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

ANDRA
La maîtrise des déchets radioactifs

EDITORIAL

Marie-Claude Dupuis
Chief Executive Officer of Andra

François-Michel GONNOT
Chairman of the Board of Andra

"France was one of the first countries to become aware of the need for establishing a responsible, proactive policy on the management of radioactive waste. In passing the 1991 Bataille Act on radioactive waste management, the French Parliament placed France's nuclear policy on the path to the search for long-term, safe solutions for disposing of radioactive waste and avoid saddling future generations with the radioactive waste we produce on a daily basis.

Each year, radioactive waste in France is generated primarily at the country's nuclear power plants and by its defence, industrial, healthcare and research sectors. Operational solutions already exist for the vast majority of waste. Indeed, 90% of the total volume of radioactive waste generated each year in France is disposed of at Andra's engineered facilities

However, the most highly radioactive and long-lived waste – some of which can remain hazardous for more than 100,000 years – cannot be disposed of in surface or near-surface facilities for the reason that there is no guarantee that radioactivity can be contained over such time scales.

It is for this reason that, in 2006, France's Parliament chose deep disposal as the only solution for ensuring the long-term safety of radioactive waste and lightening the burden on future generations. This choice was reinforced by a 2011 EU Council Directive. Furthermore, many countries are also conducting research on deep geological disposal, and Sweden and Finland are currently reviewing applications for licences to build underground repositories.

The 2006 Planning Act vested Andra with a task to design and build an engineered disposal facility for this waste. Several years later, enough progress has been made on the Cigeo geological disposal facility project to allow it to be presented for public debate. The feedback from this public debate will be taken into consideration when finalising the project.

The public debate organised in 2013 by the National Public Debate Commission is an essential prerequisite to Andra's filing of its licence application in 2015. This application will then be reviewed over a period of several years. During this period, the project will be considered by the National Assessment Board, the French Nuclear Safety Authority, the local authorities and Parliament. The licence will be granted only after a new act laying down the reversibility conditions of disposal is passed and a local public inquiry is held.

This public debate will allow Andra to present its proposals for satisfying the requirement set out in the Act of 2006 that disposal must be reversible for at least 100 years. The reversibility arrangements proposed by Andra do not compromise the safety of the repository and are industrially realistic. They will make it possible to reconsider decisions, if Andra is asked to do so by civil society, reschedule the progressive closure of the repository and retrieve the packages if necessary.

This debate will also be a key forum of discussion with citizens in the Meuse and Haute-Marne departments and elsewhere in France. During this public debate we hope to answer all the citizens' legitimate questions about the proposed facility, and convince them that it is the best solution for assuming the responsibility incumbent on French society to make a permanently safe final disposal facility for radioactive waste, providing communities are willing to host it.

The Cigeo project proposed by Andra for public debate today was brought about by a dedicated team of men and women whose unfailing efforts and keen sense of responsibility have helped, in their individual fields of expertise, to develop the safest solutions for present and future generations, in line with the precautionary principle."

Marie-Claude DUPUIS

François-Michel GONNOT

GENERAL OVERVIEW OF ANDRA

Andra, the French National Radioactive Waste Management Agency, is charged with finding and implementing safe solutions for the management of all types of radioactive waste in France in order to protect current and future generations from the hazards posed by such waste. Independent of radioactive waste producers, Andra is under the supervision of France's ministers for energy, research and the environment respectively.

Andra's role was defined by two successive acts of French legislation. The first, the 1991 Bataille Act, created Andra as an industrial and commercial public body and entrusted it with the task of conducting research on deep geological disposal of high-level long-lived radioactive waste. The second, the Planning Act of 28 June 2006 on sustainable management of radioactive materials and waste, defined its scope of action and entrusted it with the following tasks:

- DESIGN, SCIENTIFIC RESEARCH AND TECHNOLOGICAL DEVELOPMENT:
  - Design and implement sustainable solutions for the management of high-level waste (HLW), intermediate-level long-lived waste (ILW-LL) and low-level long-lived waste (LLW-LL) placed in temporary storage.

- INDUSTRIAL ACTIVITIES:
  - Handle radioactive waste produced by the nuclear sector, the non-nuclear power industry, national defence operations, research and the healthcare sector;
  - Operate and monitor radioactive waste disposal facilities so as to protect people and the environment.

- PUBLIC SERVICE AND INFORMATION:
  - Retrieve radioactive objects from private individuals and local authorities;
  - Clean up and remediate sites contaminated by radioactivity;
  - Draw up and publish, once every three years, a national inventory of radioactive materials and waste in France;
  - Provide clear and verifiable information on the management of radioactive waste;
  - Promote meetings and dialogue with all stakeholders.

- PROMOTION OF EXPERTISE IN FRANCE AND ABROAD:
  - Develop scientific collaboration throughout France and the world;
  - Promote Andra's entire range of services throughout France and the world;
  - Disseminate scientific and technical culture as widely as possible.

KEY FIGURES (as at 31/12/2012)

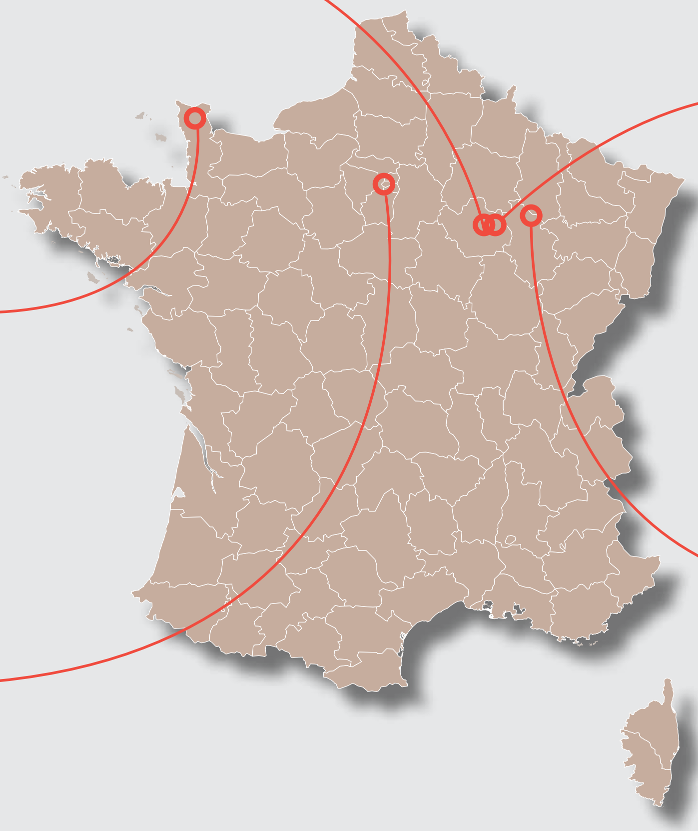
570 employees

4 sites:

- **Three waste disposal facilities:**
  2 in northeastern France:
  Cires and CSA,
  1 in northwestern France (CSM)
- **A Meuse/Haute-Marne site (CMHM) consisting of:**
  - an Underground Research Laboratory
  - a Technological Exhibition Facility
  - a Perennial Observatory of the Environment
  - an Écothèque (sample data bank)

CSA waste disposal facility

Industrial facility for radioactive waste grouping storage and disposal (Cires)



CSM waste disposal facility

Meuse/Haute-Marne Centre

Headquarters

Andra locations: headquarters at Châtenay-Malabry, the CSM waste disposal facility in the Manche department, the CSA waste disposal facilities in the Aube department and the Meuse/Haute-Marne Centre.

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RADIOACTIVE WASTE

1

INTRODUCTION Since its discovery more than one century ago, radioactivity is used in many applications for its properties. These same applications generate waste that requires special handling in order to protect people and the environment from their harmful effects.

Many years ago, France chose disposal in repositories as its long-term solution for managing radioactive waste. Ninety percent of the waste generated each year is disposed of in an operational facility.

However, disposal facilities are needed for certain types of other waste, particularly the high-level waste (HLW) and intermediate-level long-lived waste (ILW-LL) that is generated primarily by the nuclear power sector.

1.1.
Sources of radioactive waste

The properties of both natural and artificial radioactivity have been used in many applications for several decades.

Like any human activity, these applications produce waste, some of which is radioactive.

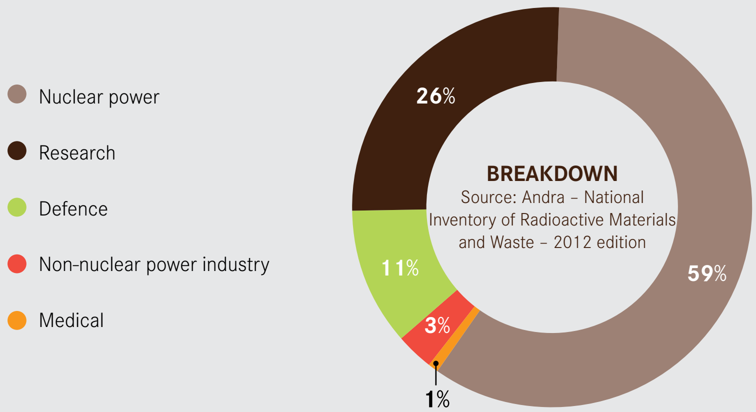
The vast majority of this waste is commonplace in appearance, ranging from tools and clothing to scrap metal, plastic, rubble and more. However, the radioactivity of this waste can be hazardous to people and the environment.

Radioactivity is used primarily in the following **five industries:**

- **NUCLEAR POWER PRODUCTION:** nuclear power plants and fuel fabrication and reprocessing facilities (activities such as uranium ore mining and processing, fuel fabrication and spent fuel reprocessing).
- **NATIONAL DEFENCE:** activities associated with nuclear deterrence and nuclear propulsion of various ships and submarines, along with the associated research.
- **CONVENTIONAL INDUSTRY:** rare-earth mining, fabrication of radioactive sources and other various applications (such as weld inspection, medical equipment sterilisation and food sterilisation and preservation).
- **RESEARCH:** primarily nuclear research conducted by the CEA and, to a lesser extent, in fields such as particle physics, agricultural economics, chemistry and biology.
- **MEDICINE:** medical research, diagnosis and treatment.

Altogether, these many uses produce the equivalent of **2 kg** of radioactive waste per inhabitant per year in France.

GENERATION OF RADIOACTIVE WASTE BY ECONOMIC SECTOR



The Bugey nuclear power plant.

1.2.
Types of radioactive waste

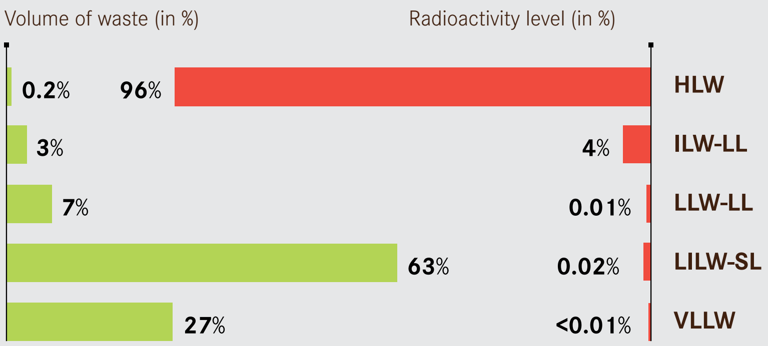
Radioactive waste refers to **radioactive substances for which no subsequent use is planned or envisaged.**

They contain radioactive atoms (radionuclides) such as caesium, uranium, iodine, cobalt, radium and tritium, to name a few. Depending on the quantity and nature of these radionuclides, this waste remains more or less radioactive for varying lengths of time.

Around 1.32 million m³ of radioactive waste had been generated in France by late 2010.

VOLUMES AND RADIOACTIVITY LEVELS OF RADIOACTIVE WASTE

(Source: Andra – National Inventory of Nuclear Materials and Radioactive Waste – 2012)



Waste metal from the structures surrounding spent fuel (hulls and end caps) that makes up ILW-LL.

CLASSIFICATION OF RADIOACTIVE WASTE

In France, radioactive waste is classified into **five categories:**

- **very-low-level waste** (VLLW);
- **low- and intermediate-level short-lived waste** (LILW-SL);
- **low-level long-lived waste** (LLW-LL);
- **intermediate-level long-lived waste** (ILW-LL);
- **high-level waste** (HLW).

This classification is based on many criteria, notably:

- **the radioactivity level of waste,** expressed in becquerels (Bq) per gram. This radioactivity (or just activity) can be very low, low, intermediate or high.
- **the longevity of waste**, which depends on the radioactive half-life associated with each radionuclide it contains. For simplicity, waste mainly comprising short-lived radionuclides (half-life of no more than 31 years) is referred to as short-lived waste, whereas waste containing significant quantities of long-lived radionuclides (half-life of more than 31 years) is referred to as long-lived waste.

The becquerel

The becquerel is the unit used to measure radioactivity, or the number of atom disintegrations per second. It is a very small unit. 1 Bq equals one atom disintegration per second.

Radioactive half-life

The term "half-life" refers to the amount of time it takes for half the atoms in a given radionuclide to decay. This ranges from 8 days for iodine-131, 13 years for tritium and 31 years for caesium-137, to 1,600 years for radium-226 and 5,700 years for carbon-14. For example, a 1-gram sample of caesium-137 would dwindle to just 0.5 grams after 31 years. The sample would therefore be half as radioactive. At the end of 10 half-lives (310 years), it would be 1,000 times less radioactive (only 1 milligram would remain).

1.3.
Management of radioactive waste

French law forbids the disposal of foreign radioactive waste in France. As a result, no foreign waste will be disposed of at Cigeo. The HLW and ILW-LL to be disposed of there are generated mainly at France's nuclear power facilities and nuclear fuel reprocessing facilities.

France's national policy on the management of radioactive waste was **defined by the French Parliament.** Its objectives are to reduce the volumes of waste generated, either at the source or through processing, develop safe and sustainable conditioning solutions and search for long-term management solutions.

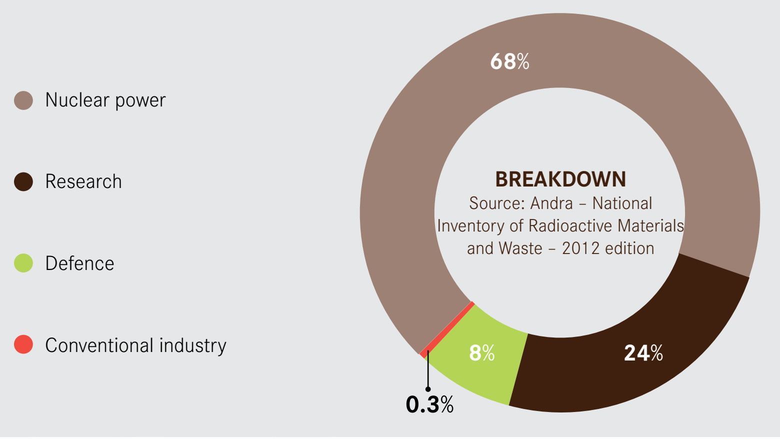
Like many other countries, France has chosen to set up a long-term solution for managing radioactive waste. This solution is based on **disposal to isolate waste while it is hazardous** so that its radioactivity in contact with humans and the environment does not represent a health hazard.

A waste management strategy of the 1950s and 1960s consisted in making use of the capacity of the oceans to dilute radionuclides and disposing of radioactive waste in the sea. The first radioactive waste disposal facility in France was commissioned in the northwest of the country in 1969. The facility was closed in 1994 and Andra now monitors it. **More than 90% of the volume of radioactive waste generated each year in France is disposed of at Andra's two disposal facilities in northeastern France.** This waste is very-low-level or short-lived.

To round out this industrial system, **Andra is tasked with studying the design of disposal facilities for high-level or long-lived waste.** In the meantime, this waste is temporarily stored in special facilities.

1.4.
Waste to be disposed of at Cigeo

SOURCES OF ILW-LL ALREADY GENERATED



Cigeo is designed to house **waste with radioactivity levels and half-lives that prevent their safe, long-term disposal in surface facilities or in the near-surface disposal facility also studied by Andra.**

High-level waste (HLW) and **intermediate-level long-lived waste (ILW-LL)** is produced mainly by the nuclear power industry and its associated research activities as well as, to a lesser extent, national defence operations.

INTERMEDIATE-LEVEL LONG-LIVED WASTE (ILW-LL)

There are various types of ILW-LL:

- **Residues arising from spent nuclear fuels** (used to generate electricity or propel submarines and ships of the French Navy) and the fabrication of certain types of fuel (uranium and plutonium mixed oxide fuels, or MOX);

- **compounds apart from fuel** that have resided in nuclear reactors;
- **technological waste** resulting from maintenance of nuclear facilities, laboratories, defence-related facilities, dismantling, etc.

Several conditioning methods (vitrification, cementation, bituminisation) are used depending on the nature of the waste. Conditioning is a series of operations in which waste is solidified and immobilised in a non-dispersible form and placed in a container for easy handling and storage.

The radioactivity level of ILW-LL generally ranges anywhere between one million and one billion becquerels per gram. ILW-LL contain significant quantities of long-lived radionuclides.

Some ILW-LL emit low amounts of radioactive gases, such as tritium, carbon-14 and krypton-85. Furthermore, some contain organic matter (such as polymers and cellulose) that generate hydrogen and other gases through radiolysis.

The amount of ILW-LL generated by late 2010 represented:
- **3% of the total volume** of radioactive waste
- **approx 4% of the total radioactivity** of radioactive waste.

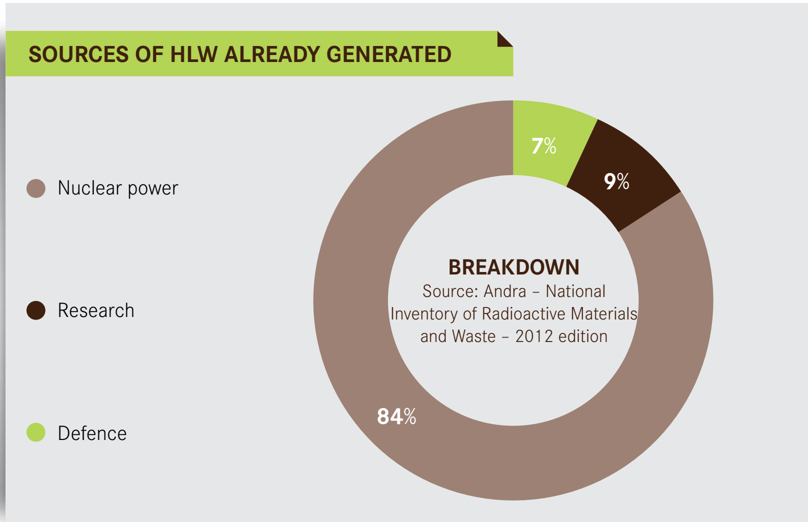
HIGH-LEVEL WASTE (HLW)

High-level waste (HLW) corresponds mainly to **highly radioactive residues arising from spent fuel reprocessing operations** (sfuels used to generate electricity and, to a very minor extent, fuels related to national defence activities).

Their radioactivity is anywhere between a few billion and several tens of billions of becquerels per gram. They contain various short- and long-lived radionuclides. Some of these are very long-lived, such as chlorine-36 (half-life of 300,000years) and iodine-129 (half-life of 16 million years). Due to the presence of certain fission products (such as strontium-90 and caesium-137) and actinides (primarily americium-241), **high-level waste generates heat**.

These high-level residues are held in tanks before being calcined to powder then incorporated into a glass melt with a lasting high containment capacity. This glass-waste matrix is then poured into a stainless steel package. An HLW package contains approximately 400 kg of glass and 70 kg of waste.

The amount of HLW generated by late 2010 represented:
- **0.2% of the total volume of** radioactive waste
- **approx 96% of the total radioactivity** of radioactive waste.



WHAT ABOUT SPENT FUELS?

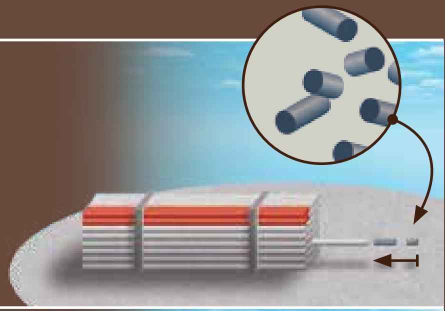
In France, spent fuels from nuclear power plants are not viewed as waste but rather as recyclable materials. As such, they are not destined for disposal. Only spent fuels from the Brennilis heavy water reactor (approx. 27 m³), which do not have a sufficient recycling potential, are destined to be disposed of in Cigeo.

NUCLEAR FUELS AND THEIR REPROCESSING

Nuclear power plants operate using fuels that are mainly composed of uranium. After several years in the reactor core, these fuels become less efficient and are removed from the reactor. France has chosen to reprocess these 'spent' fuels in order to recover the radioactive materials they contain and which can be reused.

1 FUEL FABRICATION

In its natural state, uranium contains a mixture of uranium-238 and uranium-235, which is fissile. It is enriched to increase its uranium-235 content, then formed into pellets for use as fuel.

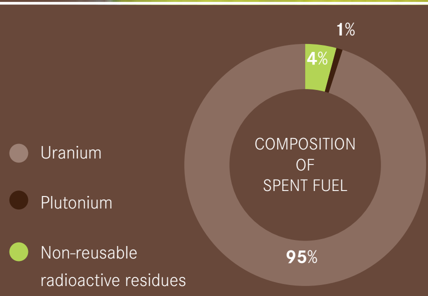


2 USE IN REACTORS

Once placed inside a reactor, nuclear fuels release energy through fission for a period of three to four years, after which they start releasing less energy. They are then removed from the reactor and stored for several months in a cooling pool near the reactor to lower their temperature.

3 SPENT FUEL REPROCESSING

Spent fuels are reprocessed at the Areva NC La Hague facility. The metal structures surrounding these fuels are sheared into small sections that are dissolved in a chemical solution in order to separate the reusable radioactive materials (uranium and plutonium) from the highly radioactive non-reusable residues.



4 RECYCLING

All the plutonium and a portion of the uranium recovered are used to make new fuels (MOX). The remaining portion of the recovered uranium is kept in storage pending future use.

After being used in EDF's power plants, MOX fuels are stored until they can be recycled in future reactors.

1.5.
Cigeo's estimated disposal capacities

THE ASSUMPTIONS USED FOR DESIGNING CIGEO

The current reference scenario for Cigeo's design assumes that nuclear power production will **continue and that existing facilities will have operating lives of 50 years.** This assumption does not prejudge whether the public authorities will decide to authorise extending the operating lives of the reactors. It takes into account waste that will be generated by nuclear facilities under construction (the Flamanville EPR, the Jules Horowitz experimental reactor, the ITER research facilities)

but excludes waste generated by a possible future reactor fleet.

The volumes of waste to be disposed of at the Cigeo geological disposal facility are estimated at:

- approx **10,000 m³ of HLW** (approx. 60,000 waste packages);
- approx. **70,000 m³ of ILW-LL** (approx. 180,000 waste packages).

These volumes correspond to the amounts of waste conditioned by their generators. The resulting waste packages will then be placed in disposal containers. Around 30,000 m³of HLW and 350,000 m³ of ILW-LL will thus be conditioned in disposal packages.

i

30%

of HLW

and **60%**

of ILW-LL

intended for disposal in the Cigeo facility has already been produced.

As a precautionary measure, **additional waste volume reserves will be set aside at Cigeo for:**

- waste **that might result from the operation and dismantling of a second EPR, which is** provided for in the multi-year investment programme for electricity production for the period 2009-2020 (approx. 200 m³ of HLW and 500 m³ of ILW-LL waste); and
- waste **that cannot be disposed of in the near-surface facility** for ILW-LL under study by Andra (reserve of approx. 20% of the volume of ILW-LL to be disposed of).

The inventory authorised for Cigeo will be determined by the decree authorising the facility's construction. Any significant changes in this inventory will have to undergo another licensing process that will include a public inquiry and another licensing decree.

Concrete package of HLW
(Height: 1.5 m, dia: 1 cm, approx. weight: 2 tonnes).

WASTE THAT HAS ALREADY BEEN, OR IS BOUND TO BE, GENERATED

The main types of waste to be disposed of at Cigeo will be **HLW and ILW-LL** that has already been generated as well as HLW and ILW-LL that is bound to be generated regardless of future energy choices. The latter group will **result from dismantling** of current nuclear facilities and **the reprocessing of spent fuels that have already been fabricated.**

THE VOLUMES PRESENTED BELOW CORRESPOND TO AN ASSESSMENT MADE BY THE END OF 2010

	Waste already generated	Waste that will arise from dismantling	Waste arising from reprocessing of the 38,200 spent fuel assemblies already fabricated	Total
HLW	approx. 2,700 m^3	0 m^3	approx. 3,000 m^3	approx. 5,700 m^3
ILW-LL	approx. 40,000 m^3	approx. 12,500 m^3	approx. 5,000 m^3	approx. 57,500 m^3

IMPACT OF THE ENERGY POLICY ON CIGEO'S INVENTORY

The nature and volume of waste that might be generated in coming years depend on the policy choices concerning the fate of France's nuclear power industry. Various intentionally contrasted scenarios are presented in the 2012 edition of Andra's *National Inventory*.

