Radioactive Waste Management Centre in Croatia

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ABSTRACT

The Republic of Croatia has the obligation to ensure the safe long-term management of half of the low- and intermediate-level radioactive waste (LILW) generated by the regular operation and decommissioning of the Krško Nuclear Power Plant (NPP), as well as institutional radioactive waste and disused sealed radioactive sources generated on the territory of the Republic of Croatia. Obligations are defined by the Act on Radiological and Nuclear Safety (Official Gazette 141/13, 39/15, 130/17, 118/18, 21/22, 114/22), the Strategy for the Management of Radioactive Waste, Disused Sources and Spent Nuclear Fuel (Official Gazette 125/14), the National Program for Implementation of the Strategy for the Management of Radioactive Waste, Disused Sources and Spent Nuclear Fuel (Program for the Period Until 2025 with a View to 2060) (Official Gazette 100/18, 156/22), and the Bilateral Agreement between the Government of the Republic of Croatia and the Government of the Republic of Slovenia on regulating status and other legal relations related to investment, exploitation and decommissioning of the Krško NPP (Official Gazette, International Agreements 9/02).

For management of the radioactive waste and disused sources arising from medicine, industry, science, education, and past public use, as well as for half of the LILW from the Krško NPP, Fund for financing the decommissioning of the Krško NPP has obligation to establish the Radioactive Waste Management (RWM) Centre at preferred site of Čerkezovac on Trgovska gora mountain. In order to construct and licence storage facilities and radioactive waste management activities, Fund has to undertake required steps, including field investigation works, preparation of design and transport documentation, development of safety case (SC), safety assessment (SA) and environmental impact assessment (EIA) studies. So far into the project, all investigation works were completed, as well as RWM Centre feasibility study, conceptual and preliminary design and safety assessment, and EIA studies are still being prepared, all for the purpose of obtaining location permit and in accordance with Croatian regulations and international treaties, IAEA safety fundamentals, requirements and guidelines and good international practice. After obtaining location permit, update of SC and main design will be prepared for the purpose of obtaining building permit which will serve as basis for contracting construction works and building RWM Center facilities in time to be able to meet Krško NPP LILW takeover deadline set at the beginning of 2028 by the Intergovernmental Commission.

Keywords: *radioactive waste, RWM Centre, storage, licencing*

1 INTRODUCTION

As a preferred site for establishing Radioactive Waste Management (RWM) Centre, National Program for Implementation of the Strategy for the Management of Radioactive Waste, Disused Sources and Spent Nuclear Fuel (Program for the Period Until 2025 with a View to 2060) (Official Gazette 100/18, 156/22) determines former military logistical complex Čerkezovac on Trgovska gora massif.

The Trgovska gora massif extends in a northwest-southeast direction with a length of about 30 km and a width of up to 15 km. In its southern part, the massif is located on the territory of neighbouring Bosnia and Herzegovina. The main orographic axis of the massif is also a hydrographic watershed. The highest elevations of Trgovska gora (Lipova glava 468 m, Radoč 629 m, also the highest peak of Trgovska gora, Čuluma kosa 589 m and Ćorkovača 603 m) stretch along the central part of the massif (ridge). In the south-eastern part of the massif, the heights gradually decrease, and the highest point is Čerkezovac (319 m). At the foot of that elevation, on a plateau located at an altitude of about 295 m, the construction of the Center is planned.

Figure 1: Location of Trgovska gora with the Čerkezovac site

This plateau, and in a measure larger surrounding area, was subject to different investigation works in order to gain insight about terrain characteristics. Information acquired by conducting field investigation will serve as input for creating the RWM Centre design documentation, safety documentation and environmental impact assessment. These three key documents are basis for licencing and constructing the RWM Centre.

Establishment of RWM Centre go through three different phases:

- Obtaining location permit,
- Obtaining building permit and
- Obtaining operation licence

These phases can also be defined as milestones in RWM Centre establishment project, and figure 2 shows key elements for licencing each phase.

