ANDRA
Agence nationale pour la gestion des déchets radioactifs

Issuing organisation
ANDRA
Type of issuing organisation
Project Owner
Project Owner WBS code
CMBD
Order number
NA
Mission
NA

Distribution
Communicable

Cigeo – Proposed Operations Master Plan (PDE)

CG-TE-D-NTE-AMOA-SDR-0000-15-0063

Rev.	Date	Written by	Checkers Technical	Checkers Quality	Approved by
A	13/07/16	P. C. Leverd	F. Launeau F. Plas S. Thabet Group (see list on the following pages)	N. Pereira	P.-M. Abadie

Authors

Name	Chapter(s)	Name	Chapter(s)
A. Chabiron	Glossary		
Entire document			
P. Bréger	Images in all the chapters	S. Muzerelle	Images in all the chapters
C. Le Véo	Formatting of all the chapters		

Checkers

Name	Chapter(s)	Name	Chapter(s)
A. Bonneville	Chapters 2.2 to 2.8 and 3	L. Kovacic	Chapter 1
J.-M. Hoorelbeke	Chapter 4	F. Liébard	Chapter 2.1

Proofreading committee (29/01/16)	Chapter(s)	Proofreading committee (29/01/16)	Chapter(s)
A. Bonneville	All chapters	C. Kergrais	All chapters
J.-M. Bosgiraud	All chapters	L. Kovacic	All chapters
C. Bauer	All chapters	J.-M. Krieguer	All chapters
A. Chabiron	All chapters	T. Lassabaterre	All chapters
R. Champion	All chapters	N. Pereira	All chapters
J.-M. Hoorelbeke	All chapters	S. Voinis	All chapters

Revision history

Rev.	Date	Changes made
A	See page 1/100	First issue.

Contents

EXECUTIVE SUMMARY

The drafting of a proposed Operations Master Plan (PDE) for Cigeo was decided by Andra's Governing Board at its meeting on 5 May 2014 on the actions to be taken following the public debate on Cigeo.

The purpose of the proposed Operations Master Plan (PDE) is to describe the so-called "reference" progression of the Cigeo project, as envisaged by Andra at the end of the basic engineering design, explain the objectives of the industrial pilot phase, and present the choices offered by retrievability as regards the management of the Cigeo project.

This benchmark execution comprises the waste inventory taken into account during the Cigeo project design studies. The waste intended for disposal at Cigeo is intermediate-level long-lived waste (ILW-LL) and high-level waste (HLW). Cigeo has a reference inventory of 73,600 m^3 for ILW-LL and 10,100 m^3 for HLW. The purpose of Cigeo is to dispose of waste that has already been and will be generated by existing nuclear facilities as well as nuclear facilities that have been granted a building licence, including up to their expected date of decommissioning and dismantling. The average useful service life of France's current fleet of nuclear reactors, including the Flamanville EPR under construction, is 50 years. The longevity of the fuel cycle facilities is commensurate with that of the nuclear power plant fleet. It is assumed that all spent fuel will have been reprocessed. The research facilities (CEA reactors and laboratories) currently in operation, as well as the Jules Horowitz reactor currently under construction, have an expected service life of 50 years. The ITER reactor is expected to operate for only 20 years. Cigeo's reference inventory is consistent with France's national inventory.

The benchmark execution also comprises the projected construction and operating periods and milestones leading up to Cigeo's completion, i.e., completion of the structures used to emplace all the packages in Cigeo's reference inventory. Throughout Cigeo's operating life, the repository zones will be extended during consecutive periods lasting around 10 years each. The projected closure milestones have been identified as well. Subject to obtaining the necessary licences, Andra has proposed the following provisional timetable:

- Around 2025 – Start of the industrial pilot phase;
- Around 2030 – Emplacement of the first ILW-LL and HLW0 packages;
- Around 2035 – Routine operation;
- Around 2070 – Construction of surface facilities and repository structures for HA1 and HA2 packages;
- Partial closure of Cigeo is scheduled to occur around:
  - ✓ 2070 for the HLW0 repository zone.
  - ✓ 2100 for the ILW-LL repository zone.
  - ✓ 2145 for the HA1/HA2 repository zone.
- Final closure of Cigeo is scheduled to occur by 2150.

The industrial pilot phase will begin with the commissioning tests of the facility and end when Cigeo transitions to routine operation. It is estimated to last for a total of 10 years consisting of four years of inactive tests (at the same time that construction on the structures ends and said structures are nuclearised) and around six years of operation following emplacement of the first waste packages.

Its purpose is to confirm, under real conditions and in addition to tests conducted in the underground research laboratory:

- Risk management under operating conditions.
- Performance of industrial equipment.
- The ability to retrieve waste packages from their disposal cells.
- The ability to monitor repository structures.
- The ability to close off and seal disposal cells and drifts.
- Avenues of technical and economic optimisation.

Ethical concerns for reversibility originate in the time scale required to manage the most harmful radioactive waste and particularly Cigeo's century-long service life (around five generations). Disposal reversibility is defined as the ability to leave future generations options regarding long-term management of radioactive waste. In practice, its implementation is based on governance tools and technical project management tools. The cost of technical measures taken to ensure reversibility is factored into in the project, meaning that current generations are providing future generations with easier options for acting on the disposal process. However, should future generations decide to exercise these options, for example, to modify the repository to allow the emplacement of new types of waste or remove waste packages, they will have to take responsibility for their decisions.

The technical tools of project management regarding reversibility are as follows:

- The 'incremental development' of Cigeo gives future generations the possibility to delay or accelerate Cigeo's construction. It promotes the inclusion of future phases of construction and all improvements made possible throughout the project's century-long service life by scientific and technical advances and feedback;
- Cigeo's 'operational flexibility' gives future generations the possibility to move backward, move forward, or accelerate the flow of packages emplaced within Cigeo. It also makes it possible to emplace wastes from France's reference inventory that are conditioned in forms other than the initially intended form, provided that they fulfil the emplacement conditions in force at Cigeo. It also makes it possible to amend the reference closure scheme to foresee or delay partial closure operations;
- The 'adaptability' of Cigeo's facilities makes it possible to modify the project to take into account changes in its initial design assumptions. Cigeo's design means that it can be adapted to the disposal of spent fuel or waste that is currently intended for near-surface disposal facilities (low-level long-lived wastes). Disposal of these wastes is not in and of itself a technical challenge; they may be emplaced in future sections of Cigeo provided a specific licensing procedure is followed. However, integrating these wastes in Cigeo's reference inventory would be premature at this stage. Furthermore, it might not be understood by all the stakeholders due to the current lack of changes to France's national waste management policy and the continuation of studies on management options that appear more proportionate;
- 'Retrievability' gives future generations the possibility to reconsider the decision to use deep geological disposal as a way of managing all or part of the radioactive waste packages emplaced at Cigeo.

The proposed Operations Master Plan (PDE) will be submitted to the stakeholders for consultation. It is the forerunner of a project governance tool, which will be periodically updated during Cigeo's operation.

GLOSSARY

Active tests — Tests involving equipment or packages containing radioactive substances.

Adaptability — Ability to modify the facility to adapt to new sizing assumptions (e.g.: changes to the inventory), involving significant modifications to existing equipment or construction of new structures.

Backfill — Material used to fill in the surface-to-bottom connections and the disposal drifts, with the exception of the sections occupied by the sealing structures.

Cask (transfer cask) — Shielded mobile container used to transfer disposal packages within the installations, in compliance with the radiation protection and containment rules.

Cell — The basic structure of a disposal facility. Cells are designed to contain radioactive waste packages.

Cell retrievability levels — Successive closure states (from partial to final) of the disposal facility, used to represent the increase in the degree of effort required to retrieve packages from Cigeo.

Closure structures — Structures complementing the geological barriers in order to ensure the proper operation of the repository after its closure, i.e., in order to ensure its passive safety.

Co-disposal — Disposal, within the same cell, of packages that are of different types yet are compatible in terms of operational safety and post-closure functions and in terms of their geometry.

Conditioning — Radioactive waste is produced in raw, gaseous, liquid or solid forms. In order to be able to manage this waste, it must be placed into 'waste packages'. Conditioning can be defined as all the operations performed to place radioactive waste, which may be reprocessed beforehand and may or may not be incorporated into an embedding material, into a suitable container forming a waste package for transport, storage, or disposal. Conditioning operations include, for example, compacting, embedding, vitrification, cementation, bituminisation, and containerisation.

Construction logistics support zone — Zone in the underground facility whose purpose is to provide support for underground structure construction and fitting-out operations.

Construction zone — Part of the facility in which construction work is carried out. It is physically separated from the operating zone.

Containment — Implementation of a set of measures to prevent the dispersion of unacceptable quantities of substances outside a predetermined area. By extension, containment is the set of measures taken to prevent such dispersion.

Demonstration of nuclear safety	All the elements contained or used in the Preliminary Safety Analysis Report and the safety analysis reports mentioned in Articles 8, 20, 37 and 43 of the Decree of 2 November 2007 relating to basic nuclear installations and to checks on nuclear safety, the transport of radioactive substances and contributing to the demonstration mentioned in the second paragraph of Article L.593-7 of the French Environmental Code, which prove that accident risks, radiological or otherwise, and the degree of their consequences are, given the state of knowledge, practices and environmental vulnerability of the facility, as low as possible in acceptable economic conditions
Demonstrator	Inactive structure (i.e., not containing radioactive waste packages) of the underground facility that is used for tests, feasibility demonstrations, component and equipment development, and training operating and monitoring teams. It is designed to represent the industrial structures as accurately as possible for the purpose of demonstrating their industrial feasibility or showing that these structure meet the required performance levels in a physical environment representative of the planned operating conditions. Disposal cell, sealing and hydraulic cut-off demonstrators are planned for Cigeo.
Direct disposal	Disposal of the ILW-LL packages delivered by their producer without being inserted into a disposal container first.
Disposal container	Movable, sealed vessel made of concrete or steel in which one or more primary packages have been placed prior to emplacement in a repository. It is made up of a body and a lid.
Disposal package (CS)	Radioactive waste package that may emplaced as is in the disposal facility. Primary packages from waste generators may be enclosed in a overpack.
Disturbance	Phenomenon modifying a disposal element in relation to its state or its natural evolution.
Dose rate	Quotient of the dose variation during time interval dt by time interval dt, in grays per second, although the unit frequently used in radiation protection is micrograys per hour ($\mu Gy.h^{-1}$).
Effluent	Any liquid or gaseous fluid produced by the facility and liable to be directly or indirectly discharged into the receiving environment.
Element important for protection (EIP)	Element important for the protection of the interests mentioned in Article L.593-1 of the French Environmental Code (public safety, health and welfare, and the protection of nature and the environment), i.e., structure, equipment, system (programmed or otherwise), hardware, component or software present in a basic nuclear installation or placed under the responsibility of the operator and performing a function required in the demonstration mentioned in the second paragraph of Article L.593-7 of the Environmental Code or checking that this function is performed.
Engineering contractor	Legal person governed by private law or group of legal persons governed by private law, to which the project owner entrusts a task that must provide an architectural, technical and economic answer to the programme concerned. In particular, it may be entrusted with the following design and support elements: conceptual design studies, preliminary design studies, project studies, etc.

Final radioactive waste	Radioactive waste that can no longer be processed under current technical and economic conditions, chiefly by extraction of recoverable materials or by reduction of its pollution or hazard potential.
Flexibility	Ability of the facility to adapt to changes in the industrial programme (reception schedule, reception flows, date of partial closure, changes in reference inventory package conditioning methods).
High-level waste (HLW)	High-level waste High-level waste (HLW) mainly comes from fuel reprocessing. The activity level of this waste is around several billion becquerels per gram.
Hulls	Waste consisting of cladding fragments left following the chemical dissolution of fuel element cladding sections obtained by shearing fuel rods or assemblies during their processing operations.
Hydraulic cutoff (of the damaged zone around a seal)	Seal component dividing some or all of the damaged area of the surrounding rock in order to reduce water flows along the seal. In practice, it is made in the form of a groove filled with a swelling, low-permeability material.
ILW-LL waste	Intermediate-level long-lived waste Intermediate-level long-lived waste (ILW-LL) mainly comes from fuel reprocessing and activities involved in the maintenance and operation of processing plants. It includes structural waste from fuel assemblies, end caps and cladding hulls, technological waste (used tools, equipment, etc.) and waste resulting from the treatment of effluents, such as certain sludges. The activity of this waste is from around one million to one billion becquerels per gram.
Inactive tests	Tests involving equipment or packages that do not contain radioactive substances. Tests and inspections of radiation protection equipment are considered as inactive tests.
Industrial pilot phase	Project phase that begins when the first tests in the underground facility commence and ends with the transition to normal operation. Andra will issue a report on this phase (operation, safety, reversibility). The transition to routine operation will follow a process to be validated by ASN and the project's stakeholders. The regulatory nature of this process has yet to be defined.
Licensing decree	License authorising the creation or dismantling of a basic nuclear installation in accordance with Articles L.593-7 and 28 of the French Environmental Code respectively.
Minor actinides	Some actinides produced through irradiation of nuclear fuel. They include neptunium, americium and curium. Neither uranium nor plutonium are minor actinides.
Monitoring	Continuous or periodic systematic measurement of a number of quantities in order to i) check the operation of the facility as soon it has been constructed, throughout the entire operational phase and following closure in order to check that the facility remains within the defined operating range, ii) identify any discrepancies in the operation of the facility, and iii) check the package removal capacity.
Muck	Rock removed during excavation and earthmoving work.

Muck piles	Part of the surface facilities intended for the disposal of muck and material excavated when constructing underground facilities. By extension, material disposed of on the surface.
National Inventory of Radioactive Materials and Waste	Inventory of all the radioactive materials and waste currently in France, with forecasts for their future production. The inventory is updated every year and published by Andra every three years.
Normal operation	Facility operating regime that includes all normal states and operations of the facility, including scheduled maintenance or outage situations, irrespective of whether or not radioactive substances are present; the term “normal operation” also covers any situation defined as such in the safety demonstration.
Nuclear operating zone (or nuclear zone)	Zone in which nuclear materials are or have been present and/or operations are performed upon packages containing waste or nuclear materials, or which contains equipment that has worked in a potentially contaminated zone.
Nuclear operator	Individual or company that operates a basic nuclear installation, irrespective of whether its situation is normal, or which has submitted a licence application provided for in Article L.593-7 of the French Environmental Code with the aim of operating such an installation.
Nuclear safety	Set of technical and organisational measures relating to the design, construction, operation, shutdown and dismantling of basic nuclear installations, as well as to the transport of radioactive materials, conducted with a view to preventing accidents or mitigating their effects.
Observation	Investigation of a fact or process in order to better understand it, particularly by identifying its cause. It forms part of a continuous improvement process (“responsible operator” process complying with Art. 2.7.2 of the Order of 7 February 2012 on basic nuclear installations.
Operating logistics support zone	Zone in the underground facility whose purpose is to provide support for disposal and, when applicable, package removal operations.
Performance	Characterises a component, item of equipment or system. Established by the designer with regard to user-defined criteria relating to a function.
Permeability	Parameter characterising the flow rate of a fluid (water or gas) flowing through a porous medium subject to a hydraulic head gradient (water) or pressure head gradient (gas).
Phase	Set of surface buildings and/or underground structures constructed by committing to an investment tranche, i.e. a part of the total cost of ownership.
Primary package (CP)	Waste package from conditioning facilities for wastes collected from waste generators. In practical terms, a primary package consists of a primary container, wastes and any materials used for the confinement or solidification matrix or used to fill of the container.

Radiation protection	Set of rules, procedures and means of prevention and monitoring designed to prevent or reduce the harmful effects of ionising radiation upon people — directly or indirectly — including by the harm caused to the environment.
Radioactive effluent	Effluent whose type, origin or radiological characteristics justify the implementation of measures to protect humans and the environment against the risks or nuisances associated with ionising radiation.
Radioactive half-life	Interval of time required for one-half of the atomic nuclei of a radionuclide to decay.
Radioactive waste	Radioactive substances for which no subsequent use is planned or intended.
Radioactive waste package	Conditioned and packaged radioactive waste.
Radionuclide	Radioactive isotope of an element.
Railway siding	Privately-owned track or set of tracks connected to a railway network such that industrial facilities, port facilities, and businesses may be served without any need for transshipment.
Ramp	Sloping surface-to-bottom connection linking the surface facilities with the underground facility of Cigeo.
Ramp zone	Zone consisting of surface facilities mainly used to receive and inspect waste packages and to prepare them for transfer into the underground facility.
Reference inventory	Sum of the ILW-LL and HLW packages destined for disposal in Cigeo and on which the decree licensing the construction of Cigeo is based.
Repository zone	Part of the disposal facility in which the ILW-LL waste disposal sections and HLW0 and HLW1/HLW2 waste disposal sections are located.
Requirement	Statement that stipulates a function, ability, characteristic, or limitation that the product must satisfy in the given environmental conditions.
Retrievability	Ability to remove waste packages emplaced in a deep geological formation.
Reversibility	The ability to leave future generations options regarding long-term management of radioactive waste, including sealing off repository structures or retrieving waste packages. This is ensured in particular by the progressive and flexible development of the disposal facility.
Robustness	Ability of an item of equipment, component or system to operate in a wide range of environmental conditions (heat, cold, liquid water, humidity, dry conditions, vibration, geometric deformations, presence of contamination, ageing, response to a shock, etc.) or tolerate the failure of a portion of its components or external hazards.
Roof support	Component of an underground structure or mechanism designed to ensure the mechanical stability of the structure.

Safety function	Elementary function provided to ensure the safety of a basic nuclear installation (INB) or of the transport of radioactive substances in all situations taken into account in its design, construction, operation or after closure.
Shaft zone	Zone consisting of surface facilities mainly used in underground structure excavation and construction work.
Structural waste	Radioactive waste composed of metallic structures of spent fuel assemblies from water-cooled reactors. This term is also used to refer to spent fuel assemblies from sodium-cooled fast reactors.
Surface facilities	All of the Cigeo structures, equipment and systems installed on the surface. These are divided between two surface zones (the “ramp” zone, and the “shaft” zone).
Surface-bottom connection	Structure connecting the surface and underground facilities (ramp or vertical shaft).
Technological waste	In nuclear facilities, waste from servicing and maintenance work, such as protective clothing, glovebox gloves and replaced contaminated materials in general.
Top (of a geological formation)	Upper limit of a sedimentary geological formation.
Total cost of ownership	Total cost of constructing (design and production), operating and maintaining, regenerating, renewing and dismantling a facility.
Transposition zone	Zone within which the physical and chemical characteristics of the Callovo-Oxfordian layer are similar to those observed at the underground research laboratory. It covers a surface area of approximately 250km^2.
Underground facility	All of the Cigeo structures, equipment and systems installed in the argillaceous Callovo-Oxfordian layer.
Vitrified waste	Radioactive waste conditioned in a glass matrix. Fission product solutions were the first waste to be vitrified.
Zone of interest for detailed reconnaissance	Zone located in the transposition zone that: • includes a potential site for the ramp access in the neighbouring Meuse/Haute-Marne zone; • includes a potential site for the main access shafts in a wooded area; • avoids siting any installations under the built-up areas of villages. It covers a surface area of approximately 30 km^2. A 3D seismic survey was carried out in 2010.

ILLUSTRATIONS

Figures

Tables

1

Foreword

1.1 Background

The National Public Debate Commission (CNDP) held a public debate on the Cigeo project between 15 May and 31 July 2013 and between 1st September and 15 December 2013. The minutes and report from the public debate were published on 12 February 2014 and the opinion of the Citizens' Panel from the conference organised by the CNDP was presented (1) (2) (3).

On 5 May 2014, Andra's Governing Board convened to determine the actions to be taken following the public debate on Cigeo (4). Ahead of the licence application for Cigeo's construction (DAC), and to prepare for its review, the Governing Board will provide France's government with a set of deliverables consisting of the master plan proposal for Cigeo's operations, the safety options report, and the retrievability technical options report. Currently, the DAC is scheduled to be submitted in 2018. The purpose of this is so that the DAC will include the requests resulting from the review of these deliverables by the French Nuclear Safety Authority (ASN), the assessment of these deliverables by the National Assessment Board (CNE), the results of the consultation with the stakeholders, and all the design studies.

In December 2015, Andra published a position paper presenting how reversibility is at the heart of the technical and social approach of the Cigeo's development (5). Disposal reversibility is considered to be the ability to leave future generations options regarding long-term management of radioactive waste. It is based on tools of governance (continuous improvement of knowledge; transparency and transmission of information and knowledge; involvement of society, assessment and supervision by Parliament; monitoring by ASN) and project management tools (incremental development and gradual construction; operational flexibility; adaptability of facilities; retrievability).

This document makes up the proposed Operations Master Plan (PDE) decided during the meeting of Andra's Governing Board on 5 May 2014. It is based on the basic engineering design studies (APS) conducted on Cigeo by Andra up to late 2015. The technical aspects (architecture, plans, technical definition of equipment, optimisation, etc.) and figures (dates, number of cells, number of packages, etc.) presented may change during, as well as after, the detailed engineering design phase (APD) depending on the studies and exchanges to be held with the stakeholders.

1.2 Principle and purpose of Cigeo

High-level (HLW) and intermediate-level (ILW-LL) long-lived waste cannot be disposed of in surface or near-surface facilities due to the fact that it remains hazardous for tens or hundreds of thousands of years. The 2006 Planning Act (6) charged Andra with the task of designing and building a reversible disposal facility for this final waste. This facility is known, as the Cigeo geological disposal facility. The protection of human health and the environment is the fundamental objective of Cigeo.

The depth, design and construction of this repository in impermeable argillaceous rock in a stable geological formation will make it possible to protect radioactive waste from human activities and natural surface phenomena (such as erosion) and confine these substances over very long periods of time.

The facility will no longer require human intervention after it is closed up. This means that the waste contained in Cigeo is protected and the burden of its management is not placed on future generations.

1.3 Purpose of the proposed Operations Master Plan (PDE)

The proposed Operations Master Plan (PDE) describes the reference progression of the Cigeo project, i.e. the waste inventory to be emplaced in it and the consecutive steps in building the industrial, operational and closure facilities as envisaged by Andra based on studies conducted up to 2015 (see Chapter 2 herein).

The industrial implementation of Cigeo, particularly the industrial pilot phase that will begin when the facility commences operation, is explained in detail in Chapter 3 herein.

The proposed Operations Master Plan (PDE) also describes how Cigeo, in terms of reversibility and during its entire service life, will not bind future generations to the choices our generation has made. Rather, it will provide them with options for managing radioactive waste (see Chapter 4 herein). These options may relate to future developments of the facility, changes to the inventory — particularly in the event of changes to France's energy policy (e.g. the decision to dispose of spent fuel) — or the removal of emplaced packages.

The proposed Operations Master Plan (PDE) will be submitted to the stakeholders for consultation according to the process outlined below.

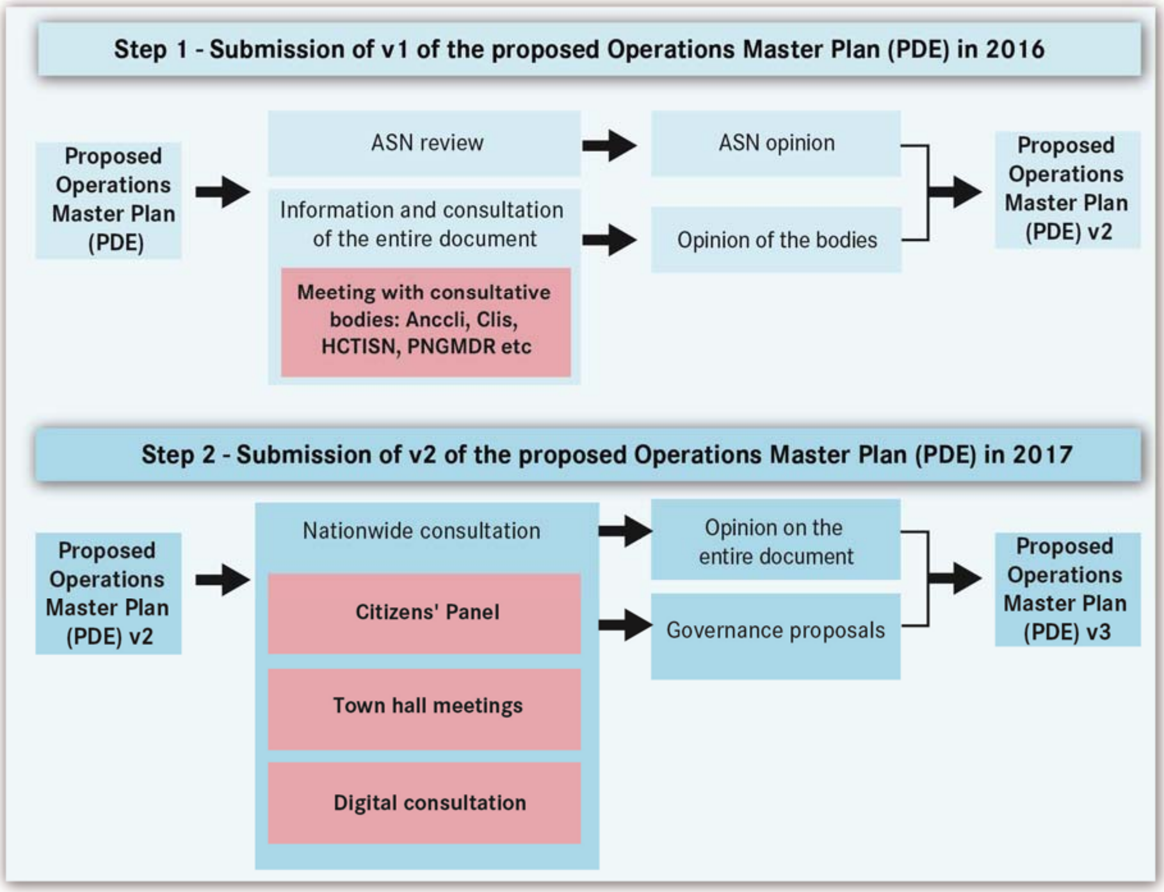


Figure 1-1 *Diagram showing the consultations on the proposed Operations Master Plan (PDE).*

The proposed Operations Master Plan (PDE) will be reviewed by ASN.

Once the stakeholders are consulted and the proposed Operations Master Plan (PDE) is reviewed by ASN, it will be submitted to France's government. Then, following the same rationale, Andra will submit proposals for updating the PDE over the course of the project. These proposals, and particularly those regarding the commissioning of Cigeo, will be made during the industrial pilot phase and at least once every 10 years. The will take into account the operating experience feedback at Cigeo, i.e.

developments in knowledge resulting from studies and research on disposal methods complementary to the management of radioactive waste. These studies will be undertaken by Andra and waste generators in order to find an optimised method for managing radioactive waste (see Section 2.4 and Chapter 4 herein).

This document is not intended to be a technical document. It is the forerunner of a project governance tool whose purpose is to be periodically updated with decisions taken throughout Cigeo's operation.

In order to promote the involvement of the stakeholders, the proposed Operations Master Plan (PDE) lists the timetable of the decision-making milestones envisaged at this stage.

2

Reference progression of the Cigeo project

2.1 Inventory of the waste to be disposed of in Cigeo

2.1.1 *Introduction*

Cigeo is designed to manage final waste with radioactivity levels and half-lives that prevent their safe, long-term disposal in surface or near-surface disposal facilities. This waste is generated by the nuclear power industry and its associated research activities — primarily Areva, the CEA and EDF — as well as, to a lesser extent, national defence operations. It accounts for a limited volume (about 3% of the current volume of radioactive waste) and consists virtually entirely of all the radioactivity in radioactive waste (more than 99%).

According to Article L542-1-1 of France's Environmental Code, final radioactive waste is defined as "*waste that can no longer be processed under current technical and economic conditions, chiefly by extraction of recoverable materials or by reduction of its pollution or hazard potential*".

The waste intended for disposal at Cigeo is intermediate-level long-lived waste (ILW-LL) and high-level waste (HLW). In accordance with prevailing regulations (7), Cigeo's construction license decree will set the reference inventory of the waste to be emplaced there.

ILW–LL contains significant quantities of long-lived radionuclides. Its level of radioactivity is generally anywhere between 1 million and 1 billion becquerels per gram[1]. It consists primarily of:

- residues resulting from irradiated nuclear fuel after processing;
- compounds that have resided in nuclear reactors;
- technological waste resulting from maintenance of nuclear facilities, laboratories, defence-related facilities, and dismantling of these facilities.

HLW has a radioactivity level of between several billion becquerels per gram and gives off heat. Some of the radionuclides contained in it have very long half-lives[2]. HLW waste consists primarily of residues removed from reprocessed nuclear fuel (fission products and minor actinides) then vitrified. A distinction is made between HLW0 waste, which has a moderate heat output, and waste with a higher heat output (referred to a HLW1 and HLW2).

Waste that will be emplaced within Cigeo will be received as waste packages conditioned via vitrification, cementation, bituminisation, compaction, or other methods[3]. Conditioning, which will be conducted at sites operated by Areva, the CEA, and EDF, consists in solidifying and immobilising waste in a non-dispersible form and placing it inside a container designed to facilitate its handling, storage, transport, and disposal. Conditioned waste packages that will be received at Cigeo are also referred to as 'primary packages' to differentiate them from 'disposal packages', which refer to packages that are disposed of within Cigeo. They result from the possible addition of a disposal container, an operation carried out at one of Cigeo's surface facilities (see Section 2.2 herein) before transfer to the underground disposal facility.

---

1 The becquerel (Bq) is used to measure the level of radioactivity (or activity), i.e. the number of disintegrations per second. One Bq equals one disintegration per second. As a comparison, the radioactivity of the waste managed at the CSA waste disposal facility is generally between a few hundred and one million becquerels per gram.

2 Two million years for example in case of neptunium-237.

3 Radioactive waste is produced in raw, gaseous, liquid or solid forms. In order to be able to manage this waste, it must be conditioned into 'waste packages'. Conditioning can be defined as all the operations performed to place radioactive waste, which may be processed beforehand into a suitable container where they may or may not be incorporated into an embedding material, forming a waste package.

2.1.2 *Main assumptions*

The purpose of Cigeo is to dispose of waste that has already been and will be generated by existing nuclear facilities as well as nuclear facilities that have been granted a building licence, including up to their expected date of decommissioning and dismantling. [4] The main facilities involved are identified in appendix 1.

Some generated waste will have to be conditioned before being sent to Cigeo. Conditioning assumptions must therefore be defined to describe the volumes for disposal that the waste already generated will ultimately represent. More generally, the estimated volume of waste packages remaining to be produced is defined using assumptions on both the operation of the facilities and the production and conditioning of the resulting waste.

For this purpose, Areva, the CEA, and EDF have defined, in line with their supervisory ministries and in accordance with energy policy guidelines, an industrial operation scenario for their nuclear facilities. The scope of these assumptions is wider than that of the Cigéo project. Cigeo's ability to accommodate possible changes to these assumptions is studied within the scope of the project's reversibility (see Section 4.4 herein).

The average useful service life of France's current fleet of nuclear reactors, including the Flamanville EPR under construction, is 50 years. This period should be taken as an indicative average, for, from a waste perspective, a lower service life of one reactor can offset the longer service life of another. This scenario prejudges neither the results of the ten-yearly safety review of these reactors nor the conditions, where relevant, for extending their service life beyond the 50-year reference period.

It is assumed that all spent fuel, including fuel not completely spent at the end of a reactor's service life (last cores and management reserves[5]) will have been reprocessed. The reprocessing of MOX fuel from around 2030 onward[6] will make it possible to reclaim the plutonium contained in this waste and recycle it in a future reactor fleet comprising Generation IV fast reactors. The waste generated by this future fleet is not taken into account herein in order to avoid pre-empting future decisions. By convention, the industrial scenario considers that fuel processing facilities will adjust their service life to match that of the current nuclear reactor fleet.

The research facilities (CEA reactors and laboratories) currently in operation, as well as the Jules Horowitz reactor currently under construction, have an expected service life of 50 years. The ITER reactor is expected to operate for only 20 years.

2.1.3 *Quantitative data*

The following tables list the volumes[7] of HLW and ILW-LL primary waste packages intended for Cigeo and based on the aforementioned assumptions. Approximately 30% of HLW waste packages and 60% of ILW-LL waste packages represent the volumes of waste that have already been generated.

Margins have been applied to cover uncertainties on the future volume of waste to be generated or the volume of old waste that will have to be recovered and reconditioned, conditioning procedures, and the characteristics of some types of waste.

[4] The term 'operation' herein refers to the 'running' of the facility. Cigeo's operation will be followed by its final closure (see Section 2.3 herein).

[5] The residual energy potential of the management reserves corresponding to these fuel assemblies is still significant. This fuel is stored in the event it needs to be returned to the reactor core to replace assemblies damaged during handling operations.

[6] This pertains also to ERU fuel manufactured from recycled uranium.

[7] The indicated volumes correspond to the volume of water displaced by submersing the primary packages.

Table 2-1: Volume[7] of HLW primary waste packages intended for Cigeo

	Cigeo Inventory (m^3)	Volume already generated as at 31/12/2014 (m^3) (National Inventory data)
Vitrified waste	10,025	3,281
of which HLW	*729*	*Not provided in the NI[8]*
Other HLW (spent sealed sources, technological waste, etc.)[9]	47	53
TOTAL	~10,100	~3,334

Table 2-2: Volume[7] of ILW-LL primary waste packages intended for Cigeo

	Cigeo inventory (m^3)	Volume already generated as at 31/12/2014 (m^3) (National Inventory data)
Spent waste from structural fuel assemblies[10]	13,585	6,106
Waste from operations and dismantling	60,024	37,290
including dismantling waste yet to be generated	*12,500*	*Not provided in the NI[8]*
TOTAL	~73,600	~43,396

The distribution of the volumes to be emplaced, among the various families of HLW and ILW-LL packages in the National Inventory (NI), is listed in appendix 2. They represent around 60,000 and 180,000 primary packages, respectively.

The volumes of the spent fuel and waste that might be emplaced within Cigeo (see Section 4.4 herein), if ever a decision to change its reference inventory were taken for the purposes of the repository's adaptability, are not presented in the above tables.

