Position Paper on Reversibility

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ANDRA
French national radioactive waste management agency

CONTENTS

By passing the 1991 Bataille Act on radioactive waste management, the French Parliament placed France's high-level and long-lived waste management policy on the path to seeking long-term, safe solutions. It created Andra, an autonomous body, independent of waste producers, which is supervised by the ministries responsible for energy, research and the environment.

In 2006, Parliament passed an Act in which it adopted deep geological disposal as the long-term management solution for high-level waste (HLW) and intermediate-level long-lived waste (ILW-LL).

Extract from Planning Act 2006-739 dated 28 June 2006

Article 5: [...] the disposal of radioactive wastes in deep geological formations is the disposal of these substances in a specially laid out underground installation, with due regard for the reversibility principle.

Article 12: [...] no authorisation can be granted to create a disposal centre in a deep geological formation that does not guarantee reversibility in the manner laid down by this Act. [...]

The authorisation sets the minimum time during which, as a precautionary measure, disposal must be reversible. This period cannot be less than one hundred years. [...]

Since then, Andra has been conducting a large-scale dialogue approach aiming to provide a coherent response to the law and the expectations of society. This process took place on all levels: local (commission on reversibility of the Local Information and Oversight Committee for Andra's underground laboratory, meetings with the public and local stakeholders etc.), national (scientific colloquia, discussions with the French Nuclear Safety Authority and review bodies, meetings with organisations), and international (international project under the aegis of the OECD's Nuclear Energy Agency, and an international conference in Reims in December 2010). These discussions aimed to result in a concrete proposal for the public debate on the Cigeo geological disposal facility project, which was held in 2013. Following the public debate, Andra continued its considerations and supplemented its approach with regard to reversibility.

The purpose of this document is to review the principle of deep geological disposal, to present the industrial facility that Andra is designing and its current state of development, to explain the benefits of progressing to the creation of Cigeo at this time and how reversibility is at the heart of Andra's technical and social approach. It thereby aims to contribute to the parliamentary debate on the reversibility of disposal.

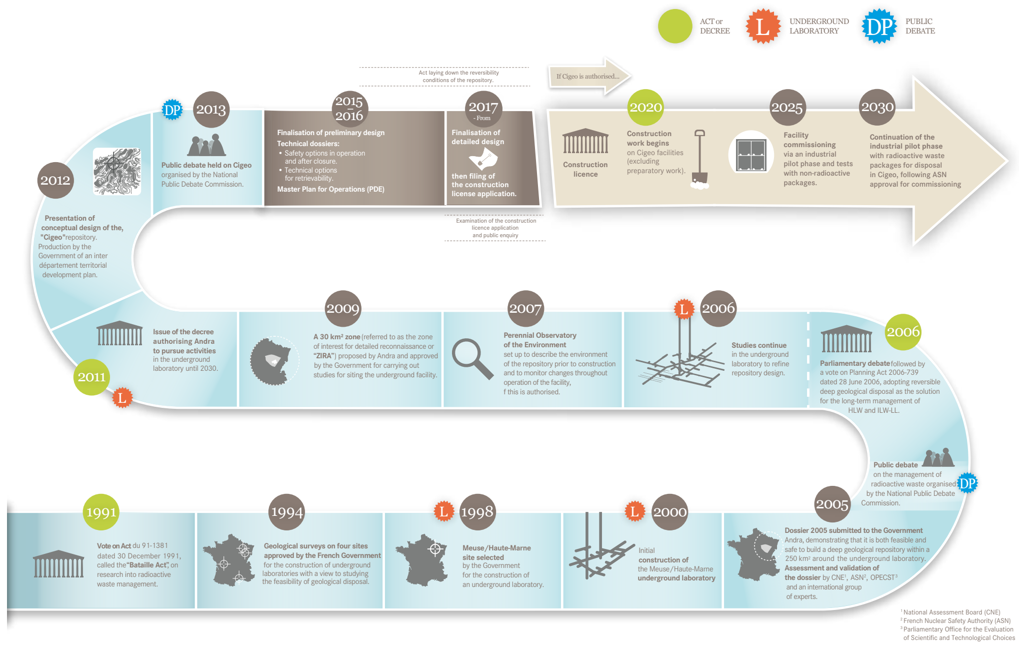
Definition of reversibility following the 2013 Cigeo public debate[1]

Reversibility is the ability to leave future generations options regarding long-term management of radioactive waste, including sealing off disposal structures or retrieving waste packages. This is ensured in particular by the progressive and flexible development of the disposal facility.

1. "*Délibération du conseil d'administration de l'Andra du 5 mai 2014 relative aux suites à donner au débat public sur le projet Cigéo* (Deliberations of Andra's board on 5 May 2014 pertaining to the follow-up of the public debate on the Cigeo Geological Disposal Facility project)", *Ministère de l'écologie, du développement durable et de l'énergie* (2014), *Journal Officiel*, No. 108, p. 7851-7854

Introduction

Radioactive waste is mainly produced by the nuclear power industry but also by Defence activities, industry, and the health and research sectors. The vast majority of these producers benefit from current solutions: 90% of the total volume of radioactive waste generated each year in France is disposed of in Andra's surface disposal facilities. However, high-level and intermediate-level long-lived waste cannot be disposed of in surface or near-surface facilities due to the long-term risks: such waste remains hazardous for tens or hundreds of thousands of years.



See Appendices for details

For this reason, after 25 years of research, in particular at the underground laboratory in the Meuse and Haute-Marne *départements*, and a feasibility study produced by Andra in 2005, which was assessed internationally, in 2006 the French Parliament decided to implement a reversible deep geological disposal repository, as a reference solution to ensure the long-term safe disposal of high-level and intermediate-level long-lived waste. Deep geological disposal limits the burden placed on future generations. Its reversibility ensures opportunities for options and development with regard to the decisions taken by our generation, including the ability to reconsider earlier choices if desired. It involves society in governance of the geological disposal facility.

The 2006 Planning Act gave Andra the task of designing and building a reversible disposal facility for this waste: the Cigeo geological disposal facility.

Surface, near-surface or deep: solutions proportionate to risks

For a radioactive waste repository, as for any nuclear facility, protection of people and the environment depends on the site chosen, its design, and the quality of its construction, operation and monitoring operations. Various types of disposal have been designed in accordance with the sites and types of waste involved. In particular, the following are noted:

- Surface disposal,
- Near-surface disposal, up to a few tens of meters' depth,
- Deep geological disposal, beyond 200m depth.

The type of disposal adopted for a type of waste mainly depends on its activity level and the time for which it remains harmful and must be confined and isolated from the environment.

1. Disposal principles

High-level and intermediate-level long-lived waste

High-level waste (HLW) and intermediate-level long-lived waste (ILW–LL) represent a limited volume (about 3% of the volume of existing radioactive waste) and include almost all of the radioactivity in such waste (over 99%).

This waste mainly comes from the nuclear power industry (spent fuel processing) and associated research activities, and to a lesser extent from CEA activities associated with the nuclear deterrent and naval nuclear propulsion.

ILW-LL contains significant quantities of long-lived radionuclides. The radioactivity level is generally between 1 million and 1 billion becquerels[2] per gram[3].

