Abstract. The Cigeo project has been in the works for 25 years. Numerous studies have been conducted, 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 more than 5 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 was finalised in preparation for the detailed design phase, with the aim of gradual commissioning during the latter part of the next decade.

1. Introduction

Since the Act of December 1991 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. 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 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 mid 2018 in agreement with safety authorities.

1. Development of Cigeo Project

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.

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 design phase began, particularly with the preparation of the preliminary design. A first draft was submitted for public debate in 2013. 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.

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.

3. Launch of the design 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 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 standardization has been implemented via use of disposal containers.
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.

4. Cigeo lifecycle phase 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;

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”.

Construction and operation will be gradually developed in line with the forecasts for waste package delivery.

5. 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.

6. **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.

7. **Conclusion**

The vision of the Cigeo project had long remained fairly static. It had 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, in the frame of pilot industrial phase starting by trials in the mid-2020s and a completion of commissioning in the mid-2030s.