 1.5 % to the total activity.

The radionuclide composition of the waste was then estimated on the presumption that it would be close to the typical radionuclide vector for radioactive waste of Chernobyl accident origin listed in Table I below.

TABLE I: Radionuclide vector for radioactive waste of Chernobyl accident origin.

Radionuclide	Contribution to total activity %	Radionuclide	Contribution to total activity %
Sr-90	20.70	Pu-239/240	0.64
Cs-134	1.10	Pu-241	30.00
Cs-137	46.60	Am-241	0.65
Pu-238	0.23		

Consequently, detailed information on the radionuclide content of waste disposed of at RWDF Buryakovka is limited. In agreement with the operator of RWDF Buryakovka, State Specialized Company “Complex”, the inventory of the existing trenches (including forecasted inventory for the remaining capacity) listed in Table II was considered as best estimate for the long-term safety assessment of the facility.

For future waste it is assumed that its characteristics will be similar to those of the solid radioactive waste received during the period 2000 - 2003. Based on information about the specific activities of waste from this period, the total future inventory of the planned trenches has been calculated by using a waste density of 1630 kg/m³ and a total waste volume of 120000 m³. Table II shows that the additional activity will be less than 5 % of the inventory already disposed of at RWDF Buryakovka. The specific activities for future waste have been used as best estimate values for the operational safety assessment of both reports, the SAR and the PSAR.

SAFETY ASSESSMENT APPROACH AND METHODOLOGY

Even at the time of planning and construction of the Buryakovka facility, the technology of radioactive waste disposal in trenches did not meet the Ukrainian sanitary rules for radioactive waste handling. Accordingly – given today’s increased requirements in the respective legislation – the used technology, together with facility design in general, do not meet the requirements of the current Ukrainian norms and regulations.

The most critical aspect in evaluating the long-term safety of Buryakovka facility is the total inventory of long-lived alpha- and beta-emitting radionuclides and their specific activities. It is obvious that within the period of up to 300 years after closure (possible date for ending institutional control for short-lived waste), the clearance levels regarding the reduction of radioactivity will be achieved only for beta- and gamma-emitting nuclides, while the activity of the alpha-emitters will decrease only negligibly and will not be in compliance with regulatory limits for near surface disposal.

Another requirement that is not met by RWDF Buryakovka is the prerequisite for the

acceptability of bulk waste: the existence of a multi-barrier waste confinement system. There exist only two engineering safety barriers- the upper clay layer restricting the infiltration of water into the trenches, and the lower clay layer, which limits migration of radionuclides into the geosphere due to its sorption properties. As it is practically impossible to improve the protective properties of the base barrier, there is little potential for technical improvement of this situation.

TABLE II: Total inventory for the existing facility and the planned enlargement.

Existing Trenches 1-30 Radionuclide	Total Activity (Bq)	Planned Trenches 1-6 Radionuclide	Specific Activity (Bq/g)	Total Activity (Bq)
Co-60	1,99E+11			
Sr-90	6,22E+14	Sr-90	2.01E+02	3.93E+13
Nb-94	4,12E+10			
Cs-134	3,48E+13	Cs-134	3.95E-01	7.73E+10
Cs-137	1,404E+15	Cs-137	2.40E+02	4.69E+13
Eu-154	5,02E+11	Eu-154	4.28E+00	8.37E+11
Eu-155	7,90E+09			
Pu-241	9,03E+14	Pu-241	1.02E+02	2.00E+13
		Np-237	3.72E-04	7.28E+07
Pu-238	6,75E+12	Pu-238	1.55E+00	3.03E+11
Pu-239/240	1,91E+13	Pu-239	1.33E+00	2.60E+11
		Pu-240	2.17E+00	4.24E+11
Am-241	1,91E+13	Am-241	5.21E+00	1.02E+12
		Pu-242	3.45E-03	6.75E+08
		Am-243	1.35E-02	2.64E+09
		CM-244	2.82E-01	5.52E+10
<i>α-Sum</i>	<i>4.50E+13</i>	<i>α-Sum</i>	<i>1.06E+01</i>	<i>2.07E+12</i>
Total	3,01E+15	Total	5.57E+02	1.09E+14

The existence of Buryakovka facility as well as its past and future operation has to be regarded as part of the large scale intervention measures following the Chernobyl NPP accident. It does not therefore seem to be appropriate to base the assessment of its safety on legal requirements, developed for the construction and operation of similar facilities under normal conditions and within normal and undisturbed environment.