HLW has a level of radioactivity of between a few billion and several tens of billions of becquerels per gram and it gives off heat. Some radionuclides have very long half-lives (e.g., neptunium-237 has a half-life of 2 million years).

Highly dangerous waste

In France, the average natural background radiation dose is approximately 2.4 mSv. In comparison, 50 milliseconds spent at one metre from a HLW package is equivalent to a year of natural radiation, and 1 second to 20 years of natural radiation. Approximately 5 seconds spent at one metre from an ILW-LL package is equivalent to a year of natural radiation.

The Cigeo geological disposal facility project is designed to cater for all the HLW and ILW-LL that has been produced and will be produced by existing nuclear facilities. Waste that will be produced by nuclear facilities currently being built (Flamanville EPR, ITER and the Jules Horowitz experimental reactor) has also been taken into account.

2. The becquerel (Bq), measures the level of radioactivity (or activity), i.e. the number of disintegrations per second. 1 Bq equals 1 disintegration per second.

3. In comparison, very low-level waste (VLLW, 30% of volume) generally has a radioactivity level of less than 100 becquerels per gram, while low-and intermediate-level short-lived waste (LILW-SL, 60% of volume) generally has a radioactivity level of between a few hundred and a million becquerels per gram.

The Cigeo project has therefore been designed to receive approximately 10,000 m^3 of HLW and 75,000 m^3 of ILW-LL. Of this, 60% of ILW-LL and 30% of HLW has already been produced.

Such waste is stored on production sites until a long-term management solution has been found. For certain types of waste, in particular HLW, storage for several decades is necessary before it can be accepted for disposal, corresponding to an initial phase of radioactive decay.

Ultimate waste

As for other categories of radioactive waste, HLW and ILW-LL are the subject of producer programmes to reduce their volume and harmfulness. Confinement by vitrification, cementation and even bituminisation, contribute to the short and medium-term confinement of radioactivity.

HLW and ILW-LL are ultimate waste in the sense that studies performed over several decades have not found any economic benefit in their reuse.

- HLW is the residue from spent fuel reprocessing operations whose objective is to separate potentially valuable nuclear materials (uranium and plutonium) from non-reusable substances which are then vitrified (fission products and minor actinides [americium, curium, etc.]).
- ILW-LL comprises highly-irradiated metal parts, in particular, those that surround removed spent fuel (hulls and end-caps), solidified liquid effluents and waste from the maintenance or decommissioning of nuclear facilities, laboratories or Defence-related facilities.

The ethical need to deal with nuclear waste

The fact that HLW and ILW-LL is highly dangerous and very long lasting means that the generations that benefit from the advantages of the nuclear industry have an ethical responsibility to find and implement short-, medium- and long-term solutions to ensure that people and the environment are protected from the danger presented by this waste, both now and in the future.

Currently, the HLW and ILW-LL that have already been produced are safely and securely placed in storage facilities. This is a temporary management solution. It is therefore necessary to find, study and implement a sustainable management solution. This has been the subject of research that Andra has performed for over 20 years regarding deep geological disposal. This facility is designed to ensure the very long-term confinement of the radioactive waste that will be placed there. This solution limits the burden placed on future generations, because in contrast to storage, once closed, it no longer requires human intervention to ensure safety.

Our generation also has the responsibility of not committing future generations to the choices we have made. For this reason, at the request of the French Parliament, Andra has developed a reversible disposal project.

Project funding

As part of assuming responsibility, funding of the design, construction, operation and closure of the Cigeo geological disposal facility is provided by current generations so that it is not a burden for those that follow. This is ensured by the regularly revised provisions made by EDF, CEA and Areva, the three producers of this waste.

The cost of the technical provisions made to provide for reversibility (a cost that provides future generations with options) is included in the project. Current generations thereby offer future generations options and ways of modifying the disposal process in the future. However, if future generations do decide to use this option, for example to modify the repository, remove the packages or push back the date for definitive closure, they will naturally need to bear the associated costs.

A solution: reversible deep geological disposal

The depth of the repository, its design, and its construction in impermeable argillaceous rock in a stable geological formation will make it possible to protect the waste from human activities and natural phenomena on the surface (such as erosion) and confine the radioactive substances it contains over very long timescales. Once the facility has been sealed, it no longer requires human intervention. Therefore, the burden of managing waste is not placed on future generations and their protection is ensured.

Over time, the waste packages and the facility's underground structures will deteriorate in contact with the water contained in the rock. After several hundred years, some radionuclides may dissolve. The clay will then take over the role of retaining them and slowing their migration. The repository thereby ensures the confinement of radioactivity. Only some highly mobile radionuclides could migrate out of the clay layer, at the timescale of hundreds of thousands of years and gradually over a long period, which would significantly reduce their concentration. The effect of these pollutants on people has been studied. Their impact would be less than that of natural radioactivity.

Opinion of the French Nuclear Safety Authority (ASN) of 1 February 2006 on the research carried out under the Bataille Act[4]

"The Dossier 2005 Argile report submitted by Andra to its supervising ministers in June 2005 has been reviewed by IRSN and was the subject of an opinion delivered by the expert advisory committee on radioactive waste management during its session of 12-13 December 2005. These reviews reveal that key results related to the feasibility and safety of a geological repository have been obtained at the Bure site. It is the view of the ASN that deep geological disposal is the only disposal solution possible."

A solution with international consensus

Nuclear power countries are all adopting deep geological disposal as the definitive, safe, long-term management solution for their most radioactive waste. The designs and host geological environments selected for repositories vary from country to country. Many countries have already started to study deep geological disposal. Alongside France, this is the case for Finland (which obtained its construction license in 2015), Sweden (where the construction license application was filed in 2011), Canada, China, Belgium, Switzerland, Germany, the UK and Japan.

Furthermore, the International Atomic Energy Agency (IAEA) has stated that: "*The safety of geological disposal is widely accepted amongst the technical community and a number of countries have now decided to move forward with this option*" (The Long-Term Storage of Radioactive Waste: Safety and Sustainability - A Position Paper of International Experts, IAEA 2003).

European Council Directive 2011/70/EURATOM dated 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste states that "deep geological disposal represents the safest and most sustainable option as the end point of the management of high-level waste".

In November 2015, the Finnish Government gave the go ahead for construction of the Onkalo spent nuclear fuel repository at Olkinuoto. Posiva, the body responsible for the disposal of radioactive waste, had filed its construction license application in December 2012. The project was approved by the Finnish nuclear safety authority STUK in February 2015.

4. www.ASN.fr/Media/Files/L-avis-de-l-ASN-rendu-au-Gouvernement.pdf

Complementary management methods

Under the 1991 Bataille Act, research on other management options was undertaken in parallel to research on deep geological disposal: partitioning and transmutation of long-lived radionuclides in waste, and long-term storage.

- Partitioning and transmutation of radionuclides, studied by the CEA, aims to reduce the quantity and harmfulness of radioactive waste. First, the various radionuclides contained in waste are separated from each other. Then, the long-lived radionuclides are converted into shorter-lived radionuclides through a series of nuclear reactions. The CEA's results showed that partitioning and transmutation do not obviate the need for deep geological disposal: application of the technique is only possible for waste produced in the future and would only be feasible for some radionuclides contained in waste, i.e. those of the uranium series known as minor actinides (americium, curium and neptunium). Furthermore, the nuclear facilities required to implement the technique would in turn generate waste that would also have to be isolated in a deep geological repository for safety reasons.