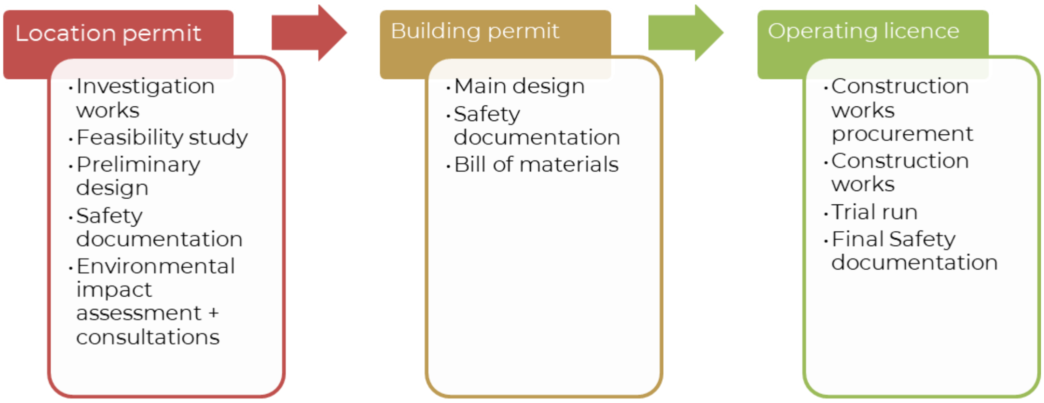

Figure 2: Different phases of RWM Centre establishment

Currently, by the end of year 2024., RWM Centre is in phase of obtaining location permit, and status of the project will be described in this paper.

2 PREPARATORY ACTIVITIES

2.1 Demining

During the war in Croatia in early 1990s, landmines were used to protect military and other important facilities. Also, large and strategic areas which were hard to defend were covered with landmines to prevent or at least hinder military movement. The remnants of that time can be seen today in the fact that on the territory of the Republic of Croatia there are still about 71 square kilometres of mine-suspected areas, of which about 1 square kilometre refers to the RWM Centre (Čerkezovac) site [1].

In order to ensure the safe conduct of field investigation works and the determination of the zero-radiological state of the RWM Centre site, the Fund contracted the demining of certain parts of the location. Demining was carried out in four different phases and a total of 570,000 m^2 was demined. Figure 3 shows demining activities at RWM Centre site.

Figure 3: Demining activities at RWM Centre site

After demining for purposes of site investigation, there still remains around 500.000 m^2 of mine-suspected areas at RWM Centre site. According to Ministry of Interior plans for demining activities, whole territory of Republic of Croatia will be cleared of mines at the beginning of year 2026. [2].

2.2 Field investigation works

The main purpose of the field investigation works was to gain a complete and precise insight into the geological composition and structure of the terrain of the location planned for the construction of the RWM Centre. Research will enable the RWM Centre site evaluation and characterization, then the design of buildings for the storage of radioactive waste and the necessary infrastructure facilities and will provide important data necessary for drafting and implementing environmental impact assessment. Research includes geo-research, determination of hydrological and hydro-geological characteristics of the location and the implementation of limited field research related to the state of flora and fauna, forest ecosystems and the use of agricultural land in the immediate vicinity of the location, and are divided into three groups of activities:

1. Geological research
2. Geophysical research
3. Exploratory drilling

Geological research included detailed mapping of the narrower area of the Center's location with an area of 1.2 km^2 by creating maps at a scale of 1:5000 and mapping of the wider area of the Center's location with an area of 19 km^2 for the creation of maps of a scale of 1:25000. It was established that the research area is located on the border of two basic structural tectonic blocks, facially two different areas of the inner Dinarides. These are: the carbonate platform of the Outer Dinarides on the one hand and the ophiolitic complex of the Inner Dinarides on the other. The researched terrain belongs to the transitional part of the Paleozoic deposits of the ophiolite belt of the Inner Dinarides, which were dragged from the north and northeast. The inner Dinarides are exclusively a basin sedimentation area. The contact of these deposits with other deposits is tectonic, as a result of these contacts, these deposits were uplifted. Paleozoic deposits are unique, complete and homogeneous, as a result of thrusting during the geological past, the rock is intersected by dislocations. The basic and most important engineering-geological and physical-mechanical characteristic of the deposit is the compactness and impermeability of the deposit, and relatively low uniaxial strength. After the geological research, it can be concluded that the geological rocks belong to compact, clastic deposits that were bent and broken by subsequent geotectonic stresses. The resulting dislocations are less and less gaping with depth, and the dislocations are filled with a soft filling, so that they are practically impermeable, with no possibility for any mutual communication. Deluvial - proluvial deposits lie on the bedrock, which are mostly a mixture of bedrock fragments, clay and dust.

