Cigeo, The French Geological Disposal Facility Project: Preliminary Design (APS) Phase

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ABSTRACT

The Cigeo project has been in the works for 25 years. Numerous studies have been conducted, increasingly associated with the Meuse/Haute-Marne site, with further specific research thanks to direct access to the Callovo-Oxfordian clay formation from the underground laboratory of Bure-Saudron. These studies and research initially aimed to demonstrate the feasibility of the repository. They also helped gain a high level of understanding of phenomena to support design studies and demonstrate safety. Transition to the industrial phase began with the development of a plan for delivering waste to the facility for disposal. The plan introduced sequencing for the various types of waste to be disposed of, and was optimised to determine the size of inspection, transfer and handling facilities. In describing the life of the repository and therefore the vision for its operation, it has become obvious that our generation should not impose choices on future generations. We must provide them with reference technical solutions, with the financial resources to implement them. It is also our duty to begin the construction and initial operating phases. However, because the facility will operate over several generations, we must leave a degree of flexibility so that they may reassess the options that we define and adopt their own solutions, as necessary. They will also benefit from operational experience gathered as facility operations develop. This is the context in which the preliminary design phase is being finalised in preparation for the detailed design phase, with the aim of gradual commissioning during the latter part of the next decade.

INTRODUCTION

Since the Act of December 1991 [1] concerning research into the management of radioactive waste, Andra has been conducting the programme for geological disposal in compliance with the objectives set forth. The initial 15-year phase was mainly dedicated to research, including research into alternatives to geological disposal. Following the various bids for the creation of an underground laboratory, in 1998 the French Government selected the Bure-Saudron facility in the Meuse and Haute-Marne departments of north-eastern France. In 2005, Andra compiled the results and analysed them in the Dossier 2005 Argile report [2]. The main finding of Dossier 2005 was that geological disposal is feasible in the clay formation studied (Callovo-Oxfordian clay) and that its safety could be proven. Based on the various results, French Parliament passed the Planning Act [3] in 2006, establishing geological disposal as the reference solution for managing high-level waste (HLW) and intermediate-level long-lived waste (ILW-LL). The facilities should be planned in a formation previously studied using an underground laboratory, which indicates the Callovo-Oxfordian near Bure-

Saudron. More detailed investigations therefore focused on this region and in 2009, Andra proposed the location for underground facilities. Upon completion of a series of assessments and opinions, the French Government validated the location for the underground repository in March 2010. This began the industrialisation process for the Cigeo project, followed by a public debate in 2013, which became useful for later deliberations. When the preliminary design phase was completed and before beginning the detailed design phase, the life and operation of the disposal facility were reviewed using updated information to bring a new perspective to the industrial project. Due to changes to regulatory requirements in France, Cigeo's detailed design must be used for the repository construction license application. The construction license application will therefore be submitted progressively between late 2015 and early 2018 in agreement with safety authorities.

DEVELOPMENT OF THE CIGEO PROJECT

Preliminary discussions on the geological disposal project began in 1996, as soon as the construction license application for the Bure-Saudron underground laboratory was submitted. The goal was to propose an initial vision of the disposal concept in order to verify that the site could be adapted for potential future disposal of all HLW and ILW-LL produced by the French nuclear power plant fleet throughout its entire operation.

The decision to build the underground laboratory was therefore made based on the apparent suitability of the geological formation for waste disposal. Using this initial repository concept, Andra teams continued their efforts to define the main options and identify necessary developments. Among the major decisions made, positioning the repository in the middle of the 130 m thick clay formation offered a viable compromise, with regard to both the rock's mechanical characteristics in terms of construction feasibility and long-term safety. A buffer of more than 50 m above and below provides good containment of radionuclides. Initial architectures preventing water circulation risks were considered, with relatively simple disposal concepts.

Finally, co-disposal of different types of waste, particularly with different physical and chemical properties, is feasible, without any risk of interference between disposal compartments.

Based on this initial research, Andra proposed an initial project in 2001, which was followed by a detailed safety assessment. This was submitted for international review and created the basis for Dossier 2005. The demonstration provided was supported by an understanding of the phenomena affecting the behaviour of the repository gained from a sustained research effort. The repository was no longer viewed as a single object placed in the geological environment, but rather as a group of structures and components developing over time and subject to relatively complex physical-chemical and sometimes combined phenomena. The approach, now called Phenomenological Analysis of

Repository Situations, has demonstrated an unparalleled ability to describe repository operation [4]. Figure 1 shows an example of the sequencing of phenomena as identified within a high-level vitrified waste disposal cell.