RWDF Buryakovka is located within the Exclusion Zone. It has to be expected that inside this zone there will always exist some restriction that will prevent people from living here. Therefore, while assessing its safety, the health impact of radionuclides being released from the repository due to the non-hermetic function of the engineered barriers, should be considered only for scenarios where exposure groups are located outside the exclusion zone and not in the direct vicinity of the repository.

In agreement with the different stakeholders in the licensing procedure for the planned enlargement, it was decided that the radiological safety of RWDF Buryakovka would be assessed in terms of its compliance with the nuclear legislation of Ukraine and in regard to its real and potential environmental impact. Considering its status as result of intervention measures, it was further agreed to evaluate the outcome of the safety assessment not strictly based on formal compliance with regulatory requirements developed for purposes like site selection or acceptability of bulk waste. Instead the assessment of potential release of radionuclides from the facility and the related radiological impact on potential exposure groups at present, during institutional control and thereafter should be decisive for the evaluation.

For normal evaluation of the repository, the chosen criterion to evaluate the radiological impact for a critical group was compliance with the 10 $\mu\text{Sv}/\text{yr}$ regulatory limit according to the stipulations of NRB1997/D-2000 [1]. For potential exposure, the limits of 1 mSv/yr (Level B) and 50 mSv/yr (Level A) were to be used as pointed out in the same regulation: exposure below Level B demonstrates compliance with the regulation and exposure values between the two limits can be evaluated by the regulator on an individual basis.

By using this approach, an implementable solution was developed to address the unique requirements of the Chernobyl Exclusion Zone while ensuring human and environmental safety.

Development of relevant scenarios to assess the operational and the post-closure safety of both, the facility in its present state and the facility in its planned extended state was carried out according to the ISAM Methodology [2].

For the operational safety assessment, the scenarios developed in IAEA TECDOC 1380 [3] were used after adaption to the specific conditions of operation at RWDF Buryakovka. The resulting dose rates for different scenarios and various worker groups were compared with regulatory limits and recommendations were given how to reduce exposure rates

For the post-closure assessment, the normal long-term evolution of the repository is based on radionuclide release via the groundwater pathway with the critical group using the groundwater being located outside of the Exclusion Zone. For disturbed evolution, the mandatory scenarios of Ukrainian regulation NRB1997/D-2000 [1] were used, comprising:

- Scenario 1: Critical group dwelling at the facility site and using a local water well
- Scenario 2: Growing agricultural products on heavily contaminated soil and eating them
- Scenario 3: Destruction of covering layers by human intrusion to some extent and
 - a) Living at the site and inhaling contaminated dust
 - b) Spending time at site or contaminated areas (area for recreation or sports)
 - c) road building or agricultural work on the site area
- Scenario 4: External irradiation due to stay in area covered with radioactive waste
- Scenario 5: Ingestion of small fragments of soil (radioactive waste)

The results of normal evolution scenario and disturbed evolution scenario were then compared to the regulatory limits to determine compliance of the existing repository and its enlargement plans with the requirements for radiological safety.

OPERATIONAL SAFETY ASSESSMENT

From the results of the operational safety assessment, it seems unlikely that dose limits will be exceeded for workers during operations conducted at RWDF Buryakovka. The most exposed worker would be the bulldozer driver who would receive a maximum dose rate of 5 mSv/yr, which could easily be reduced by better shielding of the bulldozer including a dust tight drivers cabin. All other exposure rates are lower and therefore below the regulatory limit of 20 mSv/yr. The results were used to define maximum specific activities per radionuclide for waste to be disposed of at RWDF Buryakovka under today's operational conditions, which proved to be in compliance with current waste acceptance criteria.

POST-CLOSURE SAFETY ASSESSMENT

Normal Evolution Scenario

The development of the normal evolution scenario for RWDF Buryakovka is based on the screening of features, events, and processes. It further takes into consideration expectations in regard to future use of the area as described above. This essentially means that it is expected that during normal evolution no exposure groups will be living permanently in the direct vicinity of the repository inside the Zone of Special Radiological Hazard.