Cigeo is **designed to be flexible enough to adapt to potential changes in France's energy policy** and the consequences of such changes on the nature and volumes of the subsequent waste generated. Given the volume of existing waste to be disposed of, the impact of a change in France's energy policy would not affect Cigeo's operation until sometime around 2070.

1 / ESTIMATED CHANGES IN HLW AND ILW-LL VOLUMES IN THE EVENT NUCLEAR POWER IS MAINTAINED

This scenario envisages the continuation of both the nuclear power industry and France's current spent nuclear fuel reprocessing strategy. It is based on various assumptions, including:

- **reprocessing of all fuels used** by the 59-reactor fleet (58 PWRs in operation and the Flamanville EPR);
- **availability of a new fleet of reactors** able to consume plutonium that will not be recycled in the current fleet.

The volume of waste generated by the existing facilities in this scenario depends on the operating lives of the reactors. Waste generated by a potential future fleet of reactors is not taken into account.

Package of vitrified HLW (Height: 1.3 m, dia: 43 cm, approx. weight: 500 kg).

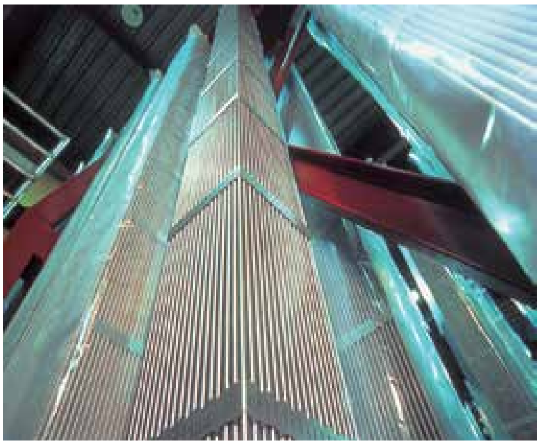
	Shutdown of existing facilities (based on the operating lives of the reactors)		
	40 years	**50 years***	**60 years**
HLW	approx. 8,000 m^3	approx. 10,000 m^3	approx. 12,000 m^3
ILW-LL	approx. 67,500 m^3	approx. 70,000 m^3	approx. 72,500 m^3

**Assumption used for designing Cigeo.*

2 / ESTIMATED CHANGES IN THE NATURE AND VOLUME OF HLW AND ILW-LL IN THE EVENT NUCLEAR POWER IS ABANDONED

Andra's *National Inventory* uses the following assumptions for this scenario:

- **40-year operating life** for all the reactors;
- **discontinuation of spent fuel reprocessing in 2019** so as to avoid recovering plutonium, which, due to the shutdown of reactors that can run on this type of fuel, could no longer be recycled as MOX;
- **direct disposal of spent fuels**, which would be treated as waste.



Fuel assemblies.

HLW**	**Spent UOX fuel***	approx. 50,000 assemblies
	Spent FNR fuel*	approx. 1,000 assemblies
	Spent MOX fuel*	approx. 6,000 assemblies
	Vitrified waste	approx. 3,500 m^3
ILW-LL		approx. 59,000 m^3

** Types of spent fuel: UOX (uranium oxide), FNR (fast neutron reactor) and MOX (mixture of uranium oxide and plutonium oxide).*
*** Once conditioned, the 57,000 spent fuel assemblies would represent a volume of around 90,000 m^3.*

IF SPENT FUELS WERE ULTIMATELY CONSIDERED AS WASTE, HOW COULD WE DISPOSE OF THEM?

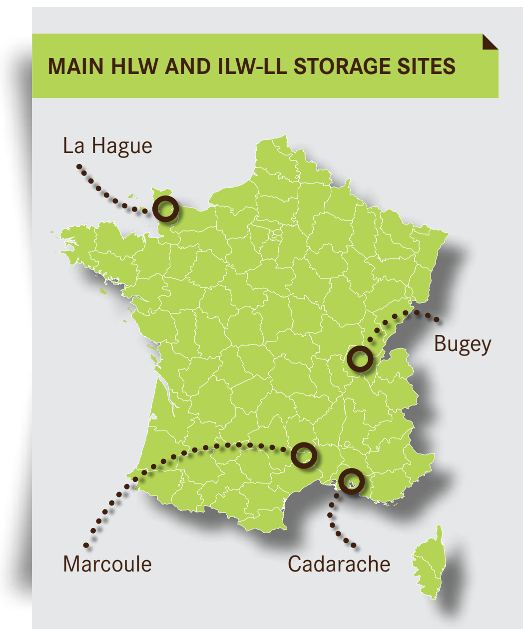
In order to take into account all the possible options, deep geological disposal of spent fuels was studied by Andra under the 1991 Bataille Act and its basic feasibility was demonstrated in 2005. Andra's study showed that its very long-term radiological impact was higher than for waste arising from the reprocessing of spent fuels but remained much lower than the impact of natural radioactivity.

Andra is continuing, particularly in relation with the CEA, to conduct studies on the direct disposal of spent fuels as required by the French National Radioactive Materials and Waste Management Plan. This plan requests that Andra verify, as a precautionary measure, whether the disposal designs selected for Cigeo are still compatible with the assumption for the direct disposal of spent fuels if they ever were to be considered as waste. Under such an assumption, disposal of spent fuels – which, like most HLW, have to cool over several decades – would not be possible until somewhere between 2070 and 2080.

In 2012 Andra proposed a programme of supplementary studies on the technical options to be implemented for their potential disposal.

1.6.

Where is HLW and ILW-LL being stored until Cigeo is commissioned?



Until Cigeo is commissioned, existing packages of HLW and ILW-LL have been temporarily placed in dry storage in buildings at the facilities where they were generated, primarily La Hague, Marcoule, Cadarache and, for a limited volume, Valduc. A storage facility for certain types of waste arising from the operation and dismantling of reactors is currently being built at the Bugey facility.

More than 40,000 m³ of HLW and ILW-LL have already been emplaced at these facilities.

If Cigeo is licensed, these waste packages will be transferred to the disposal facility over the course of its operating life. However, some waste, such as heat-generating HLW, will have to remain in storage for several decades for cooling before final disposal.

If Cigeo is not licensed, new storage capacities will be needed to house future HLW and ILW-LL and replace storage facilities that reach the end of their useful lives.

Storage hall for HLW at the Areva NC La Hague plant.

WHY DEEP GEOLOGICAL DISPOSAL?

2

INTRODUCTION The issue of radioactive waste management was raised in the 1950s with the advent of nuclear-generated electricity. Various management strategies were considered.

It was during the 1960s and 1970s that the international scientific community began looking at disposal – and particularly deep geological disposal for high-level long-lived waste – as a possible management solution.

Plans were made in the 1980s to search for potential host sites for underground research laboratories. However, discussions remained limited to technical and scientific experts and public opinion opposed the projects. France's Parliament took up the issue of radioactive waste management and, in 1991, passed its first act of legislation defining a research programme for high-level long-lived waste. After 15 years of research, assessment and public debate, Parliament passed a second act in 2006. This act designated deep geological disposal as both a long-term solution for this waste and one that would lighten the burden on future generations.


V. Un décret détermine, en tant que de besoin, les conditions et modalités d'application du présent article, notamment dans le respect des normes comptables applicables, les modalités d'évaluation des charges mentionnées au I et de calcul des provisions prévues au II, ainsi que les informations que les exploitants sont tenus de rendre publiques et les règles de publicité y afférentes.
Article 6-I de la loi n°2006-739
Article L. 542-1-2
I. Un plan national de gestion des matières et des déchets radioactifs dresse le bilan des modes de gestion existants des matières et des déchets radioactifs, recense les besoins prévisibles d'installations d'entreposage ou de stockage, précise les capacités nécessaires pour ces installations et les durées d'entreposage et, pour les déchets radioactifs qui ne font pas encore l'objet d'un mode de gestion définitif, détermine les objectifs à atteindre.
Conformément aux orientations définies aux articles 3 et 4 de la loi n°2006-739 du 28 juin 2006 de programme relative à la gestion durable des matières et des déchets radioactifs, le plan national organise la mise en œuvre des recherches et études sur la gestion des matières et des déchets radioactifs en fixant des échéances pour la mise en œuvre de nouveaux modes de gestion, la création d'installations ou la modification des installations existantes de nature à répondre aux besoins et aux objectifs définis au premier alinéa.
Il comporte, en annexe, une synthèse des réalisations et des recherches conduites dans les pays étrangers.
II. Le plan national et le décret qui en établit les prescriptions respectent les orientations suivantes :
1° La réduction de la quantité et de la nocivité des déchets radioactifs est recherchée notamment par le traitement des combustibles usés
6 Article L.1333-10 du code de la santé publique
7 Article L.1333-4 du code de la santé publique :
8 Article L. 541-45 du code de l'environnement :
« Diffusion technologique »
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es et déchets
actifs
rogramme du 28 juin 2006
solidé par l'Andra en date du 20 septembre 2011
ANDRA

2.1.
A 15-year research programme

The Bataille Act of 30 December 1991: France's first law on the management of radioactive waste.

France's Parliament actively took up the issue of the management of radioactive waste as early as 1991. **The first piece of legislation on the management of radioactive waste — known as the Bataille Act,** after its author — set the main focuses of research to be conducted on the management of high-level long-lived waste.

Three areas were selected:

1 / PARTITIONING AND TRANSMUTATION OF LONG-LIVED RADIONUCLIDES IN WASTE

The objective of this two-step technique, which was researched by the CEA, is to reduce the volume and toxicity 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.

2 / LONG-TERM STORAGE

The CEA also looked into designs of surface and near-surface storage facilities intended to last for periods of around 300 years.

3 / DEEP GEOLOGICAL DISPOSAL

Andra was tasked with identifying geological sites suitable for hosting a deep geological disposal facility and to study its safety and feasibility.

The Bataille Act set into motion a **15-year research period** to allow each of the three aforementioned areas to be supported by a scientifically and technically sound proposal **that would be submitted before the French Parliament in 2006.**

2.2.
Presentation and assessment of the research results

Andra and the CEA submitted the results of the three areas of their research to the French Government in 2005.

1 / PARTITIONING AND TRANSMUTATION

The CEA's results showed that **partitioning and transmutation do not obviate the need for deep geological disposal** for the reason that the technique would be feasible for only certain radionuclides contained in waste, i.e. those of the uranium series and 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.

2 / LONG-TERM STORAGE

The CEA concluded that although the designs of the facilities studied were particularly robust against external technical or man-made hazards, they **required surveillance and monitoring throughout their lifetime in order to guarantee the retrievability of the waste packages emplaced in them.** 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.

After analysing these results, the ASN rejected **long-term storage as a final solution** for the reasons that it required sustained monitoring by society and passed on the burden of dealing with waste to future generations, neither of which would be easy to guarantee across periods of several hundred years.

3 / DEEP GEOLOGICAL DISPOSAL

By drawing on the body of research, particularly that conducted during the geological exploration programmes in its URL, **Andra showed that the clay layer at the site studied in Meuse/Haute-Marne showed all the right characteristics for hosting a long-term deep disposal facility for radioactive waste.** These results, together with the technical guidelines for the design and operation of the future repository, were **assessed by the National Assessment Board (CNE, created by Parliament) and the Nuclear Safety Authority (ASN).** At the Government's request, Andra's work was also reviewed by an international group of experts. **These reviews confirmed Andra's results** on the feasibility and safety of building a deep geological disposal facility at the site studied in Meuse/Haute-Marne.

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

"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."

"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."

"The Dossier 2005 Argile report submitted by Andra to its supervising ministers in June 2005 has been reviewed by IRSN and is 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 geological disposal have been obtained at the Bure site. It is the view of the ASN that deep geological disposal is the only definitive solution possible."

2.3.
The public debate of 2005-2006

The results of the research carried out under the 1991 Bataille Act were also the subject of a national public debate on France's radioactive waste management policy that got under way in late 2005. Organised by the National Public Debate Commission (CNDP) at the request of France's environment and industry ministers, this debate consisted of 13 public meetings attended by 3,000 people to discuss the various management strategies studied.

The public debate ended in early 2006.

The proceedings of the public debate brought to light two options – storage and disposal – and an ethical choice – *"trust either society or geology"*. One of the options considers geological disposal as a solution, while taking into account the requirement of reversibility. The second option consisted in establishing a "two-tier *in-situ* test programme", with one tier in Bure for geological disposal and another tier on a site to be determined for long-term storage, and to postpone the decision until sometime around 2020

2.4.
Deep geological disposal ratified by the 2006 Planning Act

On the basis of the results obtained from the 15 years of research, their review by the various bodies and the 2005-2006 public debate, the French Government drafted a bill in accordance with the 1991 Bataille Act.

In passing the 2006 Planning Act, **France's Parliament ratified the choice of reversible deep geological disposal for long-term management of HLW and ILW-LL** and set deadlines for its implementation. This decision fulfilled the objective of safe long-term management of radioactive waste and **lighten the burden that future generations will have to bear.**

Andra was tasked with continuing the studies and research in order to design and site a deep geological disposal facility so that its licence application could be reviewed in 2015. The 2006 Planning Act stipulates that, subject to licensing, the facility **will be commissioned in 2025.** Parliament also requested that disposal be **reversible** for at least 100 years. The conditions of this reversibility will be defined in a future act of legislation that will have to be passed before the licence for the facility may be granted.

Another public debate will be held before the licence application is filed.

The Planning Act of 28 June 2006 on sustainable management of radioactive materials and waste:

"Storage is the operation of temporarily placing radioactive substances or waste in a surface or near-surface facility specially engineered for such purpose until they can be retrieved."

"Disposal is the operation of placing radioactive waste in a facility specially engineered for potentially permanent disposal of said waste."

"After storage, ultimate radioactive waste that, for reasons of nuclear safety and radiation protection, cannot be disposed of in a surface or near-surface facility shall be disposed of in a deep geological repository."

Regarding deep repository disposal:

"The appropriate studies and research shall be conducted for choosing a site and designing a waste disposal facility, so that once the results of the studies are available, the licence application provided for under Article L. 542-10-1 of the Environmental Code may be examined in 2015 and, subject to this licence, the facility may be commissioned in 2025."

A SPECIFIC LICENSING PROCESS

The specific review procedure for the licence application to build Cigeo is set out in the 2006 Planning Act.

The licence application that Andra will submit in 2015 will be reviewed by the National Assessment Board, the Nuclear Safety Authority (ASN), local authorities and the French Parliamentary Office for the Evaluation of Scientific and Technological Choices (OPECST) before an act of legislation laying down the reversibility conditions is passed. Once this act is passed, Andra will have to supplement its application to demonstrate that it is in compliance with the act. The assessment by the ASN will continue and a public inquiry will be held before the licensing decree may be signed. The entire process will take at least three years.

The disposal licensing decree will lay down the inventory of waste destined for disposal at Cigeo and will define the assessment milestones and hold points that will guide the facility's gradual expansion in accordance with the rationale of reversibility.

2.5.
The 2006 Planning Act: other areas of research complementary to deep geological disposal

The Planning Act also called for **continuing research on partitioning and transmutation in conjunction with research on future generations of nuclear reactors** and accelerator-driven waste-transmutation reactors. In late 2012, the CEA submitted a dossier on the technique's industrial opportunities to the French Government.

The focus of the studies and research on storage was shifted to applied studies aimed at expanding existing facilities or creating new ones. The results obtained were taken into consideration in the expansion of the HLW storage facility being built by Areva at the La Hague plant. **The Planning Act entrusted Andra with leading these storage studies and to coordinate them with those on deep geological disposal with a view to ensuring complementarity.** In late 2012, Andra conducted an assessment of the studies and research on storage (see www.debatpublic-cigeo.org, site in French).

2.6.
The situation in other countries

Countries with nuclear energy **have chosen deep geological disposal as a safe, final** solution for managing the most highly radioactive waste over the long term.

Like France, many of them are carrying out research on geological disposal, as for instance, the USA, Finland, Sweden, Canada, China, Belgium, Switzerland, the UK and Japan. The designs and host geological environments selected for repositories vary from country to country. For over a decade, the US Government has been disposing of ILW-LL arising from its defence activities 700 m below ground at the Waste Isolation Pilot Plant, or WIPP, in the state of New Mexico.

Plans to build the Yucca Mountain repository in Nevada were halted in 2010. The same year, the Blue Ribbon Commission on America's Nuclear Future was formed to conduct a comprehensive review of alternatives for managing spent fuels and high-level radioactive waste. The commission concluded that it was necessary to resume studies on the design of a deep geological repository.

In Sweden and Finland, licence applications to build repositories in granite formations are currently being reviewed.

The International Atomic Energy Agency (IAEA) has stated that *"The safety of geological disposal is widely accepted among 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 of 19 July 2011 Establishing a Community Framework for the Responsible and Safe Management of Spent Fuel and Radioactive Waste states that "geological disposal represents the safest and most sustainable option as the end point of the management of high-level waste."

THE PRINCIPLE OF DEEP GEOLOGICAL DISPOSAL

Over time, radioactive waste becomes less hazardous through a natural process called radioactive decay. The principle of deep disposal is to confine this waste and isolate it from people and the environment for very long periods of time.

1 / WASTE PACKAGES

The first barrier of safe geological disposal is the materials used to condition waste. These materials are selected for their robustness and ability to limit or slow down the release of radionuclides. One example is steel, which is used to fabricate disposal canisters in which the most highly radioactive waste (HLW) is encapsulated and which must remain tight for several hundred years. This waste is also incorporated into a glass structure that dissolves very slowly, thus delaying the release of radionuclides over a period of several hundred thousand years. Concrete, used for ILW-LL, also helps to slow radionuclide migration.

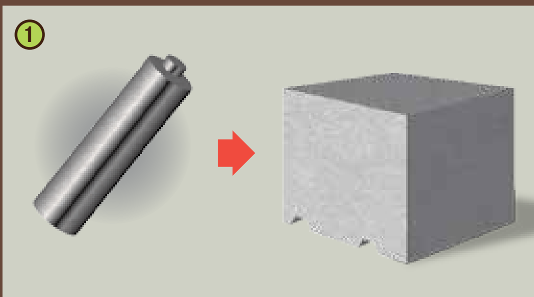
Clay, as seen under a scanning electron microscope.

2 / ARGILLACEOUS ROCK: AN IMPERMEABLE ROCK

Argillaceous rock acts as an impermeable natural barrier that can contain radionuclides when they eventually are released by waste packages. The vast majority of radionuclides that are released will never reach the surface. Some, such as those of the uranium series, are not very mobile in clay and will migrate along a distance of only a few metres over the course of several hundred thousand years. Others will naturally lose their radioactivity through decay.

Only a few mobile radionuclides with a long half-life (chiefly iodine-129 and chlorine-36) might migrate to the boundaries of the clay layer, but only after several tens of thousands of years. It is possible that they could reach the surface, but only in extremely small quantities and after a period of 100,000 years. These radionuclides will thus take more than 100,000 years to migrate through the more than 130-metre-thick layer of clay. As a result, their potential impact on humans and the environment is much lower than that of radioactivity that is naturally present in the environment.

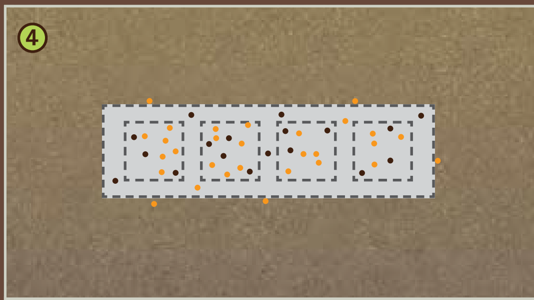
The depth, design and emplacement of a repository in impermeable argillaceous rock and in a stable geological medium make it possible to protect waste from human activities and natural phenomena (such as erosion) and isolate HLW and ILW-LL from humans for very long periods of time. Once a repository is closed up, it no longer requires human intervention and thus avoids placing the burden of dealing with such waste on future generations.



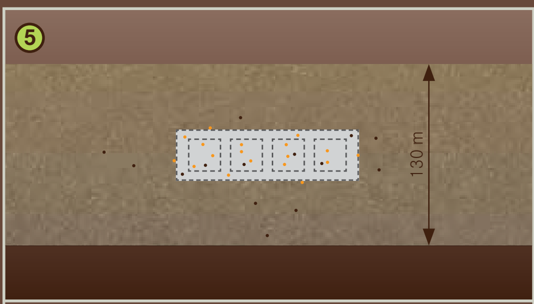
Radioactive waste is first conditioned in packages designed to confine the substances contained in them.

These packages are then placed in underground vaults that provide a second barrier during the repository's operation.

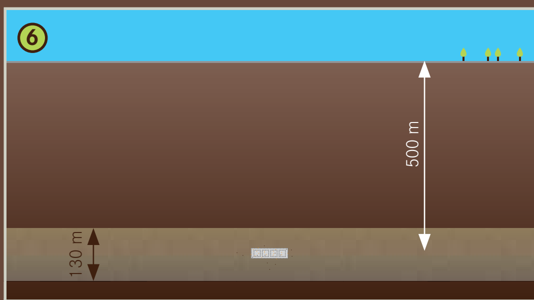
Over time, the packages and vaults will slowly be corroded by the water contained in the surrounding rock. After several hundred years, some radionuclides may dissolve into this water.



It is then up to the impermeable clay rock to trap the radionuclides and slow down their migration. As a result, the repository ensures that radionuclides are confined over very long time scales.



There is the possibility that highly mobile long-lived radionuclides will migrate to the boundaries of the clay layer, but only very slowly over time (more than one hundred thousand years). This spreading will significantly reduce their concentration.



The potential pathways of transfer of radionuclides to humans have been investigated. They will have a lower radiological impact than that of naturally occurring radioactivity.

- Low-mobility radionuclides
- Mobile radionuclides

WHY THE MEUSE/ HAUTE-MARNE SITE?

3

INTRODUCTION Subject to licensing, Cigeo will be built along the border of the Meuse and Haute-Marne departments in eastern France, where research conducted since the 1990s has identified a site with geology favourable to the siting of a deep geological disposal facility. Andra has been working with local stakeholders over the past few years to identify areas that could host Cigeo's underground and surface installations. Many scientific, industrial, environmental and socio-economic criteria have been taken into account.

3.1.
Selection of the Meuse and Haute-Marne site to host an underground research laboratory

The Bataille Act provided for the creation of underground research laboratories (URLs) to study radioactive waste disposal in deep geological formations. **At the end of 1992, a consultation mission was launched at the end of 1992 to determine which sites could host these laboratories. The mission continued until the end of 1993.**

At the end of the mission, **four interested departments were selected** on the basis of their geological characteristics: an argillaceous layer in three departments (Gard, Meuse and Haute-Marne) and a granite massif in the fourth department (Vienne). Andra received authorisation from the French Government to conduct **geological investigations in the departments after consultation with the local** authorities (nearby municipalities and department councils), which were in favour of the project. **In 1996 Andra submitted three applications to build underground research laboratories.**

2000:
start of construction of an underground research laboratory
on the dedicated site in the Meuse and Haute-Marne departments.

The entire body of results revealed that the **geological medium of the Meuse and Haute-Marne departments, which had been grouped into a single unit on account of the continuity of the argillaceous layer studied, was particularly suitable. No scientific consensus** on the possibility of building a safe repository was reached for the candidate site in the department of Vienne. Lastly, the candidate site in **Gard posed a scientific challenge** related to its long-term geodynamic evolution. The project was shelved in the face of strong local opposition.

In 1998 the French Government authorised the construction of an underground research laboratory in Meuse/Haute-Marne and the continuation of studies to search for a site in granite different from the one studied in Vienne. Construction on the URL began in 2000 in Bure while Andra continued to conduct local geological exploration programmes.

That same year, the failure of the consultation mission led to the abandonment of the search for a site in granite. Despite this, Andra continued studies and research on granite until 2005, building on the work conducted in URLs sited in other countries such as Sweden and Canada.

In 2004 the URL's shaft reached the layer of argillaceous rock that would be the focus of the studies. Since then, scientists have been conducting many experiments to study the rock and its behaviour.