2.1.4 *Provisional delivery terms*

Waste packages are stored at sites operated by Areva, the CEA, and EDF pending their transport to Cigeo. The first waste packages will be shipped in time for Cigeo's commissioning (pending approval of its construction licence). Subsequent shipments will occur throughout Cigeo's service life (see Section 2.6 herein), thereby gradually decreasing the volumes in storage.

In any case, HLW1 and HLW2 waste require storage before they can be shipped. This is because both their activity and decay heat must be sufficiently brought down before they can be shipped and emplaced. As a result, no HLW1 or HLW2 waste packages will be shipped to Cigeo before 2075. Between Cigeo's commissioning and 2075, only ILW-LL and HLW0 waste packages will be emplaced in the repository.

At the same time, it is envisaged that HLW0 and ILW-LL waste packages will be emplaced starting from the industrial pilot phase so that Cigeo's facilities will handle waste packages that are representative of

---

8 NI stands for 'National Inventory'.

9 The difference of 6 m^3 is related to a change in the inventory of HLW technological waste (subsequent to the drafting of the waste-generator industrial scenario) already taken into account in the inventories reported in the National Inventory (NI) in late 2014.

10 Structural waste consists of the metal parts of fuel assemblies separated during reprocessing.

the entire inventory (see Section 3.3.1 herein). The rate at which waste packages will be received will be gradually ramped up.

Waste generators define the provisional shipping schedule as well as the technical conditions of delivery, particularly regarding transport casks and the most suitable means of transport (rail and road). These data are integrated by Andra into Cigeo's design. During the industrial operation phase, an operational shipping schedule will be defined and kept up to date. Convoy departures will result in a delivery agreement provided by Andra.

Storage capacities currently available at sites operated by waste generators are unable to accommodate all the inventoried waste prior to its shipment to Cigeo. Consequently, these generators have embarked on projects to build new storage facilities[11]. Ultimately, the capacities of these storage facilities may be adjusted to Cigeo's operations schedule. Storage requirements are periodically assessed and tracked as part of France's National Radioactive Materials and Waste Management Plan (PNGMDR).

2.1.5 *Summary of the waste inventory to be emplaced within Cigeo*

The purpose of Cigeo is to dispose of waste that has already been and will be generated by existing nuclear facilities as well as nuclear facilities that have been granted a building licence, including up to their expected date of decommissioning and dismantling.

The typical useful service life of all nuclear reactors, including the Flamanville EPR under construction, is 50 years. It is assumed that all spent fuel will have been reprocessed. The longevity of the fuel cycle facilities is commensurate with that of the nuclear power plant fleet. The research facilities (CEA reactors and laboratories) currently in operation, as well as the Jules Horowitz reactor currently under construction, have an expected service life of 50 years. The ITER reactor is expected to operate for only 20 years.

The waste intended for disposal at Cigeo is intermediate-level long-lived waste (ILW-LL) and high-level waste (HLW). Cigeo has a reference inventory of 73,600 m^3 for ILW-LL and 10,100 m^3 for HLW.

ILW–LL contains significant quantities of long-lived radionuclides, and its level of radioactivity is generally between 1 million and 1 billion becquerels per gram. HLW has a radioactivity level of between several billion becquerels per gram and gives off heat. Some of the radionuclides contained in it have very long half-lives. A distinction is made between HLW0 waste, which has a moderate heat output, and HLW1 and HLW2 waste, which has a higher heat output.

HLW1 and HLW2 waste require storage to decrease their activity and decay heat before they can be shipped. No HLW1 or HLW2 waste packages will be shipped to Cigeo before 2075. Between Cigeo's commissioning and 2075, only ILW-LL and HLW0 waste packages will be emplaced in the repository.

[11] Some new storage facilities are already under construction.

2.2 Overview of Cigeo

The Cigeo reversible geological repository is a project comprising a number of facilities that make up a single basic nuclear installation (INB). It comprises:

- Surface facilities divided into two distinct sets:
  - ✓ A zone (referred to as the 'ramp zone') for receiving, inspecting, and preparing HLW and ILW-LL primary packages for disposal. In this zone, the first facility that will be built (EP1) will be used to receive HLW0 and ILW-LL packages. The second facility (EP2) will be used to receive HLW1 and HLW2 packages. This zone is adjacent to the underground research laboratory, which is currently authorised to operate until 2030 (8).
  - ✓ A zone (referred to as the 'shaft zone') for underground work support activities. This zone includes the entrances to the vertical shafts and muck piles for storing rock extracted from below ground during the excavation operations.
- An underground facility comprising:
  - ✓ Ramps (slanted tunnels) for lowering waste packages into the repository via a funicular, and vertical access shafts for staff and for lowering equipment and materials during the excavation work.
  - ✓ Repository zones containing waste-package disposal cells and drifts. Specific zones will be dedicated to HLW0, ILW-LL and HLW1/HLW2 packages.
  - ✓ A logistics support zone.

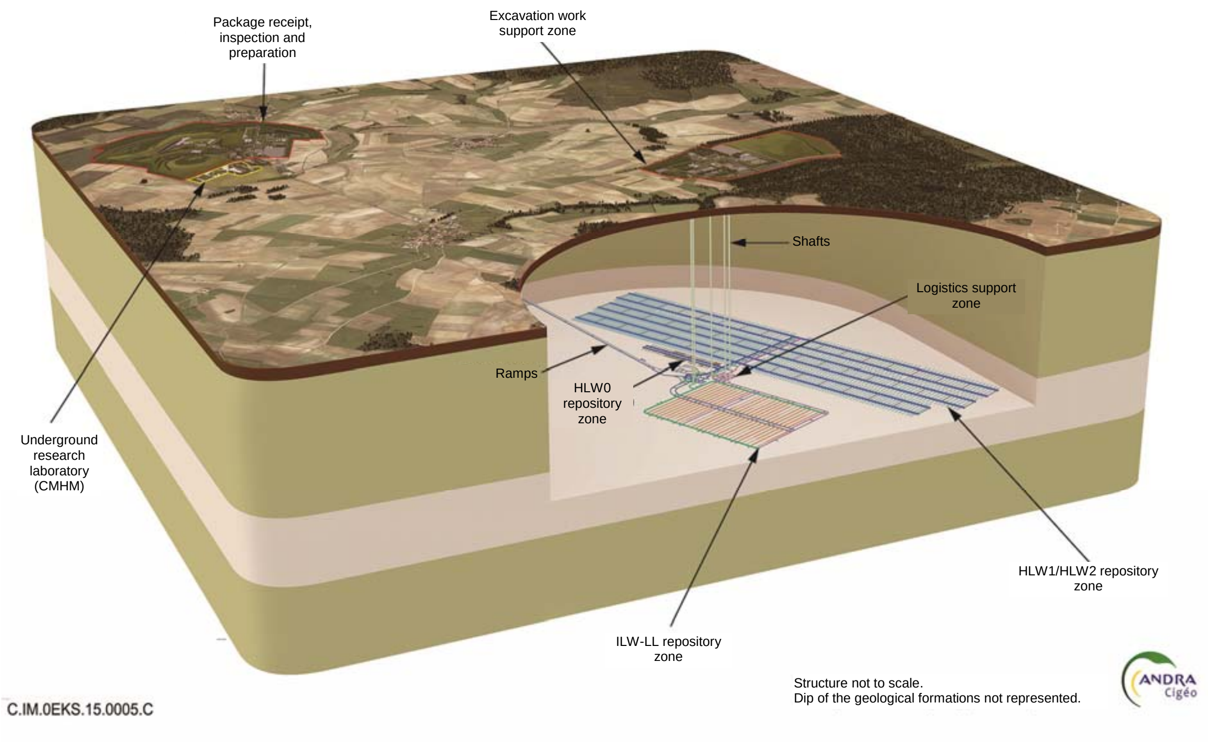


Figure 2-1 3D view of Cigeo's surface and underground facilities (diagram at the end of the basic engineering design).

Additionally, a set of conventional surface facilities (guardhouse, public information centre, carparks, railhead for shipments of building materials, etc.) and infrastructure (substations, railway connection, water system, etc.) will be built near the repository.

2.3 Main phases of the Cigeo project

The Cigéo project will comprise the following consecutive phases:

- Initial design of the facility (outline studies, basic engineering design, detailed engineering design, project design studies, and construction studies) (9). During this phase, the facility's structures, buildings and processes will be specified technically. This is the current phase of the project. Cigeo's design is assessed regularly (ASN, National Assessment Board, industrial reviews) and includes the application for a licence to build the repository. Initial work on the site — particularly surveys (rescue archaeology, geotechnical reconnaissance, geological and hydrological reconnaissance, construction preparation work, off-site support facilities) — may be conducted during the initial design phase.
- ***Initial construction*** of Cigeo, during which the first part (or 'phase')[12] of the facility is built. Provided that the licence to build Cigeo is granted, this work will primarily consist in erecting the surface buildings associated with operation of the surface nuclear facility, and in excavating the surface-to-bottom connections and the underground structures for receiving the first waste packages. During this initial construction period (and depending on the schedule of work), construction studies will be conducted on the components and equipment up to their effective completion.
- ***Operation***, which will take place for around 100 years and during which packages will be received and emplaced and work will be conducted to expand the underground facility, via consecutive phases, so that Cigeo can continue to receive packages in the inventory. Operation will commence after the operating licence is granted by ASN (receipt of the first radioactive waste package used for the active tests). Pending approval of Cigeo's construction licence, operation will also include partial closure work (closure of the cells and repository zones). In addition, construction, modification, and renovation work will be carried out on the surface buildings. The studies will be continued during Cigeo's operation to improve its design, particularly in order to optimise the consecutive phases.
- Subject to authorisation to do so by law[13], Cigeo will be definitively closed and its surface facilities dismantled. Cigeo will then enter its ***monitoring phase***.

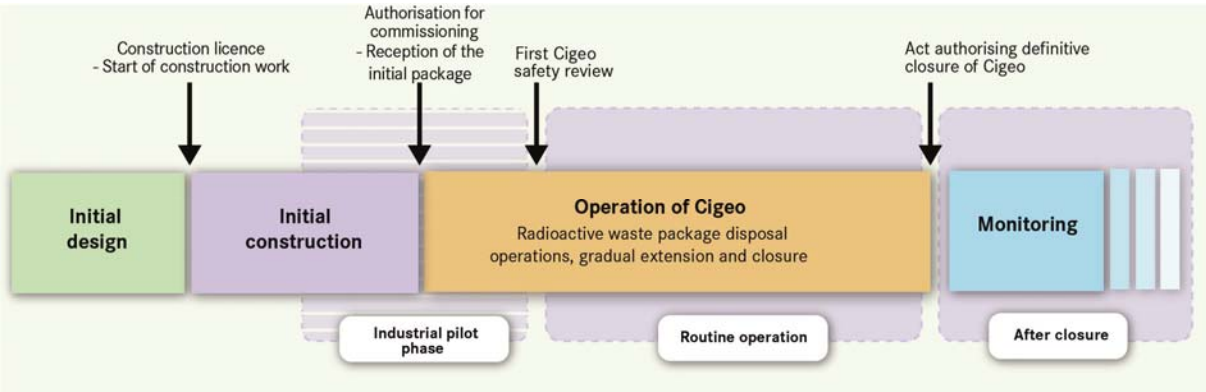


Figure 2-2 Diagram of the main phases of the Cigeo project.

An ***industrial pilot*** phase will begin when Cigeo is commissioned. It will start during the Cigeo's initial construction and continue until the start of the repository's operations. This phase comprises 'active' operations — such as tests performed on installed equipment — and 'inactive' operations, i.e. operations in the presence of waste packages. The role and aim of the industrial pilot phase are described in Chapter 3 herein.

12 A phase corresponds to a set of surface buildings and/or underground structures built through an investment outlay, i.e. a portion of the total cost of ownership.
13 Article L542-10-1 of the French Environmental Code states that "*During the review of the license application [for a deep-geological repository for radioactive waste], the safety afforded by the facility will be evaluated in terms of the various stages of its management, including its final closure, which may only be authorised by law.*"

2.4 Design

The Planning Act on Sustainable Management of Radioactive Materials and Wastestates that "*as final radioactive waste cannot, for reasons of nuclear safety and radiation protection, be disposed of in surface facilities or near-surface facilities, it must be emplaced in a deep-geological repository following storage thereof,*" and charges Andra with the task of "*designing, siting, building and managing … radioactive waste disposal facilities*" (6).

For its research on deep geological disposal, Andra has called on the scientific community in a wide variety of fields (earth and environmental sciences, materials science, instrumentation, etc.). It is also very involved in international projects, in particular with its foreign counterparts. Andra also has its own scientific resources — the underground laboratory in Meuse/Haute-Marne, computing facilities and the Perennial Observatory of the Environment — designed to meet Cigeo's specific research needs. Studies conducted for over 20 years have been regularly assessed by the National Assessment Board, ASN, and international experts. They have demonstrated Cigeo's safety and validated its feasibility.

Based on the results of these studies and their assessments, in 2010 Andra embarked on an initial design phase of studies (see Section 2.3 herein) to draw up a preliminary project of Cigeo. The outline studies of the facilities were finalised in early 2013 and the engineering design studies have been started. For these studies, Andra is drawing on engineering contractors to design, to the appropriate degree of detail, a safe industrial facility that will pass ASN's review, a prerequisite of its construction licence application (DAC). Andra is scheduled to file the DAC in 2018. Once the DAC is filed, the work on defining Cigeo will be continued by project design studies and construction studies the aim of which will be to prepare, if the construction licence is granted, the building of the first structures.

In addition to the engineering studies conducted by these contractors, Andra is continuing its own studies, tests and research to clarify design options, assess the contractors' technical proposals, develop production techniques, and obtain additional substantiating evidence and demonstrations to prepare Cigeo's licence application and its review.

As mentioned in Section 2.3, Cigeo's design will be continued beyond its initial design, particularly as part of its continuous improvement and incremental development (see Section 4.2 herein).

The main stages in Cigeo's development since 1991 are shown in the figure below.

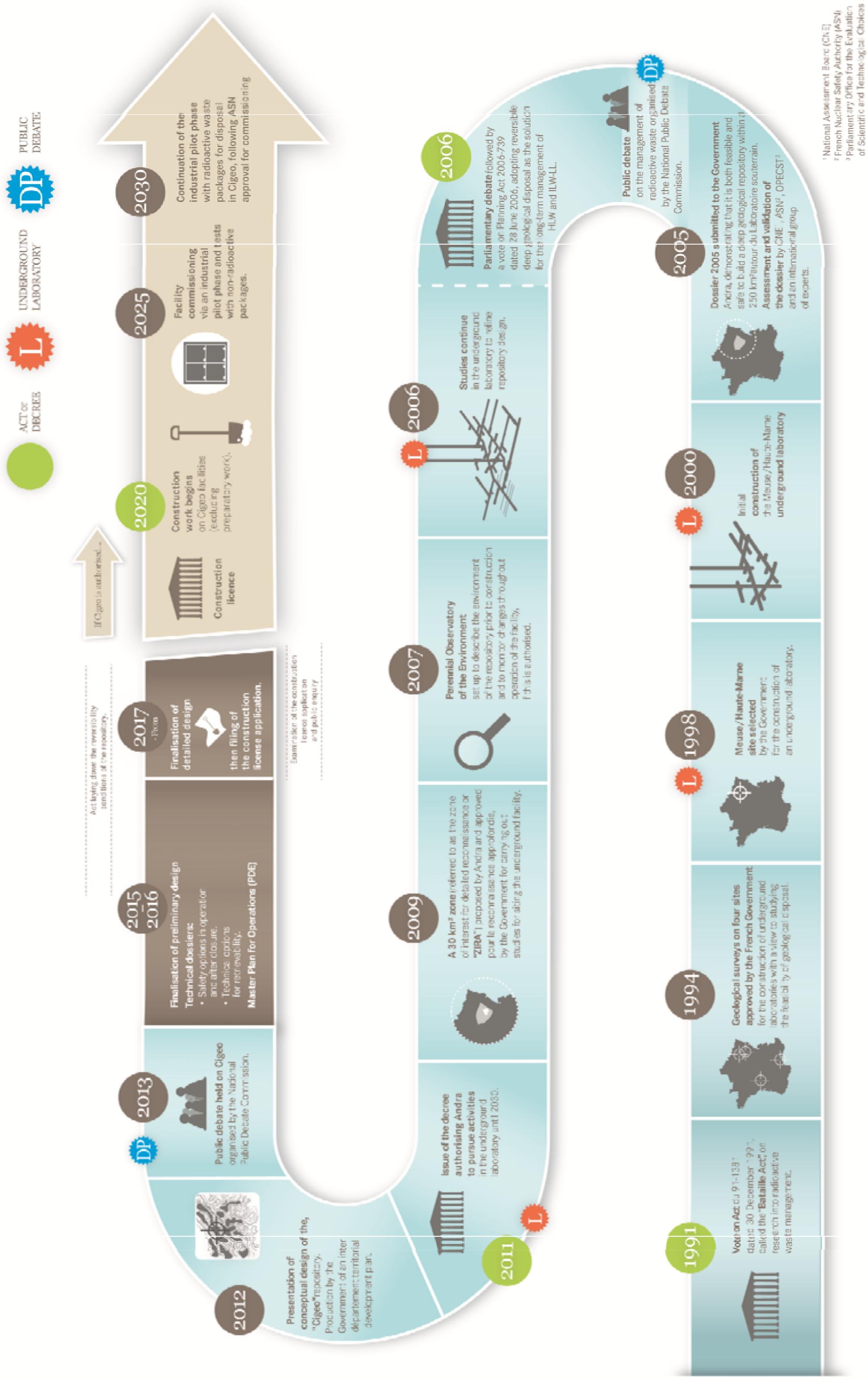


Figure 2-3 *Main stages in the development of the Cigeo project since 1991.*

Andra chose to use the international TRL (Technology Readiness Level) scale as an indicator for assessing the technical progress of the components of the Cigeo project during the initial design phase and beyond. This international scale is used to quantify the level of technology maturity achieved by an element (equipment, component, system, etc.). It is the subject of ISO standard 16290:2013. Developed primarily for space systems, the TRL scale can be transposed to other sectors to assess the technology maturity of a project or measure the progress of a technology throughout its development.

The TRL scale has nine levels. The lowest level (TRL 1) corresponds to the academic research leading to the discovery and understanding of a physical phenomenon with potential applications (e.g. the discovery of radioactivity by Henri Becquerel in 1896). The highest level (TRL 9) is attained when the element is fully defined by a set of reproducible processes, including manufacture, tests and operation, and when it meets the performance requirements assigned to it in the real operational environment (e.g., surface disposal of radioactive waste at the CSA waste disposal facility). TRL 5 is achieved when the technological feasibility of an element has been demonstrated in a representative environment. Cigeo's main components are currently at this level.

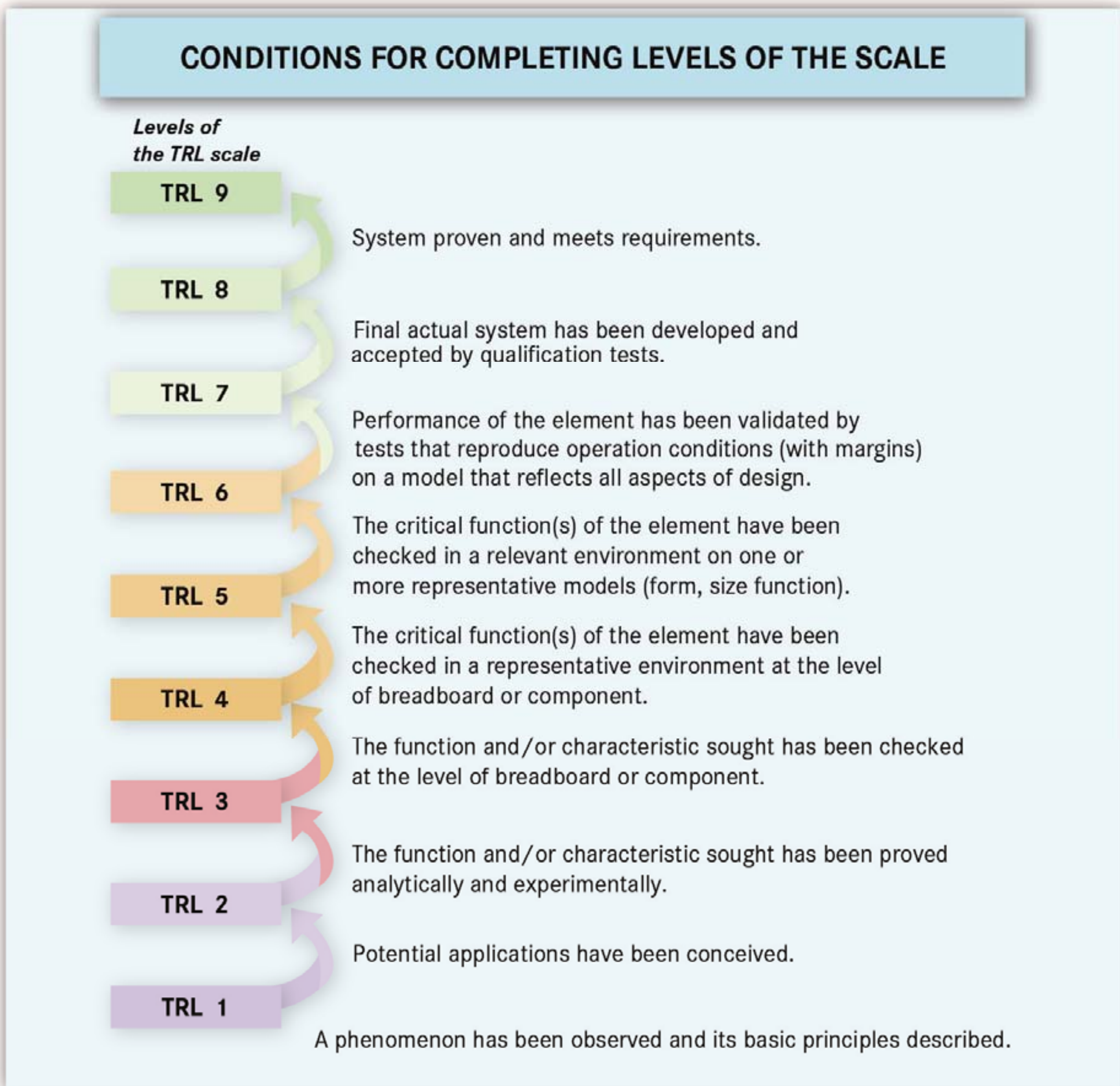


Figure 2-4 TRL for assessing the level of technology maturity of an element.

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

Laboratory tests on models that are as representative as possible of the final design are conducted to ensure that initial progress can be made in component design and support the construction license application (achievement of TRL6) in 2018.

For the following stages, given the size of the equipment used and the structures to be built within Cigeo (containers of several tons, use of a funicular, drift and repository structure measuring around ten meters in cross-section, etc.), qualification of Cigeo's operating and production procedures[14] and validation of equipment performance cannot be carried out in the underground laboratory. The cross-section of the laboratory's logistical means is not large enough for equipment to pass or conduct the necessary tests. For that matter, radioactive waste is not authorised in them. It is therefore only within Cigeo that it will be possible, during the industrial pilot phase (see Chapter 3 herein), to proceed to the subsequent steps in the development of the components (TRL 7 and 8) that will make it possible to ultimately achieve a disposal facility that both demonstrates its ability to contain radioactive waste packages and meets safety and reversibility requirements (TRL 9). Its operation will then be considered as routine.

Andra has a plan for the development of the repository components (10). The first version of this plan describes the strategy behind Cigeo's design and has been submitted to ASN. It sets out, for each component, the sequence of studies and research, tests and construction of the repository, the organisation of the tests conducted at the underground research laboratory and at Cigeo, the provisional state of knowledge, and technological demonstrations at the key milestones. In 2018, Andra will specify in the construction licence application the consecutive steps in the development of the components and the evaluations that will be made in this regard.

Component changes that will be incorporated into Cigeo's design as part of its incremental development, particularly during the phases following the initial phase (T1) (see Sections 2.6.1 and 4.2 herein), will be developed and integrated into the repository with the same steps and according to the same development rationale. In 2018, Andra will specify in the construction licence application the design changes planned for the phases following T1, the development programme for these optimisations, the associated evaluations, and their estimated dates of implementation within Cigeo (see Section 3.3.6 herein). Naturally, the number and type of these optimisations may increase over the course of the technological advances. As an example, a list of optimisations selected from among those identified at this stage is provided in Section 3.3.6 herein.

2.5 Initial construction

The initial construction phase is the period in which, provided the licence to build Cigeo is granted, work is begun on building the facilities, structures, equipment, and systems that will make it possible to receive the first waste packages in Cigeo's surface facilities and then dispose of them. Its aim is to make the first phase of Cigeo (T1) [15]operational for Andra, the repository's operator, for the industrial emplacement of waste packages in 2030. Provided the licence to build Cigeo is granted, work on the initial construction phase is scheduled to begin in 2021.

The initial construction phase plays a vital role in the Cigeo's reference progression. It is in the structures built during this phase that operations of the industrial pilot phase will be conducted. And it is during the industrial pilot phase that all the operations (testing, demonstrators, operation, monitoring) required to successfully commission Cigeo and take it forward to full operation will be carried out (see Chapter 3 herein). Furthermore, these structures will be the first to be commissioned for the emplacement and disposal of packages. Some of the structures built during this phase — such

[14] Construction of the underground structures includes excavation, roof supports and cladding.

[15] Nuclear buildings referred to as EP1, surface buildings related to Cigeo's operations, surface-to-bottom connections, underground support facility, all or part of the HLW0 disposal cells, and the first ILW-LL disposal cells.

as the ramps, shafts and logistics support zone ('operation' and 'construction' portions — will be used throughout Cigeo's operation. It is therefore important that they be sized to enable, not limit, the development and construction of the subsequent phases.

The underground structures built during the initial construction phase are schematically represented below. Details on the architecture of the drifts and cells, together with the series of work phases, are shown in appendix 3. It is important to note that the number of cells in the HLW0 section to be built during the T1 phase, shown in this diagram, is provided purely for informational purposes. It corresponds to the total number of HLW0 cells required to dispose of all the HLW0 packages in the reference inventory. The portion of the HLW0 cells to be built during the T1 phase may be optimised.

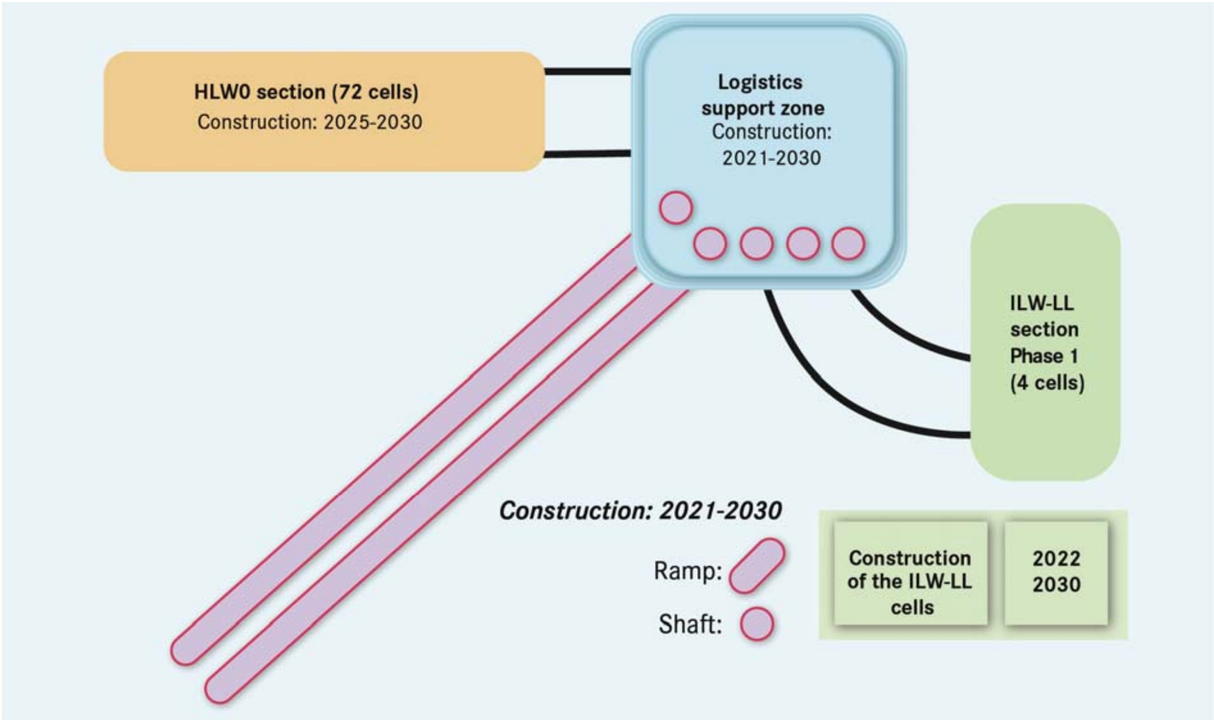


Figure 2-5 Schematic diagram of the steps involved in the building of the underground structures during the T1 phase (estimated dates at the end of the basic engineering design).

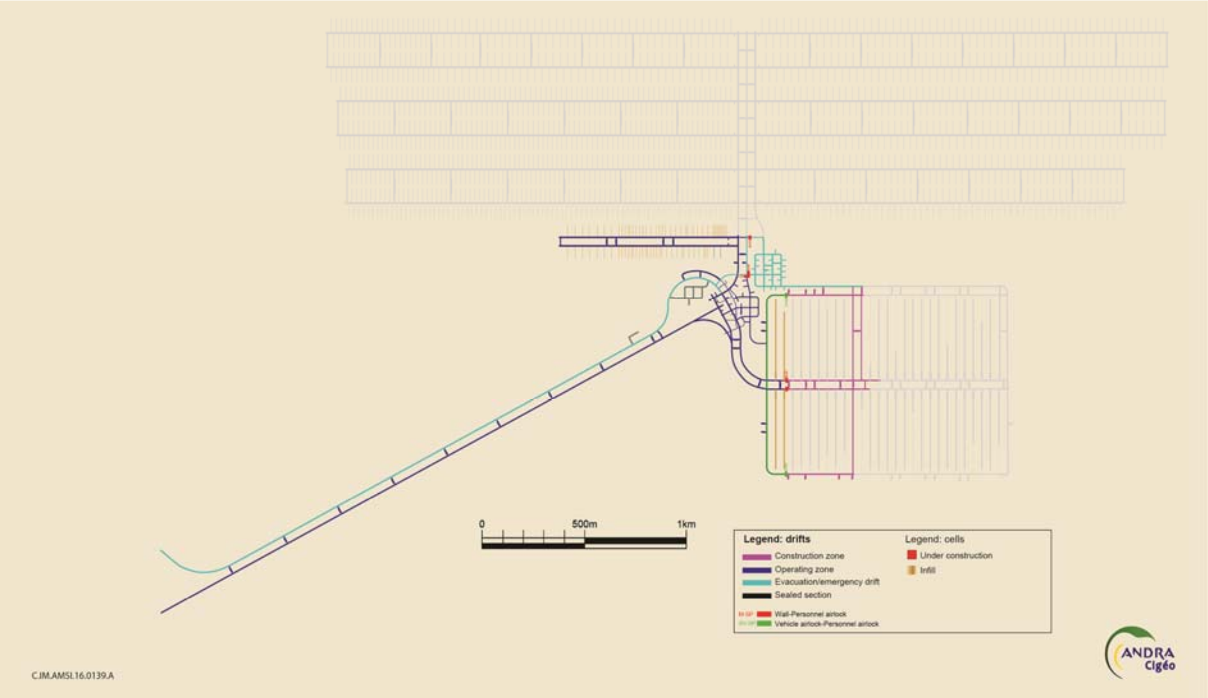


Figure 2-6 *Diagram of the underground structures to be built during the T1 phase (based on the basic engineering design – see details in Appendix 5).*

The surface structures that will be built in the zone reserved for the receipt, inspection, and preparation of waste packages (referred to as the 'ramp zone') and in the excavation work support zone (referred to as the 'shaft zone') are shown in the 3D views below.

Figure 2-7 *3D view of the surface structures in the zone reserved for the receipt, inspection, and preparation of waste packages to be built during the T1 phase (ramp zone) (based on the basic engineering design).*

Figure 2-8 3D view of the surface structures in the excavation work support zone during the T1 phase (shaft zone) (based on the basic engineering design).

Initial work and infrastructure may be carried out on the site prior to the initial construction phase. This work is divided into three categories:

1. Surveys such as geotechnical investigations, boreholes for surface hydrogeology investigations, rescue archaeology, and land surveys. As these surveys are necessary in order to define the project's technical aspects, they must be carried prior to the filing of the construction licence application. They have already begun.
2. Site preparation work to make the site viable and organise the facility's plan area for future construction and operation stages (laying of roads and networks, preparation for the supply of water and electricity, etc.). This work will be started once the necessary permits have been obtained. As the work involved is not reserved exclusively for nuclear purposes, it may be started before Cigeo's construction licence is obtained. If ever this licence is not granted, this infrastructure could be easily dismantled or even used for other purposes. By foreseeing its construction, Andra will be able to meet the 2025 deadline for the start of the industrial pilot phase.
3. Preparation work for Cigeo's construction (earthwork, preparation and assembly of the tunnel-boring machine for excavation of the ramps, excavation of the retention basins, etc.). The purpose of this work, which may be started once the public inquiry on Cigeo's construction licence application ends, is to enable construction on Cigeo to begin once its construction license decree has been obtained. This public inquiry is scheduled to end around 2020. As with the site preparation work, foreseeing the preparation work for Cigeo's construction will enable Andra to meet the 2025 deadline for the start of the industrial pilot phase.

2.6 Operation

2.6.1 Cigeo's operation and the simultaneous construction of the repository zones

Once Cigeo's operating licence is issued by ASN, scheduled for around 2030, the structures built during the initial period will be used for the disposal of packages.