The basic assumptions for the Normal Evolution Scenario are the following:

- Climate conditions remain essentially the same as today
- After closure of the repository, there will be a period of 100 yr of active institutional control and a period of further 200 yr of passive institutional control
- It is assumed that the total inventory is accessible to infiltrating water from the time of repository closure, that is: no radionuclides are bound in some kind of waste matrix.
- After the end of passive institutional control, restrictions limiting access to the region and land use will remain.
- Geosphere conditions will remain as today.
- Construction, closure and performance of technical barriers will be according to design.

Deviations from these assumptions were partly considered by sensitivity analyses or by alternative scenarios.

In the normal evolution scenario, the only release pathway for radionuclides from the repository is the groundwater pathway. Independent from the probability of associated scenarios, other pathways, i.e., air, biological ways, environmental air, and direct irradiation, have significantly

reduced distribution radii and are therefore not considered for the normal evolution and its radiological impact as no exposure group is supposed to live permanently near the area. Surface water pathways do not exist in the direct vicinity and due to the topographical situation of the facility and the high permeability of underlying sediment layers, their future existence is highly improbable.

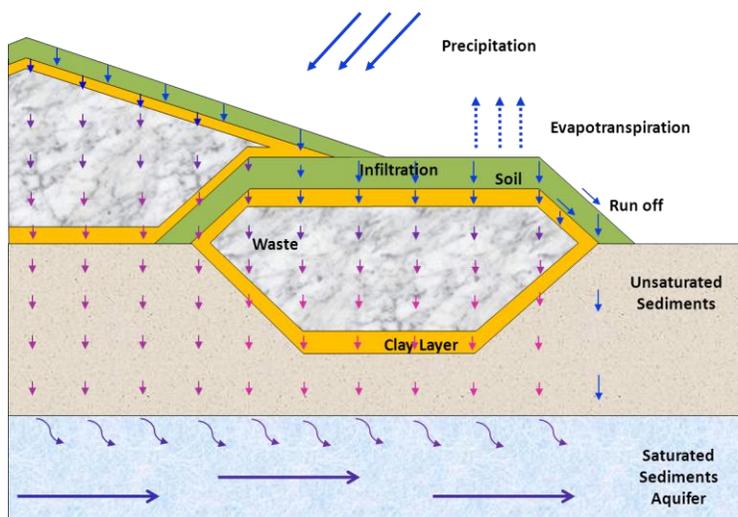


Fig. 4: Schematic draft of conceptual model for the repository.

The conceptual model for the repository is outlined in Fig. 4. The major part of the precipitation reaching the disposal trenches will be returned into the atmosphere by evapotranspiration but there will be an excess of precipitation that percolates further downward through the covering layers of the trenches. It is assumed that from the time of closure, a certain amount of precipitation will percolate downwards and reach the top clay layer. According to the design permeability of the clay layer, this infiltration can pass through the clay towards the waste body. The infiltration reaching the clay layer and consequently also the waste underneath is supposed to start with a value of 75 % of today's infiltration in the Buryakovka region at the time of closure. Due to a certain degradation of the cover during the next 300 years the infiltration is assumed to increase to 200 % of that value. It is assumed that a minimum cover of vegetation, soil, and clay will always exist to keep up an evapotranspiration rate that will limit the infiltration to this value. Accordingly, the infiltration rate is kept constant for times greater than 300 years.

On its way through the waste, the water becomes contaminated by mixing with the waste material and the moisture and bound water along the pathway. Contaminated water reaching the bottom clay layer from above will percolate further downwards through the layer. While migrating through the clay, radionuclides will be retarded by its sorption capacity but, a certain radionuclide concentration will remain in the water leaking through the clay, leading to advective flow from the repository into the unsaturated zone below. Apart from the advective transport through the bottom clay layers of the trenches, there will also be diffusive fluxes between the

waste body and the bottom clay layer on the one hand and the bottom clay layer and the top layer of the unsaturated zone on the other hand. By the combination of advective and diffusive fluxes, eventually all radionuclides will be transported from the waste body into the lower clay layer and further down through the unsaturated zone and into the aquifer.

Entering the aquifer, the contaminated water will become diluted. In much lower concentrations, the radionuclides will migrate with the groundwater through the aquifer. Depending on the sorption capacity of the aquifer, there will be further retardation for most of the radionuclides.