Figure 4 shows example of terrain modelling for the purposes of conducting geological research.

Figure 4: Example of digital terrain model with (a) and without layers and shading (b) created for the need of terrain survey [3]

Geophysical research included (i) Geoelectrical sounding, (ii) Reflection seismic surveys, (iii) Refraction seismic surveys, (iv) Tomographic profiling and (v) Georadar recording.

Geophysical investigations included the execution of three seismic refraction profiles with a total length of 895 m. Based on the obtained velocity models and correlation with exploration wells, a conditional classification of the rock mass was performed. The thicknesses of the surface wear zone, the upper wear zone and the depth to the bedrock are defined. Corroded and broken zones, cracks and faults are marked on the profiles.

Seismic reflection was performed on two profiles with a total length of 950 m. Layer surfaces, discontinuities, fracture and fault zones were interpreted on the processed profiles.

Geoelectrical tomography was performed on two profiles with a total length of 805 m. According to the calculated electrical resistivities and correlation with the exploration wells, a conditional soil classification was performed. Four types of material are defined: shales with a predominantly clayey composition, alternation of sandstones and shales, sandstones and compact sandstones. Cracks and faults are marked on the profiles.

Geoelectrical sounding was performed at 23 locations. Calculated electrical resistivities were used for soil classification, in accordance with geoelectrical tomography. Four prognostic sounding profiles were constructed by combining geoelectric probes.

The ground-penetrating radar method was used on two profiles with a total length of 600 m. Recorded reflections of electromagnetic waves at the border of the centers defined the contact between the bulk material and the surface clay cover with the underlying rock.

The downhole method is performed in the deepest well. A diagram of the speed distribution of transverse, P and longitudinal, S-waves was constructed, dynamic modules were calculated and Vs-30 was determined.

Figure 5: Example of geoelectrical sounding profile [3]

Exploratory drilling and excavations included the execution of four deeper structural boreholes (one borehole up to 30 m, two boreholes up to 40 m and one up to 198 m deep) and fifteen shallow geomechanical boreholes (eleven boreholes up to 10 m and four boreholes up to 20 m deep) with coring and continuous core interpretation. 16 excavations were also carried out, 0.5 - 2.6 m deep, with mapping.

Figure 6: Drilling and core samples from borehole 198 m deep [3]

All results obtained from field investigation works will be used for developing safety and design documentation and interpreted within environmental impact assessment.

2.3 Determining zero-radiological state

The purpose of this research was to determine a complete overview of the zero (existing) state of radioactivity in the wider area of the municipality of Dvor and in the vicinity of the Čerkezovac location and to assess the contributions to the effective dose that come from exposure to natural and artificial radionuclides in the environment for a reference resident of the area. All measurements, sampling, analysis, processing of the results and calculation of the contribution to the effective dose were carried out according to prescribed internationally recognized methodologies.

In all samples analysed in this research, only natural radionuclides (^{238}U, ^{232}Th(^{228}Ra), ^{226}Ra, ^{40}K, ^{7}Be and ^{3}H), and ^{137}Cs and ^{90}Sr were detected, while other anthropogenic radionuclides were below the detection limits. The presence of ^{137}Cs and ^{90}Sr in the environment is expected as a result of global contamination caused by a large number of nuclear weapons tests in the past and nuclear accidents, especially Chernobyl.

Estimates of the average contribution to the annual effective dose are at the average level for northwestern Croatia and range from < 0.717 to < 0.817 mSv/year for children (7-12 years), and from < 0.417 to < 0.464 mSv/year for adults (> 17 years) depending on the area of interest. If we consider all four research areas as a whole, the estimated average effective doses were < 0.803 mSv/year for children and < 0.463 mSv/year for adults.

The values of concentrations/mass activities of natural radionuclides and ^{137}Cs and ^{90}Sr detected in all analysed samples are comparable and do not deviate from the values detected in similar or the same types of samples during the monitoring of the state of radioactivity in the environment in the Republic of Croatia, monitoring of the state of radioactivity in the Sava and Danube rivers.