- The CEA also looked into designs of surface and near-surface storage facilities intended to last for periods in the region of 300 years. The CEA concluded that the designs of the facilities studied were particularly robust against external, technical and man-made hazards. However, they required monitoring by society and removal of the waste packages by future generations. Indeed, an essential component to any design is the retrievability of waste packages from a storage facility that reaches the end of its useful life so that they may be reconditioned and a new storage facility built.

Opinion of the French Nuclear Safety Authority (ASN) dated 1 February 2006 on the research carried out under the Bataille Act[5]

With regard to partitioning and transmutation

"It is the view of the ASN that the technological feasibility of partitioning and transmutation has not yet been demonstrated. Even if the solution were implemented, it would not be possible to completely dispose of the high-level long-lived radioactive waste generated. Another reference solution must be found." Furthermore, the ASN issued another opinion on partitioning and transmutation on 4 July 2013[6].

With regard to long-term storage

"Research performed to study conditioning and long-term storage processes for this waste confirms that storage is a necessary step to allow certain waste packages to cool prior to their disposal in a deep geological formation".

"However, the ASN considers that it would not be reasonable to adopt as a reference solution one which consists of renewing long-term storage multiple times, as this assumes maintenance of monitoring by society and removal of the waste packages by future generations, which seems difficult to ensure over periods of several centuries".

"It is the view of the ASN that long-term storage cannot provide a final solution for the management of high-level long-lived radioactive waste."

Currently, in the context of the 2006 Planning Act, partitioning/transmutation and storage are management options that are complementary to disposal.

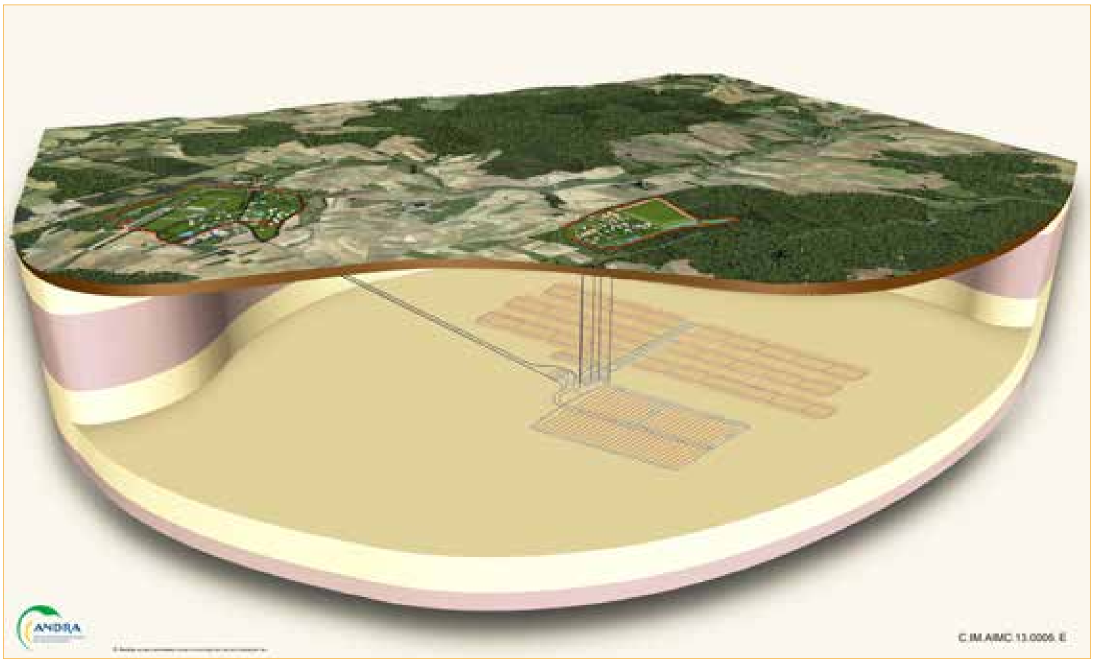
5. www.ASN.fr/Media/Files/L-avis-de-l-ASN-rendu-au-Gouvernement.pdf

6. http://www.asn.fr/Reglementer/Bulletin-officiel-de-l-ASN/Avis-de-l-ASN/Avis-n-2013-AV-0187-de-l-ASN-du-4-juil-let-2013

2. Cigeo, the technical answer

The Cigeo reversible disposal project comprises a set of facilities that constitute a single regulated nuclear facility:

- surface facilities divided into two distinct sets:
    - ✓ the zone for receiving HLW and ILW-LL primary packages, inspecting them and preparing them for disposal;
    - ✓ the zone for underground work support activities;
- an underground facility comprising:
    - ✓ surface-bottom connections (ramps to transfer packages to the bottom using a funicular, and shafts for personnel access and for works),
    - ✓ package disposal sections (disposal cells and access drift),
    - ✓ logistics support zones.



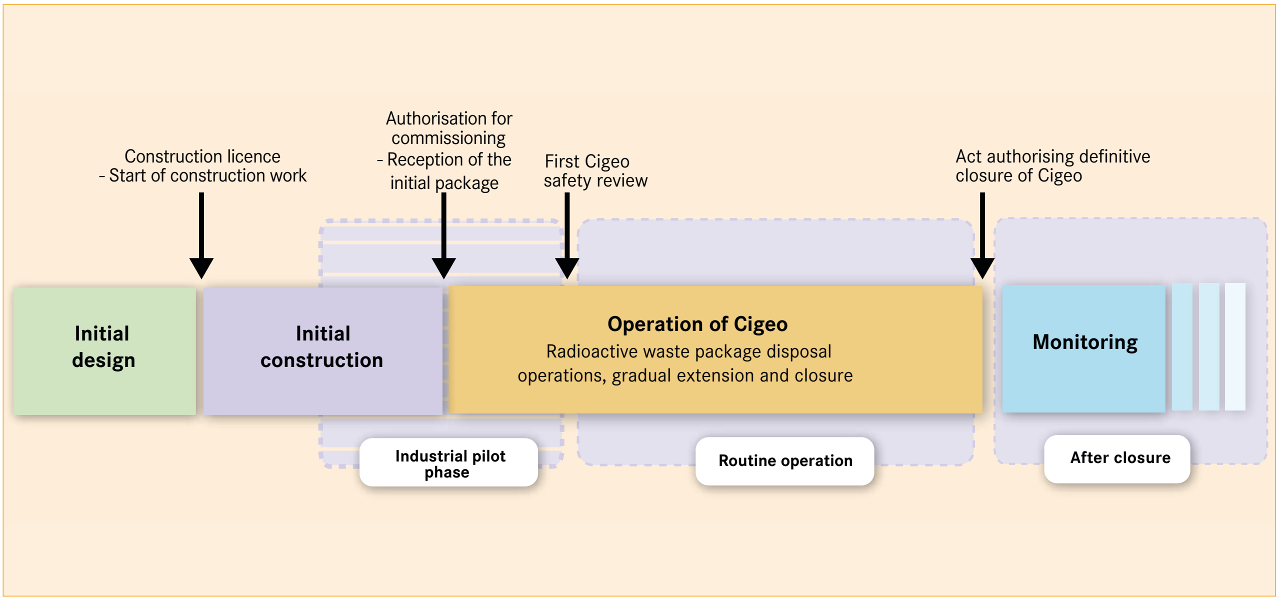
See Appendices for details

The Cigeo project includes the following main successive phases:

- **Initial design of the facility** (conceptual, preliminary and detailed design, construction design) during which the facility's structures, buildings and processes are specified technically. This is the current project phase. The design of Cigeo is subject to regular assessments. It includes the construction license application. Design studies will continue beyond this initial phase, during the entire operating life of the facility, so that optimisations can be incorporated.