The repository zones will gradually be extended to match the disposal needs. The first extension, which will correspond to the second investment outlay (T2), will be to the ILW-LL section (addition of six cells). Construction on this extension is scheduled to start in 2032, during the industrial pilot phase (see Chapter 3 herein), and it is scheduled to be commissioned in 2040.

Then, over the course of Cigeo's planned 100-year service life, the underground facility will be regularly expanded in order to be able to contain all of the waste packages in its inventory. Ten new phases (T3 to T12) will thus in turn be built and commissioned up to Cigeo's completion, i.e. when all the structures enabling the disposal of all the packages in its inventory have been built.

Compared to the initial design, design changes envisaged for the phases subsequent to the T1 phase (see Sections 2.4 and 4.2 herein) will, if licensing for such changes is granted, be integrated into Cigeo during the start of work on the consecutive phases. The safety milestones and exchanges associated with these changes will be identified in the construction licence application.

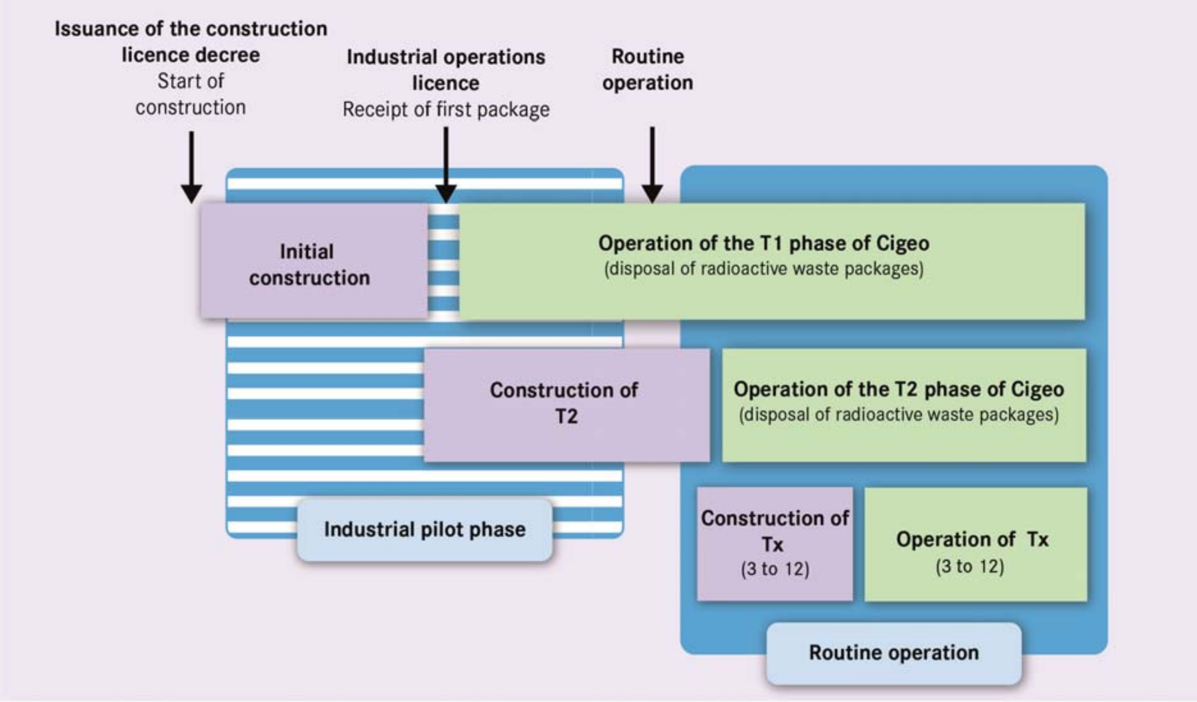


Figure 2-9 *Diagram showing the sequence of construction work and operation of the consecutive phases*

The repository zone for ILW-LL waste packages will mainly be built first, followed by, around 2070, the repository zone for HLW1 and HLW2 packages. Each construction phase will take around no more than 10 years to more easily accommodate Cigeo's incremental development (see Section 4.2 herein).

For safety reasons, the nuclear operating zones will always be physically separated from the construction zones (control of coactivity risks) so that construction work may be carried out without interrupting emplacement operations (separate, closed-off worksite) (11).

The underground structures that will be built up to completion, as well as their construction and commissioning dates, are shown in the schematic diagram below. Details on the architecture of the drifts and cells are shown in appendix 3.

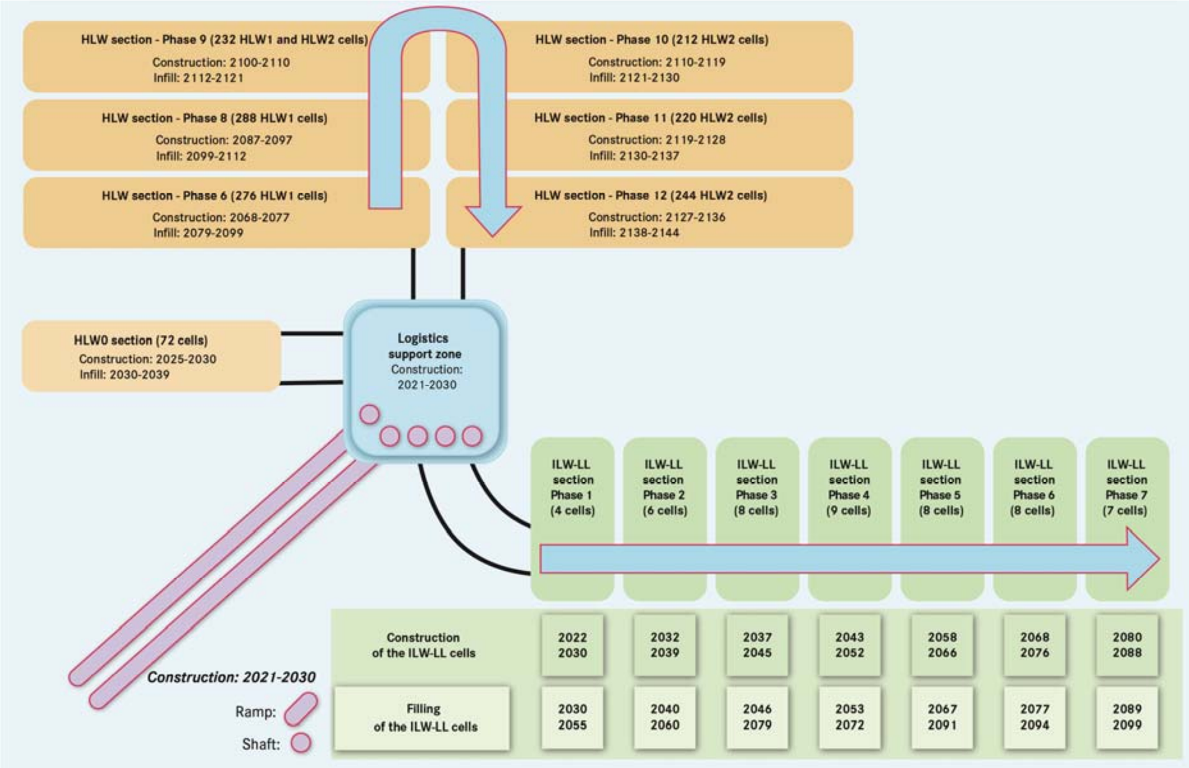


Figure 2-10 *Schematic diagram of the steps involved in the building and operation of the underground structures up to completion (estimated dates at the end of the basic engineering design). The measures that will be taken to separate the nuclear operating zones from the construction zones are not shown.*

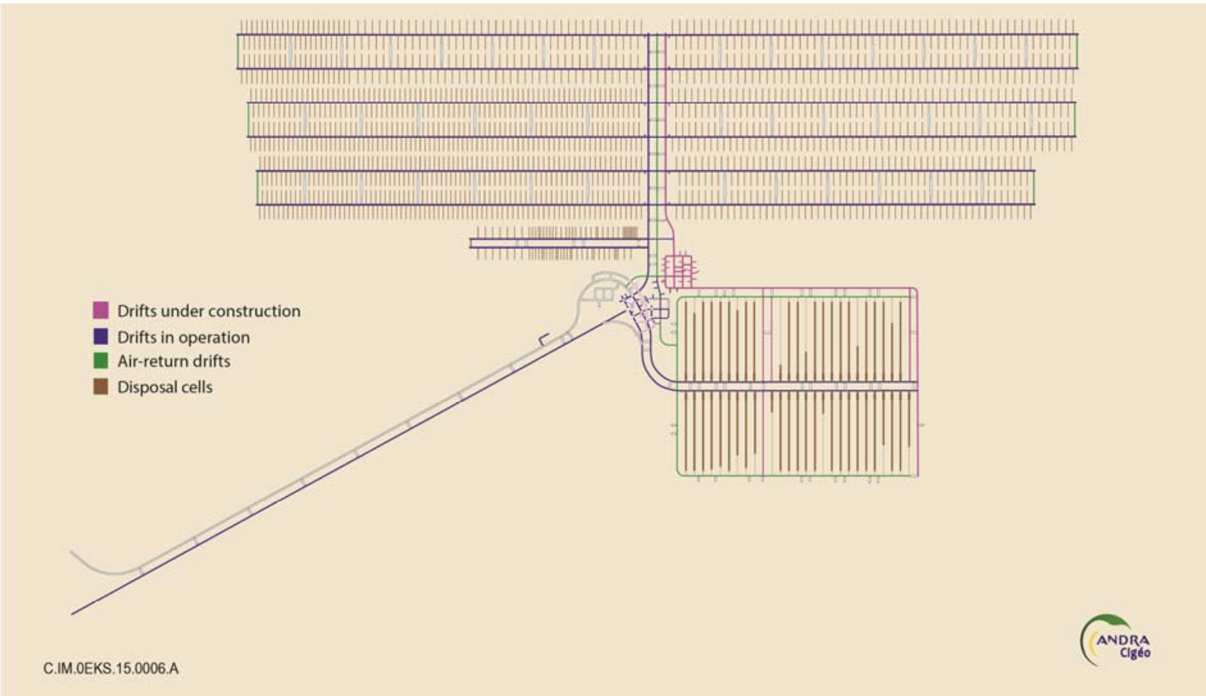


Figure 2-11 *Diagram of the underground structures to be built up to completion (based on the basic engineering design – appendix 3 see details in).*

In order to be able to emplace HLW1 and HLW2 packages, new surface facilities (EP2) will have to be built around 2068 at the locations kept vacant for this purpose in the zone reserved for the receipt, inspection, and preparation of HLW and ILW-LL primary packages.

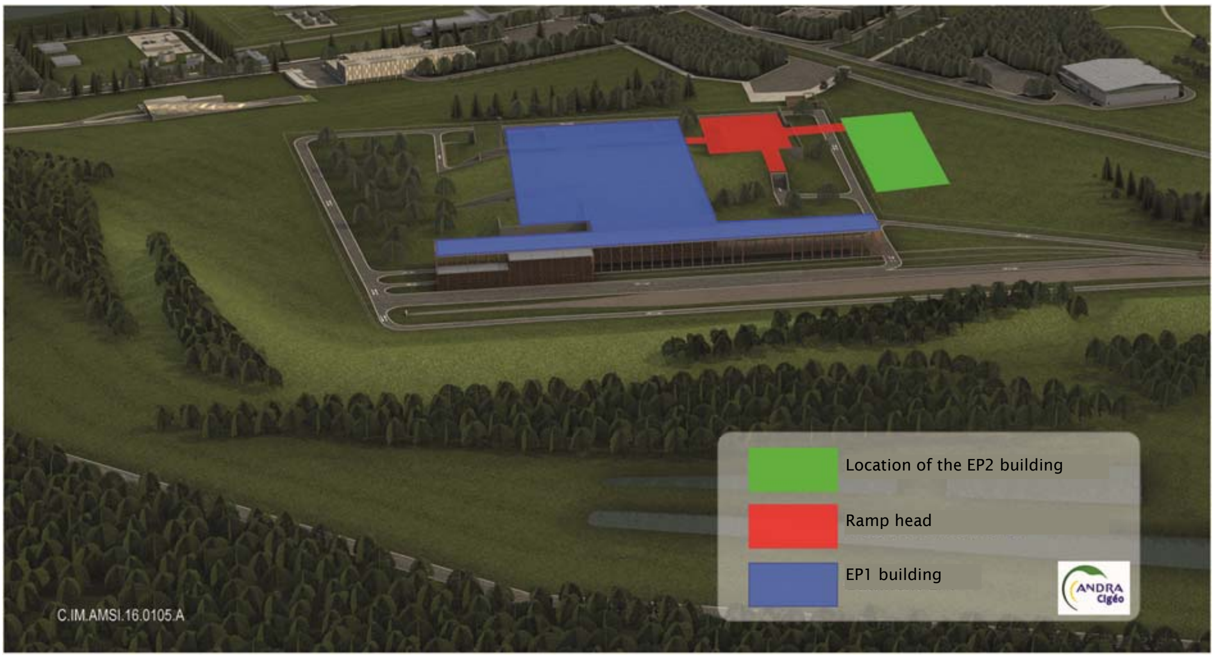


Figure 2-12 Schematic diagram showing the locations of the EP1 and EP2 buildings and the ramp head (based on the basic engineering design).

The outlay of costs to build the first phase (T1) will be followed by other investments until the end of Cigeo's operation, the final closure of the underground facility, and the complete dismantling of the surface facilities. The project's requirements and the associated investments will thus be distributed across a period of 100 years.

2.6.2 Gradual closure

Cigeo's underground structures will have to be closed off in order to ensure that the waste emplaced in it remains undisturbed for a very long period. This closure will be carried out gradually, according to a specific licensing process. The geological medium and the repository have been chosen and designed to ensure passive safety after Cigeo's final closure, i.e. people and the environment will be protected for the radioactive substances and toxic chemicals contained in the waste without the need for human intervention (12).

Prior to Cigeo's final closure (see Section 2.7 herein), a first series of 'partial' closure operations will be carried out zone by zone within the repository. In practical terms, these partial closure operations will consist of dismantling the equipment used to build and operate the structures, complementary to the geological barrier, to ensure the proper operation of the repository once it is definitively closed. The flip side of the progression towards passive operation of Cigeo is that each closure operation will increase the degree of effort required to retrieve waste packages, should such a decision be taken. The international retrievability scale (13), developed by the Nuclear Energy Agency (NEA) of the Organisation for Economic co-operation and Development (OECD), assesses the ability to retrieve waste packages based on the progression towards the most passive level of operation of a facility. This scale is shown in Appendix 4 herein.

The purpose of partial-closure structures is to:

- Close off the disposal cells.
- Backfill the drifts.
- Seal off the drifts[16].

The drifts will be backfilled with the clay removed during the excavation of the repository and stored on the muck piles on the surface.

Cigeo is designed so that these partial closure operations can be undertaken by Andra throughout Cigeo's entire service life. Based on the choice taken, these operations may be started as early as possible (as soon as filling of the cells is completed), as late as possible (at the end of Cigeo's operation), or at dates therebetween. The proposed closure schedule presented below is thus flexible and may be adjusted for reversibility (see Chapter 4 herein).

During the design development phase, Andra conducted studies to establish the reference closure scheme for Cigeo. The aims were to:

- Maintain the chosen objectives and functions to ensure post-closure safety.
- Operational safety, which calls primarily for limiting coactivity risks (operation and package emplacement) between nuclear activities and construction on the closure structures.
- Limiting disturbances on emplacement workflows caused by closure operations .
- Maintaining long monitoring of the cells and disposal sections (several decades).
- Implementing a gradual approach in order to gain experience in closure operations.
- Maintaining a high level of retrievability over a substantial period (several decades).
- Technical and economic optimisation, and particularly the search for more efficient closure operations without having to split them up.

Furthermore, it is specified that work performed to close the HLW0 section must not disrupt the operation of the HLW1/HLW2 repository zone (particularly the drifts serving the HLW1/HLW2 repository zone) and that the closure date of HLW0 section must be preceded by at least 10 years of operating experience feedback before work on closing the ILW-LL section may begin. This date may therefore change if modifications are made to these milestones.

The studies conducted at this stage have found that the optimum closure scheme in line with the aforementioned objectives consists of:

- Closing the HLW0 section at around 2070 (approx. 40 years at the highest level of monitoring and retrievability).
- Closing the ILW-LL section at around 2100 (approx. 70 years at the highest level of monitoring and retrievability).
- Closing the HLW1/HLW2 sections at around 2145 (based on the sections up to approx. 60 years at the highest level of monitoring and retrievability).

Each section will be sealed in a single operation comprising the construction of the structures used to close all the cells and backfilling and sealing of the drifts leading to each section. This arrangement will optimise the organisation of the closure work.

[16] The main function of drift seals is to prevent the circulation of water and thus contribute to the long-term containment of waste.

The sequence of the partial closure operations is shown in the schematic diagram below. The closure steps will be started in accordance with a specific licensing process.

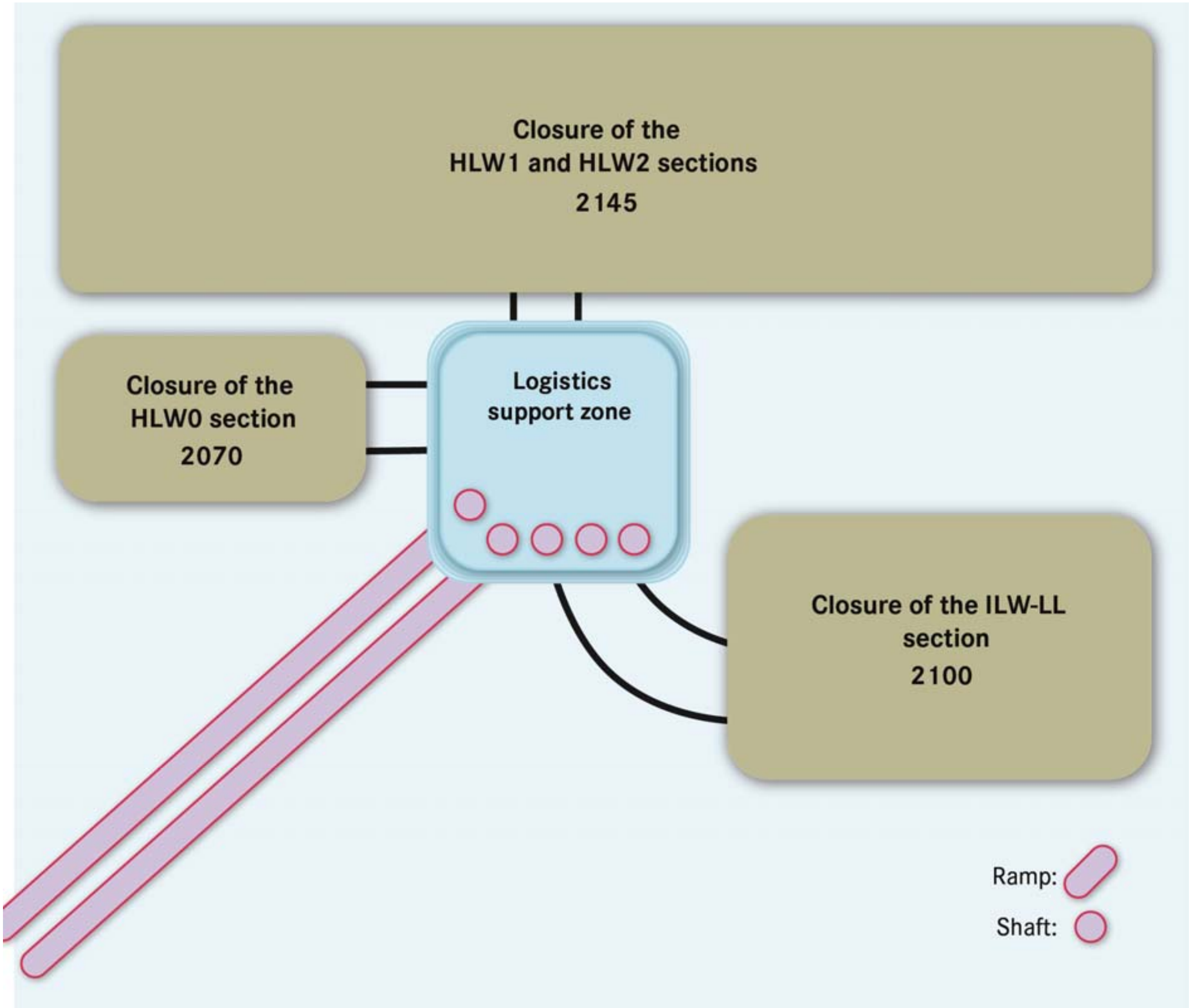


Figure 2-13 *Schematic diagram of the steps involved in the partial closure of underground structures (estimated dates at the end of the basic engineering design).*

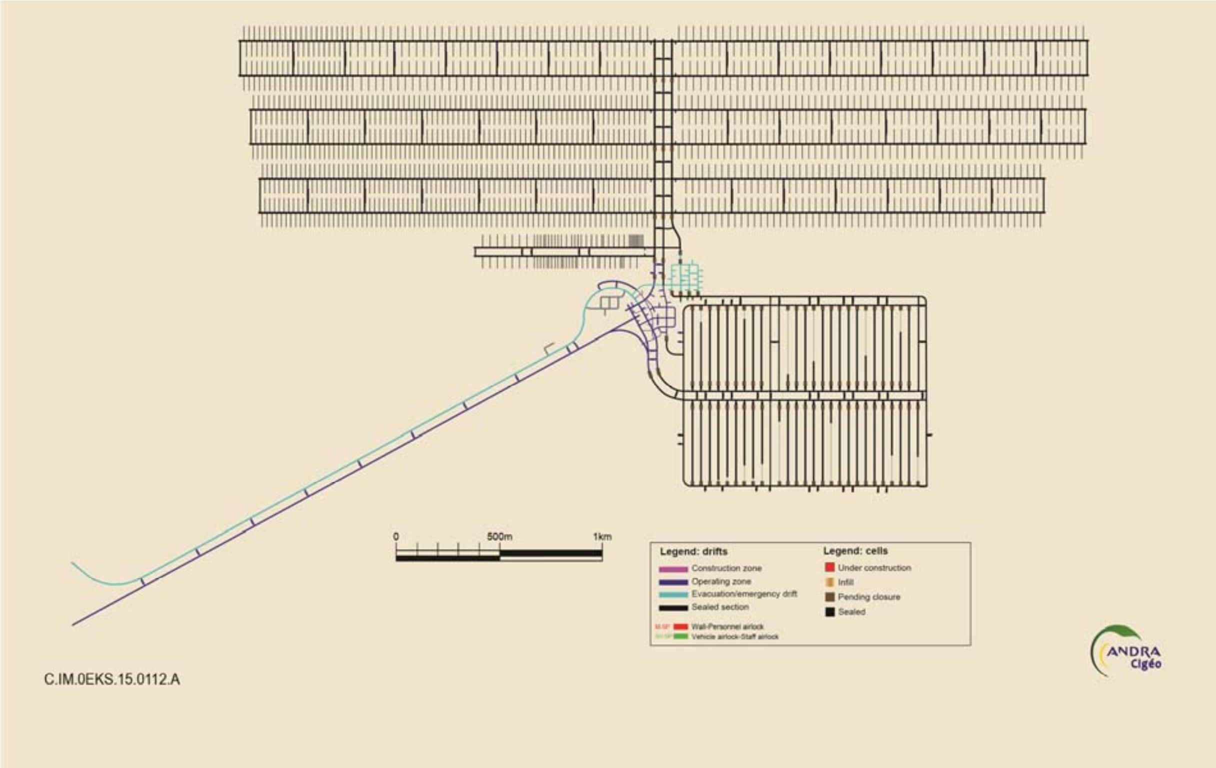


Figure 2-14 *Diagram of the underground structures at the end of partial closure (based on the basic engineering design – see details in Appendix 5).*

At the same time as the partial closure of the repository zones, the surface facilities will be dismantled once they are no longer of use. The main dismantling operation planned before Cigeo's final closure is that of the EP1 building, around 2100. It will occur at the end of the filling and closure of the ILW-LL section.

Throughout Cigeo's service life, and particularly during the periodic safety reviews, checks based on the continuous acquisition of knowledge — particularly that related to the operating experience feedback and monitoring of Cigeo — will be conducted to ensure that the closure steps of the reference progression, including the closure steps, are in line with the objectives and the continuation of the post-closure safety functions.

More particularly, if another, more relevant closure scheme is ever identified through improvements in knowledge, Cigeo's design makes it possible, throughout its operation, to bring forward, delay, or reorganise the partial closure steps for the purposes of reversibility (see Chapter 4 and Section 4.3 herein).

2.7 Final closure

At final closure, the last shafts in Cigeo's logistics support zone will be backfilled and its shafts and ramps will be sealed and backfilled. The surface facilities will be dismantled.

The 2006 Planning Act states that Cigeo's final closure may be authorised through only one act. According to the current schedule, Cigeo will close definitively around 2150.

The dismantling of the surface facilities will continue for a few years after the final closure of Cigeo's underground facility.

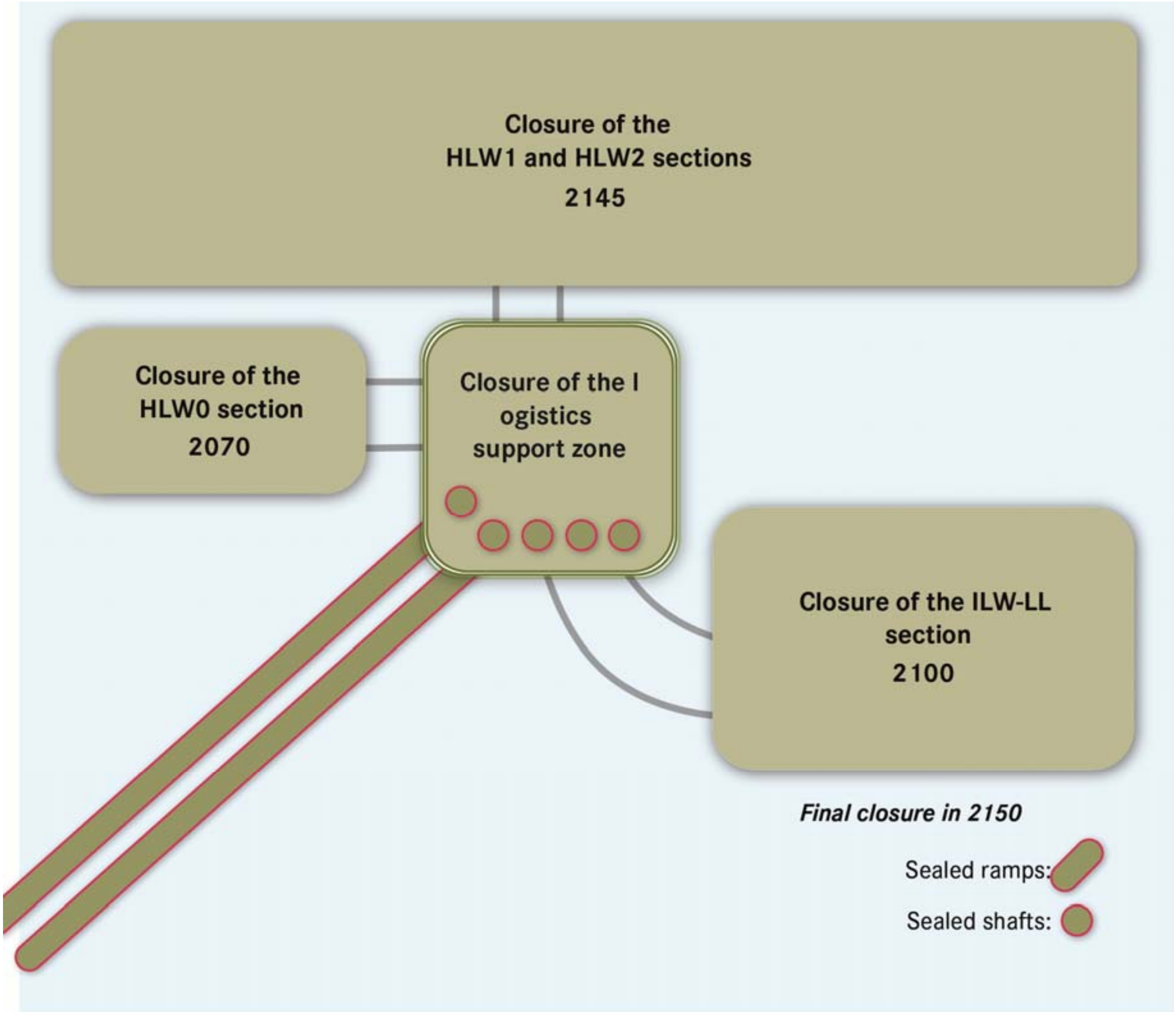


Figure 2-15 *Schematic diagram of the steps involved in the closure of underground structures (estimated dates at the end of the basic engineering design).*

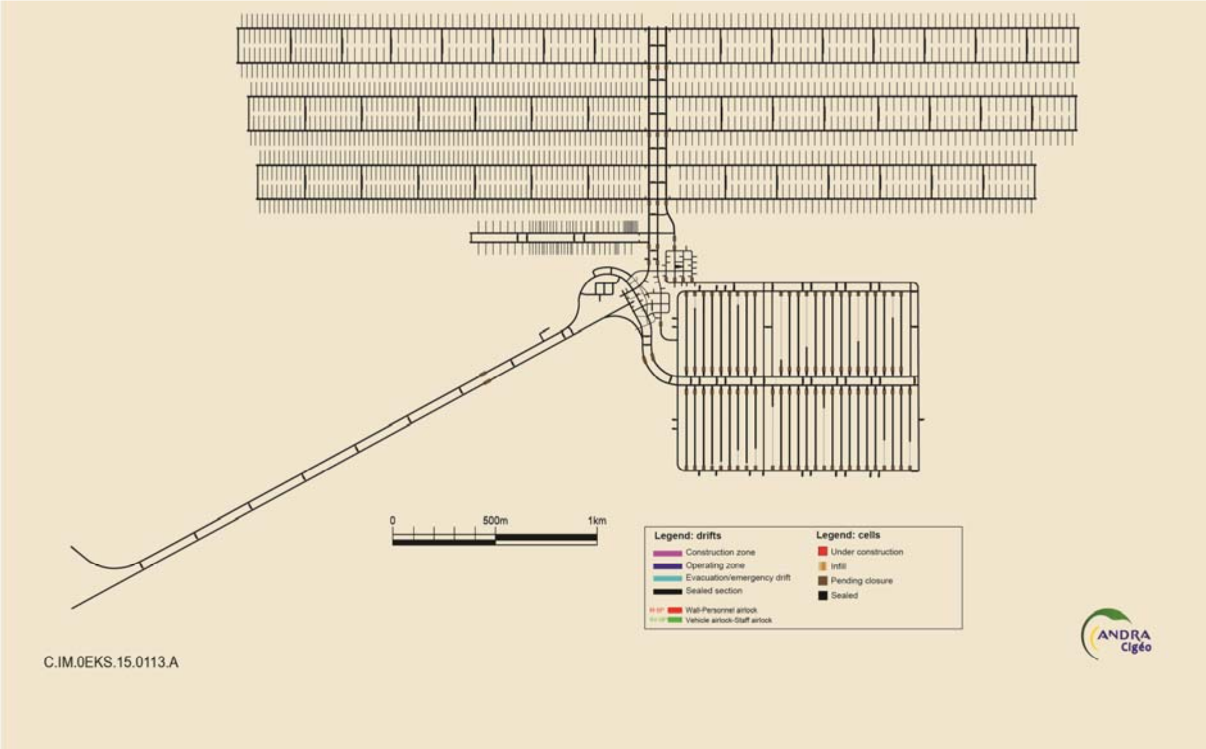


Figure 2-16 *Diagram of the underground structures at the end of final closure (based on the basic engineering design – see details in Appendix 5).*

2.8 Summary of the reference progression

The reference progression of the Cigeo project is summarised in the box below and in the table on the following page.

Subject to obtaining the necessary licences, Andra has proposed the following provisional timetable:

- Between 2015 and until 2020 – Initial local work (rescue archaeology, building of substations, changes to some roads, preparation of the site's rail sidings, preparation of the electrical and water supplies, etc.).
- In 2018 – Filing of the construction licence application (DAC);
- Around 2020 – Start of preparation work on building the repository (general earthwork, testing of excavation equipment, etc.) at the end of the public inquiry.
- Around 2021 – Granting of Cigéo construction licence and start of work on building of the repository (excavation of the ramps, shafts, and surface buildings).
- Around 2025 – Start of the industrial pilot phase (start of the first tests of the facility).
- Around 2030 – Granting of the industrial operations licence. The industrial pilot phase will continue with active tests followed by emplacement of the first waste packages. The facility will ramp up to full operation and the second phase of underground structures will be built.
- Throughout Cigeo's operating life, the repository zones will be extended during consecutive periods lasting around 10 years each.
- Around 2035 – Routine operation.
- Around 2070 – Construction of surface facilities and repository structures for HA1 and HA2 packages;
- Partial closure of Cigeo is scheduled to occur around:
  - ✓ 2070 for the HLW0 repository zone.
  - ✓ 2100 for the ILW-LL repository zone.
  - ✓ 2145 for the HA1/HA2 repository zone.
- Final closure of Cigeo is scheduled to occur by 2150.

The development of Cigeo's components will be continued after the construction licence application and up to commissioning. It will comprise *in situ* validation steps during the industrial pilot phase (see Section 3 herein). In 2018, Andra will specify in the construction licence application the consecutive steps in the development of the relevant components and the evaluations that will be made in this regard.

After the structures in the first phase (T1) are completed, authorised design changes having a sufficient degree of technology maturity may be gradually integrated into Cigeo as the work on building the consecutive phases will start. Safety milestones and exchanges associated with these changes will be proposed in the construction licence application.

