Safety Assessment for the Radon-Type Surface Disposal Facility at Saakadze, Georgia – 15406

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ABSTRACT

The Saakadze disposal facility is located about 40 km from Tbilisi and was planned and constructed during Soviet times as Radon-type surface facility to accommodate up to 600 m^3 of low and intermediate level waste generated on the territory of Georgia. The disposal facility was operated from 1963 until its closure in 1995. The vast majority of waste in the Saakadze facility has been disposed of in two near surface concrete vaults with typical Radon-type dimensions, which cover layers already show significant structural damages. In order to assess the present safety of the site and provide the competent Georgian authorities with the necessary basis to take decisions in regard to the future of the repository, the European Commission launched and financially supported a project, which was assigned to a consortium of TÜV-Nord ENSYS GmbH and DBE TECHNOLOGY GmbH. The safety assessment of Saakadze facility, which was an essential part of this project and which is the subject of this paper was carried out by DBE TECHNOLOGY GmbH. The Government of Georgia has been gradually increasing efforts to improve the regulatory processes and the legislation on nuclear and radiation safety, and, in particular, on safe management of radioactive waste and sealed radioactive sources. Currently, however, there are still areas where specific Georgian laws and regulations do not exist. Accordingly, in certain aspects IAEA recommendations and best practices were used as guidelines for the methodology of the safety assessment. In spite of the large uncertainties to be considered, especially in regard to the inventory, preliminary results of the safety assessment indicate that scenarios related to the groundwater pathway do not lead to radiological impacts that are above or near to limiting values. However, human intrusion scenarios might lead to dose rates for the critical group that are exceeding these values. This is mainly due to the fact that today there is no proper engineered cover on top of the concrete vaults. Based on the comparison of existing options and considering the results of the long-term safety assessment, it is recommended to backfill the remaining voids inside the concrete vaults and to construct an engineered cover to reduce the probability of human intrusion scenarios and to minimize their potential impact.

INTRODUCTION

Radioactive Waste Management in Georgia

The Saakadze disposal facility was established during Soviet times as Radon-type surface facility to accommodate up to 600 m^3 of low and intermediate level waste generated on the territory of Georgia. It is located about 40 km from Tbilisi and was operated from 1963 until its closure in 1995. Today it belongs to the Georgian Ministry of Economy and is under the surveillance of the Ministry of Environment and Natural Resources Protection of Georgia.

Until recently, the site was practically abandoned and neither environmental monitoring nor technical arrangements to ensure the appropriate level of safety and physical protection had been implemented. During the last decade several external donor assistance programs have supported Georgia in the area of nuclear safety, such as the Instrument for Nuclear Safety Cooperation (INSC) managed by the European Commission (EC). One of the projects funded by the INSC since cooperation between Georgia and the EC began in 2004 was to support the Georgian Authorities through the preparation of safety assessments of the Central Storage Facility (CSF) and the disposal facility at Saakadze. Another objective of this project was the assessment of the potential impact if additional radioactive waste were disposed of in a new facility at the same site. Implementation of the project was awarded in 2012 to a consortium of TÜV Nord and DBE TECHNOLOGY GmbH. The subject of this paper has been restricted to the safety assessment of Saakadze disposal facility, which has been carried out by DBE TECHNOLOGY GmbH.

In general the knowledge about the site is limited and historical information concerning the inventory and the detailed construction of the facility is practically non-existent. Respective information given below are taken from the results of a preceding INSC project [1], during which available information on the content of the repository and the hydrogeological situation at the site was compiled and supplemented by new survey data.

RADON-TYPE SURFACE REPOSITORY SAAKADZE

Description of the Facility

The Saakadze disposal site, which covers in total an area of approximatively 90 000 m² with a length of 700 m, is located on top of a small hill. It contains two near surface concrete vaults, where solid waste was disposed of and three tanks for temporary storage of liquid wastes with one of them still containing liquid waste. Both, vaults and tanks show significant structural damages.

The potential impact of the liquid waste on the long-term assessment of Saakadze facility has been assessed and found to be of minor significance for the Normal Evolution Scenario. Still, the recommendation has been given to remove the liquid waste from the tank to prevent human intrusion scenarios connected with the tank and to comply with the obligation to minimize potential radiological impact from the facility if achievable with reasonable effort. For the purpose of this paper, it has been assumed that this recommendation will be followed in the near future. The tanks and the liquid waste are therefore not considered in the following discussion.

Since no specific design documentation for the Saakadze disposal site is available, the description of the vaults for the solid waste is based on observations, design documentation of similar facilities and on the information provided by local experts and former employees, which were interviewed during the course of the previous INSC project. The dimensions of each of the two aligned vaults of the repository are 22 m (length) x 5 m (width) x 3 m (depth), which leads to a surface area of 220 m² and an inner volume of ca. 300 m^3. The thickness of the vertical concrete walls varies between 0.15 m and 0.25 m and the thickness of the concrete bottom of the repository is expected to be 0.10 m. Each vault is covered with 28 concrete slabs of 0.30 m thickness. The joints of these slabs and their surface are supposed to be finished with bitumen and covered with a layer of asphalt.

