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Approach for the Prospective Assessment of Radiological Impact to the Population from Decommissioning of "RADON" Type Radioactive Waste Storage Facility in Lithuania

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ABSTRACT

The Maišiagala radioactive waste storage facility in the Republic of Lithuania is of a former Soviet Union "Radon" type facility design and initially was planned for the disposal of institutional waste. It consists of one 200 m^3 sub-surface vault for disposal of solid waste and several auxiliary installations and buildings. The facility started operation in 1963 and was closed in 1989 being partially filled with waste. The waste is of various types: disused sealed radioactive sources, surface and bulk contaminated items from industry, military, and medicine applications. The inventory is estimated to be 7.7×10^{13} Bq.

The Maišiagala facility cannot be upgraded to a disposal facility that meets the modern environmental and radiation safety standards. Therefore, a decision was taken to retrieve the waste and decommission the site to a "green field" condition.

The release of airborne radionuclides to the environment during the decommissioning activities is estimated to be up to 1.8×10^{12} Bq in a single year and is governed by release of gaseous Rn-222. The release of aerosols is smaller by several orders, i.e., 3.9×10^{7} Bq. The most activity contributing radionuclide is H-3. The release is expected to be irregular and will vary during the year, week, day and the performed activity. The knowledge on the stored waste inventory is uncertain and cautious assumptions are made, especially regarding the emission of gaseous Rn-222. The paper discusses the approach to the assessment of the expected releases of radionuclides into the environment under normal operation conditions and the approach to the consideration of the radiological impact on the population.

The increase of external radiation fields in the close proximity to the site and during the waste transport will create additional exposure pathways. The assessment of direct irradiation is discussed only in the context of its significance to the overall impact of the planned activity.

Low radiological impact of the decommissioning of the "RADON" type radioactive waste storage facility in Lithuania on the population is expected under normal operation conditions. The assessed annual effective dose to any of the considered representative persons is below 10 μSv.

1 INTRODUCTION

The Maišiagala radioactive waste (RW) storage facility in the Republic of Lithuania is located approximately 30 km to North-West from the capital city Vilnius. The facility's design is of a former Soviet Union "Radon" type facility and initially was planned for the disposal of institutional waste.

The area of the Maišiagala RW storage facility site is approximately 2.7 ha, see Figure 1 [1]. During the waste disposal, the site was divided into two zones: the "clean" zone and the potentially "contaminated" zone. The "clean" zone includes the administrative building, the garage and warehouse building, the electricity and water supply utilities. The potentially "contaminated" zone includes one waste disposal vault of 200 m^3 volume and the auxiliary infrastructure: a decontamination building coupled with a liquid RW storage tank. The waste acceptance and disposal operations took place in the potentially "contaminated" zone.