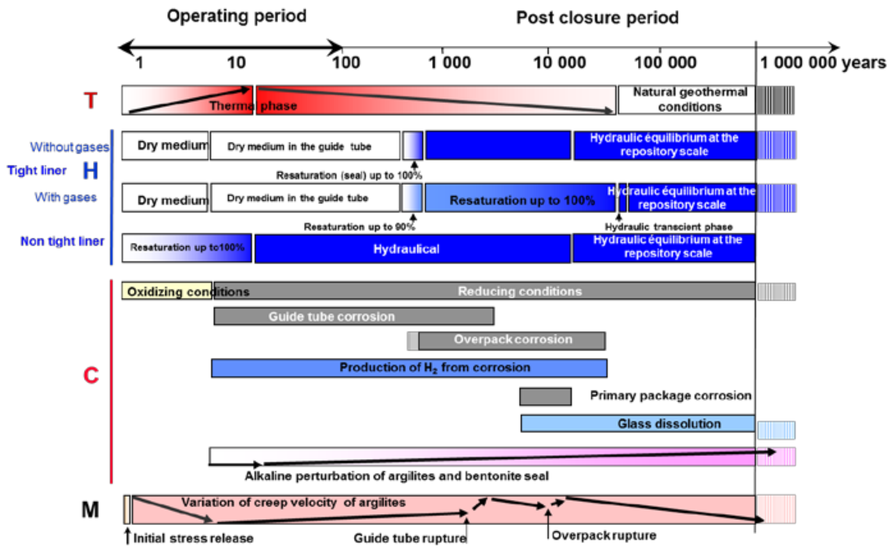

Figure 1: Summary of phenomena analysed during the life of a high-level vitrified waste disposal cell.

Based on this analysis, new developments and improvements to the characteristics of the structures and components were made. An overall architecture was developed as a working basis to begin the initial industrial development phases. Once the location of the future repository was known, more detailed drawings were produced, thus validating the overall architecture comprising:

- Surface nuclear facilities used for receiving, inspecting and conditioning waste, then transferring packages underground via a funicular;
- An approximately 4.2 km long ramp to transfer surface waste packages underground;
- A surface mining facility, including access shafts to underground facilities;
- An underground facility with a disposal area for ILW-LL, and a disposal area for high-level vitrified waste.

In 2010, this overview of the main options was confirmed. Based on these main options, the industrial phase began, particularly with the preparation of the preliminary design. A first draft was submitted for public debate in 2013 [5]. It was used as the basis for later discussions with local and regional representatives concerning the location of surface facilities. After public debate, the location was decided on and is shown in Figure 2.

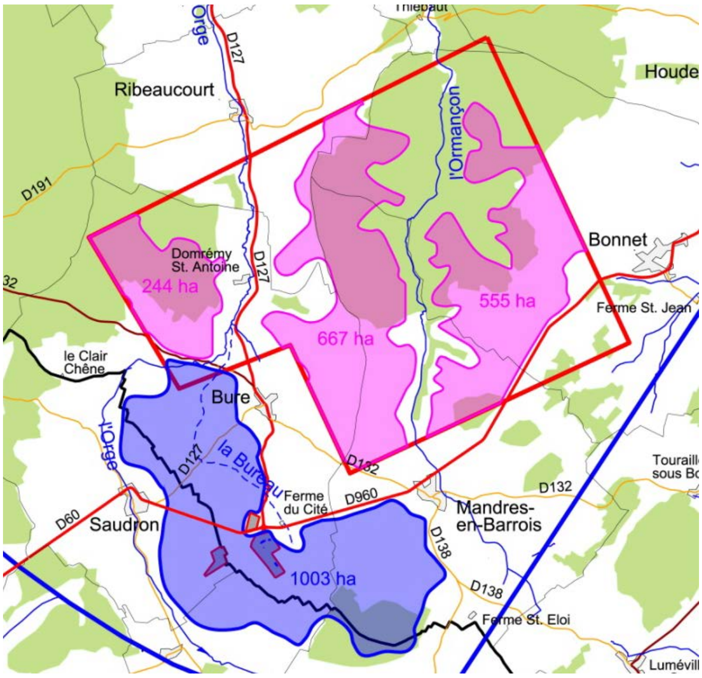

Figure 2: location of the underground repository (red boundary) and areas planned for surface facilities (shown in pink, directly above underground facilities, in blue for nuclear facilities)

Several possible zones were identified directly below surface facilities for mining activities. Local representatives preferred wooded areas in order to avoid encroaching on farmland. For nuclear facilities, the planned sector is located directly next to the underground laboratory, straddling the border between the Meuse and Haute-Marne departments.