During recent site surveys a physical inspection of the repository internal structures was not possible, however, some deviations of the Saakadze repository from the typical Radon design could be identified:

- In one of the vaults, one concrete slab has been replaced by a metal sheet (used as temporary replacement of the concrete slab during vault loading/concreting), which later has been covered by the asphalt layer. In this area, an open gap of about 0.02 m by 0.30 m in the joint between the metal sheet and concrete wall was observed;

- The two vaults were divided by inner walls forming sub-vaults with dimensions of 3m x 5m; and
- Only half of the repository surface is covered with a layer of unevenly distributed topsoil, starting with a thickness of about 0.05 - 0.10 m from the middle of the repository and increasing to its maximum of 1.5 m at one of its ends. The other half of the two vaults lack any topsoil cover.

There are many plants in the area of the non-covered part of the vaults, which often root directly at the joint between asphalt cover and concrete walls, where the asphalt layer has partly already weathered away (see Fig. 1). The asphalt cover is obviously in an advanced state of degradation and its sealing function has to be considered as already significantly impaired.

Figure 1: Surface area of the two vaults, in the foreground the surface of the asphalt layer can be seen and in the background the partly soil covered end of the vaults (width ca. 10 m, length 22 m).

The typical sequence of the sedimentary layers at the site is from top to bottom: a highly permeable layer of vegetated loamy soil with a thickness of a few meters followed by two layers of low permeability: a clay layer of few meter thickness and clayey conglomerate with very low porosity. Up to a depth of 50 m no aquifer has been found, accordingly the conglomerate layer has been assumed reach down to 50 m.

The main runoff direction from the small hill hoisting Saakadze site is to the South-East, where a small eastward stream receiving the surface water discharges from the site passes the hill at a level of approximately 35 m below the surface of the vaults. This stream is water bearing, however, only during short periods during the year, which confirms that the main feeding source of this stream is the surface water runoff and that the stream does not receive discharge from groundwater.

Inventory

A significant part of the waste disposed of at Saakadze are various sealed and unsealed ionizing radiation sources, which were used during the Soviet period by different institutions, facilities, and military bases throughout Georgia. In addition also other low-level waste like operational waste from the formerly operated research reactor was disposed of at the site. Generally, radioactive waste management practices were rather primitive and, in most of cases, limited to the collection and disposal of the radioactive waste in the Radon type disposal facility at the Saakadze disposal site. The waste was placed in the vaults without any further conditioning at the site. The individual sub-vaults of the two vaults would normally be filled with solid waste until 80-85% of their total volume was reached and then completely backfilled with some kind of concrete. Subsequently the sub-vaults were covered with concrete slabs and filling of adjacent sub-vaults started.

The inner structure of the vaults could not be confirmed during recent investigations in the course of the preceding INSC program but pictures could be taken through the mentioned gap at the joint between asphalt layer and concrete wall. These pictures confirmed the use of backfilling but also revealed large voids above the waste layer in this part of the vault and a large number of sealed sources and unconditioned waste lying loosely on top of the waste mass. The best estimate for the activity disposed of in the two vaults of the repository is given in Table 1 below.

TABLE 1: Activity per radionuclide disposed of in the Saakadze repository.

Radionuclide	**Activity [TBq]**
Co-60	23
Cs-137	12
C-14, Sr-90, Ra-226, Th-226, Th-232, Pu-238, Pu-239 and Am-241	0.1

OBJECTIVES OF SAFETY ASSESSMENT AND METHODOLOGY

The execution of the safety assessment for the near-surface Saakadze disposal site is required to assess the long-term safety conditions of the facility and its potential impact on the environment and on members of the public. It shall also provide the basis for the decisions to be taken by the competent Georgian authorities in regard to necessary measures for improving the conditions at the site, and evaluation of the impact, a possible future disposal facility at the same site might have on its level of safety.

Currently the legal framework in the field of radioactive waste in Georgia is being revised and amended. At the time being, there are no legal requirements for undertaking safety assessments for near-surface disposal facilities in Georgia. For this reason, this safety assessment is based on the current state of the art and on the procedures defined by international standards and best practices. The main documents that have been taken into consideration for the derivation of scenarios and as guideline for performing the safety analysis are the ISAM Methodology report [2], developed for safety assessments of near-surface repositories for radioactive waste, and the IAEA TECDOC-1380 [3]. As boundary limits for the radiological impact during normal evolution of the repository and for scenarios of its disturbed evolution the internationally accepted values of 0.1 mSv/y and 1 mSv/y have been chosen, respectively.