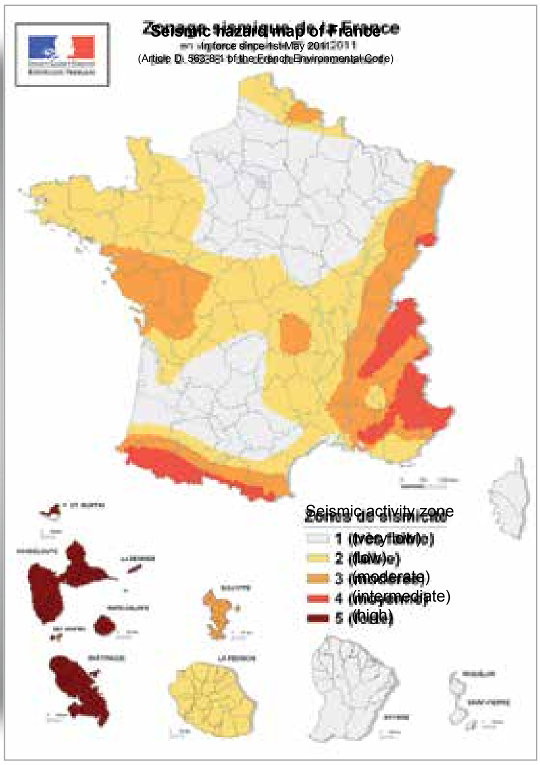
Drilling platform.

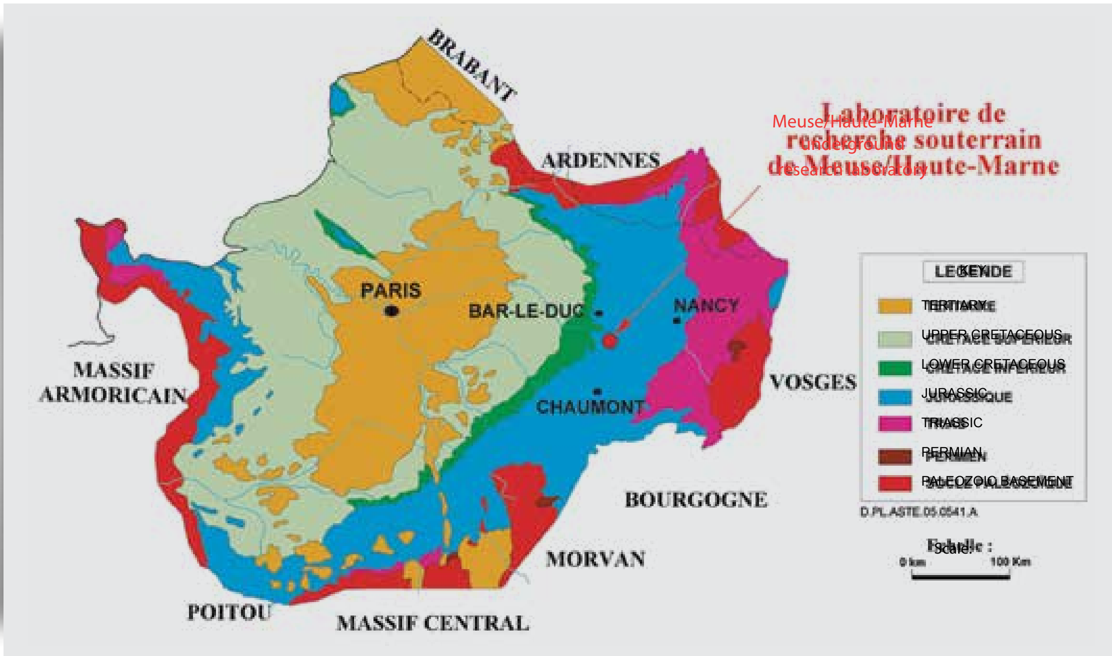
3.2.
The geological formation in the Meuse and Haute-Marne site

Since 1994, Andra has conducted many geological surveys at the Meuse/Haute-Marne site that have allowed it to thoroughly understand the geological formation and the properties of the argillaceous rock.

The site lies in the eastern section of the Paris Basin. It is a **geologically simple domain** with a succession of layers of limestone, marl and argillaceous rock deposited in ancient oceans. The geometry of the geological layers is simple and even. **Sample analyses from a 2,000-metre deep borehole have confirmed** that there are no notable natural resources directly above the zone surveyed for deep geological disposal. The National Assessment Board reached the same conclusions in its report of 4 June 2010: *"Under the current technological and economic conditions, the Triassic layer in the Bure area has no attractive potential as a geothermal resource."*

Furthermore, the Paris Basin is a highly stable geological environment characterised by low seismicity.





3.3.
Callovo-Oxfordian clay

The argillaceous layer studied by Andra in Meuse/Haute-Marne was deposited around 160 million years ago. It is homogeneous across a wide surface area and **very thick** (more than 130 metres). **No faults** affecting this layer have been identified in the studied zone. The only known faults are located outside this zone (the Marne fault, the Poissons/Roche-Betaincourt fault and the Gondrecourt graben).

This argillaceous rock has **properties that enable radionuclides contained in waste to be confined** over very long periods:

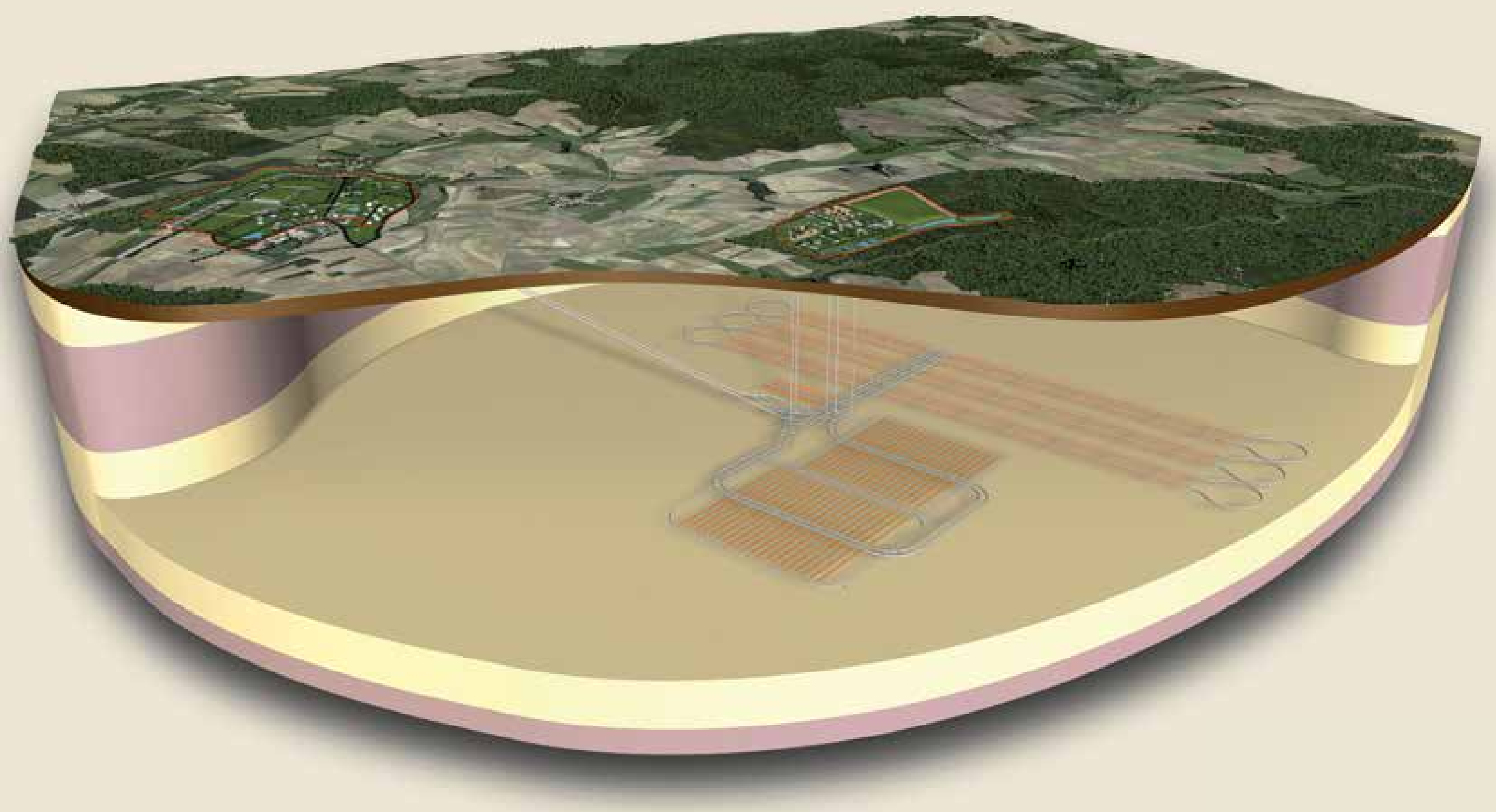
- its **very low permeability** limits the flow of water through the layer and prevents radionuclides from being carried away by moving water (convection). Migration of soluble chemical elements occurs very slowly by means of diffusion (movement of the elements in water);
- the chemical composition of the rock and the water contained in it **limit the dissolution of many radionuclides,** such as those of the uranium series (actinides), and thus prevent them from migrating through the rock;
- in addition to its very low permeability, **its confinement properties stem from the argillaceous nature of the rock,** which is made up of stacked sheets between which radionuclides can be trapped.

The geological layers overlying and underlying the clay layer also have low permeability. As a result, the flow of water through them is very slow.

Callovo-Oxfordian clay studied at the Meuse/Haute-Marne site.

3.4.
Siting of Cigeo's installations

If licensed, Cigeo will consist of an underground facility in which packages of radioactive waste will be emplaced. Throughout the facility's life, waste packages will be received, inspected and prepared at the ramp zone facility before being transferred to the underground facility. The shaft zone facility will house the logistics operations for the work to be carried out underground.



General layout of Cigeo facilities

UNDERGROUND FACILITY

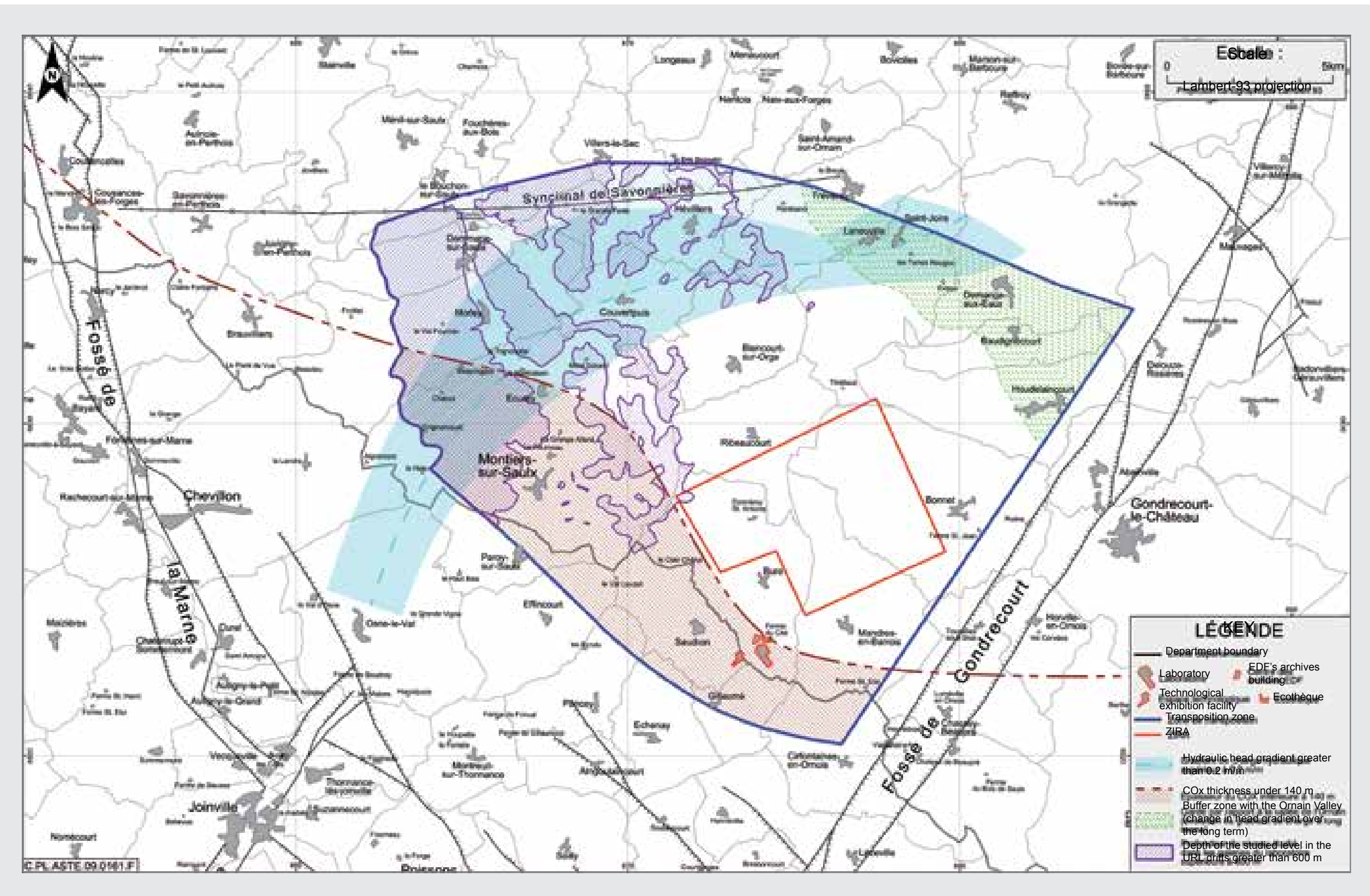
To study the siting of the underground facility, in 2009 Andra proposed to the French Government a **30 km² underground zone** (ZIRA, or zone of interest for detailed survey) located in the heart of a 250 km² zone defined in 2005 and in which the results of the URL can be transposed.

Technical **criteria related to safety and geology** (thickness of the layer, depth, etc.) were taken into account, as **were criteria related to planning** and local integration of the project (such as compatibility with siting of the ramp in the bordering Meuse/Haute-Marne area and with potential siting of access shafts in a wooded area, avoidance of siting the facility under inhabited areas).

The zone proposed by Andra, located a few kilometres from the URL, was **approved by the Government** following a position issued by the Nuclear Safety Authority (ASN), the National Assessment Board (CNE) and following consultation with elected officials and the Local Information and Oversight Committee (CLIS) for the URL.

Andra subsequently performed geological surveys, the results of which confirmed that the clay layer in the zone exhibits characteristics favourable to the siting of a deep geological disposal facility.

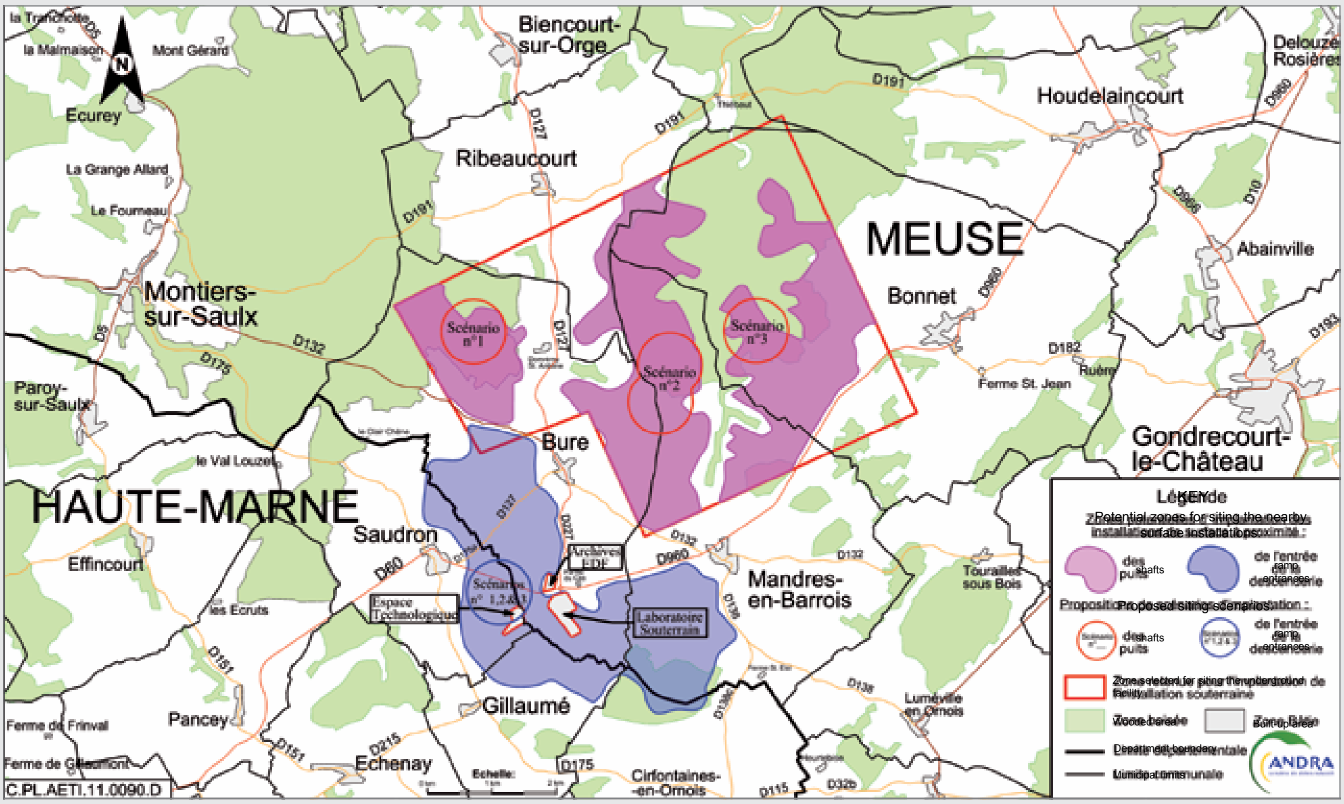
If licensed, the underground facility will be sited in this zone.



SURFACE INSTALLATIONS

Andra has identified several zones for studying the siting of Cigeo's surface installations. These zones take into account constraints related to aspects such as flood zones, inhabited areas, protected natural areas and flyover zones.

The local elected officials have asked Andra to **look into siting the repository access ramps in an area located in the "inter-department" zone,** on the Haute-Marne side and adjacent to the Meuse department. This zone is located around the URL and along the secondary road. Furthermore, this zone may be served by a railway line if such an option is chosen (the route of the old line between Gondrecourt-le-Château and Joinville runs nearby). **Several siting scenarios have been studied for the shaft zone facility**, with emphasis being placed on siting in a wooded area so as to limit the amount of agricultural land taken. Scenario 1 calls for siting the facility in Montiers-sur-Saulx forest. From a technical point of view, such a site is too far from the ZIRA and would cause problems for the subsequent operation of the underground facility. Scenarios 2 and 3 call for siting the facility in the centre of the ZIRA, in the Ormançon Valley forest (a site along the edge of the forest was also considered for scenario 2). These scenarios are more conducive to the operation of the underground facility. However, scenario 3 requires longer ramps. On 4 February 2013 the High-level Committee endorsed the siting proposed by Andra for the ramp zone and the two options to be explored for siting the shaft zone (scenarios two and three).



General view of the surface zone set aside for the receipt, inspection and preparation of waste packages - General layout including assumption of an on-site railhead.

General view of the surface zone set aside for the underground work.
Example according to scenario 2 mentioned on page 35.

HOW WILL CIGEO OPERATE?

4

INTRODUCTION Cigeo will consist of surface installations for operations such as waste package receipt, inspection and preparation, an underground disposal installation and infrastructure that will connect the underground installation with the surface. The repository will operate for more than 100 years and be expanded as needed. To guarantee its role and ensure that waste is confined over very long time periods without the need for human intervention, the underground structures at Cigeo will be gradually closed up.

4.1.
The installations at Cigeo

Cigeo will be a basic nuclear installation (INB) consisting of surface installations distributed across two sites, shafts and ramps and an underground facility.

The Cigeo project is now in the industrial design phase, which draws on the results and evaluation of 20 years of R&D efforts. Andra and its prime contractor, the Gaiya group formed by Technip and Ingerop, investigated several options in 2012). This industrial outline is reviewed in 2013 by a group of experts and evaluated by the ASN and the National Assessment Board.

The recommendations stemming from these evaluations, the avenues for optimisation identified by Andra and any changes made to the project following the public debate will be taken into account in the following study phase before the repository licence application is filed.

The technical description presented on this website is based on the technical options favoured by Andra at this phase of the studies.

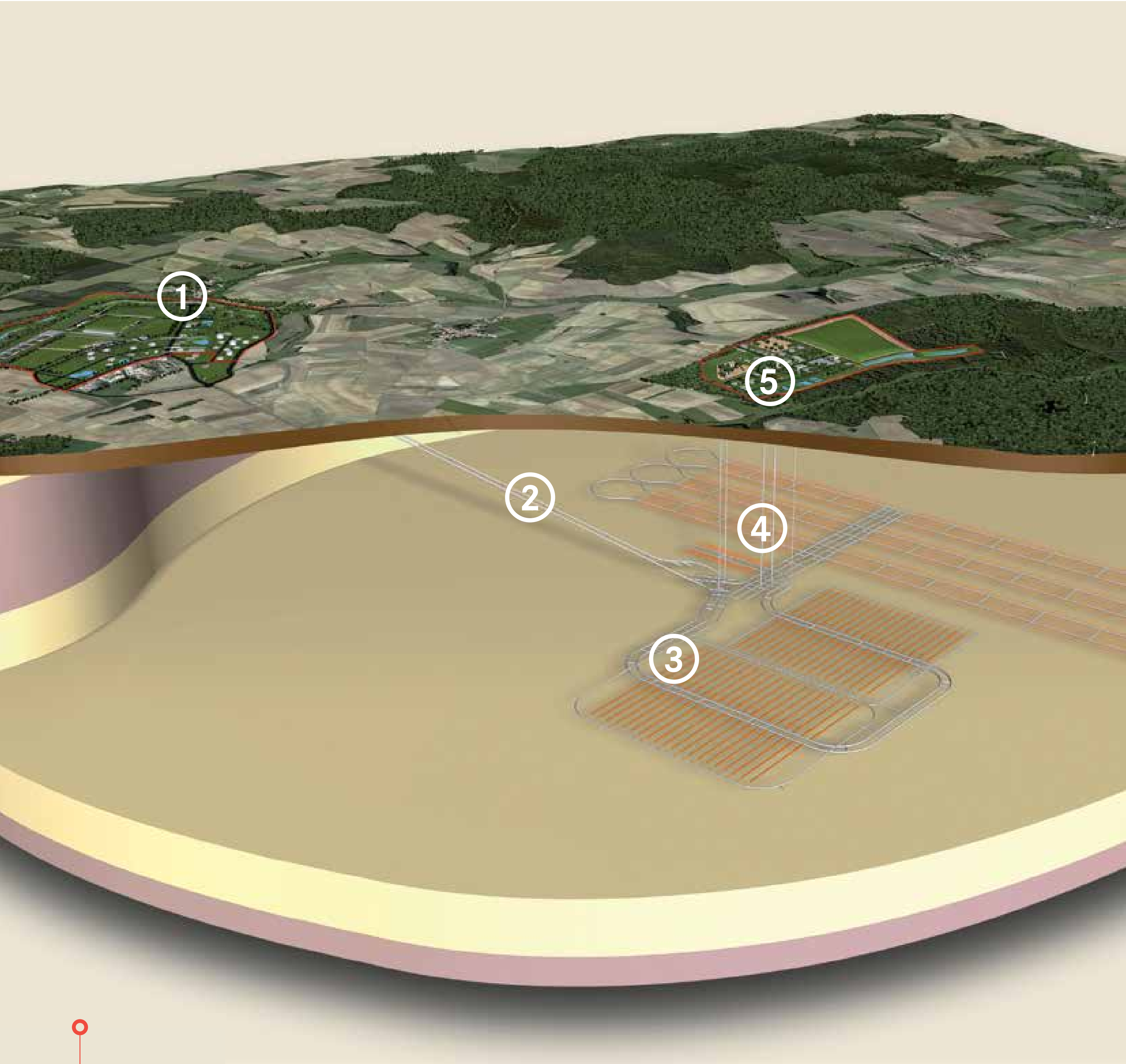
1. **WASTE PACKAGE RECEIPT AND PREPARATION ZONE**
   Located a few kilometres away from the excavation site, this zone will consist of buildings for receiving, inspecting and preparing waste packages before their transfer to the underground facility.

2. **RAMPS**
   One ramp will be used to transfer waste packages to the underground facility, while another will be used as a technical access drift.

3. **UNDERGROUND FACILITY**
   The Cigeo underground facility will be expanded as needed during its operation and will be divided into various zones.

4. **SHAFT**
   Five vertical shafts will connect the underground facility to the surface work zone. They will be used to transport personnel, materials and equipment up and down, carry excavated rock to the surface and supply fresh air to the underground installations.