LAUNCH OF THE INDUSTRIAL PHASE

The technical feasibility of the geological repository relied on simple, robust technical concepts. Studies and research conducted since have explored avenues for optimisation and provided more specific details for the basic options in order to develop a preliminary design for a disposal facility.

The design studies and in-depth reconnaissance work conducted in 2010-2011 led to a more detailed technical description of the facilities. The Cigeo project was presented for public debate in 2013, particularly to examine potential scenarios for interim storage, transport, and disposal and for the location of the facilities. Andra drew conclusions from the public debate and improved its vision from the recommendations that were received [6].

The Cigeo geological repository must be able to hold a wide variety of waste packages, particularly those generated from decades of research and development of industrial processes. Packages will include cemented intermediate-level waste, bituminised waste, and packages in various forms with different characteristics. To simplify operations, the various packages were divided into types for which disposal packages had to be developed. System standardisation has been implemented via use of disposal containers, as shown in the example in Figure 3.

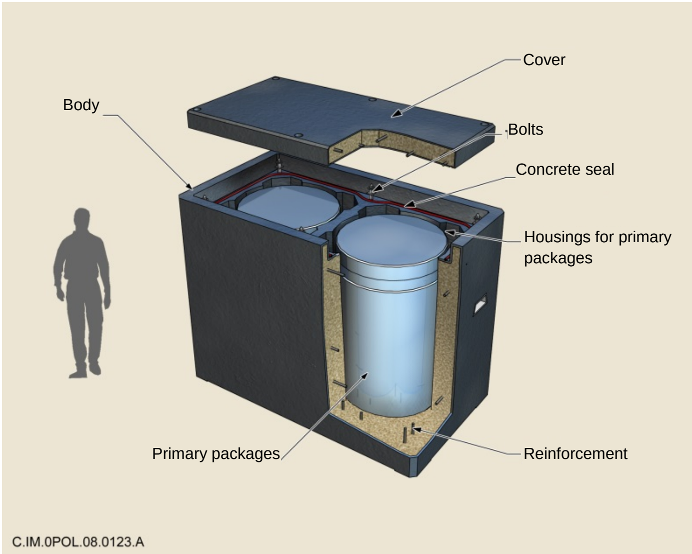

Figure 3: example of a disposal package for ILW-LL

However most of the radioactivity is generated from spent fuel processing. The process separates plutonium and uranium with the aim to recycle them into MOX fuel. Residues from processing and all materials that cannot be recycled in current economic conditions are considered as waste. This includes vitrified residues, characterised by their minor actinide and fission product content, and the metal components of spent fuel. All these residues are conditioned in standard stainless steel containers. Vitrified waste is cast in packages called CSD-V, and metal parts are compacted in CSD-C packages. Figure 4 shows an illustration of these standard packages. For disposal purposes, the primary package for vitrified waste will be installed in an overpack. Besides acting as a radiation shield, the overpack must also be corrosion-resistant during the waste's thermal phase in disposal conditions, i.e. several centuries. CSD-C packages are less exothermal than glass packages and are grouped in disposal packages similar to those in Figure 3.

The inventory of waste to be disposed of in Cigeo includes 10,000 m^3 of vitrified high-level waste and 70,000 m^3 of ILW-LL. The repository is therefore designed to be large enough to hold this inventory, and operating facilities must be capable of handling the waste and emplacing it in the repository.

The repository architecture groups together the disposal cells for different waste categories within specific repository zones. ILW-LL and HLW repository zones will therefore be physically separated from one another. This will ensure phenomenological independence between each zone over the long term. Disposal zones will be built gradually in successive phases, as new packages are received. They will therefore be designed in modules.

During the operation of the repository, surface facilities will manage waste packages before they are transferred to underground disposal facilities. They will also support underground operations. These facilities are designed to be decommissioned when the closure decision is made.