Table 2-3: Summary of the construction (building and equipment), operation, and closure stages of Cigeo's structures (estimated dates at the end of the basic engineering design)

Phases	Facility structures	Construction	Filling	Closure	Dismantling
Phase 1	EP1 surface facilities	2021-2030	-	-	2100
	Ramps and shafts	2021-2030	-	2150	
	Logistics support zone (ZSL)	2021-2030	-	2150	
	Complete HLW0 disposal section (drifts and 72 cells)	2025-2030	2030-2039	2070	
	ILW-LL disposal section (drifts and first 4 cells)	2022-2030	2030-2055	2100	
Phase 2	First extension of the ILW-LL disposal section (6 cells)	2032-2039	2040-2060	2100	
Phase 3	Second extension of the ILW-LL disposal section (8 cells)	2037-2045	2046-2079	2100	
Phase 4	Third extension of the ILW-LL disposal section (extension of the drifts and 9 cells)	2043-2052	2053-2072	2100	
Phase 5	Fourth extension of the ILW-LL disposal section (8 cells)	2058-2066	2067-2091	2100	
Phase 6	EP2 surface facilities	2068-2077	-	-	2150
	Fifth extension of the ILW-LL disposal section (8 cells)		2077-2094	2100	-
	First HLW section (drifts and 276 HLW1 cells)		2079-2099	2145	
	HLW0 section closure structures		-	-	
Phase 7	Final extension of the ILW-LL disposal section (7 cells)	2080-2088	2089-2099	2100	
Phase 8	Second HLW section (drifts and 288 HLW1 cells)	2087-2097	2099-2112	2145	
Phase 9	Third HLW section (drifts and 232 HLW1 and HLW2 cells)	2100-2110	2112-2121	2145	
	ILW-LL section closure structures		-	-	
Phase 10	Fourth HLW section (drifts and 212 HLW2 cells)	2110-2119	2121-2130	2145	
Phase 11	Fifth HLW section (drifts and 220 HLW2 cells)	2119-2128	2130-2137	2145	
Phase12	Final HLW section (drifts and 244 HLW2 cells)	2127-2136	2138-2144	2145	
Phase 13	HLW section closure structures	2145-2150	-	-	-
Phase 14	Final closure structures (ZSL, shafts and ramp)	2150	-	-	-

3

The industrial pilot phase

3.1 Background

Commissioning a complex industrial facility obviously requires adopting a gradual, cautious approach. Given the uniqueness of Cigeo's underground facility, the commissioning steps include a set of *in situ* full-scale validation and qualification operations conducted in conjunction with the systematic approach to the development of the aforementioned components (see Section 2.4 herein). These steps are fully consistent with the incremental development of the project, which requires confirmation of design assumptions within the actual operational environment. Furthermore, advantage will be taken of commissioning to acquire knowledge that will make it possible to confirm plans for subsequent changes to Cigeo and implement demonstrators (seals, test cells, etc.) to provide information on options for reversibility. In addition, the commissioning of a basic nuclear installation (INB) requires the publication of reports and a specific authorisation by ASN is required for the emplacement of the very first waste packages (7). The commissioning of Cigeo will thus mobilise the key systems for reversibility outlined in further detail in Chapter 4 herein[17].

Thus, at its meeting on 5 May 2014 (4), Andra's Governing Board indicated that an industrial pilot phase would occur between the start-up of Cigeo and before the facility's full licensing in order to confirm — under real conditions and in addition to the tests to be conducted in the underground research laboratory — the facility's design measures. Andra proposed that the report of this industrial pilot phase be sent to ASN and submitted to Parliament and the project's stakeholders.

The objectives of the industrial pilot phase defined by Andra's Governing Board concern:

- Risk management under operating conditions.
- Performance of industrial equipment.
- The ability to retrieve waste packages from their disposal cells.
- The ability to monitor repository structures.
- The ability to close off and seal disposal cells and drifts.
- Testing of avenues for technical and economic optimisation.

The scheduling of the industrial pilot phase indicates two commitments by Andra — (i) to build, commission, and operate Cigeo prudently and gradually, and, (ii) at an early stage of Cigeo's development, to account for, before ASN and the stakeholders, confirmations of design data and expected performance levels, any difficulties encountered, and possible modifications or optimisations via a specific report on the first years of Cigeo's operation.

Cigeo's Operations Master Plan, which will be in force at Cigeo's start-up, may be updated after the industrial pilot phase to take into account accumulated experience.

3.2 Definition of the industrial pilot phase

The industrial pilot phase is a period of the Cigeo project, not a 'purpose' as such. Its objective will be to conduct all the testing operations, all the operations for setting up the demonstrators (e.g. for the sealing of cells), and all the operation and monitoring operations that will be necessary to successfully commission Cigeo and take it forward to full operation.

Andra has proposed that the industrial pilot phase should begin during the initial construction phase (see Section 2.5 herein) when, once the 'correct installation' of the industrial equipment (tracks, handling cranes, etc.) has been checked, the first inactive start-up tests will be started (testing of basic and operational equipment, of the functions and process as a whole [conducted on dummy packages representative of the waste packages], and safety tests[18]). These tests are scheduled to start around

[17] Continuous improvement of knowledge on the management of radioactive waste; transparency and transmission of information and knowledge; involvement of society; monitoring by the French government and by review bodies under the supervision of Parliament; incremental development and gradual construction; operational flexibility; adaptability of facilities; retrievability of waste packages.

[18] Tests, conducted during normal operation and which simulate degraded operation, to check that safety-system equipment performs to specification and that it operates together to ensure that safety functions are reliably carried out. They are conducted during inactive operations, prior to the commissioning of the facility.

2025 and will be conducted at the same time that construction on the structures ends and said structures are nuclearised.

These start-up tests will be followed by active commissioning tests conducted using radioactive waste packages[19], once authorisation for their emplacement is received from ASN. This authorisation is scheduled to be received around 2030. Different types of waste package will be used during these tests then disposed of during the industrial pilot phase (see Section 3.3.1 herein).

The principles and objectives of the test programme to be conducted within Cigeo during the industrial pilot phase are described in Section 3.3 below. This test programme will be updated and finalised during the detailed engineering design and then during the project design studies and the construction studies (see Section 2.4 herein) by the contractors that will be in charge of building and equipping Cigeo if the repository's licence is indeed granted. They will be described in due course (based on the construction studies) in a specific document structure (test plan).

Once these commissioning tests are completed and found to be satisfactory, Andra will gradually take Cigeo forward to full operation. This period, which will starts around 2030 and continue for around six years (until late 2035), will make it possible to increase the emplacement workflow from a few hundred to a few thousand primary packages each year.

The tests and operations conducted during the industrial pilot phase will be documented in specific reports drawn up by Andra (operation, safety, reversibility).

In practical terms, the full range of objectives set by Andra's Governing Board will have been acquired by the time Cigeo is taken forward to full operation. Andra thus suggests that report on the industrial pilot phase be finalised by then. This report will assess the elements acquired in terms of Cigeo's operation, safety, and reversibility. The transition to routine operation will follow a process to be validated by ASN and the project's stakeholders. The regulatory nature of this process has yet to be defined. For administrative processing reasons, the formalisation of this process will have to avoid any interruptions in Cigeo's operation even though all the conditions for transition to routine operation might be met.

[19] These will be waste packages intended for disposal within Cigeo.

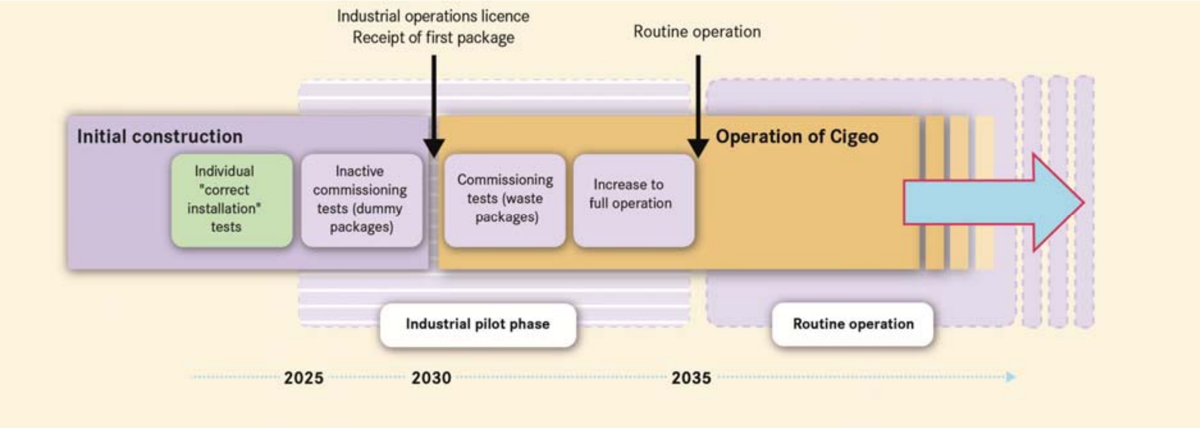


Figure 3-1 *Diagram showing the sequence of steps in the industrial pilot phase and the initial construction and operation phases.*

As of the writing of this document, the industrial pilot phase is estimated to last for around 10 years.

3.3 Objectives of the industrial pilot phase

3.3.1 Risk management under operating conditions

Safety at Cigeo means protecting the staff operating the facility, as well as the public and the environment, from risks associated with the presence, and possible release, of hazardous radioactive and chemical substances in the waste emplaced within Cigeo. This protection is ensured by implementing 'safety functions' which are deduced from the main exposure pathways and risks induced by the presence of the radioactive waste within the facility.

The safety functions at Cigeo will be provided with the construction licence application (particularly in the preliminary safety report and the document presenting the proposed methods for its final closure and subsequent monitoring) (7). These functions include the containment of radioactive substances, the protection of people from exposure to ionising radiation, criticality hazard control, the removal of decay heat from waste, and the removal of radiolysis and corrosion gases.

In accordance with the Order of 7 February 2012 laying down the general rules on basic nuclear installations (INB), structures, equipment, and systems described as being 'elements important for protection' (EIP) will be associated with these safety functions. These EIP will be used in the safety demonstration that will be presented in the preliminary safety report when the application to create Cigeo is submitted (7).

During the industrial pilot phase, all the operating procedures associated with safety (alarm management, fire-fighting procedures, safe shutdown in the event of failure, etc.), and particularly those involving EIP in operation, will be tested and finalised [20]. In addition, the start of construction on Phase 2, scheduled for 2032 at the end of two years operation of the T1 phase, will make it possible to confirm the procedures for managing risks between the nuclear operating zone and the construction zone during the industrial pilot phase.

Lastly, the types of packages that will be emplaced during the industrial pilot phase (cemented, vitrified, bituminised, or compacted) and their physical and chemical characteristics (thermal properties, gas releases, presence of flammable materials, dose rate, etc.) will make it possible to address all the key characteristics taken into account in Cigeo's design. The report on the industrial pilot phase will therefore provide a complete picture of Cigeo's ability to handle the characteristics of the packages and emplace the entire inventory even if the characteristics of the first packages emplaced within Cigeo do not quantitatively cover the maximum characteristics factored into Cigeo's

[20] Inactive demonstrators will be built during the industrial pilot phase as part of the development of the closure structures for long-term safety of the repository (see Section 3.3.5 herein).

design, such as the decay heat to be managed during disposal of HLW1 and HLW2 packages after 2075. The emplacement of packages during the industrial pilot phase will be scheduled in several steps in order to gradually expand the range of emplaced packages and containerisation solutions adopted for Cigeo.

At the end of the period during which Cigeo will be taken forward to full operation (around 6 years), the report on the industrial pilot phase will make it possible to assess the safety level at Cigeo across a set of configurations representative of its operation and to recommend improvements to be made for the facility's routine operation.

3.3.2 Performance of the industrial equipment

The test programme that will be conducted during the industrial pilot phase will make it possible to validate the operation of all the equipment and functions at Cigeo, including during the incident conditions described in the Preliminary Safety Report. The main objective of this programme is to reduce as far as possible the risks of equipment malfunction that could affect the Cigeo's industrial capacity or lead to incident or even accident situations (14). Periodic checks and inspections will continue throughout Cigeo's service life.

This test programme will make it possible to check the individual and collective performance of all the equipment within Cigeo's actual industrial environment (receipt of incoming packages, preparation for disposal, inspection, package handling, monitoring, equipment maintenance, etc.).

Equipment tests will be conducted over several phases, first at the place of manufacture, then within Cigeo. They will be performed on each individual item of equipment, then collectively on all the equipment installed within Cigeo. The tests performed within Cigeo will be documented in reports sent to ASN and specific inspections conducted for the operating license required in order to be able to emplace the very first package.

These tests will cover all the equipment and structures built during the first phase of Cigeo (T1, see Section 2.5 herein). Following this phase, start-up tests will be conducted on each new Cigeo extension. These tests will cover the equipment and industrial functions of each extension as well as the overall operation of Cigeo, all phases combined.

Once this test period is completed, the phase during which Cigeo will be gradually and carefully taken forward to full operation will make it possible to adjust the facility's organisation and operating procedures to its operating experience feedback and demonstrate, based on the facility's real operational performance, that it indeed can handle the planned package flows.

In addition, at the start of the industrial pilot phase, Andra will implement one inactive ILW-LL cell demonstrator and at least one inactive HLW cell demonstrator. These demonstrators will be used in the tests that will be conducted to finalise the development of the components (advancement to TRL levels 7 and 8) and may be used throughout Cigeo's operation to train its operating teams or develop optimisation opportunities (see Sections 2.4, 3.3.3 and 3.3.6, respectively, herein).

3.3.3 Ability to retrieve emplaced packages

Cigeo's design makes it possible to retrieve waste packages from disposal cells throughout the facility's century-long service life. Packages and cells are thus designed such that their properties that enable retrieval (mechanical strength of the packages, functional clearances) are maintained .

During the industrial pilot phase, a specific testing programme will be integrated into the start-up tests and commissioning tests. This programme will consist of retrieving, from their respective disposal cells, dummy HLW and ILW-LL packages followed by real waste packages. The equipment used specifically for retrieval (e.g. the robot for retrieving HLW0 disposal packages) will undergo the same testing as the equipment used for emplacing the waste packages. The handling equipment (transfer cart, funicular, casks) will be included in this programme. The performance of this equipment will be checked in the same way in both directions (emplacement and retrieval). The performance of the equipment used to receive (and possibly reship) primary packages will also be checked in both directions without reshipment of the packages (transport cask operations).

All the retrieval equipment will be immediately operational during the industrial pilot phase. Cigeo will thus be at maximum retrievability. In addition, no structures intended to be used to actually close a disposal cell containing waste packages or a disposal section drift will be built. However, inactive closure structure demonstrators will be built (see Section 3.3.5 herein).

The inactive demonstrators for the ILW-LL and HLW cells will be used throughout Cigeo's operation to train the facility's operating teams in retrieval operations, maintain skills, and perhaps test new retrieval techniques.

3.3.4 Ability to monitor repository structures

Monitoring a basic nuclear installation (INB) consists in conducting continuous or periodic routine measurements of a number of quantities used to check the facility's operation . It begins with the facility's construction and continues at least throughout its operation. In a disposal facility, monitoring continues for a given period after final closure.

Generally speaking, the main purposes of monitoring an INB are:

- To check that the facility remains within its operating range, as defined in the Safety Analysis and specified in the General Operating Rules (RGE).
- Identify any operational drift that could take the facility out of its range of normal operation if corrective measures are not applied beforehand.

In the case of Cigeo, monitoring relates more particularly to the underground facility and its geological formation in conjunction with the objective of post-closure safety. Its specific objective will be to ensure that the state and behaviour of the components important to the safety of the repository, defined to guarantee post-closure safety, are within a range that enables them to fulfil their functions after the repository's closure. Another objective of monitoring will be to verify the ability to retrieve emplaced packages.

Monitoring is regulatory in nature. Its purpose is to protect the interests specified in Article L.593-1 of the French Environmental Code (public security, health and safety, protection of nature and the environment). In Cigeo's case, another objective of monitoring will be to verify the ability to retrieve emplaced packages. The implementation of the monitoring programme and the reporting of its results constitute a commitment made by Andra to ASN.

Cigeo's monitoring programme will start with the facility's construction, in 2021, and continue, with necessary developments, during its operation and after its closure. A first Cigeo monitoring programme will be presented in the construction licence application (DAC) in 2018. In particular, its aspects on radiological monitoring of the environment during the facility's operation will be discussed in detail for the granting of the operating licence, expected for around 2030.

During the industrial pilot phase, monitoring will particularly cover the facility's operating parameters (temperature, ambient radiation, position of the packages, etc.), more particularly after actual waste packages will have been emplaced in it. To this end, the performance of the equipment, means and sensors selected to monitor the facility will be systematically checked at commissioning, and then periodically during operation (alarm signalling, performance of measurement systems, overall management of data sent to the control room, correct operation and effectiveness of operators' facility displays etc.).

The monitoring programme will also cover parameters related to the design and behaviour of the structures during the facility's century-long service life. For example, a specific monitoring programme will be conducted to verify the maintenance of the functional clearance required for package retrieval. It will continue after the industrial pilot phase.

Moreover, verification of the important characteristics of the host rock — used as input data in the post-closure safety assessment (mechanical behaviour, expansion, structure and permeability of the damaged zone around the structures, etc.) — will be integrated into the monitoring programme conducted during and after the industrial pilot phase.

This verification will be expanded specifically to the engineered components important to post-closure safety. In this general context, some portions of the underground facility (HLW and ILW-LL cells, ramp and shaft sections, gallery sections or intersections) selected for their representativeness of a set of structures or for their specific position in relation to the operational and post-closure safety objectives (e.g. at the location of a future seal) will be the subject of specific monitoring measures. These structures are referred to as 'reference structures'. The specific information collected in these reference structures will be integrated and used in Cigeo's monitoring programme. Their roles and the functions of the specific measurements that they house will be defined in the construction licence application file.

A report on the entire range of aspects of monitoring at Cigeo (environment, operation of the facility, parameters used for design and post-closure safety, reference structures) will make it possible to assess the relevance of monitoring, the quality of its performance by Andra, and potential necessary changes (further extension or repurposing, frequency of measurements, etc.). This report will be included with the report on the industrial pilot phase.

In addition, as part of the project's incremental development, Andra will conduct an observation programme [21] within Cigeo and which will start at the industrial pilot phase (see Section 4.2 herein).

3.3.5 Ability to close off and seal cells, drifts, and ramps

In accordance with the reference closure scheme (see Sections 2.6.2 and 2.7 herein), the first industrial closure structures within Cigeo will be built around 2070 (HLW0 section) then around 2100 (ILW-LL section). The start of the operations will be covered by specific licensing procedures.

Although the implementation of the facility closure operations appears distant, Andra has envisaged to verify the ability to build the closure structures in the operational environment as soon as the industrial pilot phase starts. This verification will be conducted within Cigeo by the building of inactive demonstrators that will be representative of the structures envisaged for the facility's operation.

Given the various types of closure structure to built within Cigeo, the following inactive demonstrators will be built during the industrial pilot phase:

- A ramp sealing demonstrator.
- A drift sealing demonstrator.
- A hydraulic cut-off demonstrator (representative of the operation of the drift seal concept studied as a variant).
- A sealed HLW cell demonstrator.

At this stage, these structures will be built in a dedicated zone located at the bottom of the ramps. This zone's location may change over the course of the design studies in order to limit constraints related to the workflows and benefit from a greater plan area for its potential development (excluding the ramp sealing demonstrator, which would remain on the upper boundary of the host formation).

[21] Observation is defined as the investigation of facts and processes in order to better understand them, particularly by identifying their causes. It is not regulatory in nature. It is carried as part of continuous improvement of knowledge, particularly to optimise Cigeo.

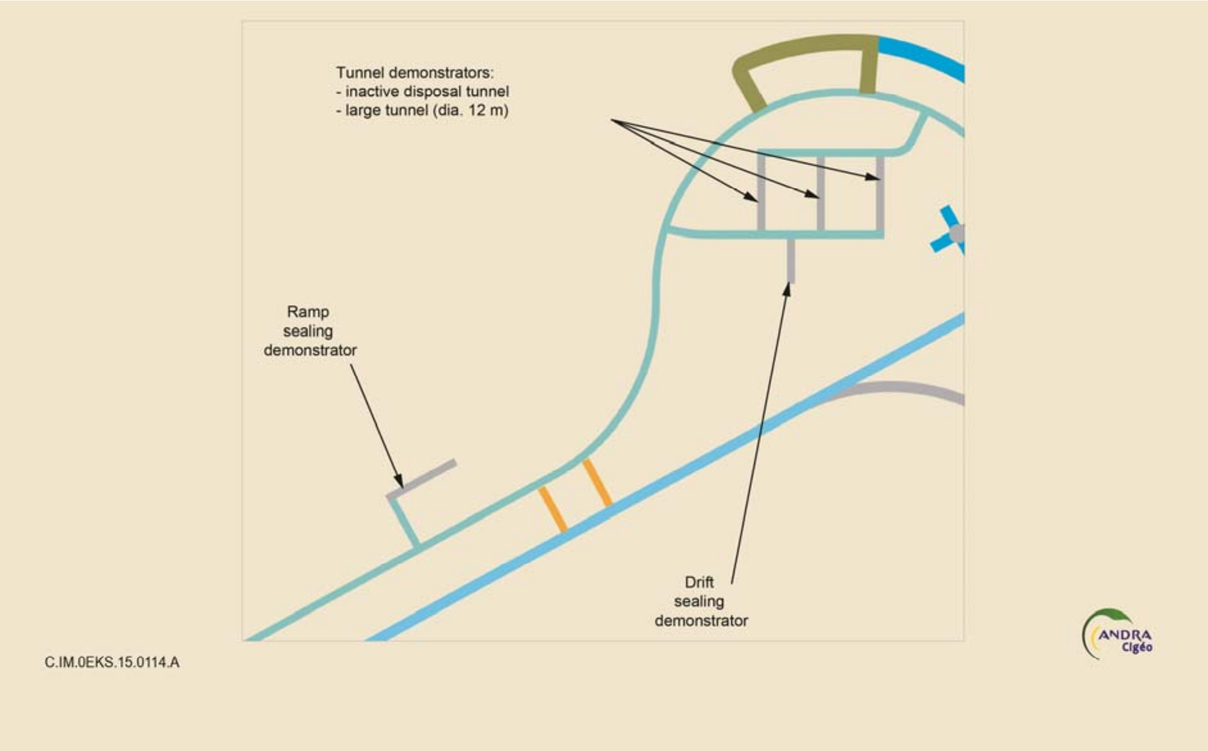


Figure 3-2 *Diagram showing the locations of the demonstrators (Based on the basic engineering design. HLW cell and hydraulic cut-off demonstrators not shown. The location of the zone within the underground facility may change over the course of the design studies).*

The report on the construction and monitoring of these structures will be incorporated into the report on the industrial pilot phase. This monitoring will continue throughout Cigeo's service life in order to have a significant amount of operating experience feedback on their behaviour and performance once operations to close Cigeo are started.

3.3.6 Avenues of optimisation

On the basis of studies conducted up to 2015, Andra has identified potential avenues of technical and economic optimisation for Cigeo's design. This identification systematically takes in account the potential impact of these safety optimisations. In conjunction with the project's incremental development (see 4.2 herein), Andra will continue the process of identifying and studying new optimisations throughout Cigeo's design and operation. The aim is to extend these optimisations to the widest number of structures to be built.

The study on optimisations that have already been identified will be further developed by Andra during the detailed engineering design. The aim is to integrate these optimisations into Cigeo's reference design, which will be included in the construction licence application. Gradual changes in Cigeo's reference design are normal in the course of the development of a preliminary design.

However, depending on the progress made on the studies, some avenues of optimisation may not yet reach the requisite level of technology maturity to be included in the reference design in 2018. In order for them to be operationally integrated into Cigeo's construction, their development will have to be finalised (see Section 2.4 herein) and their inclusion in the project will have to be specifically authorised.

Any optimisations not yet fully investigated by the end of the detailed engineering design will be presented in the construction licence application and associated with proposals for licensing appointments, presentation reports on expected demonstration elements, and estimated implementation dates[22].

Examples of the main avenues of optimisation identified at this stage are presented in the box below.

Optimisation Opportunities	Benefits
Drift and cell roof support: use of compressible segments	Decrease in excavated cross-sections
ILW-LL cell excavation methods	Use of a tunnel-boring machine
ILW-LL cells of greater cross-section	Increase the disposal capacity of the ILW-LL cells to reduce the number and length of the drifts leading to them
Closure structures in the ILW-LL section	Reduce the number of seals and simplify their creation
Direct disposal of ILW-LL packages[23]	Reduce the number of ILW-LL cells and the length of the drifts leading to them
Longer HLW cells	Reduce the number of HLW cells and the length of the drifts leading to them
Optimisation of the HLW1/HLW2 disposal sections based on thermo-hydro-mechanical (THM) criteria	Reduce the size of the HLW section (number of cells and length of the drifts)
ILW-LL packages as HLW spacing buffers	Reduce the number of ILW-LL cells and the length of the drifts leading to them

Specific studies will be conducted on some avenues of optimisation during the industrial pilot phase. In this regard, Andra has already planned to build a large inactive disposal tunnel demonstrator in order to study the possibility of widening the diameter of the ILW-LL cells (see Figure 3-2). If the results of the measurements and tests to be conducted on this demonstrator are satisfactory, disposal cells of this size will, provided that licensing is obtained, be built for some package families during the subsequent phases. Implementation of other avenues of optimisation, such as for extending the HLW1/HLW2 cells (their construction is currently scheduled to start around 2068) and direct disposal of ILW-LL packages (handling and emplacement tests) may also be studied in suitable inactive demonstrators at the start of the industrial pilot phase.

The overall process of development and integration of avenues of optimisation for Cigeo will be described in greater detail in the construction licence application.

[22] At the construction licence application deadline, project reference will comprise the entire set of (i) the robust, demonstrated solution for the T1 phase and the subsequent phases until completion, (ii) the design changes envisaged for each phase following the T1 phase, and (iii) the method and the estimated schedule for their demonstration and gradual integration into Cigeo's construction.

[23] Disposal of ILW-LL packages received from a waste generator without first being placed in a disposal container.

3.4 Summary of the industrial pilot phase

The description of the industrial pilot phase is summarised in the box below.

Andra has submitted the following proposals provided that the necessary licences are granted:

- The industrial pilot phase will begin with the start-up tests of the facility and end when Cigeo transitions to routine operation. It will be documented in a report to be sent to ASN and submitted to Parliament and the project's stakeholders. The transition to routine operation will follow a process associating ASN and the project's stakeholders. The regulatory nature of this process has yet to be defined.
- Cigeo's Operations Master Plan, which will be in force at Cigeo's start-up, may be updated after the industrial pilot phase to take into account accumulated experience.
- The industrial pilot phase will comprise a phase of inactive start-up tests (conducted on dummy packages), commissioning tests conducted on waste packages, and the gradual and careful bring-up to full operation.
- The industrial pilot phase is estimated to last for around 10 years. This period will consist of around four years of inactive tests followed by, after the emplacement of the very first waste packages, around six years of taking the facility gradually forward to full operation.
- The aim of the industrial pilot phase is to confirm, under real conditions and in addition to tests conducted in the underground research laboratory:
  - ✓ Risk management under operating conditions.
  - ✓ Performance of industrial equipment.
  - ✓ The ability to retrieve waste packages from their disposal cells.
  - ✓ The ability to monitor repository structures.
  - ✓ The ability to close off and seal cells, drifts, and ramps.
  - ✓ Avenues of technical and economic optimisation.
- The following inactive demonstrators will be implemented during the industrial pilot phase:
  - ✓ One HLW disposal cell.
  - ✓ One ILW-LL disposal cell.
  - ✓ One large ILW-LL disposal cell.
  - ✓ One ramp sealing demonstrator.
  - ✓ One drift sealing demonstrator.
  - ✓ One drift hydraulic cut-off demonstrator.
  - ✓ One closed HLW disposal cell.

4

Project management choices offered by reversibility

4.1 Reversibility

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

Currently, the HLW and ILW-LL waste that have already been generated are safely placed in storage facilities. But this is a temporary management solution. A sustainable management solution must be found, studied and implemented. In its opinion issued on 1 February 2006, ASN deemed that "*deep-geological disposal appears to be an unavoidable final management solution*" for the management of HLW and ILW-LL waste.

The aim of Andra's research, as laid down by the 2006 Planning Act (6), is thus to design a facility that makes it possible to ensure, over the very long term, the containment of radioactive waste and reduce the burden on future generations. Indeed, unlike a storage facility, no further human intervention will be needed to ensure the safety of Cigeo once it is closed.

Our generation also has the responsibility to not bind future generations to the choices our generation has made. It is for this reason that, at the request of the French Parliament, Andra is developing a project for a reversible disposal facility.

The ethical concern for reversibility comes from the time scale required for managing the most harmful radioactive waste. In particular, given the century-long service life planned for Cigeo (see Sections 2.5, 2.6 and 2.7 herein), it is the responsibility of our generation to design and pass on safe facility that future generations (should they choose not to continue as planned) will be able to modify or improve, depending on their own objectives and constraints, or replace with other management facilities, if other options become available, made possible by technical advances. Following the public debate on Cigeo, Andra’s Governing Board proposed defining reversibility (4) as the "*ability to leave future generations options regarding long-term management of radioactive waste, including sealing off repository structures or retrieving waste packages. This is ensured in particular by the progressive and flexible development of the disposal facility*".

Among the choices on offer in the possibility to reconsider decisions taken by the previous generation. Reversibility thus aim to provide future generations with a full range of choices.

In practice, its implementation is based on governance tools and technical project management tools.

These tools, their definitions, the roles that they may play in future decisions, and examples of the potential impact on the Cigeo project are presented in the table in appendix 6. They have been defined to concretely help in the taking of decisions on radioactive waste management. In particular, they ensure that the various options available are preserved or unlocked over time. Their sequence of steps is summarised in the following diagram.

The continuous process of the implementation of reversibility tools helps to build and maintain the collective confidence choices retained by the society in the waste management sphere.

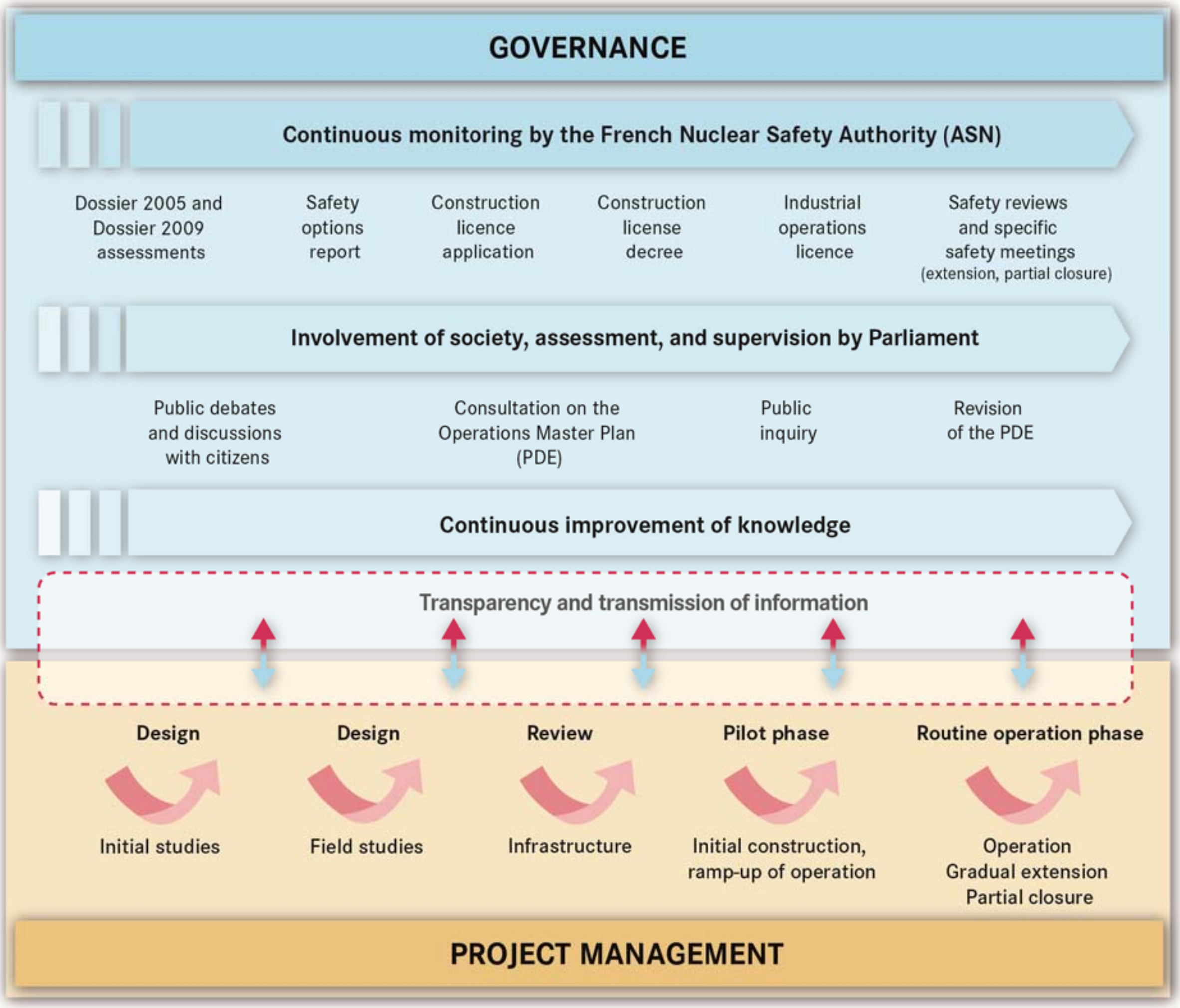


Figure 4-1 *Diagram showing the systems for reversibility in terms of project governance and management.*

The tools of governance are as follows:

- Continuous improvement of knowledge on the management of radioactive waste.
- Transparency and transmission of information and knowledge.
- Involvement of society, assessment and supervision by Parliament.
- Monitoring by the French Nuclear Safety Authority (ASN).

Andra will participate in the governance of the project, primarily by conduction research programmes and by making data available to stakeholders. Cigeo's construction licence application and the report on the industrial pilot phase are both examples of data that will be used for governance of the project. Andra may also guide and prepare the participation of society and the evaluation and supervision by Parliament. In accordance with regulations, it will be available for inspections by ASN.