The selection of scenarios has been carried out according to [3], which contains the description of a safety assessment for a generic Radon-type facility. For the scenario development, criteria and scenario parameters given there were adjusted to the specific conditions of Saakadze disposal facility. As result from this process four scenarios were selected for the long-term safety assessment. For the normal evolution of the repository, release of radionuclides via the groundwater pathway has been considered as the only significant release pathway. As second scenario an earthquake scenario has been investigated, which is supposed to conservatively cover the potential impact of all kind of natural catastrophes. For this scenario also radionuclide release via the groundwater pathway and subsequent consumption of contaminated water has been assumed. To assess the potential impact on future human activities two human intrusion scenarios have been used, which were modelled according to [3]. Both of them consider different exposure pathways. In context with the occurrence of human intrusion scenarios, the period of institutional control has been assumed to last for 300 years after closure of the repository (1995).

The general approach to the safety assessment is a conservative one. To close gaps in the available data set for Saakadze disposal facility, in general best estimates or conservative values and model assumptions have been selected. Taking into consideration the insufficient knowledge about a number of important parameters for the safety calculations, sensitivity analyses have been performed for all parameters that are known to be crucial for the outcome of the safety calculations.

For the long-term calculations a mathematical model has been developed using the GoldSim simulation environment. The human intrusion scenarios and the associated equations have been adapted from [3].

REPOSITORY MODEL FOR NORMAL EVOLUTION SCENARIO CALCULATIONS

The Normal Evolution Scenario chosen for Saakadze facility corresponds to the use of ground or surface water that has become contaminated through the process of precipitation water entering the vaults, leaching radionuclides from the waste and subsequently migrating through the geosphere until reaching some interface to the biosphere. The interface between the geosphere and the biosphere can be either a well intercepting the radioactive plume in the aquifer downstream of the disposal facility, or a surface water body (river or stream). The surface water bodies are considered on a site specific basis, the well is arbitrarily located in an off-site location nearby.

The main assumptions forming the basis for the normal evolution scenario are listed below:

- Climate conditions remain essentially the same as today.
- 300 yr of institutional control, without active maintenance of the vault cover.
- It is assumed that the total inventory is accessible to infiltrating water from the time of closure:
    - No radionuclides are bound in any kind of waste matrix,
    - No waste container will delay the accessibility of waste, and
    - All infiltration will be equally distributed over the complete waste volume.
- Geosphere conditions will remain as today.
- There will be no technical improvement of the existing technical barriers (backfilling and cover).

Deviations from these assumptions are partly considered by sensitivity analyses or consideration of alternative scenarios.

To assess the radiological impact of Saakadze repository a very simple biosphere model has been used to calculate potential radiological doses for members of the public. This drinking water scenario assumes that a member of the public will drink 2 l of water per day from a contaminated source. In case of the groundwater aquifer pathway this source would be water from a drinking water well or from Lochini

River. In case of the near surface pathway towards the stream, the source is the stream, but accounting for the circumstance that the stream is temporarily dry it is considered as source for drinking water for 10% of the year only. This simple biosphere model has been chosen because it is considered to give a good estimate of what could be the radiological impact under unfavorable conditions. More complex biosphere models like a typical farm biosphere model of a self-supporting community that lives at the site would probably lead to maximum doses that are 2-4 times higher than the drinking water doses. However, such scenarios require a significant amount of water drawn from the aquifer per day, which is not plausible for Saakadze site conditions.

Conceptual Repository Model

The conceptual repository model used for the long-term calculations of radionuclide release via the water pathways is based on the description of the repository system components and their conditions as given in [1]. The main components of the repository conceptual model and the near field together with the water fluxes are outlined in Fig. 2. The sketched condition of the concrete cover illustrates a possible future state when its barrier function will have been completely destroyed.

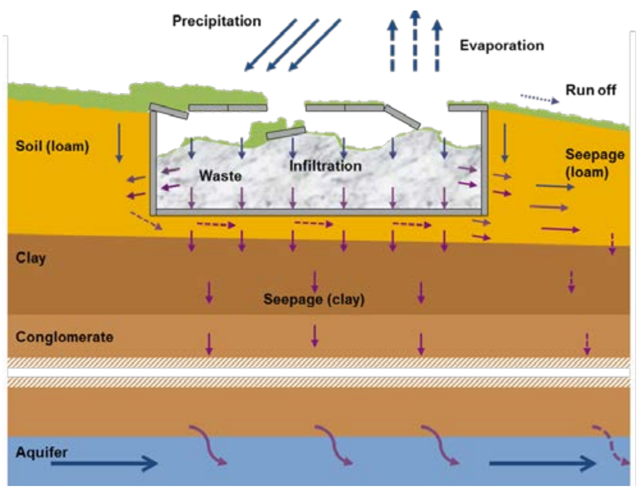

Figure 2: Schematic draft of conceptual model for the repository

The two possible release pathways are near surface flow through the loamy soil layer towards the nearby stream and vertical seepage through clay/conglomerate layers into the hypothetical aquifer. The following chapter summarizes the main safety aspects of the different elements and their expected evolution with time.