Disposal of high-level waste (HLW)

The HLW disposal cells were designed on the basis of the search for a physical and chemical environment suited to the packages and the thermal design associated with heat dissipation via conduction in the rock, which helps limit the thermal load per unit surface area, in both the cell and for the entire disposal facility.

The HLW disposal cells are dead-end horizontal boreholes or micro-tunnels with an excavated diameter of approximately 0.7 meters. Their length is currently fixed at 100 meters, for which the technical feasibility has been demonstrated via tests, some of which took place in the Bure-Saudron underground laboratory. They have a metal sleeve covering, which supports the argillite, allowing for package handling, both for emplacement and possible retrieval, and in the longer term, protects the disposal container from any mechanical loading by the argillite. During an initial “reversibility” period, the sleeve limits corrosion possibilities and facilitates the possible retrieval of disposal packages. The fundamental concept is illustrated in Figure 4.

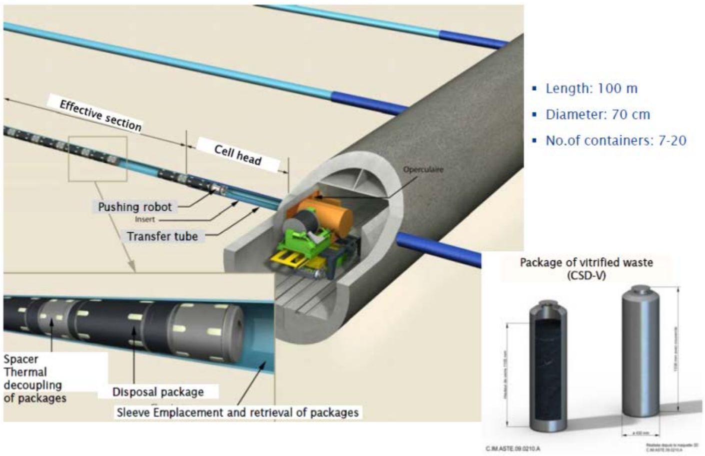

Figure 4: CSD-V vitrified waste packages (right) placed in their disposal overpack (left) for disposal in the horizontal cells off the drifts.

The disposal packages are lowered into the underground facilities and transferred to the cells using a retrievable “cask” to shield against external exposure in order to keep all drifts accessible to operators. Each package is extracted from the cask at the entrance of the cell and then pushed into its disposal position. Packages can be retrieved by reversing this process.

For highly exothermic HLW, the disposal design is adapted to take into account the thermal output of waste during disposal via the spacing of packages inside a cell and the spacing of cells. Waste radioactivity must have sufficiently decayed in order to comply with disposal temperature criteria. It is therefore impossible to dispose of highly exothermic HLW prior to around fifty years of interim storage for cooling.

In addition to this period of radioactive decay and storage, the footprint and excavated volume needed for package disposal diminish in line with the age of the package when stored, with a particularly notable decline over approximately a further two decades. The thermal design therefore supposes approximately 70 years of cooling for the most exothermic packages. The direct consequence of this thermal requirement is that high-level waste disposal sections will only be built and operated after this period. Disposal cells will therefore be built gradually to receive waste as it arrives, across a significant time period consistent with the reactor fleet operating life.

Disposal of intermediate-level long-lived waste (ILW-LL)

The ILW-LL disposal cells are horizontal tunnels, limited to a few hundred meters in length. The excavated diameter of cells is primarily the result of geotechnical analysis and the search for compactness. The concrete drift lining ensures the mechanical stability of the facility. A concrete lining was primarily chosen for its mechanical qualities and durability, which promotes reversibility. Its physical and chemical properties also contribute to the repository's long-term safety functions. Its internal cross-section is rectangular and forms the chamber in which the disposal packages are stacked. The spaces between disposal packages are minimised in order to facilitate closure operations. The automatic handling chamber is illustrated in Figure 5, with packages stacked in the disposal drift.