In terms of governance, — once the documents following the public debate on Cigeo, including this proposed Operations Master Plan (PDE), have been produced and reviewed — the main decision and technical deadlines and the main safety milestones of the project will be:

- The consultation on the proposed Operations Master Plan (PDE).
- The submission of Cigeo's construction licence application and application for declaration of public utility.
- The act laying down the reversibility conditions.
- The public inquiry on Cigeo.
- The construction licence decree.

- The start of the industrial pilot phase.
- The commissioning of Cigeo.
- The transition to routine operation.
- The first safety review.
- The start of expansion work on the facility.
- The consecutive safety reviews.
- The integration of optimisations in the subsequent phases.
- The start of initial closure work.
- Cigeo's final closure.

An initial list of these main steps is given in Appendix 7. This list will be given in full in the construction licence application along with the main steps in the development of Cigeo's components (see Section 2.4 herein).

The project management tools are:

- Incremental development and gradual construction of Cigeo's facilities.
- Operational flexibility.
- Adaptability of the facilities.
- Retrievability of the waste packages.

The project management tools are technical. Materially speaking, they reflect the operational or construction operations that would be conducted in Cigeo following governance decisions. In practice, their use would change the reference progression of the project proposed by Andra (see Chapter 2 herein). The possibilities they offer and their potential impact on Cigeo's reference progression are described in Subsections 4.2 to 4.5 below.

Cigeo's design, construction, and closure is funded by current generations so as not to shift this burden on future generations. This is ensured by the regularly revised provisions made by EDF, CEA and Areva, the three producers of this waste. The cost of technical measures taken to ensure reversibility is factored into in the project, meaning that current generations are providing future generations with easier options for acting on the disposal process. However, should future generations decide to exercise these options — for example, to modify the repository to allow the emplacement of new types of waste or remove waste packages — they will of course have to take responsibility for their decisions.

4.2 Incremental development of the project

The incremental development of the Cigeo project corresponds to the continuous, regular, and prudent sequencing of the operations involved throughout the facility's service life. It is punctuated by the twelve consecutive construction phases that, in the reference progression, are scheduled to last for around 10 years each (see Section 2.6.1 herein). Up to its completion, and associated with design choices taken by Andra, this reference progression will constitute the initial roadmap for the project's development. It may be reviewed at the various stages of updates to the proposed Operations Master Plan (PDE) (see Section 1.2 herein).

The principle behind Cigeo's incremental development provides future generations with the possibility of accelerating (construction of larger phases) or delaying (construction of smaller phases or over longer periods) Cigeo's development, for example to take changes in the package delivery programme into account.

Furthermore, it promotes the inclusion of future phases of construction and all improvements made possible throughout the project's century-long service life by scientific and technical advances and feedback. If a better technical solution than one previously envisaged is developed and reaches a sufficient degree of technology maturity (see Section 2.4 herein) allowing it to be integrated into a future phase of Cigeo's construction, Andra may, provided the necessary licensing is obtained, install it within Cigeo. The construction and operation of the HLW0 section, some 40 years before the implementation of the HLW1/HLW2 sections (see Section 2.6.1 herein) will therefore make it possible to gain valuable operating experience feedback for defining optimisations for these sections.

In this respect, it should be pointed out that the studies and research on the development of the repository will continue after the industrial pilot phase in an aim to optimise the technical and economic aspects of the project's design and continuously improve, within the meaning of the Order of 7 February 2012 (14), the safety measures taken. Incremental development promotes both the control of disposal costs and the maintenance of the highest level of safety. Regarding this last point, design changes might result from requests made by ASN during the periodic safety reviews.

In addition, Andra will carry out an observation programme within Cigeo. Observation consist in investigating facts and processes in order to better understand them, particularly by identifying their causes. It provides further knowledge in addition to that obtained during the design and R&D studies conducted before or at the same time as the building and operation of the repository, in particular in the underground research laboratory. Particularly, it aims to better understand the margins used in the design of the equipment and structures and thus optimise the design of future phases. The purposes of this observation programme and its implementation measures will be described a first time in Cigeo's licence application. The observation programme may be changed during Cigeo's operation.

On top of the aforementioned main avenues of optimisation (see Section 3.3.6 herein: longer HLW cells, ILW-LL cells of greater cross-section, direct disposal of ILW-LL packages) are scientific advances in materials engineering and Earth sciences (such as the thermal and mechanical behaviour of the clay layer) that may significantly optimise Cigeo's design. Andra will continue its research efforts in the two areas in particular. The conditioning methods foreseen for the packages could also change. The main consequence of the integration of these changes within Cigeo would be to reduce the number of underground structures to be built. The overall underground architecture (distribution into sections, deployment principle) as presented in appendix 3 is designed to make future changes possible. It would not be significantly modified.

4.3 Operational flexibility

Operational flexibility is defined as the ability of Cigeo to adapt to changes in the industrial package delivery programme (reception schedule, reception flows, date of partial closure) without modifications to its infrastructure or existing equipment and without the building of new structures.

It gives future generations the possibility to delay or accelerate (within certain limits related to equipment performance, equipment usage rates, and operator availability) the flow of packages emplaced within Cigeo. This situation could be encountered if, for example, a waste generator wished to store then ship to Cigeo a waste package at a time or rate other than those initially planned. Cigeo is thus designed to ensure that its safety will not be dependent on the order in which packages are delivered.

Operational flexibility also makes it possible to allow future generations to change the reference closure scheme (see Sections 2.6.2 and 2.7 herein). Early closure of the cells, as they are filled (by closure phase started once every 10 years or so), has been studied by Andra. These early closure scenarios have not been adopted by Andra at this stage, particularly to mitigate operating risks and maintain a high level of monitoring and retrievability (see Section 2.6.2 herein). If future generations ever decided otherwise, these scenarios would be technically possible. No significant changes to the receipt schedule would be required. However, the operational flexibility would be significantly reduced.

Conversely, later partial closure operations of the disposal sections are also possible. Andra has studied scenarios in which closure operations are started at the end of Cigeo's operation, i.e. in 2145. These later scenarios have not been adopted by Andra at this stage, particularly because they do not make it possible to acquire sufficient and gradual operating experience feedback of closure operations. However, if future generations ever decided otherwise, they would be technically possible. Indeed, the disposal containers and structures are designed to be robust enough to allow the closure schedule to be delayed without affecting safety.

4.4 Adaptability of Cigeo's facilities

The adaptability of Cigeo's facilities is defined as the ability to modify them in order to accommodate new design assumptions. Adaptability can include significant modifications to existing equipment or the construction of new structures.

In order to define long-term solutions for managing radioactive waste, it is important to take into account the principle of proportionality with respect to the risk and the impact, as well as the optimisation between the costs (monetary, human, etc.) and the expected benefits of implementing a specific management solution. This principle on its own is not easy to apply, particularly because it requires consideration of the costs and benefits over various periods that can be very distant in the future (15).

The main design assumption of Cigeo that may be revised over time is that of its inventory, i.e. the number and types of waste package for which it is currently designed. Throughout Cigeo's operation, changes in France's national waste-management policy could result in waste not initially planned during the design stage to be emplaced within Cigeo. Depending on the volumes and types of such waste, such decisions could pose various technical challenges ranging from mere adjustments in the Cigeo's design and operation (e.g. in order to dispose of low-level long-lived waste (LLW-LL) intended for near-surface disposal) to significant architectural changes (e.g. scenarios involving the disposal of spent fuel). As a precautionary measure, safety assessments conducted on an inventory broader than that currently planned could be submitted to Andra at the same time as the construction licence application, but disposal of this waste in Cigeo would not be considered as the reference solution.

If Cigeo is built, the first objective of its operation will be to dispose of the reference inventory (see Section 2.1 herein) and within the capacity limits set at its creation[24]. If, during Cigeo's century-long service life, a decision is taken to emplace in Cigeo waste other than that initially planned, Andra will have to file a specific licence application for review by ASN.

In this respect, following the referral to the minister of ecology, sustainable development and energy, the High Committee for Transparency and Information on Nuclear Safety (HCTISN) drafted a survey report on inventory of radioactive waste intended for emplacement within Cigeo in the light of France's energy policy choices (16). The HCTISN noted that approximately 30% of the high-level waste and 60% of the intermediate-level long-lived waste intended for Cigeo have already been generated. As for future waste, the HCTISN emphasised "*[that] such waste depends little on the exact management policy that will be chosen for France's current nuclear fleet (subject to the validity of the assumption on the ultimate full recycling of all types of spent fuel).... However, an energy policy that would challenge the assumption on the ultimate full recycling of all types of spent fuel in France's current fleet would heavily impact the very nature of the waste to be disposed of within Cigeo, but only toward the end of the century*". In its recommendations, the HCTISN considered that a major modification to the disposal facility "*such as that which, near the end of the century, would consist in disposing of non-processed spent fuel, would justify the involvement of public beyond just a public inquiry*".

Andra has designed Cigeo to be compatible with the disposal of spent fuel provided some retrofits are made. These retrofits would primarily consist in changing the transfer process into the underground facility to accommodate the disposal of fuel packages. In any case, due to the decay heat of spent fuel, 2085 is the earliest date any spent fuel from the current fleet could be disposed of at Cigeo.

---

[24] French Decree 2007-1557 of 2 November 2007 on basic nuclear installations and nuclear safety inspections for the transportation of radioactive substances. Consolidated version dated 27 February 2014. (2007). No. 02/11/2007) states that the peak capacity of a basic nuclear installation is set by its construction license decree and that this capacity can be increased only by an amendment to this decree.

As part of the France's National Radioactive Materials and Waste Management Plan (PNGMDR) for 2013-2015, Andra has studied a number of scenarios associated with potential disposal of spent fuel packages within Cigeo. These studies show how, should the need arise, Cigeo can be accommodated to enable such disposal.

One of the main differences between Cigeo with or without the inclusion of spent fuel is the replacement of disposal sections for HLW1/HLW2 packages by fuel disposal sections (if ever spent fuel is disposed of within Cigeo, any HLW1/HLW2 packages resulting from the reprocessing of this fuel would not be produced). The impact on the HLW0 and ILW-LL disposal sections is very limited. The EP2 surface facility, which is scheduled to begin construction around 2068, could be accommodated to the disposal of these packages.

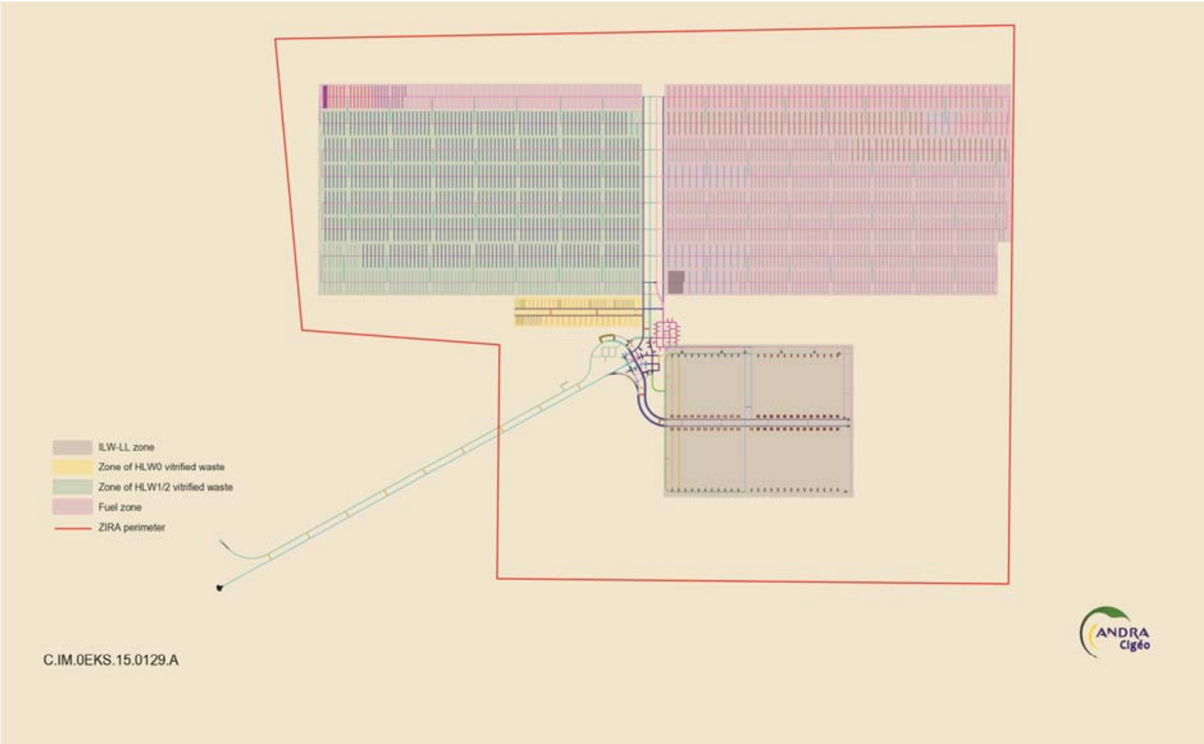


Figure 4-2 *Diagram showing an example of an underground structure incorporating disposal of spent fuel (based on the basic engineering design).*

In addition to the decision to dispose of spent fuel within Cigeo, changes to the reference inventory could also be decided if changes are made to the preferred management solution for some types of waste. For example, low-level long-lived waste (LLW-LL) intended for near-surface disposal, could ultimately be disposed of within Cigeo. If such a decision were taken, on the condition that it were approved, these additional packages would be disposed of in the same type of cell as the ILW-LL cells. They could be placed in the ILW-LL section or another dedicated adjacent section. Cigeo's underground structure will be large enough to accommodate the addition of these cells, including within the ZIRA.[25]

[25] Zone of interest for detailed reconnaissance This zone a) is compatible with potential siting of the ramp access point at the boundary between the Meuse and Haute-Marne departments; b) is compatible with potential siting of the main access shafts in wooded areas; and c) avoids siting the facility under the built-up areas of nearby villages. It covers a surface area of approximately 30 km^2. A 3D seismic survey was carried out in 2010.

4.5 Retrievability of emplaced packages

Retrievability is defined as the ability to retrieve waste packages emplaced in a deep geological facility..

At its meeting on 5 May 2014 (4), Andra's Governing Board confirmed that Cigeo's design studies were continued "*to leave open the possibility, during Cigeo's 100-year service life, of retrieving the waste packages emplaced there*".

The main technical options that make it possible to ensure the retrievability of the waste packages emplaced within Cigeo are presented in the Retrievability Options File (DORec)[26]. These options encompass robust design measures for the repository components and equipment, tests for verifying their proper operation, and conservative operational measures, particularly in terms of monitoring. The aim of these measures is to be able to carry out retrieval operations without affecting safety (e.g. by using handing equipment equivalent to that used for emplacement).

The studies conducted by Andra also cover the suitability of partial closure structures to be dismantled should retrieval decisions be taken after the completion of a closure operation. In such cases, the degree of effort required to retrieve these waste packages would be greater[27]. In accordance with the reference progression (see Section 2.6.2 herein), the first partial closure structures are expected to be completed in the HLW0 repository zone, provided that special licensing is obtained, in 2070. A specific testing programme is being conducted to validate the techniques and methods used to dismantle the closure structures (drift sealing, backfill, closure structure for the HLW and ILW-LL cells). This programme will continue during and after the industrial pilot phase. It will be described in greater detail in Cigeo's construction licence application.

Retrievability is associated with technical measures that prove to be effective during the disposal facility's century-long service life. Operations are possible beyond this period, but technically embarking on a demonstration of their feasibility conditions would not be a realistic option. Nevertheless, the design measures continue to facilitate retrievability (functional clearances, robustness of components) even after the expected period. If subsequent generations choose to postpone Cigeo's final closure, they will have to take the necessary measures to do so.

Retrievability is one of the tools that facilitate the choices made by future generations in term of radioactive waste management. It is not an end in itself. It is meaningful only if it is used with the other systems for reversibility described above (see Section 4.1 herein), more particularly the acquisition of knowledge gained through Cigeo's operation and the continuation of R&D programmes on waste.

Retrievability gives future generations the possibility to reconsider the decision to use deep geological disposal as a way of managing all or part of the radioactive waste packages emplaced at Cigeo. If such a decision is ever taken, the packages retrieved from Cigeo would be taken off-site and processed via the chosen alternative management solution. There are no plans to store these packages within Cigeo's surface facilities.

---

[26] The main design options that make retrievability possible are the robustness of the containers, cells and retrieval equipment, precautionary measures to ensure the possibility of retrieval operations, and the ability of closure structures to be dismantled. Specific operating measures — such as monitoring of retrieval conditions, knowledge management, and periodic review of retrieval conditions — are also planned.

[27] The international retrievability scale (Reversibility of decisions and retrievability of radioactive waste. Considerations for National Geological Disposal Programmes. OECD Nuclear Energy Agency (2012). Radioactive waste management. NEA Report No.°7105. 33 pages) drafted by the Nuclear Energy Agency (NEA) of the Organisation for Economic Co-operation and Development (OECD) discusses the retrievability of waste packages during the steps involved in partial or final closure of a repository.

Depending on when and how these retrieval operations are carried out (with or without interrupting disposal operations), to what extent (one package, several cells, or all the cells), and the retrieval and reshipment workflows (equal or greater than those for which buildings EP1 and EP2 were designed), it may be necessary to build additional surface facilities. The potential functions of these buildings — complementary to those in buildings EP1 and EP2 — will be to prepare and store packages for shipment, reship packages, and provide operational support for the reopening of closed portions of the repository. Areas near the surface facilities will be left vacant so that these buildings may be built.

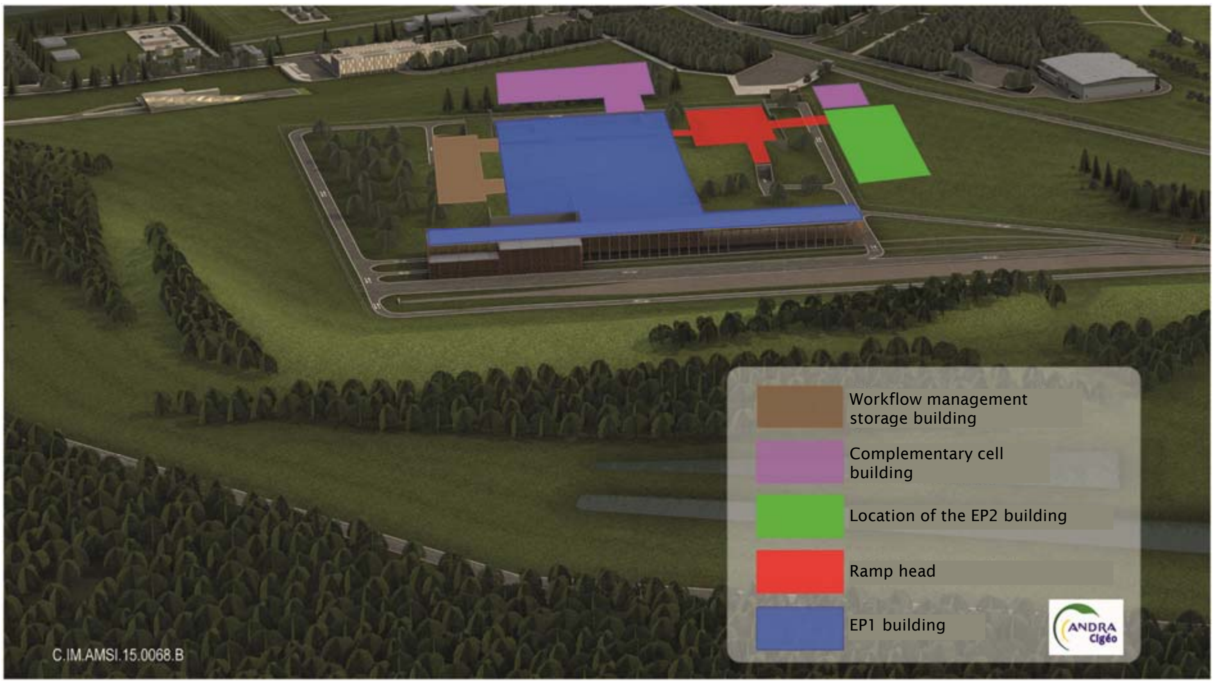


Figure 4-3 *Locations of the surface facilities intended for retrievability (based on the basic engineering design).*

4.6 Summary of reversibility

Ethical concerns for reversibility originate in the time scale required to manage the most harmful radioactive waste and especially Cigeo's century-long service life.

Disposal reversibility is the ability to leave future generations options regarding long-term management of radioactive waste.

In practice, its implementation is based on governance tools and technical project management tools.

The tools of governance are as follows:

- Continuous improvement of knowledge on the management of radioactive waste.
- Transparency and transmission of information and knowledge.
- Involvement of society, assessment and supervision by Parliament.
- Monitoring by ASN.

The project management tools are:

- Incremental development and gradual construction of Cigeo's facilities.
- Operational flexibility.
- Adaptability of the facilities.
- Package retrievability.

The cost of technical measures taken to ensure reversibility is factored into in the project, meaning that current generations are providing future generations with easier options for acting on the disposal process. However, should future generations decide to exercise these options, for example, to modify the repository to allow the emplacement of new types of waste or remove waste packages, they will have to take responsibility for their decisions.

The 'incremental development' of Cigeo gives future generations the possibility to accelerate or delay Cigeo's construction. It promotes the inclusion of future phases of construction and all improvements made possible throughout the project's century-long service life by scientific and technical advances and feedback. More particularly, optimisation opportunities that have already been identified but which have not yet reached a sufficient degree of technology maturity for inclusion in the construction licence application to be filed 2018, may, if their licensing is granted, be integrated into subsequent stages of the project.

Operational flexibility gives future generations the possibility delay or accelerate (within certain limits related to equipment performance, equipment usage rates, and operator availability) the flow of packages emplaced within Cigeo. It also makes it possible to amend the reference closure scheme to foresee or delay partial closure operations.

The adaptability of Cigeo's facilities makes it possible to modify the project following changes in its initial design assumptions, such as its reference inventory (number and type of waste package families for Cigeo has been designed). Cigeo's design means that it can be adapted to the disposal of spent fuel or waste that is currently intended for near-surface disposal facilities (low-level long-lived wastes).

Retrievability gives future generations the possibility to reconsider the decision to use deep geological disposal as a way of managing all or part of the radioactive waste packages emplaced at Cigeo.

APPENDICES

Appendix 1 Nuclear facilities that generate waste intended for emplacement within Cigeo

This appendix identifies the main sources of radioactive waste intended for Cigeo.

- Nuclear power reactors

Several consecutive generations of power reactor have been developed in France:

- ✓ The first generation, no longer in operation, comprised nine gas-cooled reactor (GCR) built between 1950 and 1960 at CEA's Marcoule site (reactors G1, G2, and G3) and at EDF's Chinon (Chinon reactors A1, A2 and A3), Bugey (Bugey reactor 1) and Saint-Laurent (Saint-Laurent reactors A1 and A2) sites.
- ✓ The second generation, still in operation, comprises 58 pressurised water reactors (PWR) reactors[28] commissioned between 1977 and 1999 on 19 sites.
- ✓ The third generation is the Flamanville EPR currently under construction[29].

In addition to the GCR generation, other power reactors have been shut down. These include (i) the EL4, industrial prototype (Brennilis) of type of heavy-water reactor no longer being developed; (ii) the Chooz A reactor, a French PWR prototype; (iii) Phénix and Superphénix fast-neutron reactors at Marcoule and Creys-Malville, respectively.

- Fuel cycle plants

Uranium enrichment, nuclear fuel fabrication, and the reprocessing of this fuel following its use in reactors is carried out in various facilities operated by Areva. Industrial reprocessing of spent fuel began first in 1958 at the UP1 plant at Marcoule, then in 1966 at the UP2-400 plant at La Hague. These facilities are now closed. Currently, fuel is reprocessing in the UP2-800 and UP3 plants at La Hague.

The MELOX plant at Marcoule produces MOX fuel and recycles the plutonium extracted through its reprocessing.

- CEA research facilities

CEA operates many facilities (experimental reactors, such as the Rapsodie prototype fast-neutron reactor and the Orphée and Osiris reactors; and laboratories, particularly Atalante, that perform research on fuel or the back end of the fuel cycle) that, for the most part, are located at Cadarache, Saclay and Marcoule. These sites also have support facilities for the storage and processing of waste and effluents. Some have been closed or are being remediated and dismantled.

- New facilities

In addition to the EPR at Flamanville, three facilities have received a licence for construction on CEA's Cadarache site — the Jules Horowitz experimental reactor; the ITER magnetic-confinement fusion facility; and the RES experimental nuclear-propulsion reactor.

---

[28] The PWR fleet comprises thirty-four 900 MW units, twenty 1300 MW units, and four 1450 MW units, for a total power output of 63.1 GWe.

[29] Power output of 1650 MWe.

Appendix 2 Inventory of waste packages intended for Cigeo (based on the industrial operation scenario for the facilities drawn up by Areva, CEA and EDF)

- High-level waste

National inventory identifier	Waste type	Number of packages	Estimated volume[30] (m^3)
F1-3-01	CSD-V vitrified waste packages (Areva/La Hague)	51,511	9,274
F1-3-02	Packages of molybdic-acid solutions of vitrified fission products (Areva/La Hague)	1,000	180
F1-4-01	Packages of vitrified AVM waste (CEA/Marcoule)	3,159	553
F1-5-01	Packages of vitrified PIVER waste (CEA/Marcoule)	96	17
-	Packages of vitrified Atalante waste (CEA/Marcoule)	5	1
F1-3-03	Packages of technological waste from the vitrification facilities (Areva/La Hague)	200	36
F1-3-04	Packages of strontium titanate capsules (Areva/La Hague)	3	1
F1-3-05	Waste from ELAN IIB elution columns conditioned into standard containers (Areva/La Hague)	52	9
S01	Spent sealed sources	7	1

[30] The indicated volumes correspond to the volume of water displaced by submersing a primary package.

- **Intermediate-level long-lived waste**[31]

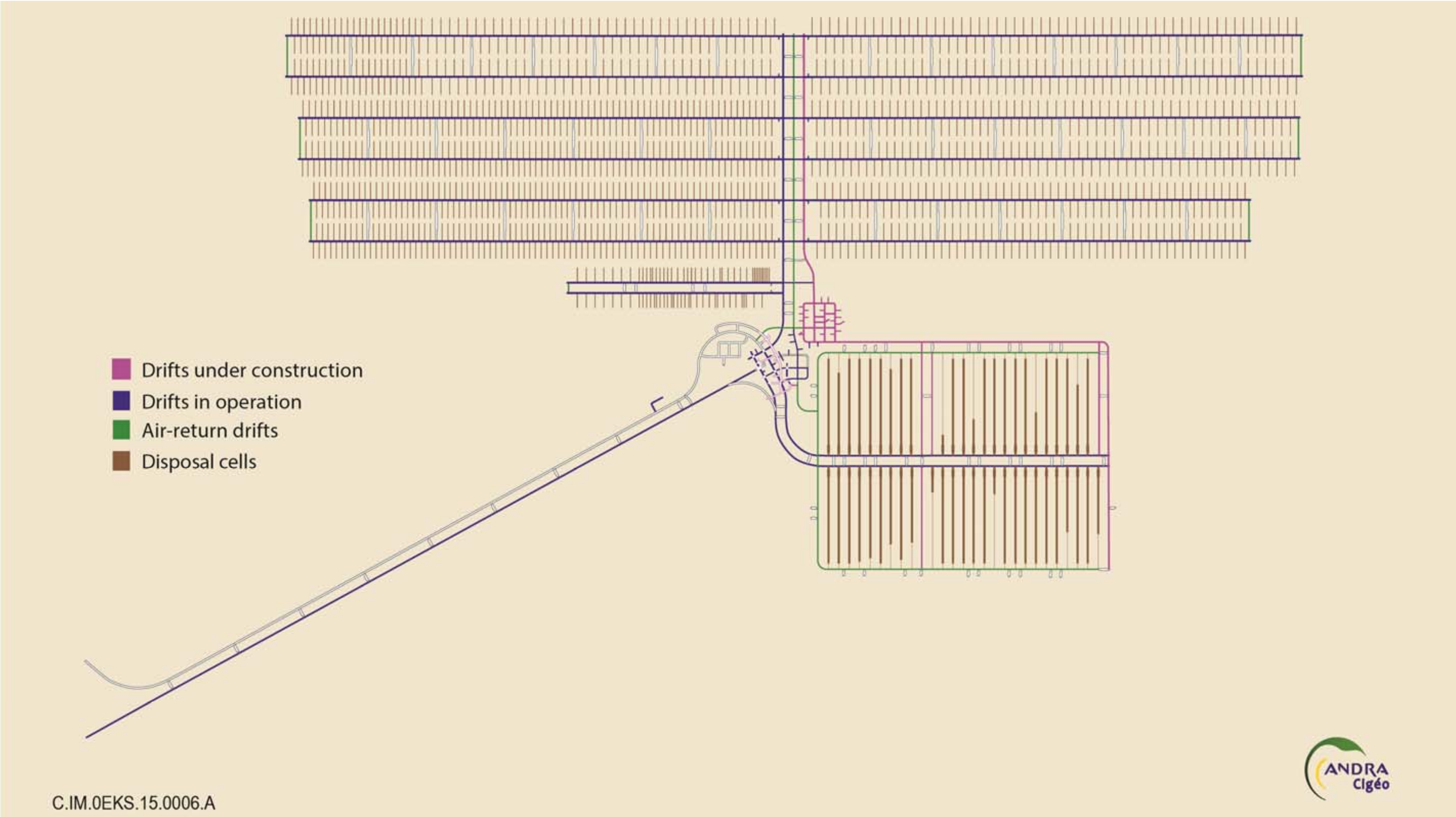
National inventory identifier	Waste type	Number of packages	Estimated volume (m^3)
F2-3-01	Packages of hulls and end caps cemented inside metal drums (Areva/La Hague)	1,517	2,276
F2-3-02	Waste packages compacted inside standard CSD-C containers (Areva/La Hague)	50,910	9,165
F2-4-07	Metal structural waste packages (CEA/Marcoule)	1,320	502
F2-4-09	Magnesium structural waste packages (CEA/Marcoule)	7,464	1,642
F2-3-04	Bitumen-embedded packages produced from effluents treated in STE3 (Areva/La Hague)	11,900	2,642
F2-3-05	Bitumen-embedded packages produced from effluents treated in STE2 (Areva/La Hague)	340	75
F2-4-03	Bitumen-embedded packages produced since January 1995 (CEA/Marcoule)	4,409	1,676
F2-4-04	Bitumen-embedded packages produced before January 1995 (CEA/Marcoule)	24,422	9,280
F2-2-03	Activated waste from EDF reactors, excluding sodium waste (EDF)	1,900	3,800
F2-4-15	Pins from the control rods of fast neutron reactors (EDF, CEA)	8	13
F2-3-02	Waste packages compacted inside standard CSD-C containers (Areva/La Hague)	4,950	891
F2-3-07	Packages of cemented solid operations waste produced before 1994 (AREVA/La Hague)	324	382
F2-3-08	Packages of cemented solid operations waste produced since 1994 (AREVA/La Hague)	9,738	11,490
F2-3-10	Waste contaminated with alpha-emitters (Areva/La Hague)	4,400	1,025
F2-3-11	Vitrified waste packages (CSD-B): washwater effluent (Areva/La Hague)	900	162
F2-3-12	Packages of dried and compacted STE2 sludge (Areva/La Hague)	14,429	3,867

[31] Solutions for long-term management of waste collected by Andra not suitable for surface disposal are being studied by Andra. Currently, the volume of such waste intended for disposal within Cigeo is estimated to be 18 m^3.