5. **BASE OF UNDERGROUND EXCAVATION AND CONSTRUCTION WORK**
   Located directly above the underground facility, this zone will be used in particular as a base for excavating and building the underground structures. The rock excavated during the building of these structures will be piled in this zone.



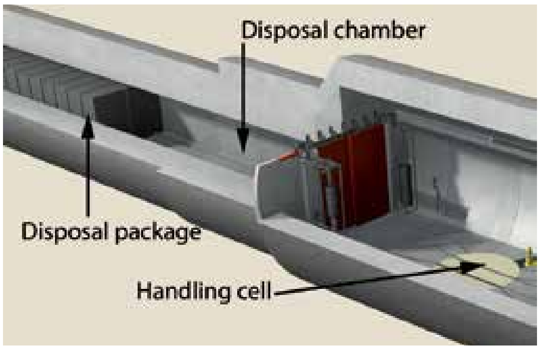
General layout of Cigeo facilities.

THE UNDERGROUND FACILITY

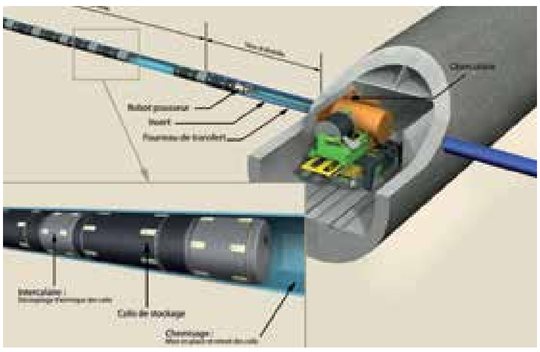
Located at a depth of around 500 metres, the Cigeo underground facility will be expanded over the course of its operations. It will consist of separate disposal zones for HLW and ILW-LL, connecting drifts and technical facilities. **By its 100th year of operation, Cigeo's footprint will be around 15 km².**

Robots will emplace waste packages in horizontal tunnels, known as cells, excavated in the heart of clay layer. HLW will be emplaced in metal-lined cells measuring a few hundred metres in length and around 70 cm in diameter. ILW-LL will be emplaced in horizontal disposal cells measuring a few hundred metres in length and some ten metres in diameter.

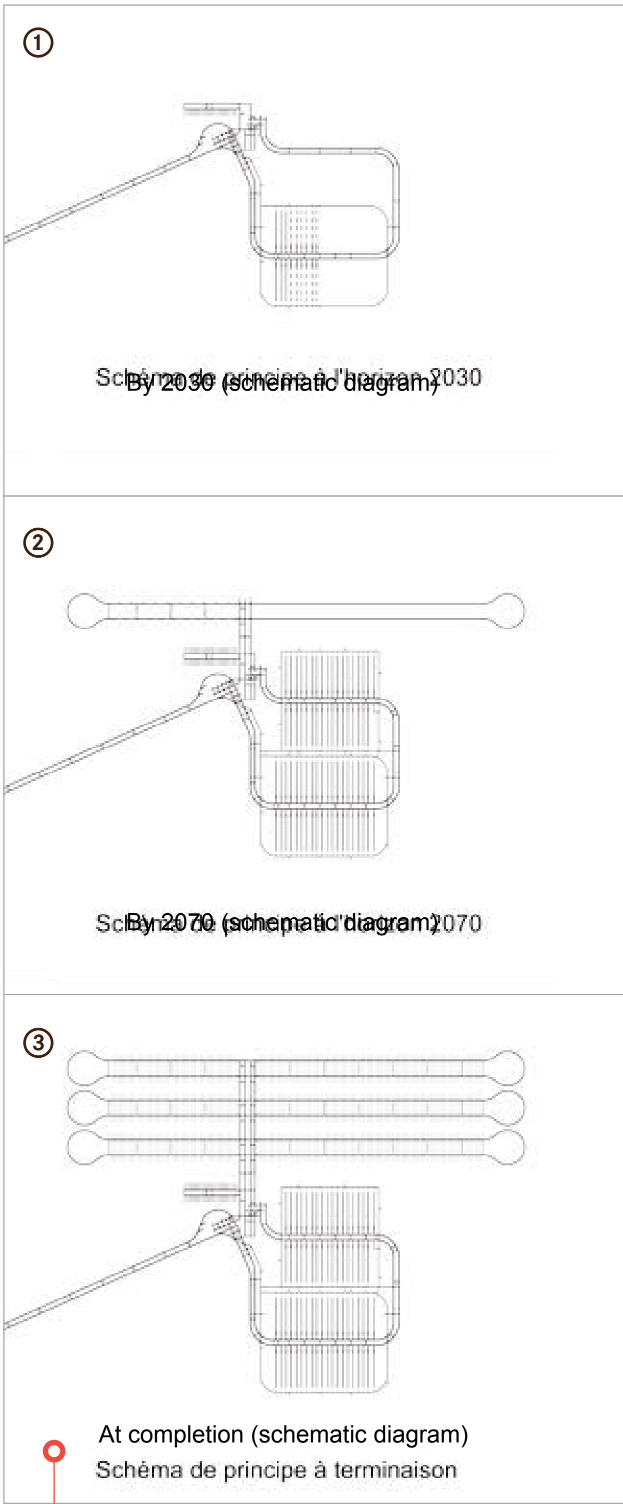
The **disposal zones** will be **modular in design** to allow waste disposal tunnels to be **built over time**.



Basic diagram of an ILW-LL package disposal cell.



Basic diagram of an HLW package disposal cell.



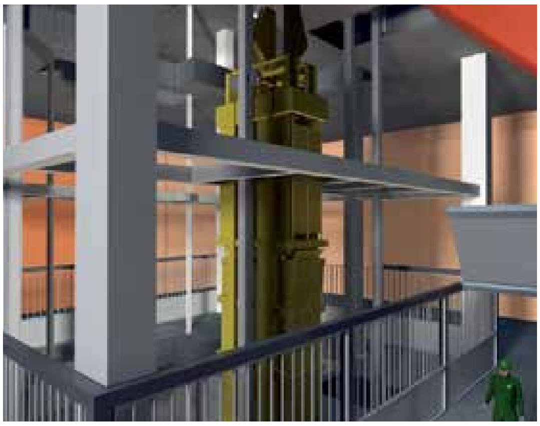
The underground facility will be expanded as needed during the repository's operation.

CONNECTION INFRASTRUCTURE

Two types of infrastructure will connect Cigeo's surface installations with the underground facility. **Vertical shafts** will be used to transfer personnel, construction equipment and materials and ventilate the underground installations.

Waste packages will be transferred by a funicular along a tube known as an **access ramp**.

Transfer via funicular inside a ramp.



Entrance of a shaft.

SURFACE INSTALLATIONS

Cigeo's surface installations will be split across **two sites** (ramp zone and shaft zone) located a few kilometres apart.

The ramp facility will be built in the zone already prepared around the URL (Technological Exhibition Facility, Écothèque, EDF's archives building) and integrated with the site's physical features.

The rock excavated from the ramp zone will be transported to the shaft zone, where it will be piled. The possibility of using a conveyor to reduce the amount of traffic between the two sites is being looked into.

The surface installations will have their own emergency response and security installations (fire station, security office, etc.).

The facility in surface zone 1 (ramp zone) will include buildings for **receiving and inspecting waste packages and preparing them for transfer** into the underground facility via a ramp. With a footprint of around **200 hectares,** this zone will consist of:

- a complex of nuclear installations where waste packages will be received, inspected, conditioned into disposal packages and grouped together pending their transfer to the underground disposal cells;
- an area that may be the site of a railhead if the option to transport waste packages to Cigeo by rail is chosen;
- infrastructure required to run the facilities (electrical substations, storm basins, wastewater treatment plant, etc.);
- a zone for construction work and maintenance of the installations;
- a vistors centre;
- a works compound with a canteen and offices.

General view of the surface zone set aside for the receipt, inspection and preparation of waste packages - Artist's impression including assumption of an on-site railhead.

Surface zone 2 (shaft zone) will be located some 5 kilometres from surface zone 1. Its installations will be mainly used for the **excavation and construction of the underground structures.** With a footprint of around **110 hectares (excluding the piles of excavated rock),** this zone will be located directly above the underground facility and consist of:

- an area for underground work;
- a nuclear area consisting of maintenance installations and shafts for transporting personnel and ventilating the underground facility;
- infrastructure required to run the installations (electrical substations, storm basins, wastewater treatment plant, etc.

Rock excavated from the underground facility will be piled near this zone and landscaped over. These piles will be formed gradually over an estimated area of around 130 hectares.

General view of the surface zone set aside for the construction and excavation of the underground structures – Artist's impression according to siting scenario 2 mentioned in chapter 3.

4.2.
Construction of Cigeo

The repository will be built very gradually. The first structures to be built will be the installations needed to conduct the excavation work and start operations at the repository.

Once operations are under way, work on building the underground facility will occur on an as-needed basis in a series of phases. Zones under construction will be physically isolated from operating zones. Ventilation will be similarly separated. The package transfer drifts will have their own ventilation network, separate from that of the working drifts.

The rock removed during the excavation of the underground facility will represent a volume in the order of 10 million cubic metres produced over more than 100 years.

The piles of excavated rock will be regulated by special provisions to protect the environment and allow a portion of the rock to be used for Cigeo closure (around 40% will be reused to backfill the underground structures).

For comparison, the same volume of rock is excavated during large tunnel projects, but over a period of a dozen years (around 7 million cubic metres for the Channel Tunnel and around 15 million cubic metres for the base tunnel of the future Turin-Lyon high-speed railway).

4.3.
Transport of waste packages

International regulations on the transport of radioactive substances are set by the International Atomic Energy Agency (IAEA). In France, the ASN is responsible for regulating the safe transport of radioactive substances for peaceful purposes. The Senior Official for Defence and Security of France's Ministry of Ecology, Sustainable Development and Energy is responsible for the secure transport of sensitive materials (physical protection).

Radioactive substances are transported by authorised specialised companies. Waste packages to be transported are characterised in full by the consignor. This allows the carrier to define the type of packaging necessary and specify the conditions of transport.

Waste is transported in sealed containers designed to retain its integrity even in the event of an accident (collision, fire, submersion, etc.). These containers are made of a variety of materials that reduce the radiation levels of the waste contained in them to below the regulatory limit of 0.1 millisieverts of radiation received by a person standing within 2 metres of a transport vehicle for one hour, regardless of the type of waste being transported. At the end of loading, the consignor checks the compliance of the packaging with the relevant regulations.

The nuclear fuel cycle in France requires an estimated total of around 11,000 trips for EDF's nuclear power plant operations. Around 200 of these trips are made to carry spent fuel from France's reactors to the Areva NC La Hague plant. Most of these trips to the La Hague plant are made first by rail to the Valognes railhead 40 kilometres from the plant and then by road.

Transport between waste generation sites and Cigeo

Areva, the CEA and EDF currently anticipate sending 700 to 900 packages a year to Cigeo by 2030-2040. Rail will be the preferred mode of transport. This would mean no more than 100 or so trains (of ten or so cars per train) a year, or two trains per week during peak periods and an average of two trains a month throughout the facility's operation. The CEA anticipates transporting the limited volumes of waste packages from its Valduc site by road. Cigeo is designed on this basis to ensure the emplacement of waste packages as and when needed.

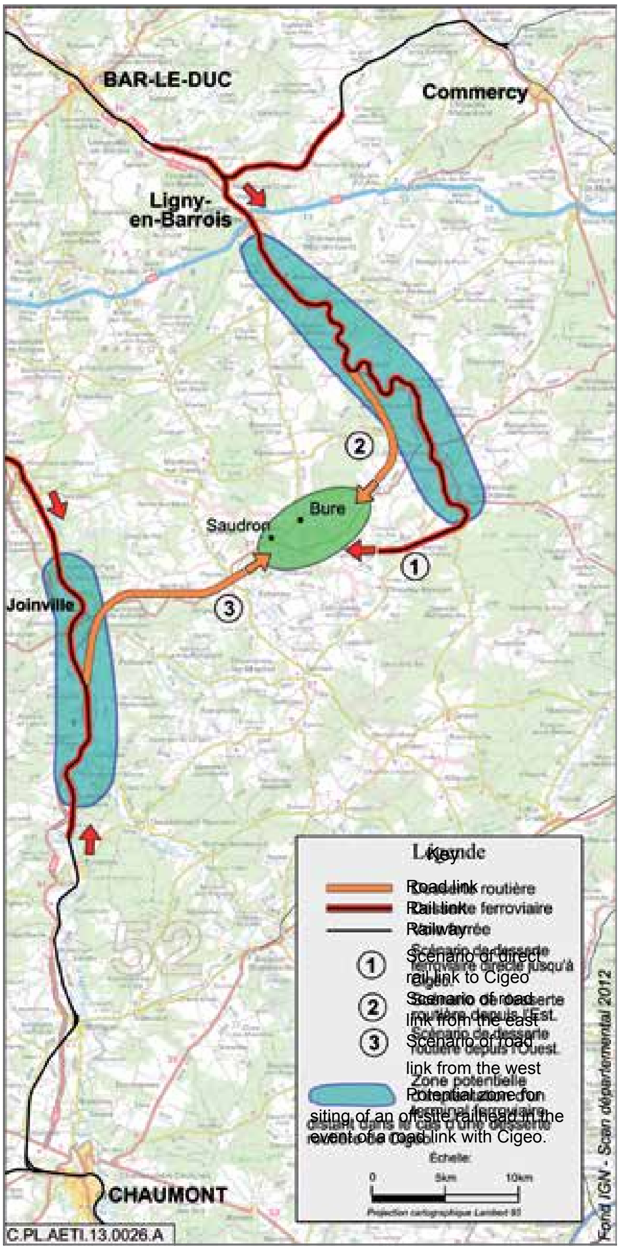
Areva, the CEA and EDF are looking into arrangements for transporting waste packages from their sites of generation to Cigeo. France's railway network has lines that will enable loads to be carried all the way to a point near Cigeo. Routes from the La Hague plant and the Cadarache, Marcoule and Bugey sites in the Rhône Valley are being considered.

Various routes for carrying waste packages to Cigeo are being considered.

Scenarios for local transport links to Cigeo

Trains will arrive and be unloaded at a special railhead. This railhead may be located either on an existing railway line (which will require intermediate reloading and final transport by rail to Cigeo) or directly on the site of Cigeo's surface installations (which will require extending the current railway network).

A number of scenarios were considered and were the subject of discussions during the development of the interdepartmental development plan. Three scenarios were selected for further analysis during the last meeting of the High-level Committee. The first scenario calls for building a direct rail link between Cigeo and the existing railway network in the Ornain Valley, which would eliminate the need for intermediate reloading. Work to upgrade the existing railway infrastructure (e.g. consolidation of the existing line) will be managed by Réseau Ferré de France, which owns and manages France's national railway network. Work to build the connecting line all the way to Cigeo, some 15 kilometres away, would be delegated by Andra. The second scenario consists in building the railhead along the existing railway network in the Ornain Valley, while the third provides for building it along the existing railway network in the Marne Valley. In the latter two scenarios, waste packages would carried from the railhead to Cigeo by road.

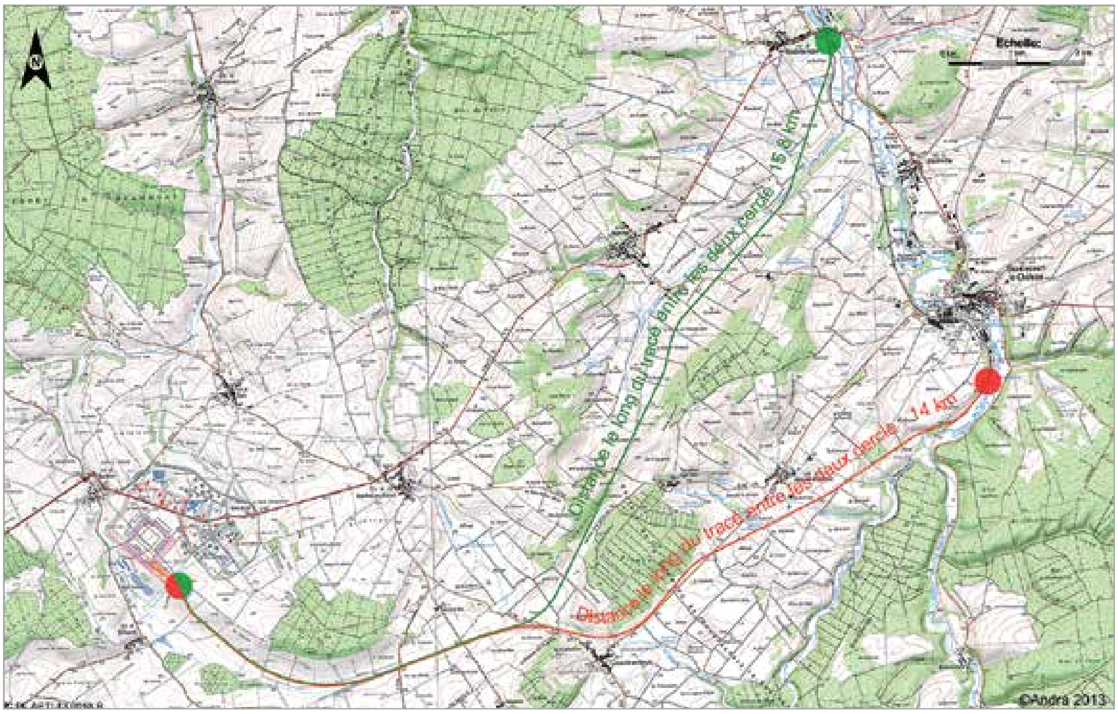


Schematic map of the local rail link scenarios.

Optional direct rail link to Cigeo

From a technical point of view, a connecting line from the existing railway network in the Ornain Valley offers more advantages than a rail link from the Marne Valley.

Various options for building a connection to the existing railway line from the municipalities of Gondrecourt-le-Château and Houdelaincourt have been looked into. A connecting line from Gondrecourt-le-Château could allow a portion of the route of the old railway line to be used.



Map showing the possible rail links between the existing railway network and Cigeo.

Transport cask in which HLW packages will be placed for transport. Each cask will be inspected prior to shipment.

4.4.
Operation of Cigeo

PRODUCTION OF WASTE PACKAGES ON GENERATORS' SITES

Waste **is conditioned and waste packages are produced under the responsibility of their generators.** The quality of the packages is verified by the generators during conditioning and before shipment to Cigeo. The generators' facilities are subject to **inspection by the relevant safety authorities** (the ASN or the Nuclear Safety Authority for Defence-related facilities and activities, ASND). Andra monitors generators to **ensure that they implement a quality assurance programme for waste packages.**

Cigeo will operate for **more than 100 years.**

RECEIPT OF WASTE PACKAGES AT CIGEO

Waste packages will not be allowed in the facility until they have undergone a process to ensure that they meet the technical criteria for repository safety set by Andra and approved by the ASN. Generators will thus have to file an **acceptance application** to Andra. This application will have to demonstrate that the **waste packages in question meet these technical criteria.** After waste acceptance by Andra, the packages may be sent to Cigeo.

WASTE PACKAGE DISPOSAL

Upon arriving at Cigeo, waste packages will be transferred to buildings where they will be **taken out of their transport casks and inspected** (absence of contamination, dose rates, etc.). These buildings will also be used to manage flows of packages prior to their transfer into the underground facility. **These facilities are not intended to replace generators' own storage facilities,** particularly those used to allow waste to cool sufficiently prior to their emplacement in the repository. Waste packages will then be placed in **disposal containers.** Some waste packages from generators may arrive ready for emplacement in the repository. Disposal packages will be placed in **casks** to shield against radiation. The cask will be loaded onto a funicular that will descend all the way to the cells at the same speed as a person walking on foot. Emplacement of waste packages in the cells may be remotely controlled. The transfer cask will dock with the door of the cell in order to create a seal while the door is open. The door will not be able to open until the transfer cask is correctly docked. The handling system will then transfer the packages into the cell and the door of the cell will be closed. **Radiation protection will be ensured during each operation.**

PILOT ZONE FOR HLW

HLW are characterised by radioactivity concentrations that make them highly irradiating and cause them to generate more heat than ILW-LL.

The conditions of their disposal are being tested in full-scale experiments in the URL (such as cell excavation and thermal loading). Their handling has been studied and full-scale prototypes have been created using dummy packages fitted with radiation shielding. These prototypes are on public display at the technological exhibition facility in Saudron. These results will be used to support the safety demonstration to be presented as part of the repository licence application that will be filed in 2015.

Starting in 2025 the first batches of HLW packages will be placed in a pilot zone of the repository. The waste to be emplaced there will represent 5% of the total amount of HLW. The pilot zone will be monitored for 50 years or so before the remaining 95% is disposed of in the repository.

4.5.
Closure of Cigeo

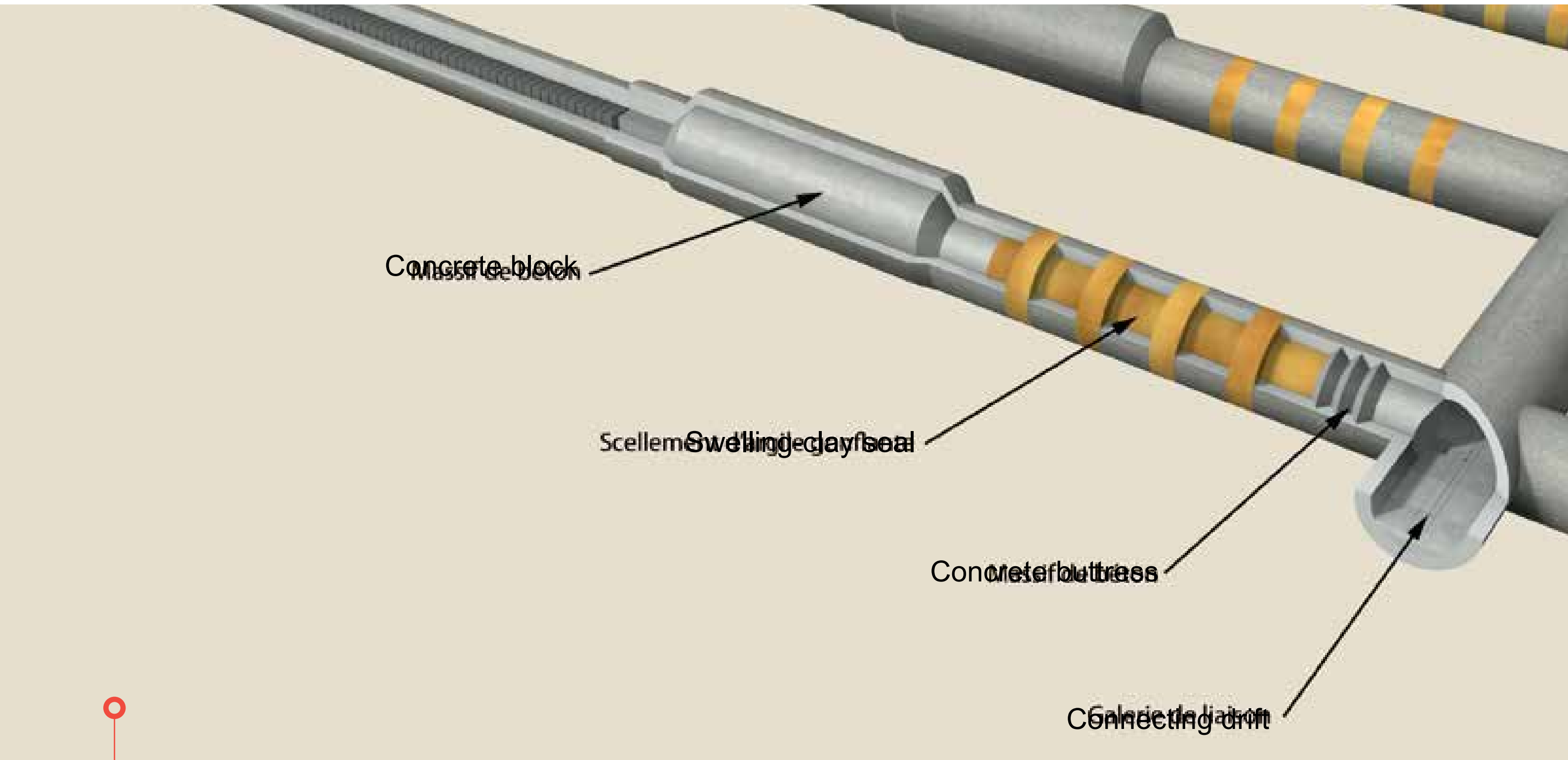
To guarantee its role and ensure that waste is confined over very long time periods without the need for human intervention, **the underground structures at Cigeo** will be closed up **gradually** according to a decision-making process that is expected to be defined in the future act that will lay down the conditions for reversibility of disposal.