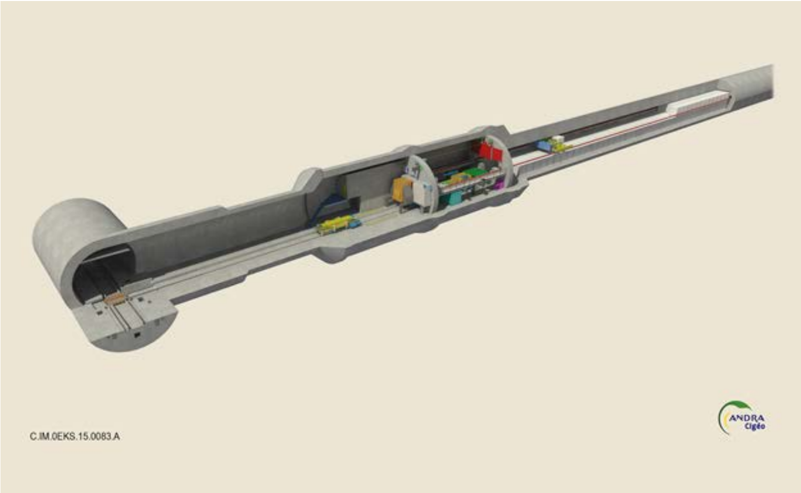

Figure 5: method for emplacing intermediate-level long-lived packages in the disposal cell

A cell remains ventilated until it is closed. One aim is to evacuate the radiolysis hydrogen generated by some types of waste. Furthermore, ventilation maintains low humidity in the cell to promote the durability of the containers and lining.

Usually, a single cell will house only one waste package geometry. In addition, packages containing significant quantities of organic matter (e.g. bitumen, plastic) will not be disposed of in the same cells as packages without organic matter. Similarly, each cell can only receive a limited number of package types or a single package type.

As for HLW, ILW-LL cells are built one after the other.

Provisional disposal forecasts

In order to move away from a vision of a static facility to operation over approximately 120 years, it is useful to check the waste package delivery forecasts for geological disposal. These forecasts are also used to check the availability of interim storage facilities prior to geological disposal. Finally, they can be optimised, in order to avoid oversized equipment in the acceptance, inspection and conditioning of facilities for disposal.

The configuration of Cigeo enables package disposal operations to be carried out in parallel with the construction of new disposal modules in the long term. This simultaneous activity is managed by the physical separation of the two types of activity, with the nuclear operating area gradually extended as work advances. In this way, packages can be continuously disposed of over time.

Deliveries of the various types of waste packages are sequenced for the disposal of ILW-LL packages during the first 50-year phase, before a priority for high-level waste from 2080. This scenario is consistent with the industrial design of the necessary facilities and the existing or planned capacity for interim storage.

Using conceptual models for disposal and this initial delivery sequence, Andra moved away from a static vision of disposal to a dynamic vision that seeks to determine the entire lifecycle of facilities, from current design studies to decommissioning. This information supported initial design of the facility, particularly for surface operations, and package transfer and installation equipment.

CIGEO LIFECYCLE PHASES AND GOVERNANCE

The main, successive phases of the Cigeo project are as follows:

1. facility "design", including the technical specification of the facility structures, buildings and procedures. This phase ends with the completion of detailed design and the construction license application;

Subject to authorisation by decree (construction license):

2. “initial construction” of Cigeo when the first part 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;
3. following issue of the operating license for Cigeo, “operation” by successive phases over around one hundred years with package acceptance and disposal carried out in parallel to underground facility extension work, in order to continue acceptance of packages in the inventory. Partial closure work (moving to Stages 3 and 4 on the International Retrievability Scale) is also carried out in addition to construction, adaptation and regeneration work on surface buildings;
4. the “pilot industrial phase” planned for the launch of Cigeo operation before the switch to normal operation. This pilot industrial phase will include tests designed to demonstrate the ability to remove waste packages disposed of in Cigeo under real conditions;
5. after operation has finished, the decommissioning and final closure of Cigeo, which can only be authorised by the passing of an Act of Parliament. Cigeo then enters its “monitoring phase”.

These phases are illustrated in Figure 7.