Subject to authorisation by decree (construction license):

- **Initial construction of Cigeo** during which the first part (or "phase") of the facility is built. This includes surface buildings associated with operation of the surface nuclear facility, surface-to-bottom connections and underground structures to receive the first waste packages;
- After obtaining Cigeo's operating license (and reception of the first nuclear waste package), **operation** in successive phases, which will continue for about a hundred years, during which reception and disposal of packages and extension work on the underground facilities will take place in parallel so that all the inventory packages can be accepted. Subject to authorisation, partial closure works (moving to levels 3 and 4 of the International Retrievability Scale[7]) will also be performed, along with construction, modification and renovation work on surface buildings;
- **An industrial pilot phase** is planned at Cigeo's operational start-up before transition to routine operation. In particular, this industrial pilot phase will include tests to confirm, under real conditions, the ability to remove waste packages emplaced in Cigeo;
- After operation has finished, the decommissioning and final closure of Cigeo, which can only be authorised by an Act of Parliament. Cigeo will then enter its **monitoring phase**.



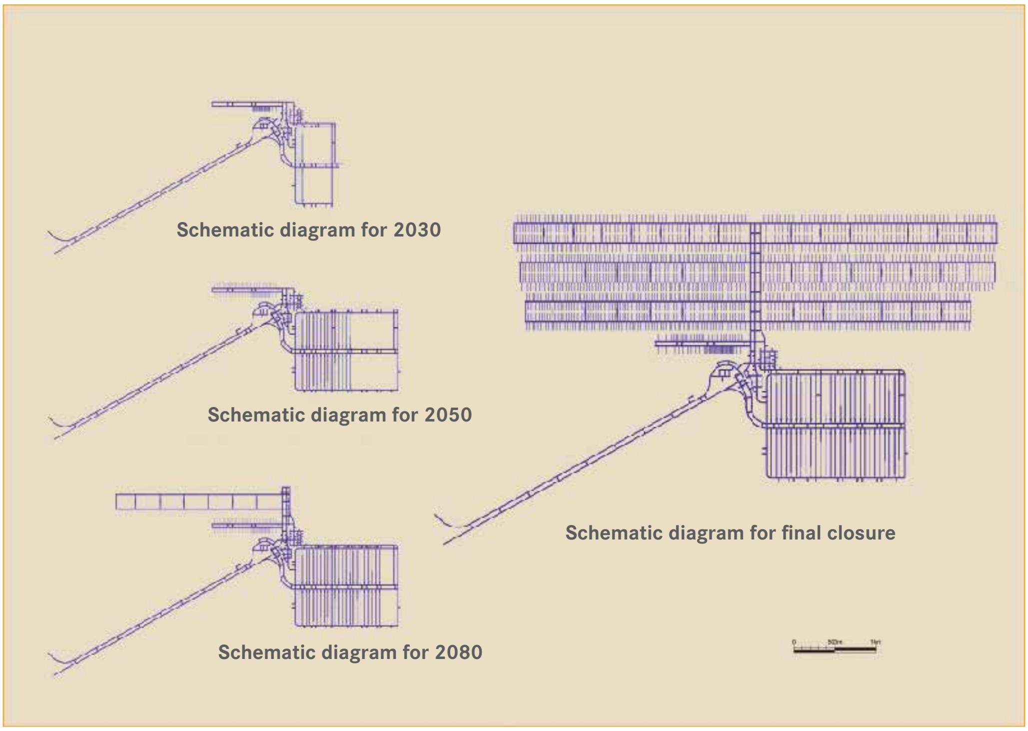


Illustration of the gradual development of the Cigeo underground facility over time.

3. Development of Cigeo

For its research on deep geological disposal, Andra has called on the scientific community in a wide variety of fields (earth and environmental sciences, materials science, instrumentation, etc.). It is also very involved in international projects, in particular with its foreign counterparts. Andra also has its own scientific resources - the underground laboratory in Meuse/Haute-Marne, computing facilities and the Perennial Observatory of the Environment – designed to meet Cigeo's specific research needs. Studies performed over the past 20 years, which have been regularly assessed by the National Review Board (CNE), the Nuclear Safety Authority (ASN) and the Andra Scientific Council, have demonstrated the safety and feasibility of reversible deep geological disposal: currently Cigeo has reached Technological Readiness Level 5 (TRL5 - **see Box below**).

International TRL scale

Andra has chosen to use the international Technology Readiness Level (*TRL*) scale as a tool to assess technical progress of the various components of the Cigeo project.

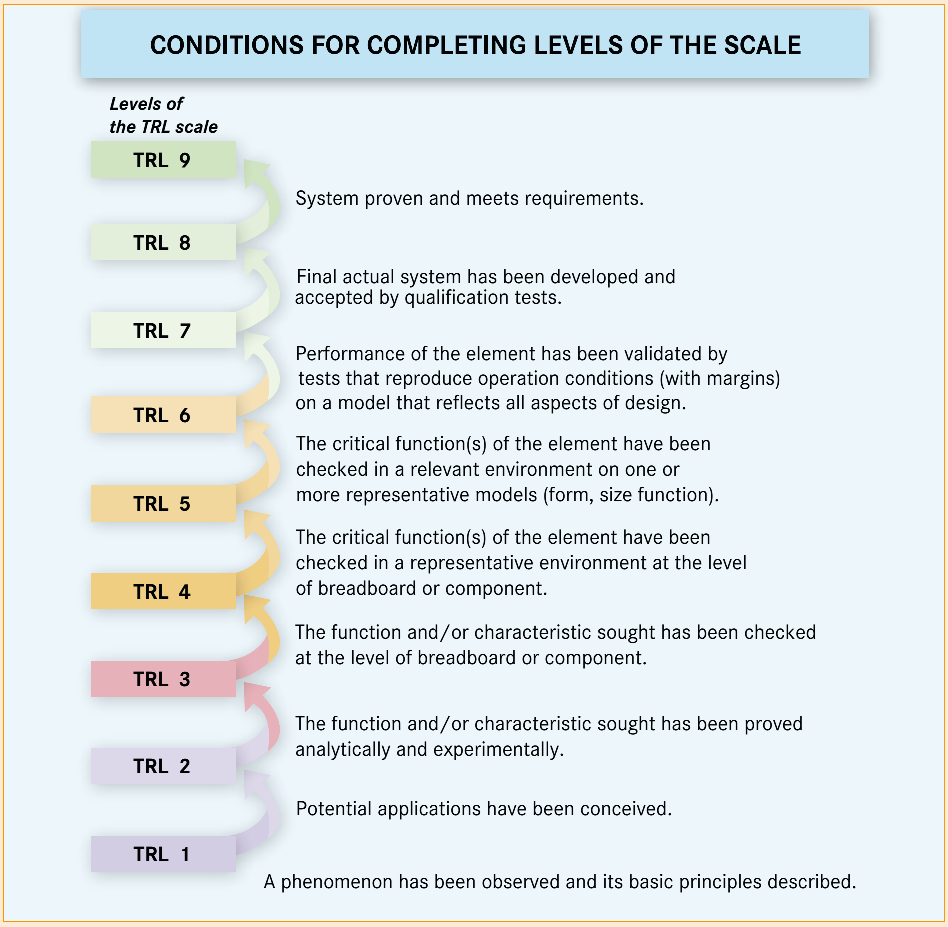
The international TRL scale is used to quantify the technical maturity level of an item (equipment, component, system, etc.). It is the subject of an International Standard (ISO 16290:2013). It was primarily developed mainly for space systems, but can be transposed to other sectors to assess the technical maturity of a project or to measure the progress of a technology throughout its development.