The underground facility will be closed up zone by zone:

- the disposal cells will be plugged;
- seals will be put in place (swelling clay structure designed to give the backfilled drifts a high degree of impermeability) and the drifts leading to the cells will be backfilled, followed by the main drifts;
- the shafts then the ramps will be backfilled and sealed.

The structures will be backfilled with the clay removed during the excavation of the repository and stored at the surface. The seals will be made of swelling clay and concrete to limit the flow of water through the drifts and the surface-underground connections over the long term.

The surface installations will be dismantled at the same time as the underground installation is closed up.



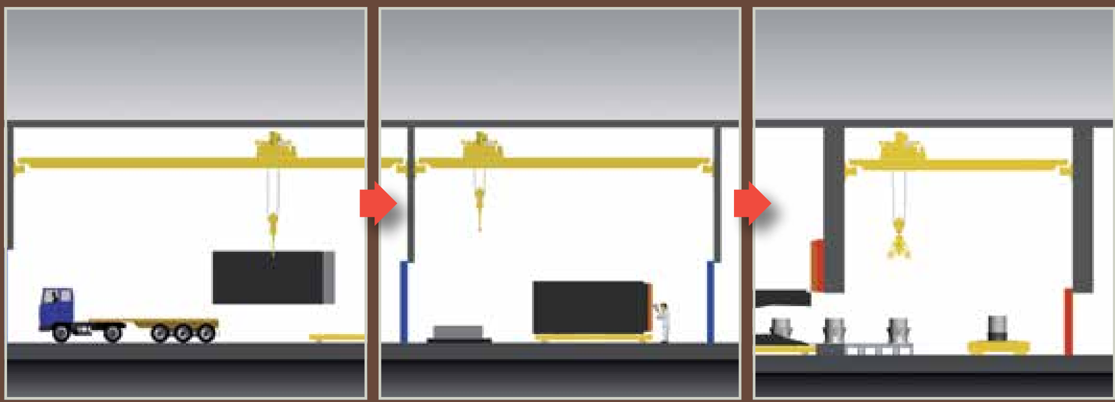
Closure of an ILW-LL disposal cell.

ROUTE OF HLW AND ILW-LL, FROM THEIR ARRIVAL AT CIGEO TO THEIR DISPOSAL UNDERGROUND

1

RECEIPT OF INCOMING PACKAGES

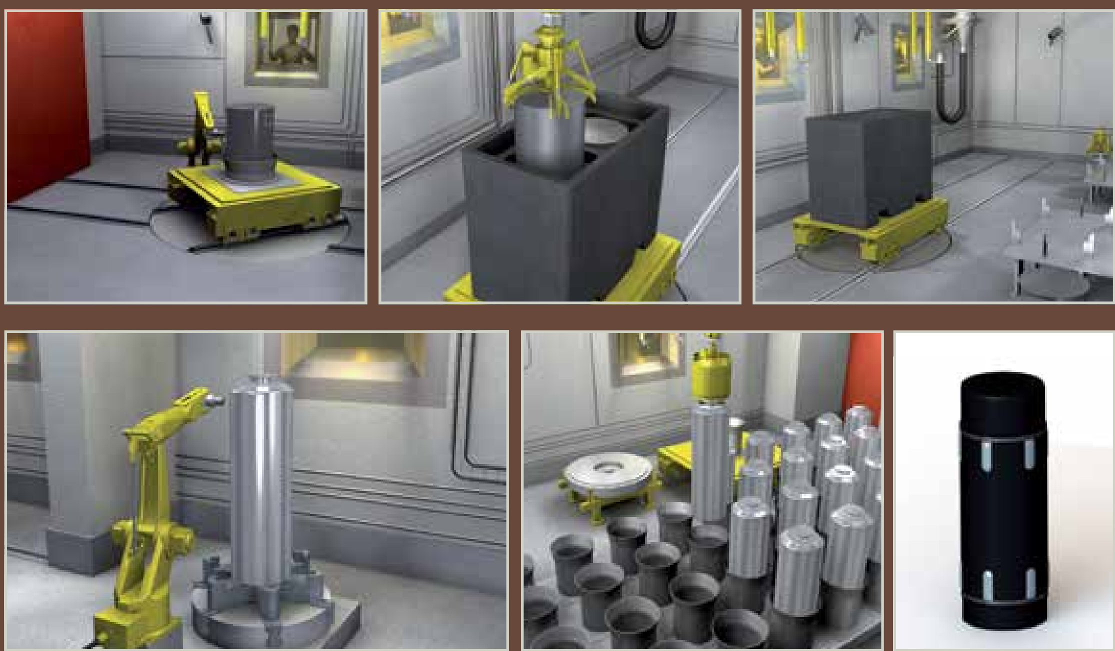
Incoming waste packages will be placed in buildings where they will be inspected a first time and removed from their transport casks.



2

INSPECTION AND PREPARATION OF WASTE PACKAGES

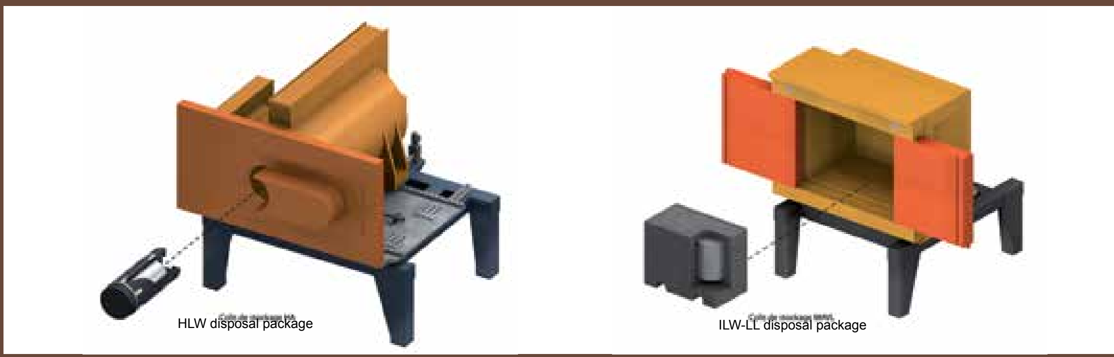
They will then be reinspected and placed, if necessary, in disposal containers.



3

EMPLACEMENT IN TRANSFER CASKS

Before being transferred underground, disposal packages will be placed in casks to shield against radiation.



4

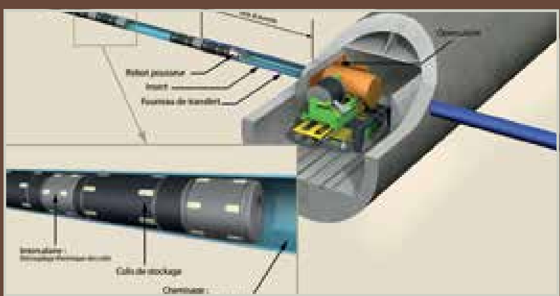
TRANSFER OF PACKAGES TO THE UNDERGROUND FACILITY

Each cask will be placed on a funicular and carried to the underground facility via an access ramp.

5

DISPOSAL OF WASTE PACKAGES

Waste will be emplaced in disposal cells by robots.



SAFETY AT CIGEO

5

INTRODUCTION Radioactive waste contains hazardous substances which, if dispersed, may irradiate a person in the vicinity or contaminate humans and the environment. The basic aim of Cigeo is to protect human health and the environment from this waste over very long periods of time.

Cigeo is designed to remain safe during its construction and operation and after closure. The approach is based on a large number of measures designed to avoid uncontrolled dispersion of radioactivity, ensuring that the quantity of radioactivity to which workers and local populations are exposed remains very low and does not pose a health risk. After closure of the repository, safety must be ensured passively and require no human intervention. Monitoring will nevertheless continue after closure, and actions will be implemented to create a perpetual reminder of the facility's existence.

5.1.
Repository safety during operation

During the repository's operating life, waste is confined in packages and repository structures. To ensure the safety of the facility throughout its operating life, **right from the design phase, Andra identified all potential hazards that could have a radiological impact** on humans and the environment. The defence-in-depth concept applies to Cigeo as it does to other nuclear facilities:

- for each identified hazard, Andra provides for design and operating measures to **eliminate the hazard if possible, prevent it and reduce the probability of its occurrence;**
- **inspection and monitoring action** will be taken to detect any malfunction and return the facility to normal operating conditions;
- in spite of these measures, **Andra assumes that potential accident situations could occur** and provides for additional measures to control the situation and minimise its impact.

COACTIVITY AT THE REPOSITORY

One characteristic of Cigeo is that underground excavation work will continue throughout the facility's lifetime, alongside the operation of the nuclear facility. As two very different activities are involved, Andra has made sure to **separate excavation and construction from nuclear activities.** The two types of activity will be carried out in **separate areas,** with separate access and their own respective ventilation systems. The excavation site is a conventional work site, with the appropriate measures for managing underground work. The nuclear part of the facility is subject to measures corresponding to the specific risks and hazards involved, as described below.

RISKS TAKEN INTO ACCOUNT FOR THE NUCLEAR FACILITY

Whether external or internal, natural or industrial, all types of risks have been taken into account: earthquake, flooding, extreme climate conditions (wind, snow, rain, lightning, etc.), plane crash, industrial environment (circulation routes, presence of other facilities presenting risks, etc.), malicious acts, handling, fire and explosion, etc. These have been characterised and the facilities are designed to withstand them, in accordance with the rules defined by the French Nuclear Safety Authority (ASN).

1 / NATURAL HAZARDS

From the facility site selection phase, natural hazards have been assessed in order to choose a site with favourable conditions, i.e. a place where the risks are slight enough not to affect the safety of Cigeo (low natural seismicity, away from flood zones, etc.) Safety standards stipulate that the installations at Cigeo (both above and below ground) must be designed to withstand earthquakes five times stronger than those considered possible on the site.

2 / FIRE HAZARD

One prevention measure consists in limiting the amount of combustible or flammable products in repository handling equipment. Unlike in road tunnels, where the fuel in vehicles represents a significant fire hazard, there will be no internal combustion vehicles in the nuclear zone at Cigeo. Fire detection systems and automatic fire-fighting systems will be distributed throughout the facilities to quickly detect, locate and extinguish any fire.

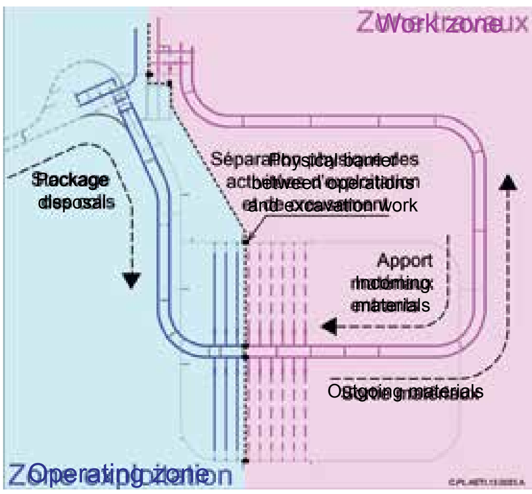


Diagram showing the physical separation of activities in the repository.

Despite these measures, the risk of fire has been considered as a precaution. Compartmentalisation and ventilation systems are planned to limit the propagation and consequences of a fire. The underground architecture will allow emergency response teams to operate in the drifts away from smoke, and facilitate the evacuation of personnel. Filtering in the disposal cells will limit dispersion into the environment of substances which may have been released during a fire.

How is the risk of radioactivity dispersion controlled?

Cigeo's primary function is to confine the radioactivity contained in the waste, and this must be guaranteed throughout the entire operation phase, in both normal and accident situations. The packages are the first barrier that retains the radioactive particles. In the ramp and transfer drifts, these packages are placed inside a cask, which is the second envelope protecting the packages against hazards (dropping, fire, etc.). In ILW-LL disposal cells, highly effective filters guarantee that even if a package breaks, dispersion of radioactive particles will be confined to the cell and not released into the environment.

3 / EXPLOSION HAZARD

Some ILW-LL, particularly those containing organic compounds, generate hydrogen. This non-radioactive hydrogen in the molecules of organic compounds is released under the effect of radiation. Above a certain quantity of hydrogen, there is a risk of explosion in the presence of oxygen. To control this risk, Andra has defined a strict limit for the quantities of hydrogen given off by each package. This will be subject to checks and inspections.

To avoid hydrogen accumulation, the underground and surface installations will be ventilated during their operating life, as are the storage facilities currently housing the waste. Given the importance of its role in ensuring safety, the ventilation system will be subject to reliability measures to reduce the risk of failure. In addition, monitoring systems will be set up to detect any malfunction in the ventilation system. Loss of ventilation situations have been considered. Andra's analyses show that, in the event of loss of ventilation, there will be a ten-day window in which to restore ventilation, allowing enough time to take the necessary measures.

Nevertheless, the consequences of an explosion inside a disposal cell have been assessed. The results show that the packages would sustain only slight damage without compromising the confinement of the substances they contain.

4 / ELECTRICAL OUTAGE HAZARD

In the event of electrical outage, Cigeo, like all nuclear facilities, will be equipped with emergency electrical equipment, including a variety of redundant generator sets. This equipment will be tested regularly in order to ensure multiple levels of backup power for sensitive equipment (nuclear ventilation, supply pumps for the fire-fighting system, radiological monitoring systems, etc.).

5 / HAZARDS RELATED TO PACKAGE HANDLING

The facility is designed to minimise the risks of accident during transfer operations: for example, speed limits for vehicles and handling machinery will be very low (around 10 km/hour for transfers on ramps and in drifts, less than 1 km/hour for package emplacement or withdrawal operations in the disposal cells). Package handling heights are limited (lower than in the drop tests conducted). Similarly, transporters are designed to withstand collision and equipped with multiple redundant safety systems.

The risk analysis also sets out the measures to be taken to restore the facility to proper operation following a blocked equipment or dropped package incident: this type of situation must not compromise the safety of the repository or hinder operation.

HLW-LL container demonstrator after a drop test.

6 / CRITICALITY HAZARD

Criticality refers to the triggering of uncontrolled fission reactions in fissile materials such as uranium-235 or plutonium. This type of hazard can only occur when the concentration of fissile material is high enough.

The waste in the deep geological repository contains small quantities of fissile materials. As a precaution, the criticality hazard is systematically assessed, and package geometry and layout in the repository are verified to rule out any such risk.

7 / IRRADIATION HAZARD

The facility's design complies with the applicable worker protection regulations and the ALARA principle, which aims to limit worker exposure to radiation as far as possible. Exposure at the workstations will be well below the regulatory threshold values. This is ensured by physically separating work zones and nuclear zones, setting up radiological protection devices, and studying possibilities for automating package transfer operations.

Radiological monitoring of personnel leaving the controlled-access area.

THE ALARA PRINCIPLE

This international radiological protection principle, which stands for "As Low As Reasonably Achievable", consists in striving not only to comply with regulatory limits but also to keep human exposure to ionising radiation as low as reasonably achievable level, considering current technology and economic and social factors.

5.2.
Repository safety after closure

The basic aim of Cigeo is to protect human health and the environment from radioactive waste over very long periods of time. **The long-term safety of the repository needs to be ensured passively, without requiring any human intervention. This principle depends in particular on the choice of geological medium and repository design.**

REPOSITORY DESIGN

The repository's primary function is to **isolate the waste from surface activities.** The repository will be located some 500 metres below ground. This depth protects it from the effects of phenomena such as erosion or glaciations, which will only affect the ground down to a depth of less than 200 metres over hundreds of thousands of years.

The repository's second function is to **confine the radioactive substances** and **control the transfer pathways which may in the long term bring radionuclides into contact with humans and the environment.** These phenomena operate over very long time scales, during which the waste becomes less hazardous owing to radioactive decay.

The way in which the underground facility is organised and the design of certain repository components, such as the packages and seals, help confine the radioactivity and limit water flows within the repository after closure.

Confinement in the long term relies on **the highly favourable characteristics of the clay layer in which the repository will be built.** The repository is therefore designed to limit any disturbances caused by its construction. This means, for example, favouring construction methods which limit damage to rock, and limiting residual voids in the repository (backfilling drifts), chemical disturbances related to repository materials or any rise in temperature, in order to maintain the rock's properties.

ASSESSMENT OF THE REPOSITORY'S LONG-TERM SAFETY

The safety guidelines prepared by the French Nuclear Safety Authority (ASN) define the methods for assessing repository safety after closure. They provide for an iterative assessment approach to accompany all phases of the repository's development, up to its closure.

The safety assessments have shown that the repository's very long-term impact will be well below that of naturally occurring radioactivity. To ensure that the repository remains safe under all circumstances, **all phenomena liable to have an adverse effect on its performance and safety have been taken into account** (earthquake, erosion, intrusion, etc.) and their impact evaluated.

Cigeo's underground facility, for example, is designed to withstand any earthquakes that might occur in the very long term. Studies have been conducted to define the strongest earthquake that would be geologically possible over these long time scales. They have shown that Cigeo would withstand earthquakes of this magnitude.

Any uncertainties identified concerning safety-related repository components have also been taken into account, to ensure that the repository has no impact on human health in the event of design errors or failures, for example, if the argillaceous rock proves ten times more permeable than the conservative values based on scientific observations, if the glass in which HLW is incorporated dissolves in thousands of years instead of hundreds of thousands of years, or if the seals installed to close off the repository fail.

Studies have also been carried out to verify that in the event of intrusion into the repository (e.g. due to boring), its confinement capability would still be sufficient to keep its impact within regulatory standards.

5.3.
Safety monitoring at Cigeo

As its operator, Andra is responsible for safety at Cigeo. Safety objectives have priority over other project requirements.

Given the type of the waste it will house, Cigeo will be classed as a **basic nuclear installation** (INB). In accordance with regulations on basic nuclear installations (INB), Andra continually assesses safety performance as from the design phase. New measures may be implemented at any time based on the results of these assessments, changes in standards or technological progress.

The French Nuclear Safety Authority (ASN) and its technical support organisations, the French Institute for Radiological Protection and Nuclear Safety (IRSN) and the Advisory Committee for Waste, have conducted regular safety assessments of Andra's work since 1996.

Cigeo must observe the safety rules defined by the ASN. The construction licence application to be filed by Andra in 2015 will undergo **detailed review by the ASN** and its technical support organisations. **The licence will only be granted if Andra has demonstrated that the repository is safe and that all risks are controlled.** Commissioning of Cigeo will also be subject to ASN authorisation.

Thereafter, periodic safety reviews will be carried out (at least every ten years) over the entire course of Cigeo's operating life.

During the construction and operating phases, Cigeo will undergo inspections by the ASN, like all nuclear facilities. The ASN carries out regular inspections (several times a year, some of which are unscheduled) on Andra's facilities, and may impose additional requirements or even shut down the facility if it considers that a risk is not properly controlled.

5.4.
Radiological impact of Cigeo

DURING FACILITY OPERATION

Since the packages of waste received at Cigeo will contain no liquids and only small amounts of gaseous radionuclides, discharges from the facility during its operating phase will be very limited.

Almost all discharges from Cigeo will come from radioactive gases (carbon-14, tritium, krypton-85, etc.) released from certain ILW-LL packages. These gases will be channelled, measured and strictly controlled before being dispersed and diluted in the air. Discharges and their limits will be subject to authorisation by the French Nuclear Safety Authority (ASN) and will be strictly controlled during the entire operating phase.

An initial assessment, based on pessimistic assumptions, indicates that the **impact of the discharges will be approximately 0.01 millisievert per year (mSv/year) near the facility,** which is well below the regulatory standard (1 mSv/year) and considerably lower than the impact of naturally occurring radioactivity (2.4 mSv/year on average in France).

Liquid effluents liable to be contaminated with radioactivity will be collected via a specific network. Once collected, they will be analysed to check their level of radioactivity. If contamination is detected, they will be treated and managed as appropriate.

AFTER REPOSITORY CLOSURE

The long-term impact of the repository is evaluated both under normal operating conditions and in a degraded situation, to ensure that its impact will be as low as possible. The studies have shown that the **repository will have no impact for 100,000 years, and that in a nor-**

mal evolution scenario, its impact will be around 0.01 millisievert. In a **degraded situation** (human intrusion, failure of a repository component, etc.), the studies show that the repository's impact would still be **below 0.25 millisievert.**

This evaluation is based on research on thermal, chemical, mechanical, hydraulic, radiological or biological phenomena occurring inside the repository. This research has also identified the main areas of uncertainty and defined different scenarios to make pessimistic assessments of the impact of various foreseeable situations.

This methodology is implemented within a specific framework, defined by safety baselines defined at the international level by the International Atomic Energy Agency (IAEA) and the OECD's Nuclear Energy Agency (NEA), and at the national level by the French Nuclear Safety Authority (ASN). The safety guidelines prepared by the ASN define the methods to be used to assess the safety of the facility after closure. They provide for an iterative assessment approach to accompany all phases of the repository's development, up to its closure.

Dosimeter used to measure radioactivity around disposal facilities.

EXAMPLES OF RADIOACTIVITY EXPOSURE DOSES

The French public health code limits annual exposure for the population as a result of nuclear activities to 1 mSv per person (R.1333-8). For exposed workers, exposure must not exceed 20 mSv over a period of twelve consecutive months (Article R.4451-12 of the Labour Code).

- **0.01** mSv/year — **Estimated impact of Cigeo during operation**
- **0.02** mSv — Dose received during a chest x-ray
- **0.03** mSv — Exposure during a flight from Paris to New York
- **0.25** mSv/year — Andra's self-imposed limit for public exposure
- **1** mSv/year — Regulatory limit for public exposure in connection with industrial facilities
- **2.4** mSv/year — Average exposure to naturally occurring radioactivity in France
- **10** mSv — Order of magnitude for an abdominal scan
- **20** mSv/year — Regulatory limit for exposed workers
- **100** mSv — Occasional exposure dose below which no adverse health effect has been observed.

5.5.
Monitoring the repository and its environment

Andra has planned **various inspection, observation and monitoring measures for the repository and its environment,** throughout its operating life and after closure.

PREDISPOSAL INSPECTION OF PACKAGES

A **series of inspections** are and will be carried out on the packages before emplacement in the repository, both at the producers' sites prior to delivery and at Cigeo. These include:

- inspections carried out under the producers' responsibility, as part of the waste generation process and the request submitted to Andra for disposal of the waste at Cigeo;
- inspections carried out under Andra's responsibility, to ensure that the packages comply with the producers' declarations and Cigeo's safety specifications;
- second-level inspections, by coring, also carried out under Andra's responsibility as part of package quality monitoring.

REPOSITORY MONITORING

A monitoring programme will be implemented at Cigeo as from the construction phase and throughout its operating life, to keep track of repository safety-related parameters, such as machinery speed, hydrogen concentration, THE filter performance and ventilation air, etc.

ILW-LL reference cells

ILW-LL cells will be built gradually throughout Cigeo's operating life. The first will be **highly instrumented** to allow detailed observation. In addition, Andra proposes to seal one of these **reference cells** several years after waste package emplacement to continue observations in an enclosed configuration. The decision to close ILW-LL cells could then be based on the **results of these observations**.

In addition to monitoring in the strict sense of the term, parameters affecting the repository's medium- and long-term evolution will also be tracked and observed, such as: ambient air temperature, changes in diameter of structures (convergence of tunnels), concrete strength, steel corrosion, etc.

Individual monitoring for reference packages will be carried out in special rooms in which each reference package can be easily accessed and examined at regular intervals.

Reference structures representative of the repository's different components (seals, cells, etc.) and specifically dedicated to observation and monitoring will also be produced during the first phase of Cigeo construction. These structures will be equipped with many instruments to allow detailed monitoring of their behaviour and how they change over time.

Tens of thousands of sensors will be installed in Cigeo

The planned monitoring equipment includes existing sensors already in use in the nuclear industry and civil engineering, where significant experience feedback is available (after decades of use on nuclear reactors, dams, etc.), and innovative equipment being developed through R&D programmes.

ENVIRONMENTAL MONITORING

In 2007, Andra set up a “Perennial Observatory of the Environment” (OPE). One aim of the OPE is to determine the **initial state of the current environment around the future repository,** for a ten-year period, and then **to monitor changes during Cigeo's construction and throughout its operating life.** This will make is possible to verify that Cigeo has very little environmental impact.

The zone studied by the OPE covers an area of 900 km^2 around the possible Cigeo site. Within this area, more detailed studies are being conducted on a reference sector of around 240 km^2.

The system of studies in place is based on several hundred observation points supplemented by data and satellite and aerial photographs, experimentation plots and continuous monitoring stations (forest, agriculture, atmosphere and water).

Each year, more than 2,000 points are monitored for fauna and flora, and around a hundred more for crops and the physico-chemical and biological soil quality. In addition, over a ton of samples are collected and analysed, and more than 85,000 data items are recorded using protocols in accordance with current best practices.