MAIN COMPONENTS OF THE SAFETY ASSESSMENT MODEL

Technical Barriers of Disposal Vaults

The main safety functions of the top cover, concrete walls and bottom are to limit the percentage of precipitation that infiltrates into the repository, to prevent erosion by surface water or wind and to protect the repository against human or biological (animals or plant roots) intrusion. It has also a shielding function against direct irradiation. Further safety functions are: Minimizing diffusion and supporting retention of radioactive substances inside the repository. For the conceptual model of the Normal Evolution Scenario, only the limitation of infiltration has been considered. All other safety functions have been conservatively neglected or considered during scenario development.

During the first decades after closure, a large part of the precipitation reaching the cover of the repository will be returned into the atmosphere by evapotranspiration. Only a small amount depending on the initial permeability of the cover will be able to enter the vault. With progressing degradation of the cover, the amount of water entering the vault will increase until a certain maximum value will be reached.

According to the available information on the meteorological conditions at Saakadze site, an average precipitation of 550 mm/y and high evapotranspiration is to be expected. For the vegetated area around the repository a value of 80% has been selected to represent normal evolution evapotranspiration conditions. Precipitation on degraded (failed) top cover is, however, only reduced by partial evaporation. Therefore, maximum infiltration into the vault and the waste body has been chosen as 75% of average precipitation.

For the Reference Case of the Normal Evolution Scenario, assumptions regarding the degradation rate and permeability for the vault's base, walls, and cover do not allow bathtubbing to take place. Bathtubbing has been assessed, however, in the course of the sensitivity analysis and found to be of minor significance for the Normal Evolution Scenario. It could provide, however, additional risks in regard to human intrusion scenarios, because water filled vaults could be used as water reservoirs.

Source Term

As mentioned before, there is only vague information in regard to the constitution of the waste. Information that was confirmed by inside inspection of the disposal chamber (through the existing gap between wall and cover) was the use of backfill and waste canisters. It is assumed, that the waste body consists of a mixture of packaged and non-packaged waste, partly concreted or cemented, and backfill. The volume of the waste/backfill body is estimated to approximately 270 m^3 or 45% of the vault volume.

As there is no reliable information in relation to the part of the waste, which has been disposed of in special containments or conditioned form that may delay the release of radionuclides, these technical barriers have been conservatively neglected, although for a certain part of the waste such barriers certainly exist. For the same reason of lacking data, the chemical barrier function, which the waste itself and conditioning material like concrete should have due to the sorption capacity of their basic materials, has also been conservatively neglected.

Geosphere - Hydrological pathways and balance

The geosphere underneath the repository consists mainly of loamy and clayey sedimentary layers. The distance between the top surface and the upper aquifer is supposed to be at least 50 m. Accordingly, this value, which is probably a conservative one, has been chosen as depth of the hypothetical aquifer considered for the Reference Case of the Normal Evolution Scenario. For thickness of the aquifer and groundwater velocity model assumptions have been chosen, which later were subject to sensitivity analysis.

According to the sedimentary investigations, it can be assumed that there is mainly loam and clay within the geosphere, which normally have relatively high sorption capacities. For the Reference Case, sorption to clay, loam and conglomerate layers have been considered by referring to generic data bases. For the assumed sandy aquifer layer sorption has been conservatively neglected.

To estimate the radiological hazard, for the Normal Evolution Scenario, it is assumed that members of the critical group will drink water from the nearby stream or from a groundwater well at a certain distance from the repository. The area around Saakadze site belongs to the watershed of the Lochini River. Therefore, alternatively, the radiological impact that would result from the complete discharge of the contaminated groundwater into the Lochini River at a distance of 5000 m has also been evaluated. Due to the strong dilution by the river water the estimated radiological impact was insignificant compared to the results for the Well-Pathway. The results for River Pathway are therefore not further discussed here.

GOLDSIM MODEL FOR NORMAL EVOLUTION SCENARIO

The computer code used for implementing the repository model for Saakadze site and carrying out the long-term calculations is the GoldSim Simulation Environment extended by the Radionuclide Transport Module. GoldSim simulates the material transport and takes care of radioactive decay and the ingrowth of daughter nuclides. The essential part of the GoldSim Geosphere Model is shown in a slightly simplified way in Fig.3 as example of the Computer Model developed for Saakadze disposal facility.