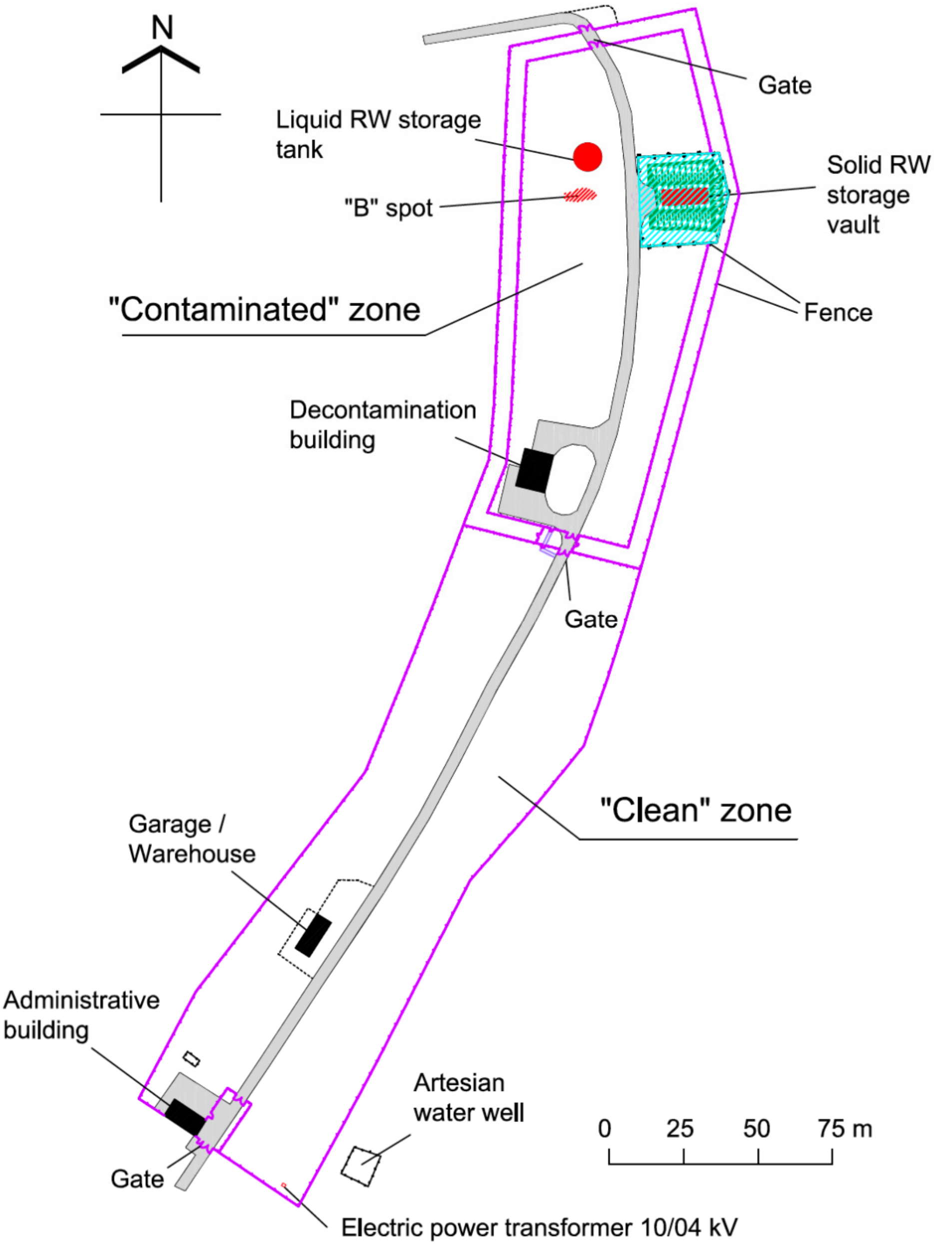

Figure 1. The layout of the Maišiagala radioactive waste storage facility site

The facility started operation in 1963. Disused sealed radioactive sources (DSRS) and solid waste from industry, military, and medicine applications from Lithuania and neighboring countries (the Russian Federation, the Republic of Belarus) were disposed of in bulk in the sub-surface reinforced concrete vault. The waste disposal ended in 1989 with the vault filled with waste up to 60 % of its volume. The residual volume was filled with concrete and sand.

The waste in the vault is of various types and forms: DSRS in their biological shielding, two stainless steel containers loaded with DSRS without shielding, various surface and bulk contaminated items (clothes, used filters, laboratory equipment, cemented liquids, salts, etc.). The waste items had been packed into various size and material (metal, wood) boxes and plastic bags. Three high-active DSRS (two Co-60 therapy sources and Cs-137 irradiation source) in their biological shielding are placed separately from the other waste.

The total inventory in the vault is estimated to be 7.7×10^{13} Bq. The activity of the DSRS is approximately 2.9×10^{13} Bq or 37% from the total inventory. The rest of the activity (4.9×10^{13} Bq) is distributed in the solid RW. The most activity contributing radionuclide is short-lived H-3 (4.8×10^{13} Bq). Other significant activities are long-lived radionuclides C-14 (1.7×10^{11} Bq), Ra-226 (1.0×10^{11} Bq), Pb-210 (6.4×10^{10} Bq), Po-210 (6.3×10^{10} Bq) and Ni-63 (3.3×10^{10} Bq). The activities of Cs-137, Cl-36 and Sr-90 are of order of 1.0×10^{9} Bq.

The Maišiagala facility cannot be upgraded to a disposal facility that meets the modern environmental and radiation safety standards. Therefore, a decision was taken to retrieve the waste, pre-sort and transport it to the Ignalina Nuclear Power Plant (NPP) site, where the waste could be appropriately characterized, sorted and disposed of or interim stored until an appropriate disposal facility will become available in Lithuania. The current operator of the facility, the Ignalina NPP, is responsible for the implementation of decommissioning activities.