The TRL scale has nine levels. The lowest level (Level 1) corresponds to the discovery and understanding of a physical phenomenon with potential applications in the context of academic research (e.g., the discovery of radioactivity by Henri Becquerel in 1896). The highest level (Level 9) is attained when the item is fully defined by a set of reproducible processes, including manufacture, tests and operation, and when it meets the performance requirements assigned to it in the real operational environment (e.g., surface disposal of radioactive waste at Andra's CSA waste disposal facility in north-east France that caters for LILW-SL). Achievement of TRL5 means that the feasibility of an item has been demonstrated in a representative environment.

With a view to eventually having a facility that provides the expected industrial service, the next development steps for the Cigeo project consist of producing and testing items (containers, operating equipment, seals, etc.), gradually moving closer to the planned design for disposal structures in terms of size, the materials used, production and installation methods, and operating conditions.

Laboratory tests on models that are as representative as possible of the final design will ensure that initial progress can be made in system design and support the construction license application (TRL6 - **see Box above**).

For the following stages, given the size of the equipment used and the structures to be produced for Cigeo (containers of several tonnes, use of a funicular, drift and disposal structure of tens of meters in cross-section, etc.), qualification of Cigeo's operating and production procedures and validation of equipment performance cannot be carried out in the underground laboratory. The cross-section of the laboratory shaft means that large pieces of equipment cannot be introduced, and the tests required for Cigeo cannot be performed there.



Therefore, the following Cigeo development stages (TRL7 and 8) can only be made one by one during the industrial pilot phase, eventually leading to a tried-and-tested disposal facility that has demonstrated its ability to cater for radioactive waste packages while meeting safety and reversibility requirements (TRL9). Its operation will then be considered normal operation.

To this should be added incremental development of the Cigeo project, in particular with regard to phases after the initial phase. While Cigeo is designed on the basis of currently tried-and-tested technologies, its construction in successive phases over a period of several decades, means that improvements made possible by scientific and technical progress, and experience feedback from its operation, will be able to be incorporated. For this, the operator of Cigeo will submit design modification requests to the ASN, and subject to its authorisation, implement them on Cigeo.

4. Why Cigeo now?

For our generation, pursuit of the process that seeks to make a deep geological repository available, subject to authorisation, is an ethical necessity as strong as that of seeking to provide future generations with options including the ability to reconsider any decisions taken. In both instances, it is about not committing these generations to the choices we make or fail to make.

It is our generation and the previous one which built nuclear power plants and enjoyed the benefits in terms of development and lifestyle. We must therefore bear the investment cost for managing the waste produced.

Currently, technology and financial resources are available to perform the first steps of development. Nuclear power plants are still operating and will continue in the medium term to contribute to the funding of Cigeo's future investment phases.

Gradual implementation of Cigeo and the commitment to disposal of the initial HLW produced (now producing little heat and called “HLW0”), and all ILW-LL, will allow for preparation to store HLW that produces more heat (HLW1/HLW2), and prevent any temporal break in the management of waste over Cigeo's operating life (“cold” HLW and ILW-LL then “hot” HLW1/HLW2).

Conversely, over a longer time period, maintenance of the technological skills needed to produce such a nuclear facility cannot be guaranteed, in particular if relevant know-how were to decline following changes in energy policy. Neither can it be guaranteed that its production would be cheaper in the future or that future generations will find a management solution that avoids the need for geological disposal.

The drive in studies over the years has led to the conclusion that disposal is the optimum technical solution and to the construction of a credible industrial project near Andra's underground laboratory in Meuse/Haute-Marne. Our generation is responsible for moving towards the concrete realisation of geological disposal, while implementing governance and project management tools to guarantee its reversibility. Stopping this drive would limit options for our generation and those that follow.

For Andra, ethics with respect to future generations means that action is needed. Failure to implement the Cigeo project would mean refusing to provide future generations with "indispensable"[8] means for the long-term management of the radioactive waste produced by our generation.

8. This is stated in the ASN Opinion dated 1 February 2006: www.ASN.fr/Media/Files/L-avis-de-l-ASN-rendu-au-Gouvernement.pdf

5. Reversibility and its systems

The ethical concern for reversibility comes from the time scale required for managing the most harmful radioactive waste. In particular, given the century-long timescale for operation of the geological repository, it is the responsibility of our generation to design and pass on to future generations a safe facility, which they are able to modify or improve depending on their own objectives and constraints, or indeed replace with other management facilities, if other options become available, in particular due to technical progress. The reversibility of disposal is considered to be the ability to leave the next generation options concerning the long-term management of radioactive waste.

Safety After Closure

The fundamental objective of a radioactive waste repository, the reason for which it is built, is to passively protect people and the environment against the risks associated with the dissemination of the radioactive and toxic substances contained in waste over very long periods of time. For this reason, its is designed for eventual closure.

In practice, the closure operations necessary for the definitive safety of waste consist of removing the equipment used for operation and of installing structures, to complement the geological barrier (seals), that ensure the correct operation of the repository after closure. As a counterpart to progress towards passive operation of the facility, each closure operation increases the effort required for possible reopening of the closed cells or drifts, or removal of a waste package.

Operating safety

During the operating period, including closure operations, Andra will implement, subject to ASN approval, active and passive measures for prevention, detection/monitoring and protection, to protect the public, the environment and operations staff from the risks associated with operations for the disposal of the waste packages received at Cigeo.