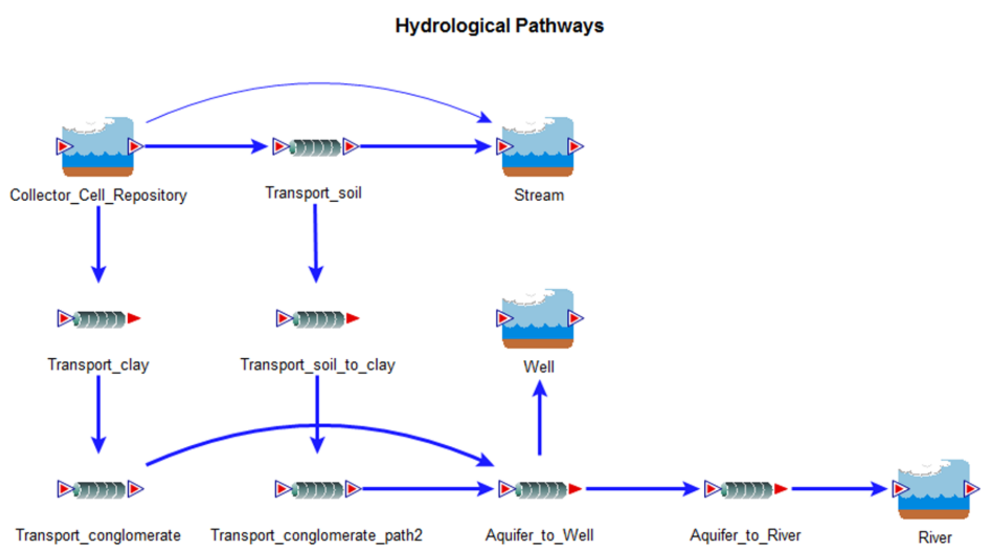

Figure 3: GoldSim model of geosphere pathways from the repository to stream, well or river location

The rectangular icons, symbolizing cells containing some combination of gases, fluids and solids are mixing cells, which means that GoldSim mixes the total content of any these cells at each time step during the calculation. Depending on the sorption capacities of solid materials and liquids inside the cell, GoldSim assigns the proper share of any activity inside the cell to the different media. For each cell, data are defined for kind and mass of solids and kind and volume of liquid contents as well as diffusive and advective fluxes between the mixing cells and linked transport elements. To implement simplified geosphere models, GoldSim provides so called aquifer elements (see pipe-like icons in Fig. 3). These elements are characterized by the dimensions and the properties of the porous medium through which the water is flowing, its water saturation, flow rates, and the estimated dispersivity.

RESULTS FOR NORMAL EVOLUTION SCENARIO

Reference Case for Normal Evolution Scenario

Fig. 4 shows the total annual dose and the annual doses by individual radionuclides with time for the Well Pathway. In this graph, only those radionuclides are included with individual curves that give significant contribution to the total dose. The total dose curve shows the sum for all radionuclides considered in the calculations including those of other radionuclide that are part of the initial inventory and long-lived progeny of initial radionuclides that are not shown in the figure.

The curve of total dose rate shows a maximum of 80 nSv/y after 3400 years, caused by C-14 (blue curve, completely covered by curve for total dose). A late and much lower second maximum is carried by a set of longer-lived radionuclides at approximately 100000 years after closure.

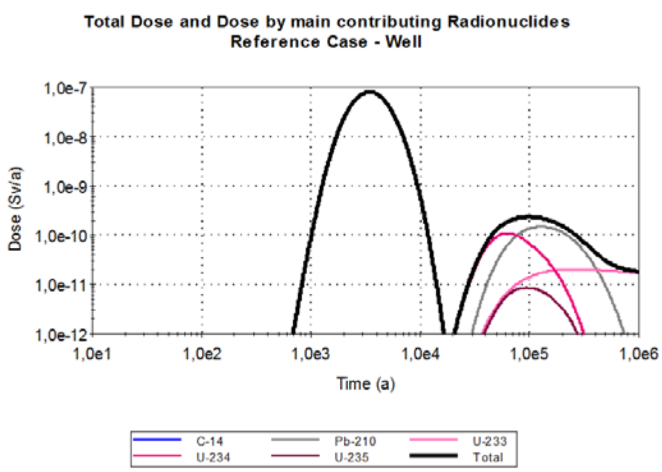

Figure 4: Total annual dose and annual dose by major radionuclides per person for drinking well scenario for the Reference Case of the normal evolution of the repository.

The short-lived radionuclides, which form the major part of the initial activity at Saakadze: Cs-137 and Co-60 do not appear in the figures above, as they are retarded in the geosphere for a long time compared to their half-lives, so that no significant amount reaches the aquifer.

In addition to radionuclide release via the groundwater aquifer pathways, the near surface discharge to a nearby stream has been considered. The results are shown in Fig. 5. Compared to the Well Pathway, the early maximum, carried by C-14 has a notably reduced value of approximately 1 nSv/y and is observed somewhat earlier at 2925 years. A second larger maximum, this time carried by Pu-239, of 24 nSv/y arises 28300 years after closure of the repository.

It can be taken from the two dose rate curves that both Pathways lead to similar maximum dose rates for the Reference Case. The relative importance of the individual radionuclides differ for the two pathways: For the Stream Pathway Np-237, C-14 and Pu-239 are the decisive radionuclides and for the Well Pathway C-14, Pb-210 and U-234 give the main contribution. This is primarily due to the fact, that loam soil has slightly different generic sorption properties than those assumed for clay and conglomerate.