2 THE APPROACH TO THE ASSESSMENT OF AIRBORNE RELEASES

The following radioactive sources will be removed during the decommissioning of the Maišiagala RW storage facility:

- The RW and filling materials from the vault;
- The vault structure and the contaminated soil around and below the vault;
- Other radioactively contaminated structures or their parts:
  - The liquid RW storage tank;
  - The floor of the decontamination building;
  - The underground pipeline from the decontamination building to the liquid RW storage tank;
  - The soil contaminated with Ra-226 (the so named “B” spot).

The formation of radioactive aerosols and solid particles (dust) is expected during the retrieval and packing of the RW. There may be radioactive gases in the vault, e.g., the decay of Ra-226 leads to the formation of Rn-222. In order to limit and control the release of radionuclides into the environment, the waste retrieval concept foresees the construction of a light, air-tight structure, the Confinement, which will enclose the waste storage vault and where the waste retrieval, pre-sorting and packaging equipment will operate. Controlled releases into the environment will be filtered with HEPA filters and released through a single ventilation stack.

The contamination of other objects on the site is considerably lower in comparison to the contamination of the vault and the waste inside it. A tent coupled with a mobile ventilation unit will be constructed above the liquid RW storage tank during the dismantling of the tank’s internal lining. The demolition of the reinforced concrete structure of the liquid RW tank, the dismantling of the underground pipeline, the removal of the floor of the decontamination building and the removal of the "B" spot will be performed in open-air conditions. Dust spread can be suppressed, if necessary, by misting water sprays. The dispersion of radioactive aerosols outside the site during these decommissioning activities is considered as insignificant.

The work on waste retrieval, packaging and off-site shipment will be carried out during the warm season of the year, presumable from April till November. Three seasons will be required for the decommissioning of the site and its release for unrestricted use. Different decommissioning works will be performed each year and different RW will be managed. Due to the specifics of work organization, the radioactive releases into the environment will be uneven and will change:

- During the year; the removal and shipment of the radioactive materials are expected to take place from April till November. During the cold season, the vault will be covered with panels and the ventilation systems will be turned off or operate in the reduced flow mode, or will be turned on periodically according to the need;
- During the week; the works on retrieval of the radioactive materials will take place during working days. The works during weekends and public holidays will be paused, the ventilation systems will operate in the reduced flow mode;
- During the day; the works on removal of the radioactive materials will be organized in several shifts per day. During the shift, the ventilation systems will operate in the normal flow mode. The highest releases during this time are expected. During the night, the ventilation systems will be switched to the reduced flow mode.

The legislation of the Republic of Lithuania requires assuring that the annual effective dose to members of the population due to the operation and decommissioning of a nuclear facility will not exceed the dose constraint (equal to 0.2 mSv per year). The highest emissions and the impact are expected during the second season of the decommissioning works. The radiological impact of the second season's works is, therefore, used as a bounding case for the demonstration of compliance with the regulatory requirements.

2.1 Release of radon

Different types of Ra-226 containing waste were disposed in the vault, e.g., self-luminous items, radium salts, contaminated soil, clothes, paper, glassware. Surface-contaminated objects dominate, constituting approximately 70% of the total Ra-226 activity. Emanation of Rn-222 from the waste was assessed conservatively, assuming that the emanation coefficient can reach 0.5. In practice, lower values are usually measured [2], [3].

The flux of Rn-222 at the surface of the RW was estimated using analytical solution of one-dimensional diffusion equation for a Rn-222 flux across the surface of bare residues [2]:

$$\mathrm{f_r} = \mathrm{R} \times \lambda \times \mathrm{E} \times \mathrm{L_r} \times \tanh\left(\frac{\mathrm{z_r}}{\mathrm{L_r}}\right) \quad (1)$$

Where: f_r is the flux of Rn-222 at the surface of RW, Bq/m^2 s; R is the volumetric activity of Ra-226 in RW, Bq/m^3; λ is the decay constant of Rn-222, 1/s; E is the emanation coefficient of Rn-222, dimensionless; L_r is the diffusion length of Rn-222 in RW, m; z_r is the thickness of RW, m. The diffusion length is defined as:

$$\mathrm{L_r} = \sqrt{\frac{D}{\lambda}} \quad (2)$$

Where: D is the diffusion coefficient of Rn-222 in RW, m^2/s.

