Disposal Project for Low-Level Long-Lived Radioactive Waste in France

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ABSTRACT

In accordance with the French Planning Act of 28 June 2006, Andra is responsible for developing disposal solutions for low-level long-lived waste. The purpose of the work conducted in 2007 was to prepare for the search of a suitable disposal site, which has been already started since mid-2008. The investigation for a disposal site relies on the voluntary participation of local towns. Andra sent a presentation dossier to over 3,000 towns in France, which substratum might have adequate characteristics for a disposal. Candidate towns shall express their interest until end October 2008. The investigations should be conducted on the preselected places in 2009 and 2010.

Graphite waste results from the operation and dismantling of EDF's natural-uranium-fuelled, graphite-moderated and gas-cooled reactors and of the CEA's experimental reactors.

Most radium-bearing waste originates from the treatment of ores containing rare earths, the development of uranium-ore concentration processes, and is still generated by the rehabilitation of industrial sites contaminated with radium.

The radioactive half-life of LL-LL waste does not allow those residues to be disposed in the surface disposal facilities currently located in the Aube District. Their low radioactivity does not justify either their deep geological disposal as in the case of high-level and intermediate-level long-lived waste. Andra is therefore studying the feasibility of a shallow disposal facility within a slightly-permeable highly-clayish or marly geological formation at a sufficient depth.

The launching of the site-search campaign in 2008 has been conducted with a view to submitting in 2013 the licensing application for the implementation of the disposal facility and to commissioning it in 2019. The schedule will be confirmed in 2009 depending on the progress achieved in the search for a suitable site.

INTRODUCTION

The disposal of LLW-LL (low-level long-lived radioactive waste) is the subject of a specific requirement prescribed by the *2006 Planning Act* [1] and its implementation documents. The disposal facility must be commissioned in 2019. With the operating phase, the first step is to find a suitable site for the implementation of a disposal facility. Andra teams have dedicated many years of effort in order to gain information about the waste and to study various disposal concepts. Based on a sound analysis, one of the major results was to consider an intermediate depth facility to comply with some of the long-lived radionuclides safety requirements.

LLW-LL is not very radioactive, but remains radioactive for a long time, because they contain radioactive elements that decay very slowly. Those residues consist essentially of radium-bearing and graphite waste, the production of which has already stopped or should stop soon. Until now, they have been stored in dedicated facilities or on their production sites, pending a disposal solution, as follows:

- radium-bearing waste take their name from the radium they contain. Most of them originate from the processing of different minerals, such as zirconium, uranium ore, monazite, etc., that are used, for instance, in the automobile industry and in fine metallurgy.

  All those residues are stored mainly on the sites of industrial waste producers, such Rhodia Electronics and Catalysis, *Cézus Chimie,* and

- graphite waste, as the name implies, contains graphite. It results mainly from the operation of nine reactors from the first generations of French nuclear power stations fuelled by uranium, moderated by graphite and cooled by gas, known as GGRs, that were in service between the 1960s and the 1990s.

The cumulated volume of both radium-bearing and graphite waste is estimated to be in the order of 170,000 m^3.

The first part of this paper will present the analysis, while the second one will describe the siting process implemented since June 2008.

PRELIMINARY ANALYSIS OF THE WASTE REQUIREMENTS

Before searching for a disposal site for low-level long-lived waste, Andra conducted a series of studies and analyses on the basis of realistic data on generic sites in order to select suitable repository concepts likely to fulfil safety requirements and to identify the priorities of the relevant research programmes. The basic initial options to consider were a repository under an intact cover for graphite waste, and under an intact or reworked cover for radium-bearing waste.

Requirements for the disposal of graphite waste

The total activity of the graphite waste is low (21,200 TBq in 2013) and decreases by two orders of magnitude over a few tens of thousands of years. Graphite waste contains a large variety of radionuclides. The highest long-lived activities correspond to carbon 14 (radioactive half-life of 5,730 years) and nickel 63 (100 years). The repository concept will allow for those radionuclides to be isolated long enough in relation to their radioactive half-lives. Among the overall radiological inventory of graphite waste, chlorine 36 was selected for sizing purposes due to its concentration and its lability in graphite waste, its high mobility and its long half-life (302,000 years). In order to mitigate the flow rate of chlorine 36 into the environment, the selected concept includes an intact cover, which constitutes a thick barrier with a view to dispersing the flow rate.