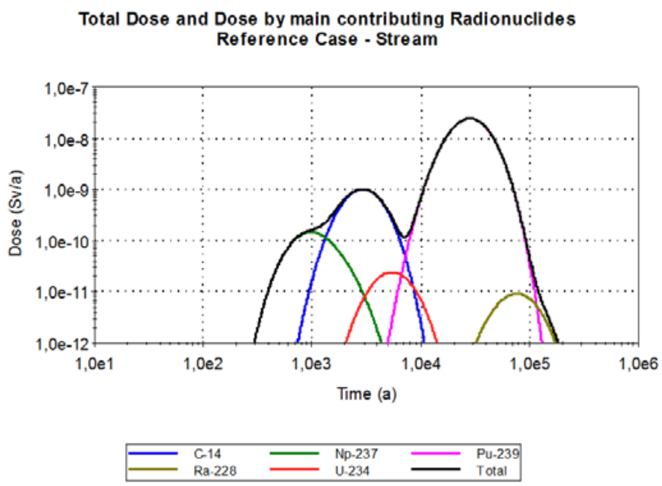

Figure 5: Total annual dose and annual dose by major radionuclides per person for stream water scenario for the Reference Case for normal evolution of the repository.

Sensitivity Analysis

An intensive sensitivity analysis has been carried out to investigate the influence the uncertainties of various parameters have on the results of the long-term assessment. To analyses the sensitivity of the model towards variation of individual parameters, all parameters for the Reference Case were kept constant, while for the parameters of interest, extreme values were selected.

The most influential parameters that are also associated with a large uncertainty are:
- Parameters defining the relative importance of Stream Pathway and Well Pathway
- Retardation of radionuclides within the repository and along their release pathways
- Assumptions in regard to the aquifer pathway

Parameters that are decisive for the relative share of leakage from the vaults that travels via the Well Pathway or the Stream Pathway are the permeability of the unsaturated layers and the infiltration rates.

The largest dose rates are estimated for the case that the total leakage is transported vertically downwards through the unsaturated layers into the aquifer and with the groundwater towards the location of the well. This situation would result in an increase of the peak dose rate by a factor 10.

The retardation of radionuclides inside the repository and along the migration pathway has also a large influence on the final results and a large uncertainty. It is to be noted that the change of dose rates can be significantly larger than the change in assumed Kd values. The uncertainty in regard to the sorption capacity of the unsaturated sediments is estimated as 1-2 orders of magnitude.

The assumptions in regard to the groundwater conditions, mainly groundwater velocity and thickness of aquifer are linearly influencing the peak dose calculated from the Well Pathway. It has to be taken into consideration that the assumptions in regard to the aquifer can partly be considered as rather conservative. The depth of the aquifer is with 50 m a conservative estimate as it is known from the site exploration work that up to 50 m there has been no evidence of an aquifer. The assumptions in regard to the width of the aquifer cross section and the negligence of side ward dispersion during radionuclide transport are also conservative. Further no sorption has been assumed for the aquifer and the distance to be travelled within the aquifer is a very short one. Still, site specific information on the aquifer dimensions and the groundwater flow might also lead to an increase in the calculated dose rates for the Well Pathway.

To evaluate the conservatism of the Normal Evolution Scenario, the most important “pessimistic” assumptions used for the model are listed below:

- No consideration of waste containment or conditioning (immediate accessibility of radionuclides)
- No sorption to waste mass or backfilling material
- No backfilling of voids in vaults and no construction of new cover
- Conservative assumptions for groundwater pathways
    - No side wards dispersion, no sorption to aquifer, direct flow of contaminated water to location of water abstraction

For the results of the long-term calculations, the most influential boundary conditions are the assumptions that the vaults will not be backfilled, that no new cover will be constructed on top of them, and that there will be no sorption to waste.

A more realistic situation would be to expect that the voids of the vaults will be backfilled with concrete, that an engineered cover will be placed on top of the vaults, and that the additional concrete as well as the waste/backfill mixture inside the vaults will have at least a certain sorption capacity, even if it might be below typical generic values. Assuming that these boundary conditions will be changed and assigning 10% of typical generic Kd values (according to [2]) to the new backfill material and 20% of typical generic Kd values (according to [3]) to the waste/backfill mixture will decrease the dose rates for both pathways to values below 1% of the Reference Case values.

In general it can be concluded that the approach for modelling the source term and the engineered barriers is also a rather conservative one, especially neglecting any sorption capacity of the waste/backfill mixture. Assuming only 1% of the generic sorption capacity for similar waste to the material inside the vaults reduces the peak dose rates already to less than 10%. The biosphere model is not considered as strictly conservative, but as pessimistic.