To estimate the radiological hazard, for the normal evolution scenario, it is assumed that members of the critical group will drink water from a well at a certain distance from the repository. The distance chosen for the normal evolution scenario is 1200 m, which is equal to the minimum distance to the border of the zone of special radiation hazard that should remain free from permanent settlements. Without detailed knowledge about the hydrogeology in the Buryakovka area, it is conservatively assumed that groundwater flow will be directly from RWDF Buryakovka to the point of discharge.

The computer code used for implementing the repository model for RWDF Buryakovka and carrying out the long-term calculations is the GoldSim Simulation Environment extended by the Radionuclide Transport Module, which takes not only care of the transport equations describing the mass transport between the different compartments of the model but also of radioactive decay and ingrowth of daughter nuclides with time.

Results - Normal Evolution Scenario

The reference case for the Normal Evolution Scenario leads to two maxima of similar height, one early maximum of 0.62 $\mu\text{Sv/a}$ at 2150 years after closure, caused by Np-237, and one later maximum of 0.61 $\mu\text{Sv/a}$ at 105200 years after closure carried by Pu-239 (Fig. 5).

An intensive sensitivity analysis has been carried out to demonstrate the influence the uncertainties of various parameters have on the results of the long-term assessment. Main objectives of these calculations were to identify parameters, for which additional research may be required to increase the accuracy of the long-term assessment and to determine whether overly optimistic or overly pessimistic (conservative) assumptions and parameters have been used for the Normal Evolution Scenario.

It is remarkable that the parameters defining the model network of cells and their interrelated advective and diffusive fluxes for the source and the near field have only little influence on the overall results. The parameters that strongly influence the results are listed below:

- Final infiltration (assumed constant value for times > 300 yr after closure)
- Sorption to waste
- Total inventory
- Sorption to clay (Partition coefficients for clay)

- Sorption to sand (Partition coefficients for sand)
- Groundwater velocity

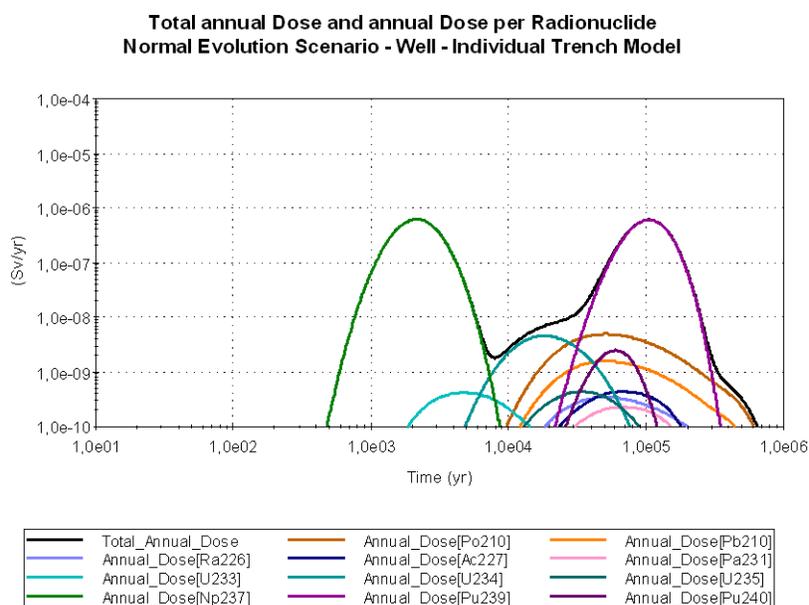


Fig. 5: Total annual dose and annual dose by radionuclides for normal evolution of the repository.

Results of the sensitivity calculations related to the sorption capacity of clay, the sorption capacity to sand, the final infiltration into the trenches, groundwater velocity, and total inventory demonstrate that uncertainties associated with their values could lead to a significant increase of the calculated annual dose.

Data chosen for inventory, groundwater velocity, and infiltration are considered as best estimate values or conservative best estimate values. Accordingly, more precise data in these areas are not supposed to lead to significantly increased dose rates. The partition coefficients describing the sorption capacity of clay and sand are generic values for this type of sediment, and little is known in how far these are to be considered as optimistic or pessimistic values compared to the real conditions. Taking into account that uncertainties associated with these parameters might be as large as 1-2 orders of magnitude, and the fact that their influence on the overall results can be extremely large, it has to be concluded that the uncertainty in this field might lead to uncertainties in the results of the safety calculations in the same order of magnitude or even more. Better site related data on sorption capacity of clay and sediments would considerably decrease the existing uncertainty. In spite of the rather large uncertainties, variations of the decisive parameters mentioned above do not seem to have a biased effect on the results in either favorable or unfavorable direction.