Part of the chlorine 36 may have been leached during the dismantling of certain Graphite Gas Reactors (GGR). It thus may have been transferred towards anionic resins, as process waste. Other elements initially present in graphite piles and known for their mobility, such as caesium, may have been retained on cationic resins and thus also transferred to process waste. As a precaution, the overall initial radiological inventory of graphite waste was taken into account in the studies for concept and preliminary designs.

In order to slowing down the waste-degradation and dissolution processes, and most of all, to minimising the convective-transport of the solutes, the first objective of the repository for graphite waste is to limit water circulation. A clay host rock would be suitable to fulfil this very specific requirement, but it involves also essentially searching for low hydraulic gradients and a low permeability of the formation. For a series of realistic hypotheses, for example, simulations have shown that passing from a permeability of 10^{-11} to 10^{-13} m/s brings down the convective component to a negligible level and reduces the flow rates of chlorine 36 released by the repository by almost an order of magnitude. In addition, the design of the repository architecture will help limiting water circulation: the position and geometry of the layer structures influence the drained-water flow rates and the speed of convective transport in those structures; low-permeability seals may compensate for any hydraulic disturbances that would be induced ultimately by access structures, especially if the repository was implemented as an adit.

The second objective is to limit all radionuclide releases from the waste, as well as their dissolution and mobility in water. Favourable factors include the reducing conditions, which are guaranteed by the implementation depth, and an alkaline cementitious environment provided by the packages themselves and the repository structures. Reducing conditions strongly immobilise actinides by precipitation, help maintaining the inorganic speciation of carbon 14 and limit the mobility of other radionuclides in solution, such as technetium 99. Alkaline conditions help in reducing the dissolution of certain elements, such as nickel and cobalt.

Lastly, the third objective of the repository concept is to retard and to mitigate the flow rate of dissolved radionuclides into the environment. If the retardation time reaches the order of magnitude of a radionuclide’s half-life, the combination of that delay and of the radioactive decay provides a significant mitigation of the released activity into the environment.

That phenomenon concerns particularly radionuclides with intermediate half-lives, such as carbon 14, which remains strongly attached, notably in the concrete of the packages and of the structures. Simulations have shown that taking into account the sorption of carbon 14 in concrete reduces releases by two orders of magnitude with an altered concrete (partition coefficient $Kd = 0.15\ m^3/kg$) and up to five orders of magnitude with a healthy concrete ($Kd = 0.5\ m^3/kg$).

In the case of chlorine 36, which is not very easily retained, the dispersion and spread over time of the flow rate released from the repository are proportional to the significance of diffusive migration and to the thickness of the diffusive barrier. From that standpoint, simulations have shown that the option under an intact cover is more favourable than the other solution under a reworked cover, which had been under study until then. They also showed that the mitigation power of the outbound flow rate by a thicker layer is inversely proportional to the permeability level. Hence, for a predominantly-diffusive layer with a hectometric thickness, the share of the initial chlorine 36 inventory having reached the environment after 10,000 years is still negligible; the maximum release only occurs after 100,000 years.

It is rather premature at this stage to present any assessment of the radiological impact on human beings, independently from the knowledge of the site. However, it was possible to verify that the configurations of the site with a clay thickness of 50 m, and of the repository would ensure compliance with the constraint involving individual committed effective doses.

The depth of the repository isolates waste from human activities and natural phenomena. Perpendicularly to major valleys in high tectonic-uplift regions, an incision rate in the order of 1 m every 10,000 years, on average, is predictable (Figure 1). However, under the geomorphological conditions of the desired sites, the ablation rate appears to be much lower (0.1 to 0.3 m per 100,000 years for the plateau zones located in Eastern France). Moreover, after a specific assessment to be conducted on the selected sites, the eroding velocities should prove to be sufficiently low to preserve the long-term functionalities of the repository regarding the limitation of water circulation and the mitigation of radionuclide flow rates.