In regard to the unsaturated zone and the geosphere, the question of conservatism is more difficult to answer. The Kd values selected to calculate sorption to the sedimentary materials are decisive for radionuclide transport and have a large influence on the calculated annual doses. They were taken from generic data collections for similar media and represent best estimates. However, it is well known that this parameter has a broad bandwidth of variation in natural media. Consequently the underground pathway model has to be considered as a best estimate model with considerable uncertainty associated with it.

In total, the model and the Reference Case data set for the Normal Evolution Scenario are considered to lead to a fairly conservative assessment of the future evolution of the repository. Considering the difference of three orders of magnitude between the maximum dose rates and the limiting value of 100 µSv/y, it can be stated that the radiological impact for the normal evolution of the Saakadze disposal site is well below the relevant limits.

RESULTS FOR DISTURBED EVOLUTION SCENARIOS

As mentioned above, three scenarios have been selected to assess the disturbed evolution of the repository: the Earthquake Scenario and two human intrusion scenarios, the On-Site Residence Scenario and as a major human intrusion scenario and the Road Construction Scenario as a more moderate intrusion scenario. Here only the results of the more severe Human Intrusion Scenario are discussed.

Earthquake

For the Earthquake Scenario, the same release groundwater release pathways have been considered as for the Normal Evolution Scenario and therefore the same computer model has been used for the calculations. The model parameters were adjusted to simulate the expected strong impact on the repository system and the underground by a severe Earthquake.

As consequence of a severe earthquake, a permanent destruction of all technical barriers is assumed that lead to an increased infiltration of water into the repository vaults and an equally increased leakage from the vaults into the unsaturated sediments below. It has been further assumed that fast pathways would develop within the unsaturated sediment layers leading to an increased and faster water flow from the repository to the aquifer. It is expected that these fast pathways will heal with time, so that after a certain period chosen as 100 years for this scenario, the permeability of the unsaturated layers have reached again their initial values.

Compared to the Reference Case most of these changes have only very limited effect, because the assumptions for the Reference Case are rather conservative in regard to the functionality of technical barriers. The main effect for the model results is therefore related to the expected spontaneous increase of permeability by three orders of magnitude for the unsaturated sediments underneath the repository upon occurrence of the earthquake. The result is a moderate increase of the maximum dose rate for the Well Pathway of 25% compared to the Residence Case of the Normal Evolution Scenario, while the dose rates for the Stream Pathway remain practically unchanged.

It has to be taken into consideration though that even if the Earthquake Scenario does not significantly increase that maximum dose rate for the groundwater pathway, a completely destructed technical cover of the repository vaults will increase the possibility and probability of a broad scope of human intrusion scenarios due to the easy direct access to the waste inside the vaults if no backfilling and proper covering of the vaults has been carried out before the earthquake event.

On-Site Residence Scenario

The On-Site Residence Scenario expects the technical barriers of the repository as well as the waste as completely degraded. The exposed residents in this scenario are supposed to live in a house that had been erected directly on top of the vaults. During construction of the foundation to a maximum depth of 3 m waste has been excavated and distributed in the environment. Due to this distribution of waste material, the soil around the house is expected to have a specific activity which is equal to the specific activity of the waste divided by a dilution factor. On the soil, residents grow vegetables for their own consumption. The earliest time for this scenario to happen has been set to the end of institutional control 300 years after repository closure.

The model assumes that 30 % of specific activity that at the time of human intrusion is still inside the vaults (without release by air or water pathways) will be in the soil. That means that a certain mixture with soil is expected that would lead to dilution of the specific activity. If all 270 m³ of waste were excavated during the intrusion activities and distributed within the uppermost 30 cm of soil, which are most relevant for soil to plant transfer of radionuclides, then the complete waste would have to be distributed on a 3000 m² area, where vegetables would be grown for later consumption. It is also assumed that on this area the house would be erected and for estimation of irradiation dose the exposed member of the resident group is supposed to spend the whole year on this area of about 55 m x 55 m.

Fig. 6 shows the results for total annual dose for this scenario and total doses for the individual exposure pathways considered for this scenario. It is obvious that for this scenario, the consumption of vegetables grown on contaminated soil is the decisive one.

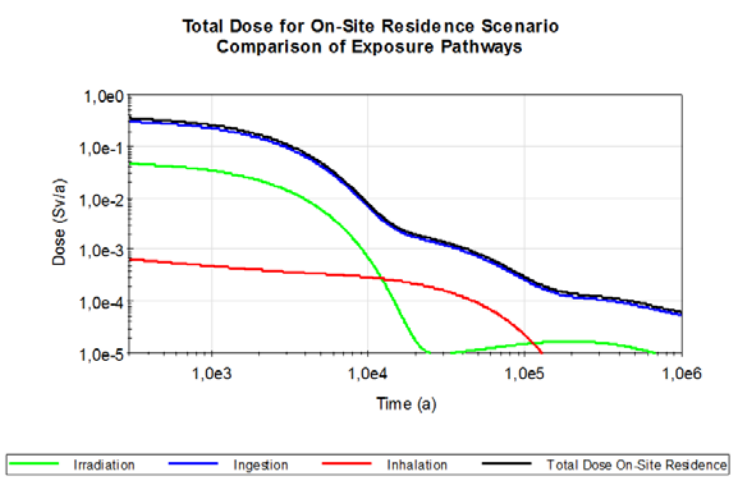

Figure 6: Total annual dose and total doses for different On-Site Residence exposure pathways.