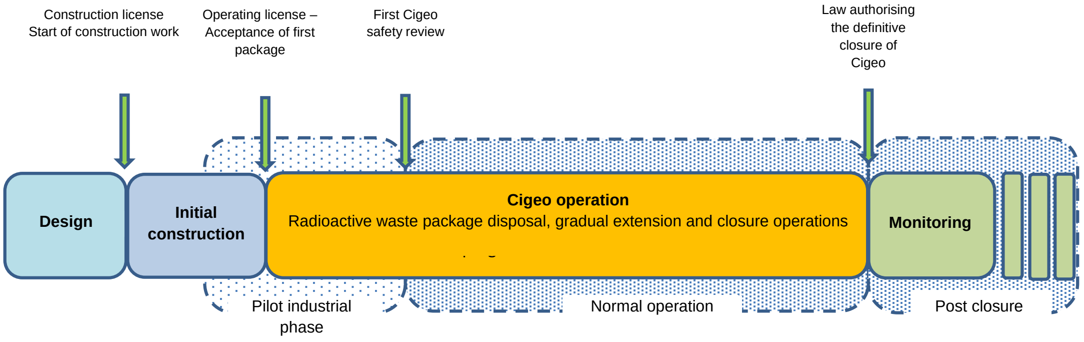

Figure 7: sequence of successive phases in the Cigeo lifecycle

Construction and operation will be gradually developed in line with the forecasts for waste package delivery. Figure 8 shows possible structure developments during operation.

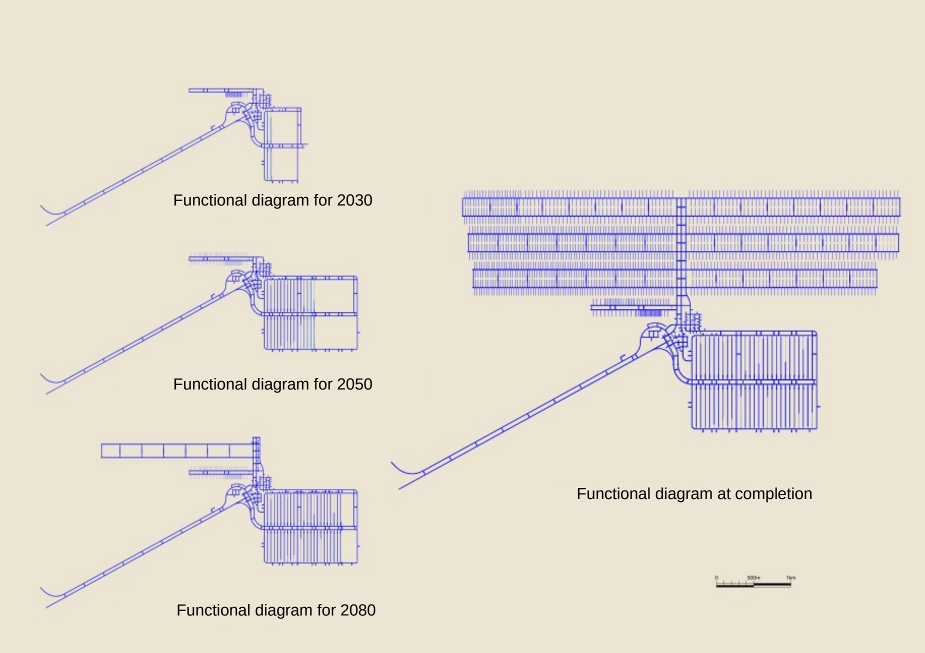

Figure 8: development of Cigeo underground facilities over time

Studies carried out over the past 20 years, with regular assessment by the French National Assessment Board (CNE), the French Nuclear Safety Authority (ASN) and Andra's Scientific Council, have demonstrated the safety and feasibility of reversible deep geological disposal.

To ensure availability of the industrial disposal facility, the Cigeo project must now test containers, operating equipment, seals and other components in conditions closer to those of construction and planned operation at facility commissioning. Laboratory tests on models as representative as possible of the final design will initially enable progress to be made on systems design and support the construction license application. For the following stages, given the size of the equipment used and the structures to produce for Cigeo (containers weighing several metric tons, the use of a funicular, drift and disposal structures with a cross-section measuring tens of meters, etc.), qualification of Cigeo's procedures and validation of equipment performance cannot be performed in the underground laboratory. The next stages in Cigeo development can therefore only be carried out during the pilot industrial phase, resulting, in the long term, in a tried-and-tested disposal facility, which has proven its capacity to receive radioactive waste packages while meeting safety and reversibility requirements. Its operation will then be considered normal operation, which includes the acceptance, preparation and disposal of waste packages, and also the construction of the next disposal units.

Gradual development

Pursuing the process of creating a deep geological disposal facility is an ethical obligation for our generation as important as ensuring that coming generations are able 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. The technology and financial resources required to carry out the first stages of Cigeo development are now available. Nuclear power plants are still in operation and will continue to support the funding of future investment phases in the medium term.