Safety and reversibility

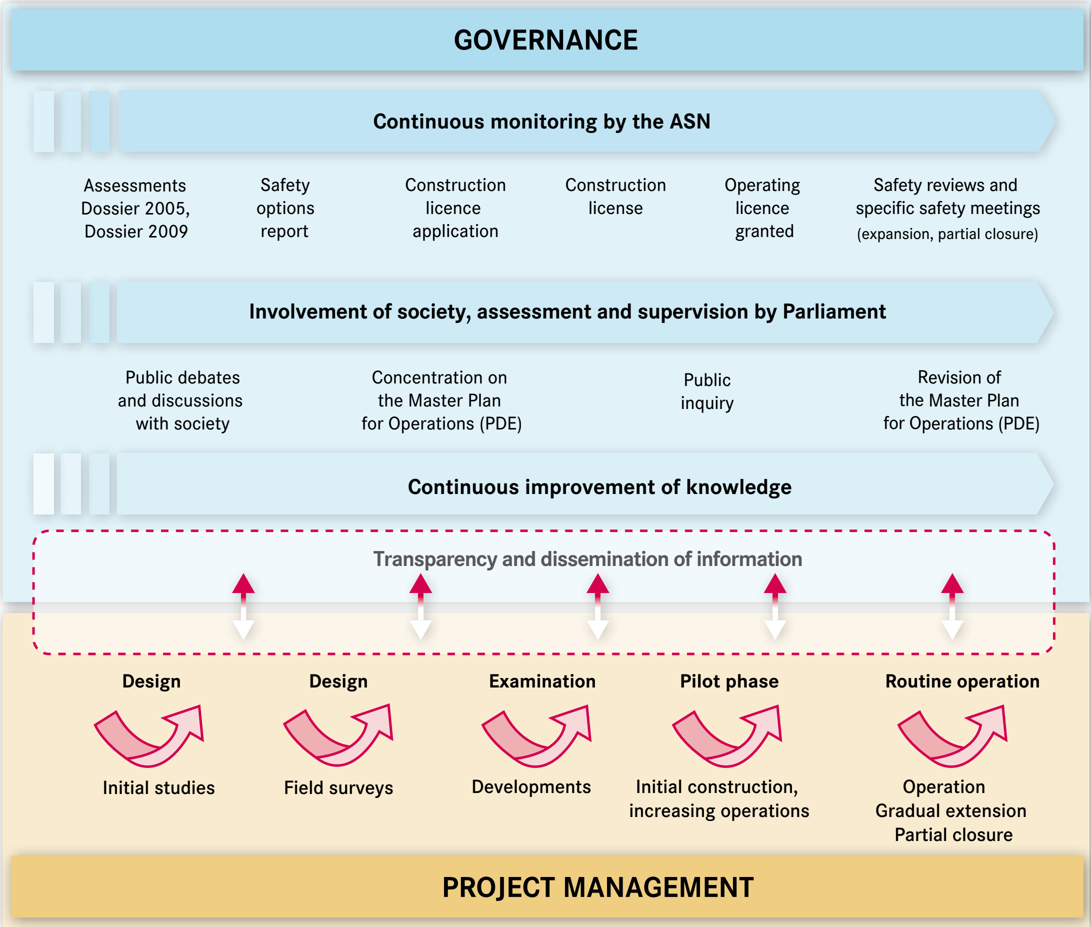
Cigeo is designed so that the options provided to future generations via reversibility can be implemented with adequate levels of safety, equivalent to those of operations planned by our generation. Furthermore, Andra has ensured that the provisions made for reversibility in no way jeopardise safety in operation or after closure. On the contrary, incremental development of the project promotes incorporation of improvements and experience feedback and thereby contributes to maintaining the facility at the highest level of safety.

In practice, reversibility is based on governance systems and technical project management systems:

- **Governance systems:** continuous improvement of knowledge regarding radioactive waste management, transparency and transmission of information and knowledge, monitoring by the ASN, the involvement of society, and assessment and supervision by Parliament.

- **Project management systems:** incremental development and gradual construction of the Cigeo facilities, flexibility offered by their operation, adaptability of the facilities and retrievability of packages.

These tools support decision-making for radioactive waste management. In particular, they ensure that the various options available are preserved or unlocked over time.



These systems and the role that they could play in future decisions and their impact on the Cigeo project are presented in summary form in the table below.

In early 2016, as the first tangible basis for reversibility, in particular to facilitate the involvement of society and in the context of transparency and the forwarding of information and knowledge, Andra produced a proposed Master Plan for Operations (PDE) presenting the reference progression of the Cigeo project (project design inventory, forecast construction schedule and closure milestones), the conditions for its commissioning (industrial pilot phase) and possible modifications in the context of applying reversibility. This proposed Master Plan for Operations (PDE) will be subject to consultation. The reference progression may be reviewed periodically to incorporate decisions made during Cigeo operation.

The PDE is thus a basis for dialogue and joint production of the collective governance for reversibility.

	SYSTEMS FOR REVERSIBILITY	POSSIBLE ROLES IN THE REVERSIBILITY OF DECISIONS	EXAMPLES OF OPERATIONAL IMPLEMENTATIONS IN CIGEO
Governance	**Continuous improvement of knowledge** An organised set of actions and work that aims to increase the body of knowledge regarding radioactive waste and management methods, and the use of this body of knowledge to improve its management	• Reveal new options for the management of various types of radioactive waste that are different from or complementary to disposal (e.g.: transmutation) • Improve waste management on production sites (e.g.: develop new conditioning methods or reduce the quantity of waste produced) • Improve Cigeo for greater efficiency (e.g.: improve equipment performance or the size of structures) • Periodically reassess the forecast operating life of the facility • Make use of experience feedback from repository operation	• Specific tests and measurements carried out in the Cigeo facility during and beyond the industrial pilot phase: ✓ Specific study programmes performed in demonstrators or test works (cell or component) ✓ Dedicated test zone in the underground facility • Dissemination of data from monitoring • Periodically producing and publishing reports on knowledge concerning Cigeo
Project management	**Incremental development and gradual construction** The continuous, regular and prudent nature of the sequencing of construction operations for the disposal facility throughout its operating life	• In successive phases, integrate the lessons learned from continuous improvement of knowledge into the design of Cigeo • Delay or speed up Cigeo construction	• Industrial pilot phase at commissioning that includes a gradual increase in the scale of operation • Modular facilities designed to be gradually extended as waste package disposal progresses • Construction of successive phases of underground structures, integrating technological developments and optimisations • Disposal of HLW0 waste (producing little heat) from the industrial pilot phase, to constitute a pilot project for the disposal of HLW1/HLW2 planned for later phases
	Operational flexibility The ability of the facility to adapt to changes in the industrial programme (reception schedule, reception flows, date of partial closure)	• Modify the flows and schedules for package reception and disposal • Modify the dates for partial closure of the underground facility	• Availability of an operational margin in Cigeo operations to temporarily or permanently increase resource use (e.g. transition from 2-shift operation to 3-shift (24hrs a day) or 5-shift (24/7)