The assumptions for the On-Site Residence Scenario are certainly very conservative; especially the assumption that there will be no release of activity via the groundwater pathway, although it is assumed that waste and technical barriers are completely degraded to allow for the equal distribution of the waste. In spite of the conservative assumptions, which might be subject to discussion, the results show in any case that large scale human intrusion activities can lead to radiological exposure above or near to the limiting value of 1 mSv/y for up to several thousand years.

RECOMMENDATIONS FOR SAFETY IMPROVEMENTS

In general Saakadze site can be considered as having very favorable environmental conditions for a surface disposal facility for radioactive waste. The climate at the site, in combination with the geology, provides conditions for high evapotranspiration and low infiltration of precipitation. The clay and conglomerate layers underneath the vaults show low permeabilities and should typically have large sorption capacities. In addition the aquifer depth at the site is larger than 50 m. This situation leads to effective retardation of radionuclides that are released from the vaults via the groundwater pathway and an estimated dose rate for the normal evolution of the repository, which is approximately 2-3 orders of magnitude below the limiting value. Compared to the favorable normal evolution of the repository human intrusion scenarios could lead to critical radiological impacts if the present conditions at the site are not changed.

The recommended measures described below are mainly dedicated to prevent the critical human intrusion scenarios from occurring or to reduce the potential radiological impact from such scenarios down to levels below the boundary limit and to decrease infiltration into the vaults and to decrease existing uncertainties:

- Keeping up institutional control for 300 years after closure
- Backfilling of voids inside the vaults
- Construction of an appropriate cover for the facility

Recently there has been significant improvement in the level of physical security at Saakadze site by renewing the fencing system and improving the surveillance routine. The physical security is considered as very important during the present state of the facility, which would allow intrusion into the vaults with limited physical effort. As currently sealed sources and other waste packages are partly lying loosely inside the vaults, it would be relatively easy to take such objects out of the vaults. Today the existing cover might still present sufficient resistance to physical intrusion but judging from its present state in a few decades at latest, physical intrusion will be no difficulty.

Even after backfilling and construction of a new cover, some kind of physical protection is recommended but in general institutional control with regularly inspections would seem appropriate. As period for the institutional control 300 years are recommended in compliance with generally accepted control periods.

Backfilling the voids within the vaults with concrete would lead to a number of improvements in regard to the long-term safety for normal evolution of the facility and for human intrusion scenarios. It would lead to the formation of a large concrete block, which would considerably complicate the removal of waste packages or particles from the site. It would also create an additional shielding and would prevent the accumulation of water inside the vaults that might be used as water reservoir if no cover layers would be constructed on top of the vaults. The backfilling material would also form an additional chemical barrier as it would increase the sorption capacity of the waste/backfill content of the vaults and thereby increase the retardation of radionuclides inside the vaults.

Construction of new cover would have two main effects. First, new sealing cover layers on top of the vaults would decrease the infiltration as long as the sealing function of the cover layer is supposed to work properly. It would also limit the maximum infiltration by increasing the evapotranspiration rate to typical values for vegetated areas. The second and more important effect of the new cover would be the increased distance between the surface and the waste. This increased distance will prevent the occurrence of inadvertent human intrusion scenarios like the On-Site Residence Scenario, where it is assumed that the resident's home will be erected directly at the vault location and that all the waste excavated during construction of the foundation would be distributes around the house. The additional material will also further decrease the probability of advertent intrusion scenarios.

CONCLUSION

This assessment lead to the result that release of activity from the disposal facility via the groundwater pathway for its normal evolution scenario is likely to cause only very minor dose rates, which are smaller than internationally accepted regulatory limits for the normal evolution by 2-3 orders of magnitude. Human intrusion scenarios, however, lead to significant dose rates that clearly exceed the internationally accepted levels for this kind of disturbed evolution. The main reason for the large hazard associated with human intrusion scenarios is the unsufficient backfilling and covering of the facility.

It is obvious that the present state of the repository does not comply with the state-of-the-art and best practices, but in regard to the future of the disposal facility, the results for normal evolution of the facility indicate that there is no clear necessity to retrieve and transfer the waste to some future repository which does not exist yet. However, in case that the relevant authorities decide to leave the waste at its present place of disposal it is strongly recommended to backfill the vaults with concrete and to implement an appropriate engineered cover, which will prevent the occurrence of human intrusion scenarios or effectively mitigate their potential radiological impact.

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