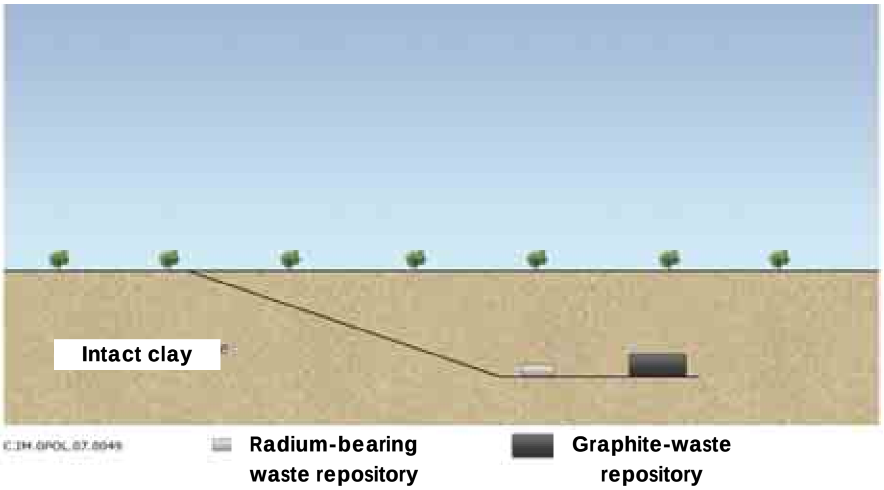

Fig.1. Basic option for the disposal of graphite waste

Requirements for the disposal of radium-bearing waste

Radium-bearing waste is characterised by a rather limited radiological content with mainly Ra, U, Th, Pa, Ac, Pb, etc.. Radium bearing waste have a much lower activity, in the order of a few tens of terabecquerels, in comparison to the initial activity of graphite waste. It should be noted that the uranium 238 contained in some of those residues is to be related to the radium 226.

The first objective of a repository for radium-bearing waste is to limit the exhalation of radon 222 gas towards the surface. Modelling shows that 30 cm of saturated clay or 4 m of 60%-saturated clay are able to delay sufficiently the flow rate of radon gas in order to allow for its decay before reaching the environment. Consequently, a reworked cover of at least 15 m or an intact cover will fulfil that objective.

Similarly to graphite waste, any limitation of water circulation in the repository will favour diffusive transport.

The repository concept relies significantly on the low solubility and mobility of the radionuclides contained in radium-bearing waste. Limiting the release of those radionuclides requires a sound control of various conditions, such as redox (a reducing potential is more favourable), pH (a pH from neutral to basic is sought) and eventual complexation phenomena by various chemical species, notably organic ones, contained in the waste.

Lastly, the purpose of a repository for radium-bearing waste is to retard any aqueous migration of radionuclides towards the environment. The combination of slow transport, high sorption capability of the clay and its radioactive decay ensures the decay of radium 226 within the repository and its reworked or intact cover. Radium-bearing waste does not require a diffusive barrier as thick as for graphite waste in order to ensure flow-rate dispersion. That is the reason why the option with a reworked cover is being considered for radium-bearing waste in parallel with the intact cover on the same site as the repository for graphite waste or on another site (Figure 2).

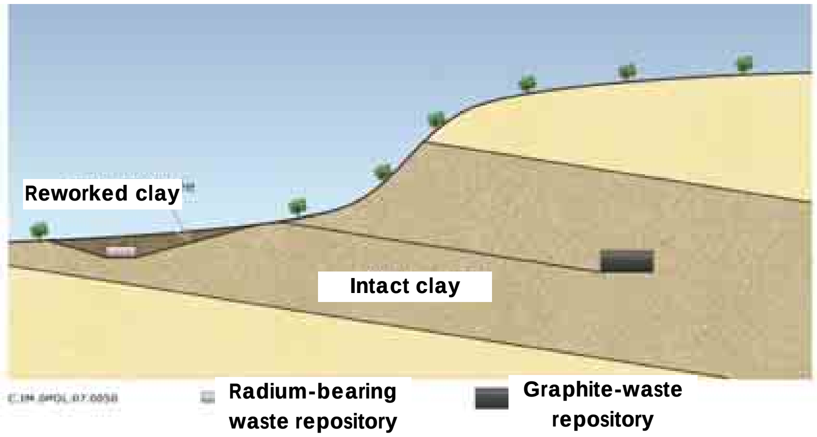

Fig. 2. Alternate option for the combined disposal of radium-bearing and graphite waste at intermediate depth

Feasibility of repository architectures

Repository architectures under intact and reworked covers were the subject of the first set of industrial feasibility studies during the last years.

At this stage of the studies, using the tunnel-boring machine for excavating a repository under an intact cover has several advantages: adaptability to the geotechnical conditions of the site, EDZ minimisation, cost. On the other hand, that type of excavation imposes rather heavy constraints on the repository architecture. Future studies should highlight and confront advantages and disadvantages in relation to the safety functions mentioned above.