	SYSTEMS FOR REVERSIBILITY	POSSIBLE ROLES IN THE REVERSIBILITY OF DECISIONS	EXAMPLES OF OPERATIONAL IMPLEMENTATIONS IN CIGEO
Project management	without modifying infrastructure or existing equipment and without building new structures	• Receive waste conditioned using new conditioning methods	• The design of the facility (design and architecture of the underground structures, and circulation of flows) means that works for partial closure of the underground facility can be organised (closure of cells and drifts) soon after their filling or at any time up to the end of disposal operations • Design of containers, structures and procedures such that they can easily be allocated to the reception of various types of package (e.g.: standardisation of lifting equipment) • Co-disposal of ILW-LL waste packages • Robust behaviour of containers enabling adaptation to the adopted closure schedule
	Adaptability of facilities Ability to modify the facility to adapt to new sizing assumptions (e.g.: changes to the inventory), involving significant modifications to existing equipment or construction of new structures	• Deal with waste not planned in the initial inventory, due to changes in energy policy or changes in the management of radioactive waste • Modify the facility to increase its performance, for example to increase package reception and reshipment flows	• Diameter of the surface-bottom connections with possible disposal of spent fuel • Footprint margins retained on the surface for the construction of buildings providing additional functions • Position and dimensions of the repository in the zone of interest for detailed reconnaissance (ZIRA), preserving rock volumes for possible extension (e.g., construction of additional disposal cells)
	Retrievability Ability to remove waste packages emplaced in a deep geological formation	• Provide flexibility in operating the repository • Reconsider the choice of a waste packaging method (repackaging) before return to disposal • Or even reconsider geological disposal as the management method for some or all of the waste during repository operation	• Durability of waste packages ensuring their ability to be handled • Durability of structures ensuring the maintenance of functional free play • Removal operations performed without jeopardising safety (e.g.: using lifting equipment equivalent to that used for emplacement) • Aptitude for dismantling of partial closure components (for cells and drifts) and for reequipping the facility (back-fill and seals could be dismantled). Dismantling tests for these components will be performed in Cigeo prior to initial partial closure work.

SYSTEMS FOR REVERSIBILITY		POSSIBLE ROLES IN THE REVERSIBILITY OF DECISIONS	EXAMPLES OF OPERATIONAL IMPLEMENTATIONS IN CIGEO
Governance	**Transparency and transmission of information and knowledge** All actions aiming to make data available regarding the facility, the operations performed there and factors that substantiated the decisions taken for its development	• Provide information for future decision-making on the basis of precise knowledge of the facility and the factors that led to the previous decisions • Organise repository records and their transmission	• Implementing an approach that provides traceability for earlier decisions and their substantiations • Understanding the facility's configuration • Implementing specific methods for archiving data, so that it can be kept for as long as possible • Forwarding data concerning costs, safety, waste emplaced and activities performed (construction, changes, etc.) to relevant stakeholders • Regular discussions with the Local Information and Oversight Committee (CLIS) and/or the Local Information Committee (CLI)
Governance	**Involvement of society, assessment and supervision by Parliament** All resources, systems and processes which ensure that stakeholders can contribute to the decisions taken for development of the repository	• Inform stakeholders of the issues associated with geological disposal and management of radioactive waste • Legitimise the decisions taken regarding management of radioactive waste, including local and national socio-economic consequences	• Continuous assessment by the National Assessment Board (CNE) • Production of a proposed Master Plan for Operations (PDE) presenting the reference progression of the Cigeo project (schedules for Cigeo construction and closure), the objectives of the pilot phase and the main issues regarding reversibility • Stakeholder involvement in the production of the Cigeo Master Plan for Operations (PDE) submitted to the French government • Stakeholder involvement in the production of periodic updates to the Master Plan for Operations (PDE) • Involvement of local stakeholders in local development and its monitoring
Governance	**Monitoring by the French Nuclear Safety Authority (ASN)** All actions aiming to check repository operator compliance with rules, specifications, commitments and missions	• Authorise safe management methods for waste, during operation and in the long term • Report on safety conditions for the facilities • Assess the state of knowledge regarding the management of radioactive waste	• Expert assessment of the project by technical assessors (IRSN, Advisory Committees, etc.) • Perform periodic safety reviews for Cigeo • Safety milestones: major extension decisions (HLW1/HLW2), safety demonstrations to incorporate optimisations and innovations • Continuously monitor Cigeo operation (inspections) • Incremental authorisation process, meaning that Cigeo can gradually develop and widen its operational scope • Continuous monitoring of advances in the Andra study programme on Cigeo • Production and monitoring of the framework specified in the construction license

APPENDICES

Act laying down the reversibili
conditions of the repository.

DP **2013**

Public debate held on Cigeo organised by the National Public Debate Commission.

2015 – 2016

Finalisation of preliminary design

Technical dossiers:

- Safety options in operation and after closure.
- Technical options for retrievability.

Master Plan for Operations (PDE)

2017 - From

Finalisation detailed des

then filing o the constru license appli

Examination of licence a and publ

2012

Presentation of conceptual design of the, "Cigeo"repository. Production by the Government of an inter département territorial development plan.

2009

A 30 km² zone (referred to as the zone of interest for detailed reconnaissance or **"ZIRA"**) proposed by Andra and approved by the Government for carrying out studies for siting the underground facility.

2011 **L**

Issue of the decree authorising Andra to pursue activities in the underground laboratory until 2030.

1991

Vote on Act du 91-1381 dated 30 December 1991, called the**"Bataille Act"**, on research into radioactive waste management.

1994

Geological surveys on four sites approved by the French Government for the construction of underground laboratories with a view to studying the feasibility of geological disposal.

L **1998**

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ACT or DECREE

L UNDERGROUND LABORATORY

DP PUBLIC DEBATE

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If Cigeo is authorised...

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Construction licence

2020

Construction work begins on Cigeo facilities (excluding preparatory work).

2025

Facility commissioning via an industrial pilot phase and tests with non-radioactive packages.

2030

Continuation of the industrial pilot phase with radioactive waste packages for disposal in Cigeo, following ASN approval for commissioning

2007

Perennial Observatory of the Environment set up to describe the environment of the repository prior to construction and to monitor changes throughout operation of the facility, f this is authorised.

L **2006**

Studies continue in the underground laboratory to refine repository design.

2006

Parliamentary debate followed by a vote on Planning Act 2006-739 dated 28 June 2006, adopting reversible deep geological disposal as the solution for the long-term management of HLW and ILW-LL.

Public debate on the management of radioactive waste organised by the National Public Debate Commission. DP

2005

Dossier 2005 submitted to the Government Andra, demonstrating that it is both feasible and safe to build a deep geological repository within a 250 km^2 around the underground laboratory. **Assessment and validation of the dossier** by CNE[1], ASN[2], OPECST[3] and an international group of experts.