By gradually implementing Cigeo, it is possible both to prepare for disposal of the HLW that produces the most heat and to avoid any time gaps in waste management throughout the Cigeo operation period. It should be noted that the very first vitrified waste packages produced in the 1970s will be sent for initial highly instrumented disposal, in order to prepare for the highly exothermic vitrified waste packages from 2080.

Studies carried out over the years have come to the conclusion that disposal is the optimum technical solution and the challenge is now to develop a credible industrial project, which is currently in the design phase in the Meuse/Haute-Marne region. 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 progress would risk limiting choices for our generation and the ones to come.

Reversibility and tools

The ethical concern for reversibility comes from the time scale required for managing the most harmful radioactive waste. Particularly given the planned duration of approximately 120 years for the geological disposal facility operation, it is our generation's responsibility to design and provide future generations with a safe facility that they will be able to modify or improve in accordance with their own objectives and requirements, or even replace by other management facilities if other choices become available, particularly due to technical advances. The reversibility of disposal is considered to be the ability to leave the next generation choices concerning the long-term management of radioactive waste, including the choice of reconsidering the decisions made by the previous generation.

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

- Governance tools: continuous improvement of understanding of radioactive waste management, transparency and passing down of information and knowledge, the involvement of society and checks by the government and assessment bodies.
- Project management tools: incremental development and gradual approach to the construction of Cigeo facilities, flexible operation, adaptability of facilities and retrievability of packages.

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

With this new understanding of operation, retrievability is simply a technical possibility given to the following generations so that they can implement their own options. To this end, our responsibility is to provide facilities that are designed from the offset to be able to reconsider our choices at a later time if required. As well as passing down high-quality options, we are offering the necessary funds for their implementation. However, future generations will have to bear the cost of any changes in direction.

The Cigeo project's preliminary design phase is therefore completed on the basis of a gradual approach to construction, operation and closure. An assessment based on suitable reviews will be produced, primarily in order to substantiate and stabilise the input data for the detailed design phase. The various detailed design studies, particularly for safety, will be finalised on this basis for the Cigeo construction license application, which is set be submitted to the French Nuclear Safety Authority in 2018. Providing that regular information is produced, the examination could be relatively quick. We believe that it could take approximately 3 years, with work carried out for the commissioning phase by 2025.

CONCLUSION

The vision of the Cigeo project has long remained fairly static. Until now, it has been about creating an overview with the aim of carrying out phenomenological studies and many safety analyses in the long term. These steps have been completed, in particular between the promulgation of French Acts of 1991 and 2010. As the industrial phase approaches, the vision is becoming increasingly dynamic, incorporating designers in the disposal lifecycle. Disposal operation will be carried out very gradually, starting in the late 2020s.

REFERENCES

[1] French law 91-1381 of 30 December 1991 relating to research on the management of radioactive waste

[2] *Dossier 2005 Argile:* Evaluation of the Feasibility of a Geological Repository in an Argillaceous Formation, http://www.andra.fr/interne.php3?id_rubrique=161

[3] Consolidated version of Planning Act No. 2006-739 Concerning the Sustainable Management of Radioactive Materials and Waste, http://www.andra.fr/download/andra-international-en/document/editions/305va.pdf

[4] The phenomenological analysis of repository situations (PARS) – Application within the dossier 2005 argile (Meuse/Haute-Marne site), F. Plas, P. Landais, in Safety Cases for Deep Geological Disposal of Radioactive Waste: Where Do We Stand? Symposium Proceedings, Paris, France 23-25 January 2007, OECD Nuclear Energy Agency (NEA), ISBN 978-92-64-99050-0

[5] The Cigeo project Meuse/Haute-Marne reversible geological disposal facility for radioactive waste, Project Owner File, Public debate of 15 May to 15 October 2013, http://www.andra.fr/download/andra-international-en/document/editions/504va.pdf

[6] Press pack – 6 May 2014, Follow-up of the Cigeo project by Andra after public debate, http://www.andra.fr/international/download/andra-international-en/document/news/andra-mai-2014-v13_en-der_web.pdf

[7] Reversibility of Decisions and Retrievability of Radioactive Waste, Considerations for National Radioactive Waste programmes, 2012 OECD Nuclear Energy Agency (NEA) https://www.oecd-nea.org/rwm/reports/2012/7085-reversibilite.pdf