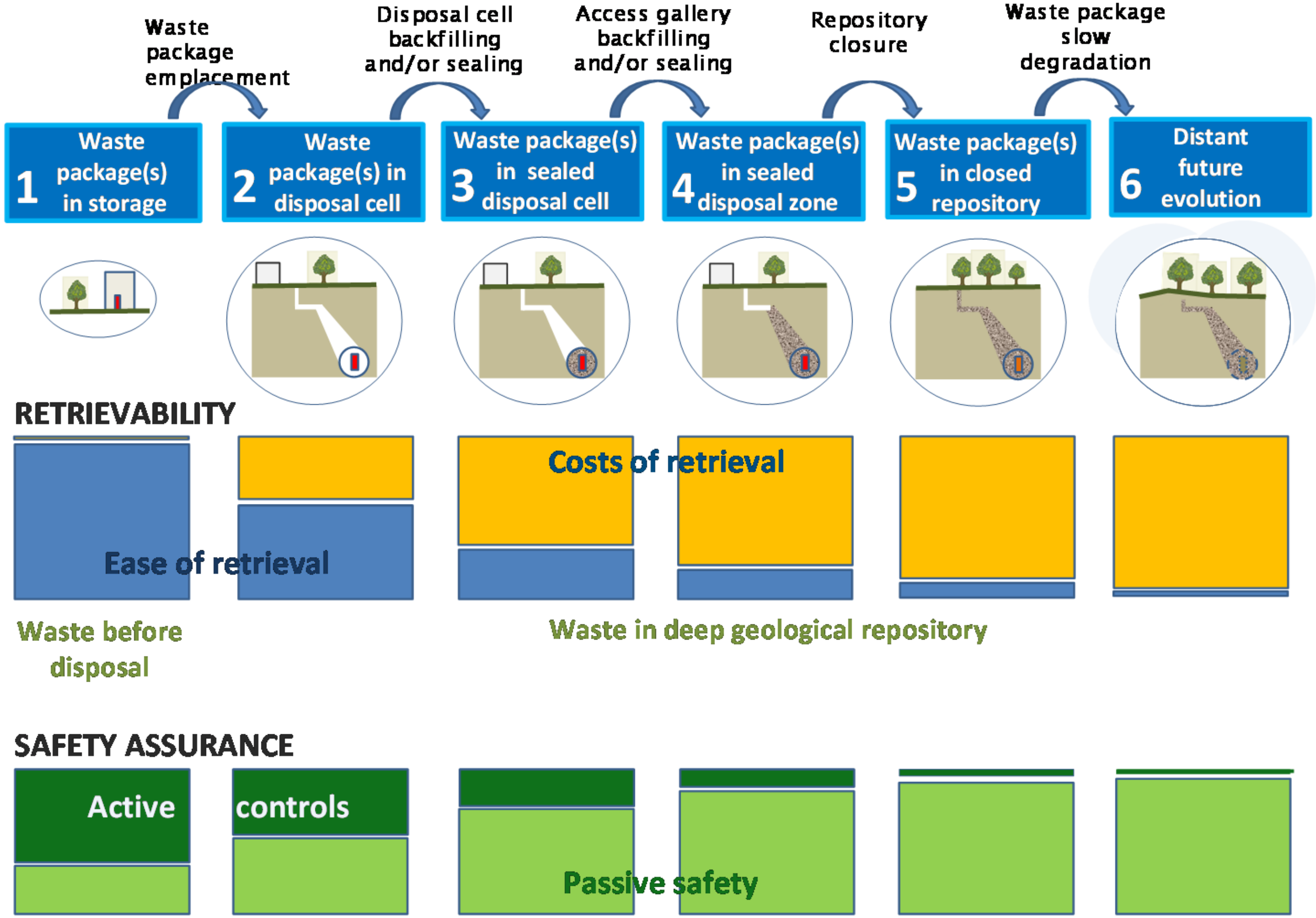
National inventory identifier	Waste type	Number of packages	Estimated volume (m³)
F2-3-13	Packages of fines suspensions and resins from the HAO silo (Areva/La Hague)	121	182
F2-4-05	Packages of solid AVM operations waste in stainless steel containers (CEA/Marcoule)	188	33
F2-4-10	Packages of process waste and cemented effluent waste (CEA/Marcoule)	3,133	1,191
F2-4-11	Metal and organic technological waste (CEA/Marcoule)	1,353	514
F2-4-12	Waste from the core of the Phoenix reactor (CEA/Marcoule)	789	163
F2-4-13	Vitrified packages of AVM washwater effluent (CEA/Marcoule)	147	26
F2-4-14	Packages of structural waste emplaced in the APM and waste from the dismantling of the APM (CEA/Marcoule)	510	115
F2-5-01	Packages of radium-bearing lead sulphates (CEA/Cadarache)	971	457
F2-5-02	Packages of filtration sludge cemented inside 500 l concrete shells (CEA/Cadarache)	4,870	1,908
F2-5-03	80-l metal containers containing a 700-l drum of cemented concentrates (CEA/Cadarache)	40	44
F2-5-04	Packages of solid operations waste cemented inside metal drums (CEA/Cadarache)	7,744	6,815
F2-5-05	Packages of medium-level irradiating solid operations waste inside 500 l drums (CEA/Cadarache)	3,887	1,944
F2-5-06	Concrete shells (1800 and 1000 l) of cemented solid waste (cement or cement-bitumen) (CEA/Cadarache)	268	502
F2-6-02	Packages of sludge and concentrates cemented inside metal drums (CEA/Valduc)	360	80
F2-6-03	Stainless steel containers containing radioactive effluents from Pu recycling (CEA/Valduc)	300	54
F2-9-01	'Source block' packages (CEA/Cadarache)	41	125
S01	Spent sealed sources	80	58
Other families	Miscellaneous waste from the ITER reactor	4,676	3,211
	Activated dismantling waste (DAD) from PWR reactors	6,360	7,000

National inventory identifier	Waste type	Number of packages	Estimated volume (m^3)
	Stainless steel containers (Phoenix waste canisters) containing irradiating waste	200	41
	Miscellaneous operations and dismantling waste generated by CEA	530	108
	Waste from the dismantling of CEA's Valduc facilities	40	35
	Miscellaneous ILW-LL waste (including waste from the irradiated materials facility at Chinon)	423	97

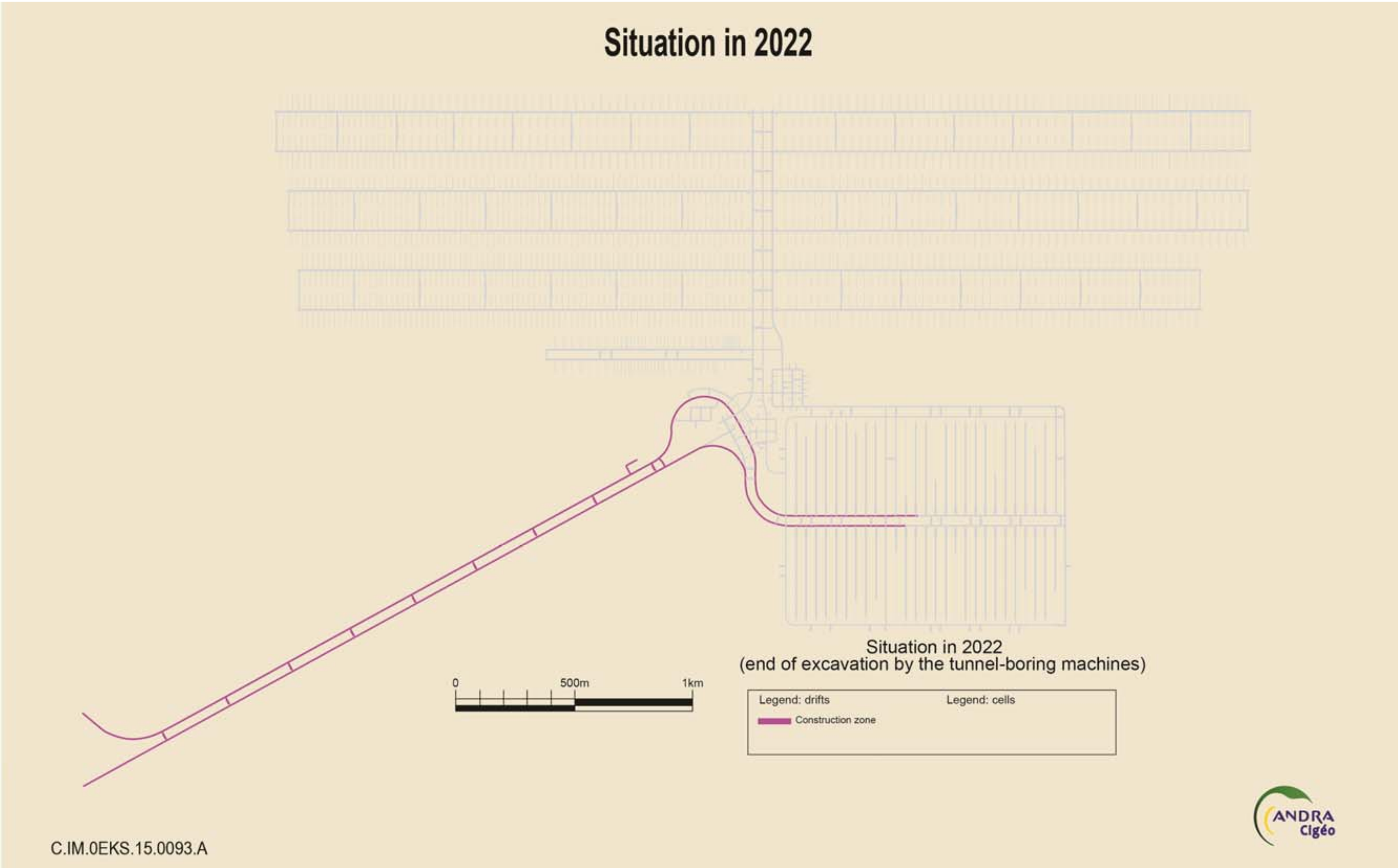
Appendix 3 Overview of Cigeo's underground architecture (illustration based on studies at the end of the basic engineering design)

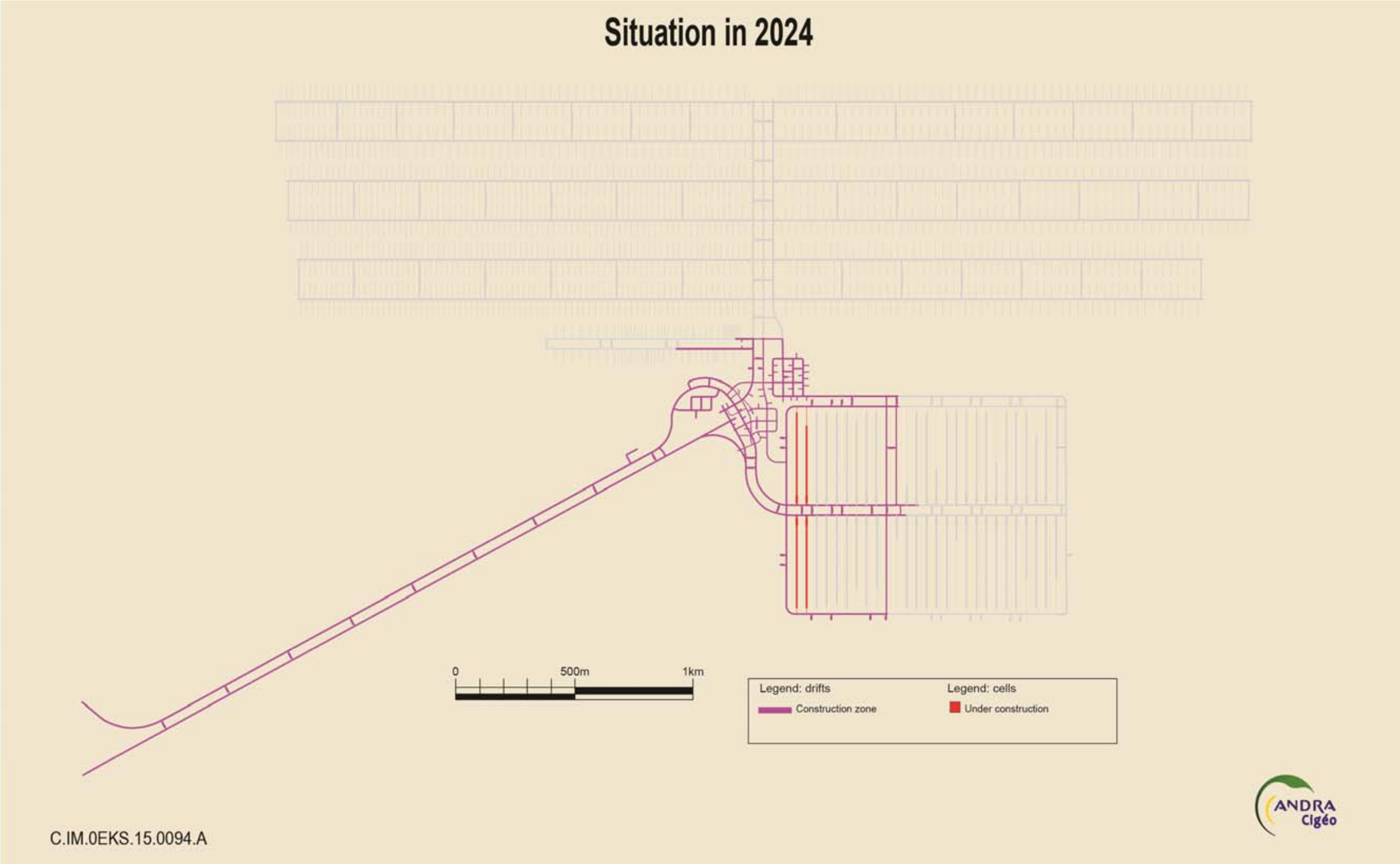


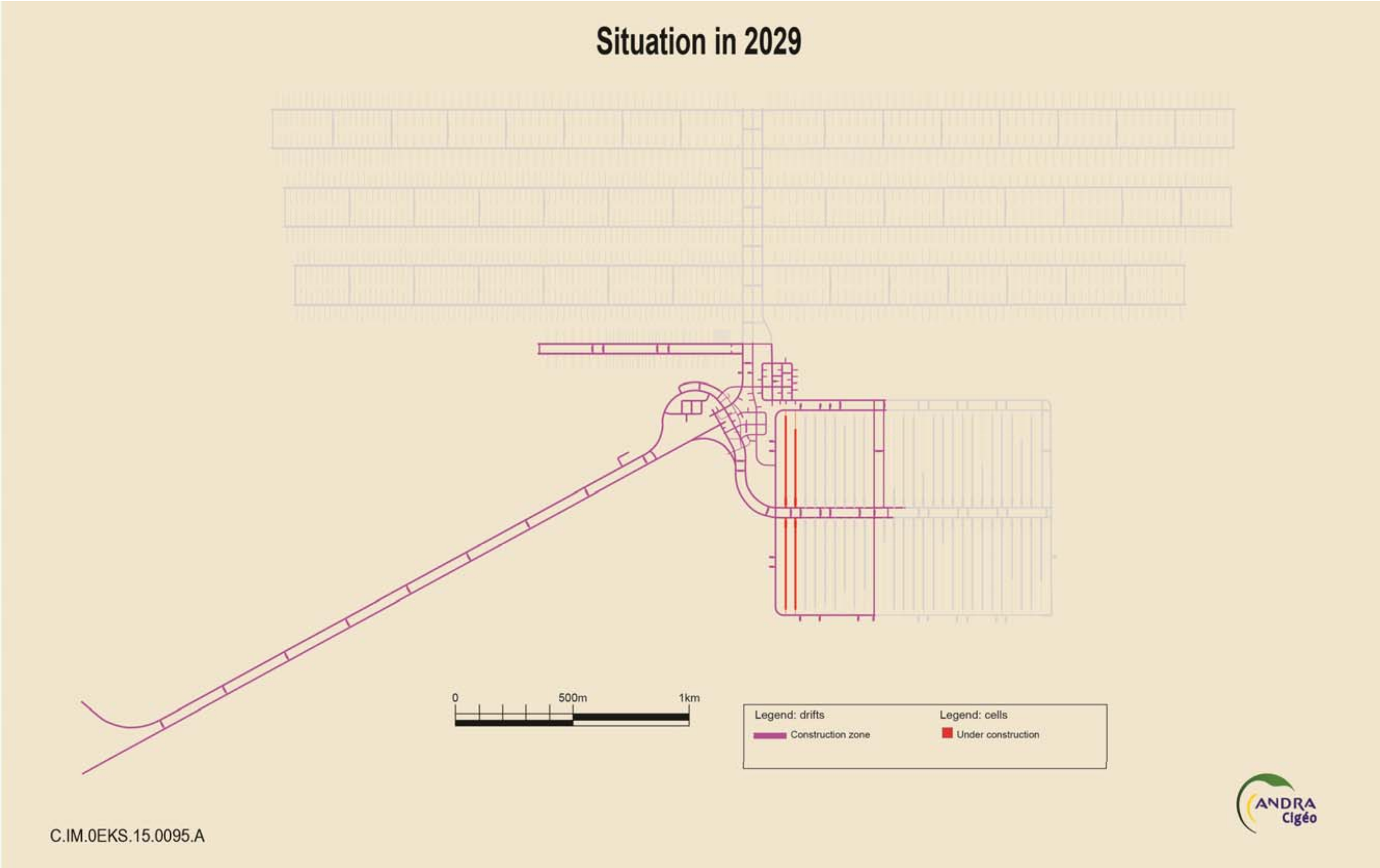
Appendix 4 International retrievability scale (13)

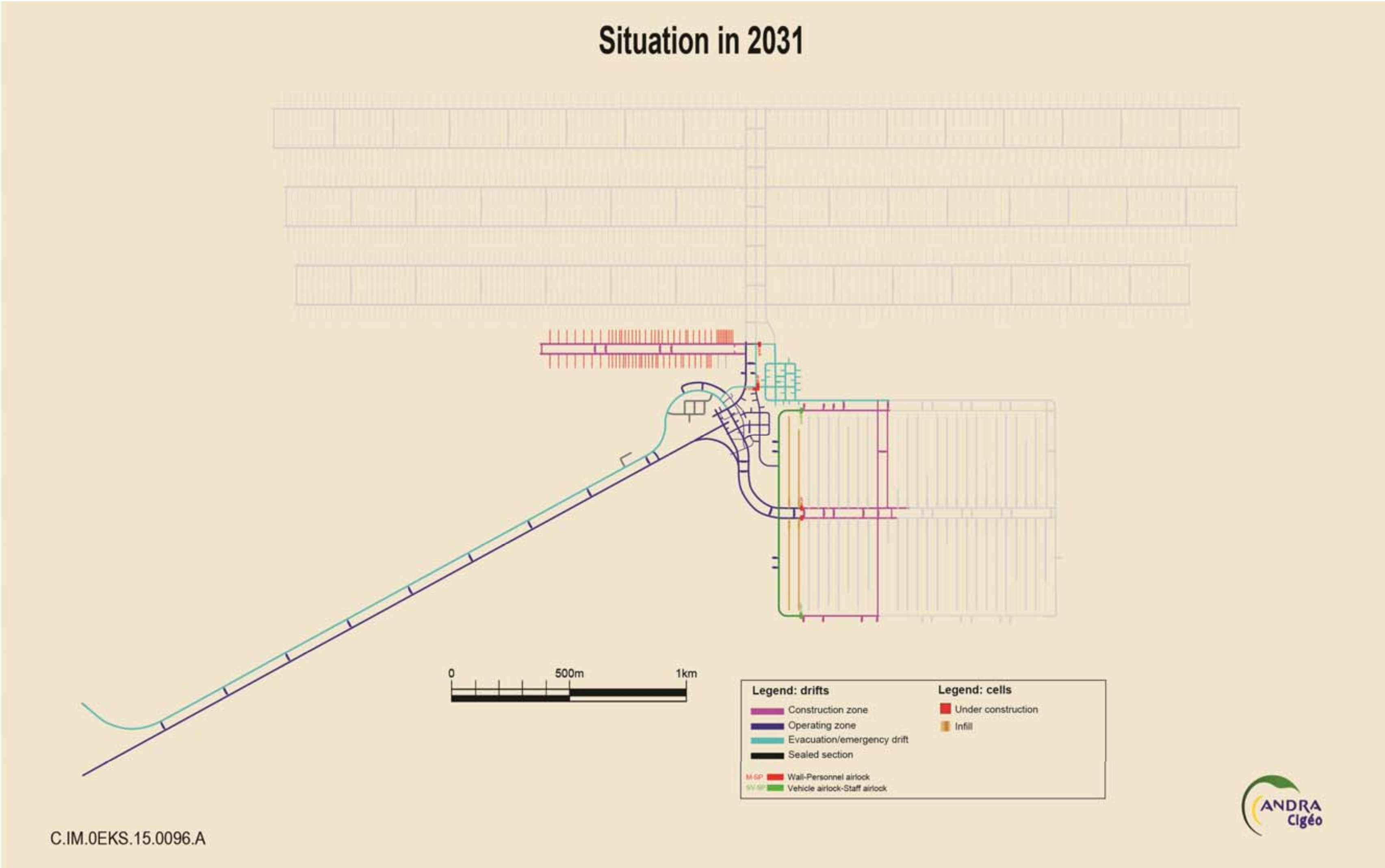


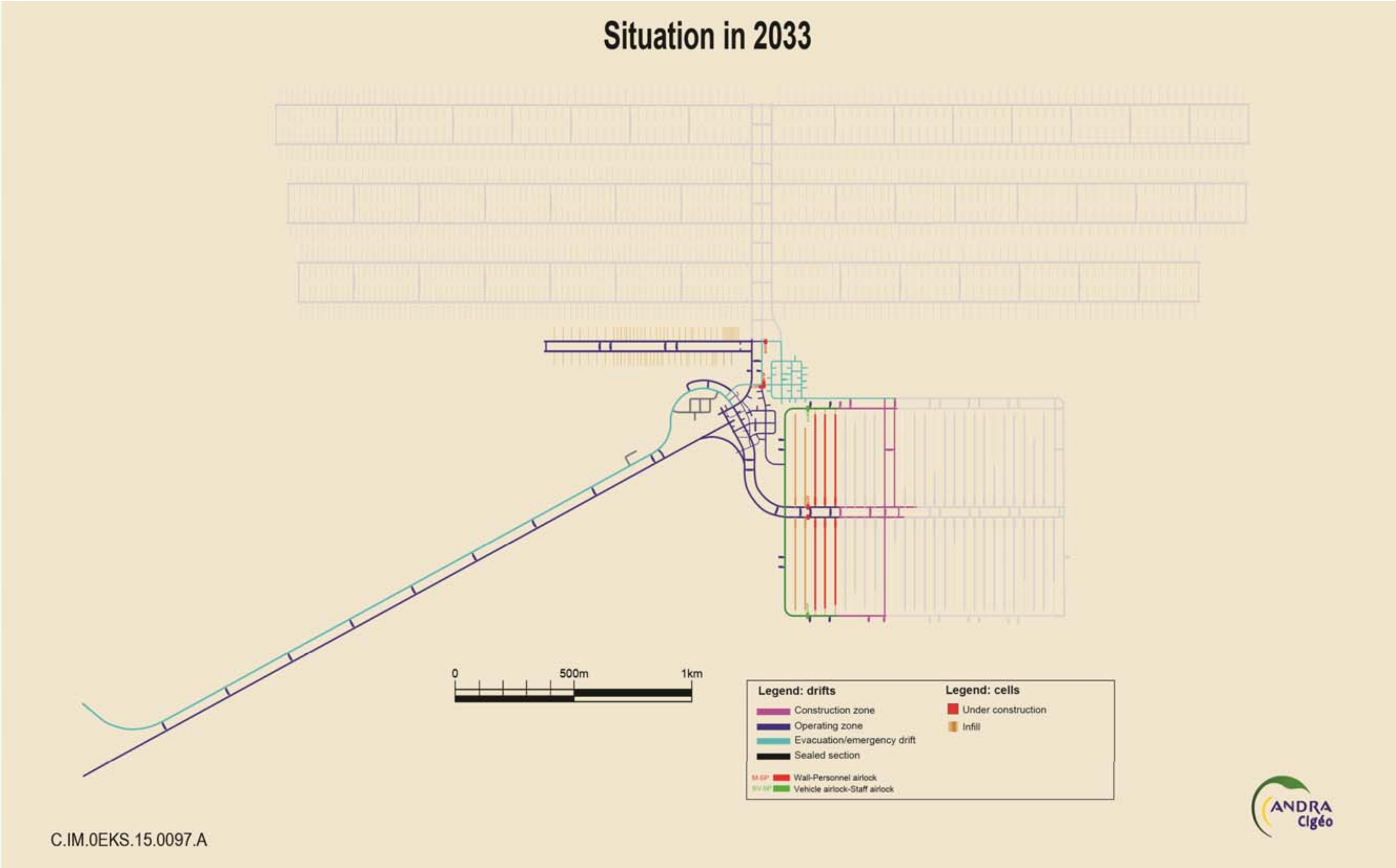
Appendix 5 Reference progression of construction of the underground facility (illustrations based on studies at the end of the basic engineering design)

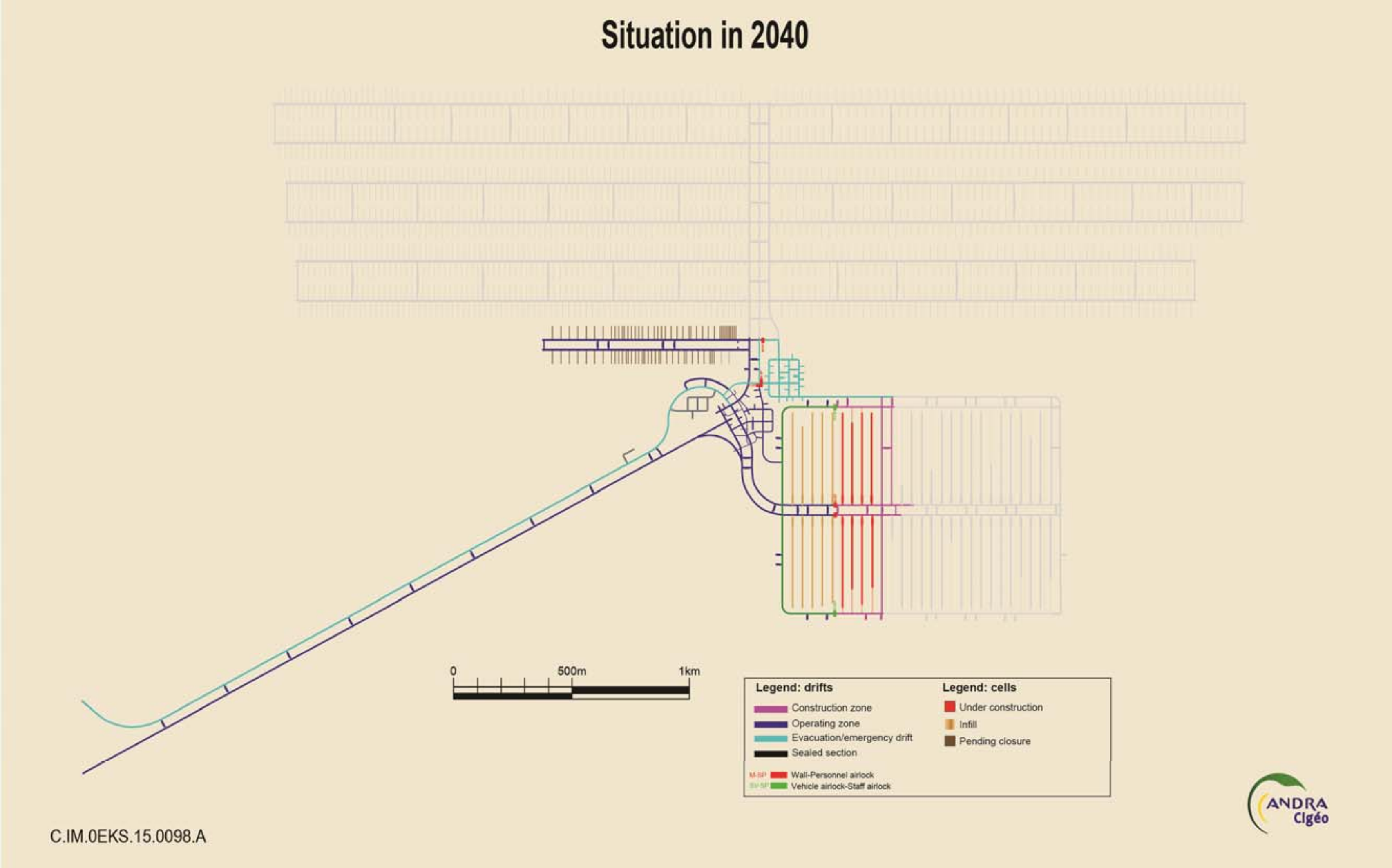


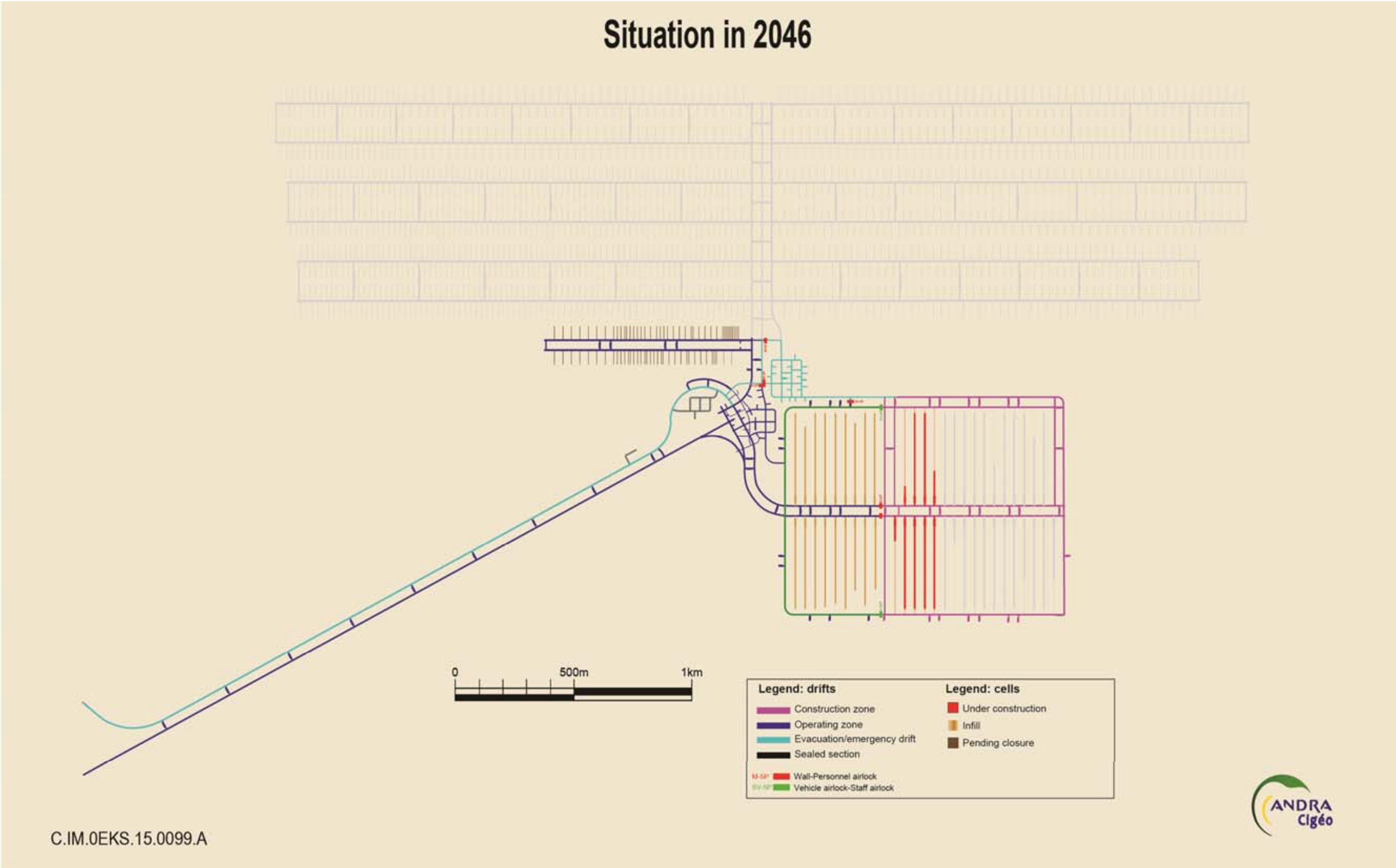

Situation in 2024
0
500m
1km
Legend: drifts
Construction zone
Legend: cells
Under construction
ANDRA
Cigéo
C.IM.0EKS.15.0094.A

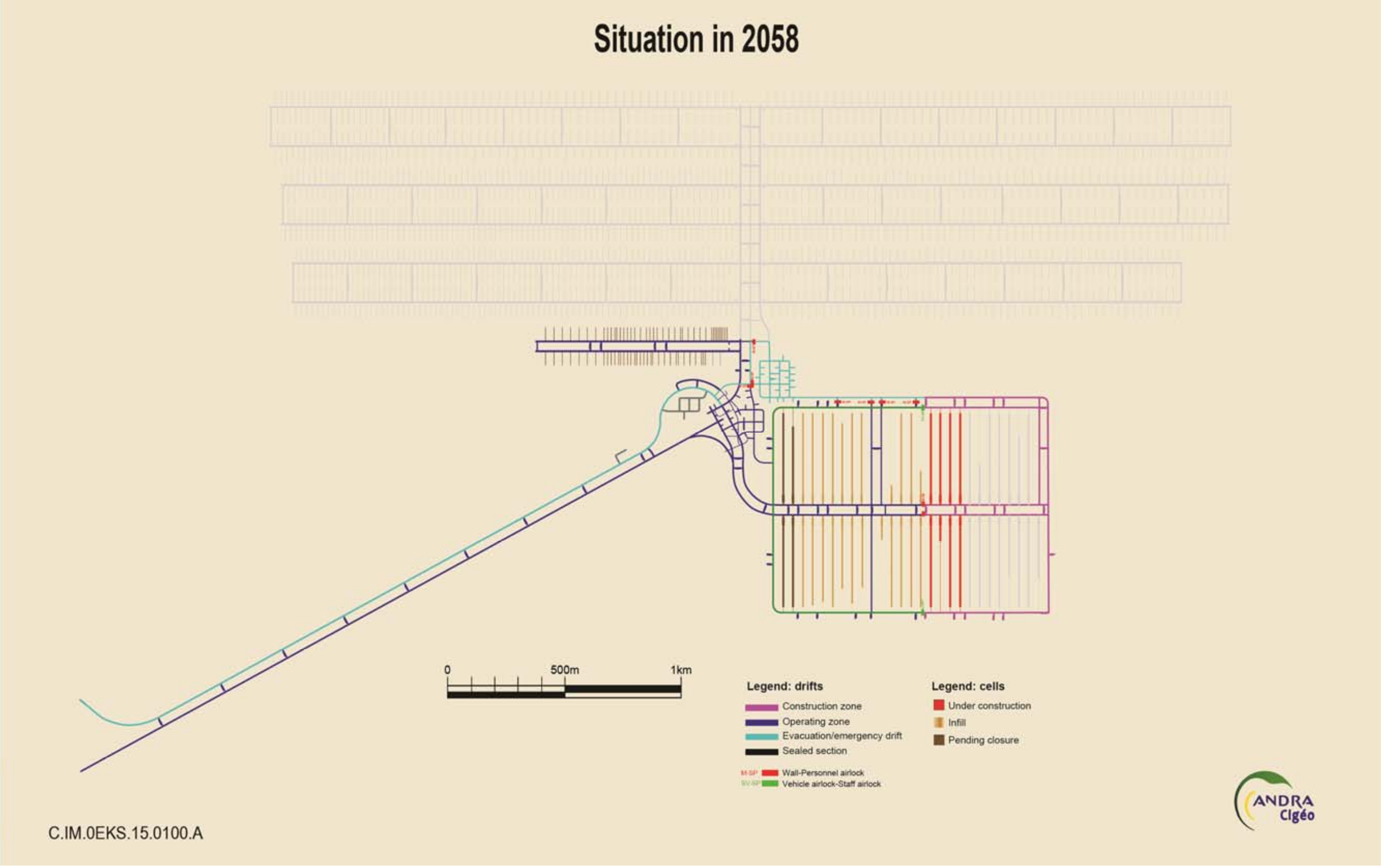

Situation in 2029
0
500m
1km
Legend: drifts
Construction zone
Legend: cells
Under construction
ANDRA
Cigéo
C.IM.0EKS.15.0095.A