L **2000**

Initial **construction of** the Meuse/Haute-Marne **underground laboratory**

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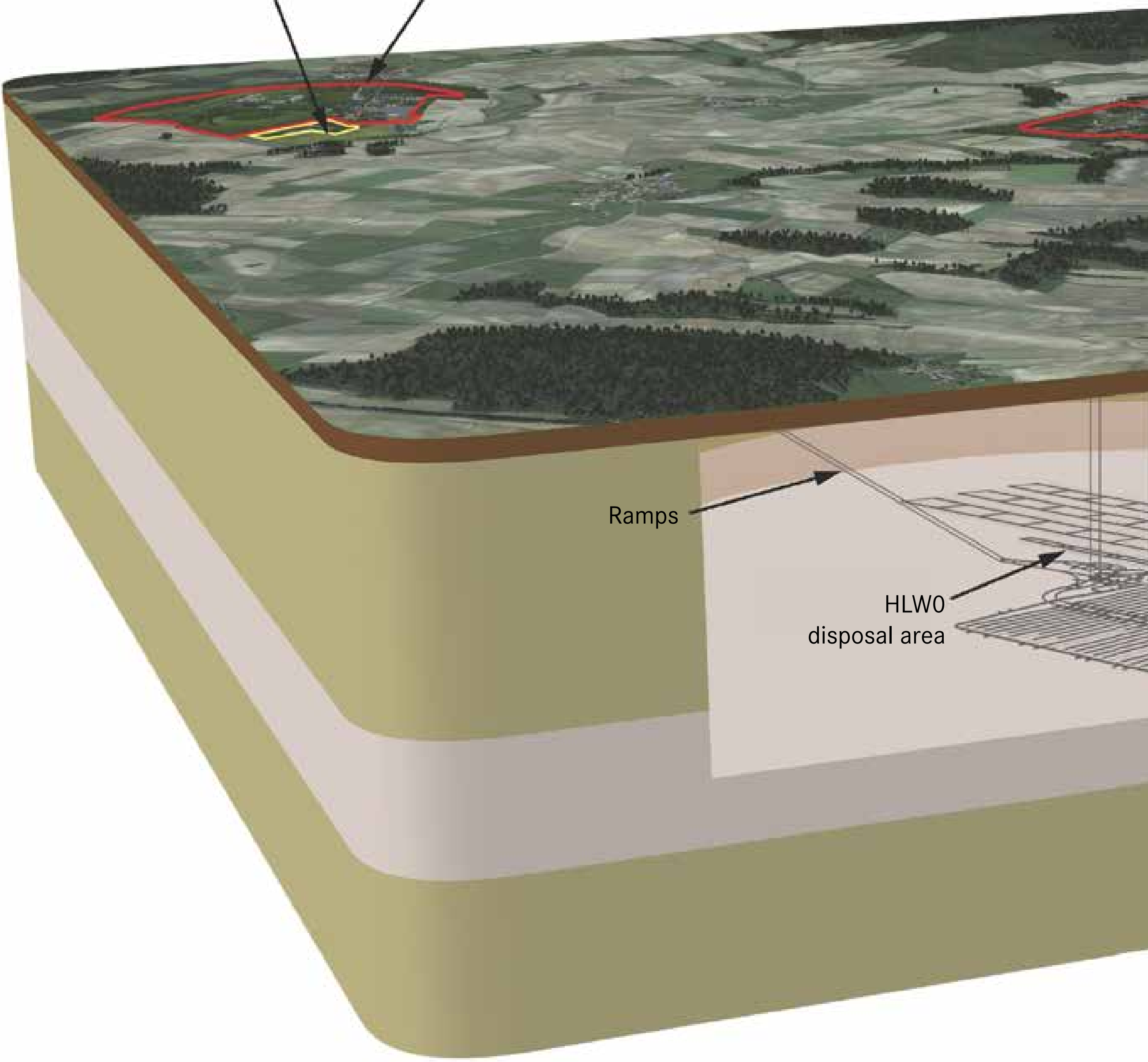
round laboratory.

[1] National Assessment Board (CNE)
[2] French Nuclear Safety Authority (ASN)
[3] Parliamentary Office for the Evaluation of Scientific and Technological Choices

3D block diagra



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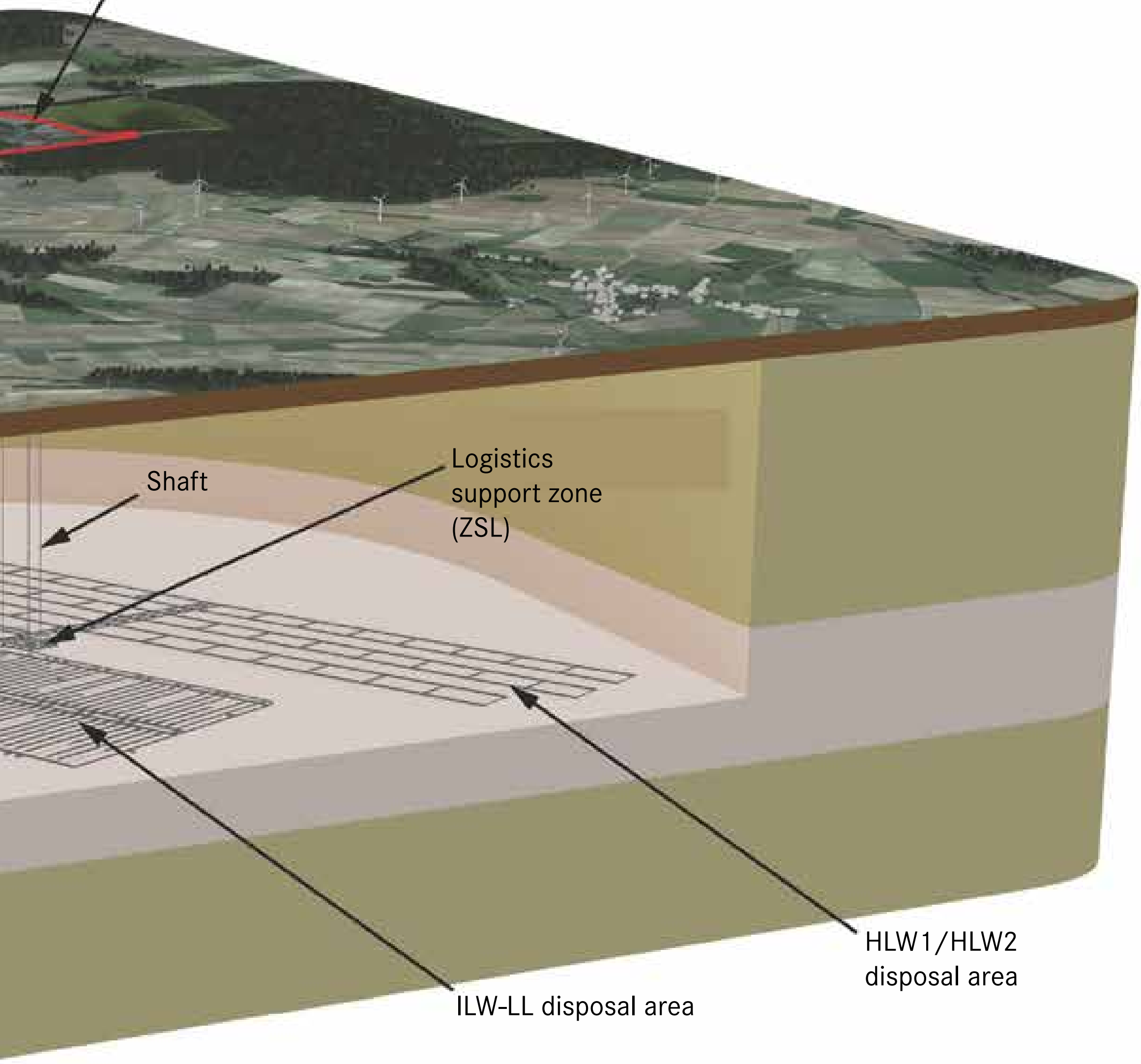

Structures not to scale.
Strike and dip of geological formations not shown.

www.cigéo.com

The reference website for information
on the Cigeo geological repository project
for French radioactive waste

FRENCH NATIONAL RADIOACTIVE WASTE MANAGEMENT AGENCY

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92298 Châtenay-Malabry cedex - France

www.andra.fr

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