All values of the ambient dose equivalent, and the concentration of activity/mass activity of radionuclides measured as part of the determination of the zero (existing) state of radioactivity in the environment are significantly below the limits prescribed by the Ordinance on exposure limits, recommended dose limits and assessment of personal exposure (Official Gazette 38/18, 8/22), the Ordinance on compliance parameters, analysis methods, monitoring and safety plans for water for human consumption and the manner of keeping the register of legal entities performing public water supply activities (Official Gazette 125/17), Council Directive 2013/59/EURATOM (from 5 December 2013 on basic safety standards for protection against dangers arising from exposure to ionizing radiation), and Commission Regulation (EU) 1158/2020 (from 5 August 2020 on the conditions governing the import of food and animal feed originating from third countries after a nuclear accident power plant in Chernobyl).

Considering the radiological risk, from the conducted research and analysis of the results, it is concluded that the dominant risks expressed by the effective dose of the inhabitants are not closely related to the environment itself and the presence of radionuclides in the environment.

All results obtained from determining zero-radiological state will be used for developing safety and design documentation and interpreted within environmental impact assessment.

3 RADIOACTIVE WASTE MANAGEMENT CENTRE

For the purpose of safe and secure management of radioactive waste (to be centralised) it is required to establish the Radioactive Waste Management (RWM) Centre in accordance with National Strategy and Programme, as well as in accordance with regulatory requirements, IAEA standards and guidelines and best international practice. RWM Centre will include:

- Central storage for institutional radioactive waste (IRW) and disused sealed radioactive sources (DSRS)
- Long-term storage for Low and Intermediate Level Waste (LILW) from Krško NPP
- Administrative building
- Centre infrastructure: roads, parking bays and manipulation areas.

Pursuant to the Radiological and Nuclear Safety Act (OG 141/13, 39/15, 130/17, 118/18 and 21/22) and Act on the Fund for Financing the Decommissioning of the Krško Nuclear Power Plant and the Disposal of NEK Radioactive Waste and Spent Nuclear Fuel (OG 107/07 and 21/22), the Fund for financing the decommissioning of the Krško NPP (Fund) is required to establish the RWM Centre in Croatia and manage it as one of the Fund’s organisational units. The Centre will store exclusively solid low and intermediate level radioactive waste. It will not store any liquid or gaseous waste.

According to the National Programme, the preferred site for the future RWM Centre is the Čerkezovac Military Logistics Complex (MLC) in the Dvor Municipality on the southern slopes of the Trgovska Gora massif. The Ministry of Defence and the Armed Forces of the Republic of Croatia classified the site as without a future use. On 31 March 2020, the Fund took over the former Čerkezovac MLC in the Dvor Municipality from the Ministry of Environmental Protection and Energy (now, the Ministry of Economy).

Figure 7: Microlocation of RWM Centre storage facilities at the Čerkezovac site [4]

The start of the operation the RWM Centre is planned for year 2028. The operation of the Long-term storage for LILW form Krško NPP is planned until 2060, and its decommissioning in 2061. As for the Central storage for IRW and DSRS, its decommissioning is planned after the establishment of a disposal facility for IRW and DSRS, which will consist of new Central storage building.

3.1. Central storage for IRW and DSRS

For the purpose of storing the IRW and DSRS at RWM Centre site, a Central storage consisting of two building connected with road is planned:

- reception building and
- storage building.

Figure 8: Reception (left) and storage (right) buildings of Central IRW and DSRS storage facility [4]

Hence, two existing arch storage objects U-20 type will be reconstructed. The total useful surface of one existing storage object is 209 m^2.

For the purpose of storing the IRW and DSRS, as a precaution and in case of an emergency event and if the IRW and DSRS do not comply with the waste acceptance criteria (WAC), within the reception building of the Central storage, space for storing such packages that do not meet the conditions for storage (WAC criteria), until when they will be taken over by an authorized institution for treatment and conditioning, is planned.

All activities related to the management of IRW and DSRS will be organized in two buildings that are used as a single technological unit and in this respect have a unified infrastructure system (physical and technical protection, radiological monitoring, roads, hydrant network, electrical energy, water supply and potentially contaminated drainage from manipulative surfaces) and a separate system for draining contaminated liquid from buildings. Sanitary water installation is not planned inside the storage. The use of water in the process-technological sense is not foreseen in either building, and only conditioned solid waste will be stored, and the generation of contaminated wastewater is not foreseen.

3.1.1. Reception building

The reception building is not intended for storage of IRW and DSRS but serves for the reception/takeover and inspection of received IRW and DSRS. As a precaution in the emergency event and if the IRW/DSRS do not comply with the acceptance criteria, space for storing such packages that do not meet the conditions for storage (WAC criteria), until when they will be taken over by an authorized institution for treatment and conditioning, is planned.