To ensure the traceability and preservation of the data collected by the OPE, Andra is building a sample data bank (**écothèque**) to be commissioned in 2013. This is where the **samples will be preserved**, i.e. samples taken from matrices such as local farm produce (milk, cheese, maize, vegetables, fruit, etc), forest ecosystems (leaves, mushrooms, wood, game, etc.) and aquatic ecosystems (water, fish, etc.). The écothèque will operate for at least 100 years to monitor environmental changes throughout Cigeo's operating life. The related scientific tasks are carried out within national and international partnerships, as part of a certified observation system.

HEALTH SURVEILLANCE

On several occasions, local populations have expressed a desire for health surveillance around the repository. An expert panel has been set up to propose technical methods for this purpose. Andra has submitted the matter to its supervisory ministries to define the governance and organisation of such measures.

5.6. Creating a perpetual reminder of the facility's existence

In order **to inform future generations of Cigeo's existence** and content, systems already exist for ensuring that future generations remain aware of the repository once it is closed. In particular, this will protect against accidental intrusion. These are institutional archiving systems, which are supplemented by potential means of social transmission of knowledge from one generation to the next.

Andra has already implemented these measures at the CSM waste disposal facility. A detailed record, printed on archival paper and containing relevant technical documentation for monitoring and understanding how the repository operates, has been saved in several places. In addition, a summary document laying out the most important information relating to the repository has been designed for wide distribution among local authorities, notaries, local residents, government entities, etc.

At Cigeo, a “memory centre” will be maintained on the site. It will be open to the public and, in particular, will house the repository archives. Monitoring the site will also help ensure that the memory of the repository is passed on for as long as future generations consider necessary.

In general, local stakeholders should also be involved in preserving the memory of the site. In addition to their current contribution to implementing the relevant measures, they shall remain involved in the long term to keep this memory alive. **In this way, each generation will be responsible for passing this memory on to the next.**

STUDIES ON DEEP GEOLOGICAL DISPOSAL

6

INTRODUCTION For its research on deep geological disposal, Andra has called on the scientific community in a wide variety of fields (earth and environmental sciences, chemistry, materials science, applied mathematics, human and social sciences, etc.) through partnerships with research organisations and French higher education institutions. It is also very closely involved in international cooperation, in particular with its foreign counterparts, through collaborations or international bodies.

Research conducted over the past 20 years has served to demonstrate the feasibility and safety of deep geological disposal. Today, this research is paving the way for the construction and operation of Cigeo, as well as its closure and monitoring.

6.1.
Andra's instruments

In addition to major research equipment available through its partners, Andra has also developed **three R&D instruments** of its own, tailored to the specific needs of Cigeo.

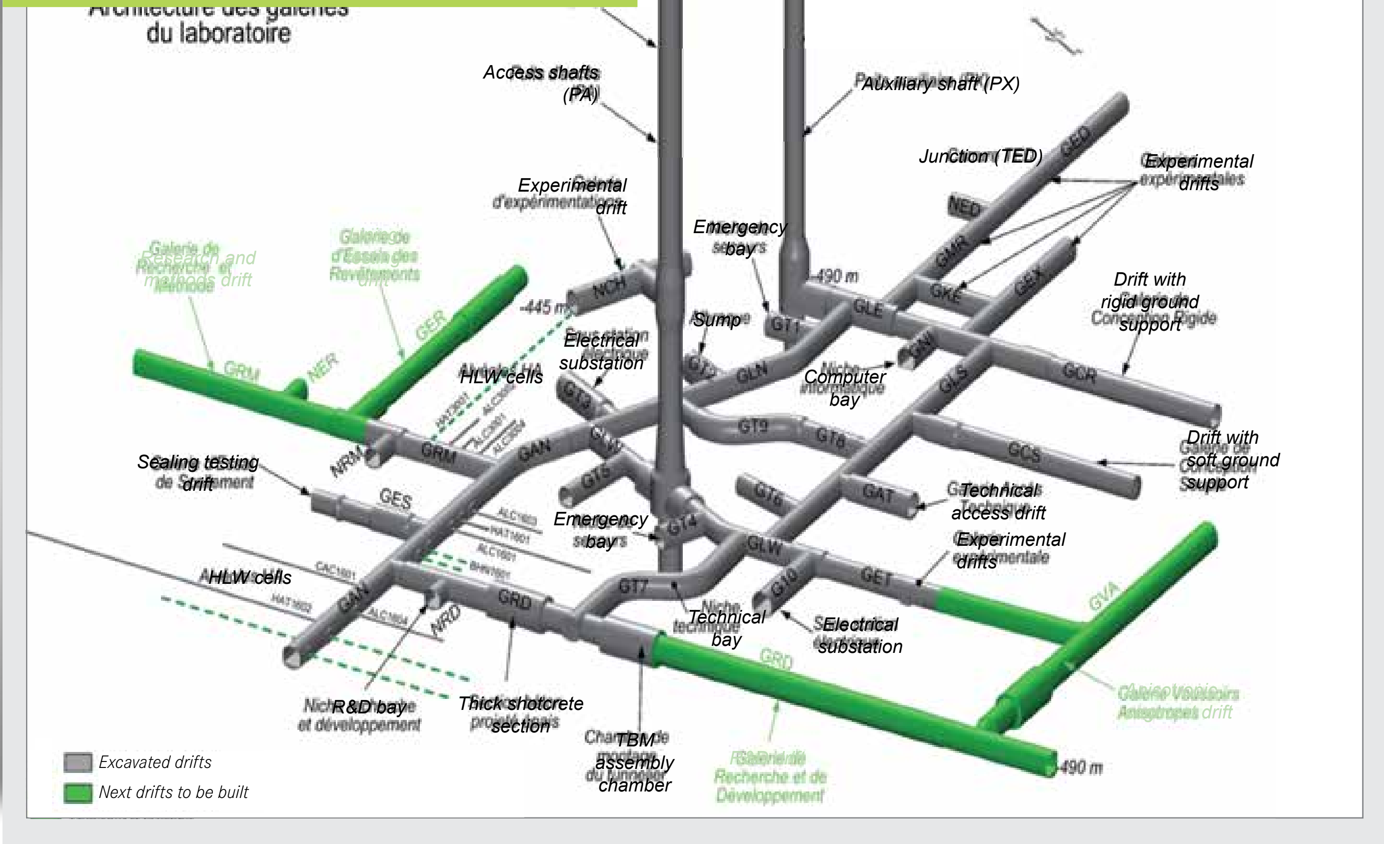
UNDERGROUND RESEARCH LABORATORY

Excavated directly in the clay formation, some 500 metres below ground, the underground research laboratory created in 2000 is a vital resource for successfully completing the studies and tests required for the Cigeo project. In particular, it allows the teams ***on site* to characterise** the thermal-hydro-mechanical and chemical properties of the clay, **determine the interactions between the geological medium and materials** that will be brought in during disposal, **develop construction methods for the structures,** observe how the structures perform over time, and test observation and monitoring methods.

The underground laboratory has an operating licence until 2030, which will allow it to accompany Cigeo up to its startup phase (2025-2030) and help train Cigeo personnel.

Since the laboratory's creation, **more than 40 experiments** have been set up in the underground drifts, almost **3,000 measuring points** (pressure, deformation, flow rate and temperature sensors, etc.) have been installed there and **more than 40,000 rock samples** have been taken.

ARCHITECTURE OF THE UNDERGROUND LABORATORY



SIMULATION AND NUMERICAL CALCULATION TOOLS

These tools are used to represent **complex phenomena over scales of time and space** that are not available in laboratory experiments. Numerical methods are thus a valuable tool for finding answers to the scientific issues raised by disposal, particularly for long-term safety assessment.

Studies are also being conducted to analyse any uncertainties and take them into account in repository design.

THE PERENNIAL OBSERVATORY OF THE ENVIRONMENT (OPE)

This novel facility is linked to many **national and international scientific networks** and has been certified as a **"Long-term observation and experimentation system for environmental research"** by the French National Alliance for Environmental Research (Allenvi).

Flux tower installed as part of the OPE project.

KEY FIGURES ON ANDRA'S R&D

- **15 boreholes** drilled from the surface between 2007 and 2008
- more than **1,200 metres of drifts** excavated in the underground laboratory
- more than **10 partner organisations** or **higher education institutions**
- **8 laboratory groups**
- more than **70 associated academic laboratories**
- participation in **12 European programmes** since 2006
- **member of the executive group of the European platform "IGD-TP"** *(Implementing Geological Disposal of Radioactive Waste Technology Platform)*
- **28 theses defended** since 2006
- **50 to 70 international scientific publications** per year for the past ten years
- some **twenty patents** registered in the past five years
- **5 international conferences organised** between 2002 and 2012 *"Clays in Natural & Engineered Barriers for Radioactive Waste Confinement"*

6.2.
Fields and goals of scientific studies

In 2025, Andra will have more **than 20 years of operating experience feedback** from the underground laboratory.

The scientific studies conducted over the past 20 years on the Cigeo project have drawn on complementary approaches and fields. The primary aim of these studies is to acquire the basic information needed to create a strong base for project development, particularly:

- the detailed content (chemical and radiological) of waste packages;
- basic parameters relating to radionuclides (e.g. solubility) and repository materials for subsequent assessment of their behaviour under disposal conditions;
- the properties of the geological medium (such as permeability, the composition of water contained in the pores or thermal conductivity) on different scales (from a centimetre to ten metres) to ensure that it is suitable for housing a repository and limiting the transfer of radioactivity;
- the mechanisms, such as diffusion and convection, by which elements are transferred to the materials, geological medium or biosphere, to learn more about how these elements are dispersed in the geological medium, in what quantities and on what scales of time and space;
- the dynamics of geological phenomena such as erosion or hydrogeological flows in the layers of the Paris Basin to ensure that the repository will remain stable over very long periods of time.

The results of this research have been collected by Andra and its scientific partners within national and international programmes. They have undergone peer reviews, appeared in scientific journals, been discussed at conferences and provided subject matter for theses. R&D thus plays a valuable part in steering Cigeo's development and supporting its operations. It serves to define the optimum geometry (size, orientation, etc.) for repository structures, select design dimensions and ensure that construction does not impair the confinement properties of the geological medium.

6.3.
Research aims

1 / SITING CIGEO

Characterising the geological medium, based on regional studies, boreholes, geophysical measurements and observations made in the underground laboratory, has provided detailed knowledge of the formations in terms of geometry, structure, stability, uniformity and continuity, etc.). This characterisation is the basis for gradually choosing a site for Cigeo, deploying its facilities and, at a later stage, providing operating support.

2 / DEFINING WASTE DISPOSAL PROCEDURES

Research here is based on detailed knowledge of the waste packages and helps identify disposal methods (packaging, materials used, distribution of packages in cells, etc.) so as to control the evolution of the waste as closely as possible, operate the repository safely and limit radionuclide release in the long term.

3 / DETERMINING REPOSITORY BEHAVIOUR DURING ITS OPERATING LIFE AND AFTER CLOSURE

Cigeo design and safety analysis require careful identification and quantification of various processes that will unfold for up to a million years once the repository is opened. These processes may be thermal (heating of rock by waste packages), mechanical (damage to and convergence of rock), hydraulic (movement of fluids) or chemical (alteration of materials and interactions with waste). They have been reproduced under experimental conditions, observed in the underground laboratory and simulated to assess their long-term evolution.

4 / DESIGNING THE STRUCTURES TO ENSURE OPERATIONAL SAFETY AND PRESERVE THE GEOLOGICAL MEDIUM

Insight into the behaviour of repository components gained through experiments and technological testing is crucial to package and repository structure design. This allows design teams to select the best material formulations (steel, concrete, clay), define methods for their use, and characterise the structures to be built (thickness, density, etc.).

5 / TESTING INDUSTRIAL SOLUTIONS

Based on the knowledge acquired through the above research, technological testing can be performed to assess the industrial solutions that may be used to build, operate and close the repository. These tests concern, for example, container manufacturing and disposal cell construction, package handling and repository monitoring and closure methods.

Sealing experiment in an underground laboratory drift.

Excavation and ground support

The 1,200 metres of drifts excavated in the underground laboratory are used to test various construction methods for repository drifts and to monitor how structures change over time.

Operation

The rock's reactions to conditions representative of the future repository have been observed at the underground laboratory through studies on the impact of operating conditions, particularly ventilation, during the different phases. Prototypes of repository containers and handling machinery have also been made for use in full-scale tests on processes that could be used for emplacing packages in the disposal cells and retrieving them if necessary.

Closure

Seals are important for safety at Cigeo after closure as they prevent water from circulating in the repository. Andra has set up a major test programme to verify sealing feasibility for the purposes of the repository licence application. A full-scale industrial experiment is currently in progress to test the construction of a swelling clay-based core with the repository's concrete confinement buttresses. This test is being conducted with European cooperation initiated by IGD-TP. Various tests are also under way at the underground laboratory (compression test or test on the interruption of a damaged zone, construction of a half-scale sealing core which will subsequently be resaturated, etc.). These are in preparation for the construction of sealing demonstrators in Cigeo to be implemented during the first phase of construction.

5 / MONITORING OPERATION AND PROVIDING FOR REVERSIBILITY

An overall strategy encompassing package inspection and structure, environmental observation and monitoring is being developed as part of the project. It will enable repository performance to be monitored and provide valuable operating experience feedback for use in designing the following phases and reviewing safety and reversibility conditions at regular intervals. More specifically, suitable observation and monitoring means are required to ensure that the disposal process is reversible for a period of about one hundred years. In particular, the results of scientific studies can be used to identify which changes to monitor, ensure the redundancy, complementarity and robustness of the measurement system, and provide discrete, stand-alone sensors that are robust over time. At the same time, in the aim of supporting technical work on reversibility, human and social science research is being conducted on intergenerational transmission of knowledge and understanding long time scales and memory.

Cigeo's transition to an industrial design phase does not mean that Andra no longer has any need to maintain high-level R&D. It must provide scientific and technical support for the repository licence application, and for the periodic reviews that the repository will have to undergo. More generally, continuing the R&D on radioactive waste and its conditioning and disposal will contribute to Cigeo's safety and reversibility, and allow technical and economic improvements to be made during its operating life.

Scientific experiments conducted in drifts at the underground laboratory.

6.4.
How is Andra research evaluated?

Andra's R&D activities are regularly assessed by various bodies, including:

- the National Assessment Board (CNE). The CNE's annual report is submitted to the Government and to Parliament (Parliamentary Office for the Evaluation of Scientific and Technology Choices) and published;
- the French National Safety Authority (ASN), which relies on the scientific and technical expertise of the French Institute for Radiological Protection and Nuclear Safety (IRSN) and the advisory committees;
- Andra's Scientific Council, which evaluates the Agency's scientific strategy and the divisions' activities. It is consulted on research and development programmes conducted by the Agency, and evaluates results. The Guidance and Monitoring Committee (COS) of the Underground Research Laboratory, which reports to the Scientific Council, is more specifically tasked with evaluating the experiments carried out at the underground laboratory.

At the request of the French Government, the major scientific and technical dossiers which Andra submits as required by law can be subject to international reviews conducted under the aegis of the Nuclear Energy Agency (OECD/NEA).

Andra was also evaluated in 2012 by the French Agency for the Evaluation of Research and Higher Education (AERES).

Lastly, the Local Information and Oversight Committee for the Underground Research Laboratory orders regular expert surveys regarding Andra's large dossiers or more specific topics.

The French Agency for the Evaluation of Research and Higher Education (AERES) has stated that Andra is ***"the recognised international leader in waste disposal in an underground clay medium"*** and can pride itself on its *"exceptional technical expertise",* thanks to the specific research tools which the Agency has developed (Assessment Report on the French National Radioactive Waste Management Agency - September 2012).

ASSESSMENT REPORT NO.6 BY THE NATIONAL ASSESSMENT BOARD NOVEMBER 2012

- *Glass and clay in a deep geological layer act as effective confinement barriers for fission products and actinides for hundreds of thousands of years. This timeframe is sufficient to lower toxicity to a level that no longer represents any threat to populations living above the repository;*
- *The Meuse/Haute-Marne geological site was chosen for detailed investigations because a layer of clay more than 130 metres thick, and 500 metres below ground, showed excellent confinement properties: stability for at least 100 million years, very slow circulation of water, high element retention capacity;*
- *Repository design (shafts, drifts, cells, ventilation, seals) and the methods and procedures needed to ensure safety, both during operation and after definitive closure, are being developed. Enough progress has been made in these areas to begin the industrial phase, in accordance with the law. This is a concrete construction project, with all the necessary development, innovation and engineering stages. It requires careful oversight, and review of the repository licence application in 2015 will be an important milestone in this regard.*

GOVERNANCE AND REVERSIBILITY

7

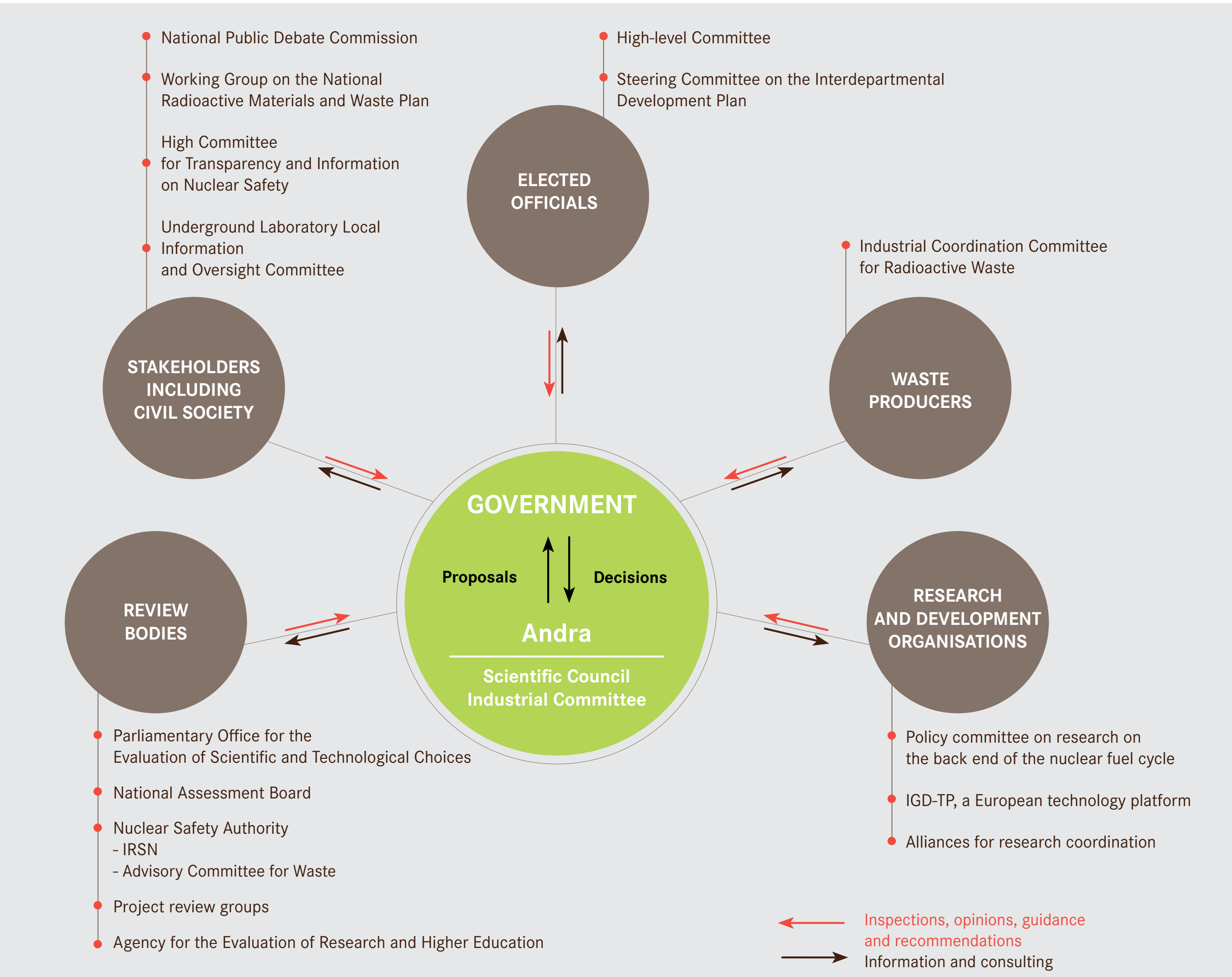
INTRODUCTION Disposal at Cigeo is designed to be reversible for at least 100 years. In order to meet this requirement by Parliament, Andra has taken industrially realistic technical measures that not only allow waste packages to be retrieved from the repository, but also ensure that Cigeo can adapt to future changes without compromising its safety.

Many stakeholders (including review bodies, elected officials, representatives of civil society and waste producers) are already involved in the governance of the project to address the many safety-related, social and industrial issues involved. Following on from the step-by-step process set out in the 1991 Bataille Act, Andra suggests that milestones for regular meetings with these stakeholders should be scheduled once Cigeo has been commissioned.


ADOC

7.1.
The governance of Cigeo

The Cigeo project must address many safety-related, industrial and social issues. The governance of the project involves various parties and stakeholders concerned with these issues and allows them to express their points of view and expectations, under the supervision of the Government and review bodies. Andra recommends that this process, which was set up at the start of the project in 1991, should remain in place throughout Cigeo's lifetime.



Governance of the Cigeo project

ADDRESSING SOCIAL CHALLENGES

Andra provides local elected officials and socio-economic stakeholders with regular updates on the project's progress and considers what they have to say. For example, the choice of site for the Cigeo underground facility in 2009 took into account regional planning and local integration criteria put forward by local stakeholders.

As its name implies, the Bure Laboratory's Local Information and Oversight Committee (CLIS) is generally concerned with oversight, information and consultation regarding research into radioactive waste management, particularly deep geological disposal. Discussions with the special commissions set up by the CLIS (for example, on reversibility, environment and health, possible repository siting, communication) help identify local expectations. Andra then considers to what extent these can be taken on board in the project.

At the national level, the High-level Committee, chaired by the Minister of Energy, is responsible for overseeing and spurring support and economic development measures in connection with the Laboratory and later with Cigeo. It monitors progress on the interdepartmental development plan, under the aegis of the Prefect of the Meuse department, who acts as coordinating prefect.

Under the Act of 28 June 2006, the High Committee for Transparency and Information on Nuclear Safety is responsible for periodically organising meetings and debates on the sustainable management of radioactive materials and waste. Looking ahead to the public debate, the Minister of Energy has asked the High Committee to prepare a report providing an inventory of radioactive waste considered by the Cigeo project and describing the decision-making process behind the project's definition.

The French National Radioactive Materials and Waste Management Plan (PNGMDR) is prepared and updated every three years by a pluralistic working group. This group is co-chaired by the Ministry of Energy and ASN, the French Nuclear Safety Authority. Its members include representatives of waste producers, Andra, environmental protection societies, elected officials, public authorities and review bodies. The plan estimates the foreseeable need for storage and disposal facilities, specifies the required capacities and sets the goals to be achieved for radioactive waste without a final management solution.

ADDRESSING SCIENTIFIC AND SAFETY CHALLENGES

Andra is the nuclear operator of Cigeo and, as such, is responsible for its safety. The Agency is therefore particularly responsible for design choices and their implementation, which are a long-term commitment.

The French Nuclear Safety Authority (ASN) and its technical support organisations, the French Institute for Radiological Protection and Nuclear Safety (IRSN) and the Advisory Committee for Waste have conducted regular safety assessments of Andra's work since 1996. In addition, the ASN defines requirements to be met by Cigeo and carries out regular inspections.

The French National Assessment Board (CNE) was set up under the 1991 Bataille Act to carry out annual reviews of progress in research programmes and studies on the management of radioactive materials and waste. Its annual report also includes foreign research activities. The report is submitted to Parliament and published.

The French Agency for the Evaluation of Research and Higher Education assessed Andra's work in 2012.

Andra's research activities are coordinated with those of other R&D organisations, particularly in connection with the Monitoring Committee on Research on the Back End of the Nuclear Fuel Cycle (COSRAC).

ADDRESSING INDUSTRIAL CHALLENGES

Andra was assigned the task of designing the repository under the Act of 28 June 2006 so that the licence application could be examined in 2015. The Agency must constantly coordinate R&D, safety-related and engineering activities to find technical solutions that meet all the requirements as closely as possible. Andra calls on prime contractors specialising in fields such as nuclear facilities and underground work to carry out industrial studies. The Scientific Council and the Industrial Committee, which both report to Andra's Governing Board, are advisory bodies. External experts from industry are invited to attend regular project reviews, organised under the aegis of the Ministry of Energy, to assess the project.