The sizing of waste containers depends on the waste-transport and emplacement requirements: dose rate, drop resistance, lifting and stacking equipment, with the latter tending to favour parallelepipedic containers. Studies have also shown the advantage of using remote-control devices to emplace the waste packages in disposal cells in order to limit professional exposures.

Residual voids within a repository under an intact cover are minimised in order to limit any deformation of the host formation. In order to reach that goal, an option consists in pre-forming the cell in such a way as to limit the flue space around parallelepipedic containers, as studies on intermediate-level long-lived waste have demonstrated. The *in-situ* injection of those flue spaces was also investigated during the first studies. Depending on the volume of those spaces to be backfilled, the process may require to proceed by successive sections of cells.

Earthworks studies of the repository with a reworked cover emphasised the sizing character of runoff management and the stability of the adit slopes; consequently, the technico-economical limit of that option lies at a depth of approximately 30 m. Construction prescriptions will aim at limiting not only any differential settlement likely to affect the cover (first of all by an appropriate backfill of residual voids in structures and packages), but also the impact of any residual settlement (e.g., by the placement of intermediate bentonite layers at the roof of the structures, located at the base of the reworked cover).

Until a site is selected, all exploration work and repository studies and models will deal primarily with recognising the homogeneity and geometry of the host formation, determining its permeability and transport properties, recognising and modelling the hydrogeological context, modelling the migration of gaseous and dissolved radionuclides and describing the geodynamic evolution (sensitivity to erosion and glaciation). The geomechanical behaviour of the formation will be studied for the sizing of the repository (mechanical strength, deformation module) and should help to assess the long-term behaviour of the intact or reworked cover (elastoplastic behaviour, deferred behaviour).

In parallel, the behaviour of the waste is also being investigated. Apart from ongoing work on graphite waste, those investigations concern the chemical content and behaviour of radium-bearing waste in relation to the release and mobility of radionuclides.

Technical studies will continue in order to compare different architecture options with regard to industrial feasibility, operational safety and long-term safety. As they progress, they help in clarifying the container specifications. They should also enlighten the issue about co-activity (operation through successive excavation and package-emplacement campaigns *versus* the performance of parallel excavation activities and nuclear operations).

DISPOSING OF LLW-LL: SEARCHING FOR A SUITABLE SITE

In order to carry out the site search effectively and to comply with the legal prescription to commission a facility by 2019, siting process must be undertaken. The Ministry of Ecology, Energy, Sustainable Development and Spatial Planning (MEEDDAT) and Andra have decided to adopt an open and stepwise approach based on the volunteer application of local communities for that purpose.
The first step was to identify possible sites in France complying with the geological requirements as specified in the first part of this paper.

In June 2008, local communities that are deemed geologically favorable in principle for the implementation of such facility were informed about the approach. Since the project is of national interest, Andra has wished to associate several organizations and institutional representatives in order to ensure the seriousness and integrity of its approach. In its emphasis on openness, Andra also plans to extend its outreach to other organizations that might be interested by the project.

A stepwise site search campaign

The site-search phase started in June 2008 by sending a fact file to the different communities involved.
Local communities, where geological properties are suitable in principle for the implementation of the project, had until 31 October 2008 to express their interest to Andra and to agree that preliminary investigations be conducted *in situ*. Among over 3000 sites, over 40 volunteered. By the end of 2008, if at all possible, Andra should be in a position to propose to the government a pre-selection of the most appropriate zones, based on the collected information (documentary complements on local geology, local interest in the project, etc.).

In 2009, investigations will begin on the pre-selected sites. Those investigations will provide a fine analysis of the geological environment and confirm or not the technical feasibility of the construction of the future facility in that zone, based on the technical requirements as described above.

In parallel and in consultation with the National Commission on Public Debate (CNDP), meetings will be organised with local stakeholders (residents, socio-economic actors, elected officials, associations, etc.) in relation to their expectations, with a view to presenting and to explaining the project to them, as well as to responding to their questions.

A multi-criterion site search campaign

At the end of 2010, once the local communities will have confirmed their application to host a disposal facility, Andra will present an assessment report to the government in order to select the most appropriate site. The report will include several sections, as follows:

- the conclusions of geological investigations;
- the presentation of the territorial-development projects planned by the communities that applied to host the new disposal facility, and
- the outcome of the public consultation.