The reception building contains spatially functional areas in which the following activities will be carried out:

- area for takeover of IRW and DSRS,
- manipulative area for internal transport of radioactive waste packages,
- area for temporary storage of packages that do not meet the conditions (WAC) for storage
- area for temporary storage of secondary radioactive waste
- area for decontamination of people and
- administrative area.

3.1.2. Storage building

The storage building is intended for storing all amounts of IRW and DSRS generated by the 60-year use of ionizing radiation sources in medicine, industry, science, military and public use in the Republic of Croatia, as well as IRW and DSRS that will be generated in activities after the establishment of the Central Storage.

The Central storage for IRW and DSRS (after obtaining the necessary permits, licenses and approvals) is obliged to accept or takeover all IRW and DSRS from the Republic of Croatia, and therefore WAC criteria will be confirmed in the process of finalizing safety case for the RWM Centre. IRW and DSRS that will be transported to the location of the Central storage must meet the conditions for transport according to the Dangerous Goods Transport Act (OG 79/07 and 70/17) and the Ordinance on Conditions and Method of Issuing and Withdrawing Approvals for Packaging Used in Transport of Radioactive and Nuclear Materials (OG 42/13 and 19/17). All IRW and DSRS should be prepared and transported to the location of the Central storage in accordance with the waste acceptance criteria for storage. During takeover, all IRW and DSRS packages must be characterized, including preliminary and final characterization. The details of the RW package characterization process will be elaborated in the next phases of the project. If the packages do not meet the WAC for storage, a protected area is provided in the reception building where these packages will be temporarily stored. The treatment and/or conditioning of these packages will not be carried out in the reception area, but in the premises of the authorized institution, which will take over, treat and condition the mentioned IRW/DSRS.

3.2. Long-term storage for Low and Intermediate Level Waste from Krško NPP

For the purpose of storing Croatian half of the operational LILW from Krško NPP generated until 2023, the construction of a new building with a surface area of 6330 m^2 and a height of 17.2 m is planned. LILW will be stored in reinforced concrete containers (RCC), which are a new generation of containers intended for transportation, storage and disposal of LILW. RCC will have a cube shape with external dimensions of 1.7x1.7x1.7 m, a maximum weight of 15 tons, and a useful internal volume of 2.85 m^3. The total required storage capacity is 2450 RCC, and the total possible storage capacity is 2484 RCC.