Areva, the CEA and EDF are responsible for the characteristics of the waste packages they deliver to Andra and for transporting them to the repository. They are also responsible for funding studies and research work on Cigeo and the construction, operation and closure of the facility. Under a cooperation agreement signed with Andra, the project can benefit from their operating experience feedback as nuclear facility operators, in accordance with each party's responsibilities.

The Industrial Coordination Committee for Radioactive Waste gives opinions and makes recommendations on organising, developing and optimising radioactive waste management solutions. Its members are representatives of the Ministry of Energy, Andra and waste producers.

GOVERNANCE AND REVERSIBILITY

The Advisory Committee for the Implementation of the Information and Consultation Plan (COESDIC), set up under the aegis of Andra's Scientific Council, draws attention to the connection between governance and reversibility: *"The implementation of reversibility, which refers to a particular form of decision-making, implies novel governance structures. These must seek to ease the integration of technical and scientific progress in repository design and operation, and promote adaptability to changes in demand by society".*

7.2. Reversibility: Andra's proposals

Responding to a strong demand by society, the Parliament required in 2006 that disposal be reversible for at least 100 years. The conditions for reversibility will be set by a new law that will be passed before Cigeo is licensed.

What is expected of a reversible disposal facility?

- Safe disposal
- A facility where waste packages can be retrieved
- A process by which current decisions can be reversed: Which waste will be disposed of? When will disposal begin for each type of waste? When will the repository be closed?

Andra's proposals are intended to respond to the expectations related to reversibility that were identified as part of an extensive dialogue that has taken place since 2006. This process took place on all levels: local (commission on reversibility of the Local Information and Oversight Committee, meetings with the public and local stakeholders), national (scientific colloquia, exchanges with review bodies, meetings with organisations), and international (international project sponsored by the OECD's Nuclear Energy Agency, and an international conference in Reims in December 2010).

1 / TECHNICAL CONCEPTS FOR ENTIRELY SAFE RETRIEVABILITY OF WASTE PACKAGES

Equipment designed to place waste packages in disposal cells is also designed to retrieve them if necessary. To facilitate retrieval, packages are designed with specific handling interfaces (for example, ceramic runners for sliding HLW packages in the disposal cell). Space will be left around packages after their emplacement in the cell. The waste packages and disposal cells are designed using best industrial practices to ensure durability and robustness. Systems for monitoring disposal cells will provide the information on technical conditions necessary for a retrieval operation.

Will retrieval of waste packages be necessary in the event of an accident?

In such an event, the facility will be secured by rapid installation of temporary equipment (ventilation, confinement barrier, etc.) rather than by retrieval of packages. Once the facility is secure, the operator will consider measures to implement for a return to normal operation. Keeping the packages in place, even if damaged, or possible retrieval, could then be decided without urgency.

Andra has already created prototype equipment for package handling. Full-scale retrieval tests have already been performed with mockups to simulate situations in which the disposal cell is deformed. Retrieval tests will also be performed in Cigeo before it receives its operating licence. Tests will continue once Cigeo is in operation.

If the decision is taken to retrieve a large number of waste packages, special facilities would need to be built on the surface to manage them (for storage, onward shipping, processing, etc.).

Any significant operation to retrieve waste packages would require special authorisation.

2 / A REPOSITORY THAT CAN BE ADAPTED

Cigeo is designed so that the architecture of the underground facility can evolve over its operating lifetime. It will be built in successive phases that could take into account:

- possible changes in the inventory of waste to be disposed of, e.g., in accordance with changes to France's energy policy,
- scientific and technical changes,
- operating experience feedback, particularly from repository monitoring.

Any significant change in the inventory will be subject to new authorisation and a new public inquiry.

Test for emplacement and retrieval of ILW-LL waste packages

Test to retrieve a high-level waste package in a highly deformed disposal cell.

3 / GRADUAL CLOSURE

The deep radioactive waste repository is a facility intended to be closed definitively to limit exposure of future generations. Closure of the repository will occur gradually, from closure of disposal cells to shaft and ramp sealing. Each step in the closure process will add additional "passive" safety systems and reduce the need for human actions to monitor safety.

The European directive of 19 July 2011 defines disposal as “the emplacement of spent fuel or radioactive waste in a facility without the intention of future retrieval”.

The retrievability scale published by the OECD’s Nuclear Energy Agency shows the progress of passive safety in the repository through the steps of the closure process. It also shows retrieval of waste packages will be increasingly complex with the completion of these steps, which will constitute the most significant decisions of Cigeo’s operation.

A reference schedule of the closing steps will be established as part of Cigeo's repository licence. The decision calendar will thus be available to all organisations involved. This schedule may be changed during operation, since with Cigeo’s design, each closing step can be delayed.

Each step in the repository closing process will require specific authorisation. The first closing step will not take place before 2040.

4 / MILESTONES FOR REGULAR MEETINGS AFTER COMMISSIONING

Andra has proposed to continue the step-by-step process initiated by the 1991 Act by organising milestones for regular meetings with all groups concerned to prepare decisions concerning plans for development and closure of the repository and reassessing reversibility conditions.

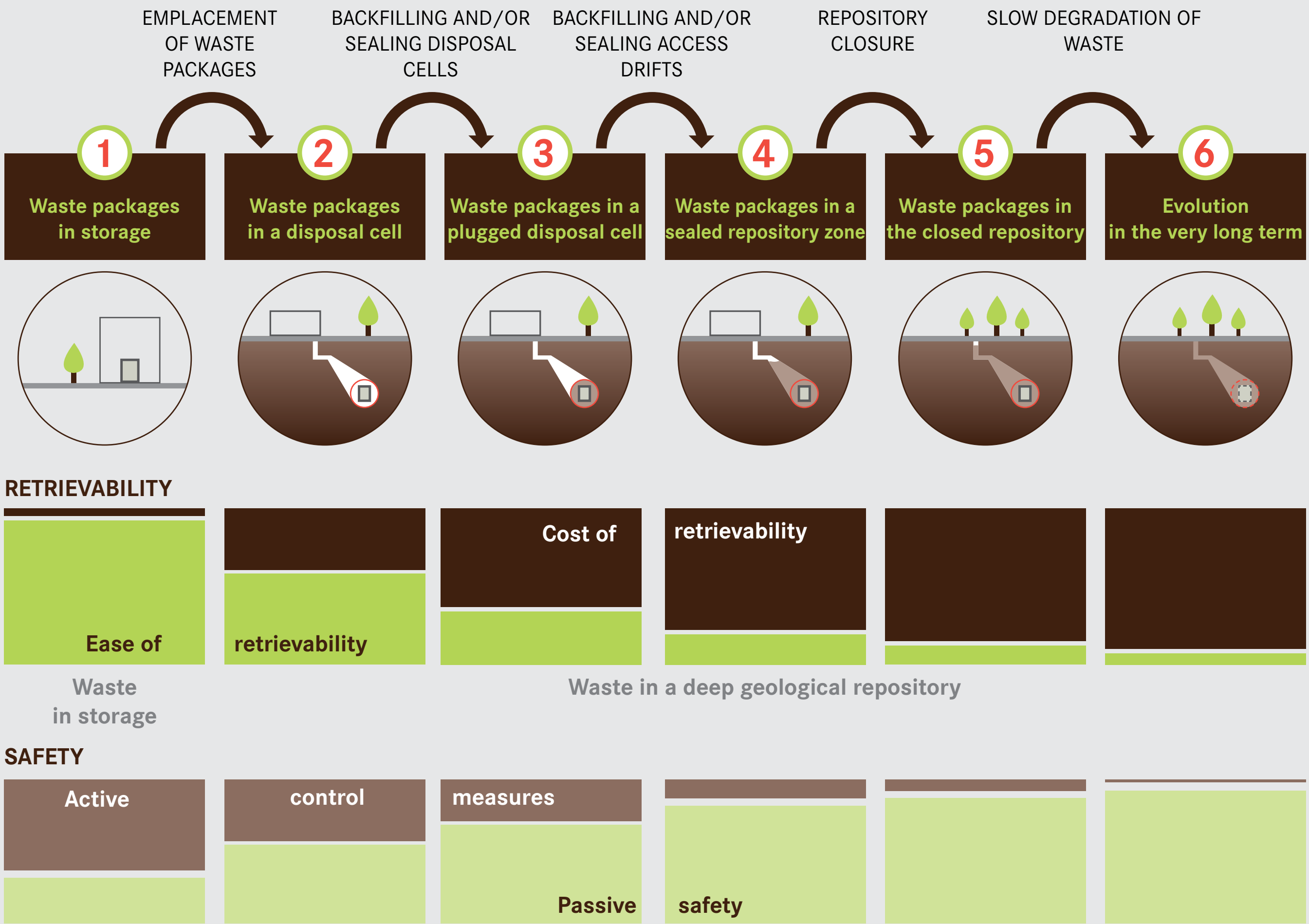
During these meetings, which may take place every ten years, a report will be prepared on the operation of the repository. It will take into account periodic safety reviews, lessons drawn from observations of the repository and its environment, and economic and social outcomes. Changes in scientific and technical knowledge as well as the objectives of the French National Radioactive Materials and Waste Management Plan will also be presented.

Andra is proposing that the first of these meetings be held five years after Cigeo is commissioned.

WITH REVERSIBLE DISPOSAL, IT IS POSSIBLE TO **RECONSIDER DECISIONS, MODIFY THE REPOSITORY CLOSURE SCHEDULE** UP TO DEFINITIVE CLOSURE AND **RETRIEVE PACKAGES IF NECESSARY.**

EVEN-HANDED GENERATIONAL SHARING FOR FINANCING REVERSIBILITY

Current generations shall finance the resources required for final, safe disposal of their radioactive waste (construction, operation and closure of Cigeo). This includes the cost of technical measures taken to ensure reversibility. Current generations are thus offering future generations options for acting on the disposal process. If future generations decide to modify this process, particularly by retrieving packages, they will assume the cost.



As part of the international project on *"Reversibility and Retrievability"* carried out from 2007 to 2011, the OECD Nuclear Energy Agency has established definitions and methods concerning reversibility.

The international retrievability scale which resulted from this NEA project provides a relevant framework for describing the stages in the process that leads to closing the repository.

LEVEL 1 of the international scale concerns storage of waste packages.

AT LEVEL 2, waste is transported from the storage site to the disposal site, then transferred to underground structures, which may require conditioning in disposal containers.

AT LEVEL 3, additional barriers are installed in the disposal cells to seal them. These barriers ensure phenomenological decoupling between the cells and access drifts. In general, backfill is used for rock deformations and/or seals are used to limit circulation of water and gas.

AT LEVEL 4, drifts are backfilled and/or sealed, which may correspond to closing the repository zone in which the drift is located, or even closure of the entire underground facility.

AT LEVEL 5, the repository is closed. Access from the surface is sealed and surface installations are dismantled.

LEVEL 6 designates the final state of the repository. Even if the integrity of the waste packages cannot be ensured, waste remains confined inside the facility. Safety no longer depends on maintenance or monitoring. Measures intended to ensure the conservation of knowledge and the memory of the site can continue.

Changes in the ease of retrieval and in repository safety according to the level on the international retrievability scale.

THE PROJECT AND ITS HOST COMMUNITY

8

INTRODUCTION Cigeo is a vital industrial development project for the community. Construction and operation of the repository will span more than 100 years. Infrastructure must be developed to supply the site with water and electricity and roads built for access. The construction of Cigeo requires preparing its host environment. For this purpose, the Government has tasked the Prefecture of the Meuse department with coordinating the preparation of an interdepartmental development plan covering both departments (Meuse and Haute-Marne). Andra and waste producers are also helping to prepare this plan which will be presented during the public debate.

Charmois
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D169
Ménil-
-sur-Saulx
Fouchères-
aux-Bois
Villers-
-le-Sec
D5
D111
la Saulx
le Bouchon-
sur-Saulx
D5
la Grande Ferté
Nantois
Naix-aux-Forges
Saint-Amand-
sur-Ornain
la Barboure
Boviolles
Canal de la Marne au Rhin
D140
D966
la Brie Bosselin
D127
le Breuil
Tréveray
D166
Hariésard
D140
Ornain
D31
Hévilliers
D31
St-
-Joire
Laneuville
les Terres
Rouges
D966
Evaux
Dammarie-
sur-Saulx
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D127
D31
Couvertpuis
D127b
Morley
le Val Fournier
D5
la Tranchotte
Beauregard
la Malmaison
Mont Gérard
Biencourt-
sur-Orge
Thiébaut
D191
l'Orge
D127
Chabot
Ecurey
Ribeaucourt
Grignoncourt
La Grange Allard
Le Fourneau
l'Ormançon
Montiers-
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la Haje
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Domrémy
St. Antoine
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Bonnet
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Ferme St.
Paroy-
sur-Saulx
le Haut Bois
le Clair
Chêne
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le Val Louzet
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la Bureau
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la Grande Vigne
Ferme
du Cité
D960
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Mandres-
en-Barrois
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les Ecruts
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Harpéjoute
Pancey
Ferme de Frinval
Gillaumé
la Houpette
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Heurtebise
Ferme de Gillaumont
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la Fortelle
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D257
Cirfontaines-
en-Ornois
Vandelaine
Chateau de Beaupré
Montreuil-
sur-Thonnance
Aingoulaincourt
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D175
D32
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D215
Harméville
Soulaincourt
D257
D115
D183
D251
Lézeville
la Forge
Sailly
D151
D714

8.1. The interdepartmental development plan

The construction of Cigeo requires preparing its host environment. Not only must the necessary infrastructure be built (means of transport, water and electricity supplies, digital networks, etc.), but a strategic framework for employment, economic development and drawing new residents to the area must be implemented.

The French Government requested that a development plan for both the Meuse and Haute-Marne departments be prepared. This plan is being prepared under the aegis of the Prefect of the Meuse department (who is acting as coordinating prefect) in coordination with local bodies (local authorities, consular chambers, etc.). Andra and nuclear energy companies are also participating in its preparation.

The draft scheme has already identified the issues in each field as well as scenarios. It will be rounded out with operations to be carried out and their timetables, both of which will be defined in consultation with regional development bodies. As such, it will boost the economic impact related to the construction of Cigeo and its benefits for the area as well as coordinate the actions of the various parties involved.

Apart from discussions on the hosting of hundreds of permanent jobs, discussions are being held on accommodation for itinerant workers. Temporary accommodation in the form of gîtes or furnished units near the construction site is just one of the services that may be made available to them. The plan will make it possible to coordinate housing providers so as to ensure that supply is in line with demand.

A platform for matching job offers with job seekers and coordinating training is also proposed. This mechanism is organised with public employment services in both departments (job centres, chambers of commerce and industry, sectors of industry). Andra and industry operations are participating in this approach aimed at supporting the job market with their job information sheets and job offers.

8.2. Cigeo requirements

MATERIAL AND INFRASTRUCTURE REQUIREMENTS

Infrastructure must be developed to supply Cigeo with water and electricity and roads will have to be built for access to the site.

Water requirements

Water requirements once Cigeo is commissioned in 2025 are estimated at around 100 m^3 per day (the average consumption of a population of 700). During the initial construction site phase (2019-2025), water requirements will rise to around 500 m^3 per day (average consumption of a town with a population of 3,500). This amount covers workers' requirements (catering, sanitation facilities, etc.) and those relating to the operation of Cigeo (water for making concrete, reserves for fighting fires, etc.). All site water will be recovered, inspected and dealt with as appropriate. One design objective is to limit liquid discharges. That is why Andra plans to reuse waste water from the site as much as possible, after treatment if necessary.

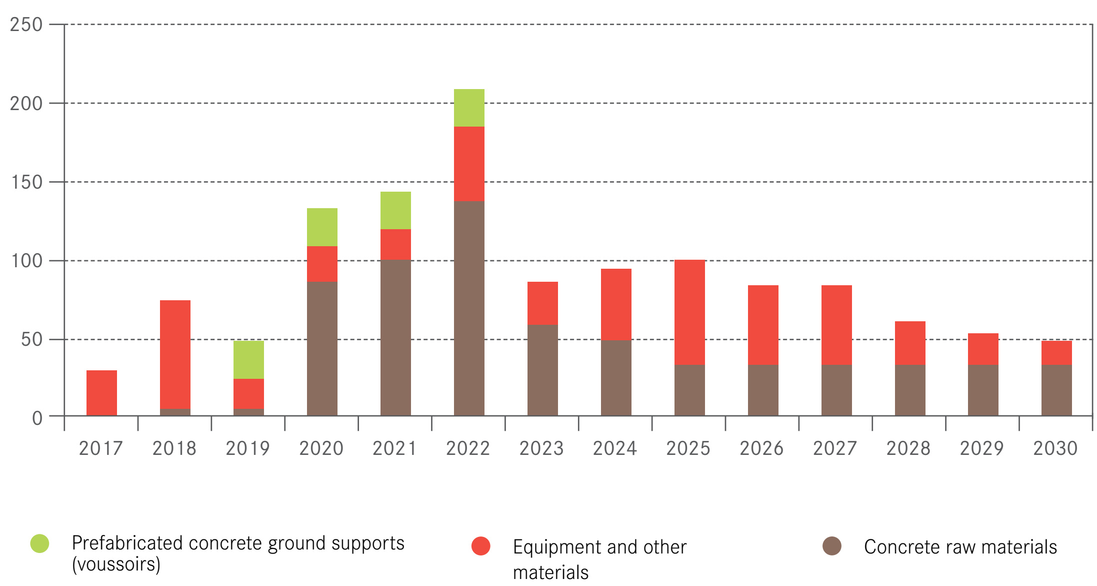
Electricity requirements

Cigeo's electricity requirements are estimated at around 90 MW. RTE is working on connecting Cigeo to a power supply based on Andra's requirements. It will also be the project owner for the electrical substation connecting up to the 400 kV grid.

Access

Building materials (aggregates, cement, etc.) for repository structures will need to be transported to the site. Studies are under way to see whether some of these materials can be transported by rail or water. Possible routes for oversized loads have been studied as part of the interdepartmental development plan. Regarding personnel, Andra's staff transport plan will focus on promoting carpooling and collective transport. Special arrangements will also need to be made for access to Cigeo's two surface sites (access to the shaft zone, diversion of the secondary road near the ramp zone, etc.).

PRELIMINARY ESTIMATE OF THE NUMBER OF SHIPMENTS REQUIRED TO SUPPLY CIGEO WITH MATERIALS DURING THE INITIAL CONSTRUCTION PHASE AND AT THE START OF OPERATION (TRUCKS PER DAY)



50 trucks are equivalent to 10/15 wagons or 2/3 “Freyssinet” barges.

PREPARATORY WORK (2016-2018)
AND INITIAL CONSTRUCTION WORK ON CIGEO BEFORE COMMISSIONING

Water requirements	About 500 m^3/day
Electricity requirements	About 90 MW
Material requirements	
Cement	About 90,000 tonnes/year
Sand	About 250,000 tonnes/year
Aggregates	About 300,000 tonnes/year
Household waste	About 350 tonnes/year
Industrial waste	About 2,800 tonnes/year

COMPLETION OF CONSTRUCTION OF THE FIRST PHASE
AND OPERATION (2025-2030)

Water requirements	About 100 m^3/day
Electricity requirements	About 90 MW
Material requirements	
Cement	About 20,000 tonnes/year
Sand	About 55,000 tonnes/year
Aggregates	About 70,000 tonnes/year
Household waste	About 200 tonnes/year
Industrial waste	About 1,000 tonnes/year

8.3.
Jobs

Direct jobs generated by Cigeo (excluding the underground laboratory):

1,300 to 2,300
jobs between 2019 and 2025

600 to 1,000
jobs during 100 years of operation.

Cigeo is an industrial development project for the community. Construction and operation will span more than 100 years.

According to Andra's estimates, between 1,300 and 2,300 people will be involved in building the first Cigeo installations over the period 2019-2025, in addition to the 335 currently involved in activities relating to the underground laboratory. During the operating phase, between 600 and 1,000 people will be employed on the site permanently to operate Cigeo while construction work continues. These preliminary construction and operating estimates will be consolidated in later studies.

In addition to these direct jobs on the site, Cigeo will generate indirect jobs, particularly with suppliers and service providers in the Lorraine and Champagne-Ardenne regions, as well as jobs induced by Cigeo employees spending in the area (purchases, housing investment, etc.). Cigeo will boost the development of local businesses. In addition, as Cigeo is guaranteed to remain in operation for over a century, some companies will most likely decide to set up locally, thus generating new business in the area.

Examples of skills and competences required at Cigeo:

- underground engineering specialists, civil engineers, geotechnicians, ventilation specialists;
- site managers, site foremen, drillers, construction vehicle drivers, skilled workers (mechanics, welders, electricians);
- safety engineers;
- laboratory technicians;
- buyers, administrative staff, warehouse clerks, procurement officers, quality technicians, logisticians;
- security personnel, cleaning and maintenance personnel.

All professions considered, about 50% of workers, 20% of supervisors, technicians and employees and 30% of managers must meet a specific qualification requirement.

8.4.
Current economic support for the project

Two public interest groups have been set up in the Meuse and Haute-Marne departments to manage facilities and amenities for easing the construction and operation of the underground laboratory and Cigeo and to carry out planning and economic development initiatives at department level. They must also support initiatives relating to training and to developing, promoting and disseminating scientific and technological knowledge. Each department received a €30 million grant in 2012.

EDF, CEA and Areva also have policies aimed at promoting local economic development. Examples include building new facilities (EDF spare parts distribution centre in Velaines, EDF and Areva archive buildings in Bure and Houdelaincourt respectively, the CEA Syndièse project in Haute-Marne), helping local firms to develop specialist expertise and boost their business with nuclear operators and working on initiatives to control the demand for energy more effectively and reduce CO_2 emissions from buildings.

EDF archives in Bure (Meuse)

8.5.
Andra in Meuse/Haute-Marne today

Andra's Meuse/Haute-Marne site generates more than 300 direct jobs (Andra employees and service providers) in connection with its various facilities: the Underground Research Laboratory, the Technological Exhibition Facility, the Core Sample Library, the monitoring stations of the Perennial Observatory of the Environment and the Ecothèque.

Andra also implements a determined policy to develop relations with local economic stakeholders and support indirect jobs in the region. Over the past four years, this policy has been supported by an annual event called "Become an Andra subcontractor", which targets local SMEs. It allows businesses to learn about Andra's requirements and procedures and prepare future markets. Énergic ST 52/55, an association that brings together businesses in the energy and public works sectors, is also involved in developing skills in partnership with Andra. This joint policy is paying off. In 2011, the two regions accounted for 10% of the total amount of invoices (excl. VAT) concerning the Cigeo project. This amount represents work with more than 250 local public and private businesses, with 60% in Lorraine and 40% in Champagne-Ardenne. Of these businesses, 30% are located in the Meuse department and 30% in Haute-Marne.

These direct and indirect jobs in the region also induce other jobs as a result of spending by employees in the area. According to a survey in 2010, 52% of Andra employees lived less than 20 km from the site and 97% less than 45 km. In addition, 77% lived in Lorraine or Champagne-Ardenne on a permanent basis, 51% were house-owners and 57% had children in primary school.