Economic incentives for host territories

Hosting a future disposal facility for LLW-LL may represent an opportunity for the economic development of the territory involved, as shown by the experience feedback from comparable facilities.
As in the case of any other large-scale project, the future disposal facility will mobilise public-works firms for the construction and will involve the creation of new waste-management jobs during the operating phase. Indirectly speaking, the disposal facility should also encourage the development of infrastructures, the implementation of local service companies, etc.

The project will result in new tax resources to the relevant communities through professional and property taxes. The site will also remain open to visits and welcome experts, thus broadening the notoriety of the surrounding area.

Upstream from the construction and operation of the disposal facility, the government and Andra will propose to all communities interested in building and implementing together an effective development project on their territory. Industrial companies that own waste, such as EDF, the CEA, AREVA, Rhodia, etc., will also be invited to participate in the approach.

In the case of comparable facilities, for instance, activities until now have focused more specifically on the following:

- promotion of local know-how and main advantages;

- support to the development of local firms and service activities;
- participation in local projects relating to greenhouse-gas effects in order to counter climate changes, and
- co-operation with research and academic institutions, thus strengthening the relations of those institutions with the local communities.

Current estimated construction and commissioning costs range between 200 and 350 million euros, whereas operating costs should vary between 10 and 30 million euros per year over at least 20 years.

Current disposal solutions under review

Today, Andra is seeking an appropriate disposal solution for each waste category intended for disposal.
In fact, the future disposal facility must be designed in such a way that the radioactivity contained in the waste be contained long enough for it to decay, for its impact on human beings and the environment to be the lowest possible and particularly lower than the impact of natural radioactivity.
In order to attain that goal, Andra applies the provisions prescribed by the Safety Authority (ASN) in order to identify the most suitable geological formation for the implementation of the future facility, as well as the type of structure and package in which the waste will be disposed of. Thanks to the studies carried out on LLW-LL, the characteristics of the most favourable geological formation, as explained in the first part of this paper are already known: it must involve a sedimentary and low-permeability layer with a clay or marl dominant and be at least 50 m in thickness; it must also be located in a geologically stable zone over the next 10,000 years at least and at a shallow depth ranging from 15 to 200 m.

Plans call for radium-bearing and graphite waste to be disposed of on the same site and according to a solution called “disposal under an intact cover”. The method consists in underground excavation. Access to the structures is provided by longitudinal drifts. The overall footprint may be in the order of 100 ha. Based on those various elements and a documentary study carried out by the French Geological Survey (BRGM), Andra was able to identify potential host zones throughout the country. In order to go even further in the design of the future LLW-LL disposal facility, Andra and the MEEDDAT are looking for a potential disposal site on which to conduct complementary field studies.

The hydrogeology of the site must be characterised by a very low permeability of the host formation, a low hydraulic gradient and the absence of reducing tectonic structures. Mountain areas were excluded due to the complexity of the structural context (faults), geodynamic context (earthquakes, erosion) or hydrogeological context (high hydraulic gradients). Consequently, the selected formations are located in large sedimentary basins or close to them.

From a subsoil-management standpoint, the site must be chosen in such a way as to discard areas with a recognised or suspected exceptional significance. At the current stage, sectors where hydrothermal, petroleum or salt-bearing resources are already exploited have been rejected. Sites located near sectors where underground extractable materials have been mined will be verified further during the application-review phase, scheduled to take place during the second half of 2008.

The inventoried stratigraphic levels date back to the Trias, Jurassic, Cretaceous and Tertiary eras.

To the general geological context mentioned above are also included various other repository-related constraints, such as:

- the thickness of the containing formation equal to at least 50 m;
- the presence of an outcropping or near-surface formation (maximum of 200 m);
- the homogeneity of the formation, and

- favourable geomechanical properties: clay formations with low mechanical strength were discarded, due to their incompatibility with the creation of disposal infrastructures.

The documentary analysis rests on a more or less detailed amount of data depending on various formations and geographical areas. Those data will need to be completed by further investigations on candidate sites in order to confirm their potential interest.

References

1. Consolidated version of *Planning Act No. 2006-739 Concerning the Sustainable Management of Radioactive Materials and Waste:* http://www.andra.fr/publication/produit/loi-VA-12122006.pdf