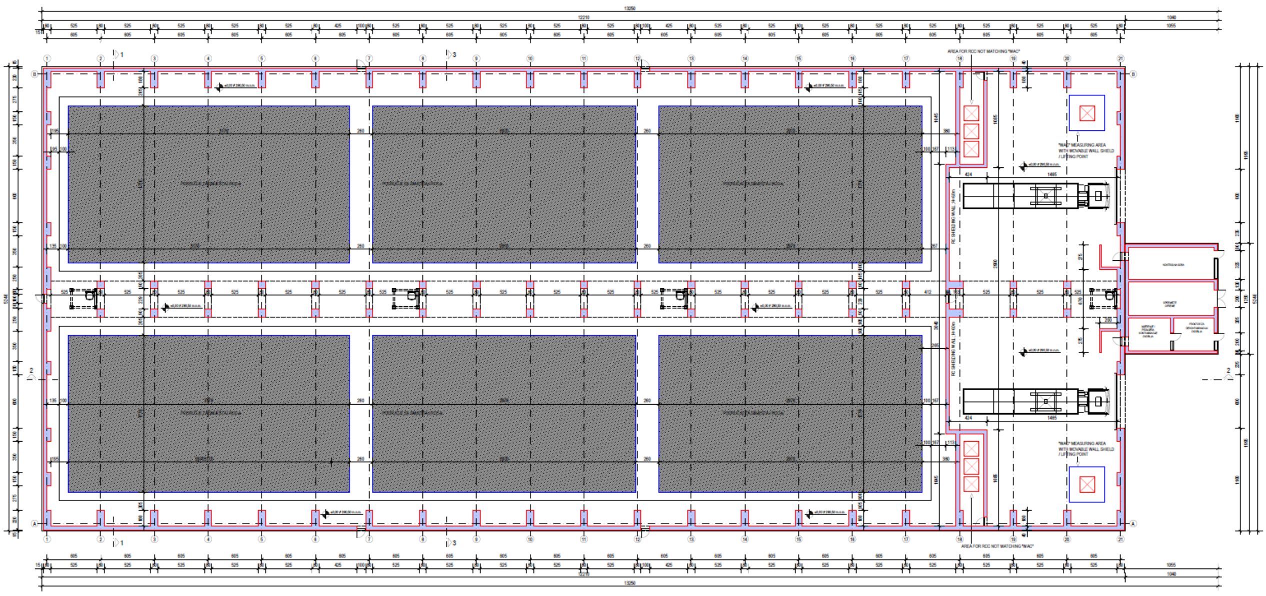

Figure 9: Top-view of Long-term storage facility [4]

According to current estimates, half of the operational LILW generated by 2023, will be placed in 2450 RCC. Operational LILW generated from 2024 until the end of the operational lifetime of Krško NPP and the decommissioning LILW will be subject of takeover in 2050. This LILW will not be stored in Long-term storage, but disposed in repository, which will be built by then, so no storage capacity is needed for that LILW. The Long-term storage facility will be decommissioned after 2061, and the stored waste will be moved to a repository.

Radiation protection for the designed storage is carried out by a system of multiple engineering barriers:

- the first engineering barrier is a cement filling for the conditioning of RW within the storage package;
- the second engineering barrier is the wall of the reinforced concrete container;
- the third engineering barrier is a radiation protection wall towards the part of the RCC unloading area, the facade wall of the storage building and an impermeable floor slab.

Full protection is already achieved by a storage container which, in order to meet transport conditions, must have a dose rate of less than 0.1 mSv/h at a distance of 1 m, or 2 mSv/h on surface. Dose rate limitation is ensured by meeting the waste acceptance criteria and waste package specifications (WPS).

The Long-term storage is a one-room building with service facilities and auxiliary areas, located in front of the entrance north facade, where there are also two driveway entrances to the storage. In front of the storage is traffic area for access of trucks with RCC. The truck enters the storage with the rear end so that the truck is fully positioned within the storage space. Behind the door to the first row of the RCC, there is a 19.0 m long space with the following areas:

- area for positioning the truck in the intended place,
- area for temporary reception (buffer zone),
- area for verification and measurement in accordance with WAC and the place of lifting the RCC during its positioning in the intended place in the storage and
- area for temporary storage for RCC that do not meet the conditions for storage (WAC criteria).

RCCs are picked up by an overhead crane, and then transported to a predetermined storage location. RCCs are stored in 9 x 46 rows on three levels in the western part and the same amount in the eastern part of the storage. Manipulation of RCCs is carried out by remote-controlled overhead crane with a span range of approx. 21.40 m, load capacity of up to 20 tons and a lifting height of approx. 8.0 m. The hanging tool must be adapted to grips on the RCC. Manipulation with overhead crane would be enabled in two ways:

- remotely via radio link and with the use of cameras (basic mode) and
- locally with a control panel (reserve mode).

Sanitary water installation is not planned inside the storage. The use of water in the process-technological sense is not foreseen in storage, and only conditioned solid waste will be stored, and the generation of contaminated wastewater is not foreseen.

4 CONCLUSION

In conclusion, Croatia's commitment to ensuring the safe and effective management of radioactive waste is rooted in its comprehensive strategy and adherence to international standards. The establishment of the RWM Centre at Čerkezovac is a significant step toward fulfilling the country's obligations under both national and international regulations. With meticulous planning and rigorous environmental impact assessments, Croatia is set to responsibly manage its share of LILW from the Krško NPP, as well as other institutional waste and disused sealed radioactive sources.

The phased approach—focused on securing necessary permits, designing, and constructing state-of-the-art storage facilities—ensures a robust framework for long-term waste management. Croatia's strategy aligns with best international practices, emphasizing safety, environmental protection, and transparency.

As the country moves forward with the operationalization of the RWM Centre, the clear roadmap ensures that Croatia will be ready to meet the 2028 deadline for waste takeover. Furthermore, the ongoing focus on safety, from field investigations to the zero-radiological state assessment, demonstrates a responsible approach to both environmental and public health concerns.

This project stands as a testament to Croatia's dedication to addressing the challenges of radioactive waste management, ensuring a safe and sustainable future for generations to come.

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