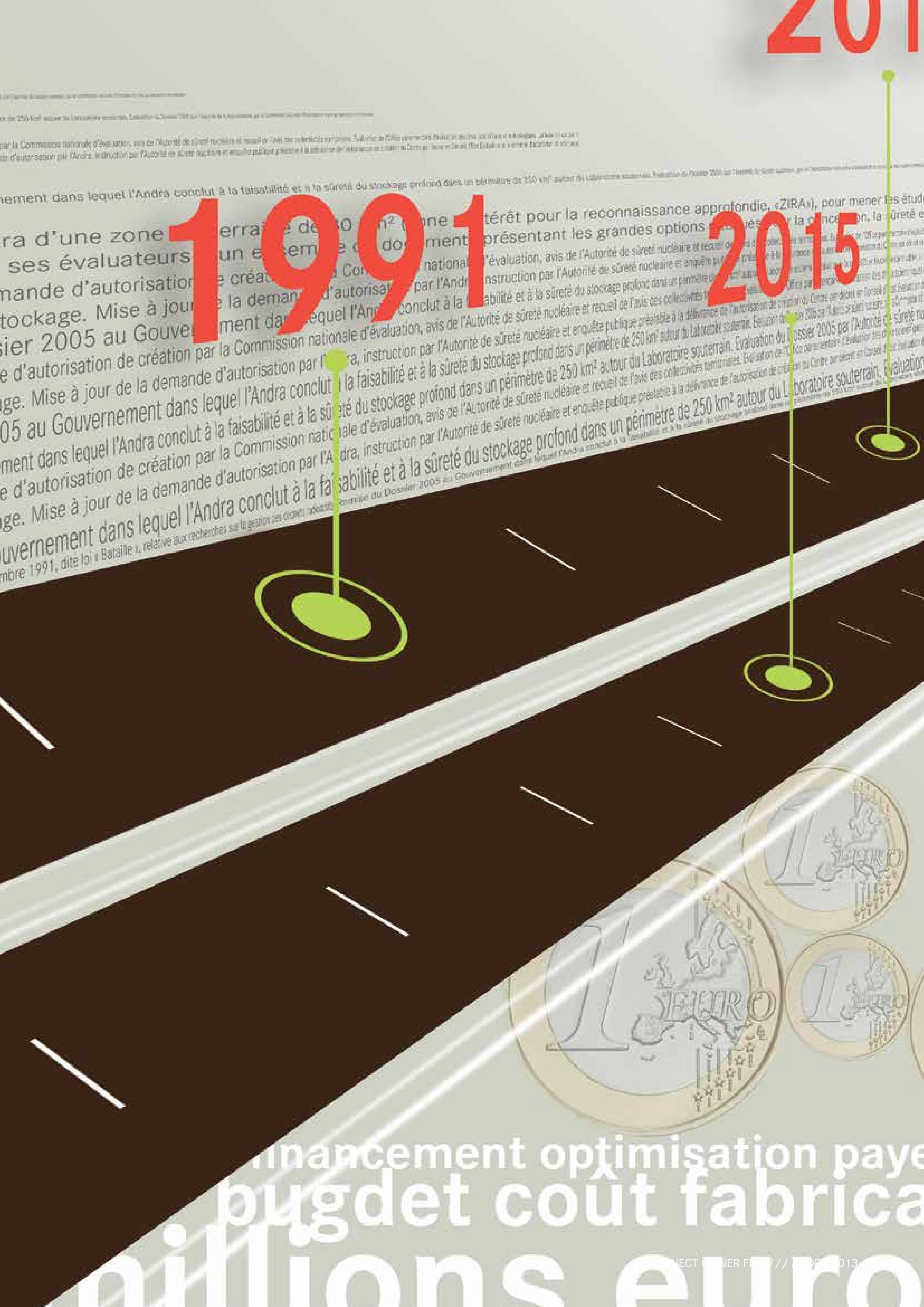
The Andra technological exhibition facility in Saudron (Haute-Marne)

FUNDING, COST AND CALENDAR

9

INTRODUCTION The project for a deep geological waste repository in France began more than 30 years ago and will continue for several more decades. These thirty years of research will culminate in the commissioning of Cigeo, if the repository licence is granted. Many scientific and political milestones have marked the project since the early 1990s and more will come throughout the repository's lifetime.

Provisions are made to estimate the cost of the project on a regular basis and guarantee its funding as of now, so that future generations will not have to bear the cost of managing radioactive waste disposed of at Cigeo.


1991
2015
optimisation
bugdet coût

9.1.
Project funding and predicted cost

The Act of 28 June 2006 set up two specific funds within Andra to fund the Cigeo project. The funds are intended to cover the costs of studies and research, as well as construction, operation and closure of the repository. All these costs will be borne entirely by waste producers. Andra is responsible for estimating all repository costs for over 100 years. Waste producers make provisions for these future costs based on the reference cost determined by the Minister of Energy, as provided for under the Act of 28 June 2006.

PROJECT FUNDING

Studies and research related to Cigeo are funded by a "research tax" on nuclear facilities set up under the Act of 28 June 2006. Between 2010 and 2012, this tax amounted to some €118 million per year, paid by EDF, the CEA and Areva, the country's three main waste producers.

Waste producers will fund the construction, operation and closure of Cigeo via contractual agreements with Andra. The breakdown will relate in particular to the waste inventory of each organisation. It is currently 78% for EDF, 17% for the CEA and 5% for Areva.

For a new nuclear reactor considered over its entire operating life, the cost of radioactive waste disposal is approximately

1 to 2%

of the total electricity generating cost.

Waste producers must plan the necessary resources for the construction and operation of Cigeo throughout its lifetime. For this purpose, they must book provisions in their accounts and secure these resources through investments ("earmarked assets"), subject to government supervision.

REPOSITORY COST ASSESSMENT PROCESS

Under the Act of 28 June 2006, the Minister of Energy determines and publishes the estimated cost of the repository based on Andra's estimates, and after considering any comments from waste producers and taking into account the opinion of the Nuclear Safety Authority (ASN). This assessment process, at the end of which the Government publishes the estimated cost of the repository, requires three to five years of work.

The last repository cost assessment by the Minister of Energy dates back to 2005. The report issued by the working group on the cost of an underground repository for high-level long-lived radioactive waste (July 2005) is public. According to the report, the basis on which costs are calculated should be regularly updated to enable the results of Andra's research activities to be gradually taken into account.

In 2009, the French Directorate General for Energy and Climate set up a working group with Andra, EDF, the CEA, Areva and the Nuclear Safety Authority to prepare the new assessment. The Minister of Energy wishes this to be completed by the end of 2013 so that a progress report can be made during the public debate.

ASSESSING THE COSTS OF CIGEO

Construction cost for the first phase of Cigeo

The first phase of Cigeo covers the construction of the facilities required to commission and start operating the repository. The estimated cost will gradually be refined for use in defining the target cost for completion of the first investment phase.

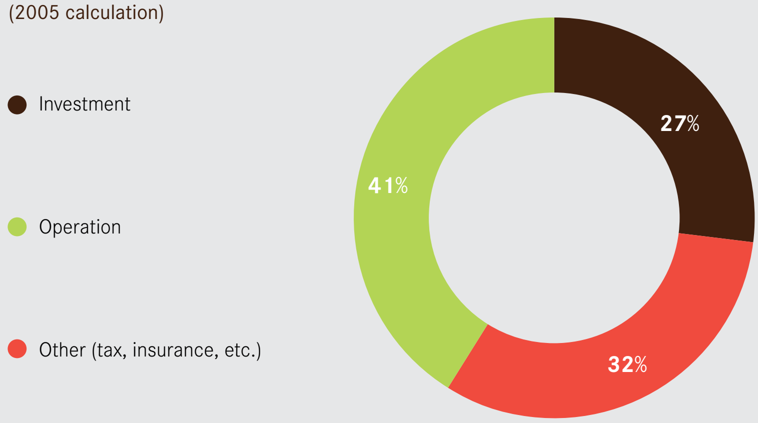
Assessment of costs up to repository closure

The Government has asked Andra to start work immediately on estimating repository costs over more than 100 years. This covers design studies, construction (civil engineering, equipment, etc.), operation (personnel, maintenance, electricity, etc.), taxes and duties, insurance, site contingencies, etc. Risks and optimisation opportunities must also be assessed. The assessment must be updated at regular intervals to take into account progress in Andra's research work.

The Government-Andra-waste producers working group for 2004-2005 estimated the cost of constructing, operating and closing the repository at between €13.5 and €16.5 billion, spread over more than 100 years. In particular, this assessment covered disposal costs for all high-level (HLW) and intermediate-level long-lived (ILW-LL) waste from French nuclear reactors over a period of 40 years.

BREAKDOWN OF THE DISPOSAL COST BY EXPENDITURE TYPE

(2005 calculation)



Between these two figures, waste producers opted for a reference cost of €14.1 billion (January 2003 economic conditions), which reflects a prudent approach to risks and opportunities. Given inflation, the estimated cost rises to some €16.5 billion under 2012 economic conditions. This is the figure used by waste producers to calculate future costs and provisions for the disposal of HLW and ILW-LL.

As the amount set aside is intended to be spent over a long period - a hundred years or so - a discounting method must be adopted to express future costs in terms of their current value. The amount is invested in dedicated funds that are secured to ensure that the return on investment covers expenditure as and when required.

Under the Act of 28 June 2006, waste producers must submit to the administrative authority a three-yearly report on long-term cost assessment, the methods used to calculate the provisions for these costs and choices made as to the composition and management of assets to cover these provisions.

Cost estimates must also take into account the quantity of waste the repository is expected to contain. The growth in HLW and ILW-LL inventory induced by plans to extend the use of EDF nuclear reactors beyond their current 40-year operating lifetime is also liable to increase repository costs.

As part of the working group set up by the Government in 2008, Andra carried out a cost estimate based on repository design and safety options put forward at that time. It was agreed with the Government and waste producers to study a number of technical options for optimising the repository. One such option was to build longer HLW disposal cells to reduce their number. The feasibility and safety of each of these options must be verified, if necessary by testing in the underground laboratory.

Various optimisation options are still under study by Andra or, in the case of waste package shipment schedules, in collaboration with waste producers. Changes in the cost of raw materials and in the waste inventory must also be considered.

Furthermore, Andra carries out a considerable amount of work on calculation tools and methods to provide the most reliable assessment of repository costs and to incorporate all the operating experience feedback available on existing nuclear facilities and other large-scale industrial facilities or underground structures. It is also takes part in international discussions on this topic.

The Cour des Comptes examined the issues relating to the above points in its public thematic report entitled "The Costs of the Nuclear Power Sector" (January 2012).

Andra will complete a new assessment in 2013 to take into account studies carried out since 2009, as well as recommendations made by the project review team, the Nuclear Safety Authority and the National Assessment Board relating to the outline studies conducted by Andra in 2012 with its prime contractor, the Gaiya group (Technip/Ingérop). Optimisation options, which will have undergone further analysis by the time the licence application is filed, will also be considered.

9.2.
Cigeo project calendar

PROJECT HISTORY

1991
Act No. 91-1381 of 30 December 1991, or "Bataille Act", on research into radioactive waste management.

1994-1996
Geological exploration programmes at four sites validated by the French Government.

1998
Meuse/Haute-Marne site selected by the Government for the construction of an underground laboratory.

FORECAST CALENDAR FOR THE CIGEO LICENSING PROCESS

2014-2015
Cigeo licence repository application prepared.

2015
Repository licence application filed by Andra.

FORECAST CALENDAR FOR THE START OF CIGEO OPERATION IF THE REPOSITORY LICENCE IS GRANTED

2019
Construction work on Cigeo facilities started (excluding preparatory work).

2025
Cigeo commissioned by Andra, subject to approval by the Nuclear Safety Authority.

2005

Dossier 2005 submitted to the Government by Andra, demonstrating that it is both feasible and safe to build a deep geological repository within a 250 km² area around the underground laboratory. Dossier 2005 assessed by the Nuclear Safety Authority and the National Assessment Board and reviewed by international experts.

2005-2006

Public debate organised by the French National Public Debate Commission on general management options concerning high-level and intermediate-level long-lived radioactive waste.

2006

Parliamentary debate held on long-term radioactive waste management strategy, followed by Planning Act no. 2006-739 of 28 June 2006, adopting reversible deep geological disposal as the solution for the long-term management of HLW and ILW-LL.

2007

Perennial Observatory of the Environment set up to describe the environment of the future repository prior to construction and to monitor changes throughout repository lifetime.

2009-2010

A 30 km² underground zone (referred to as the zone of interest for detailed reconnaissance or “ZIRA”) proposed by Andra for carrying out studies for siting underground facilities. ZIRA approved by the Government after consulting the Nuclear Safety Authority, the National Assessment Board, elected officials and the Local Information and Oversight Committee.

Document package submitted to review bodies to outline the principal design, safety and reversibility options concerning the disposal facility.

2011

Cigeo industrial design phase launched and interdepartmental development plan prepared. After the public inquiry, licence granted to continue operating the underground laboratory until 2030.

2013

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

2015-2018

Repository licence application examined by the National Assessment Board, Nuclear Safety Authority opinion issued and local authorities consulted for their opinions. Assessment carried out by the Parliamentary Office for the Evaluation of Scientific and Technological Choices. Act passed on the disposal reversibility conditions. Andra licence application updated, examination by the Nuclear Safety Authority and public inquiry carried out prior to the Conseil d'Etat decree granting the repository licence for Cigeo.

2025-2030

Cigeo startup phase.

2030 and beyond

Cigeo gradually developed with periodic safety reviews (every ten years).

RADIOACTIVITY

APPENDIX 1

INTRODUCTION

Radioactivity is a natural phenomenon that occurs in the nuclei of some unstable atoms known as radionuclides. These radionuclides possess excess energy that causes them to disintegrate, or decay, into other atoms. As they decay, radionuclides emit invisible particles of ionising radiation that can have adverse effects on health.

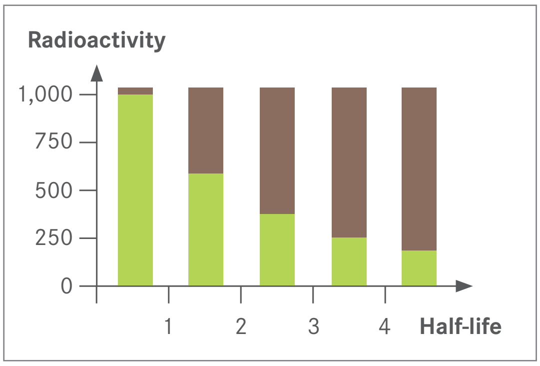
Ionising radiation is categorised by the nature and intensity of its particles:

- alpha radiation, which travels only a few centimetres in air and can be stopped by a sheet of paper,
- beta radiation, which travels a few metres in air and can be stopped by a sheet of aluminium,
- gamma radiation, which has a much higher penetrating power than the other types of radiation. Gamma radiation frequently accompanies emissions of alpha or beta particles. Depending on its energy, gamma radiation can travel up to several hundreds of metres in air and can be stopped only by a very thick layer of lead or concrete.
- Another type of ionising radiation is neutron radiation, which has energy of varying levels and can be stopped by lightweight materials containing elements such as hydrogen.

Appendix 1.1
Radioactive decay

Radioactivity spontaneously diminishes with time as radioactive atoms disintegrate into stable atoms according to the law of radioactive decay.

All radionuclides disintegrate over time. This period is specific to each radionuclide and is defined by its radioactive 'half-life'. Half-life is the time required for a radionuclide to naturally decay to half its radioactivity. For example, the amount of radioactivity remaining after 10 half-lives is 1/1000th of the original amount.



After 10 half-lives, only 1 in 1,000 radioactive atoms remains.

SOME RADIONUCLIDES AND THEIR HALF-LIVES

Radionuclide	Half-life	Emission
Iodine-131	8 days	Beta
Tritium	12 years	Beta
Caesium-137	30 years	Beta
Carbon-14	5,700 years	Beta
Plutonium-239	24,000 years	Alpha
Chlorine-36	300,000 years	Beta
Iodine-129	16 million years	Beta
Uranium-235	700 million years	Alpha
Uranium-238	4.5 billion years	Alpha

Appendix 1.2
Measuring radioactivity and its effects

Radioactivity can be measured in even very low amounts. Detection instruments commonly measure activities at levels one million times lower than those that can be harmful to health.

Two units are primarily used to measure radioactivity and its effects on organisms:

- the becquerel (Bq), which is used to measure the level of radioactivity (or activity), i.e. the number of disintegrations per second: 1 Bq equals 1 disintegration per second. It is often too small a unit for expressing radioactivity levels in sectors such as industry. This is why its multiples are used to express quantities of radioactivity:
  - 1 kilobecquerel (kBq) = 1,000 Bq,
  - 1 megabecquerel (MBq) = 1 million Bq,
  - 1 gigabecquerel (GBq) = 1 billion Bq,
  - 1 terabecquerel (TBq) = 1,000 billion Bq.
- the sievert (Sv), which is used to measure the biological effects of radiation on living organisms exposed to radioactivity. These effects vary in particular depending on the nature of the radiation and the irradiated organs. The unit used most frequently is the millisievert (mSV), which equals one-thousandth of one sievert. For example, the human body receives 0.02 mSV during a chest x-ray.

Appendix 1.3
Risks related to radioactivity

The effects of ionising radiation on the body vary depending on the doses received and the methods of exposure. Exposure to radiation can occur externally – as in the case of irradiation (exposure to radiation) or contamination through contact – or internally – as in the case of contamination via inhalation or ingestion of radionuclides. It can be chronic (such as in the case of naturally occurring, or background, radioactivity) or occasional (such as during a physical examination).

Exposure to high levels of radioactivity causes cell death. The damage incurred is significant and its severity increases with the dose. Doses in excess of 5 mSV (5 Sv) are fatal.

The effects (cancer, genetic effects) of exposure to low levels of radioactivity (less than 100 mSV) transform, rather than destroy, cells and can appear years after exposure. Moreover, they do not occur systematically. As a result, they are referred to as "probabilistic". At this dose level, it is the probability of the onset of cancer, not its severity, that increases with the dose. When cancer is discovered several years after exposure, it is impossible to pinpoint what caused it. As a result, the consequences of exposure to low doses of radioactivity are still debated within the scientific community.

Therefore, as a precautionary measure, the risk is considered to exist and be proportional to the dose received.

The use of radioactivity in various sectors has prompted the authorities to set legal exposure standards for both the general population and exposed workers. In the case of the general population, the dose added by industrial applications must not exceed 1 mSv/year or, say, the dose received during three chest x-rays or on 16 round-trip flights between Paris and New York. In the case of radiation workers (in fields such as the nuclear energy industry, radiology, medicine, etc.), the maximum legal dose is 20 mSv/year averaged over five consecutive years.

Appendix 1.4
Uses of radioactivity

Radioactivity was discovered by French physicist Henri Becquerel in 1896 and first produced artificially in the 1930s. Since then, the properties of radioactivity have been put to use in many sectors.

NUCLEAR POWER PRODUCTION
Nuclear power plants and fuel fabrication and reprocessing facilities (activities such as uranium ore mining and processing, fuel fabrication and spent fuel reprocessing).

DEFENCE INDUSTRY
Activities associated with nuclear deterrence and nuclear propulsion of various ships and submarines, along with the associated research.

RESEARCH
Research laboratories in various fields such as civil nuclear power, particle physics, agricultural economics, chemistry, biology, geology and archaeology.

CONVENTIONAL INDUSTRY (non-nuclear power)
Rare earth mining, fabrication of radioactive sources and other various applications (such as weld inspection, medical equipment sterilisation and food sterilisation and preservation).

MEDICINE
Medical research, diagnosis and treatment.

MANAGEMENT OF RADIOACTIVE WASTE IN FRANCE

APPENDIX 2

INTRODUCTION

Radioactive waste management has been a major industrial and environmental challenge for nearly 30 years. Radioactivity is used in a growing number of applications and the number of waste producers is on the rise. At the beginning of the 1990s, the French Government set up Andra, the National Radioactive Waste Management Agency.

Like most countries having to dispose of radioactive waste, France has opted for repositories that are specially designed to isolate these types of waste until they no longer represent a hazard for human health and the environment.

Such disposal facilities already exist for some categories of waste. Other categories are waiting for suitable repositories to be designed.

Appendix 2.1
Legal framework

The Planning Act of 28 June 2006 defines the framework of France's national policy on sustainable management of radioactive materials and waste as well as its organisation and funding. Its objective is the protection of health, safety and the environment.

Some of the provisions of this Planning Act have been transposed into the Frenc Environmental Code (Articles L.542-1 to 14 and L.594-1 to 13).

The Code stipulates that "research into, and implementation of the required means for the complete safety of radioactive waste, shall be undertaken in order to prevent or limit the burdens to be borne by future generations." It also prohibits the disposal in France of radioactive waste from foreign countries. The French National Radioactive Materials and Waste Management Plan (PNGMDR) reviews existing management strategies for radioactive materials and waste, lists needs and sets the goals to be achieved for radioactive waste that is not yet addressed by a definitive management strategy. The plan is public and is updated once every three years by the French Government and submitted to Parliament. The National Plan for 2013-2025 was submitted to Parliament at the end of 2012.

Appendix 2.2
Key principles of radioactive waste management

Radioactive waste is defined as radioactive substances for which no subsequent use is planned or envisaged. Treatment and conditioning are the two main methods used to reduce their volume and toxicity. The objectives are to reduce the volume of waste generated, obtain the most inert physical and chemical forms possible for disposal, both during operation and over the long term, and reinforce containment of waste within packages.

Over time, radioactive waste becomes less hazardous through a natural process called radioactive decay. According to the waste type, this decay can take anywhere from a few days to several hundred thousand years. The principle of disposal consists in isolating the waste to ensure that the radioactivity in contact with humans presents no health risk.

Appendix 2.3
Radioactive waste disposal solutions

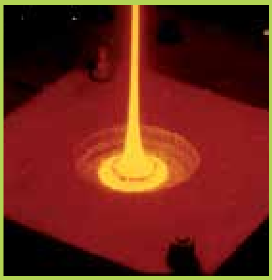
A number of disposal solutions for the entire volume of radioactive waste generated in France are already operational or planned. They are adapted to the radioactivity levels and half-lives of the waste they will host. The radioactive waste management system must be consistent and technically and economically optimised. The disposal facilities, which are few in number and have limited capacities, must be managed like scarce resources.

RADIOACTIVE WASTE MANAGEMENT

1 CONDITIONING

After having been sorted according to its characteristics, the waste is treated (compaction, incineration, solidification, etc.) then conditioned by the producer in packages designed to prevent the dispersion of the radioactivity they contain.

Compacted VLLW packages



High-level waste vitrification

2 STORAGE

Prior to disposal, or while awaiting the creation of a suitable disposal facility, waste is temporarily stored in dedicated buildings, usually at its site of generation.

High-level waste storage

Intermediate-level, long-lived waste storage

3 DISPOSAL

After checking their conformity, waste packages are disposed of by Andra in facilities compatible with the hazard they represent and how this hazard varies over time.

The role of these facilities is to isolate the radioactive waste for as long as it presents a hazard for human health and the environment.

Industrial repositories rely on a series of engineered or natural barriers to isolate the substances contained in the waste: the packages, the repository structures and the geological medium that constitutes a very effective natural barrier over very long periods of time.

Very-low-level waste disposal

Low- and intermediate-level waste disposal

SURFACE DISPOSAL FACILITIES

There are already three surface disposal facilities in France. They are located in the Manche and Aube departments and are operated and monitored by Andra. Together, they hold more than 90% of the volume of radioactive waste generated each year: very-low-level waste (VLLW) and short-lived waste (LILW-SL). It should be noted that, in the past, some types of radioactive waste were managed using other strategies (sea dumping, disposal in abandoned mining sites, and 'conventional' disposal in mounds, landfills or lagoons near nuclear facilities or plants).

France's first radioactive waste disposal facility, CSM, was commissioned in the Manche department in 1969. A volume of 527,225 m^3 of waste was disposed of there during its 25 years of operation. Now closed, the CSM facility is covered with several layers of materials to protect the structures from external disturbances such as rain water. Since then, Andra regularly monitors the facility to check its evolution and monitor its impact on the environment. Andra is also carrying out work to maintain the durability of the cap. This monitoring will be performed for at least 300 years.

Aerial view of the CSM waste disposal facility.

Drawing on more than 25 years of expertise acquired at the CSM facility, Andra's CSA waste disposal facility in northeastern France has been receiving LILW-SL generated around France since 1992. It covers 95 hectares, of which 30 are dedicated to surface disposal. Waste is disposed of in reinforced concrete structures that, once filled, are covered with a concrete slab and then sealed with an impermeable coating.

When the facility ceases operation, the structures will be buried under a cap with clay materials to confine waste over the long term.

Commissioned by Andra in 2003, the Cires, industrial facility for radioactive waste grouping storage and disposal, is located near the CSA facility and is designed for disposing of very-low-level waste. It covers 45 hectares, of which 28.5 are dedicated to the repository. Waste batches are conditioned, identified and emplaced in cells excavated a few metres below ground in a clay layer. Once filled, the cells are closed and buried under a cap consisting primarily of an impervious membrane and clay.

Aerial view of the CSA waste disposal facility

Disposal of a waste package in a CSA cell

Aerial view of the Cires, industrial facility for radioactive waste grouping storage and disposal

Disposal of a VLLW package in a cell at Cires

NEAR-SURFACE DISPOSAL BEING EXPLORED

Andra is exploring several options for the disposal of low-level long-lived waste (LLW-LL).

With the French Government's approval, in June 2008 Andra began looking around France for a site to build an LLW-LL repository. In late 2008 it provided the Government with a report analysing the geological, environmental and socio-economic aspects of the forty-odd municipalities that expressed an interest in the project.

After the withdrawal of the two municipalities chosen in 2009 to conduct geological investigations, the government asked Andra to re-explore the various management options for graphite and radium-bearing waste, focusing in particular on ways to manage these types of waste separately.

The High Committee for Transparency and Information on Nuclear Safety (HCTISN) created a working group to provide feedback on the search for a site for LLW-LL. Andra submitted a report to the Government in late 2012. This report contains proposals for continuing the search and draw in particular on the HCTISN's recommendations.

PROJECT FOR A REVERSIBLE DEEP GEOLOGICAL DISPOSAL FACILITY

Project for a deep geological disposal facility described in this document.

ANDRA
La maîtrise des déchets radioactifs

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