A cautious approach was used for the selection of parameter values, i.e., the selected values tend to maximize the release of Rn-222. The decrease of emission due to the waste retrieval was not taken into account. Approximately 70 % of the total Ra-226 activity is located in the section that will be emptied the last. Therefore, it is assumed that the flux of Rn-222 remains permanent and maximal until the complete retrieval of the RW from the vault. With the total activity of Ra-226 of 1.0×10^{12} Bq, the flux of Rn-222 from the RW was estimated to be 1.8×10^{12} Bq during the second year.

2.2 Release of aerosols

The generation and release of airborne aerosols from RW retrieval and handling activities can be assessed using the following general equation [4]:

$$\mathrm{Q} = MAR \times DR \times ARF \times RF \times LPF \quad (3)$$

Where: Q is the activity of radionuclides released into the environment, Bq; MAR is the activity of radionuclides in the waste, Bq (i.e. Material at Risk); DR is a fraction of MAR impacted by the considered impact conditions, (i.e. Damage Ratio); ARF is the coefficient defining the amount of material from the waste that becomes airborne under considered impact conditions (i.e. Activity Release Fraction); RF is the fraction of airborne material that can be inhaled into the human respiratory system (i.e. Respirable Fraction); LPF is the fraction of airborne material passing through a deposition or filtration mechanism (i.e. Leak Path Factor).

For continuous process ARF is calculated as:

$$\mathrm{ARF} = \mathrm{ARR} \times \Delta\mathrm{t} \quad (4)$$

Where: ARR is the coefficient defining the airborne rate under considered impact conditions, 1/h (i.e., Activity Release Rate); Δt is the duration of considered impact conditions, h.

The selection of ARF, ARR and RF values was based on U.S. Department of Energy Handbook [4] recommendations. The bounding value for a free fall spill and impaction stress for surface contaminated solids (1×10^{-3}) was used as ARF for the waste retrieval and packing activities. The bounding value for surface contaminated solids exposed to normal ventilation flow (1×10^{-5} 1/h) was used as ARR for resuspension from RW venting by circulating air flow. All releases after HEPA filtration assumed to be of respirable size.

The release of aerosols from RW retrieval from the vault and packaging operations, from decontamination of internal vault structure and excavation of contaminated soil around the vault was analysed as one MAR. The contamination of the vault structure and the soil around it results from the radionuclides that had leaked from the stored waste. The activity and distribution of the contamination are unknown. Therefore, it was assumed that the MAR for this source correspond to the activity of the RW in the vault, excluding the activity of the DSRS (which are assumed to be intact). It is also assumed that the duration of airborne release from this source corresponds to the duration of the RW retrieval.

The estimation of airborne releases from the dismantling of the internal lining from the liquid RW storage tank was based on the analysis of the amount of cut-out material. The airborne release was evaluated as being very low, and for radionuclide dispersion calculations, the release was combined with the releases from the vault. The total release of aerosols was evaluated to be 3.9×10^{7} Bq. The main contributing radionuclide is H-3 with the release of 3.8×10^{7} Bq. The releases of radionuclides C-14, Ra-226, Pb-210, Po-210, Ni-63 are of order 10^{5}–10^{4} Bq, and the releases of radionuclides Cs-137, Cl-36, Sr-90, Pu-239 are of order 10^{3}–10^{2} Bq.

3 APPROACH TO THE PUBLIC DOSE ASSESSMENT

The Maišiagala site is in a remote location. There are no permanent inhabitants in the distance of more than 2 km around the site. Only occasional public visitors can pass the forest surrounding the site. The exposure of the population was assessed taking into account local lifestyle. Two age groups were considered: the adult member of the population and the one-year-old child [5]. Representative persons were grouped into three groups:

- Representative group 1. The adult member of this group is an occasional visitor in the forest near the Maišiagala site. The representative person may receive internal and external exposure due to the release of airborne radionuclides and external exposure due to the management of the RW at the site. The one-year-old child does not visit the site; however, it may ingest forest foodstuff collected by the adult;
- Representative group 2. The persons of this group are permanent residents living at the distance of 2 km from the Maišiagala site, running a small farm and consuming locally grown food. The persons can also receive exposure during occasional visits close to the Maišiagala site;
- Representative group 3. This group includes only adult member of the population and is used to assess external exposure from the RW transport from the Maišiagala site to the Ignalina nuclear power plant site.

The representative persons and their exposure pathways are summarized in Table 1.