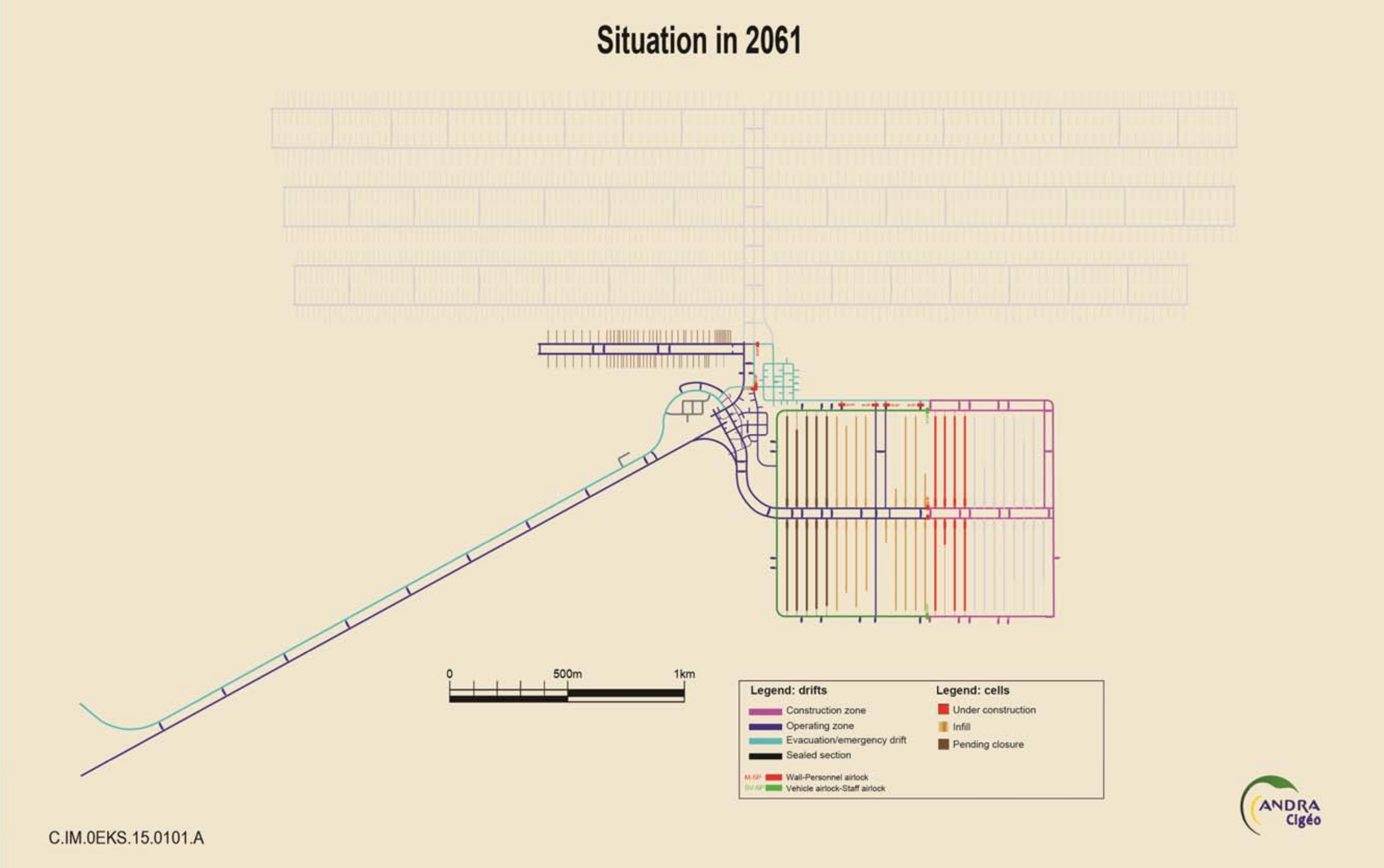

Situation in 2031
0
500m
1km
Legend: drifts
Construction zone
Operating zone
Evacuation/emergency drift
Sealed section
M-SP
Wall-Personnel airlock
SV-SP
Vehicle airlock-Staff airlock
Legend: cells
Under construction
Infill
ANDRA
Cigéo
C.IM.0EKS.15.0096.A

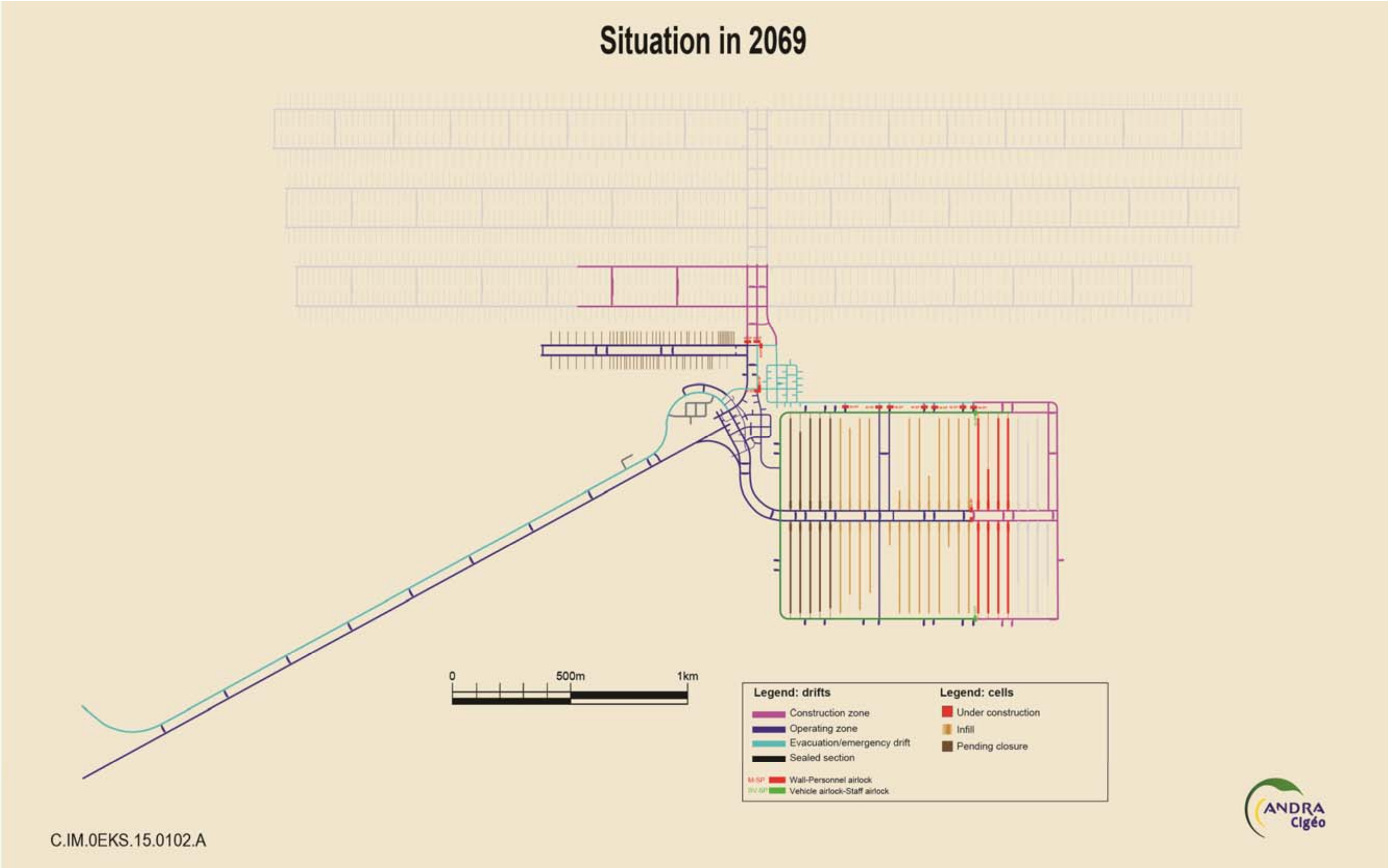

Situation in 2033
0
500m
1km
Legend: drifts
Construction zone
Operating zone
Evacuation/emergency drift
Sealed section
M-SP
Wall-Personnel airlock
SV-SP
Vehicle airlock-Staff airlock
Legend: cells
Under construction
Infill
ANDRA
Cigéo
C.IM.0EKS.15.0097.A

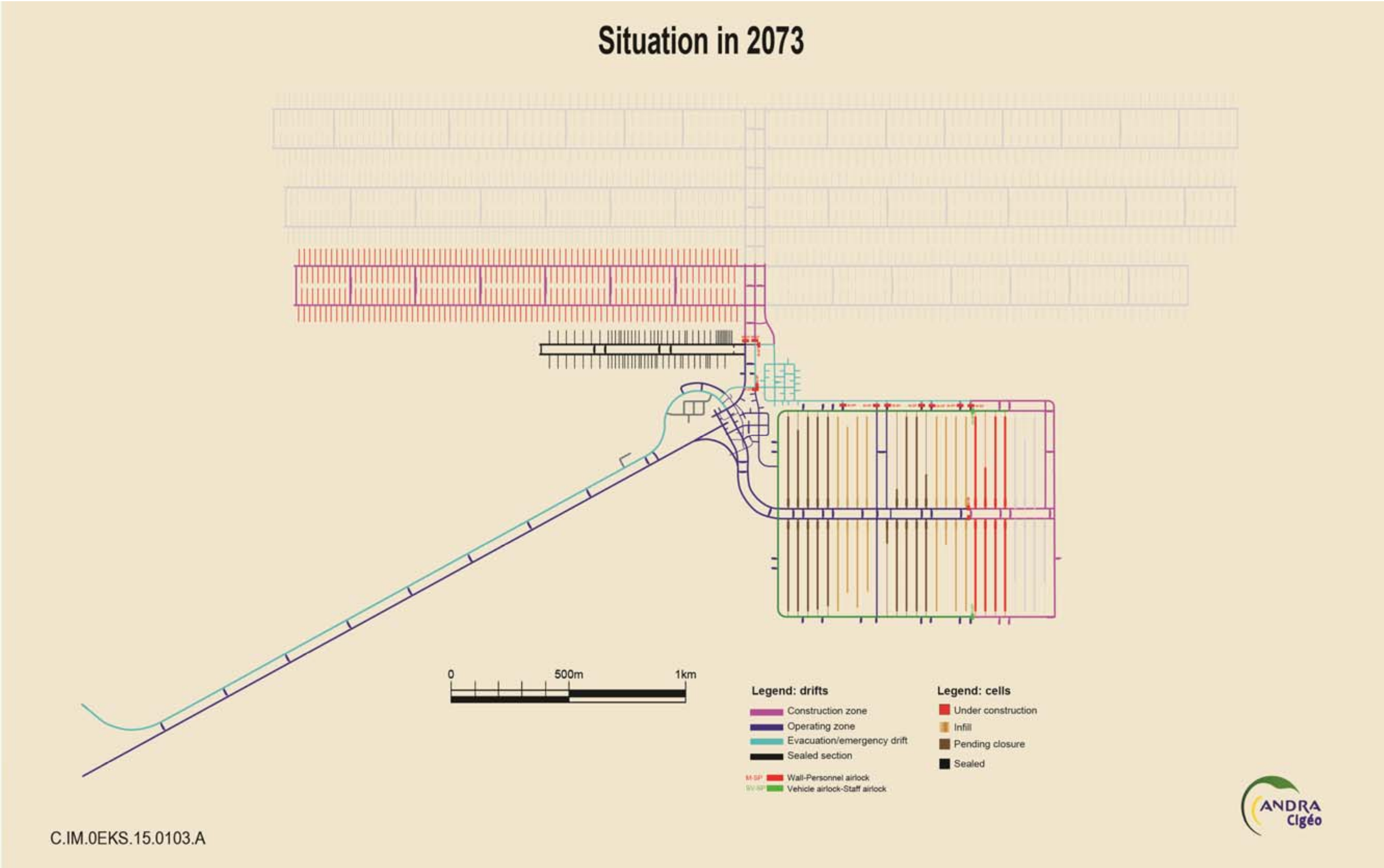

Situation in 2040
0
500m
1km
Legend: drifts
Construction zone
Operating zone
Evacuation/emergency drift
Sealed section
M-SP
Wall-Personnel airlock
Vehicle airlock-Staff airlock
Legend: cells
Under construction
Infill
Pending closure
ANDRA
Cigéo
C.IM.0EKS.15.0098.A

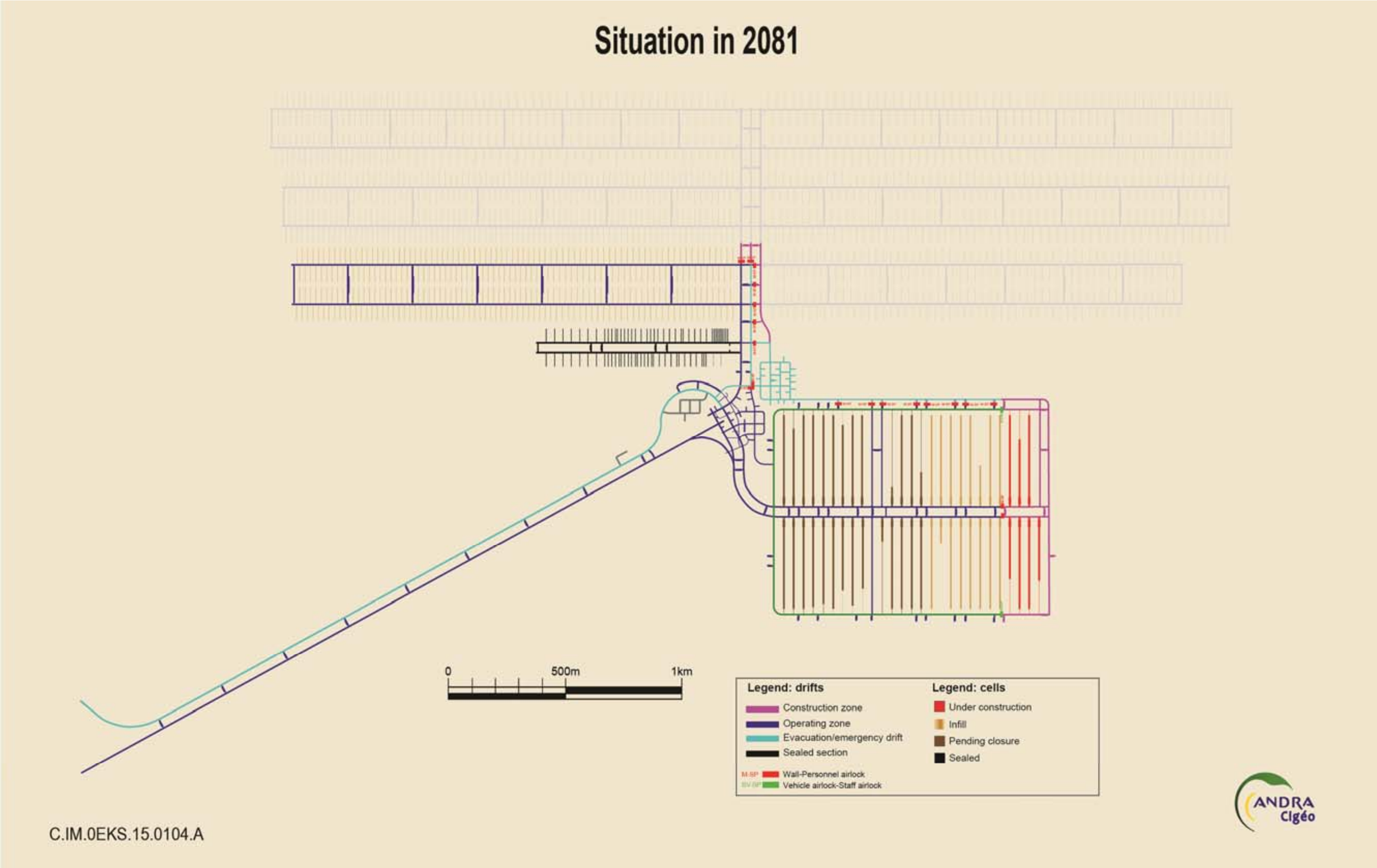

Situation in 2046
0
500m
1km
Legend: drifts
Construction zone
Operating zone
Evacuation/emergency drift
Sealed section
Wall-Personnel airlock
Vehicle airlock-Staff airlock
Legend: cells
Under construction
Infill
Pending closure
ANDRA
Cigéo
C.IM.0EKS.15.0099.A

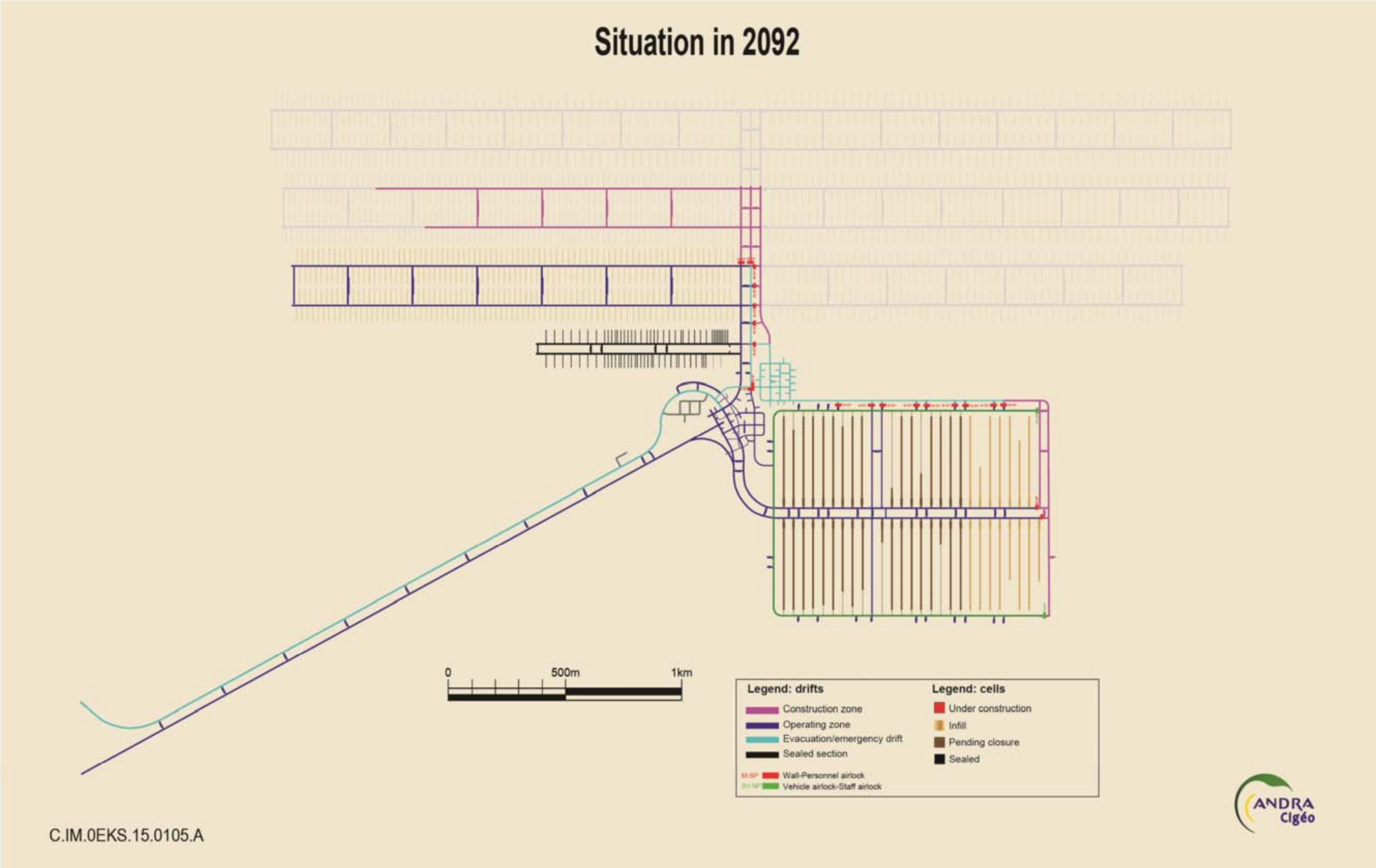

Situation in 2058
0
500m
1km
Legend: drifts
Construction zone
Operating zone
Evacuation/emergency drift
Sealed section
M-SP
Wall-Personnel airlock
Vehicle airlock-Staff airlock
Legend: cells
Under construction
Infill
Pending closure
ANDRA
Cigéo
C.IM.0EKS.15.0100.A

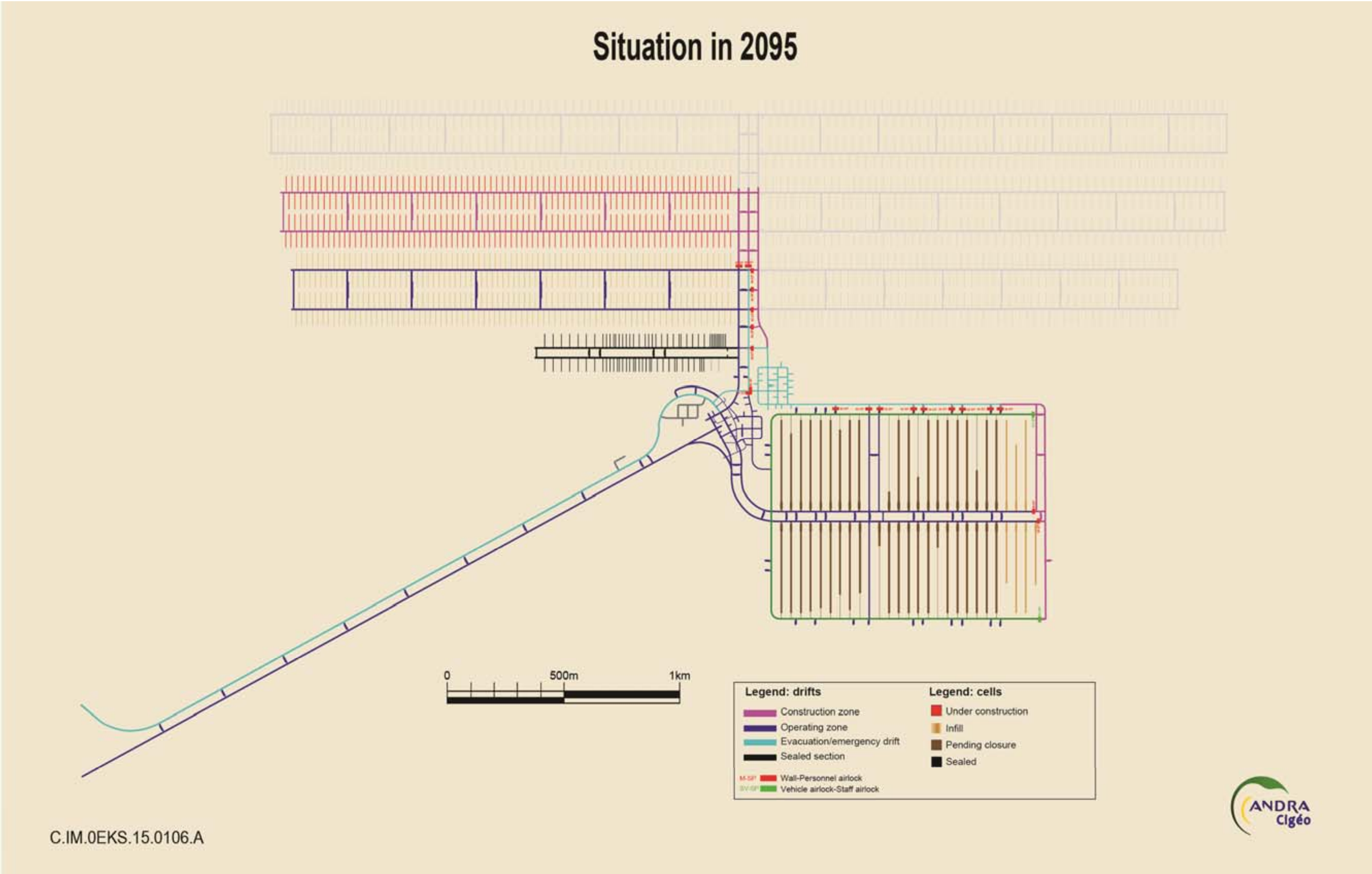

Situation in 2061
0
500m
1km
Legend: drifts
Construction zone
Operating zone
Evacuation/emergency drift
Sealed section
M-SP
Wall-Personnel airlock
Vehicle airlock-Staff airlock
Legend: cells
Under construction
Infill
Pending closure
ANDRA
Cigéo
C.IM.0EKS.15.0101.A

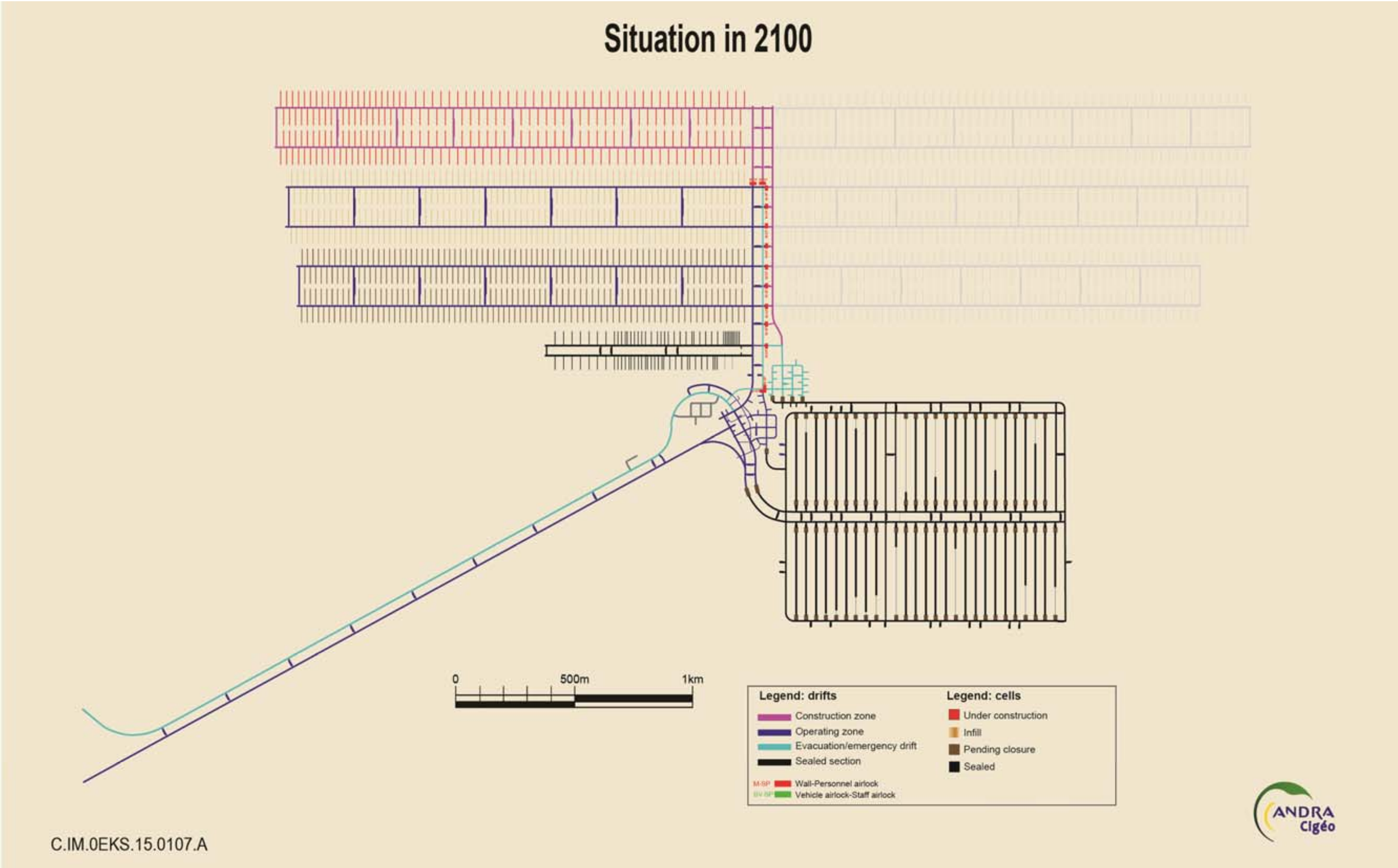

Situation in 2069
0
500m
1km
Legend: drifts
Construction zone
Operating zone
Evacuation/emergency drift
Sealed section
M-SP
Wall-Personnel airlock
Vehicle airlock-Staff airlock
Legend: cells
Under construction
Infill
Pending closure
C.IM.0EKS.15.0102.A

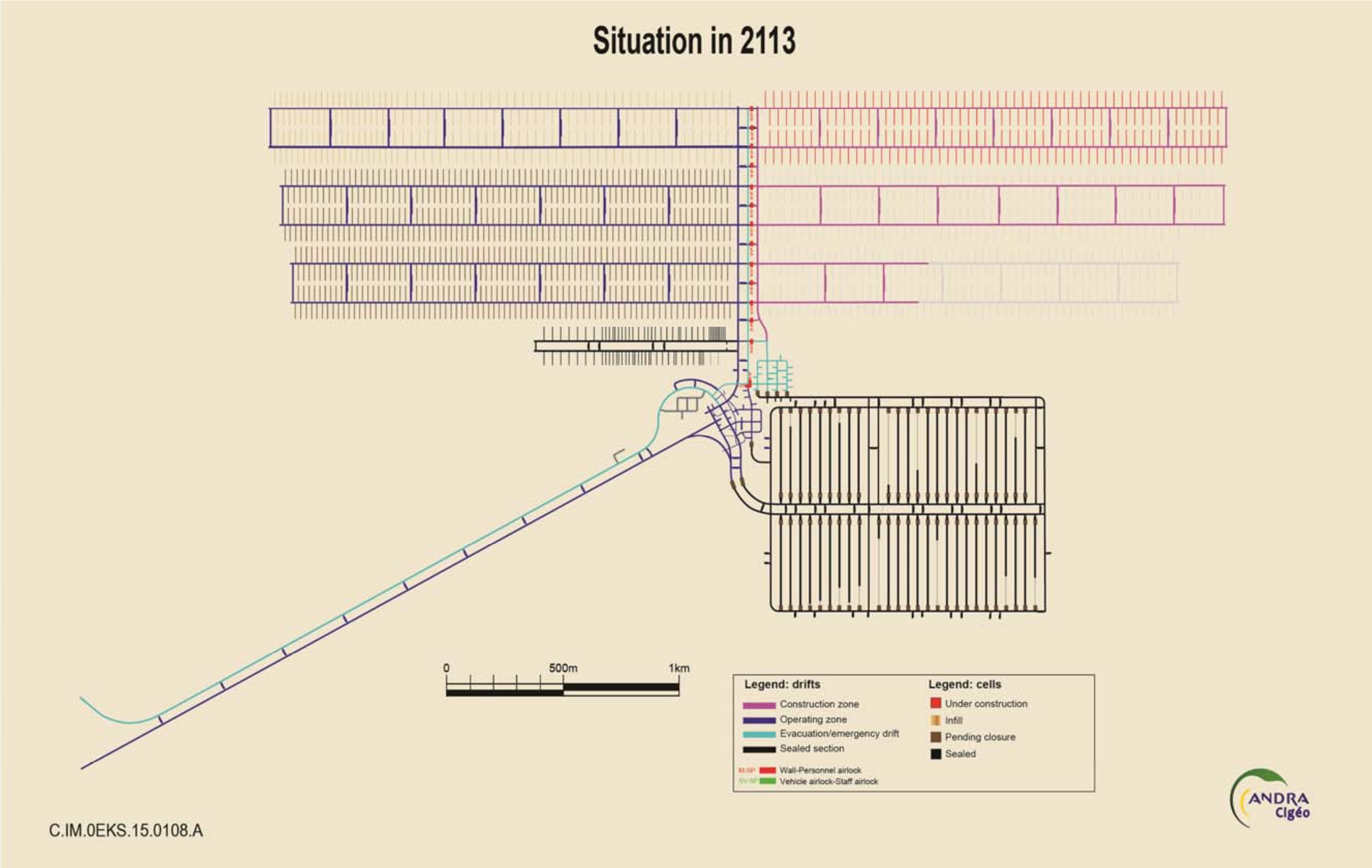

Situation in 2073
0
500m
1km
Legend: drifts
Construction zone
Operating zone
Evacuation/emergency drift
Sealed section
Wall-Personnel airlock
Vehicle airlock-Staff airlock
Legend: cells
Under construction
Infill
Pending closure
Sealed
ANDRA
Cigéo
C.IM.0EKS.15.0103.A