In contrast to this, several conservative assumptions have been made for the reference case,

where it is clear that more realistic data or assumptions will have a decreasing influence on the annual dose rates. The most important one is the assumption that there will be no sorption to waste. Assigning 50 % of the sorption capacity of sand to the waste material causes the peak dose rates for the two maxima of the reference case to drop to 20 % and 4 %, respectively, of their former values. It is known that the waste consists to about 40 % of concrete, soil, and reinforced concrete. Other materials building up the waste matrix will probably also have a certain amount of sorption capacity. The assumption that waste has about 50 % of the sorption capacity of sand therefore seems to be realistic.

In summary, though some parameters could lead to a significant increase in the calculated dose rates for the normal evolution scenario, there should be a sufficient amount of conservatism implemented in the model, especially by neglecting sorption to waste.

In order to evaluate the share, future waste of the planned repository extension will have in the radiological impact from the repository, Fig. 6 shows the total annual dose with time for the Normal Evolution Scenario for the extended state of the repository, as well as for the repository in its present state. The third curve represents the total annual dose caused by the enlargement of the facility, which was calculated by subtracting the first two curves. This result demonstrates that the enlargement of the facility will have only a minor influence on the potential post-closure radiological impact of the facility.

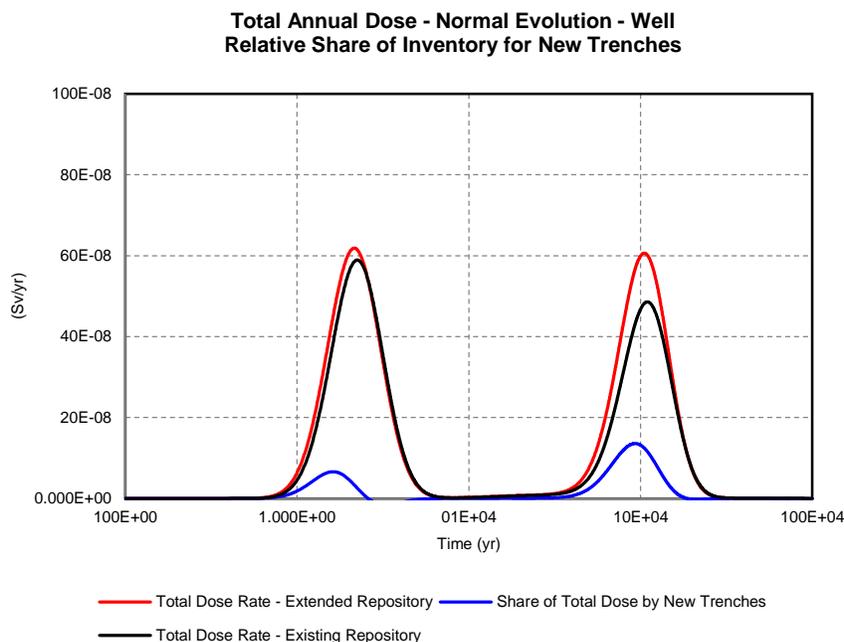


Fig. 6: Total annual dose and annual dose by radionuclides for normal evolution of the repository, existing facility and extended state.

Post-Closure Calculations – Disturbed Evolution

To investigate the consequences of disturbed evolution of the repository, the mandatory NRBU Scenarios were applied. According to the regulations, these scenarios are supposed to demonstrate compliance of planned near surface disposal of radioactive waste with regulatory requirements. In the context of this safety assessment they are used to assess the potential radiological impact associated with the radioactive waste that has already been disposed of at Buryakovka as a consequence of intervention measures after the Chernobyl accident. As restricted access to the repository is supposed also for times after the end of institutional control, these scenarios are to be considered as scenarios for potential exposure as consequence of unauthorized access to the site by members of the exposure groups.