Table 1: The selected representative persons and their exposure pathways

Exposure			Representative groups and persons				
			1st		2nd		3rd
Pathway	Location	Type	Adult	Child	Adult	Child	Adult
Airborne release into the environment	At the fence of the Maišiagala site	External	+		+		
		Inhalation	+		+		
		Ingestion	+	+	+	+	
	At the nearest resident location	External			+	+	
		Inhalation			+	+	
		Ingestion			+	+	
Direct and scattered radiation	At the fence of the Maišiagala site	External	+		+		
	At the RW transport road						+

The exposure of representative persons from aerosol release into the environment was assessed using IAEA Safety Report Series No. 19 [5] recommended models for the atmospheric dispersion, for transport of radionuclides through terrestrial food chains and for individual dose estimation. The assessment included:

- The calculation of radionuclide dispersion into the atmosphere and the calculation of radionuclide concentration in the air at the relevant exposure locations;
- The calculation of the annual effective doses from immersion in the atmospheric discharge plume and due to the inhalation of radionuclides;
- The calculation of radionuclide deposition onto the ground and the annual effective dose from the ground deposits;
- The calculation of radionuclide deposition onto the pasture, the transfer of radionuclides to products from grazing animals (milk, meat) and the annual effective dose due to the consumption of foodstuff;
- The calculation of radionuclide deposition onto the crop field, the transfer of radionuclides to the crops (grain, root crops, green vegetables, fruits) and the annual effective dose due to the consumption of foodstuff.

The dose calculations were based on the local (if available) and the generic [5] parameter values. Compared to the population nutrition surveys conducted in Lithuania or the national

Official Statistics Portal provided average food consumption data, the generic [5] values are considered as conservative.

Publication [5] does not provide recommendations for the calculation of exposure from airborne Rn-222. The annual effective dose due to the inhalation of Rn-222 and its decay products was evaluated using recommendations from the U.N. Scientific Committee on the Effects of Atomic Radiation [6] as follows:

$$E = C \times F \times DCF \times \Delta t \quad (5)$$

Where: E is the annual effective dose, mSv; C is the Rn-222 concentration in the air at the relevant exposure location, Bq/m^3. Concentration is calculated using the models described in [5]; F is the equilibrium factor for Rn-222 and its decay products, recommended [6] value for outdoors is 0.6; DCF is the Rn-222 dose coefficient, 9×10^{-6} mSv m^3/Bq h [6]; Δt is the duration of the considered exposure conditions, h.

The increase of external radiation fields in the close proximity to the site and during the waste transport will create additional exposure pathways. The direct and scattered radiation dose rate change with distance for the decommissioning related sources (the open vault, the containers with the DSRS without biological shielding, different type packages with different type of RW) were pre-calculated using the VISIPLAN 3D ALARA Planning Tool [7], the MCNP5 code [8] (for neutron sources) and the MicroSkyshine 2 [9] program. Then the dose to the representative person was assessed considering the radiation source, the distance and the time that the representative person spends at the relevant exposure location.

The annual effective dose to the representative persons from the decommissioning of the Maišiagala radioactive waste storage facility is summarized in Table 2. As can be seen, the annual effective dose to any of the considered representative persons is below 10 μSv.

Table 2: The annual effective dose to the representative persons due to the decommissioning of the Maišiagala radioactive waste storage facility

Source of exposure	Representative groups and persons				
	1st		2nd		3rd
	Adult	Child	Adult	Child	Adult
	Effective dose, mSv				
Airborne release into the environment	1.4×10^{-3}	6.2×10^{-5}	5.8×10^{-3}	4.6×10^{-3}	-
Direct and scattered radiation	2.1×10^{-3}	-	2.1×10^{-3}	-	4.7×10^{-5}
Total:	3.5×10^{-3}	6.2×10^{-5}	7.9×10^{-3}	4.6×10^{-3}	4.7×10^{-5}

4 CONCLUSIONS

The existing institutional radioactive waste storage facility at the Maišiagala site in the Republic of Lithuania cannot be upgraded to a facility that could meet modern environmental and radiation safety standards. The radioactive waste retrieval, packing and shipment out of the site will change the existing radiological situation and will lead to the release of radioactive materials into the environment.

The assessment of the population exposure due to the release of airborne activity was based on the models recommended by the International Atomic Energy Agency and the United Nations Scientific Committee on Effects of Atomic Radiation.

Low radiological impact of the decommissioning of the radioactive waste storage facility in Lithuania on the population is expected under normal operation conditions. The assessed annual effective dose to any of the considered representative persons is below 10 μSv.

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