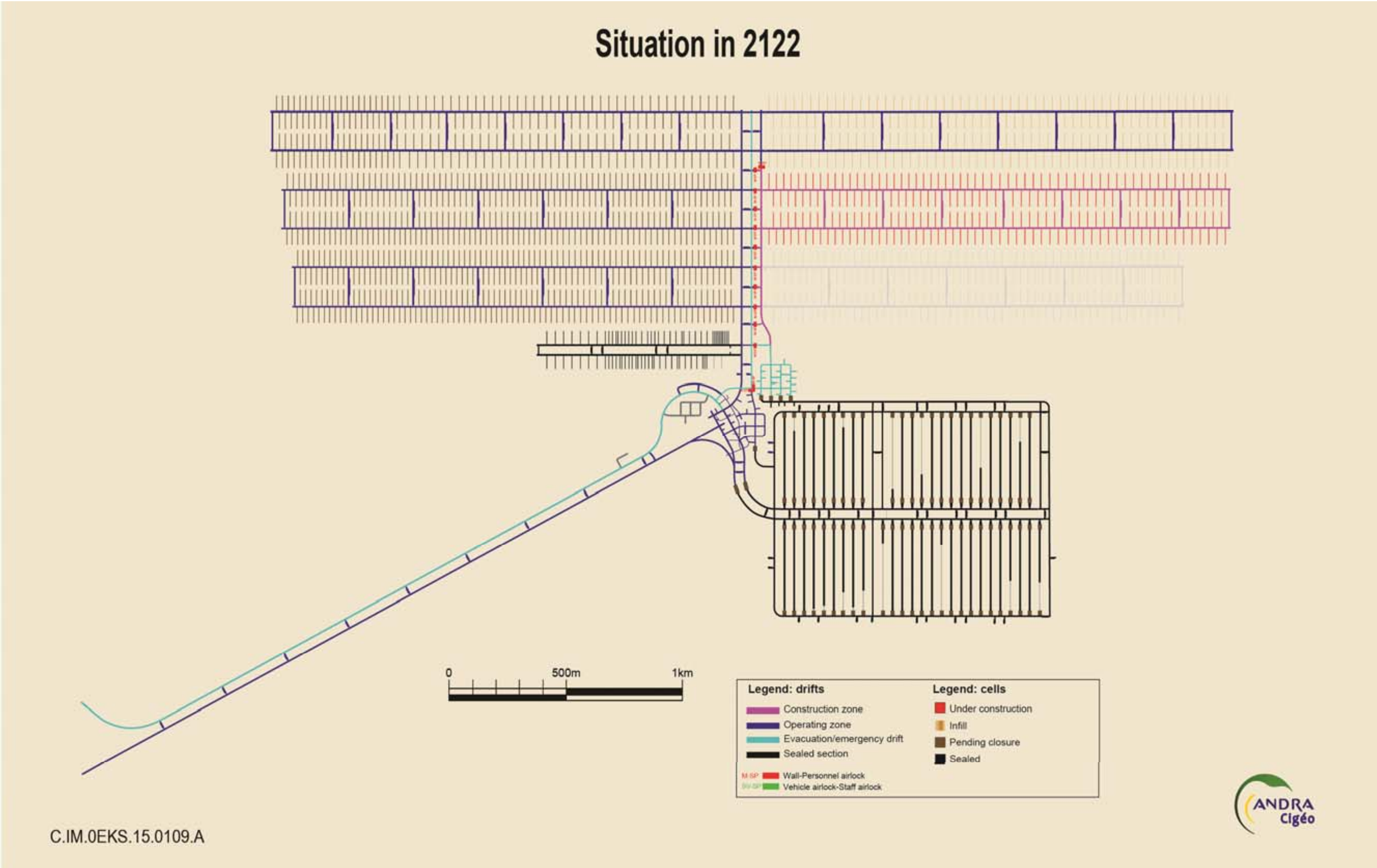

Situation in 2081
0
500m
1km
Legend: drifts
Construction zone
Operating zone
Evacuation/emergency drift
Sealed section
Wall-Personnel airlock
Vehicle airlock-Staff airlock
Legend: cells
Under construction
Infill
Pending closure
Sealed
ANDRA
Cigéo
C.IM.0EKS.15.0104.A

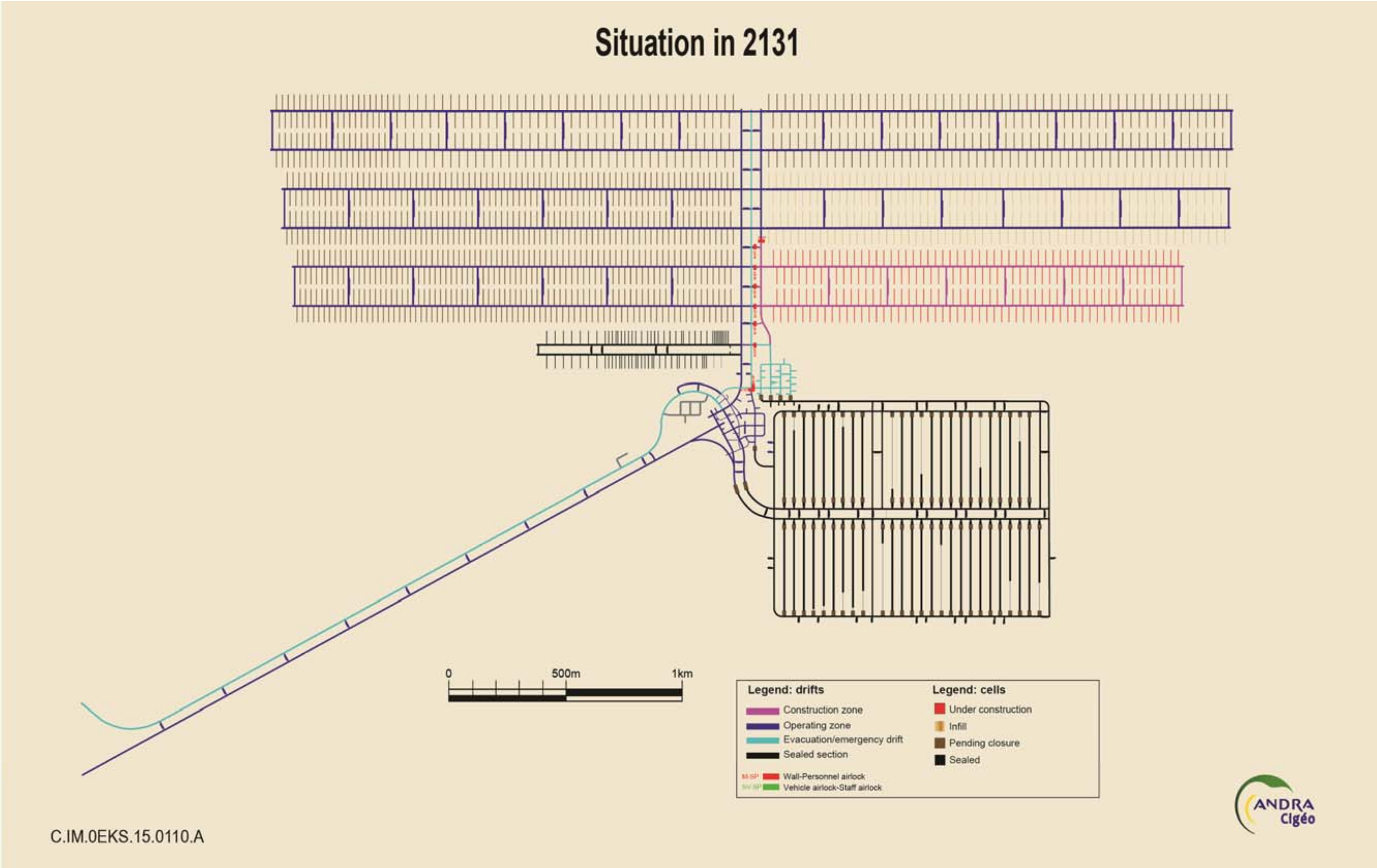

Situation in 2092
0
500m
1km
Legend: drifts
Construction zone
Operating zone
Evacuation/emergency drift
Sealed section
M-SP
Wall-Personnel airlock
Vehicle airlock-Staff airlock
Legend: cells
Under construction
Infill
Pending closure
Sealed
ANDRA
Cigéo
C.IM.0EKS.15.0105.A

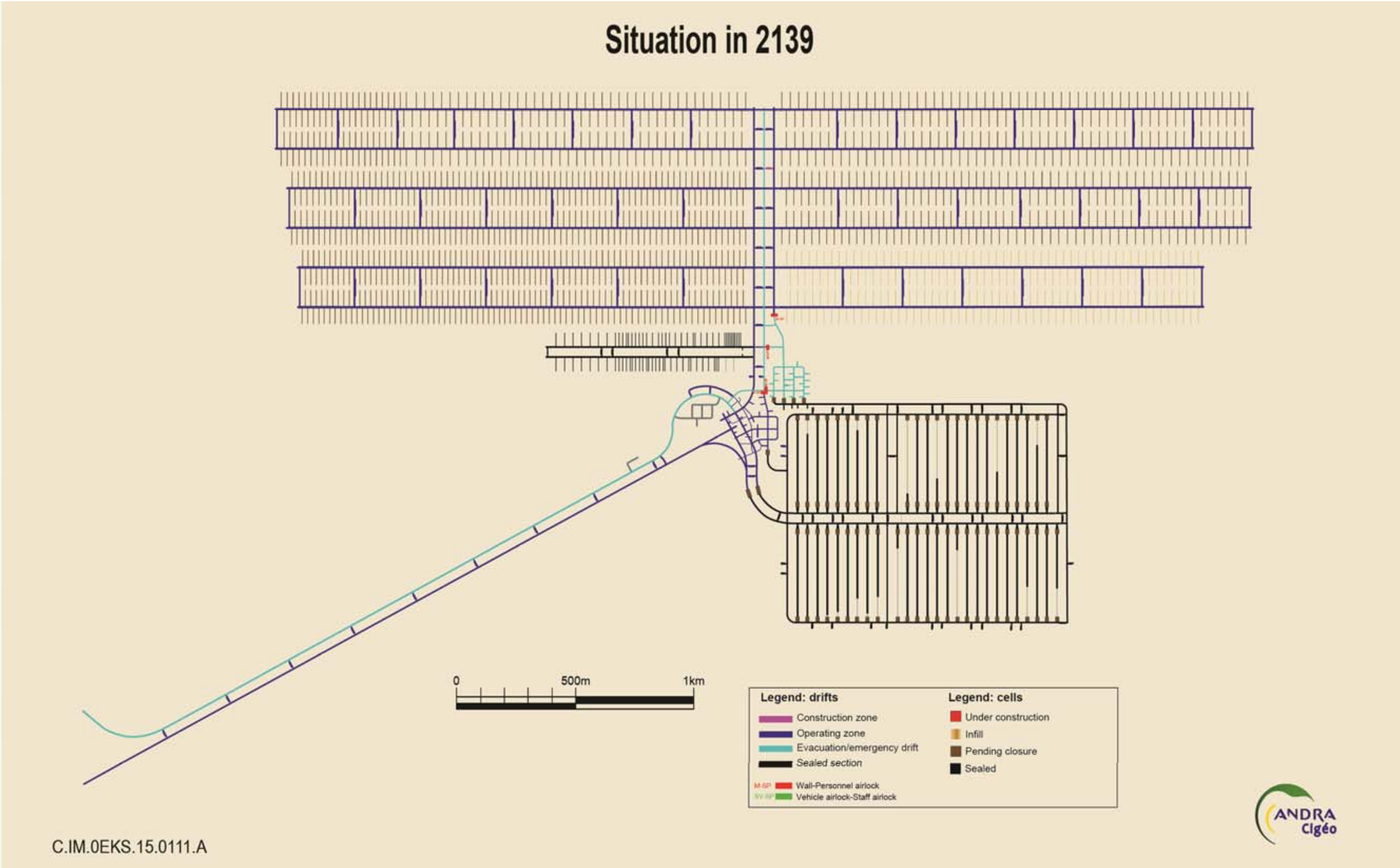

Situation in 2095
0
500m
1km
Legend: drifts
Construction zone
Operating zone
Evacuation/emergency drift
Sealed section
M-SP
Wall-Personnel airlock
Vehicle airlock-Staff airlock
Legend: cells
Under construction
Infill
Pending closure
Sealed
C.IM.0EKS.15.0106.A
ANDRA
Cigéo

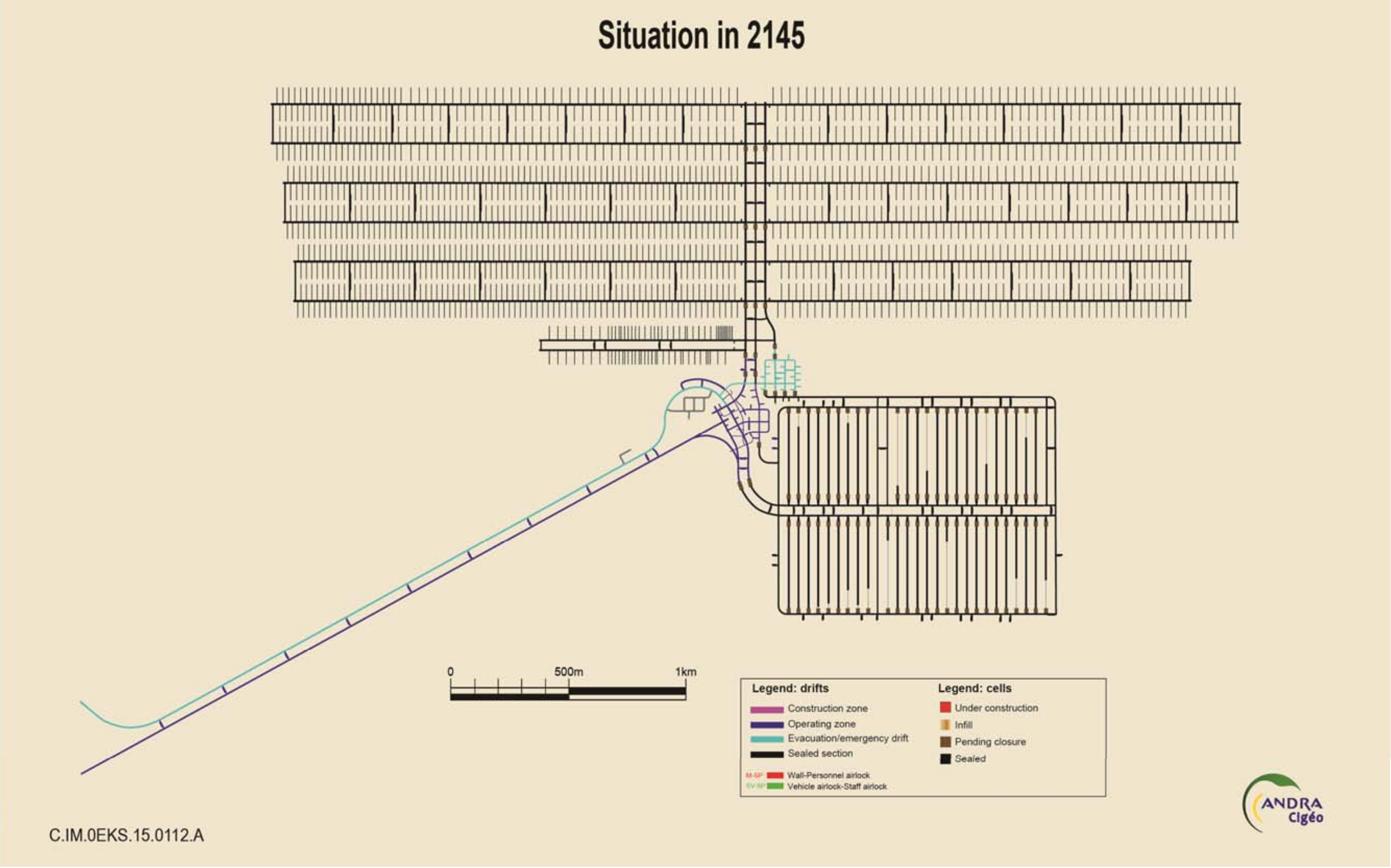

Situation in 2100
0
500m
1km
Legend: drifts
Construction zone
Operating zone
Evacuation/emergency drift
Sealed section
M-SP
Wall-Personnel airlock
Vehicle airlock-Staff airlock
Legend: cells
Under construction
Infill
Pending closure
Sealed
ANDRA
Cigéo
C.IM.0EKS.15.0107.A

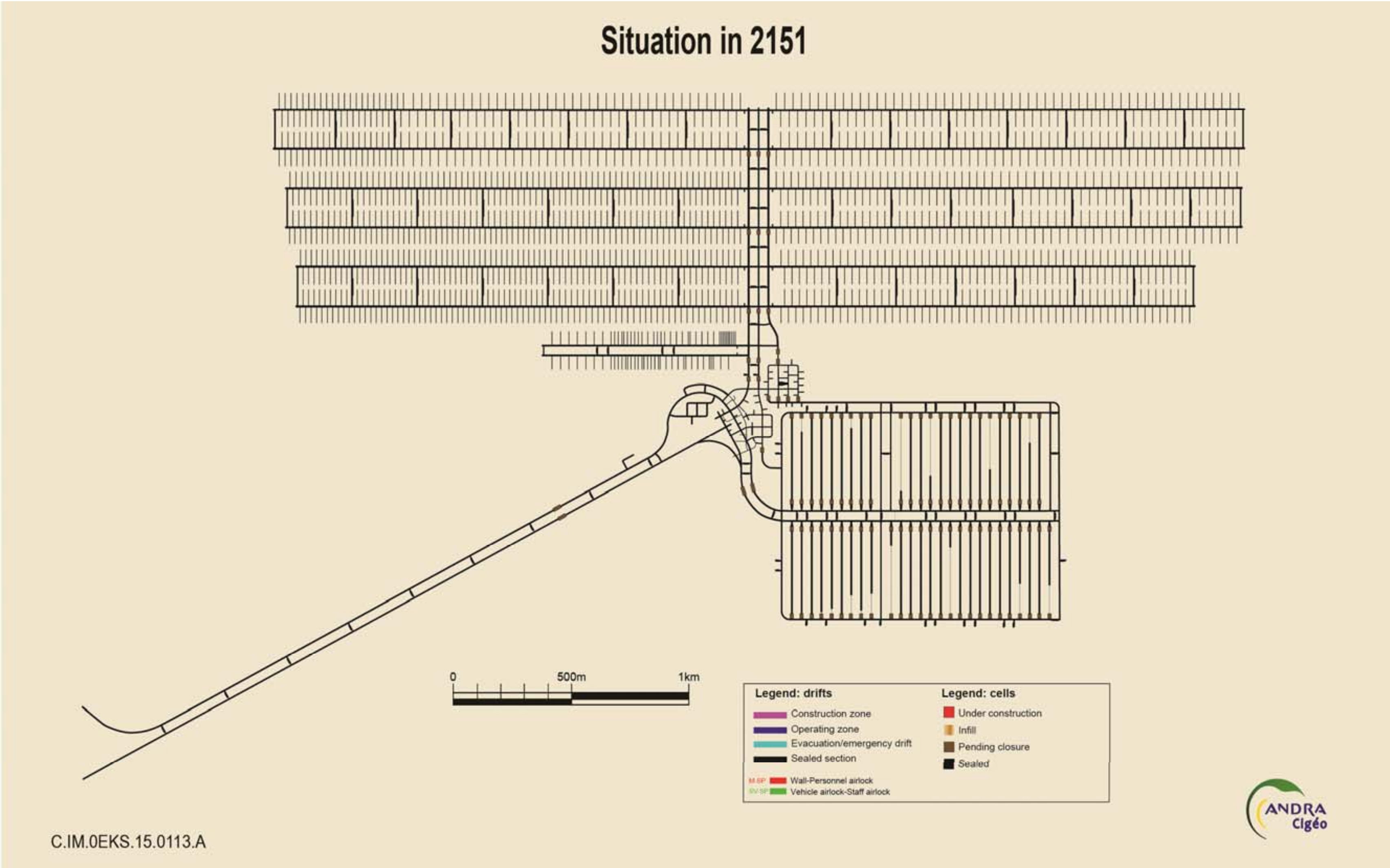

Situation in 2113
0
500m
1km
Legend: drifts
Construction zone
Operating zone
Evacuation/emergency drift
Sealed section
Wall-Personnel airlock
Vehicle airlock-Staff airlock
Legend: cells
Under construction
Infill
Pending closure
Sealed
ANDRA
Cigéo
C.IM.0EKS.15.0108.A


Situation in 2122
0
500m
1km
Legend: drifts
Construction zone
Operating zone
Evacuation/emergency drift
Sealed section
M-SP
Wall-Personnel airlock
Vehicle airlock-Staff airlock
Legend: cells
Under construction
Infill
Pending closure
Sealed
ANDRA
Cigéo
C.IM.0EKS.15.0109.A


Situation in 2131
0
500m
1km
Legend: drifts
Construction zone
Operating zone
Evacuation/emergency drift
Sealed section
M-SP
Wall-Personnel airlock
Vehicle airlock-Staff airlock
Legend: cells
Under construction
Infill
Pending closure
Sealed
ANDRA
Cigéo
C.IM.0EKS.15.0110.A


Situation in 2139
0
500m
1km
Legend: drifts
Construction zone
Operating zone
Evacuation/emergency drift
Sealed section
M-SP
Wall-Personnel airlock
Vehicle airlock-Staff airlock
Legend: cells
Under construction
Infill
Pending closure
Sealed
ANDRA
Cigéo
C.IM.0EKS.15.0111.A


Situation in 2145
0
500m
1km
Legend: drifts
Construction zone
Operating zone
Evacuation/emergency drift
Sealed section
Wall-Personnel airlock
Vehicle airlock-Staff airlock
Legend: cells
Under construction
Infill
Pending closure
Sealed
C.IM.0EKS.15.0112.A


Situation in 2151
0
500m
1km
Legend: drifts
Construction zone
Operating zone
Evacuation/emergency drift
Sealed section
Wall-Personnel airlock
Vehicle airlock-Staff airlock
Legend: cells
Under construction
Infill
Pending closure
Sealed
ANDRA
Cigéo
C.IM.0EKS.15.0113.A

Appendix 6 Systems for reversibility

SYSTEMS FOR REVERSIBILITY		POSSIBLE ROLES IN THE REVERSIBILITY OF DECISIONS	EXAMPLES OF OPERATIONAL IMPLEMENTATION WITHIN CIGEO
Governance	**Continuous improvement of knowledge** An organised set of actions and work that aims to increase the body of knowledge regarding radioactive waste and management methods, and the use of this body of knowledge to improve its management	• Reveal new options for the management of various types of radioactive waste that are different from or complementary to disposal (e.g. transmutation) • Improve waste management on production sites (e.g.: develop national conditioning methods or reduce the quantity of waste produced) • Improve Cigeo for greater efficiency (e.g.: improve equipment performance or the size of structures); • Periodically reassess the forecast operating life of the facility • Make use of experience feedback acquired through operation of the repository	• Specific tests and measurements carried out in the Cigeo facility during and beyond the industrial pilot phase: ✓ Specific study programmes performed in demonstrators (cell or component) ✓ Dedicated test zone in the underground facility • Dissemination of data from monitoring • Periodically producing and publishing reports on knowledge concerning Cigeo
Project management	**Incremental development and gradual construction** The continuous, regular and prudent nature of the sequencing of construction operations for the disposal facility throughout its operating life	• In successive phases, integrate the lessons learned from continuous improvement of knowledge into the Cigeo's design • Delay or speed up Cigeo construction	• Industrial pilot phase at commissioning that includes a gradual increase in the scale of operation • Modular facilities designed to be gradually extended as waste package disposal progresses • Construction of successive phases of underground structures, integrating technological developments and optimisations • Disposal of HLW0 waste (which produces little heat) from the industrial pilot phase, to constitute a pilot project for the disposal of HLW1/HLW2 planned for later phases

SYSTEMS FOR REVERSIBILITY		POSSIBLE ROLES IN THE REVERSIBILITY OF DECISIONS	EXAMPLES OF OPERATIONAL IMPLEMENTATION WITHIN CIGEO
Project management	**Operational flexibility** The ability of the facility to adapt to changes in the industrial programme (reception schedule, reception flows, date of partial closure) without modifying infrastructure or existing equipment and without building new structures	• Modify the flows and schedules for package reception and disposal • Modify the dates for partial closure of the underground facility • Receive waste conditioned using new conditioning methods	• Availability of an operational margin in Cigeo operations to temporarily or permanently increase resource use (e.g. transition from 2-shift operation to 3-shift (24hrs a day) or 5-shift (24/7). • The design of the facility (design and architecture of the underground structures, and circulation of flows) means that works for partial closure of the underground facility can be organised (closure of cells and drifts) soon after their filling or at any time up to the end of disposal operations • Design of containers, structures and procedures such that they can easily be allocated to the reception of various types of package (e.g.: standardisation of lifting equipment) • Co-disposal of ILW-LL waste packages • Robust behaviour of containers enabling adaptation to the adopted closure schedule
Project management	**Adaptability of the facilities** Ability to modify the facility to adapt to new sizing assumptions (e.g.: changes to the inventory), involving significant modifications to existing equipment or construction of new structures	• Dispose of waste not planned in the initial inventory, due to changes in France's energy policy or changes in the management of radioactive waste • Modify the facility to increase its performance, for example to increase package reception and reshipment flows	• Diameter of the surface-bottom connections with possible disposal of spent fuel • Footprint margins retained on the surface for the construction of buildings providing additional functions • Position and dimensions of the repository in the zone of interest for detailed reconnaissance (ZIRA), preserving rock volumes for possible extension (e.g., construction of additional disposal cells)

SYSTEMS FOR REVERSIBILITY		POSSIBLE ROLES IN THE REVERSIBILITY OF DECISIONS	EXAMPLES OF OPERATIONAL IMPLEMENTATION WITHIN CIGEO
Project management	**Retrievability** Ability to retrieve waste packages emplaced in a deep geological formation	• Provide flexibility in operating the repository • Reconsider a method used for conditioning waste packages (repackaging) before re-emplacement in the repository • Or even reconsider geological disposal as the management method for some or all of the waste during repository operation	• Durability of waste packages ensuring their ability to be handled • Durability of structures ensuring the maintenance of functional free play • Retrieval operations performed without jeopardising safety (e.g.: using lifting equipment equivalent to that used for emplacement) • Suitability of partial closure components (cells and drifts) to be dismantled and for the facility to be re-equipped (backfill and seals may be dismantled). Dismantling tests for these components will be performed in Cigeo prior to initial partial closure work.
Governance	**Transparency and transmission of information and knowledge** All actions aiming to make data available regarding the facility, the operations performed there and factors that substantiated the decisions taken for its development	• Provide information for future decision-making on the basis of precise knowledge of the facility and the factors that led to the previous decisions • Organise repository records and their transmission	• Implementing an approach that provides traceability for earlier decisions and their substantiations • Understanding the facility's configuration • Implementing specific methods for archiving data, so that it can be kept for as long as possible • Forwarding data concerning costs, safety, waste emplaced and activities performed (construction, changes, etc.) to relevant stakeholders • Regular discussions with the Local Information and Oversight Committee (CLIS) and/or the Local Information Committee (CLI)

SYSTEMS FOR REVERSIBILITY		POSSIBLE ROLES IN THE REVERSIBILITY OF DECISIONS	EXAMPLES OF OPERATIONAL IMPLEMENTATION WITHIN CIGEO
Governance	**Involvement of society, assessment and supervision by Parliament** All resources, systems and processes which ensure that stakeholders can contribute to the decisions taken for development of the repository	• Inform stakeholders of the issues associated with geological disposal and management of radioactive waste • Legitimise the decisions taken regarding management of radioactive waste, including local and national socio-economic consequences	• Continuous assessment by the National Assessment Board (CNE) • Production of a proposed Operations Master Plan (PDE) presenting the reference progression of the Cigeo project (schedules for Cigeo construction and closure), the objectives of the pilot phase and the main issues regarding reversibility • Stakeholder involvement in the production of the Cigeo Operations Master Plan (PDE) submitted to the French government • Stakeholder involvement in the production of periodic updates to the Operations Master Plan (PDE) • Involvement of local stakeholders in local development and its monitoring

SYSTEMS FOR REVERSIBILITY		POSSIBLE ROLES IN THE REVERSIBILITY OF DECISIONS	EXAMPLES OF OPERATIONAL IMPLEMENTATION WITHIN CIGEO
Governance	Monitoring by ASN All actions aiming to check repository operator compliance with rules, specifications, commitments and missions	• Authorise safe management methods for waste, during operation and in the long term • Report on safety conditions for the facilities • Assess the state of knowledge regarding the management of radioactive waste	• Expert assessment of the project by technical assessors (IRSN, Advisory Committees, etc.) • Perform periodic safety reviews for Cigeo • Safety milestones: major extension decisions (HLW1/HLW2), safety demonstrations to incorporate optimisations and innovations • Continuously monitor Cigeo operation (inspections) • Incremental licensing process, meaning that Cigeo can gradually develop and widen its operational scope • Continuous monitoring of advances in the Andra study programme on Cigeo • Production and monitoring of the framework specified in the construction license

Appendix 7 Main decision and technical deadlines envisaged for Cigeo by Andra (based on the basic engineering design and subject to changes in regulations)

2016	Act laying down reversibility conditions (or after the DAC, after 2018)	**2043**	Start of the 3rd extension of the ILW-LL zone	**2079**	Commissioning of the 1st HLW section	**2121**	Commissioning of the 4th HLW section
2016 - 2017	Consultation on the Operations Master Plan	**2045**	Commissioning of the 2nd extension of the ILW-LL zone	**2080**	5th safety review – Start of the final extension of the ILW-LL zone	**2127**	Start of construction on the final HLW section
2018	Construction licence application and application for declaration of public utility	**2046**	Commissioning of the 2nd extension of the ILW-LL zone	**2087**	Start of construction on the 2nd HLW section	**2130**	9th safety review – Commissioning of the 5th HLW section
2020	Public inquiry on Cigeo	**2050**	2nd safety review	**2089**	Commissioning of the 5th extension of the ILW-LL zone	**2135**	10nd safety review
2021	Construction license decree	**2053**	Commissioning of the 3th extension of the ILW-LL zone	**2090**	6th safety review	**2138**	Commissioning of the final HLW section
2025	Start of the industrial pilot phase	**2058**	Start of the 4rd extension of the ILW-LL zone	**2099**	Commissioning of the 2nd HLW section	**2140**	11th safety review
2030	Commissioning of Cigeo (emplacement of the first waste package)	**2060**	3th safety review	**2100**	7th safety review – Closure of the ILW-LL zone/Start of construction on the 3rd HLW section	**2145**	12th safety review/closure of the HLW sections
2032	Start of the 1st extension of the ILW-LL zone	**2067**	Commissioning of the 4th extension of the ILW-LL zone	**2110**	8th safety review – Start of construction on the 4th HLW section	**2150**	Final closure
2035	Transition to routine operation/Update to the Operations Master Plan	**2068**	Start of the 5th extension of the ILW-LL zone/Start of construction the first HLW section	**2112**	Commissioning of the 3th HLW section		
2037	Start of the 2nd extension of the ILW-LL zone	**2070**	4th safety review – Closure of the HLW0 section	**2119**	Start of construction on the 5th HLW section		
2040	1st safety review – Commissioning of the 1st extension of the ILW-LL zone	**2077**	Commissioning of the 5th extension of the ILW-LL zone	**2120**	8nd safety review		

BIBLIOGRAPHIC REFERENCES

1 Débat public CIGEO. Projet de centre de stockage réversible profond de déchets radioactifs en Meuse / Haute Marne (Cigéo), 15 mai -15 décembre 2013, Compte-rendu. Commision nationale du débat public (CNDP). (2014).

2 Bilan du débat public, Projet de centre de stockage réversible profond de déchets radioactifs en Meuse / Haute-Marne (Cigéo), 15 mai - 15 décembre 2013, dressé par le Président de la Commission nationale du débat public. Commission Nationale du Débat Public (CNDP). (2014). 20 p.

3 Débat public CIGEO. Conférence de citoyens. Présentation de l'avis du panel de citoyens. Commission Nationale du débat public (CNDP). (2014). 36 p.

4 Proceedings of Andra's Governing Board on the actions to be taken following the public debate on Cigeo (5 May 2014). Ministry of Ecology, Sustainable Development, and Energy (2014). Journal Officiel. Lois et décrets, n°108, pp.7851-7854.

5 Reversibility position paper. December 2015. Andra. (2016). Brochure No. 577. Document No. DICOD/15-0247. 28 p.

6 Planning Act No. 2006-739 of 28 June 2006 on sustainable management of radioactive materials and waste. (2006). Journal Officiel. Lois et Décrets, n°93, pp.9721.

7 Decree 2007-1557 of 2 November 2007 on basic nuclear installations and the control of radioactive material transport from the nuclear safety viewpoint. Consolidated version as of 27 February 2014 (2007).

8 Décret n° 93-940 du 16 juillet 1993 portant application de la loi n° 91-1381 du 30 décembre 1991 sur la gestion des déchets radioactifs et relatif à l'autorisation d'installation et d'exploitation d'un laboratoire souterrain. Ministère de l'Industrie, des Postes et Télécommunications et du commerce extérieur (1993). Journal Officiel de la Répubique Française du 23 Juillet 1993, n°168, pp.10379.

9 Loi n° 85-704 du 12 juillet 1985 relative à la maîtrise d'ouvrage publique et à ses rapports avec la maîtrise d'oeuvre privée. (2010). Journal Officiel Version consolidée au 9 décembre 2010, n°24/11/2010,

10 Cigeo Project Component Development Plan According to the TRL scale (ISO 16290:2013). Andra. (2014). Advancement and Development Plan No. CGPDDADPG140031.

11 Decree No. 94-1159 of 26 December 1994 on the integration of safety and the organisation of coordination of safety and health in the building and civil engineering sectors and amending the Labour Code (part two: decrees issued by the Council of State). (1994). Journal Officiel de la République Française, n°301, pp.18695.

12 Guide de sûreté relatif au stockage définitif des déchets radioactifs en formation géologique profonde. Autorité de sûreté nucléaire. (2008). Guide de l'ASN. 32 p.

13 Reversibility of Decisions and Retrievability of Radioactive Waste. Considerations for National Geological Disposal Programmes. OECD Nuclear Energy Agency (2012). Radioactive Waste Management. NEA No. 7805. 29 p.

14 Order of 7 February 2012, as amended, laying down general rules for basic nuclear installations. Consolidated version as of 5 July 2013 (2012).

15 Décret n°2013-1304 du 27 décembre 2013 pris pour application de l'article L. 542-1-2 du code de l'environnement et établissant les prescriptions du Plan national de gestion des matières et des déchets radioactifs. Ministère de l'Écologie, du dévelôppement durable et de l'Énergie (2013). Journal officiel de la République Française, n°304, pp.22347.

16 Rapport préalable au débat public sur le projet de stockage géologique profond de déchets radioactifs Cigéo. Haut Comité sur la transparence et l'information sur la sécurité nucléaire (HCTISN). (2013). 30 p.