The total dose rates estimated for NRBU Scenarios 2 (Consumption of agricultural products from contaminated soil), 3 (Destruction of cover layers by human intrusion), and 4 (External Irradiation) are below level B (1 mSv/yr) for potential dose rates, which is also the regulatory limit for the justification of intervention measures. The two critical scenarios are NRBU Scenarios 5 and 1. For NRBU Scenario 5, the assumption that a member of the age group between 0-1 yrs ingests 50 g of radioactive waste will lead to dose rates between level B and level A (50 mSv/yr) for as long as 33500 yr after repository closure, with a maximum value of 10.2 mSv/yr at 300 yrs after closure (Fig. 7).

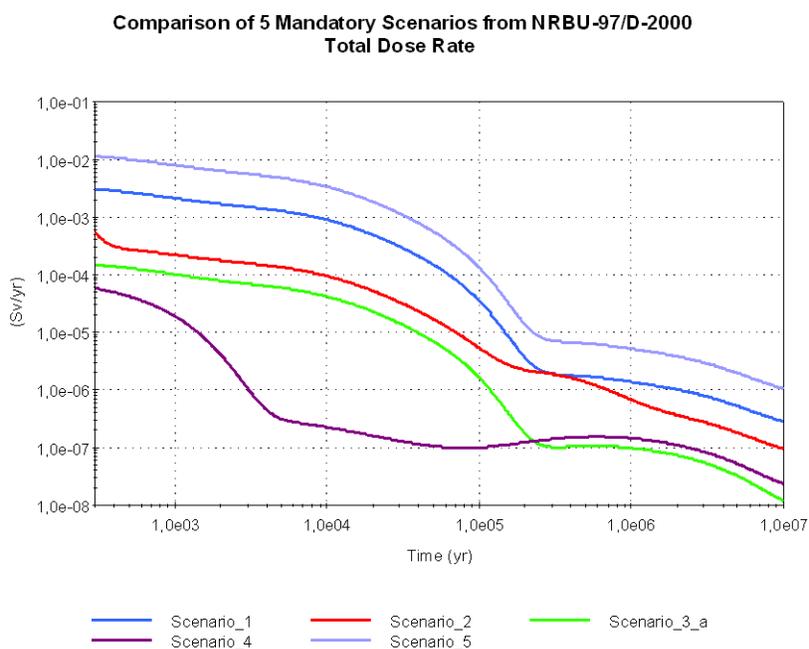


Fig. 7: Total dose for NRBU Scenarios 1-5.

NRBU Scenario 1 (Living at the site and consuming water from a borehole) yields maximum total dose rates of approximately 3.1 mSv/yr also at 300 yrs after repository closure. This

scenario is comparable with the normal evolution scenario: drinking water from a well near to the repository. The given boundary conditions for NRBU Scenario 1 are significantly less sophisticated. Especially the release of radionuclides from the repository follows a very simple and unrealistic model. The results of the NRBU Scenario 1 are therefore not considered to be of great significance.

In spite of uncertainties in regard to the level of conservatism inherent to the NRBU Scenarios, it is clear that unrestricted access of the population to the repository site after the end of institutional control and the unrestricted use of the area will potentially lead to dose rates above the limits for unconditional release from institutional control after 300 yrs. Accordingly, access to the repository site will have to be restricted for times significantly longer than the period of institutional control. However, it can be estimated that the upper regulatory dose rate level A of 50 mSv/yr will not be exceeded so that mitigation measures are not mandatory.

SUMMARY AND CONCLUSIONS

The results from the operational safety assessment are in compliance with the regulatory requirements, although, care should be taken during the operation to verify by operational monitoring that the scenarios and boundary conditions assumed for the operational safety assessment do not lead to an underestimation of the worker exposure.

The reference case for normal evolution of the repository, the well scenario, leads to a dose rate curve, which shows two equally high maxima of approximately 0.6 $\mu\text{Sv/a}$ occurring around 2000 and 100000 years after closure of the repository. The peak values are clearly below the regulatory limit of 10 $\mu\text{Sv/a}$ for normal evolution of the repository. Although considerable uncertainties exist in regard to the parameters used for the safety calculations, based on the available data base the results are considered as conservative best estimate.

Concluding, the results from the operational safety assessment and the long-term safety assessment are either within regulatory limits or as in the case of Scenarios 1 and 5 for the disturbed post-operational evolution of the repository within the limits that allows the specific evaluation of the situation by the regulator. It is therefore at the discretion of the regulator to decide in the framework of the licensing process if and under which conditions a future enlargement of the facility can be implemented.

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